Prototipo de material polimérico compuesto a base de vasos de cartón para bebidas calientes.

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Monografía presentada como requisito parcial para optar al título de ingeniero de producción

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DEDICATORIA

Al Señor de quien todo conocimiento, arte y habilidad provienen,

A mis más fieles admiradores: mis padres,

A mis hermanos por inspirarme a ser cada día mejor.

AGRADECIMIENTOS

Agradezco al ingeniero José Divitt Velosa por su apoyo constante, por impulsarme a alcanzar retos mayores y por su gran amor a la docencia. Agradezco a la Facultad de Ingeniería por su ayuda en un momento tan decisivo, a la universidad EAN proveer los laboratorios y los medios para ejecutar este proyecto, a Camilo y Aydé por brindarme su tiempo y expertiz en el uso de los equipos y a todos los que de una u otra forma hicieron posible este proyecto.

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1 RESUMEN

La transformación de un residuo como vasos de cartón para bebidas calientes en un material compuesto polimérico requiere un análisis de las propiedades de la materia prima inicial y de los procesos que pueden llevarse a cabo de acuerdo a los recursos disponibles para la manufactura del mismo.

Por medio de la selección de procedimientos experimentales, casos de estudio relevantes en el área y el uso de normas internacionales que provean un marco experimental adecuado, se realiza la caracterización del material polimérico compuesto de tal manera que las propiedades físicas, incluyendo pruebas mecánicas, tales como densidad, absorción de agua, ignición, tensión, impacto y dureza puedan ejecutarse. Las pruebas se realizan en un entorno experimental académico, apoyándose no solo en las herramientas tecnológicas disponibles en los laboratorios de la Universidad EAN, sino también en la teoría provista por las ciencias básicas y de materiales.

La caracterización preliminar del material provee un marco de referencia que permite proponer una aplicación real para el mismo, así como una base sobre la cual se pueden ejecutar proyectos de profundización futuros.

2 JUSTIFICACIÓN

El estudio de la ciencia de los materiales y su aplicación a la solución de problemas de diferentes ámbitos, resulta especialmente útil e importante ante los problemas de sostenibilidad ambiental presentes en muchas de las industrias mundiales y colombianas. La reutilización de materiales se hace cada vez más necesaria si se consideran las crecientes cifras de acumulación de los mismos en los rellenos sanitarios y la decreciente disponibilidad de materias primas para la industria.

Desde la perspectiva de la ingeniería de producción, la selección y generación de materiales involucra el ciclo de vida tanto de los productos como de los insumos y es desde esta perspectiva que se busca hacer un primer acercamiento a la solución de un problema ambiental que pasa desapercibido por muchos. En pro de la conveniencia y reducción de costos tanto para el proveedor del producto como para el consumidor, las cadenas de bebidas calientes utilizan vasos de cartón para suplir sus necesidades de envase. Sin embargo, como se ha demostrado para algunos de estos envases, los mismos componentes que lo hacen tan versátil, son los que hacen su reciclaje convencional imposible.

La oportunidad de desarrollar y proponer un material con posibles aplicaciones reales en algún sector de la industria desde un ambiente académico experimental, permite la creación de un caso de estudio en el que futuras investigaciones o propuestas se puedan basar. La generación de un prototipo de un material también permite aplicar y apreciar más a fondo la importancia que tiene no solo la ciencia de materiales en el área productiva, sino también la investigación y sus técnicas para la generación de conocimiento.

3 OBJETIVOS

El desarrollo del proyecto aquí plateado está enmarcado por los siguientes objetivos generales y específicos.

3.1 OBJETIVO GENERAL

Desarrollar un prototipo de material polimérico compuesto a base de residuos de vasos para bebidas calientes de cartón recubiertos de LDPE[1], dentro de un ambiente académico experimental.

3.2 OBJETIVOS ESPECÍFICOS

Los objetivos específicos a continuación permiten enmarcar etapas específicas de la investigación que permitan obtener resultados puntuales y relevantes para el proyecto:

- Analizar las características y la composición de los vasos para bebidas calientes de cartón recubierto de LDPE.
- Seleccionar un método de fabricación del material compuesto polimérico que cumpla con los requerimientos presupuestados, se ajuste a los recursos disponibles y sea procesable en un entorno académico experimental.
- Seleccionar un set de pruebas físicas que permitan la caracterización del prototipo de material polimérico compuesto a base de vasos para bebidas calientes de cartón recubierto de LDPE.
- Proponer una aplicación acorde con los resultados obtenidos en la fase de caracterización experimental.

[1] LEPD son las siglas para Polietileno de baja densidad (Low density polyethylene), que es una de las familias del grupo de los polietilenos. Los dos grandes grupos son Polietileno de baja densidad y Polietileno de alta densidad

4 PLANTEAMIENTO Y FORMULACIÓN DEL PROBLEMA

Los sectores de alimentos, empaques y embalajes, requieren materiales específicos que hayan sido producidos bajo ciertos estándares de salubridad. Precisamente por las ventajas que representan estos productos, es que se ha incrementado el volumen de desechos derivados de estas actividades, es decir, el 20% de hasta el 7% del peso total de los desechos generados a nivel urbano corresponden a desechos plásticos (Ecopublipack, 2009) y, para este caso específico, miles de vasos desechados son depositados diariamente en los rellenos sanitarios.

Varias organizaciones a nivel mundial han atacado diversos problemas ambientales desde el punto de vista de la ingeniería; casos que incluyen proyectos exitosos y ambiciosos como los ejecutados por Tetra Pak, quienes han diseñado materiales con diversas aplicaciones a partir de los residuos de sus empaques (Tetra Pak). No obstante, cada residuo representa un reto y materia prima única, de tal manera que no puede ser procesada y concebido a la ligera o bajo los mismos parámetros utilizados para otros productos y desechos.

A pesar de contar con materia prima en abundancia, teniendo en cuenta que Colombia consume 313040 toneladas de plástico al año, de los cuales el 35% se utilizan en la producción de productos desechables, no se cuenta con un proceso claro de caracterización de materiales que provea una metodología y un proceso experimental que permita el diseño de un prototipo de un material polimérico compuesto, también caracterizable, dentro de un entorno experimental académico

Sin embargo, a pesar del contexto ambiental que claramente envuelve este proyecto, el proyecto aquí desarrollado da respuesta a la pregunta de cuál es el proceso que debe llevarse a cabo para la manufactura de un material polimérico compuesto a base de vasos de cartón para bebidas calientes recubiertos de LEPD, de tal manera que se le pueda dar un uso o aplicación en un área de algún sector productivo. Desde la

perspectiva de la ingeniería de producción, el reto consiste en hallar un proceso de manufactura y caracterización de un prototipo de material compuesto polimérico dentro de un entorno académico experimental.

5 MARCO TEÓRICO

5.1 MATERIALES POLIEMÉRICOS COMPUESTOS

Un material compuesto se define como aquel material compuesto de dos o más materiales en donde la integración artificial de los materiales permite mejores características que las que poseen cada uno de los materiales que lo componen por separado. Los materiales compuestos cuentan con una *matriz*, usualmente identificada como el material con la fase continua, y un componente con fase discontinua considerado el *refuerzo*. La función de la matriz es soportar el refuerzo y transmitir la carga al mismo. Sin embargo, las propiedades del material compuesto están dadas no solo por sus componentes, sino también por la distribución geométrica e interacción de los mismos. (Chung, 2003)

Los materiales compuestos se clasifican en fibrosos, particulados y laminados, y de acuerdo con la naturaleza de sus componentes se clasifican en compuestos de matriz plástica, de matriz metálica, y de matriz cerámica (Mazumdar, 2002). Lo compuestos de matriz polimérica, específicamente, son ampliamente utilizados por las propiedades intrínsecas de los polímeros y sus bajos costos de fabricación, especialmente en aplicaciones livianas. (Chung, 2003). En el caso de estos compuestos, la técnica más utilizada para su fabricación es el moldeo, por medio del cual es posible aplicar capas sucesivas de matriz y refuerzo de tal manera que se forma un laminado.

Las matrices poliméricas pueden ser resinas termofijas como el epoxi, resinas fenólicas, poliéster, entre otros, o resinas termoplásticas como el nylon, el polipropileno, etc. Los refuerzos pueden presentarse en forma de fibras o de partículas y se utilizan mecanismos de refuerzos continuos o discontinuos. Para el primer caso, se encuentra que esta tiene mayores índices de elasticidad y resistencia global. Las fibras en general buscan rigidificar la matriz e incrementar su resistencia.

La ley de las mezclas proporciona un marco de referencia en el que los volúmenes de cada material contenido en cada compuesto determinarán la prevalencia de las características de uno u otro en el compuesto final.

$$\mathbf{X_c} = \boldsymbol{X_m V_m} + \boldsymbol{X_f V_f}$$

Ecuación 1: Formula de ley de las Mezclas

Donde X representa la propiedad del material, V es la fracción volumétrica del material, m es el material de la matriz, f es el refuerzo y c es el material compuesto. Desde la perspectiva de la ley de las mezclas, se entiende que la propiedad del material, dentro del compuesto, con una mayor fracción volumétrica se verá así mismo mayormente representada en el material compuesto final.

6 SELECCIÓN DE MATERIA PRIMA Y DEL PROCESO

La arquitectura del compuesto fue seleccionada teniendo en cuenta la disponibilidad de recursos tecnológicos y las propiedades intrínsecas de la materia prima inicial, por lo que, en primera instancia, se hace importante estudiar las características de los vasos de cartón.

6.1 MATERIA PRIMA: VASOS DE CARTÓN

La materia prima del material compuesto aquí propuesto son los vasos de cartón para bebidas calientes. Estos vasos están compuestos por cartón de pulpa de papel virgen y polietileno de baja densidad. El recubrimiento polimérico es aplicado para evitar la filtración del líquido contenido en el vaso. Aunque el cartón es un material de fácil biodegradación, el plástico es necesario para mantener las características de barrera necesarias en este tipo de envases incluso a altas temperaturas. El proceso general requiere de una lámina de cartón de pulpa virgen al que se adhiere una película de plástico (LDPE); de este compuesto luego se hacen cilindros del tamaño del vaso, que luego se sellarán al calor para evitar filtraciones en sus junturas.

De los dos materiales que componen un vaso de cartón para bebidas calientes, el polietileno comprende entre 1.2% y el 5% de la composición total del mismo. (Alliance for Environmental Innovation, 2000). La distribución de los componentes es homogénea sin ninguna orientación aparente. Cada vaso tiene una capa de polietileno adherida a la cara interna del vaso. Trayendo a colación la ley de las mezclas ya mencionada en la sección anterior y teniendo en cuenta la distribución porcentual de cada material dentro de cada vaso, es de esperarse que las propiedades del cartón prevalezcan en mayor manera sobre las del plástico.

El cartón del vaso, como ya se había mencionado, es fabricado con pulpa de papel virgen. Esta pulpa tiene origen en materiales orgánicos, como madera, y es procesada químicamente para lograr la calidad de impresión necesaria. El cartón, a

diferencia del papel, es utilizado para esta aplicación por sus propiedades de dureza, resistencia a la deformación y capacidad de mantener su forma original bajo estrés (American Society of Testing and Materials, 1963). Las propiedades químicas pertinentes a esta aplicación, como punto de ignición (450°C aprox) resultan altamente importantes (Borch, Lyne, Mark, & Habeger, 2002).

El polietileno de baja densidad (LDPE), es un material usualmente translúcido y fácil de doblar para grosores inferiores a 1/8". A menos que sea doblado o estirado sobremanera, las láminas son resilientes, no tienen olor o color y al ser estiradas se deforman de manera uniforme. La estructura misma del polietileno de baja densidad permite que este tenga un bajo punto de fusión (98°C-115°C) y alta flexibilidad. Todas estas propiedades hacen del polietileno un agente de barrera preciso al ser adherido al cartón, proporcionando impermeabilidad y conservación de la temperatura (Peacock, 2000).

La unión de láminas de cartón con láminas de LEPE, la materia prima original, constituyen de por sí un material polimérico compuesto laminado.

6.2 ESTRUCTURA DEL PROTOTIPO

Dentro de los varios tipos de compuestos, ya mencionados en secciones anteriores, se consideraron una a una las opciones para determinar, de acuerdo a varios criterios, cual es el más apropiado para la estructuración y manufactura del prototipo de material compuesto a desarrollar.

Iniciando con los compuestos de matriz polimérica y refuerzo particulado, se consideró la utilización de una matriz termoestable con un refuerzo particulado donde el refuerzo lo comprenderían los vasos de cartón para bebidas calientes. Este proceso y modelo fue adoptado para la manufactura de las láminas de Ecoplak fabricadas a partir de residuos de envases Tetra Pak (Tetra Pak). En el exitoso caso del Ecoplak, un tipo de madera sintética, los residuos del empaque Tetra Pak son molidos y luego compactados al calor para formar un aglomerado en el que no aditivos o aglutinantes son adicionados para su conformación. La porción polimérica contenida en los residuos, al ser sometida al calor, se transforma en el compuesto que aglutina tanto al aluminio como a la pulpa

de papel ya particulada. En este material compuesto, el polietileno conforma la matriz y el aluminio y el papel o cartón actúan como refuerzos. Para replicar este proceso de manufactura y transformación para los vasos de cartón para bebidas calientes, deben analizarse varios factores.

En un compuesto de matriz con refuerzo particulado, el tamaño y forma del refuerzo deben ser cuidadosamente definidos. La forma de la partícula puede incidir en la rigidez y la elasticidad del compuesto final (Rothon, 2003). Por otro lado, si el LDPE contenido en el mismo residuo quiere ser utilizado como aglutinante o matriz dentro del compuesto, debe considerarse si la cantidad del mismo allí contenida es suficiente para cumplir tal labor. Sin embargo, se tiene que a diferencia de los envases Tetra, con un contenido polimérico de 20% (Tetra Pak), los vasos de cartón máximo contienen 5% de LDPE; adicionalmente, la producción homogénea de las partículas requiere de molinos especializados que den un tamaño constante garantizado a las partículas que procesa. Estos molinos son de difícil adquisición, están siendo actualmente utilizados en diferentes sectores de la industria y no se dispone de uno para experimentación. Dadas las limitantes ya descritas, se decide no replicar este proceso para la manufactura del prototipo de material.

En los compuestos de matriz con refuerzo fibrosos, se debe determinar el tipo de fibra, corta o continua, de acuerdo a las ventajas y desventajas que cada una presenta. Por ejemplo, las fibras continuas tienen mayor efecto en las propiedades mecánicas, de resistividad eléctrica, conductividad terma, entre otras (Chung D. D., 2010), del material compuesto. De igual manera, las fibras deben ser colocadas dentro de una matriz polimérica que también ofrezca rigidez al material. Dentro del tipo de matrices disponibles, se encuentran las matrices termofijas como resinas epóxicas, políester, o vinilos y matrices termoplásticas tales como polietileno, PVC o polipropileno. En general los compuestos con matrices termoplásticas son más resistentes al impacto y a la fatiga, son reciclables, tienen menor tiempo de procesamiento, entre otros (Mazumdar, 2002).

Para la manufactura del prototipo de material compuesto con una estructura de matriz con refuerzo fibroso, independientemente del tipo de matriz, se teme que al entrar

en contacto con la matriz en estado líquido, el refuerzo conformado en mayor porcentaje por cartón, perderá sus características de rigidez y en últimas se deshaga antes de que finalice el curado del material final. Adicionalmente, para la conformación de las placas de material y las probetas para su prueba, se requiere de algún tipo de sistema de inyectado donde se puedan controlar variables como temperatura, velocidad de inyectado, velocidad de llenado, etc; sin embargo, dado que no se cuenta con un sistema que permita realizar o controlar este tipo de proceso, se decide buscar otro tipo de opciones.

Por último, los materiales laminados pueden ser considerados materiales o estructuras sándwich, compuestos a su vez por capas que usualmente consisten de un refuerzo impregnado de una resina polimérica y cuyas fibras pueden tener diferentes orientaciones. Las láminas de orientación unidireccional están constituidas por capas de refuerzos dispuestos paralelamente dentro de la matriz.

De acuerdo a la aplicación y las propiedades deseadas del material final, se pueden colocar tantas capas como sean necesarias, con distintas orientaciones y con tantas secuencias como lo amerite el caso. Por ejemplo, en el caso de las capas unidireccionales, se tiene que estas tienen buenas propiedades mecánicas en la dirección de las fibras y esta propiedad podrá tenerse en cuenta en el momento del diseño y fabricación del material laminado compuesto.

Teniendo en cuenta que la materia prima inicial, los vasos de cartón para bebidas calientes, puede ser considerada un compuesto en sí, se decide hacer uso de su estructura y propiedades para elaborar el material compuesto como un compuesto laminado en donde cada lámina resultante de cada vaso compondrá cada una de las capas del material laminado. Así como el proceso de de las placas de Ecoplak hacen uso de las propiedades intrínsecas del polietileno, en este caso también se utilizarán las películas de LDPE para actuar como agente adhesivo entre las capas aplicando calor no siendo así necesario agregar ningún tipo de aditivo o agente y haciendo así uso completo de cada lámina

.

6.3 MANUFACTURA DEL PROTOTIPO DE MATERIAL POLIMÉRICO COMPUESTO

La manufactura de los vasos de cartón se lleva a cabo siguiendo cada uno de los pasos o etapas descritos a continuación:

1. *Recolección de materia prima:* Los vasos de cartón para bebida calientes, ya usados y desechados, son recolectados directamente en las tiendas de una reconocida cadena de café en la ciudad de Bogotá. Se decide utilizar los vasos de cartón desechados provenientes de una misma fuente de tal manera que se garantice que los vasos sean de un mismo proveedor y hayan tenido el mismo tratamiento y uso. Los vasos recolectados están contenidos en bolsas de basura mezclados junto con otro tipo de residuos como vasos de plástico, servilletas y residuos de comida como leche, café, panecillos, galletas, etc.

Ilustración 1: Recolección de materia prima
Fuente: Adriana Jiménez, 2013

2. *Selección:* En esta etapa de selección, se busca que los vasos seleccionados cuenten con una estructura física aceptable, es decir, sin rasgaduras o partes faltantes, y que el cartón no haya sido penetrado por los mismos elementos orgánicos que contuvieron. Una vez los vasos son clasificados de acuerdo a su tamaño, se procede al proceso de limpieza y lavado.

Ilustración 2: Selección de vasos de cartón
Fuente: Adriana Jiménez, 2013

3. *Limpieza y lavado*: Para limpiar los vasos se retira todo el material orgánico del mismo y se procede a hacer un rápido lavado, evitando sumergir el material el agua para prevenir que el cartón absorba el líquido y se deshaga, arrugue o deteriore. Una vez se han lavado y se ha verificado que cualquier rastro de material orgánico se ha eliminado, los vasos se secan y se dejan reposar en corrientes de viento caliente para que la humedad que haya podido absorber el cartón seque completamente. El lavado se realiza en agua a 18°C sin utilizar ningún agente químico adicional, teniendo cuidado de no sumergir los vasos para evitar que penetre agua en los mismos. Se realiza lo que comúnmente se conoce como un enjuague rápido durante 30 segundos proseguido de un secado con toallas de papel para retirar el exceso de humedad y se finaliza al exponerlos a aire caliente durante 10 minutos para minimizar el contenido de agua en los mismos. Las ilustraciones a continuación corresponden a cada uno de los pasos descritos.

Ilustración 3: Enjuague de materia prima
Fuente: Adriana Jiménez, 2013

Ilustración 4: Retiro de exceso de humedad
Fuente: Adriana Jiménez, 2013

Ilustración 5: Secado final de materia prima
Fuente: Adriana Jiménez, 2013

4. *Corte y acondicionamiento:* Los vasos limpios y secos se abren y se remueve el fondo, los bordes y la línea de unión, dejando así una lámina de 0,5 milímetros de grosor lista para ser procesada. Este procedimiento puede llevarse a cabo utilizando tijeras, bisturí o la herramienta de preferencia, siempre y cuando pueda utilizarse de manera segura y permita la menor cantidad de desperdicios posible.

Ilustración 6: Corte y acondicionamiento de la materia prima
Fuente: Adriana Jiménez, 2013

5. *Prensado*: Para construir placas, y el nuevo material compuesto, se apilan las láminas del la materia prima inicial y se aplica calor directo una a una. Al aplicar calor y presión sobre cada una de las placas, la lámina de polietileno, al aumentar su temperatura, aumenta su viscosidad, lo que permite la adherencia de cada una de las láminas entre sí (Murathan, Murathan, Guru, & Balbasi, 2007). A cada capa se aplicó presión uniforme a una temperatura de entre 180°C y 200°C y una presión equivalente a 19 Kg durante 3 minutos hasta alcanzar espesores promedio de 1cm.

Se determinó un espesor final de 1 centímetro dado que este un calibre ampliamente utilizado para diversos materiales en la industria como el MDF, el corcho, los aglomerados e incluso e Ecopak (Tetra Pak).

Ilustración 7: Prensado de láminas para conformación de material compuesto
Fuente: Adriana Jiménez, 2013

6. *Enfriamiento:* Las placas terminadas se dejan enfriar a temperatura ambiente durante 1 hora en un ambiente poco húmedo. Las placas pueden almacenarse en pilas, en ambientes secos evitando cambios bruscos de temperatura.

Ilustración 8: Enfriamiento de placas de material polimérico laminado
Fuente: Adriana Jiménez, 2013

El proceso de manufactura completo del material polimérico laminado se resume en la ilustración 9 a continuación.

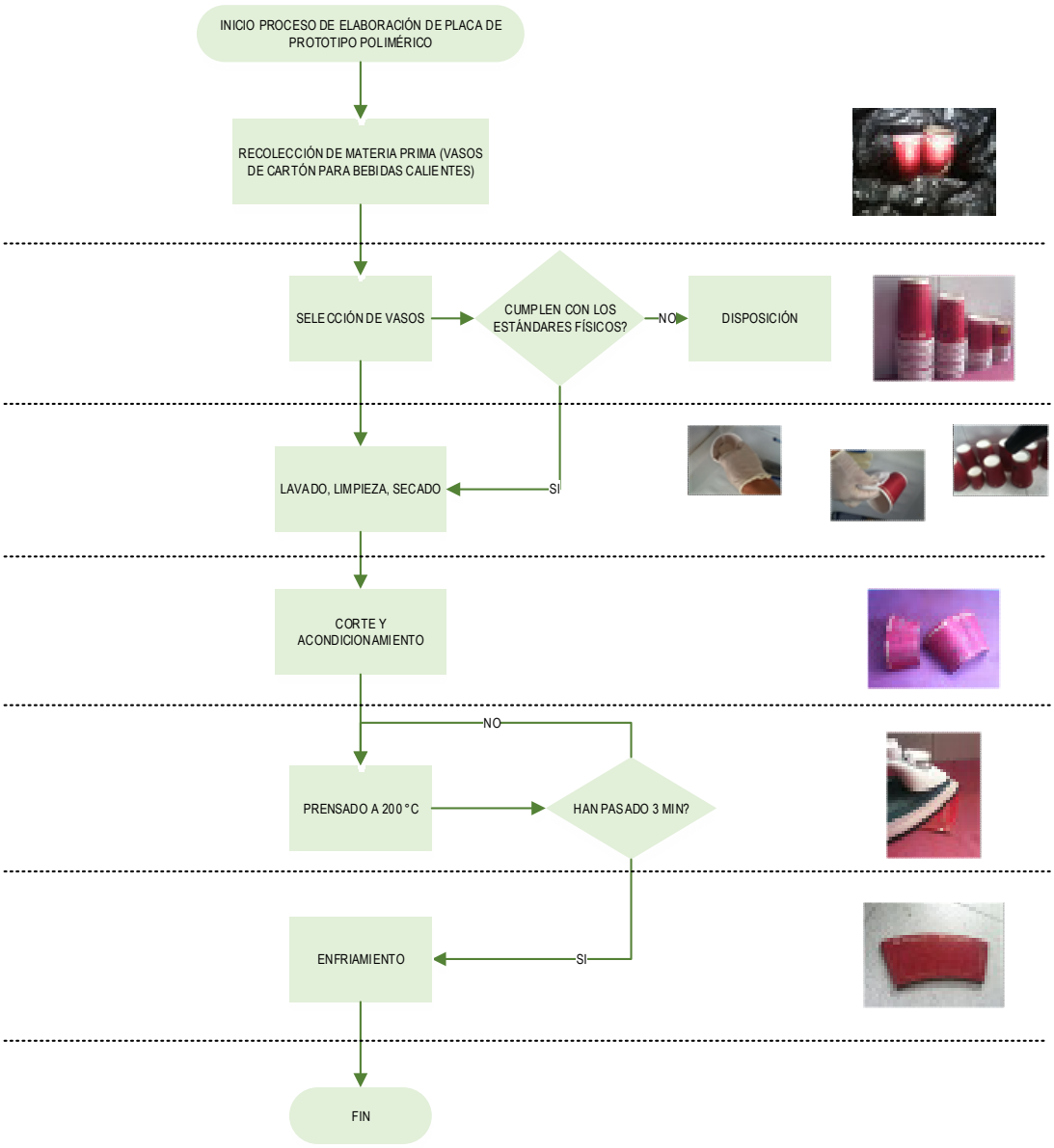

Ilustración 9: Diagrama de flujo de manufactura de material compuesto
Fuente: Adriana Jiménez, 2013

El proceso de construcción del nuevo prototipo permite la utilización de las láminas de los vasos de cartón sin ejecutar ningún proceso mecánico adicional o la inclusión de pegamentos o material polimérico.

El material resultante se clasifica como un compuesto polimérico laminado.

7 IDENTIFICACIÓN DE PROPIEDADES FÍSICAS

Para identificar las propiedades físicas del prototipo de material, se selecciona un set de pruebas físicas que permitan obtener un panorama de la estructura y características inherentes a la composición particular del prototipo de material propuesto y su interacción y comportamiento ante los elementos en condiciones específicas de especial interés para variadas aplicaciones.

Las pruebas físicas se desarrollan de acuerdo a las normas internacionales ASTM para proveer un marco experimental legítimo y parametrizado. Teniendo en cuenta que el prototipo es considerado un compuesto polimérico, se hará referencia a las normas dispuestas para polímeros y sus compuestos. Sin embargo, para aquellas pruebas para las que no se cuenten con los equipos, recursos o condiciones necesarias para lleva a cabo la prueba de acuerdo al estándar, se recurrirá a la teoría de tal manera que se obtengan resultados de referencia que permitan una aproximación. El número de probetas, las condiciones ambientales y demás consideraciones se encuentran consignadas en cada una de las normas mencionadas para cada prueba

7.1 ABSORCIÓN DE AGUA

La prueba de absorción de agua, considerada una prueba húmeda, puede dar indicios de la estabilidad del material en ambientes altamente húmedos o que impliquen un contacto directo con el agua y de su aptitud para su posible utilización en diversas aplicaciones.

Las pruebas de absorción de agua siguen los lineamientos descritos en la norma ASTM D570-98. El objetivo de la prueba es evaluar el cambio dimensional causado por la absorción de agua, y cualquier otro cambio subsecuente. Como allí se consigna, la prueba de absorción de agua se realiza sumergiendo las probetas en agua destilada a 23°C ± 2°C y a una humedad relativa de 50% ± 10. La cantidad de líquido absorbido es determinado al medir el cambio en la masa de cada muestra.

El número, las dimensiones y los acabados de las probetas se establecieron a partir de las secciones 5.3 y 6.1 de la norma, y para su mecanizado final se siguieron los lineamientos descritos en la sección 5.6 de la misma.

Las probetas cuentan con unas dimensiones de 76.2 mm de largo, 25.4 mm de ancho y 10 mm de profundidad y fueron cortadas de su placa inicial utilizando un láser CO2. Dado el efecto del láser, los bordes, aunque precisos, retienen una coloración oscura que debe ser removida utilizando lija fina a baja velocidad para evitar el calentamiento de los bordes y del material polimérico y así prevenir la alteración de las propiedades y estructura del mismo. Una vez debidamente mecanizadas, las probetas se limpian con un paño seco no abrasivo para remover cualquier material particulado o sustancia que pueda afectar los resultados.

Dado el alto porcentaje de contenido celulósico del material, se seleccionó el método de inmersión de 24 horas descrito en la sección 7.1 de la norma.

Par la ejecución de este experimento se utilizaron los siguientes implementos:

1. Mufla Barnsetad thermolyne de control digital a 23°C, utilizada para garantizar el ambiente de prueba.
2. Contenedor de vidrio de 2 L de capacidad
3. Agua destilada a 23°C
4. Termómetro de vidrio
5. Pesa analítica Sartorius referencia CP224s con precisión de hasta 0.1 mg utilizada para la precisa medición de los pesos iniciales y finales de las probetas.
6. Calibrador pie de rey digital para medir las dimensiones iniciales y finales de las probetas.
7. Máquina de gravado y corte láser CO2 marca Epilog para el corte de las probetas
8. Lija 80, 400 y 1000 para el acondicionamiento final de las probetas

Una vez mecanizadas y acondicionadas, y siguiendo las indicaciones de la sección 7.1 de la norma, las probetas son medidas y pesadas para registrar las condiciones iniciales y luego se sumergen en el recipiente con agua destilada a 23°C durante 24 horas. Para asegurar la estabilidad de la temperatura durante la duración de la prueba, se utilizó una mufla de control de temperatura digital para alojar el recipiente.

Una vez en el recipiente, debe asegurarse que, aunque floten, las probetas deben estar cubiertas en su totalidad por el líquido.

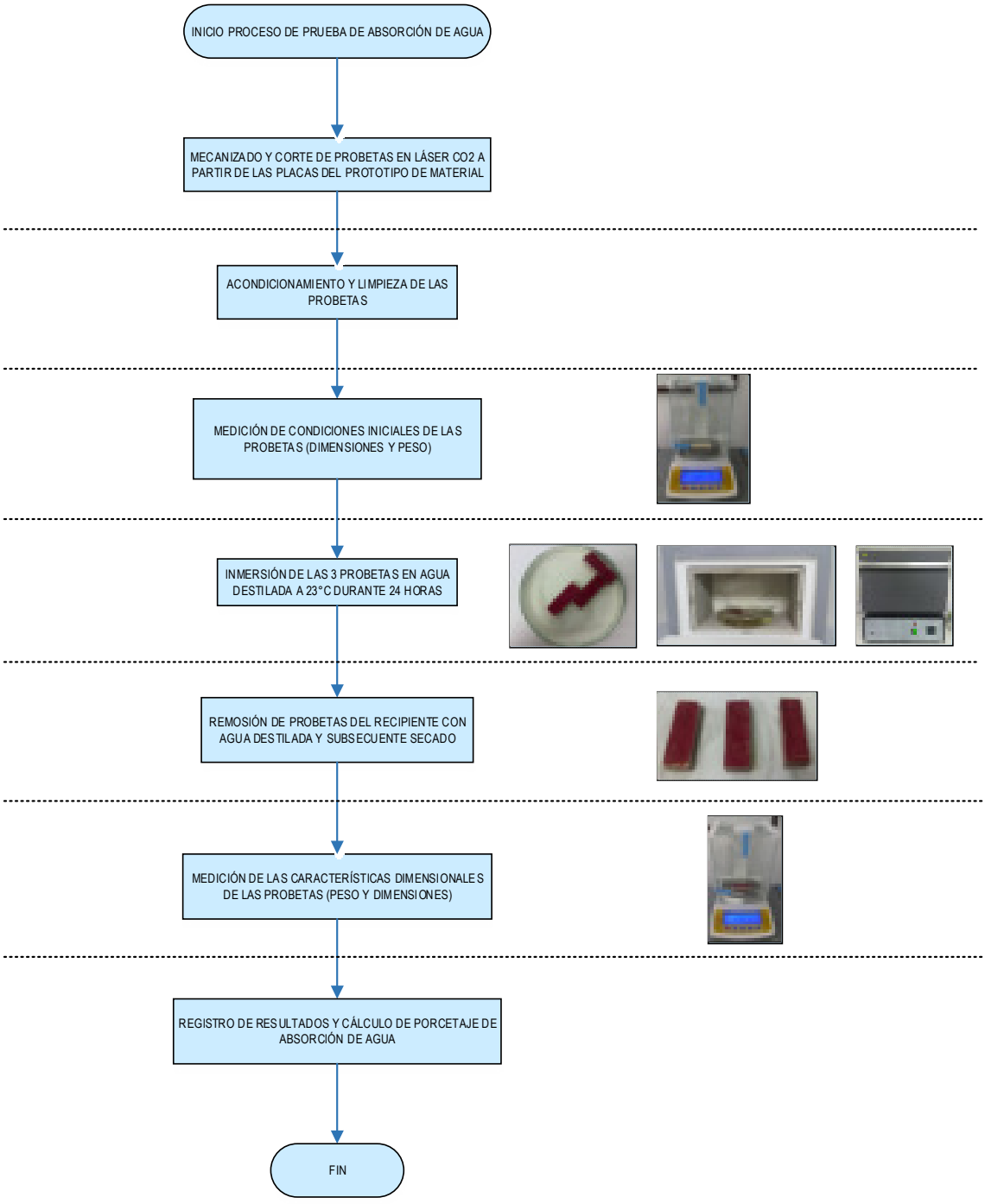

Ilustración 10: Diagrama de flujo de prueba de absorción de agua
Fuente: Adriana Jiménez, 2013

		Promedio peso inicial	Peso post-inmesión	% absorción/cambio
Probeta 1	Peso Inicial (gr)	13,6860	19,6749	43,76%
	Largo (mm)	74,8500	75,06	0,28%
	Ancho (mm)	24,8600	25,11	1,01%
	Alto (mm)	9,5100	12,67	33,23%
Probeta 2	Peso Inicial (gr)	13,6868	18,5674	35,66%
	Largo (mm)	75,8800	76,99	1,46%
	Ancho (mm)	24,8800	25,06	0,72%
	Alto (mm)	10,2100	12,5	22,43%
Probeta 3	Peso Inicial (gr)	12,4854	17,9544	43,80%
	Largo (mm)	74,7400	75,49	1,00%
	Ancho (mm)	23,5000	23,68	0,77%
	Alto (mm)	10,5500	13,26	25,69%

Tabla 1: Resultados prueba de absorción de agua

Adicional a los cambios evidenciados en las dimensiones y el peso de las probetas luego de las 24 horas de inmersión en agua destilada bajo las condiciones ya descritas, se observa un tinte particular del agua que las contenía. El agua que en un comienzo era cristalina, ahora, aunque no turbia, como se evidencia en la Ilustración 3, tiene una leve coloración de color café. Sin ninguna desintegración evidente o aparente de las probetas, se desconoce si esto es resultado de residuos orgánicos remanentes del café que en su momento contuvieron los vasos o si corresponde a la liberación de pigmentos utilizados para la impresión digital de los mismos.

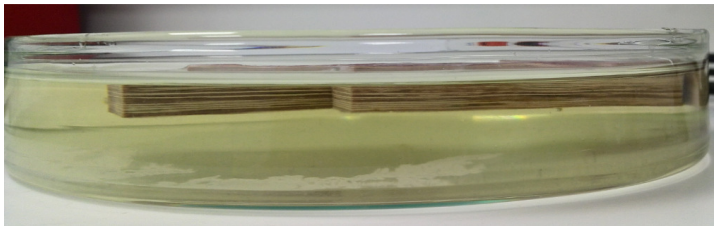

Ilustración 11: Coloración de agua en prueba de absorción de agua
Fuente: Adriana Jiménez, 2013

Luego de una examinación física de las probetas, se observa que a pesar de los cambios dimensionales de las mismas, las uniones entre las capas del laminado se mantienen aunque no se puede dar fe de su estabilidad o fuerza. No se evidencian roturas, grietas o alguna anomalía en la superficie de las muestras.

7.1.1 Análisis de resultados

Dados los altos índices de absorción de agua obtenidos para las tres muestras, es importante considerar aplicaciones dentro del área de la construcción en ambientes sin niveles excesivos de humedad o que impliquen un contacto directo con el agua o líquidos en general.

Para proporcionar un marco de referencia, a continuación se presenta un cuadro comparativo de materiales en el área de la construcción,

Material	% Absorción de agua (24h)
Durock – Cement board	15
Material prototipo laminado	35-43
Madera aglomerada	20-75

Tabla 2: Comparación de porcentaje de absorción de agua de 3 materiales [2]

El Durock, una lámina de cemento utilizada como respaldo para baldosas, presenta mejores características de impermeabilidad que el material prototipo laminado, mas este último, a su vez, puede llegar a ser menos permeable que la madera aglomerada. Los

Los valores comparados se obtuvieron, aunque bajo distintas normas, en términos de tiempo de inmersión de 24 horas.

7.2 IGNICIÓN

Para hacer una primera aproximación a las propiedades de resistencia al fuego del prototipo, se realiza la prueba de ignición que permite evaluar la facilidad de ignición y la rata de propagación de la llama.

La facilidad con la que se enciende un material es crítico al momento de evaluar que pasa en el momento en que el material entra en contacto con el fuego.

La rata a la que se propaga el fuego en el material, aunque también depende del ambiente en el que se esté desarrollando la prueba, está influenciado en gran manera por

[2] Los datos de los materiales obtenidos fueron extraídos utilizando la base de datos de materiales en línes wwww.matweb.com

el material. En esta prueba, se observa el tiempo que demora una llama en viajar una distancia de una superficie dada.

Las pruebas de ignición se llevan a cabo siguiendo los lineamientos descritos en la norma internacional ASTM D635. La norma describe el montaje, las condiciones ambientales, las dimensiones de las probetas y los comportamientos a observar durante la ejecución de la prueba.

Las dimensiones de las 3 probetas, como se especifica en la sección 7.2 de la norma, son 125 mm de largo por 13 mm de ancho y con un espesor de 10 mm. Siguiendo las instrucciones del montaje en el apartado 9 de la norma, se hacen las marcas visibles a los 10 cm y 2 cm a lo largo de la probeta y se procede a ejecutar el montaje. Las muestras son sostenidas horizontalmente utilizado una mordaza mientras se ubica en el extremo opuesto a una llama azul de gas propano de 2 cm de alto a un ángulo de 45°. La prueba debe ejecutarse dentro de una cámara de pruebas que bloquee cualquier corriente de aire y en general permita que las condiciones de temperatura, 15°C a 35°C, y humedad relativa, 45% a 75 %, puedan mantenerse y garantizarse.

Para dar cumplimiento a los requerimientos descritos por la norma para la ejecución de la prueba, se utilizaron los siguientes implementos.

1. Medidor de condiciones ambientales para temperatura y humedad relativa
2. Calibrador pie de rey digital para medir las dimensiones iniciales y finales de las probetas.
3. Cámara de pruebas de 0,5 m3 de capacidad aproximadamente
4. Pipeta de gas propano
5. Mordaza

Las probetas fueron mecanizadas y acondicionadas siguiendo los mismos procedimientos descritos en la sección de absorción de agua; se utilizó el mismo sistema láser para su corte en lo que respecta al sistema láser y lija suave para su terminado.

Una vez concluido el montaje, se procede a ejecutar la prueba bajo las condiciones ya expuestas. Una vez colocada en la posición indicada, el extremo suelto

de la muestra es expuesto durante 30 segundos a la llama. Desde el momento en que se inicia la prueba debe prestarse especial atención a las características de la llama, comportamiento de la propagación de la misma en el material, comportamiento del material y el tiempo que tarda en el que este tarda consumirse o en el que la llama alcanza la marca de los 10 cm. El diagrama de flujo en el Diagrama 3 detalla las etapas de la prueba de ignición

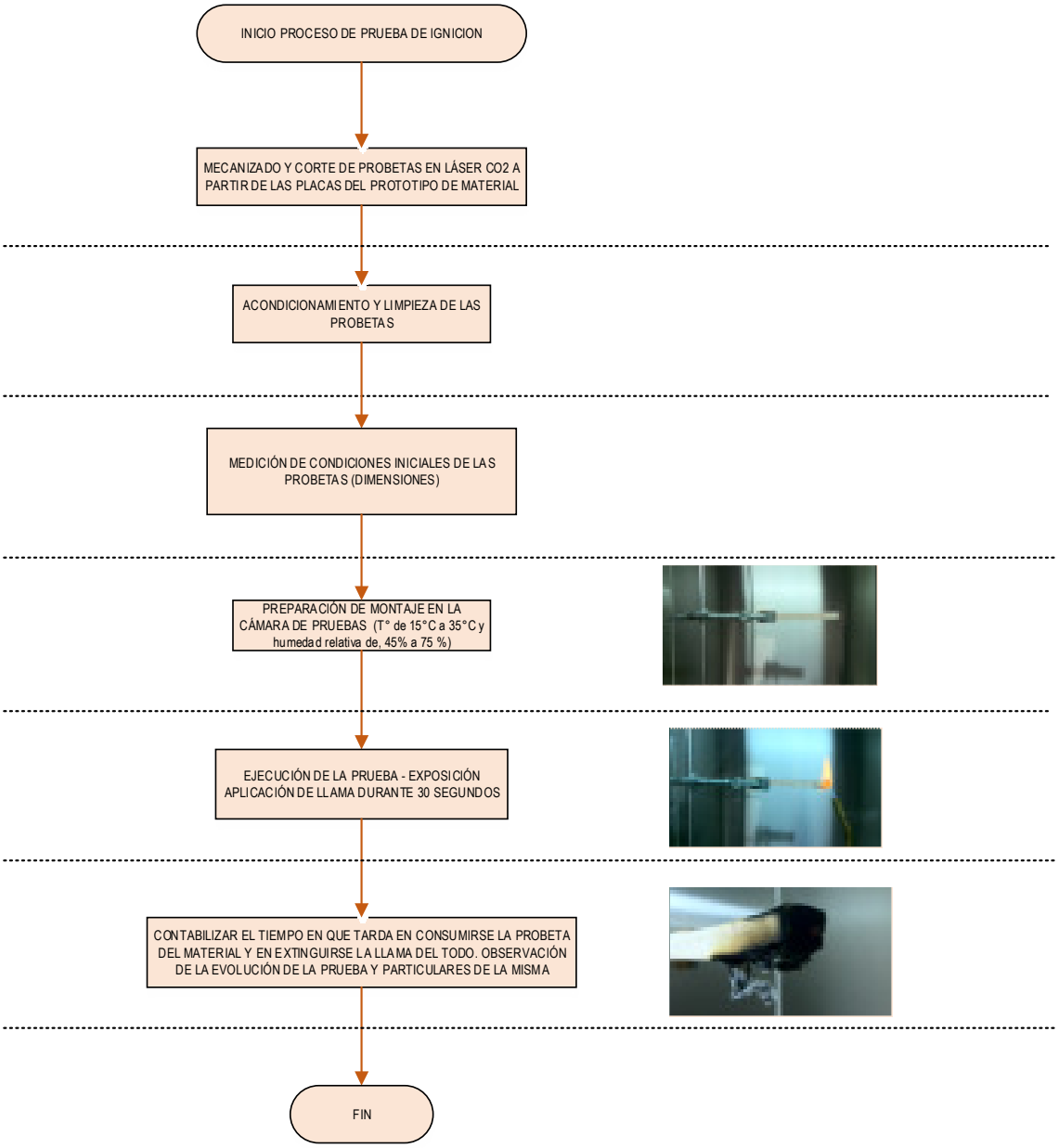

Ilustración 12: Diagrama de flujo de prueba de ignición
Fuente: Adriana Jiménez, 2013

Luego de la exposición a la llama durante 30 segundos se observa que el material se enciende generando una llama amarilla y humo blanco. Una vez retirada la llama, el material extingue su llama en aproximadamente 4 segundos (Diagrama 5), más la combustión no acaba en su totalidad pues se aprecia una continua emisión de humo y puntos de ignición aún activos (Diagrama 6).

Ilustración 13: Extinción de llama
Fuente: Adriana Jiménez, 2013

Ilustración 14: Puntos de ignición
Fuente: Adriana Jiménez, 2013

7.2.1 Análisis de resultados

La tabla 4 resume los tiempos de extinción observados para las 3 muestras. El tiempo aquí registrado inicia desde el momento en que se retira la llama hasta cuando se extingue por completo el material y no se observan humo ni puntos de ignición.

	Muestra 1	Muestra 2	Muestra 3	Promedio
Tiempo extinción llama (seg)	8	5	7	*6,67*
Tiempo total extinción completa (seg)	208	292	235	*245,0*

Tabla 3: Resultados prueba de ignición

Luego de retirar la fuente de calor externa, la llama, se observa que la llama en el material tiende a desaparecer en un periodo promedio de 6,67 segundos y en total se auto extingue en un tiempo promedio de 4 minutos y 5 segundos. Se observa en este periodo de tiempo que a medida que se consume lentamente el material su desintegración se hace capa a capa y en la medida en que cada capa estuvo más expuesta a la fuente de calor, así mismo también se enciende y desintegra. Este efecto retardante hace que el fuego no se propague transversalmente entre las capas del material. Como se puede observar en el Diagrama 6, las capas inferiores, con una aparente mayor exposición a la llama, se despegan del resto de la probeta y se consumen por separado.

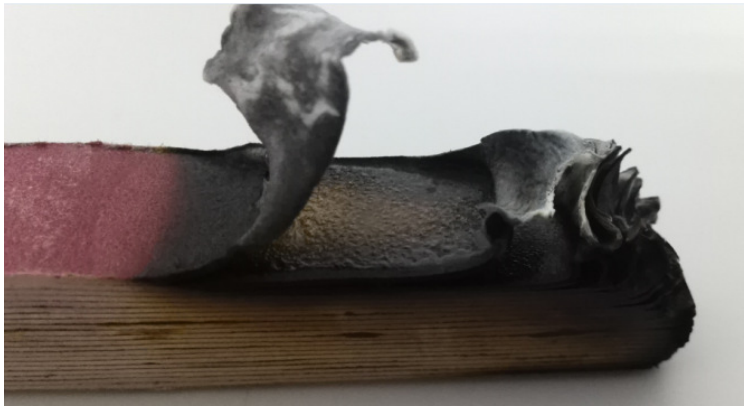

Ilustración 15: Probeta luego de prueba de ignición
Fuente: Adriana Jiménez, 2013

Aunque estas primeras capas superaron la marca de los 2.5 centímetros, las muestras en general muestran que escasamente se alcanzó a quemar, mas no a consumir, menos de un centímetro de la probeta y no se observa una propagación del fuego luego de que se retira la fuente de fuego externa.

De acuerdo con los resultados obtenidos y considerando la categorización propuesta en la norma, que también hace referencia la clasificación internacional UL 94 que clasifica a los materiales de acuerdo a su inflamabilidad, se determina que el

comportamiento del material puede ser clasificado como HB (Horizontal Burning) dado que la llama no sobrepasa la marca de los 2.5 centímetros. Los materiales en esta categoría se consideran autoextintores.

7.3 DENSIDAD

Determinar la densidad del material permite de alguna manera observar como un material interactuará con otros, en ambientes líquidos o en ciertas condiciones ambientales.

En esta oportunidad determinaremos la densidad del material teniendo en cuenta los conceptos teóricos al respecto y haciendo uso de algunos elementos para determinar las variables.

La densidad se define como la masa por unidad de volumen, y se expresa con la letra griega rho, como se indica en la ecuación

$$\rho = \frac{m}{v}$$

Ecuación 2: Fórmula de densidad

Para determinar la densidad del material de forma experimental, como se detalla en la Ilustración se cuenta con tres muestras representativas del material, las cuales son pesadas en una balanza digital para determinar su masa. Teniendo en cuenta el alto porcentaje de absorción de a agua de este material, cada muestra es recubierta con una fina capa de material impermeable (esmalte) de tal manera que al ser sumergidas en agua la medida de volumen desplazado sea lo más acertada posible. Para determinar el volumen, cada probeta es sumergida en agua destilada (con densidad 1 gr/cm³) y se registra el volumen de líquido desplazada, que en este caso corresponderá al volumen del espécimen.

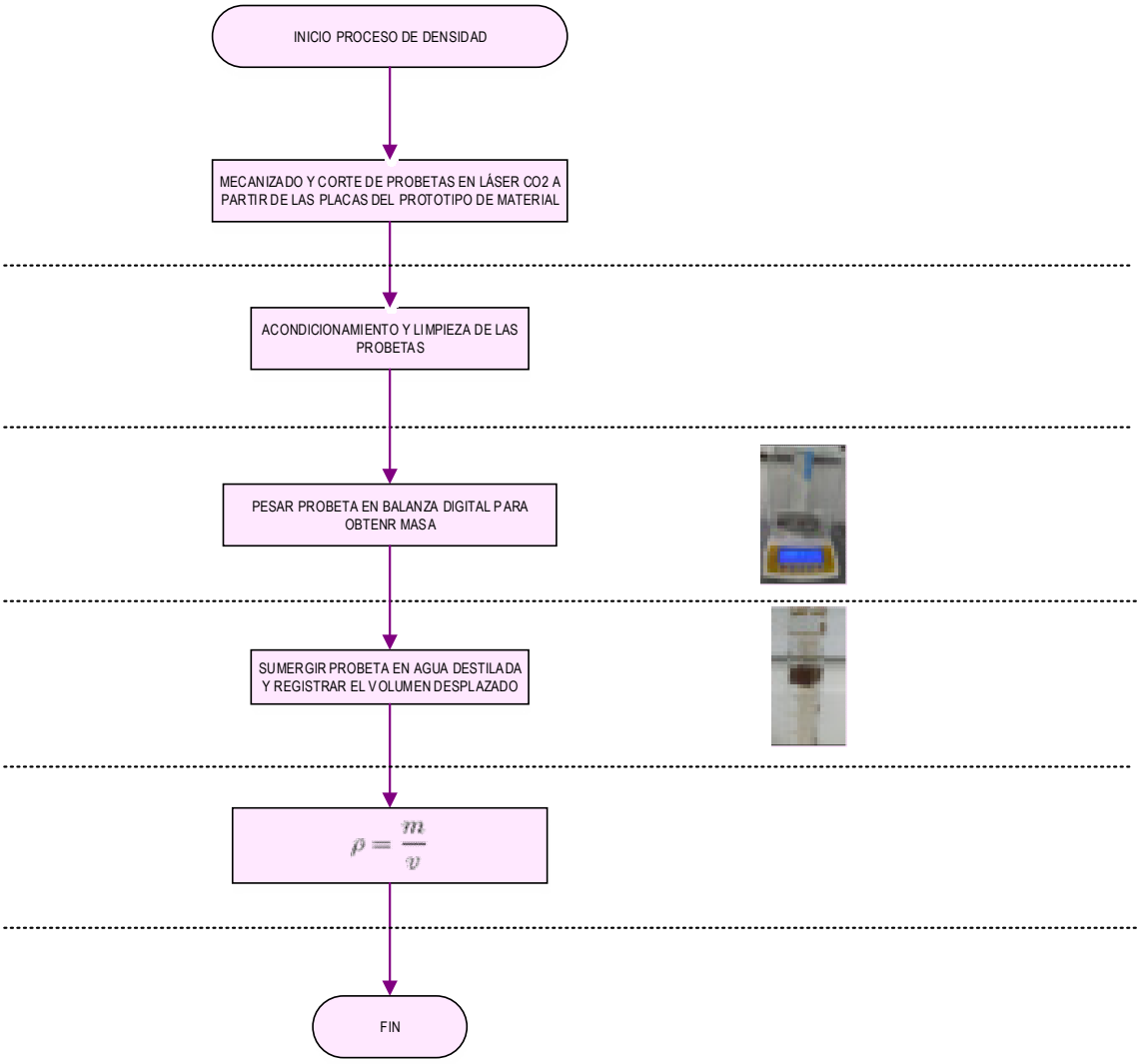

Ilustración 16: Diagrama de flujo prueba experimental de Densidad

Los resultados para las tres probetas se detallan en la Tabla 4 a continuación:

Probeta	masa (gr)	Volumen desplazado (cm³)	Densidad (gr/cm³)
1	1,6515	2	0,8258
2	1,5870	1,9	0,835
3	1,6307	2	0,8154
			0,825

Tabla 4: Resultados densidad experimental

7.3.1 Análisis de Resultados

La densidad promedio del material es inferior a la del agua; sin embargo, para presentar un marco de referencia, la tabla a continuación permite contrastar la densidad del material prototipo con respecto a otros materiales:

Material	Densidad (gr/cm³)
Balso	0,160
Ecoplak (aglomerado Tetra pak)	0,600
Material prototipo laminado	0,825

Tabla 5: Tabla comparativa de densidades[3]

El material prototipo puede llegar a ser más denso que algunos tipos de maderas e incluso que el Ecoplak, que es material polimérico compuesto particulado fabricado a partir de desechos de empaques Tetra Pak.

[3] Los datos de los materiales obtenidos fueron extraídos utilizando la base de datos de materiales en línea www.matweb.com

7.4 PRUEBAS MECÁNICAS

Las pruebas mecánicas son especialmente importantes si se quiere hacer una evaluación del comportamiento del material bajo carga mecánica o deformación.

7.4.1 TENSIÓN

La prueba de tensión permite predecir el comportamiento del material bajo una carga. Puede identificarse que tan fuerte y rígido es el material al evaluar su deformación o punto de rotura bajo estrés. El objetivo principal de esta prueba es determinar la rigidez del material por medio del módulo de Young de tal manera que se tenga una idea de cual podría ser el comportamiento del material bajo carga.

La prueba teórico-experimental aquí desarrollada busca proveer una aproximación a la identificación de las propiedades de tensión asociadas al material prototipo. Aunque las probetas cumplen con las exigencias descritas en la norma D638-10 en su apartado 6, con las dimensiones generales ilustradas en el Diagrama 17, la obtención de los resultados finales se lleva a cabo mediante un montaje experimental (Diagrama 18) que permita la aplicación de cargas a las probetas mientras se evalúa el efecto que estas tienen en deformación o rotura. El registro de la información que esto arroja permitirá graficar el comportamiento del material bajo carga y así extraer el módulo de Young o módulo de elasticidad longitudinal.

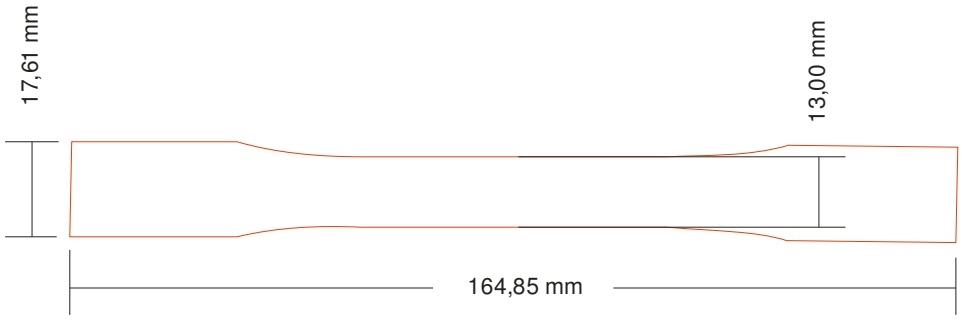

Ilustración 17: Dimensiones de probeta para prueba de tensión
Fuente: Adriana Jiménez, 2013

Ilustración 18: Montaje para prueba de tensión
Fuente: Adriana Jiménez, 2013

El mecanizado y acondicionamiento de las probetas se lleva a cabo utilizando la misma metodología aplicada para las muestras utilizadas en previas secciones y se establecieron tres sets de probetas de diferentes grosores de tal manera que se pueda evaluar como el número de capas en el material prototipo incide en las propiedades de tensión.

Para la ejecución de la prueba experimental se cuenta con los siguientes implementos:

1. Comparador de carátula con precisión de 0,01 milímetros que permite medir variaciones de mediciones, en este caso del desplazamiento o elongación de las probetas bajo prueba.
2. Montaje para la ubicación de probetas y carga de pruebas
3. Calibrador pie de rey para medición de las dimensiones de las probetas.

En términos generales, el procedimiento consiste en aplicar una carga creciente a un espécimen o probeta de tal manera que los cambios dimensionales causados por dicha carga se puedan registrar hasta que se produzca la falla del material. Los cambios en la deformación del material son luego graficados y analizados de tal manera que pueda obtenerse el módulo de Young. En el montaje utilizado las probetas son sujetas

por unas mordazas y la carga es aplicada utilizando una relación de distancias. Los micro o macro desplazamientos progresivos son registrados por un comparador de caratulas hasta que se produce la falla. Las distancias a las cuales se ubican cada uno de los elementos del montaje son cuidadosamente registrados para realizar el cálculo de las relaciones en el momento de hacer el análisis final.

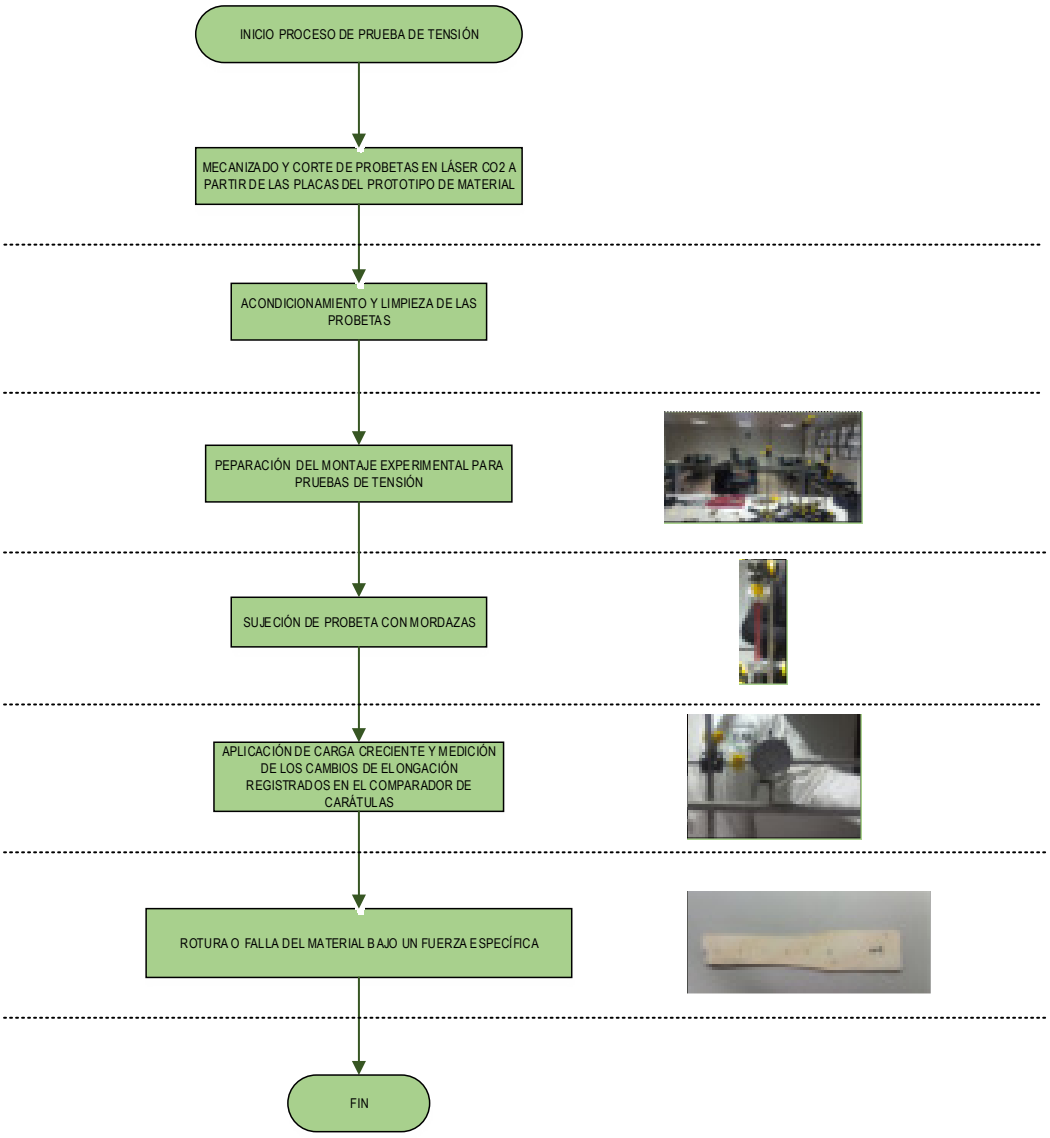

Ilustración 19: Diagrama de flujo prueba de tensión
Fuente: Adriana Jiménez, 2013

El procedimiento se llevó a cabo para tres tipos de probetas con diferentes espesores, es decir, con diferente número de capas, esto con el fin de establecer si este factor tiene alguna incidencia significativa en la elasticidad del material.

A partir de una gráfica de esfuerzo vs. deformación es posible deducir el módulo de Young si se extrae la pendiente de la porción elástica de la misma, dado que en esta sección la deformación es relativamente proporcional al esfuerzo (Wilson & Buffa, 2003).

El módulo de Young para cada probeta se obtuvo siguiendo el procedimiento descrito en el Anexo 1, en donde por medio de un método gráfico y ciñéndose a la teoría, se obtiene la constante de elasticidad. La ilustración 20 resume gráficamente los resultados obtenidos para cada una de las probetas. Las gráficas corresponden al sector elástico de la curva de esfuerzo vs. deformación dado que por las limitaciones del montaje experimental no fue posible alcanzar el sector plástico o el punto de rotura.

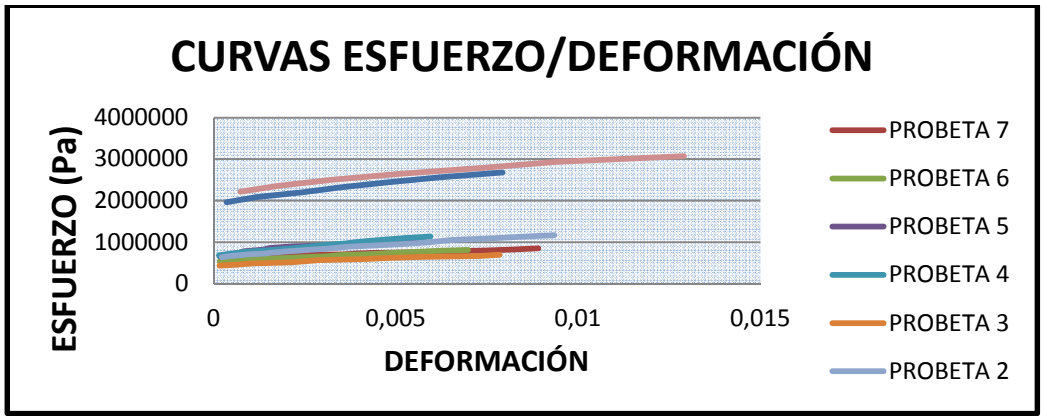

Ilustración 20: Grafica comparativa de curvas Esfuerzo/Deformación
Fuente: Adriana Jiménez, 2013

De acuerdo al procedimiento propuesto y partiendo de las gráficas obtenidas, se tiene que el módulo de Young para cada una de las probetas es el siguiente:

Probeta	Número de capas	Módulo de Young € (MPa)
0	2	70
1	2	90
2	4	60
3	6	30
4	4	70
5	4	70
6	6	40
7	6	30

Tabla 6: Módulo de Young por probeta de acuerdo al número de capas

7.4.1.1 Análisis de resultados

A pesar de la aparente diferencia que existente entre los módulos de Young para cada uno de los grupos de probetas, es necesario realizar un análisis más acertado que permita evaluar con mayor certeza si el número de capas incide en la rigidez del material.

Por otro lado, es importante notar que debido a la misma naturaleza del montaje experimental, un considerable nivel de error estará inherentemente asociado a los resultados. Es decir, por ejemplo, no es posible determinar en este momento que porcentaje de la elongación registrada corresponde a la probeta del material y que otra a la deformación de las mordazas o de las mismas barras metálicas que sostienen los pesos. Sin embargo, los rangos reportados si pueden servir como una primera aproximación a la evaluación de la rigidez del material.

Para el desarrollo del análisis experimental, se pretende determinar si el factor, el módulo de elasticidad del material, se ve afectado por los niveles, en este caso el número de capas del material. En este caso, sin embargo, solo se pretende determinar si las capas inciden o no en las propiedades de tensión del material, mas no en qué grado o de qué manera lo hace. Los tres niveles, determinan el número de capas de cada grupo de probetas. Se determinan $2k$ número de capas: 2 capas, 4 capas y seis capas. La hipótesis que se quiere corroborar es que el número de capas, los tres niveles, no tienen incidencia alguna en el factor el factor o módulo de elasticidad. La verificación aquí planteada se llevará a cabo por medio de un análisis ANOVA.

El análisis estadístico ANOVA de un factor permite evaluar como un factor, el número de capas, incide en la rigidez del material. La secuencia de operaciones para obtener los resultados del análisis se llevan a cabo utilizando herramientas de Excel, cuyos resultados se presentan en la siguiente tabla.

Origen de las Variaciones	Suma de Cuadrados	Grados de libertad	Promedio Cuadrados	F	Prob.	Valor Crítico
Entre grupos	3016.6667	2	1508.3333	22,625	0,00312	5.78613504
Dentro de los grupos	333.3333	5	66.6667			
Total	3350	7				

Tabla 7: Resultados análisis ANOVA de un solo factor

El análisis ANOVA nos muestra que F, la variación entre los tres grupos, al ser mucho mayor que el valor crítico, indica que la variable evaluada, en este caso el número de capas en el material, tiene una incidencia en la rigidez del mismo. Por otro lado, sin querer entrar en detalles en cuanto al grado en que esta variable incide en la propiedad evaluada, si se tiene que la tendencia de los valores de elasticidad observados, va al descenso. Los resultados indican que a mayor número de capas, menor es su módulo de elasticidad.

7.4.2 DUREZA SHORE

La prueba de dureza shore se emplea para medir la resistencia del material a la penetración. La escala de dureza shore utilizada para plásticos en general son la escala A y la escala C.

La prueba de dureza se ejecuta siguiendo los parámetros descritos en la norma ASTM 2240, en donde se describe las condiciones ambientales y de las muestras, junto con el equipo necesario para ejecutarlas.

Para la ejecución de la prueba de dureza se dispone de los siguientes implementos:

- Durómetro shore análogo escala A

Ilustración 21: Durómetro Shore A
Fuente: Adriana Jiménez, 2013

- Medidor de humedad y humedad relativa

Ilustración 22: Medidor de humedad relativa y temperatura
Fuente: Adriana Jiménez, 2013

Siguiendo las indicaciones en el apartado 6.1 de la norma, se disponen muestras con un espesor de 10 milímetros y se toman mediciones en puntos separados 1.5 centímetros entre sí. Las superficies de las muestras deben ser homogéneas, planas y paralelas entre si y subsecuentemente posicionadas en una superficie estable que permita la estabilidad de la muestra y el durómetro.

Al momento de realizar la prueba se registró una temperatura de 21.8°, cumpliendo con el rango establecido en la sección 8.5 de la norma.

Como también lo indica la norma en la sección 9.2, una vez posicionada la muestra, el durómetro es ubicado paralelamente a la superficie de la probeta y se ejerce presión sobre el mismo durante 1 segundo de tal manera que el in-dentador penetre el material y se pueda registrar su dureza.

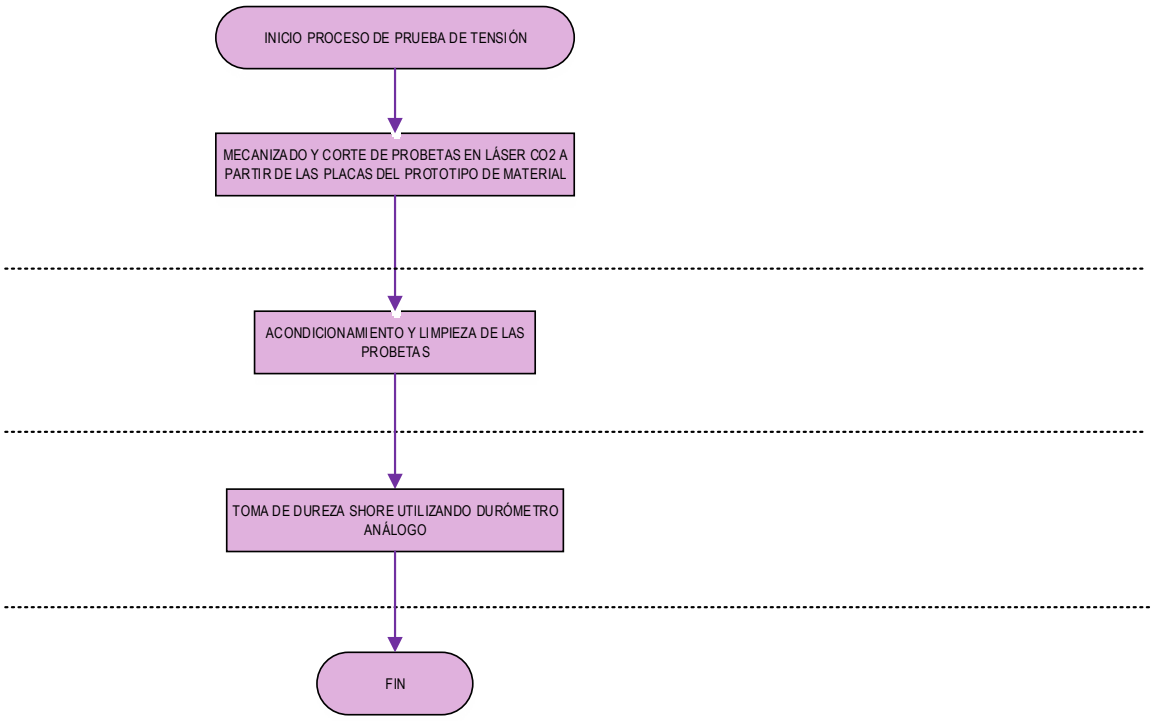

Ilustración 23: Diagrama de flujo prueba de dureza Shore
Fuente: Adriana Jiménez, 2013

Los resultados de dureza shore en escala A para el material se relacionan en la tabla a continuación:

TOMA	DUREZA SHORE ESCALA A
1	92
2	94
3	93
4	92
5	91
6	93
7	91
8	93
9	94
10	94
11	93
12	93
13	92
14	93
15	92
16	91
PROMEDIO	**92.56**

Tabla 8: Resultados prueba de dureza Shore A

7.4.2.1 Análisis de resultados

Con una dureza shore A promedio de 92.56, en la escala de 0 a 100, se puede inferir que el material prototipo tiende a ser duro. La tabla comparativa a continuación permite poner en contexto los resultados obtenidos:

Material	Dureza Shore A	Dureza Shore D
Caucho - llanta	65	20
Material prototipo laminado	92,56	40
Llanta de patín	100	50
Pelota de Golf		50

Tabla 9: Comparación de materiales de acuerdo a su dureza Shore A

Dado que los resultados obtenidos se ubican en la zona límite de la escala A, la norma recomienda ejecutar, en estos casos, la prueba utilizando un durómetro shore en la escala D. Esta escala se utiliza para polímeros duros y resulta imperativo ejecutarlo para valores superiores a 95.

7.4.3 IMPACTO CHARPY

La prueba de impacto Charpy permite medir la resistencia del material al impacto y su comportamiento de fractura. Determinar la fragilidad del material es esencial al momento de la evaluación de su aplicación.

Para la ejecución de la prueba se siguen los lineamientos descritos en la norma ASTM D6110-10. Sin embargo, dado la máquina de impacto con la que se cuenta, las dimensiones de la probeta se ajustan para acomodar dicha máquina.

Las probetas utilizadas para probar plásticos y sus compuestos tienen dimensiones de 50 mm de largo, 10 mm de ancho y 10 mm de de alto, con una muesca de 45°. El mecanizado y acondicionamiento de las probetas se lleva a cabo utilizando los procedimientos y mecanismos ya utilizados para pruebas anteriores.

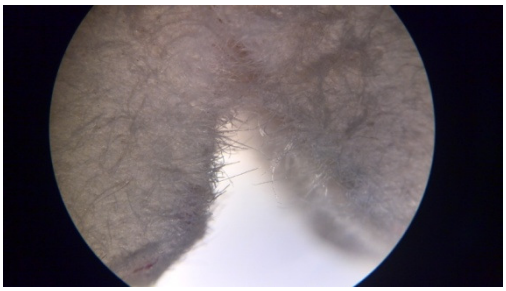

Ilustración 24: muesca de 45° en probetas de impacto Charpy
Fuente: Adriana Jiménez, 2013

Ilustración 25: Probeta prueba de Impacto Charpy con muesca de 45° **-** Transversal
Fuente: Adriana Jiménez, 2013

Para evaluar el comportamiento al impacto del material, teniendo en cuenta su estructura laminada, se hace necesario evaluar esta propiedad tanto transversal como longitudinalmente.

Ilustración 26: Probeta prueba de Impacto Charpy con muesca de 45° - Longitudinal
Fuente: Adriana Jiménez, 2013

Cada una de las 6 probetas es colocada en la máquina de impacto, habiéndose asegurado previamente que el péndulo está asegurado, que el medidor está calibrado y que las condiciones ambientales cumplen con los parámetros especificados en la sección 9.3 de la norma.

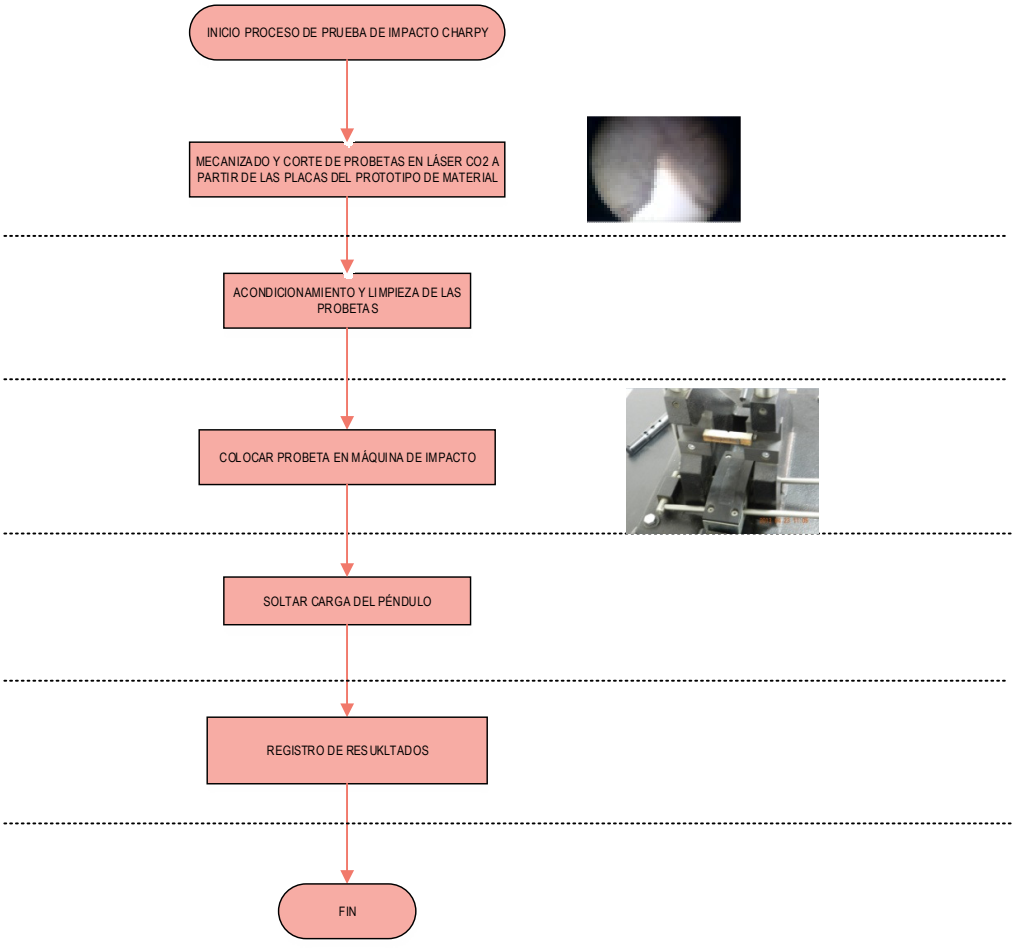

Ilustración 27: Diagrama de flujo prueba de Impacto Charpy
Fuente: Adriana Jiménez, 2013

Las pruebas se realizaron en condiciones ambientales de 21,8°C y 56% de humedad relativa. Las tablas a continuación detallan las dimensiones de cada probeta y los resultados del esfuerzo de impacto sobre las mismas:

Probeta	Alto	Largo	Ancho	Esfuerzo de Impacto (J)
1	9,79	55,89	10,12	3,2
2	9,59	56,19	10,17	3,2
3	10,11	56,32	10,12	3
4	9,76	56,04	9,97	3,9
5	9,97	56,34	10,24	3,1
6	10,02	56,17	10,04	3,8

Tabla 10: Esfuerzo de impacto por probeta - Transversal

Probeta	Alto	Largo	Ancho	Esfuerzo de Impacto (J)
1	10,08	53,10	9,63	2,7
2	10,07	56,03	9,65	2,1
3	9,99	56,09	9,83	3
4	10,10	56,12	9,82	2,8
5	9,89	55,91	9,52	2,7
6	10,12	56,24	9,92	2,6

Tabla 11: Esfuerzo de impacto por probeta - Longitudinal

7.4.3.1 Análisis de resultados

Una vez realizadas las pruebas con cada una de las probetas, los resultados en Nm son registrados y posteriormente llevados a J/m^2 para determinar el esfuerzo de impacto. Para establecer este valor, se halla la relación entre el área transversal de la probeta muescada y el esfuerzo de impacto en Julios (1 Nm = 1 J).

Probeta	Área transversal (cm^2)	Esfuerzo de impacto (J)	Esfuerzo de impacto (J/cm^2)
1	0,75	2,7	3,60
2	0,75	2,1	2,80
3	0,75	3	4,00
4	0,75	2,8	3,73
5	0,75	2,7	3,60
6	0,75	2,6	3,47
PROMEDIO			**3,53**

Tabla 12: Resultados esfuerzo de impacto (J/cm^2) - Longitudinal

Probeta	Área transversal (cm^2)	Esfuerzo de impacto (J)	Esfuerzo de impacto (J/cm^2)
1	0,75	3,2	4,27
2	0,75	3,2	4,27
3	0,75	3	4,00
4	0,75	3,9	5,20
5	0,75	3,1	4,13
6	0,75	3,8	5,07
PROMEDIO			**4,49**

Tabla 13: Resultados esfuerzo de impacto (J/cm^2) - Transversal

Para colocar en contexto los resultados encontrados, la tabla a continuación detalla los esfuerzos de impacto para otros materiales:

Material	**Esfuerzo de impacto (J/cm^2)**
Fibrolon® P 7550	0,330
Material prototipo laminado	4,49
Acrílico extruido	0.200 - 0.800
Policarbonato moldeado	0.900 - 2.30

Ilustración 28: Tabla comparativa de esfuerzo de impacto para diferentes materiales

El comportamiento del material para cada una de las orientaciones probadas fue específico y particular. En el caso de las probetas longitudinales, se observa un punto de quiebre en la sección muescada, donde las fibras del cartón claramente ceden ante el impacto mientras las junturas entre capas no presentan ninguna deformación aparente, tal como lo muestra la Ilustración 14.

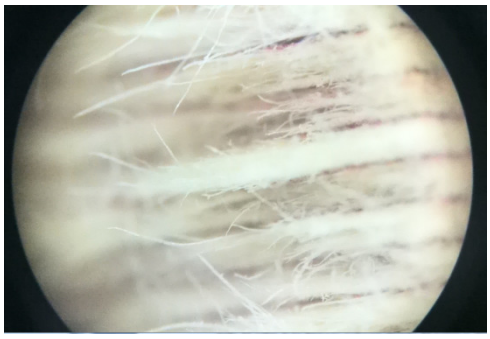

Ilustración 29: Detalle punto de quiebre prueba de impacto longitudinal.
Fuente: Adriana Jiménez, 2013

Las probetas transversales exhiben un comportamiento diferente y ninguna probeta mostró un punto de quiebre. Sin embargo, una inspección cercana da evidencia del efecto que el impacto tiene en la muestra. Tal como se muestra en la Ilustración 15, bajo un impacto transversal, las fibras resultan más resistentes y las uniones de polietileno parecen absorber la energía del impacto, por lo que se hace evidente la separación inter-capas luego del impacto.

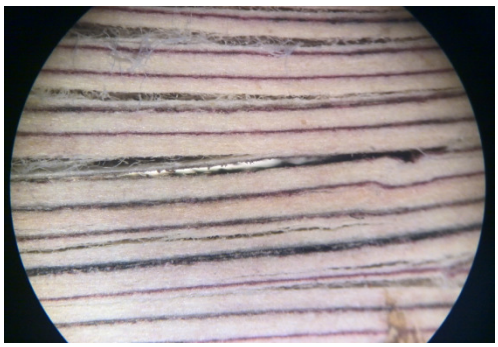

Ilustración 30: Detalle probeta post prueba de impacto transversal
Fuente: Adriana Jiménez, 2013

8 ANÁLISIS Y PROPUESTA DE APLICACIÓN

8.1 VARIABLES PARA LA MANUFACTURA

Los resultados obtenidos en las pruebas proveen un esquema de caracterización que permite visualizar holísticamente los atributos del material para su subsecuente evaluación.

Los cuadros de Ashby proveen una visión más amplia y sencilla de contextualizar el material de acuerdo a sus propiedades. El diagrama grafica la densidad vs módulo de Young para varias familias de materiales.

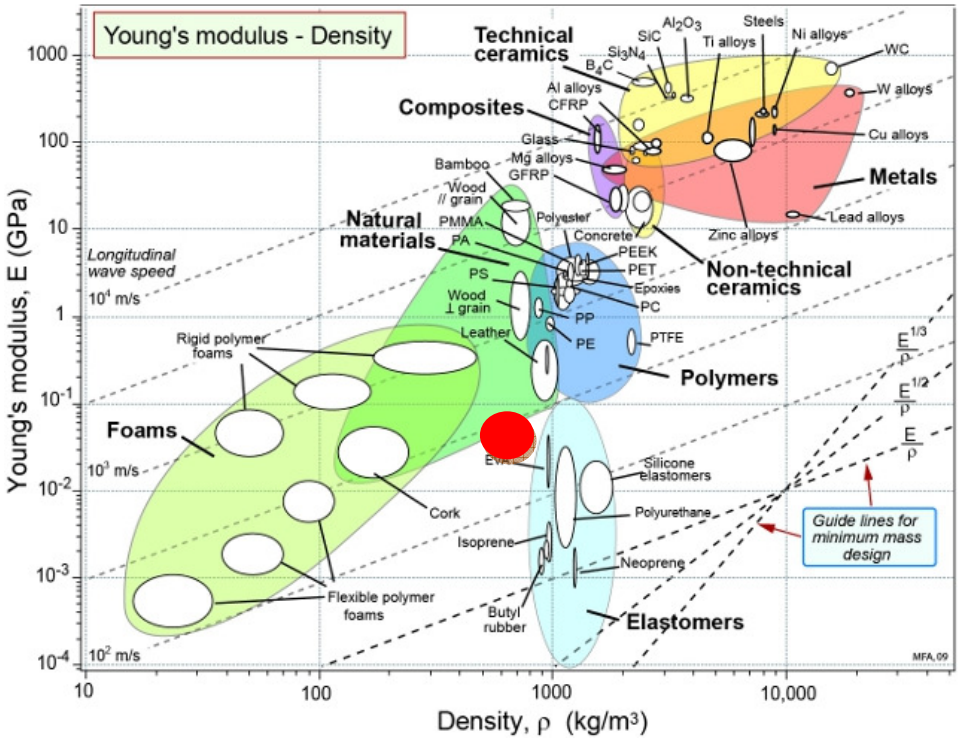

Ilustración 31: Cuadro de Ashby Densidad - Módulo de Elasticidad Modificado
Fuente: Michael Ashby, [Imagen en línea], obtenido de http://develop3d.com, 2013

El área roja resaltada en el gráfico representa el área que de acuerdo con los resultados de las pruebas de tensión y densidad ocuparía el material prototipo compuesto polimérico. Para dicha ubicación, se toman los valores de la densidad en kg/m³ y el módulo de elasticidad, o módulo de Young, en GPa, y se ubica su punto de intersección en el gráfico.

Esta gráfica permite una comparación directa con otros materiales, especialmente en el momento de seleccionar un material para el desarrollo de aplicaciones o productos. El material puede llegar a contar, por ejemplo, con mejores propiedades elásticas que algunos elastómeros y compuestos de madera y menos denso que otros polímeros y maderas.

Los gráficos de Ashby son una herramienta útil para quienes tienen como tarea el diseño de un producto. Teniendo en cuenta las características del producto y sus aplicaciones, el diseñador sabrá con que características y propiedades debe contar el material con el que lo fabrique. Es así que, una vez cuantificada esa necesidad o característica, el diseñador buscará el material utilizando las graficas de Ashby, por ejemplo, para encontrar el material ideal.

Para la fabricación del material a nivel industrial se deben tener en cuenta las siguientes variables

Variable	Valor
Temperatura de prensado	180°C - 200°C
Presión de prensado	Equivalente a 19 Kg
Tiempo de prensado	3 minutos por capa
Número de capas (lamina de 1 cm)	20
Temperatura ambiente (área de procesamiento)	18°C - 23°C

Ilustración 32: Variables de manufactura

Teniendo en cuenta los resultados obtenidos para las pruebas ejecutadas, se considera que el material prototipo compuesto puede ser utilizado en aplicaciones bajo las siguientes condiciones:

- Condiciones que no involucren ambientes altamente húmedos o de contacto directo con agua o líquidos en general.
- En páneles para insolación que en caso de una conflagración no propague el fuego o coadyuve a su extinción.
- Páneles de insolación con rigidez y dureza adecuados pero al mismo tiempo provean un valor agregado por su peso ligero.

En el mercado de la construcción se buscan materiales económicos, livianos y con las características óptimas para la creación de ambientes eficientes, pero también seguros, que reemplacen materiales costosos o poco efectivos. Algunas aplicaciones tentativas, en este sector, para el material prototipo son cielo raso o páneles de insolación.

Los cielo raso, o comúnmente llamados techo falso, requieren resistencia al fuego, que no se pandeen y que sean livianos; en términos técnicos, se requiere que tengan alta rigidez, bajo peso y densidad y alta resistencia a la propagación del fuego. En estos tres frentes, el prototipo de material polimérico compuesto cumple con los requerimientos.

El sector automotriz requiere de materiales compuestos para la fabricación de partes y rellenos en los automóviles (Mohammad, 2007). Se buscan para estas aplicaciones materiales de alta resistencia al impacto y livianos, de tal manera que coadyuven a las condiciones aerodinámicas del vehículo. Los páneles del material polimérico compuesto pueden ser tentativamente ubicados como relleno, por ejemplo, dentro de las puertas.

9 CONCLUSIONES Y RECOMENDACIÓN

El estudio y análisis de las propiedades de la materia prima base para la elaboración de un producto es primordial para establecer los procedimientos con los cuales se elaborará el mismo. Las propiedades encontradas así mismo pueden dictar en cierto grado las propiedades con las que contará el material compuesto final. Los componentes en los vasos de cartón para bebidas calientes cubiertos por LDPE, papel de pulpa virgen y una película de LDPE, proveen propiedades como dureza, resistencia a la deformación y capacidad de mantener su forma original bajo estrés, así como impermeabilidad y conservación de la temperatura. La ley de las mezclas determina de que manera cada una de estas características están presentes en el material polimérico compuesto laminado final.

La selección del método de manufactura del material polimérico compuesto se realiza de acuerdo a los recursos tecnológicos disponibles y las ventajas y desventajas de cada una de las opciones evaluadas. Bajo estas premisas, se determina que el material se estructurará como un compuesto polimérico laminado, manufacturado mediante la incorporación de presión y calor de tal manera que las películas de LDPE presentes en cada capa actúen como adhesivo. El proceso de elaboración propuesto muestra cada una de las etapas, desde la recolección de la materia prima, hasta la conformación del material compuesto polimérico laminado y las variables que deben cuidarse en el mismo.

Las pruebas físicas seleccionadas, incluyendo las pruebas mecánicas, proveen un esquema generalizado de las propiedades del material polimérico compuesto laminado. Las pruebas seleccionadas, densidad, ignición, absorción de agua, tensión, impacto y dureza, permiten identificar características puntuales dentro de un marco mucho más amplio en lo que corresponde a las pruebas para la caracterización de materiales. Las pruebas se realizaron utilizando como parámetros principal la normatividad ASTM internacional para polímeros y sus compuestos, cuyas normas dictan las condiciones de prueba, el número de probetas, el procedimiento a seguir y consideraciones especiales. Las pruebas se realizan utilizando los equipos de pruebas disponibles en los laboratorios de la Universidad EAN y haciendo uso de montajes experimentales que permiten la

aplicación de teorías y conceptos en ciencias básicas para obtener datos concretos en cuanto a las propiedades físicas del material.

Las aplicaciones propuestas, soportadas por los resultados de las pruebas físicas, ponen en evidencia el propósito del prototipo de material polimérico. El material desarrollado puede tener aplicaciones en el sector constructor o en el automotriz. Adicionalmente, una vez contando con la ubicación del material en una gráfica de Ashby, este nuevo material se hace visible para el diseño de productos de acuerdo a las necesidades requeridas por los diseñadores.

La normatividad disponible no es suficiente para cubrir nuevos materiales como los estudiados aquí, mas en estos casos el apoyarse en casos de estudio pertinentes, la teoría y las ciencias básicas, permite la generación de conocimiento y un marco teórico-académico para la caracterización de los materiales.

Este primer acercamiento al nuevo prototipo de material polimérico compuesto a base de vasos de cartón para bebidas calientes, aunque sirve como marco de referencia para futuros proyectos, da cabida a una larga lista de tareas subsecuentes, tales como la verificación de la veracidad de la aplicación aquí propuesta y de la viabilidad económica, tecnológica y de manufactura del mismo material posiblemente a nivel industrial.

Para que más proyectos como el aquí presentado se sigan generando en la Universidad EAN, es importante que se sigan enfocando esfuerzos en la disponibilidad de tecnología en los laboratorios, en el entrenamiento hacia los estudiantes en el uso de los mismos y en la profundización en diseño de experimentos y estadística aplicada incluso para el control y análisis de procesos.

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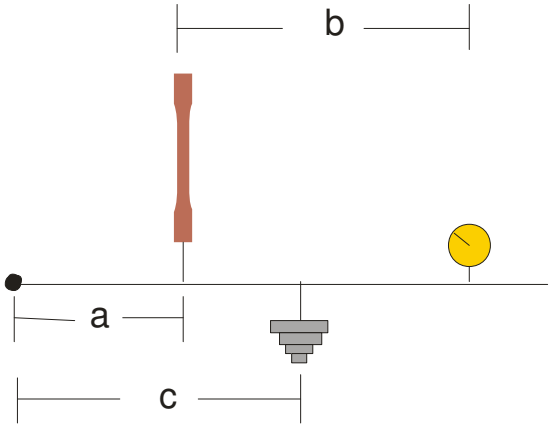
ANEXO No. 1: Procedimiento para calcular el módulo de Young

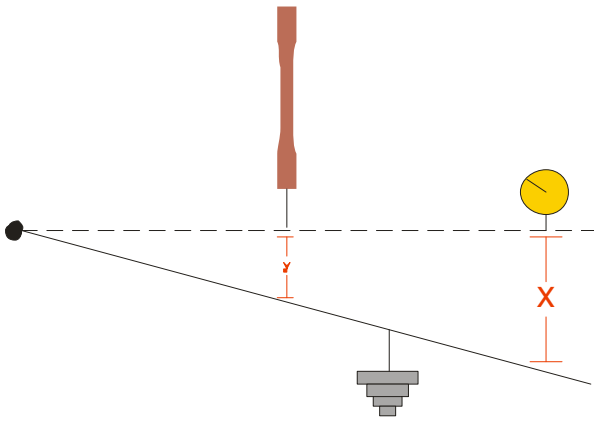
Por medio de análisis matemáticos y físicos, se obtienen los valores de fuerza y distancia necesarios para calcular el módulo de Young.

El módulo de elasticidad, o más comúnmente denominado módulo de Young, resulta de la relación, o el cociente, entre la tensión y la deformación del material. Por medio del análisis de los datos y las mediciones obtenidas del montaje se obtendrán las gráficas de tensión y deformación específicas para el material prototipo.

La Gráfica 1 muestra la posición inicial del montaje, indicando las distancias que deben tenerse en cuenta para la subsecuente cálculo de las distancias como se muestra en la Grafica 2.



Gráfica 1

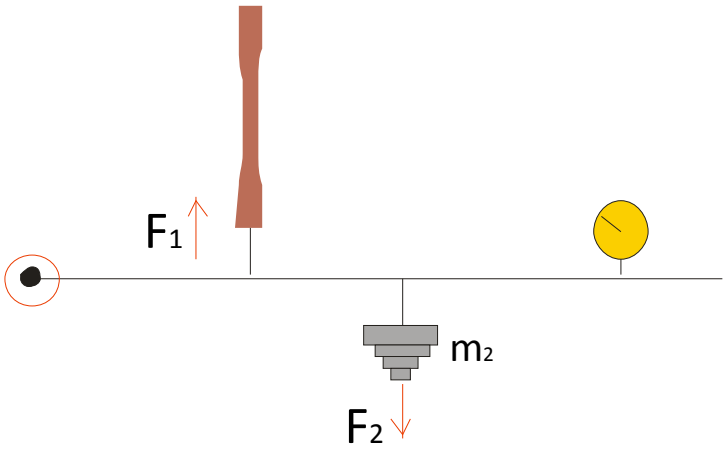


Gráfica 2

A medida que se añaden las cargas, el comparador de carátulas registra la elongación *x*, y por medio de una relación matemática se obtiene *y,* siendo *y* la elongación real del material*:*

$$\frac{x}{a+b} = \frac{y}{a}$$

Para hallar la carga ejercida sobre la probeta, se realiza un análisis de torque tal como se indica en la Gráfica 3:



Gráfica 3

El sistema funciona como una sumatoria de torques alrededor de un punto pivote:

$$0 = aF_1 - cF_2$$

Donde:

$$F_2 = gm_2 \qquad (g = gravedad)$$

$$F_2 = \frac{cF_1}{a}$$

Una vez se cuenta con la fuerza ejercida sobre la probeta se calcula la tensión sobre la misma teniendo en cuenta el área transversal *(A)*:

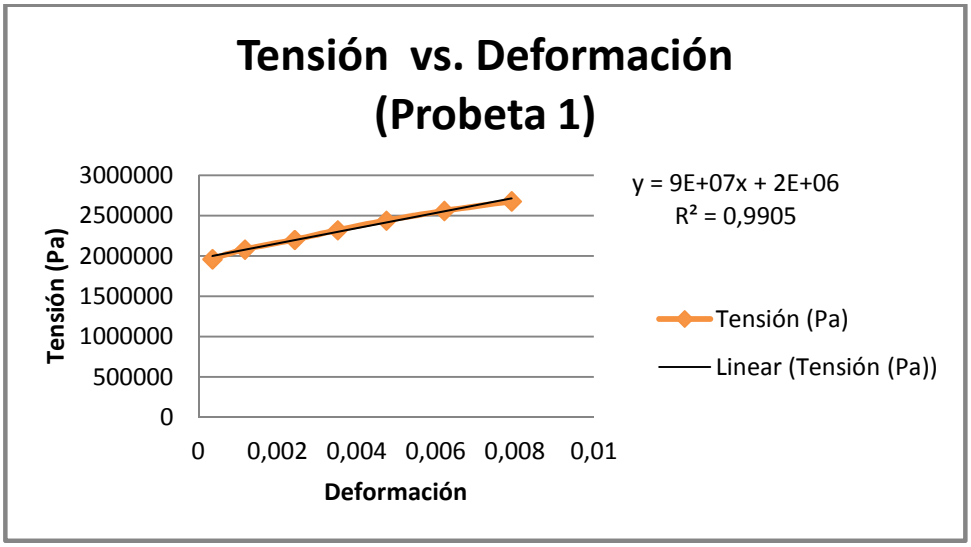
$$T = \frac{F}{A}$$

Utilizando Excel, se grafica los resultados de tensión vs. Deformación, incluyendo una línea de tendencia y su ecuación. El gráfica 4 a continuación ejemplifica la tabulación de resultados para la probeta 1:

Gage length (mm)	13.81	0.01381					
Espesor (mm)	1.08	0.00108					
a (mm)	55						
b (mm)	320						
c (mm)	200						
x (mm)	0.12	0.4	0.83	1.2	1.62	2.12	2.7
y	0.0176	0.0586667	0.1217333	0.176	0.2376	0.3109333	0.396
y en metros	0.0000176	5.867E-05	0.0001217	0.000176	0.0002376	0.0003109	0.000396
masa (gr)	820.97	870.97	920.97	970.97	1020.97	1070.97	1120.97
Peso (newton)	8.045506	8.535506	9.025506	9.515506	10.005506	10.495506	10.985506
Area (crossectional m)	1.49148E-05						
F2 (Newton)	29.25638545	31.038204	32.820022	34.60184	36.383658	38.165476	39.947295
Elongación	0.000352	0.0011733	0.0024347	0.00352	0.004752	0.0062187	0.00792
Tensión (Pa)	1961567.4	2081033.8	2200500.3	2319966.7	2439433.2	2558899.6	2678366.1

Gráfica 4

La gráfica resultante de la deformación y tensión obtenida resulta en la gráfica 5:



Gráfica 5

De la ecuación resultante de la línea de tendencia, se tiene la pendiente de dicha recta es el módulo de Young o módulo de elasticidad. Para este caso específico de la probeta 1, el módulo de Young es 90 MPa.

ANEXO No. 2: Norma ASTM D570: Standard Test Method for Water Absorption of Plastics

Designation: D570 – 98 (Reapproved 2010)$^{\varepsilon 1}$

Standard Test Method for Water Absorption of Plastics[1]

This standard is issued under the fixed designation D570; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ε[1] NOTE—Removed ASTM D647 as a referenced document editorially in June 2010.

1. Scope

1.1 This test method covers the determination of the relative rate of absorption of water by plastics when immersed. This test method is intended to apply to the testing of all types of plastics, including cast, hot-molded, and cold-molded resinous products, and both homogeneous and laminated plastics in rod and tube form and in sheets 0.13 mm (0.005 in.) or greater in thickness.

1.2 The values given in SI units are to be regarded as standard. The values stated in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—This standard is equivalent to ISO 62.

2. Referenced Documents

2.1 *ISO Standard:*
ISO 62 Plastics—Determination of Water Absorption[2]

3. Significance and Use

3.1 This test method for rate of water absorption has two chief functions: first, as a guide to the proportion of water absorbed by a material and consequently, in those cases where the relationships between moisture and electrical or mechanical properties, dimensions, or appearance have been determined, as a guide to the effects of exposure to water or humid conditions on such properties; and second, as a control test on the uniformity of a product. This second function is particularly applicable to sheet, rod, and tube arms when the test is made on the finished product.

3.2 Comparison of water absorption values of various plastics can be made on the basis of values obtained in accordance with 7.1 and 7.4.

3.3 Ideal diffusion of liquids[3] into polymers is a function of the square root of immersion time. Time to saturation is strongly dependent on specimen thickness. For example, Table 1 shows the time to approximate time saturation for various thickness of nylon-6.

3.4 The moisture content of a plastic is very intimately related to such properties as electrical insulation resistance, dielectric losses, mechanical strength, appearance, and dimensions. The effect upon these properties of change in moisture content due to water absorption depends largely on the type of exposure (by immersion in water or by exposure to high humidity), shape of the part, and inherent properties of the plastic. With nonhomogeneous materials, such as laminated forms, the rate of water absorption may be widely different through each edge and surface. Even for otherwise homogeneous materials, it may be slightly greater through cut edges than through molded surfaces. Consequently, attempts to correlate water absorption with the surface area must generally be limited to closely related materials and to similarly shaped specimens: For materials of widely varying density, relation between water-absorption values on a volume as well as a weight basis may need to be considered.

4. Apparatus

4.1 *Balance*—An analytical balance capable of reading 0.0001 g.

4.2 *Oven*, capable of maintaining uniform temperatures of 50 ± 3°C (122 ± 5.4°F) and of 105 to 110°C (221 to 230°F).

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.50 on Durability of Plastics.
Current edition approved April 1, 2010. Published June 2010. Originally approved in 1940. Last previous edition approved in 2005 as D570 - 98 (2005). DOI: 10.1520/D0570-98R10E01.

[2] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[3] Additional information regarding diffusion of liquids in polymers can be found in the following references: (*1*) *Diffusion, Mass Transfer in Fluid Systems*, E. L. Cussler, Cambridge University Press, 1985, ISBN 0-521-29846-6, (*2*) *Diffusion in Polymers*, J. Crank and G. S. Park, Academic Press, 1968, and (*3*) "Permeation, Diffusion, and Sorption of Gases and Vapors," R. M. Felder and G. S. Huvard, in *Methods of Experimental Physics*, Vol 16C, 1980, Academic Press.

TABLE 1 Time to Saturation for Various Thickness of Nylon-6

Thickness, mm	Typical Time to 95 % Saturation, h
1	100
2	400
3.2	1 000
10	10 000
25	62 000

5. Test Specimen

5.1 The test specimen for molded plastics shall be in the form of a disk 50.8 mm (2 in.) in diameter and 3.2 mm (⅛ in.) in thickness. Permissible variations in thickness are ±0.18 mm (±0.007 in.) for hot-molded and ±0.30 mm (±0.012 in.) for cold-molded or cast materials.

5.2 *ISO Standard Specimen*—The test specimen for homogeneous plastics shall be 60 by 60 by 1 mm. Tolerance for the 60-mm dimension is ±2 mm and ±0.05 mm for the 1-mm thickness. This test method and ISO 62 are technically equivalent when the test specimen described in 5.2 is used.

5.3 The test specimen for sheets shall be in the form of a bar 76.2 mm (3 in.) long by 25.4 mm (1 in.) wide by the thickness of the material. When comparison of absorption values with molded plastics is desired, specimens 3.2-mm (⅛-in.) thick should be used. Permissible variations in thickness shall be 0.20 mm (±0.008 in.) except for materials which have greater standard commercial tolerances.

5.4 The test specimen for rods shall be 25.4-mm (1-in.) long for rods 25.4 mm in diameter or under and 12.7-mm (½-in.) long for larger-diameter rods. The diameter of the specimen shall be the diameter of the finished rod.

5.5 The test specimen for tubes less than 76 mm (3 in.) in inside diameter shall be the full section of the tube and 25.4-mm (1-in.) long. For tubes 76 mm (3 in.) or more in inside diameter, a rectangular specimen shall be cut 76 mm in length in the circumferential direction of the tube and 25.4 mm in width lengthwise of the tube.

5.6 The test specimens for sheets, rods, and tubes shall be machined, sawed, or sheared from the sample so as to have smooth edges free from cracks. The cut edges shall be made smooth by finishing with No. 0 or finer sandpaper or emery cloth. Sawing, machining, and sandpapering operations shall be slow enough so that the material is not heated appreciably.

NOTE 2—If there is any oil on the surface of the specimen when received or as a result of machining operations, wash the specimen with a cloth wet with gasoline to remove oil, wipe with a dry cloth, and allow to stand in air for 2 h to permit evaporation of the gasoline. If gasoline attacks the plastic, use some suitable solvent or detergent that will evaporate within the 2-h period.

5.7 The dimensions listed in the following table for the various specimens shall be measured to the nearest 0.025 mm (0.001 in.). Dimensions not listed shall be measured within 0.8 mm (±1/32 in.).

Type of Specimen	Dimensions to Be Measured to the Nearest 0.025 mm (0.001 in.)
Molded disk	thickness
Sheet	thickness
Rod	length and diameter
Tube	inside and outside diameter, and wall thickness

6. Conditioning

6.1 Three specimens shall be conditioned as follows:

6.1.1 Specimens of materials whose water-absorption value would be appreciably affected by temperatures in the neighborhood of 110°C (230°F), shall be dried in an oven for 24 h at 50 ± 3°C (122 ± 5.4°F), cooled in a desiccator, and immediately weighed to the nearest 0.001 g.

NOTE 3—If a static charge interferes with the weighing, lightly rub the surface of the specimens with a grounded conductor.

6.1.2 Specimens of materials, such as phenolic laminated plastics and other products whose water-absorption value has been shown not to be appreciably affected by temperatures up to 110°C (230°F), shall be dried in an oven for 1 h at 105 to 110°C (221 to 230°F).

6.1.3 When data for comparison with absorption values for other plastics are desired, the specimens shall be dried in an oven for 24 h at 50 ± 3°C (122 ± 5.4°F), cooled in a desiccator, and immediately weighed to the nearest 0.001 g.

7. Procedure

7.1 *Twenty-Four Hour Immersion*—The conditioned specimens shall be placed in a container of distilled water maintained at a temperature of 23 ± 1°C (73.4 ± 1.8°F), and shall rest on edge and be entirely immersed. At the end of 24, +½, −0 h, the specimens shall be removed from the water one at a time, all surface water wiped off with a dry cloth, and weighed to the nearest 0.001 g immediately. If the specimen is 1/16 in. or less in thickness, it shall be put in a weighing bottle immediately after wiping and weighed in the bottle.

7.2 *Two-Hour Immersion*—For all thicknesses of materials having a relatively high rate of absorption, and for thin specimens of other materials which may show a significant weight increase in 2 h, the specimens shall be tested as described in 7.1 except that the time of immersion shall be reduced to 120 ± 4 min.

7.3 *Repeated Immersion*—A specimen may be weighed to the nearest 0.001 g after 2-h immersion, replaced in the water, and weighed again after 24 h.

NOTE 4—In using this test method the amount of water absorbed in 24 h may be less than it would have been had the immersion not been interrupted.

7.4 *Long-Term Immersion*—To determine the total water absorbed when substantially saturated, the conditioned specimens shall be tested as described in 7.1 except that at the end of 24 h they shall be removed from the water, wiped free of surface moisture with a dry cloth, weighed to the nearest 0.001 g immediately, and then replaced in the water. The weighings shall be repeated at the end of the first week and every two weeks thereafter until the increase in weight per two-week period, as shown by three consecutive weighings, averages less

than 1 % of the total increase in weight or 5 mg, whichever is greater; the specimen shall then be considered substantially saturated. The difference between the substantially saturated weight and the dry weight shall be considered as the water absorbed when substantially saturated.

7.5 *Two-Hour Boiling Water Immersion*—The conditioned specimens shall be placed in a container of boiling distilled water, and shall be supported on edge and be entirely immersed. At the end of 120 ± 4 min, the specimens shall be removed from the water and cooled in distilled water maintained at room temperature. After 15 ± 1 min, the specimens shall be removed from the water, one at a time, all surface water removed with a dry cloth, and the specimens weighed to the nearest 0.001 g immediately. If the specimen is 1/16 in. or less in thickness, it shall be weighed in a weighing bottle.

7.6 *One-Half-Hour Boiling Water Immersion*—For all thicknesses of materials having a relatively high rate of absorption and for thin specimens of other materials which may show a significant weight increase in ½ h, the specimens shall be tested as described in 7.5, except that the time of immersion shall be reduced to 30 ± 1 min.

7.7 *Immersion at 50°C*—The conditioned specimens shall be tested as described in 7.5, except that the time and temperature of immersion shall be 48 ± 1 h and 50 ± 1°C (122.0 ± 1.8°F), respectively, and cooling in water before weighing shall be omitted.

7.8 When data for comparison with absorption values for other plastics are desired, the 24-h immersion procedure described in 7.1 and the equilibrium value determined in 7.4 shall be used.

8. Reconditioning

8.1 When materials are known or suspected to contain any appreciable amount of water-soluble ingredients, the specimens, after immersion, shall be weighed, and then reconditioned for the same time and temperature as used in the original drying period. They shall then be cooled in a desiccator and immediately reweighed. If the reconditioned weight is lower than the conditioned weight, the difference shall be considered as water-soluble matter lost during the immersion test. For such materials, the water-absorption value shall be taken as the sum of the increase in weight on immersion and of the weight of the water-soluble matter.

9. Calculation and Report

9.1 The report shall include the values for each specimen and the average for the three specimens as follows:

9.1.1 Dimensions of the specimens before test, measured in accordance with 5.6, and reported to the nearest 0.025 mm (0.001 in.),

9.1.2 Conditioning time and temperature,

9.1.3 Immersion procedure used,

9.1.4 Time of immersion (long-term immersion procedure only),

9.1.5 Percentage increase in weight during immersion, calculated to the nearest 0.01 % as follows:

$$\text{Increase in weight, \%} = \frac{\text{wet weight} - \text{conditioned weight}}{\text{conditioned weight}} \times 100$$

9.1.6 Percentage of soluble matter lost during immersion, if determined, calculated to the nearest 0.01 % as follows (see Note 5):

$$\text{Soluble matter lost, \%} = \frac{\text{conditioned weight} - \text{reconditioned weight}}{\text{conditioned weight}} \times 100$$

NOTE 5—When the weight on reconditioning the specimen after immersion in water exceeds the conditioned weight prior to immersion, report "none" under 9.1.6.

9.1.7 For long-term immersion procedure only, prepare a graph of the increase in weight as a function of the square root of each immersion time. The initial slope of this graph is proportional to the diffusion constant of water in the plastic. The plateau region with little or no change in weight as a function of the square root of immersion time represents the saturation water content of the plastic.

NOTE 6—Deviation from the initial slope and plateau model indicates that simple diffusion may be a poor model for determining water content. In such cases, additional studies are suggested to determine a better model for water absorption.

9.1.8 The percentage of water absorbed, which is the sum of the values in 9.1.5 and 9.1.6, and

9.1.9 Any observations as to warping, cracking, or change in appearance of the specimens.

10. Precision and Bias[4]

10.1 *Precision*—An interlaboratory test program was carried out using the procedure outlined in 7.1, involving three laboratories and three materials. Analysis of this data yields the following coefficients of variation (average of three replicates).

	Within Laboratories	Between Laboratories
Average absorption above 1 % (2 materials)	2.33 %	4.88 %
Average absorption below 0.2 % (1 material)	9.01 %	16.63 %

NOTE 7—A round robin is currently under way to more completely determine repeatability and reproducibility of this test method.

10.2 *Bias*—No justifiable statement on the bias of this test method can be made, since the true value of the property cannot be established by an accepted referee method.

11. Keywords

11.1 absorption; immersion; plastics; water

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1064.

D570 – 98 (2010)ε1

ANEXO No. 3: ASTM D635 Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position

Designation: D635 – 10

Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position[1]

This standard is issued under the fixed designation D635; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This fire-test-response test method covers a small-scale laboratory screening procedure for comparing the relative linear rate of burning or extent and time of burning, or both, of plastics in the form of bars, molded or cut from sheets, plates, or panels, and tested in the horizontal position.

NOTE 1—This test method, and test method A of IEC 60695-11-10 are technically equivalent.

NOTE 2—For additional information on materials which do not burn to the first reference mark by this test, see Test Method D3801.

1.2 This test method was developed for polymeric materials used for parts in devices and appliances. The results are intended to serve as a preliminary indication of their acceptability with respect to flammability for a particular application. The final acceptance of the material is dependent upon its use in complete equipment that conforms with the standard applicable to such equipment.

1.3 The classification system described in Appendix X1 is intended for quality assurance and the preselection of component materials for products.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazards or fire risk assessment of materials, products, or assemblies under actual fire conditions.*

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific hazards statements, see 9.2.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing
D648 Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position
D883 Terminology Relating to Plastics
D1929 Test Method for Determining Ignition Temperature of Plastics
D2843 Test Method for Density of Smoke from the Burning or Decomposition of Plastics
D3801 Test Method for Measuring the Comparative Burning Characteristics of Solid Plastics in a Vertical Position
D5025 Specification for Laboratory Burner Used for Small-Scale Burning Tests on Plastic Materials
D5207 Practice for Confirmation of 20–mm (50–W) and 125–mm (500–W) Test Flames for Small-Scale Burning Tests on Plastic Materials
E84 Test Method for Surface Burning Characteristics of Building Materials
E176 Terminology of Fire Standards
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *IEC Standards:*[3]

IEC 60695-11-10 Fire Hazard Testing—Part 11-10 Test Flames—50W Horizontal and Vertical Flame Test Methods

3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.30 on Thermal Properties (Section D20.30.03).

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Publications of the International Electrotechnical Commission (IEC) and International Organization for Standardization (ISO) are available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

*A Summary of Changes section appears at the end of this standard

3.1.1 Definitions used in this test method are in accordance with Terminology D883, unless otherwise specified. For terms relating to fire, the definitions used in this test method are in accordance with Terminology E176.

4. Summary of Test Method

4.1 A bar specimen of the material to be tested is supported horizontally at one end. The free end is exposed to a specified gas flame for 30 s. Time and extent of burning are measured and reported if the specimen does not burn 100 mm. An average burning rate is reported for a material if it burns to the 100 mm mark from the ignited end.

5. Significance and Use

5.1 Tests made on a material under conditions herein prescribed are of value in comparing the rate of burning or extent and time of burning characteristics, or both, of different materials, in controlling manufacturing processes, or as a measure of deterioration or change in these burning characteristics prior to or during use. Correlation with flammability under actual use conditions is not implied.

5.2 The rate of burning and other burning phenomena will be affected by such factors as density, pigments, any anisotropy of the material and the thickness of the specimen. Test data shall be compared only for specimens of similar thickness, whether comparisons are being made with the same or different materials. The rate of burning and other burning phenomena will vary with thickness.

5.3 It is feasible that sheet materials that have been stretched during processing will relax during burning and give erratic results unless they are first heated above their deflection temperature, in accordance with Test Method D648, for a time sufficient to permit complete relaxation.

5.4 Burning tests require that certain variables be arbitrarily fixed, for example, specimen size, energy source and application time, and end points. Materials will be found that are unusually sensitive to one or more of the conditions chosen for this method leading to highly variable results. Additional burning characterization by other methods is highly desirable in such cases (see Note 2).

5.5 In this procedure, the specimens are subjected to specific laboratory test conditions. If different test conditions are substituted or the end-use conditions are changed, it will not always be possible by or from this test to predict changes in the fire-test-response characteristics measured. Therefore, the results are valid only for the fire-test-exposure conditions described in this procedure.

6. Apparatus

6.1 *Test Chamber,* enclosed laboratory hood, or chamber free of induced or forced draft during test, having an inside volume of at least 0.5 m^3. An enclosed laboratory hood with a heat-resistant glass window for observing the test and an exhaust fan for removing the products of combustion after the tests is recommended. The atmosphere in and around the test chamber shall be maintained between 15 to 35°C and 45 to 75 % relative humidity.

NOTE 3—The amount of oxygen available to support combustion is naturally important for the conduct of these fire-test-response tests. For tests conducted by this test method where burning times are protracted, chamber sizes less than 1 m^3 may not provide accurate results.

NOTE 4—Some laboratory hoods have induced drafts even with the exhaust fan off. A positive-closing damper is recommended.

NOTE 5—A mirror in the chamber, to provide a rear view of the specimen, has been found useful in some enclosures.

6.2 *Test Fixture,* A laboratory ring stand or test fixture equipped with a means of holding a 125 mm^2 wire gauze horizontal and a small clamp permitting the specimen to be held with its longitudinal axis horizontal and its transverse axis inclined at 45 ± 2° angle as illustrated in Fig. 1.

NOTE 6—A pan of water may be placed on the floor of the hood in position to catch any burning particles that may drop during the test.

6.3 *Laboratory Burner,* constructed in accordance with Specification D5025.

6.4 *Gas Supply,* a supply of technical-grade methane gas with suitable regulator and meter for uniform gas flow. Natural gas mixtures having an energy density of approximately 37 MJ/m^3 have been found to provide similar results. However, technical-grade methane gas shall be used as the referee in cases of dispute.

6.5 *Wire Gauze,* 20-mesh (approximately 20 openings per 25 mm), made with 0.43 ± 0.03 mm diameter iron wire cut to approximately 125 mm^2, to sustain burning or glowing particles falling from the specimens.

6.6 *Timing Device,* accurate to 0.5 s.

6.7 *Scale,* graduated in millimetres.

6.8 *Micrometer,* accurate to 0.05 mm.

6.9 *Conditioning Room or Chamber,* capable of being maintained at 23 ± 2°C and 50 ± 5 % relative humidity.

6.10 *Flexible Specimen Support Fixture,* used to facilitate the testing of specimens that sag and touch the wire gauze. (See 9.4 and Fig. 2.)

7. Test Specimens

7.1 All test specimens shall be cut from a representative sample of the material (sheet or end products), or shall be cast or injection-, compression-, transfer- or pultrusion-molded to the necessary form. After any cutting operation, care shall be taken to remove all dust and any particles from the surface; cut edges shall be fine sanded to have a smooth finish. Unless otherwise agreed, fabrication of test specimens shall be in accordance with the specifications of the material being tested.

7.2 Specimens shall be 125 ± 5 mm long by 13.0 ± 0.5 mm wide, and provided in the minimum thickness and in the 3.0 (−0.0 +0.2) mm thickness. The 3.0 mm thick specimens are not necessary if the minimum thickness is greater than 3.0 mm, or the maximum thickness is less than 3.0 mm. The maximum thickness shall not exceed 13 mm. The maximum width shall not exceed 13.5 mm. The edges shall be smooth, and the radius on the corners shall not exceed 1.3 mm.

7.3 It is possible that the results of tests carried out on test specimens of different colors, thicknesses, densities, molecular

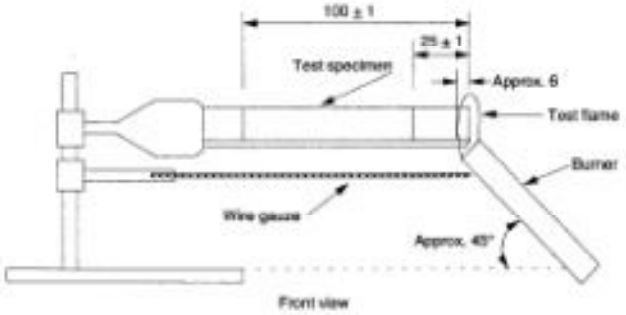


FIG. 1 Test Fixture

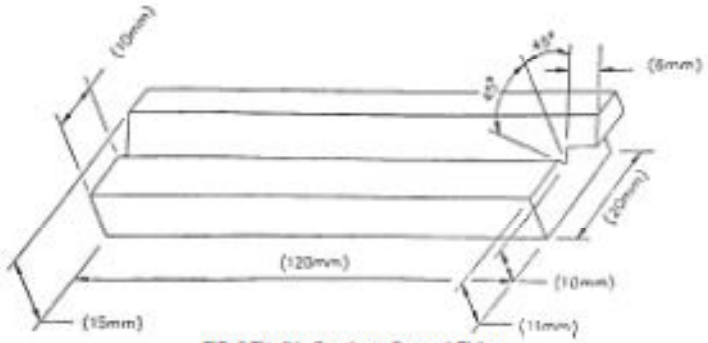


FIG. 2 Flexible Specimen Support Fixture

masses, directions of anisotropy and types, or with different additives, fillers/reinforcements will be different.

7.3.1 Test specimens in the minimum and maximum densities, melt flows and level of fillers/reinforcements contents shall be considered representative of the range, if the results yield the same flame test classification. If the burning characteristics are not essentially the same for all specimens representing the range, the evaluation is to be limited only to the materials in the densities, melt flows, and fillers/reinforcements contents tested. Additional specimens in the intermediate densities, melt flows, and fillers/reinforcements contents are to be tested.

7.3.2 Uncolored test specimens and test specimens with the highest level of organic and inorganic pigment loading by weight are considered representative of the color range, if the test results are essentially the same. When certain pigments are known to affect flammability characteristics, they are also to be tested. Specimens to be tested are those that:

(a) contain no coloring
(b) contain the highest level of organic pigments
(c) contain the highest level of inorganic pigments
(d) contain pigments which are known to adversely affect flammability characteristics

8. Conditioning

8.1 Condition ten bar specimens for each material and thickness to be tested in accordance with Procedure A of Practice D618 for a minimum of 48 hours. Once removed from the conditioning atmosphere test the specimens within 1 h. Temperature and humidity tolerances shall be in accordance with Section 7 of Practice D618.

8.2 Conduct testing in a laboratory atmosphere of 15 to 35°C and 45 to 75 % relative humidity.

9. Procedure

9.1 Prepare at least ten bar specimens. After measuring and recording the specimen thickness, mark each specimen with two lines perpendicular to the longitudinal axis of the bar, 25 ± 1 and 100 ± 1 mm from the end that is to be ignited.

9.2 Conduct the burning test in a chamber, enclosure, or laboratory hood free of induced or forced draft. (**Warning**—Products of combustion may be toxic. An enclosed laboratory hood and an exhaust fan for removing the products of combustion after the tests are recommended. The exhaust fan is turned off during the test and turned on immediately following the test in order to remove products of combustion.)

9.3 Clamp the specimen at the end farthest from the 25 mm reference mark, in a support with its longitudinal axis horizontal and its transverse axis inclined at 45 ± 2° as illustrated in Fig. 1. Clamp the wire gauze horizontally beneath the specimen, with a distance of 10 ± 1 mm between the lowest edge of the specimen and the wire gauze, and with the free end of the specimen even with the edge of the gauze. Any material remaining on the wire gauze from the previous test must be burned off or a new section of wire gauze used for each test.

9.4 If the specimen sags at its free end during the initial set up and is not able to maintain the distance of 10 ± 1 mm as specified in 9.2, the flexible specimen support fixture illustrated in Fig. 2 shall be used. Position the support fixture under the specimen with the small extending portion of the support fixture at least 20 mm from the free end of the specimen. Provide enough clearance at the clamped end of the specimen so that the support fixture can be moved freely sidewards. As the flame front progresses along the specimen, withdraw the support fixture at the same approximate rate, preventing the flame front from contacting the flexible specimen support fixture, so that there is no effect on the test flame or on the burning of the specimen.

9.5 With the central axis of the burner tube in the vertical position, place the burner remote from the specimen, ignite, and adjust it to produce a blue flame 20 mm high. Adjust the gas supply and the air ports of the burner until a 20-mm yellow-tipped blue flame is produced, and then increase the air supply until the yellow tip just disappears. Measure the height of the flame. If the flame height is not 20 ± 2 mm, adjust the burner gas supply to give the proper flame height. Once the flame has been properly set to a height of 20 ± 2 mm wait for at least 5 min to allow the burner conditions to reach equilibrium.

NOTE 7—See Practice D5207 for recommended back pressure and flow rate for the gas supply and calibration procedure for the 20 mm flame.

9.6 Place the burner so that the test flame impinges on the free end of the test specimen to a depth of approximately 6 mm starting the timing device simultaneously. The central axis of the burner tube is to be in the same vertical plane as the longitudinal bottom edge of the specimen and inclined toward the end of the specimen at an angle of approximately 45 ± 2 degrees to the horizontal. See Fig. 1. Apply the flame for 30 ± 1 s without changing its position. If the test specimen shrinks from the applied flame without ignition, the material is not suitable for evaluation by these test methods. Excessive distortion of the specimen during the test will invalidate the results. Withdraw the test flame sufficiently from the specimen (see Note 8) so that there is no effect on the specimen after 30 ± 1 s or as soon as the flame front of the specimen reaches the 25 mm mark (if less than 30 s). Restart the timing device when the flame front reaches the 25 mm reference mark.

NOTE 8—Withdrawing the burner a distance of 150 mm from the specimen has been found satisfactory.

9.7 If the specimen continues to burn, with a flame or glowing combustion (visible glow without flame), after removal of the test flame, record the elapsed time (t), in seconds, for the flame front to travel from the 25 mm reference mark to the 100 mm reference mark and record the burned length (L), as 75 mm. If the flame front passes the 25 mm reference mark but does not reach the 100 mm reference mark, record the elapsed time (t), in seconds, and the burned length (L), in millimetres between the 25 mm reference mark and where the flame front stopped.

9.8 Repeat the test procedure (9.1-9.7) until three specimens have burned to or beyond the 100 mm reference mark, or ten specimens have been tested.

NOTE 9—For classification purposes, if only one specimen does not comply with the criteria, test an additional set of specimens. See X1.3.

10. Calculation

10.1 Calculate the linear burning rate (V), in millimetres per minute, for each specimen where the flame front reaches the 100 mm reference mark using the equation:

$$V = 60L/t$$

where:

L = the burned length, in millimetres, as defined in 9.7; and

t = the time, in seconds, as defined in 9.7.

NOTE 10—If the flame front reached the 100-mm reference mark, $L = 75$.

NOTE 11—The SI units of the linear burning rate is metre per second. In practice, the unit millimetre per minute is used.

NOTE 12—It is acceptable to report the results in cm/min by using the method prescribed in 10.1 and then dividing the obtained rate by ten.

10.2 Calculate the average linear burning rate or classify the material in accordance with the appendix.

TABLE 1 Average Linear Burning Rate for Specimens Tested Without Flexible Specimen Support Fixture

Material	Nominal Specimen Thickness, mm	Rate of Linear Burning, mm/min: Average	S_r[A]	S_R[B]	r[C]	R[D]
Polyethylene (PE)	3.0	15.2	0.7	1.3	1.9	3.7
ABS	3.2	27.9	2.1	4.1	5.7	11.5
Acrylic	3.0	29.7	1.7	2.2	4.8	6.1

[A] S_r is the within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations of the test results from all of the participating laboratories:

$$S_r = [(s_1)^2 + (s_2)^2 \ldots + (s_n)^2 / n]^{1/2}$$

[B] S_R is the between-laboratories reproducibility, expressed as stated deviation:

$$S_R = [S_r^2 + S_L^2]^{1/2}$$

where: S_L = the standard deviation of laboratory means.
[C] r is the within-laboratory critical interval between two test results = $2.8 \times S_r$.
[D] R is the between-laboratories critical interval between two test results = $2.8 \times S_R$.

11. Report

11.1 Include the following in the complete report:

11.1.1 *Material Identification*—Include generic description, manufacturer, commercial designation, lot number, and color.

11.1.2 The thickness, as measured with a micrometer to the nearest 0.1 mm, of the test specimen.

11.1.3 The nominal apparent density (rigid cellular materials only).

11.1.4 The direction of any anisotropy relative to the test specimen dimensions.

11.1.5 Conditioning treatment.

11.1.6 Any prior treatment before testing, other than cutting, trimming and conditioning.

11.1.7 Whether or not the specimen continued to burn (with or without visible flame) after application of test flame.

11.1.8 Whether or not the flame front reached the 25 and 100 mm reference marks.

11.1.9 For specimens with which the flame front does not reach or pass the 25 mm reference mark, a statement that indicates the flame front did not reach or pass the 25 mm reference mark. Do not report an elapsed time (t) and burned length (L).

11.1.10 For specimens with which the flame front passed the 25 mm reference mark but did not reach the 100 mm reference mark, the elapsed time (t) and burned length (L).

11.1.11 If a specimen does not burn to the 100 mm mark because of dripping, flowing, or falling burning particles, the report must so indicate.

11.1.12 If a specimen is reignited by burning material on the gauze, the report must so state.

11.1.13 For specimens with which the flame front reached the 100 mm reference mark, the average linear burning rate, (V).

11.1.14 Whether the flexible specimen support fixture was used.

11.1.15 The caveat contained in 1.5 herein shall be incorporated in its entirety in the test report issued.

11.1.16 *Optional*—Flame classification as determined from the appendix.

12. Precision and Bias

12.1 Table 1 is based on a round robin completed in 1987[4] in accordance with Practice E691, involving three self-supporting materials tested by eleven laboratories. Each laboratory conditioned, at 23°C and 50 % relative humidity, the specimens that it tested. Each laboratory conducted the tests in a laboratory hood with the hood exhaust essentially turned off. All three materials were classified by the test as possessing an average burning rate. Each test result consisted of an average linear burning rate determined from three specimens. Each laboratory obtained three test results for each material.

12.2 Table 2 is based on a round robin completed in 1986[5] in accordance with Practice 691, involving four materials that required use of the flexible specimen support fixture and tested by six different laboratories. For each material, all samples were provided by one source. The individual specimens were cut and distributed by one laboratory. Each laboratory conditioned, at 23°C and 50 % relative humidity, the specimens that it tested. Each test result consisted of an average linear burning rate determined from three specimens. Each laboratory obtained two average linear burning rates from a total six individual specimen test results for each material.

12.3 This test method does not contain a numerical precision and bias statement for the time of burning and extent of burning for specimens where the flame front passes the 25-mm reference mark, but does not reach the 100-mm reference mark, and therefore shall not be used as a referee test method for these two characteristics in case of dispute. Due to the rarity of materials which consistently produce this result, a numerical precision and bias statement for this type of test result is not being actively pursued at this time. (**Warning**—The explanations of "r" and "R" given in 12.4-12.4.3 are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Tables 1 and 2 shall

[4] Supporting data for Table 1 are available from ASTM Headquarters. Request RR:D20-1149.
[5] Supporting data for Table 2 are available from ASTM Headquarters. Request RR:D20-1146.

TABLE 2 Average Linear Burning Rate for Specimens Tested With Flexible Specimen Support Fixture

Material	Nominal Specimen Thickness, mm	Rate of Linear Burning, mm/min				
		Average	S_r[A]	S_R[B]	r[C]	R[D]
Polyurethane (PUR)	1.3	41.6	1.0	[E]	2.9	[E]
Polyurethane (PUR)	0.8	60.9	10.9	14.4	30.6	40.4
Polyurethane (PUR)	0.4	82.3	10.6	26.6	29.8	74.4
Polyethylene terephthalate (PET)	0.1	102.0	32.2	[E]	123.7	[E]

[A] S_r = within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations of the test results from all of the participating laboratories, as follows:

$$S_r = [(s_1)^2 + (s_2)^2 \ldots + (s_n)^2/n]^{1/2}$$

[B] S_R = between-laboratories reproducibility, expressed as stated deviation, as follows:

$$S_R = [S_L^2 + S_r^2]^{1/2}$$

where S_L = the standard deviation of laboratory means.
[C] r = within-laboratory critical interval between two test results = $2.8 \times S_r$.
[D] R = between-laboratories critical interval between two test results = $2.8 \times S_R$.
[E] The number of laboratories in the interlaboratory study reporting a linear burning rate was too small to establish a between-laboratory standard deviation.

not be rigorously applied to acceptance or rejection of material, as these data apply only to the materials tested in the round robin and are unlikely to be rigorously representative of other lots, formulations, conditions, materials or laboratories. Users of this test method shall apply the principles outlined in Practice E691 to generate data specific to their materials and laboratory (or between specific laboratories). The principles of 12.4-12.4.3 would then be valid for such data.)

12.4 *Concept of "r" and "R"*—If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing three specimens for each test result, then:

12.4.1 *Repeatability, r*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "r" value for the material. "r" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

12.4.2 *Reproducibility, R*—Two test results obtained from different laboratories shall be judged not equivalent if they differ by more than the "R" value for the material. "R" is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

12.4.3 Judgments in accordance with 12.4.1 and 12.4.2 have an approximate 95 % (0.95) probability of being correct.

12.5 *Bias*—There are no recognized standards on which to base an estimate of bias for this test method.

13. Keywords

13.1 burning characteristics; combustion; extent of burning; flammability; HB; horizontal burning rate; plastics; rate of burning; small-scale burning test burning; time of burning

APPENDIXES

(Nonmandatory Information)

X1. CLASSIFICATION SYSTEM FOR DETERMINING THE RELATIVE LINEAR RATE OF BURNING AND/OR EXTENT AND TIME OF BURNING OF PLASTICS

X1.1 General

X1.1.1 This appendix covers a classification system for characterizing the burning behavior of plastic materials, supported in a horizontal position, in response to a small-flame ignition source. The use of a category designation code is optional and is determined by examining the test results of materials tested by this method. Each category code represents a preferred range of performance levels that simplifies description in material designations or specifications and may assist certification bodies to determine compliance with applicable requirements.

X1.2 *Category Designation*—The behavior of specimens shall be classified HB (HB = horizontal burning) if,

X1.2.1 There are no visible signs of combustion after the ignition source is removed, or

X1.2.2 The flame front does not pass the 25 mm reference mark, or

X1.2.3 The flame front passes the 25 mm reference mark but does not reach the 100 mm reference mark, or

X1.2.4 The flame front reaches the 100 mm reference mark and the linear burning rate does not exceed 40 mm/min for

specimens having a thickness between 3 and 13 mm or 75 mm/min for specimens having a thickness less than 3 mm.

X1.3 If only one specimen from the first set of specimens does not comply with the criteria indicated, another set of specimens is to be tested. All specimens from this second set shall comply with the criteria indicated in order for the material, of that thickness, to be classified as HB.

X1.4 If the linear burning rate does not exceed 40 mm/min when tested in the 3.0 mm ± 0.2 mm thickness, the HB category designation shall be extended to a 1.5 mm minimum thickness.

X1.5 Recording the category designation in the test report is optional.

X2. IBC REFERENCE TO TEST METHOD D635

INTRODUCTION

In the *International Building Code* (2003 Edition), this test method is referenced in section 2606.4 for LIGHT-TRANSMITTING PLASTICS. Classifications are established based on the extent of burning using this test method. The IBC states as follows:

X2.1 **2606.4 Specifications** Light-transmitting plastics, including thermoplastic, thermosetting or reinforced thermosetting plastic material, shall have a self-ignition temperature of 650°F [343°C] or greater where tested in accordance with Test Method D1929; a smoke-developed index not greater than 450 where tested in the manner intended for use in accordance with Test Method E84, or not greater than 75 where tested in the thickness intended for use in accordance with Test Method D2843 and shall conform to one of the following combustibility classifications:

X2.1.1 *Class CC1:* Plastic materials that have a burning extent of 1 in. [25 mm] or less where tested at a nominal thickness of 0.060 in. [1.5 mm], or in the thickness intended for use, in accordance with this test method,

X2.1.2 *Class CC2:* Plastic materials that have a burning rate of 2.5 inches per minute [1.06 mm/s] or less where tested at a nominal thickness of 0.060 in. [1.5 mm], or in the thickness intended for use, in accordance with this test method.

X2.2 The classification scheme shown above is limited within the *International Building Code* to light-transmitting plastics only. It is not applicable to plastics used in other construction applications. In addition, the flammability requirements given here are not the only requirements for light-transmitting plastics.

X2.3 Test Method D2843 reports values as a Smoke Density Rating.

X2.4 These classifications are not part of this test method and are not under the jurisdiction of ASTM committee D20. However, they are in common usage and are presented here for information only.

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue, D635 - 06, that may impact the use of this standard. (July 1, 2010)

(1) Revised 8.1 for consistency with Practice D618.

ANEXO No. 4: ASTM D638 – 10: Standard Test Method for Tensile Properties of Plastics

Designation: D638 – 10

Standard Test Method for Tensile Properties of Plastics[1]

This standard is issued under the fixed designation D638; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This test method covers the determination of the tensile properties of unreinforced and reinforced plastics in the form of standard dumbbell-shaped test specimens when tested under defined conditions of pretreatment, temperature, humidity, and testing machine speed.

1.2 This test method can be used for testing materials of any thickness up to 14 mm (0.55 in.). However, for testing specimens in the form of thin sheeting, including film less than 1.0 mm (0.04 in.) in thickness, Test Methods D882 is the preferred test method. Materials with a thickness greater than 14 mm (0.55 in.) must be reduced by machining.

1.3 This test method includes the option of determining Poisson's ratio at room temperature.

NOTE 1—This test method and ISO 527-1 are technically equivalent.

NOTE 2—This test method is not intended to cover precise physical procedures. It is recognized that the constant rate of crosshead movement type of test leaves much to be desired from a theoretical standpoint, that wide differences may exist between rate of crosshead movement and rate of strain between gage marks on the specimen, and that the testing speeds specified disguise important effects characteristic of materials in the plastic state. Further, it is realized that variations in the thicknesses of test specimens, which are permitted by these procedures, produce variations in the surface-volume ratios of such specimens, and that these variations may influence the test results. Hence, where directly comparable results are desired, all samples should be of equal thickness. Special additional tests should be used where more precise physical data are needed.

NOTE 3—This test method may be used for testing phenolic molded resin or laminated materials. However, where these materials are used as electrical insulation, such materials should be tested in accordance with Test Methods D229 and Test Method D651.

NOTE 4—For tensile properties of resin-matrix composites reinforced with oriented continuous or discontinuous high modulus >20-GPa (>3.0 × 10^6-psi) fibers, tests shall be made in accordance with Test Method D3039/D3039M.

1.4 Test data obtained by this test method are relevant and appropriate for use in engineering design.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D229 Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation

D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension

D618 Practice for Conditioning Plastics for Testing

D651 Test Method for Test for Tensile Strength of Molded Electrical Insulating Materials (Withdrawn 1989)[3]

D882 Test Method for Tensile Properties of Thin Plastic Sheeting

D883 Terminology Relating to Plastics

D1822 Test Method for Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials

D3039/D3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials

D4000 Classification System for Specifying Plastic Materials

D4066 Classification System for Nylon Injection and Extrusion Materials (PA) (Withdrawn 2012)[3]

D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

E4 Practices for Force Verification of Testing Machines

E83 Practice for Verification and Classification of Extensometer Systems

E132 Test Method for Poisson's Ratio at Room Temperature

E691 Practice for Conducting an Interlaboratory Study to

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.
Current edition approved May 15, 2010. Published June 2010. Originally approved in 1941. Last previous edition approved in 2008 as D638 - 08. DOI: 10.1520/D0638-10.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

*A Summary of Changes section appears at the end of this standard

Determine the Precision of a Test Method
2.2 *ISO Standard:*[4]
ISO 527-1 Determination of Tensile Properties

3. Terminology

3.1 *Definitions*—Definitions of terms applying to this test method appear in Terminology D883 and Annex A2.

4. Significance and Use

4.1 This test method is designed to produce tensile property data for the control and specification of plastic materials. These data are also useful for qualitative characterization and for research and development. For many materials, there may be a specification that requires the use of this test method, but with some procedural modifications that take precedence when adhering to the specification. Therefore, it is advisable to refer to that material specification before using this test method. Table 1 in Classification D4000 lists the ASTM materials standards that currently exist.

4.2 Tensile properties may vary with specimen preparation and with speed and environment of testing. Consequently, where precise comparative results are desired, these factors must be carefully controlled.

4.2.1 It is realized that a material cannot be tested without also testing the method of preparation of that material. Hence, when comparative tests of materials per se are desired, the greatest care must be exercised to ensure that all samples are prepared in exactly the same way, unless the test is to include the effects of sample preparation. Similarly, for referee purposes or comparisons within any given series of specimens, care must be taken to secure the maximum degree of uniformity in details of preparation, treatment, and handling.

4.3 Tensile properties may provide useful data for plastics engineering design purposes. However, because of the high degree of sensitivity exhibited by many plastics to rate of straining and environmental conditions, data obtained by this test method cannot be considered valid for applications involving load-time scales or environments widely different from those of this test method. In cases of such dissimilarity, no reliable estimation of the limit of usefulness can be made for most plastics. This sensitivity to rate of straining and environment necessitates testing over a broad load-time scale (including impact and creep) and range of environmental conditions if tensile properties are to suffice for engineering design purposes.

NOTE 5—Since the existence of a true elastic limit in plastics (as in many other organic materials and in many metals) is debatable, the propriety of applying the term "elastic modulus" in its quoted, generally accepted definition to describe the "stiffness" or "rigidity" of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are highly dependent on such factors as rate of application of stress, temperature, previous history of specimen, etc. However, stress-strain curves for plastics, determined as described in this test method, almost always show a linear region at low stresses, and a straight line drawn tangent to this portion of the curve permits calculation of an elastic modulus of the usually defined type. Such a constant is useful if its arbitrary nature and dependence on time, temperature, and similar factors are realized.

5. Apparatus

5.1 *Testing Machine*—A testing machine of the constant-rate-of-crosshead-movement type and comprising essentially the following:

5.1.1 *Fixed Member*—A fixed or essentially stationary member carrying one grip.

5.1.2 *Movable Member*—A movable member carrying a second grip.

5.1.3 *Grips*—Grips for holding the test specimen between the fixed member and the movable member of the testing machine can be either the fixed or self-aligning type.

5.1.3.1 Fixed grips are rigidly attached to the fixed and movable members of the testing machine. When this type of grip is used extreme care should be taken to ensure that the test specimen is inserted and clamped so that the long axis of the test specimen coincides with the direction of pull through the center line of the grip assembly.

5.1.3.2 Self-aligning grips are attached to the fixed and movable members of the testing machine in such a manner that they will move freely into alignment as soon as any load is applied so that the long axis of the test specimen will coincide with the direction of the applied pull through the center line of the grip assembly. The specimens should be aligned as perfectly as possible with the direction of pull so that no rotary motion that may induce slippage will occur in the grips; there is a limit to the amount of misalignment self-aligning grips will accommodate.

5.1.3.3 The test specimen shall be held in such a way that slippage relative to the grips is prevented insofar as possible. Grip surfaces that are deeply scored or serrated with a pattern similar to those of a coarse single-cut file, serrations about 2.4 mm (0.09 in.) apart and about 1.6 mm (0.06 in.) deep, have been found satisfactory for most thermoplastics. Finer serrations have been found to be more satisfactory for harder plastics, such as the thermosetting materials. The serrations should be kept clean and sharp. Breaking in the grips may occur at times, even when deep serrations or abraded specimen surfaces are used; other techniques must be used in these cases. Other techniques that have been found useful, particularly with smooth-faced grips, are abrading that portion of the surface of the specimen that will be in the grips, and interposing thin pieces of abrasive cloth, abrasive paper, or plastic, or rubber-coated fabric, commonly called hospital sheeting, between the specimen and the grip surface. No. 80 double-sided abrasive paper has been found effective in many cases. An open-mesh fabric, in which the threads are coated with abrasive, has also been effective. Reducing the cross-sectional area of the specimen may also be effective. The use of special types of grips is sometimes necessary to eliminate slippage and breakage in the grips.

5.1.4 *Drive Mechanism*—A drive mechanism for imparting to the movable member a uniform, controlled velocity with respect to the stationary member, with this velocity to be regulated as specified in Section 8.

5.1.5 *Load Indicator*—A suitable load-indicating mechanism capable of showing the total tensile load carried by the

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

test specimen when held by the grips. This mechanism shall be essentially free of inertia lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the indicated value, or better. The accuracy of the testing machine shall be verified in accordance with Practices E4.

NOTE 6—Experience has shown that many testing machines now in use are incapable of maintaining accuracy for as long as the periods between inspection recommended in Practices E4. Hence, it is recommended that each machine be studied individually and verified as often as may be found necessary. It frequently will be necessary to perform this function daily.

5.1.6 The fixed member, movable member, drive mechanism, and grips shall be constructed of such materials and in such proportions that the total elastic longitudinal strain of the system constituted by these parts does not exceed 1 % of the total longitudinal strain between the two gage marks on the test specimen at any time during the test and at any load up to the rated capacity of the machine.

5.1.7 *Crosshead Extension Indicator*—A suitable extension indicating mechanism capable of showing the amount of change in the separation of the grips, that is, crosshead movement. This mechanism shall be essentially free of inertial lag at the specified rate of testing and shall indicate the crosshead movement with an accuracy of ±10 % of the indicated value.

5.2 *Extension Indicator* (extensometer)—A suitable instrument shall be used for determining the distance between two designated points within the gage length of the test specimen as the specimen is stretched. For referee purposes, the extensometer must be set at the full gage length of the specimen, as shown in Fig. 1. It is desirable, but not essential, that this instrument automatically record this distance, or any change in it, as a function of the load on the test specimen or of the elapsed time from the start of the test, or both. If only the latter is obtained, load-time data must also be taken. This instrument shall be essentially free of inertia at the specified speed of testing. Extensometers shall be classified and their calibration periodically verified in accordance with Practice E83.

5.2.1 *Modulus-of-Elasticity Measurements*—For modulus-of-elasticity measurements, an extensometer with a maximum strain error of 0.0002 mm/mm (in./in.) that automatically and continuously records shall be used. An extensometer classified by Practice E83 as fulfilling the requirements of a B-2 classification within the range of use for modulus measurements meets this requirement.

5.2.2 *Low-Extension Measurements*—For elongation-at-yield and low-extension measurements (nominally 20 % or less), the same above extensometer, attenuated to 20 % extension, may be used. In any case, the extensometer system must meet at least Class C (Practice E83) requirements, which include a fixed strain error of 0.001 strain or ±1.0 % of the indicated strain, whichever is greater.

5.2.3 *High-Extension Measurements*—For making measurements at elongations greater than 20 %, measuring techniques with error no greater than ±10 % of the measured value are acceptable.

5.3 *Micrometers*—Apparatus for measuring the width and thickness of the test specimen shall comply with the requirements of Test Method D5947.

6. Test Specimens

6.1 *Sheet, Plate, and Molded Plastics:*

6.1.1 *Rigid and Semirigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type I specimen is the preferred specimen and shall be used where sufficient material having a thickness of 7 mm (0.28 in.) or less is available. The Type II specimen may be used when a material does not break in the narrow section with the preferred Type I specimen. The Type V specimen shall be used where only limited material having a thickness of 4 mm (0.16 in.) or less is available for evaluation, or where a large number of specimens are to be exposed in a limited space (thermal and environmental stability tests, etc.). The Type IV specimen should be used when direct comparisons are required between materials in different rigidity cases (that is, nonrigid and semirigid). The Type III specimen must be used for all materials with a thickness of greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.).

6.1.2 *Nonrigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type IV specimen shall be used for testing nonrigid plastics with a thickness of 4 mm (0.16 in.) or less. The Type III specimen must be used for all materials with a thickness greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.).

6.1.3 *Reinforced Composites*—The test specimen for reinforced composites, including highly orthotropic laminates, shall conform to the dimensions of the Type I specimen shown in Fig. 1.

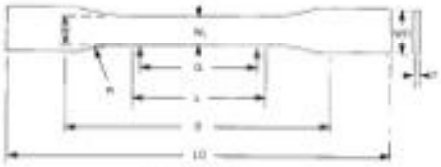
6.1.4 *Preparation*—Test specimens shall be prepared by machining operations, or die cutting, from materials in sheet, plate, slab, or similar form. Materials thicker than 14 mm (0.55 in.) must be machined to 14 mm (0.55 in.) for use as Type III specimens. Specimens can also be prepared by molding the material to be tested.

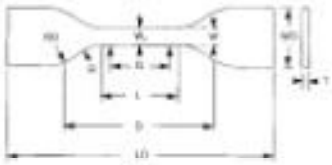
NOTE 7—Test results have shown that for some materials such as glass cloth, SMC, and BMC laminates, other specimen types should be considered to ensure breakage within the gage length of the specimen, as mandated by 7.3.

NOTE 8—When preparing specimens from certain composite laminates such as woven roving, or glass cloth, care must be exercised in cutting the specimens parallel to the reinforcement. The reinforcement will be significantly weakened by cutting on a bias, resulting in lower laminate properties, unless testing of specimens in a direction other than parallel with the reinforcement constitutes a variable being studied.

NOTE 9—Specimens prepared by injection molding may have different tensile properties than specimens prepared by machining or die-cutting because of the orientation induced. This effect may be more pronounced in specimens with narrow sections.

6.2 *Rigid Tubes*—The test specimen for rigid tubes shall be as shown in Fig. 2. The length, *L*, shall be as shown in the table in Fig. 2. A groove shall be machined around the outside of the specimen at the center of its length so that the wall section after machining shall be 60 % of the original nominal wall thickness. This groove shall consist of a straight section 57.2 mm (2.25 in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter. Steel or brass plugs having





Specimen Dimensions for Thickness, *T*, mm [in.][A]

Dimensions (see drawings)	*T* (0.28) or under		Over *T* to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 [0.50]	6 [0.25]	19 [0.75]	6 [0.25]	3.18 [0.125]	±0.5 [±0.02][E,G]
L—Length of narrow section	57 [2.25]	57 [2.25]	57 [2.25]	33 [1.30]	9.53 [0.375]	±0.5 [±0.02][G]
WO—Width overall, min[H]	19 [0.75]	19 [0.75]	29 [1.13]	19 [0.75]	...	+ 6.4 [+ 0.25]
WO—Width overall, min[H]	...	...	...	...	9.53 [0.375]	+ 3.18 [+ 0.125]
LO—Length overall, min[H]	165 [6.5]	183 [7.2]	246 [9.7]	115 [4.5]	63.5 [2.5]	no max [no max]
G—Gage length[I]	50 [2.00]	50 [2.00]	50 [2.00]	...	7.62 [0.300]	±0.25 [±0.010][G]
G—Gage length[I]	...	...	...	25 [1.00]	...	±0.13 [±0.005]
D—Distance between grips	115 [4.5]	135 [5.5]	115 [4.5]	65 [2.5][J]	25.4 [1.0]	±5 [±0.2]
R—Radius of fillet	76 [3.00]	76 [3.00]	76 [3.00]	14 [0.56]	12.7 [0.5]	±1 [±0.04][G]
RO—Outer radius (Type IV)	...	...	...	25 [1.00]	...	±1 [±0.04]

[A] Thickness, *T*, shall be 3.2 ± 0.4 mm [0.13 ± 0.02 in.] for all types of molded specimens, and for other Types I and II specimens where possible. If specimens are machined from sheets or plates, thickness, *T*, may be the thickness of the sheet or plate provided this does not exceed the range stated for the intended specimen type. For sheets of nominal thickness greater than 14 mm [0.55 in.] the specimens shall be machined to 14 ± 0.4 mm [0.55 ± 0.02 in.] in thickness, for use with the Type III specimen. For sheets of nominal thickness between 14 and 51 mm [0.55 and 2 in.] approximately equal amounts shall be machined from each surface. For thicker sheets both surfaces of the specimen shall be machined, and the location of the specimen with reference to the original thickness of the sheet shall be noted. Tolerances on thickness less than 14 mm [0.55 in.] shall be those standard for the grade of material tested.

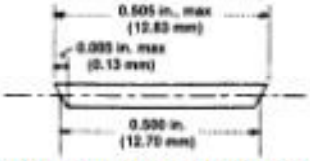
[B] For the Type IV specimen, the internal width of the narrow section of the die shall be 6.00 ± 0.05 mm [0.250 ± 0.002 in.]. The dimensions are essentially those of Die C in Test Methods D412.

[C] The Type V specimen shall be machined or die cut to the dimensions shown, or molded in a mold whose cavity has these dimensions. The dimensions shall be:
W = 3.18 ± 0.05 mm [0.125 ± 0.001 in.],
L = 9.53 ± 0.05 mm [0.375 ± 0.003 in.],
G = 7.62 ± 0.02 mm [0.300 ± 0.001 in.], and
R = 12.7 ± 0.05 mm [0.500 ± 0.003 in.].
The other tolerances are those in the table.

[D] Supporting data on the introduction of the L specimen of Test Method D1822 as the Type V specimen are available from ASTM Headquarters. Request RR:D20-1008.

[E] The width at the center *W*, shall be +0.00 mm, −0.10 mm [+0.000 in., −0.004 in.] compared with width *W* at other parts of the reduced section. Any reduction in *W* at the center shall be gradual, equally on each side so that no abrupt changes in dimension result.

[F] For molded specimens, a draft of not over 0.13 mm [0.005 in.] may be allowed for either Type I or II specimens 3.2 mm [0.13 in.] in thickness, and this should be taken into account when calculating width of the specimen. Thus a typical section of a molded Type I specimen, having the maximum allowable draft, could be as follows:



[G] Overall widths greater than the minimum indicated may be desirable for some materials in order to avoid breaking in the grips.

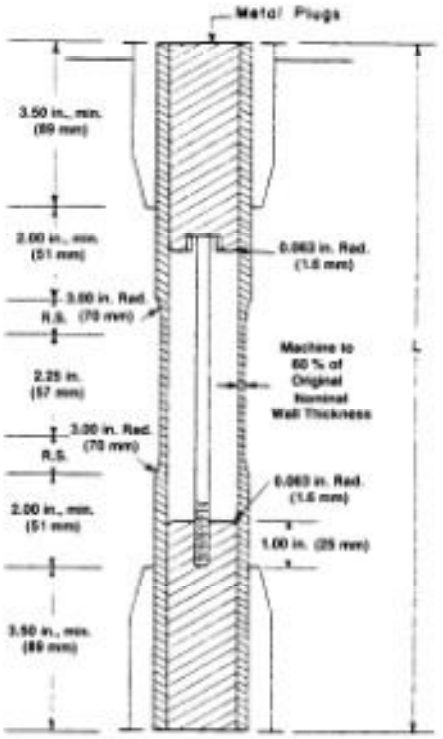
[H] Overall lengths greater than the minimum indicated may be desirable either to avoid breaking in the grips or to satisfy special test requirements.

[I] Test marks or initial extensometer span.

[J] When self-tightening grips are used, for highly extensible polymers, the distance between grips will depend upon the types of grips used and may not be critical if maintained uniform once chosen.

FIG. 1 Tension Test Specimens for Sheet, Plate, and Molded Plastics

diameters such that they will fit snugly inside the tube and having a length equal to the full jaw length plus 25 mm (1 in.) shall be placed in the ends of the specimens to prevent crushing. They can be located conveniently in the tube by separating and supporting them on a threaded metal rod. Details of plugs and test assembly are shown in Fig. 2.

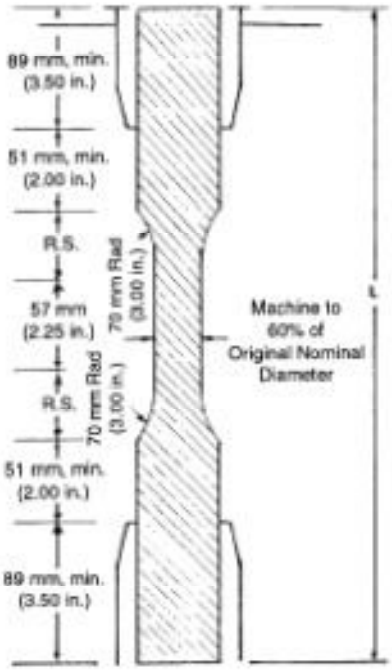


DIMENSIONS OF TUBE SPECIMENS

Nominal Wall Thickness	Length of Radial Sections, ±0.5	Total Calculated Minimum Length of Specimen	Standard Length, L, of Specimen to Be Used for 89-mm (3.5-in.) Jaws[A]
mm (in.)			
0.79 (1/32)	13.9 (0.547)	350 (13.80)	381 (15)
1.2 (3/64)	17.0 (0.670)	354 (13.92)	381 (15)
1.6 (1/16)	19.6 (0.773)	356 (14.02)	381 (15)
2.4 (3/32)	24.0 (0.946)	361 (14.20)	381 (15)
3.2 (1/8)	27.7 (1.091)	364 (14.34)	381 (15)
4.8 (3/16)	33.9 (1.333)	370 (14.58)	381 (15)
6.4 (1/4)	39.0 (1.536)	376 (14.79)	400 (15.75)
7.9 (5/16)	43.5 (1.714)	380 (14.96)	400 (15.75)
9.5 (3/8)	47.6 (1.873)	384 (15.12)	400 (15.75)
11.1 (7/16)	51.3 (2.019)	388 (15.27)	400 (15.75)
12.7 (1/2)	54.7 (2.154)	391 (15.40)	419 (16.5)

[A] For other jaws greater than 89 mm (3.5 in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (0.25 to 0.50 in.) in each jaw while maintaining the maximum length of the jaw grip.

FIG. 2 Diagram Showing Location of Tube Tension Test Specimens in Testing Machine



DIMENSIONS OF ROD SPECIMENS

Nominal Diameter	Length of Radial Sections, ±0.5	Total Calculated Minimum Length of Specimen	Standard Length, L, of Specimen to Be Used for 89-mm (3½-in.) Jaws[A]
mm (in.)			
3.2 (1/8)	19.6 (0.775)	356 (14.02)	381 (15)
4.7 (3/16)	24.0 (0.946)	361 (14.20)	381 (15)
6.4 (1/4)	27.7 (1.091)	364 (14.34)	381 (15)
8.5 (5/16)	33.9 (1.333)	370 (14.58)	381 (15)
12.7 (1/2)	39.0 (1.536)	376 (14.79)	400 (15.75)
15.9 (5/8)	43.5 (1.714)	380 (14.96)	400 (15.75)
19.0 (3/4)	47.6 (1.873)	384 (15.12)	400 (15.75)
22.2 (7/8)	51.3 (2.019)	388 (15.27)	400 (15.75)
25.4 (1)	54.7 (2.154)	391 (15.40)	419 (16.5)
31.8 (1¼)	60.9 (2.398)	398 (15.65)	419 (16.5)
38.1 (1½)	66.4 (2.615)	403 (15.87)	419 (16.5)
44.5 (1¾)	71.4 (2.812)	408 (16.06)	419 (16.5)
50.8 (2)	76.0 (2.990)	412 (16.24)	432 (17)

[A] For other jaws greater than 89 mm (3.5 in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (0.25 to 0.50 in.) in each jaw while maintaining the maximum length of the jaw grip.

FIG. 3 Diagram Showing Location of Rod Tension Test Specimen in Testing Machine

6.3 *Rigid Rods*—The test specimen for rigid rods shall be as shown in Fig. 3. The length, *L*, shall be as shown in the table in Fig. 3. A groove shall be machined around the specimen at the center of its length so that the diameter of the machined portion shall be 60 % of the original nominal diameter. This groove shall consist of a straight section 57.2 mm (2.25 in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter.

6.4 All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine file or abrasive, and the filed surfaces shall then be smoothed with abrasive paper (No. 00 or finer). The finishing sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not to disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shown in Fig. 1 shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors.

6.5 If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon or India ink that will not affect the material being tested. Gage marks shall not be scratched, punched, or impressed on the specimen.

6.6 When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.

7. Number of Test Specimens

7.1 Test at least five specimens for each sample in the case of isotropic materials.

7.2 Test ten specimens, five normal to, and five parallel with, the principle axis of anisotropy, for each sample in the case of anisotropic materials.

7.3 Discard specimens that break at some flaw, or that break outside of the narrow cross-sectional test section (Fig. 1, dimension "L"), and make retests, unless such flaws constitute a variable to be studied.

NOTE 10—Before testing, all transparent specimens should be inspected in a polariscope. Those which show atypical or concentrated strain patterns should be rejected, unless the effects of these residual strains constitute a variable to be studied.

8. Speed of Testing

8.1 Speed of testing shall be the relative rate of motion of the grips or test fixtures during the test. The rate of motion of the driven grip or fixture when the testing machine is running idle may be used, if it can be shown that the resulting speed of testing is within the limits of variation allowed.

8.2 Choose the speed of testing from Table 1. Determine this chosen speed of testing by the specification for the material being tested, or by agreement between those concerned. When the speed is not specified, use the lowest speed shown in Table 1 for the specimen geometry being used, which gives rupture within ½ to 5-min testing time.

8.3 Modulus determinations may be made at the speed selected for the other tensile properties when the recorder response and resolution are adequate.

9. Conditioning

9.1 *Conditioning*—Condition the test specimens in accordance with Procedure A of Practice D618, unless otherwise specified by contract or the relevant ASTM material specification. Conditioning time is specified as a minimum. Temperature and humidity tolerances shall be in accordance with Section 7 of Practice D618 unless specified differently by contract or material specification.

9.2 *Test Conditions*—Conduct the tests at the same temperature and humidity used for conditioning with tolerances in accordance with Section 7 of Practice D618, unless otherwise specified by contract or the relevant ASTM material specification.

TABLE 1 Designations for Speed of Testing[A]

Classification[B]	Specimen Type	Speed of Testing, mm/min [in./min]	Nominal Strain[C] Rate at Start of Test, mm/mm·min [in./in.·min]
Rigid and Semirigid	I, II, III rods and tubes	5 [0.2] ± 25 %	0.1
		50 [2] ± 10 %	1
		500 [20] ± 10 %	10
	IV	5 [0.2] ± 25 %	0.15
		50 [2] ± 10 %	1.5
		500 [20] ± 10 %	15
	V	1 [0.05] ± 25 %	0.1
		10 [0.5] ± 25 %	1
		100 [5] ± 25 %	10
Nonrigid	III	50 [2] ± 10 %	1
		500 [20] ± 10 %	10
	IV	50 [2] ± 10 %	1.5
		500 [20] ± 10 %	15

[A] Select the lowest speed that produces rupture in ½ to 5 min for the specimen geometry being used (see 8.2).
[B] See Terminology D883 for definitions.
[C] The initial rate of straining cannot be calculated exactly for dumbbell-shaped specimens because of extension, both in the reduced section outside the gage length and in the fillets. This initial strain rate can be measured from the initial slope of the tensile strain-versus-time diagram.

10. Procedure

10.1 Measure the width and thickness of each specimen to the nearest 0.025 mm (0.001 in.) using the applicable test methods in D5947.

TABLE 2 Modulus, 10^3 psi, for Eight Laboratories, Five Materials

	Mean	S_r	$S_{(r)}$	I_r	$I_{(r)}$
Polypropylene	0.210	0.0089	0.071	0.025	0.201
Cellulose acetate butyrate	0.248	0.0179	0.035	0.051	0.144
Acrylic	0.481	0.0179	0.063	0.051	0.144
Glass-reinforced nylon	1.17	0.0537	0.217	0.152	0.614
Glass-reinforced polyester	1.39	0.0894	0.266	0.253	0.753

10.1.1 Measure the width and thickness of flat specimens at the center of each specimen and within 5 mm of each end of the gage length.

10.1.2 Injection molded specimen dimensions may be determined by actual measurement of only one specimen from each sample when it has previously been demonstrated that the specimen-to-specimen variation in width and thickness is less than 1 %.

10.1.3 Take the width of specimens produced by a Type IV die as the distance between the cutting edges of the die in the narrow section.

10.1.4 Measure the diameter of rod specimens, and the inside and outside diameters of tube specimens, to the nearest 0.025 mm (0.001 in.) at a minimum of two points 90° apart; make these measurements along the groove for specimens so constructed. Use plugs in testing tube specimens, as shown in Fig. 2.

10.2 Place the specimen in the grips of the testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. The distance between the ends of the gripping surfaces, when using flat specimens, shall be as indicated in Fig. 1. On tube and rod specimens, the location for the grips shall be as shown in Fig. 2 and Fig. 3. Tighten the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test, but not to the point where the specimen would be crushed.

10.3 Attach the extension indicator. When modulus is being determined, a Class B-2 or better extensometer is required (see 5.2.1).

NOTE 11—Modulus of materials is determined from the slope of the linear portion of the stress-strain curve. For most plastics, this linear portion is very small, occurs very rapidly, and must be recorded automatically. The change in jaw separation is never to be used for calculating modulus or elongation.

10.4 Set the speed of testing at the proper rate as required in Section 8, and start the machine.

10.5 Record the load-extension curve of the specimen.

10.6 Record the load and extension at the yield point (if one exists) and the load and extension at the moment of rupture.

NOTE 12—If it is desired to measure both modulus and failure properties (yield or break, or both), it may be necessary, in the case of highly extensible materials, to run two independent tests. The high magnification extensometer normally used to determine properties up to the yield point may not be suitable for tests involving high extensibility. If allowed to remain attached to the specimen, the extensometer could be permanently damaged. A broad-range incremental extensometer or hand-rule technique may be needed when such materials are taken to rupture.

11. Calculation

11.1 Toe compensation shall be made in accordance with Annex A1, unless it can be shown that the toe region of the curve is not due to the take-up of slack, seating of the specimen, or other artifact, but rather is an authentic material response.

11.2 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load in newtons (pounds-force) by the average original cross-sectional area in the gage length segment of the specimen in square metres (square inches). Express the result in pascals (pounds-force per square inch) and report it to three significant figures as tensile strength at yield or tensile strength at break, whichever term is applicable. When a nominal yield or break load less than the maximum is present and applicable, it may be desirable also to calculate, in a similar manner, the corresponding tensile stress at yield or tensile stress at break and report it to three significant figures (see Note A2.8).

11.3 Elongation values are valid and are reported in cases where uniformity of deformation within the specimen gage length is present. Elongation values are quantitatively relevant and appropriate for engineering design. When non-uniform deformation (such as necking) occurs within the specimen gage length nominal strain values are reported. Nominal strain values are of qualitative utility only.

11.3.1 *Percent Elongation*—Percent elongation is the change in gage length relative to the original specimen gage length, expressed as a percent. Percent elongation is calculated using the apparatus described in 5.2.

11.3.1.1 *Percent Elongation at Yield*—Calculate the percent elongation at yield by reading the extension (change in gage length) at the yield point. Divide that extension by the original gage length and multiply by 100.

11.3.1.2 *Percent Elongation at Break*—Calculate the percent elongation at break by reading the extension (change in gage length) at the point of specimen rupture. Divide that extension by the original gage length and multiply by 100.

11.3.2 *Nominal Strain*—Nominal strain is the change in grip separation relative to the original grip separation expressed as a percent. Nominal strain is calculated using the apparatus described in 5.1.7.

11.3.2.1 *Nominal strain at break*—Calculate the nominal strain at break by reading the extension (change in grip separation) at the point of rupture. Divide that extension by the original grip separation and multiply by 100.

11.4 *Modulus of Elasticity*—Calculate the modulus of elasticity by extending the initial linear portion of the load-extension curve and dividing the difference in stress corresponding to any segment of section on this straight line by the corresponding difference in strain. All elastic modulus values shall be computed using the average original cross-sectional area in the gage length segment of the specimen in the calculations. The result shall be expressed in pascals (pounds-force per square inch) and reported to three significant figures.

11.5 *Secant Modulus*—At a designated strain, this shall be calculated by dividing the corresponding stress (nominal) by the designated strain. Elastic modulus values are preferable and shall be calculated whenever possible. However, for materials where no proportionality is evident, the secant value shall be calculated. Draw the tangent as directed in A1.3 and Fig. A1.2, and mark off the designated strain from the yield point where the tangent line goes through zero stress. The stress to be used in the calculation is then determined by dividing the load-extension curve by the original average cross-sectional area of the specimen.

11.6 For each series of tests, calculate the arithmetic mean of all values obtained and report it as the "average value" for the particular property in question.

11.7 Calculate the standard deviation (estimated) as follows and report it to two significant figures:

$$s = \sqrt{(\sum X^2 - n\bar{X}^2)/(n-1)} \quad (1)$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

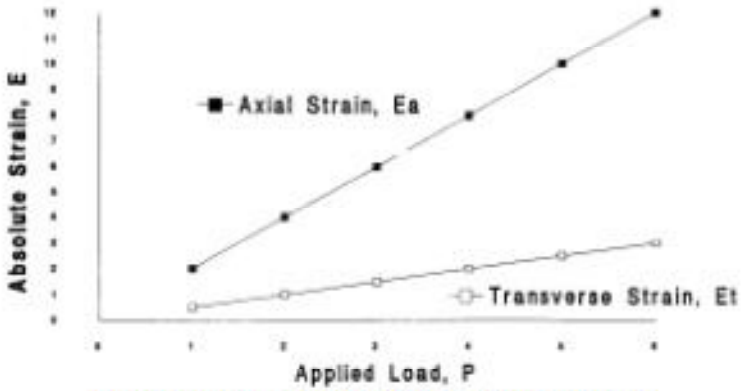


FIG. 4 Plot of Strains Versus Load for Determination of Poisson's Ratio

11.8 See Annex A1 for information on toe compensation.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code numbers, form, principal dimensions, previous history, etc.,

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimensions,

12.1.4 Conditioning procedure used,

12.1.5 Atmospheric conditions in test room,

12.1.6 Number of specimens tested,

12.1.7 Speed of testing,

12.1.8 Classification of extensometers used. A description of measuring technique and calculations employed instead of a minimum Class-C extensometer system,

12.1.9 Tensile strength at yield or break, average value, and standard deviation,

12.1.10 Tensile stress at yield or break, if applicable, average value, and standard deviation,

12.1.11 Percent elongation at yield, or break, or nominal strain at break, or all three, as applicable, average value, and standard deviation,

12.1.12 Modulus of elasticity or secant modulus, average value, and standard deviation,

TABLE 3 Tensile Strength at Break, 10^3 psi, for Eight Laboratories, Five Materials[A]

	Mean	S_r	S_R	I_r	I_R
Polypropylene	3.97	1.54	1.65	4.37	4.66
Cellulose acetate butyrate	4.82	0.058	0.180	0.164	0.509
Acrylic	8.09	0.452	0.751	1.27	2.13
Glass-reinforced polyester	20.8	0.235	0.437	0.659	1.24
Glass-reinforced nylon	23.6	0.277	0.696	0.784	1.98

[A] Tensile strength and elongation at break values obtained for unreinforced propylene plastics generally are highly variable due to inconsistencies in necking or "drawing" of the center section of the test bar. Since tensile strength and elongation at yield are more reproducible and relate in most cases to the practical usefulness of a molded part, they are generally recommended for specification purposes.

12.1.13 If measured, Poisson's ratio, average value, standard deviation, and statement of whether there was proportionality within the strain range,

12.1.14 Date of test, and

12.1.15 Revision date of Test Method D638.

13. Precision and Bias[5]

13.1 *Precision*—Tables 2-4 are based on a round-robin test conducted in 1984, involving five materials tested by eight laboratories using the Type I specimen, all of nominal 0.125-in. thickness. Each test result was based on five individual determinations. Each laboratory obtained two test results for each material.

13.1.1 Tables 5-10 are based on a round-robin test conducted by the polyolefin subcommittee in 1988, involving eight polyethylene materials tested in ten laboratories. For each material, all samples were molded at one source, but the individual specimens were prepared at the laboratories that tested them. Each test result was the average of five individual determinations. Each laboratory obtained three test results for each material. Data from some laboratories could not be used for various reasons, and this is noted in each table.

13.1.2 Table 11 is based on a repeatability study involving a single laboratory. The two materials used were unfilled polypropylene types. Measurements were performed by a single technician on a single day. Each test result is an individual determination. Testing was run using two Type B-1 extensometers for transverse and axial measurements at a test speed of 5 mm/min.

13.1.3 In Tables 2-11, for the materials indicated, and for test results that derived from testing five specimens:

13.1.3.1 S_r is the within-laboratory standard deviation of the average; $I_r = 2.83\ S_r$. (See 13.1.3.3 for application of I_r.)

13.1.3.2 S_R is the between-laboratory standard deviation of the average; $I_R = 2.83\ S_R$. (See 13.1.3.4 for application of I_R.)

[5] Supporting data are available from ASTM Headquarters. Request RR:D20-1125 for the 1984 round robin and RR:D20-1170 for the 1988 round robin.

TABLE 4 Elongation at Break, %, for Eight Laboratories, Five Materials[A]

	Mean	S_r	S_R	I_r	I_R
Glass-reinforced polyester	3.68	0.20	2.33	0.570	6.59
Glass-reinforced nylon	3.87	0.10	2.13	0.285	6.03
Acrylic	13.2	2.05	3.65	5.80	10.3
Cellulose acetate butyrate	14.1	1.87	6.62	5.29	18.7
Polypropylene	293.0	50.9	119.0	144.0	337.0

[A] Tensile strength and elongation at break values obtained for unreinforced propylene plastics generally are highly variable due to inconsistencies in necking or "drawing" of the center section of the test bar. Since tensile strength and elongation at yield are more reproducible and relate in most cases to the practical usefulness of a molded part, they are generally recommended for specification purposes.

TABLE 5 Tensile Yield Strength, for Ten Laboratories, Eight Materials

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1544	52.4	84.0	146.6	179.3
LDPE	20	1594	53.1	61.2	148.7	171.3
LLDPE	20	1879	74.2	99.9	207.6	279.7
LLDPE	20	1791	49.2	75.8	137.9	212.3
LLDPE	20	2900	55.5	87.9	155.4	246.1
LLDPE	20	1730	63.9	96.0	178.9	268.7
HDPE	2	4101	186.1	371.9	549.1	1041.3
HDPE	2	3523	175.9	479.0	492.4	1366.5

TABLE 6 Tensile Stress at Yield, 10^3 psi, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
Polypropylene	3.65	0.022	0.161	0.062	0.456
Cellulose acetate butyrate	5.01	0.058	0.227	0.164	0.642
Acrylic	10.4	0.067	0.317	0.190	0.897

TABLE 7 Elongation at Yield, %, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
Cellulose acetate butyrate	3.65	0.27	0.62	0.76	1.75
Acrylic	4.89	0.21	0.55	0.59	1.56
Polypropylene	8.79	0.45	5.86	1.27	16.5

13.1.3.3 *Repeatability*—In comparing two test results for the same material, obtained by the same operator using the same equipment on the same day, those test results should be judged not equivalent if they differ by more than the I_r value for that material and condition.

13.1.3.4 *Reproducibility*—In comparing two test results for the same material, obtained by different operators using different equipment on different days, those test results should be judged not equivalent if they differ by more than the I_R value for that material and condition. (This applies between different laboratories or between different equipment within the same laboratory.)

13.1.3.5 Any judgment in accordance with 13.1.3.3 and 13.1.3.4 will have an approximate 95 % (0.95) probability of being correct.

13.1.3.6 Other formulations may give somewhat different results.

TABLE 8 Tensile Yield Elongation, for Eight Laboratories, Eight Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	17.0	1.26	3.16	3.52	8.84
LDPE	20	14.6	1.02	2.38	2.86	6.67
LLDPE	20	15.7	1.37	2.65	3.85	7.37
LLDPE	20	16.6	1.59	3.30	4.46	9.24
LLDPE	20	11.7	1.27	2.86	3.56	8.08
LLDPE	20	15.3	1.27	2.59	3.55	7.25
HDPE	2	9.27	1.40	2.84	3.91	7.94
HDPE	2	9.63	1.23	2.75	3.45	7.71

TABLE 9 Tensile Break Strength, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1592	52.5	74.9	146.4	209.7
LDPE	20	1750	66.6	102.9	186.4	288.1
LLDPE	20	4379	127.1	219.0	355.8	613.3
LLDPE	20	2940	78.6	143.5	220.2	401.8
LLDPE	20	1679	34.3	47.0	95.96	131.6
LLDPE	20	2990	119.1	166.3	333.6	465.6

TABLE 10 Tensile Break Elongation, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	567	31.5	59.5	88.2	166.6
LDPE	20	569	61.5	89.2	172.3	249.7
LLDPE	20	590	25.7	113.6	71.9	318.7
LLDPE	20	64.4	6.66	11.7	18.7	32.8
LLDPE	20	603	25.7	104.4	71.9	292.5
LLDPE	20	782	41.6	96.7	116.6	270.8

TABLE 11 Poisson's Ratio Repeatability Data for One Laboratory and Two Polypropylene Materials

Materials	Values Expressed as a Dimensionless Ratio		
	Average	S_r	r
PP #1 Chord	0.412	0.009	0.026
PP #1 Least Squares	0.413	0.011	0.032
PP #2 Chord	0.391	0.009	0.026
PP #2 Least Squares	0.392	0.010	0.028

13.1.3.7 For further information on the methodology used in this section, see Practice E691.

13.1.3.8 The precision of this test method is very dependent upon the uniformity of specimen preparation, standard practices for which are covered in other documents.

13.2 *Bias*—There are no recognized standards on which to base an estimate of bias for this test method.

14. Keywords

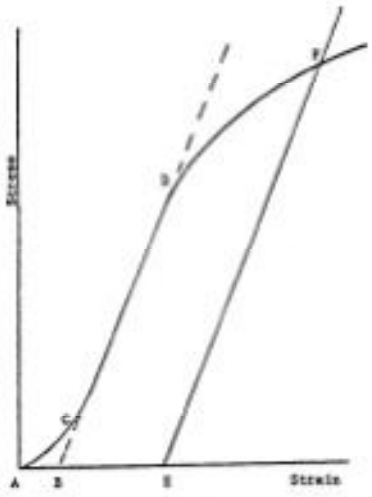
14.1 modulus of elasticity; percent elongation; plastics; tensile properties; tensile strength

ANNEXES

(Mandatory Information)

A1. TOE COMPENSATION

A1.1 In a typical stress-strain curve (Fig. A1.1) there is a toe region, *AC*, that does not represent a property of the material. It is an artifact caused by a takeup of slack and alignment or seating of the specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

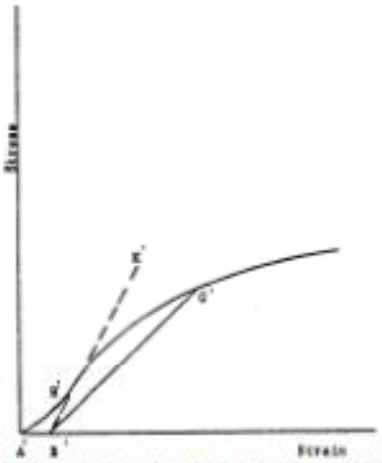


NOTE 1—
Some chart recorders plot the mirror image of this graph.

FIG. A1.1 Material with Hookean Region

A1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. A1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured, including the yield offset (*BE*), if applicable. The elastic modulus can be determined by dividing the stress at any point along the line *CD* (or its extension) by the strain at the same point (measured from Point *B*, defined as zero-strain).

A1.3 In the case of a material that does not exhibit any linear region (Fig. A1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection point (*H*). This is extended to intersect the strain axis at Point *B'*, the corrected zero-strain point. Using Point *B'* as zero strain, the stress at any point (*G*) on the curve can be divided by the strain at that point to obtain a secant modulus (slope of Line *B'G*). For those materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.



NOTE 1—Some chart recorders plot the mirror image of this graph.

FIG. A1.2 Material with No Hookean Region

A2. DEFINITIONS OF TERMS AND SYMBOLS RELATING TO TENSION TESTING OF PLASTICS

A2.1 *elastic limit*—the greatest stress which a material is capable of sustaining without any permanent strain remaining upon complete release of the stress. It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

NOTE A2.1—Measured values of proportional limit and elastic limit vary greatly with the sensitivity and accuracy of the testing equipment, eccentricity of loading, the scale to which the stress-strain diagram is plotted, and other factors. Consequently, these values are usually replaced by yield strength.

A2.2 *elongation*—the increase in length produced in the gage length of the test specimen by a tensile load. It is expressed in units of length, usually millimetres (inches). (Also known as *extension*.)

NOTE A2.2—Elongation and strain values are valid only in cases where uniformity of specimen behavior within the gage length is present. In the case of materials exhibiting necking phenomena, such values are only of qualitative utility after attainment of yield point. This is due to inability to ensure that necking will encompass the entire length between the gage marks prior to specimen failure.

A2.3 *gage length*—the original length of that portion of the specimen over which strain or change in length is determined.

A2.4 *modulus of elasticity*—the ratio of stress (nominal) to corresponding strain below the proportional limit of a material. It is expressed in force per unit area, usually megapascals (pounds-force per square inch). (Also known as *elastic modulus* or *Young's modulus*).

NOTE A2.3—The stress-strain relations of many plastics do not conform to Hooke's law throughout the elastic range but deviate therefrom even at stresses well below the elastic limit. For such materials the slope of the tangent to the stress-strain curve at a low stress is usually taken as the modulus of elasticity. Since the existence of a true proportional limit in plastics is debatable, the propriety of applying the term "modulus of elasticity" to describe the stiffness or rigidity of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are very dependent on such factors as rate of stressing, temperature, previous specimen history, etc. However, such a value is useful if its arbitrary nature and dependence on time, temperature, and other factors are realized.

A2.5 *necking*—the localized reduction in cross section which may occur in a material under tensile stress.

A2.6 *offset yield strength*—the stress at which the strain exceeds by a specified amount (the offset) an extension of the initial proportional portion of the stress-strain curve. It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

NOTE A2.4—This measurement is useful for materials whose stress-strain curve in the yield range is of gradual curvature. The offset yield strength can be derived from a stress-strain curve as follows (Fig. A2.1):

On the strain axis lay off *OM* equal to the specified offset.

Draw *OA* tangent to the initial straight-line portion of the stress-strain curve.

Through *M* draw a line *MN* parallel to *OA* and locate the intersection of *MN* with the stress-strain curve.

The stress at the point of intersection *t* is the "offset yield strength." The specified value of the offset must be stated as a percent of the original gage length in conjunction with the strength value. *Example:* 0.1 % offset yield strength = ... MPa (psi), or yield strength at 0.1 % offset ... MPa (psi).

A2.7 *percent elongation*—the elongation of a test specimen expressed as a percent of the gage length.

A2.8 *percent elongation at break and yield:*

A2.8.1 *percent elongation at break*—the percent elongation at the moment of rupture of the test specimen.

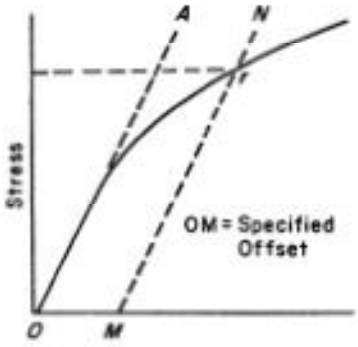


FIG. A2.1 Offset Yield Strength

A2.8.2 *percent elongation at yield*—the percent elongation at the moment the yield point (A2.22) is attained in the test specimen.

A2.9 *percent reduction of area (nominal)*—the difference between the original cross-sectional area measured at the point of rupture after breaking and after all retraction has ceased, expressed as a percent of the original area.

A2.10 *percent reduction of area (true)*—the difference between the original cross-sectional area of the test specimen and the minimum cross-sectional area within the gage boundaries prevailing at the moment of rupture, expressed as a percentage of the original area.

A2.11 *Poisson's Ratio*—The absolute value of the ratio of transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material.

A2.12 *proportional limit*—the greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

A2.13 *rate of loading*—the change in tensile load carried by the specimen per unit time. It is expressed in force per unit time, usually newtons (pounds-force) per minute. The initial rate of loading can be calculated from the initial slope of the load versus time diagram.

A2.14 *rate of straining*—the change in tensile strain per unit time. It is expressed either as strain per unit time, usually metres per metre (inches per inch) per minute, or percent elongation per unit time, usually percent elongation per minute. The initial rate of straining can be calculated from the initial slope of the tensile strain versus time diagram.

NOTE A2.5—The initial rate of straining is synonymous with the rate of crosshead movement divided by the initial distance between crossheads only in a machine with constant rate of crosshead movement and when the specimen has a uniform original cross section, does not "neck down," and does not slip in the jaws.

A2.15 *rate of stressing (nominal)*—the change in tensile stress (nominal) per unit time. It is expressed in force per unit area per unit time, usually megapascals (pounds-force per square inch) per minute. The initial rate of stressing can be calculated from the initial slope of the tensile stress (nominal) versus time diagram.

NOTE A2.6—The initial rate of stressing as determined in this manner has only limited physical significance. It does, however, roughly describe the average rate at which the initial stress (nominal) carried by the test specimen is applied. It is affected by the elasticity and flow characteristics of the materials being tested. At the yield point, the rate of stressing (true) may continue to have a positive value if the cross-sectional area is decreasing.

A2.16 *secant modulus*—the ratio of stress (nominal) to corresponding strain at any specified point on the stress-strain curve. It is expressed in force per unit area, usually megapascals (pounds-force per square inch), and reported together with the specified stress or strain.

NOTE A2.7—This measurement is usually employed in place of modulus of elasticity in the case of materials whose stress-strain diagram does not demonstrate proportionality of stress to strain.

A2.17 *strain*—the ratio of the elongation to the gage length of the test specimen, that is, the change in length per unit of original length. It is expressed as a dimensionless ratio.

A2.17.1 *nominal strain at break*—the strain at the moment of rupture relative to the original grip separation.

A2.18 *tensile strength (nominal)*—the maximum tensile stress (nominal) sustained by the specimen during a tension test. When the maximum stress occurs at the yield point (A2.22), it shall be designated tensile strength at yield. When the maximum stress occurs at break, it shall be designated tensile strength at break.

A2.19 *tensile stress (nominal)*—the tensile load per unit area of minimum original cross section, within the gage boundaries, carried by the test specimen at any given moment. It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

NOTE A2.8—The expression of tensile properties in terms of the minimum original cross section is almost universally used in practice. In the case of materials exhibiting high extensibility or necking, or both (A2.16), nominal stress calculations may not be meaningful beyond the yield point (A2.22) due to the extensive reduction in cross-sectional area that ensues. Under some circumstances it may be desirable to express the tensile properties per unit of minimum prevailing cross section. These properties are called true tensile properties (that is, true tensile stress, etc.).

A2.20 *tensile stress-strain curve*—a diagram in which values of tensile stress are plotted as ordinates against corresponding values of tensile strain as abscissas.

A2.21 *true strain* (see Fig. A2.2) is defined by the following equation for ε_v:

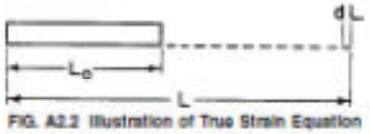


FIG. A2.2 Illustration of True Strain Equation

$$\varepsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o \qquad (A2.1)$$

where:

dL = increment of elongation when the distance between the gage marks is L,
L_o = original distance between gage marks, and
L = distance between gage marks at any time.

A2.22 *yield point*—the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress (Fig. A2.2).

NOTE A2.9—Only materials whose stress-strain curves exhibit a point of zero slope may be considered as having a yield point.

NOTE A2.10—Some materials exhibit a distinct "break" or discontinuity in the stress-strain curve in the elastic region. This break is not a yield point by definition. However, this point may prove useful for material characterization in some cases.

A2.23 *yield strength*—the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. Unless otherwise specified, this stress will be the stress at the yield point and when expressed in relation to the tensile strength shall be designated either tensile strength at yield or tensile stress at yield as required in A2.18 (Fig. A2.3). (See *offset yield strength*.)

A2.24 *Symbols*—The following symbols may be used for the above terms:

Symbol	Term
W	Load
ΔW	Increment of load
L	Distance between gage marks at any time
L_o	Original distance between gage marks
L_u	Distance between gage marks at moment of rupture
ΔL	Increment of distance between gage marks = elongation
A	Minimum cross-sectional area at any time
A_o	Original cross-sectional area
ΔA	Increment of cross-sectional area
A_u	Cross-sectional area at point of rupture measured after breaking specimen
A_T	Cross-sectional area at point of rupture, measured at the moment of rupture
t	Time
Δt	Increment of time
σ	Tensile stress
$\Delta\sigma$	Increment of stress
σ_T	True tensile stress
σ_u	Tensile strength at break (nominal)
σ_{uT}	Tensile strength at break (true)
ε	Strain
$\Delta\varepsilon$	Increment of strain
ε_u	Total strain, at break
ε_T	True strain
$\%E$	Percentage elongation
YP	Yield point
E	Modulus of elasticity

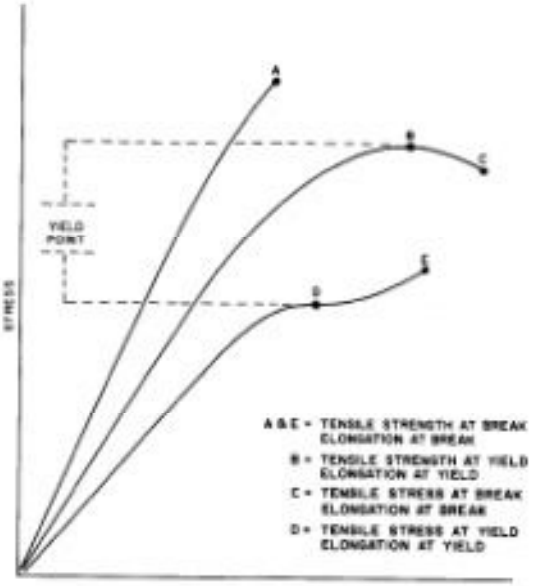


FIG. A2.3 Tensile Designations

A2.25 Relations between these various terms may be defined as follows:

$$\sigma = W/A_o$$
$$\sigma_T = W/A$$
$$\sigma_u = W/A_o \text{ (where } W \text{ is breaking load)}$$
$$\sigma_{uT} = W/A_T \text{ (where } W \text{ is breaking load)}$$
$$\varepsilon = \Delta L/L_o = (L - L_o)/L_o$$
$$\varepsilon_u = (L_u - L_o)/L_o$$
$$\varepsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o$$
$$\%E = [(L - L_o)/L_o] \times 100 = \varepsilon \times 100$$

Percent reduction of area (nominal) = $[(A_o - A_u)/A_o] \times 100$
Percent reduction of area (true) = $[(A_o - A_T)/A_o] \times 100$
Rate of loading = $\Delta W/\Delta t$
Rate of stressing (nominal) = $\Delta\sigma/\Delta = (\Delta W)/(A_o)/\Delta t$
Rate of straining = $\Delta\varepsilon/\Delta t = (\Delta L/L_o)/\Delta t$

For the case where the volume of the test specimen does not change during the test, the following three relations hold:

$$\sigma_T = \sigma(1 + \varepsilon) = \sigma L/L_o \qquad (A2.2)$$

$$\sigma_{uT} = \sigma_u(1 + \varepsilon_u) = \sigma_u L_u/L_o$$

$$A = A_o/(1 + \varepsilon)$$

A3. MEASUREMENT OF POISSON'S RATIO

A3.1. Scope

A3.1.1 This test method covers the determination of Poisson's ratio obtained from strains resulting from uniaxial stress only.

A3.1.2 Test data obtained by this test method are relevant and appropriate for use in engineering design.

A3.1.3 The values stated in SI units are regarded as the standard. The values given in parentheses are for information only.

NOTE A3.1—This standard is not equivalent to ISO 527-1.

A3.2. Referenced Documents

A3.2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing

D883 Terminology Relating to Plastics

D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

E83 Practice for Verification and Classification of Extensometer Systems

E132 Test Method for Poisson's Ratio at Room Temperature

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

A3.2.2 *ISO Standard:*[4]

ISO 527-1 Determination of Tensile Properties

A3.3. Terminology

A3.3.1 *Definitions*—Definitions of terms applying to this test method appear in Terminology D883 and Annex A2 of this standard.

A3.4. Significance and Use

A3.4.1 When uniaxial tensile force is applied to a solid, the solid stretches in the direction of the applied force (axially), but it also contracts in both dimensions perpendicular to the applied force. If the solid is homogeneous and isotropic, and the material remains elastic under the action of the applied force, the transverse strain bears a constant relationship to the axial strain. This constant, called Poisson's ratio, is defined as the negative ratio of the transverse (negative) to axial strain under uniaxial stress.

A3.4.2 Poisson's ratio is used for the design of structures in which all dimensional changes resulting from the application of force need to be taken into account and in the application of the generalized theory of elasticity to structural analysis.

NOTE A3.2—The accuracy of the determination of Poisson's ratio is usually limited by the accuracy of the transverse strain measurements because the percentage errors in these measurements are usually greater than in the axial strain measurements. Since a ratio rather than an absolute quantity is measured, it is only necessary to know accurately the relative value of the calibration factors of the extensometers. Also, in general, the value of the applied loads need not be known accurately.

A3.5. Apparatus

A3.5.1 Refer to 5.1 and 5.3 of this standard for the requirements of the testing machine and micrometers.

A3.5.2 For measurement of Poisson's Ratio use either a bi-axial extensometer or an axial extensometer in combination with a transverse extensometer. They must be capable of recording axial strain and transverse strain simultaneously. The extensometers shall be capable of measuring the change in strains with an accuracy of 1 % of the relevant value or better.

NOTE A3.3—Strain gages are used as an alternative method to measure axial and transverse strain; however, proper techniques for mounting strain gages are crucial to obtaining accurate data. Consult strain gage suppliers for instruction and training in these special techniques.

A3.6. Test Specimen

A3.6.1 *Specimen*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type I specimen is the preferred specimen and shall be used where sufficient material having a thickness of 7 mm (0.28 in.) or less is available.

A3.6.2 *Preparation*—Test specimens shall be prepared by machining operations, or die cutting, from materials in sheet, plate, slab, or similar form or be prepared by molding the material into the specimen shape to be tested.

NOTE A3.4—When preparing specimens from certain composite laminates such as woven roving, or glass cloth, care must be exercised in cutting the specimens parallel to the reinforcement, unless testing of specimens in a direction other than parallel with the reinforcement constitutes a variable being studied.

NOTE A3.5—Specimens prepared by injection molding have different tensile properties than specimens prepared by machining or die-cutting because of the orientation induced. This effect is more pronounced in specimens with narrow sections.

A3.6.3 All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine file or abrasive, and the filed surfaces shall then be smoothed with abrasive paper (No. 00 or finer). The finishing sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not to disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shown in Fig. 1 shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors.

A3.6.4 If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon or India ink that will not affect the material being tested. Gauge marks shall not be scratched, punched, or impressed on the specimen.

A3.6.5 When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.

A3.7 Number of Test Specimens

A3.7.1 Test at least five specimens for each sample in the case of isotropic materials.

A3.7.2 Test ten specimens, five normal to, and five parallel with, the principle axis of anisotropy, for each sample in the case of anisotropic materials.

A3.8. Conditioning

A3.8.1 Specimens shall be conditioned and tested in accordance with the requirement shown in Section 9 of this standard.

A3.9. Procedure

A3.9.1 Measure the width and thickness of each specimen to the nearest 0.025 mm (0.001 in.) using the applicable test methods in D5947. Follow the guidelines specified in 10.1.1 and 10.1.2 of this standard.

A3.9.2 Poisson's Ratio shall be determined at a speed of 5 mm/min.

A3.9.3 Place the specimen in the grips of the testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. The distance between the ends of the gripping surfaces, when using flat specimens, shall be as indicated in Fig. 1. Tighten the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test, but not to the point where the specimen would be crushed.

A3.9.4 Attach the biaxial extensometer or the axial and transverse extensometer combination to the specimen. The transverse extensometer should be attached to the width of the specimen.

A3.9.5 Apply a small preload (less than 5 N) to the specimen at a crosshead speed of 0.1 mm/min. This preload will eliminate any bending in the specimens.

A3.9.6 Rebalance the extensometers to zero.

A3.9.7 Run the test at 5 mm/min out to a minimum of 0.5 % strain before removing the extensometers, simultaneously recording the strain readings from the extensometers at the same applied force. The precision of the value of Poisson's Ratio will depend on the number of data points of axial and transverse strain taken. It is recommended that the data collection rate for the test be a minimum of 20 points per second (but preferably higher). This is particularly important for materials having a non linear stress to strain curve.

A3.9.8 Make the toe compensation in accordance with Annex A1. Determine the maximum strain (proportional limit) at which the curve is linear. If this strain is greater than 0.25 % the Poisson's Ratio is to be determined anywhere in this linear portion of the curve below the proportional limit. If the material does not exhibit a linear stress to strain relationship the Poisson's Ratio shall be determined within the axial strain range of 0.0005 to 0.0025 mm/mm (0.05 to 0.25 %). If the ratio is determined in this manner it shall be noted in the report that a region of proportionality of stress to strain was not evident.

NOTE A3.6—A suitable method for determination of linearity of the stress to strain curve is by making a series of tangent modulus measurements at different axial strain levels. Values equivalent at each strain level indicate linearity. Values showing a downward trend with increasing strain level indicate non linearity.

A3.10. Calculation

A3.10.1 *Poisson's Ratio*—The axial strain, ε_a, indicated by the axial extensometer, and the transverse strain, ε_t, indicated by the transverse extensometers, are plotted against the applied load, P, as shown in Fig. 4.

A3.10.1.1 For those materials where there is proportionality of stress to strain and it is possible to determine a modulus of elasticity, a straight line is drawn through each set of points within the load range used for determination of modulus, and the slopes $d\varepsilon_a / dP$ and $d\varepsilon_t / dP$, of those lines are determined. The use of a least squares method of calculation will reduce errors resulting from drawing lines. Poisson's Ratio, $|\mu|$, is then calculated as follows:

$$|\mu| = (d\varepsilon_t/dP)/(d\varepsilon_a/dP) \quad \text{(A3.1)}$$

where:

$d\varepsilon_t$ = change in transverse strain,
$d\varepsilon_a$ = change in axial strain, and
dP = change in applied load;

$$|\mu| = (d\varepsilon_t)/(d\varepsilon_a) \quad \text{(A3.2)}$$

A3.10.1.2 The errors that are introduced by drawing a straight line through the points are reduced by applying the least squares method.

A3.10.1.3 For those materials where there is no proportionality of stress to strain evident determine the ratio of $d\varepsilon_t / d\varepsilon_a$ when $d\varepsilon_a = 0.002$ (based on axial strain range of 0.0005 to 0.0025 mm/mm) and after toe compensation has been made.

$$|\mu| = d\varepsilon_t/0.002 \quad \text{(A3.3)}$$

A3.11. Report

A3.11.1 Report the following information:

A3.11.1.1 Complete identification of the material tested, including type, source, manufacturer's code numbers, form, principal dimensions, previous history, etc.,

A3.11.1.2 Method of preparing test specimens,

A3.11.1.3 Type of test specimen and dimensions,

A3.11.1.4 Conditioning procedure used,

A3.11.1.5 Atmospheric conditions in test room,

A3.11.1.6 Number of specimens tested,

A3.11.1.7 Speed of testing,

A3.11.1.8 Classification of extensometers used. A description of measuring technique and calculations employed,

A3.11.1.9 Poisson's ratio, average value, standard deviation, and statement of whether there was proportionality within the strain range,

A3.11.1.10 Date of test, and

A3.11.1.11 Revision date of Test Method D618.

A3.12. Precision and Bias

A3.12.1 *Precision*—The repeatability standard deviation has been determined to be the following (see Table A3.1.) An attempt to develop a full precision and bias statement for this test method will be made at a later date. For this reason, data on precision and bias cannot be given. Because this test method does not contain a round-robin based numerical precision and bias statement, it shall not be used as a referee test method in

TABLE A3.1 Poisson's Ratio Based on One Laboratory

Material	Extensometer Type	Average	V_x[A]	V_R[B]	r[C]	R[D]
PP Copolymer	2-point	0.406	0.011		0.031	
PP Copolymer	4-point	0.392	0.010		0.028	
PP Homopolymer with 20 % Glass	2-point	0.426	0.013		0.036	
PP Homopolymer with 20 % Glass	4-point	0.410	0.015		0.042	

[A] S_r = within-laboratory standard deviation for the indicated material. It is obtained by first pooling the within-laboratory standard deviations of the test results from all the participating laboratories:

$$S_r = [(S_1)^2 + (S_2)^2 + \ldots + (S_n)^2]/n]^{1/2}$$

[B] S_R = between-laboratories reproducibility, expressed as standard deviation: $S_R = [S_r^2 + S_L^2]^{1/2}$

[C] r = within-laboratory critical interval between two test results = $2.8 \times S_r$

[D] R = between-laboratories critical interval between two test results = $2.8 \times S_R$

case of dispute. Anyone wishing to participate in the development of precision and bias data should contact the Chairman, Subcommittee D20.10 Mechanical Properties, ASTM International, 100 Barr Harbor, West Conshohocken, PA 19428.

A3.13 Keywords

A3.13.1 axial strain; Poisson's ratio; transverse strain

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D638 - 08) that may impact the use of this standard. (May 15, 2010)

(1) Edited conditioning and test condition clauses.

ANEXO No. 5: ASTM D2240: Standard test Method for Rubber Property – Durometer Hardness

Designation: D2240 – 05 (Reapproved 2010)

Standard Test Method for Rubber Property—Durometer Hardness[1]

This standard is issued under the fixed designation D2240; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers twelve types of rubber hardness measurement devices known as durometers: Types A, B, C, D, DO, E, M, O, OO, OOO, OOO-S, and R. The procedure for determining indentation hardness of substances classified as thermoplastic elastomers, vulcanized (thermoset) rubber, elastomeric materials, cellular materials, gel-like materials, and some plastics is also described.

1.2 This test method is not equivalent to other indentation hardness methods and instrument types, specifically those described in Test Method D1415.

1.3 This test method is not applicable to the testing of coated fabrics.

1.4 All materials, instruments, or equipment used for the determination of mass, force, or dimension shall have traceability to the National Institute for Standards and Technology, or other internationally recognized organizations parallel in nature.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only. Many of the stated dimensions in SI are direct conversions from the U. S. Customary System to accommodate the instrumentation, practices, and procedures that existed prior to the Metric Conversion Act of 1975.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D374 Test Methods for Thickness of Solid Electrical Insulation

D618 Practice for Conditioning Plastics for Testing

D785 Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials

D1349 Practice for Rubber—Standard Temperatures for Testing

D1415 Test Method for Rubber Property—International Hardness

D4483 Practice for Evaluating Precision for Test Method Standards in the Rubber and Carbon Black Manufacturing Industries

F1957 Test Method for Composite Foam Hardness-Durometer Hardness

2.2 *ISO Standard:*[3]

ISO/IEC 17025: 1999 General Requirements for the Competence of Testing and Calibration Laboratories

3. Summary of Test Method

3.1 This test method permits hardness measurements based on either initial indentation or indentation after a specified period of time, or both. Durometers with maximum reading indicators used to determine maximum hardness values of a material may yield lower hardness when the maximum indicator is used.

3.2 The procedures for Type M, or micro hardness durometers, accommodate specimens that are, by their dimensions or configuration, ordinarily unable to have their durometer hardness determined by the other durometer types described. Type M durometers are intended for the testing of specimens having a thickness or cross-sectional diameter of 1.25 mm (0.050 in.) or greater, although specimens of lesser dimensions may be successfully accommodated under the conditions specified in Section 6, and have a Type M durometer hardness range between 20 and 90. Those specimens which have a durometer hardness range other than specified shall use another suitable procedure for determining durometer hardness.

[1] This test method is under the jurisdiction of ASTM Committee D11 on Rubber and is the direct responsibility of Subcommittee D11.10 on Physical Testing.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland.

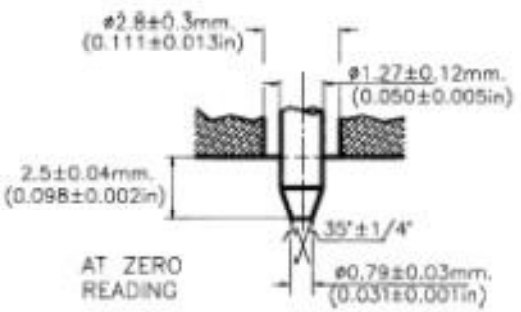


FIG. 1 (a) Type A and C Indentor

4. Significance and Use

4.1 This test method is based on the penetration of a specific type of indentor when forced into the material under specified conditions. The indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material. *The geometry of the indentor and the applied force influence the measurements such that no simple relationship exists between the measurements obtained with one type of durometer and those obtained with another type of durometer or other instruments used for measuring hardness.* This test method is an empirical test intended primarily for control purposes. No simple relationship exists between indentation hardness determined by this test method and any fundamental property of the material tested. For specification purposes, it is recommended that Test Method D785 be used for materials other than those described in 1.1.

5. Apparatus

5.1 *Hardness Measuring Apparatus, or Durometer, and an Operating Stand*, Type 1, Type 2, or Type 3 (see 5.1.2) consisting of the following components:

5.1.1 *Durometer:*

5.1.1.1 *Presser Foot*, the configuration and the total area of a durometer presser foot may produce varying results when there are significant differences between them. It is recommended that when comparing durometer hardness determinations of the same type (see 4.1), that the comparisons be between durometers of similar presser foot configurations and total area, and that the presser foot configuration and size be noted in the Hardness Measurement Report (see 10.2.4 and 5.1.1.3).

5.1.1.2 *Presser Foot*, Types A, B, C, D, DO, E, O, OO, OOO, and OOO-S, with an orifice (to allow for the protrusion of the indentor) having a diameter as specified in Fig. 1 (a, b, c, d, e, f, and g), with the center a minimum of 6.0 mm (0.24 in.) from any edge of the foot. When the presser feet is not of a flat circular design, the area shall not be less than 500 mm^2 (19.7 $in.^2$).

NOTE 1—The Type OOO and the Type OOO-S, designated herein, differ in their indentor configuration, spring force, and the results obtained. See Table 1 and Fig. 1 (e and g).

5.1.1.3 *Presser Foot*—flat circular designs designated as Type *xR*, where *x* is the standard durometer designation and *R* indicates the flat circular press foot described herein, for example, Type *aR*, *dR*, and the like. The presser foot, having a centrally located orifice (to allow for the protrusion of the indentor) of a diameter as specified in Fig. 1 (a through g). The flat circular presser feet shall be 18 ± 0.5 mm (0.71 ± 0.02 in.) in diameter. These durometer types shall be used in an operating stand (see 5.1.2).

(a) Durometers having a presser feet configuration other than that indicated in 5.1.1.3 shall not use the Type *xR* designation, and it is recommended that their presser foot configuration and size be stated in the Hardness Measurement Report (see 10.2.4).

5.1.1.4 *Presser Foot, Type M*, with a centrally located orifice (to allow for the protrusion of the indentor), having a diameter as specified in Fig. 1 (d), with the center a minimum of 1.60 mm (0.063 in.) from any edge of the flat circular presser foot. The Type M durometer shall be used in a Type 3 operating stand (see 5.1.2.4).

5.1.1.5 *Indentor*, formed from steel rod and hardened to 500 HV10 and shaped in accordance with Fig. 1 (a, b, c, d, e, or g), polished over the contact area so that no flaws are visible under 20× magnification, with an indentor extension of 2.50 ± 0.04 mm (0.098 ± 0.002 in.).

5.1.1.6 *Indentor, Type OOO-S*, formed from steel rod and hardened to 500 HV10, shaped in accordance with Fig. 1 (f), polished over the contact area so that no flaws are visible under 20× magnification, with an indentor extension of 5.00 ± 0.04 mm (0.198 ± 0.002 in.).

5.1.1.7 *Indentor, Type M*, formed from steel rod and hardened to 500 HV10 and shaped in accordance with Fig. 1 (d), polished over the contact area so that no flaws are visible under 50× magnification, with an indentor extension of 1.25 ± 0.02 mm (0.049 ± 0.001 in.).

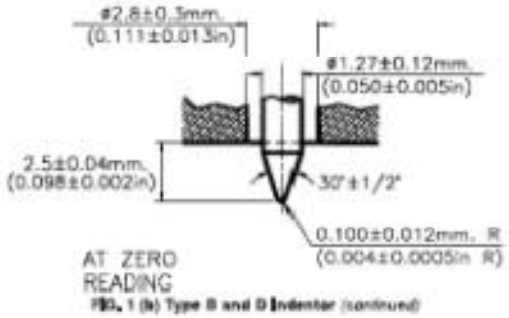


FIG. 1 (b) Type B and B Indentor (continued)

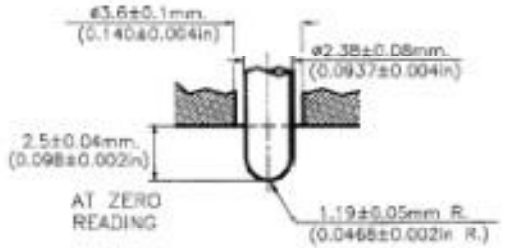


FIG. 1 (c) Type O, OO, and OO Indentor (continued)

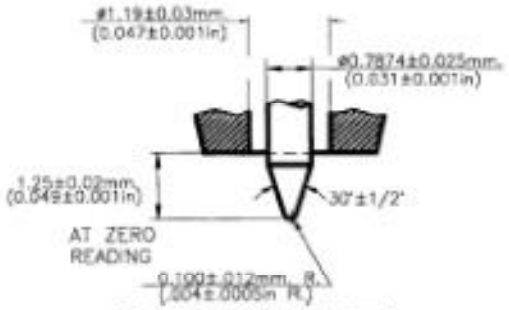


FIG. 1 (d) Type M Indentor (continued)

5.1.1.8 *Indentor Extension Indicator*, analog or digital electronic, having a display that is an inverse function of the indentor extension so that:

(1) The display shall indicate from 0 to 100 with no less than 100 equal divisions throughout the range at a rate of one hardness point for each 0.025 mm (0.001 in.) of indentor movement,

(2) The display for Type OOO-S durometers shall indicate from 0 to 100 with no less than 100 equal divisions throughout the range at a rate of one hardness point for each 0.050 mm (0.002 in.) of indentor movement,

(3) The display for Type M durometers shall indicate from 0 to 100 with no less than 100 equal divisions at a rate of one hardness point for each 0.0125 mm (0.0005 in.) of indentor movement, and

(4) In the case of analog dial indicators having a display of 360°, the points indicating 0 and 100 may be at the same point on the dial and indicate 0, 100, or both.

5.1.1.9 *Timing Device (optional)*, capable of being set to a desired elapsed time, signaling the operator or holding the hardness reading when the desired elapsed time has been reached. The timer shall be automatically activated when the presser foot is in contact with the specimen being tested, for example, the initial indentor travel has ceased. Digital electronic durometers may be equipped with electronic timing devices that shall not affect the indicated reading or determinations attained by more than one-half of the calibration tolerance stated in Table 1.

5.1.1.10 *Maximum Indicators (optional)*, maximum indicating pointers are auxiliary analog indicating hands designed to

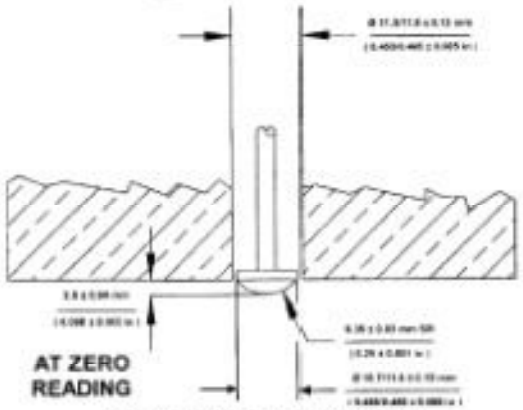


FIG. 1 (e) Type OOO Indenter (continued)

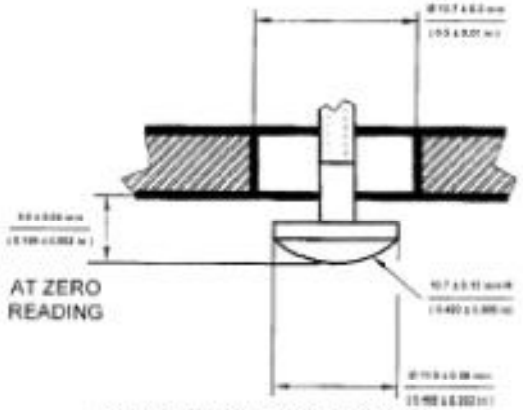


FIG. 1 (f) Type OOO-S Indenter (continued)

remain at the maximum hardness value attained until reset by the operator. Electronic maximum indicators are digital displays electronically indicating and maintaining the maximum value hardness valued achieved until reset by the operator.

5.1.1.11 Analog maximum indicating pointers have been shown to have a nominal effect on the values attained, however, this effect is greater on durometers of lesser total mainspring loads; for example, the effect of a maximum indicating pointer on Type D durometer determinations will be less than those determinations achieved using a Type A durometer. Analog style durometers may be equipped with maximum indicating pointers. The effect of a maximum indicating pointer shall be noted at the time of calibration in the calibration report (see 10.1.5), and when reporting hardness determinations (see 10.2.4). Analog Type M, OO, OOO, and Type OOO-S durometers shall not be equipped with maximum indicating pointers.

5.1.1.12 Digital electronic durometers may be equipped with electronic maximum indicators that shall not affect the indicated reading or determinations attained by more than one half of the spring calibration tolerance stated in Table 1.

5.1.1.13 *Calibrated Spring*, for applying force to the indentor, in accordance with Fig. 1 (a through g) and capable of applying the forces as specified in Table 1.

5.1.2 *Operating Stand* (Fig. 2):

5.1.2.1 Type 1, Type 2, and Type 3 shall be capable of supporting the durometer presser foot surface parallel to the specimen support table (Fig. 3) throughout the travel of each. The durometer presser foot to specimen support table parallelism shall be verified each time the test specimen support table is adjusted to accommodate specimens of varying dimensions. This may be accomplished by applying the durometer presser foot to the point of contact with the specimen support table and making adjustments by way of the durometer mounting assembly or as specified by the manufacturer.

5.1.2.2 *Operating Stand, Type 1* (specimen to indentor type), shall be capable of applying the specimen to the indentor in a manner that minimizes shock.

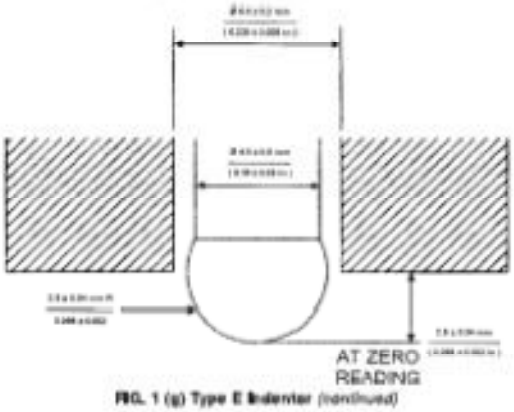


FIG. 1 (g) Type E Indenter (continued)

TABLE 1 Durometer Spring Force Calibration[A]
All Values are in N

Indicated Value	Type A, B, E, O	Type C, O, OO	Type M	Type OO, OOO	Type OOO-S
0	0,55	0	0,324	0,053	0,147
10	1,3	0,445	0,368	0,244	0,343
20	3,05	0,89	0,412	0,385	0,520
30	5,8	13,335	0,456	0,476	0,698
40	8,55	17,78	0,5	0,566	0,875
50	12,3	22,225	0,544	0,657	1,049
60	16,05	26,67	0,589	0,748	1,226
70	20,8	31,115	0,633	0,839	1,402
80	26,55	35,56	0,677	0,93	1,579
90	33,3	40,005	0,721	1,02	1,756
100	44,45	44,45	0,765	1,111	1,932
Nidurometer unit	0,075	0,4445	0,0044	0,00108	0,01765
Spring Calibration Tolerance	± 0,075 N	± 0,4445 N	± 0,0178 N	± 0,0100 N	± 0,0353 N

[A] Refer to 5.1.1.3 for the Type of designation.

5.1.2.3 *Operating Stand, Type 2* (indentor to specimen type), shall be capable of controlling the rate of descent of the indentor to the specimen at a maximum of 3.20 mm/s (0.125 in./s) and applying a force sufficient to overcome the calibrated spring force as shown in Table 1.

5.1.2.4 *Operating Stand, Type 3* (indentor to specimen type), hydraulic dampening, pneumatic dampening, or electromechanical (required for the operation of Type M durometers) shall be capable of controlling the rate of descent of the indentor to the specimen at a maximum of 3.2 mm/s (0.125 in./s) and applying a force sufficient to overcome the calibrated spring force as shown in Table 1. Manual application, Type 1 or Type 2 operating stands are not acceptable for Type M durometer operation.

5.1.2.5 The entire instrument should be plumb and level, and resting on a surface that will minimize vibration. Operating the instrument under adverse conditions will negatively affect the determinations attained.

5.1.2.6 *Specimen Support Table*, (Fig. 3) integral to the operating stand, and having a solid flat surface. The specimen support platform may have orifices designed to accept various inserts or support fixtures (Fig. 3) to provide for the support of irregularly configured specimens. When inserts are used to support test specimens, care must be taken to align the indentor to the center of the insert, or the point at which the indentor is to contact the specimen. Care should be exercised to assure that the indentor does not abruptly contact the specimen support table as damage to the indentor may result.

6. Test Specimen

6.1 The test specimens, herein referred to as "specimen" or "test specimen" interchangeably, shall be at least 6.0 mm (0.24 in.) in thickness unless it is known that results equivalent to the 6.0-mm (0.24-in.) values are obtained with a thinner specimen.

6.1.1 A specimen may be composed of plied pieces to obtain the necessary thickness, but determinations made on such specimens may not agree with those made on solid specimens, as the surfaces of the plied specimens may not be in complete contact. The lateral dimensions of the specimen shall be sufficient to permit measurements at least 12.0 mm (0.48 in.) from any edge, unless it is known that identical results are obtained when measurements are made at a lesser distance from an edge.

6.1.2 The surfaces of the specimen shall be flat and parallel over an area to permit the presser foot to contact the specimen over an area having a radius of at least 6.0 mm (0.24 in.) from

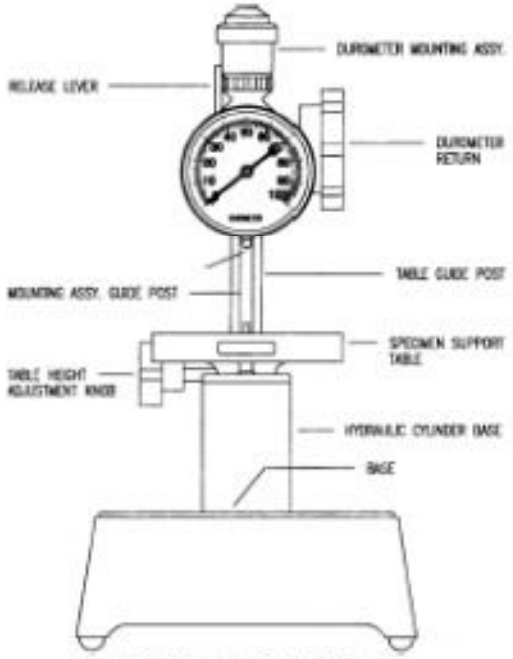
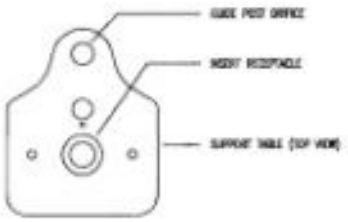


FIG. 2 Durometer Operating Stand



TYPICAL TABLE INSERTS USED FOR POSITIONING TUBING, O-RINGS AND SMALL SPECIMENS

FIG. 3 Small Specimen Support Table

the indentor point. The specimen shall be suitably supported to provide for positioning and stability. *A suitable hardness determination cannot be made on an uneven or rough point of contact with the indentor.*

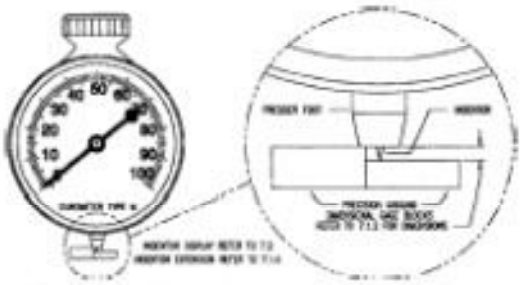


FIG. 4 Detail of Indentor Extension and Display Adjustment

6.2 Type OOO, OOO-S, and M test specimens should be at least 1.25 mm (0.05 in.) in thickness, unless it is known that results equivalent to the 1.25-mm (0.05-in.) values are obtained with a thinner specimen.

6.2.1 A Type M specimen that is not of a configuration described in 6.2.2 may be composed of plied pieces to obtain the necessary thickness, but determinations made on such specimens may not agree with those made on solid specimens because the surfaces of the plied specimens may not be in complete contact. The lateral dimensions of the specimen should be sufficient to permit measurements at least 2.50 mm (0.10 in.) from any edge unless it is known that identical results are obtained when measurements are made at lesser distance from an edge. *A suitable hardness determination cannot be made on an uneven or rough point of contact with the indentor.*

6.2.2 The Type M specimen, when configured as an o-ring, circular band, or other irregular shape shall be at least 1.25 mm (0.05 in.) in cross-sectional diameter, unless it is known that results equivalent to the 1.25-mm (0.05-in.) values are obtained with a thinner specimen. The specimen shall be suitably supported in a fixture (Fig. 3) to provide for positioning and stability.

6.3 The minimum requirement for the thickness of the specimen is dependent on the extent of penetration of the indentor into the specimen; for example, thinner specimens may be used for materials having higher hardness values. The minimum distance from the edge at which measurements may be made likewise decreases as the hardness increases.

7. Calibration

7.1 *Indentor Extension Adjustment Procedure:*

7.1.1 Place precision ground dimensional blocks (Grade B or better) on the support table and beneath the durometer presser foot and indentor. Arrange the blocks so that the durometer presser foot contacts the larger block(s) and the indentor tip just contacts the smaller block (Fig. 4). It is necessary to observe the arrangement of the blocks and the presser foot/indentor under a minimum of 20× magnification to assure proper alignment.

7.1.2 Indentor extension and shape shall be in accordance with 5.1.1.5, 5.1.1.6, or 5.1.1.7, respective to durometer type. See Fig. 1 (a through g). Examination of the indentor under 20× magnification, 50× for Type M indentors, is required to examine the indentor condition. Misshapen or damaged indentors shall be replaced.

7.1.3 A combination of dimensional gage blocks shall be used to achieve a difference of 2.54 + 0.00/−0.0254 mm (0.100 + 0.00/−0.001 in.) between them. For Type OOO-S durometers, the gage block dimensions are 5.08 + 0.00/−0.0508 mm (0.200 + 0.00/−0.002 in.). For Type M durometers, the gage block dimensions are 1.27 + 0.00/−0.0127 mm (0.050 + 0.00/−0.0005 in.) between them (Fig. 4).

7.1.4 Carefully lower the durometer presser foot until it contacts the largest dimensional block(s), the indentor tip should just contact the smaller block, verifying full indentor extension.

7.1.5 Adjust the indentor extension to 2.50 ± 0.04 mm (0.098 ± 0.002 in.). For Type OOO-S durometers, adjust the indentor extension to 5.0 ± 0.04 mm (0.196 ± 0.002 in.). For Type M durometers, adjust the indentor extension to 1.25 ± 0.02 mm (0.049 ± 0.001 in.), following the manufacturer's recommended procedure.

7.1.5.1 When performing the procedures in 7.1, care should be used so as not to cause damage to the indentor tip. Fig. 4 depicts a suitable arrangement for gaging indentor extension.

7.1.6 Parallelism of the durometer presser foot to the support surface, and hence the dimensional gage blocks, at the time of instrument calibration, may be in accordance with Test Methods D374, Machinist's Micrometers, or otherwise accomplished in accordance with the procedures specified by the manufacturer.

7.2 *Indentor Display Adjustment:*

7.2.1 After adjusting the indentor extension as indicated in 7.1, use a similar arrangement of dimensional gage blocks to verify the linear relationship between indentor travel and indicated display at two points: 0 and 100. Following the manufacturer's recommendations, make adjustments so that:

7.2.2 The indicator displays a value equal to the indentor travel measured to within:

−0.0 +1.0 durometer units measured at 0;

±0.50 durometer units measured at 100;

±1 durometer units at all other points delineated in 7.4.

7.2.3 Each durometer point indicated is equal to 0.025 mm (0.001 in.) of indentor travel, except for:

7.2.3.1 Type M Durometers, each indicated point is equal to 0.0125 mm (0.0005 in.) of indentor travel;

7.2.3.2 Type OOO-S Durometers, each indicated point is equal to 0.050 mm (0.002 in.) of indentor travel.

7.2.4 The indicator shall not display a value greater than 100 or less than 0 at the time of calibration.

7.2.5 Other means of determining indentor extension or indentor travel, such as optical or laser measurement methods, are acceptable. The instrumentation used shall have traceability as described in 1.4.

7.2.6 The durometer shall be supported in a suitable fashion when performing the procedures described in 7.1 and 7.2.

7.3 *Calibration Device:*

7.3.1 The durometer spring shall be calibrated by supporting the durometer in a calibrating device, see Fig. 5, in a vertical position and applying a measurable force to the indentor tip. The force may be measured by means of a balance

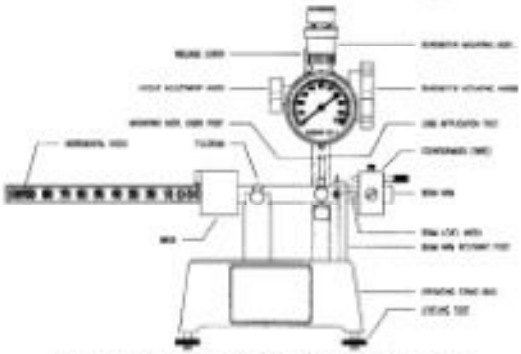


FIG. 5 Example of Durometer Calibration Apparatus

as depicted in Fig. 5, or an electronic force cell. The calibrating device shall be capable of measuring applied force to within 0.5 % of the maximum spring force necessary to achieve 100 durometer units.

7.3.2 Care should be taken to ensure that the force is applied vertically to the indentor tip, as lateral force will cause errors in calibration. See 7.1.5.1 and 7.1.6.

7.4 *Spring Calibration*—The durometer spring shall be calibrated at displayed readings of 10, 20, 30, 40, 50, 60, 70, 80, and 90. The measured force (9.8× mass in kilograms) shall be within the spring calibration tolerance specified in Table 1. Table 1 identifies the measured force applied to the indenter for the entire range of the instrument, although it is necessary only to verify the spring calibration at points listed herein.

7.5 *Spring Calibration Procedure:*

7.5.1 Ensure that the indentor extension has been adjusted in accordance with 7.1, and the linear relationship between indentor travel and display is as specified in 7.2.

7.5.2 Place the durometer in the calibration device as depicted in Fig. 5. Apply the forces indicated in Table 1 so that forces applied are aligned with the centerline of the indenter in a fashion that eliminates shock or vibration and adjust the durometer according to manufacturers' recommendations so that:

7.5.3 At the points enumerated in 7.4, the display shall indicate a value equal to 0.025 mm (0.001 in.) of indentor travel. For Type OOO-S durometers, the display shall indicate a value equal to 0.05 mm (0.002 in.) of indentor travel. For Type M durometers, the display shall indicate a value equal to 0.0125 mm (0.0005 in.) of indentor travel within the spring calibration tolerances specified in 7.6.

7.6 Spring calibration tolerances are ±1.0 durometer units for Types A, B, C, D, E, O, and DO, ±2.0 durometer units for Types OO, OOO, and OOO-S, and ±4.0 durometer units for Type M, while not indicating below 0 or above 100 at the time of calibration (see Table 1).

7.7 *Spring Force Combinations:*

7.7.1 For Type A, B, E, and O durometers:
Force, N = 0.55 + 0.075 HA
Where HA = hardness reading on Type A, B, E, and O durometers.

7.7.2 For Type C, D, and DO durometers:
Force, N = 0.4445 HD
Where HD = hardness reading on Type C, D, and DO durometers.

7.7.3 For Type M durometers:
Force, N = 0.324 + 0.0044 HM
Where HM = hardness reading on Type M durometers.

7.7.4 For Type OO and OOO durometers:
Force, N = 0.203 + 0.00908 HOO
Where HOO = hardness reading on Type OO durometers.

7.7.5 For Type OOO-S durometers:
Force, N = 0.167 + 0.01765 HOOO-S
Where HOOO-S = hardness reading on Type OOO-S durometers.

7.8 The rubber reference block(s) provided for verifying durometer operation and state of calibration are not to be relied upon as calibration standards. The calibration procedures outlined in Section 7 are the only valid calibration procedures.

7.8.1 The use of metal reference blocks is no longer recommended (see Note 2).

7.9 Verifying the state of durometer calibration, *during routine use*, may be accomplished by:

7.9.1 Verifying that the zero reading is no more than 1 indicated point above zero, and not below zero (on durometers so equipped), when the durometer is positioned so that no external force is placed upon the indentor.

7.9.2 Verifying that the 100 reading is no more than 100 and no less than 99 when the durometer is positioned on a flat surface of a non-metallic material so that the presser foot is in complete contact, causing the indentor to be fully retracted.

7.9.2.1 It is important that when performing the verification of 100, as described in 7.9.2, that extreme care be taken so as to not cause damage to the indentor. Verification of the 100 value is not recommended for durometers having a spring force greater than 10 N (Types C, D, and DO).

7.9.2.2 When performing the verification of 100, as described in 7.9.2, the non-metallic material shall be of a hardness value greater than 100 of the type (scale) of the durometer being employed. Tempered glass of a thickness greater than 6.35 mm (0.25 in.) has been found satisfactory for this application.

7.9.3 Verifying the displayed reading at any other point using commercially available rubber reference blocks which are certified to a stated value of the type (scale) of the durometer being employed. The displayed value of the durometer should be within ±2 durometer points of the reference block's stated value.

7.9.4 Verification of the zero and 100 readings of a durometer provide reasonable assurance that the linear relationship between the indicated display and the durometer mechanism remain valid.

7.9.5 Verification of points between zero and 100 provide reasonable assurance that the curvilinear relationship between the indicated display and the durometer mechanism remain valid.

7.9.6 *This is not a calibration procedure, it is a means by which a user may routinely verify that the durometer may be functioning correctly.* (See Note 2.)

8. Laboratory Atmosphere and Test Specimen Conditioning

8.1 Tests shall be conducted in the standard laboratory atmosphere, as defined in Practice D618, Section 4.2.

8.2 The instrument shall be maintained in the standard laboratory atmosphere, as defined in Practice D618, Section 4.1, for 12 h prior to performing a test.

8.3 The specimen shall be conditioned in accordance with condition 40/23 exclusive of humidity control, as described in Practice D618, Section 8.1, Procedure A and tested under the same conditions, exclusive of humidity control.

8.4 These procedures may be modified if agreed upon between laboratories or between supplier and user and are in accordance with alternative procedures identified in Practice D618.

8.5 No conclusive evaluation has been made on durometers at temperatures other than 23.0 ± 2.0°C (73.4 ± 3.6°F). Conditioning at temperatures other than the above may show changes in calibration. Durometer use at temperatures other than the above should be decided locally (see Practice D1349).

9. Procedure

9.1 *Operating Stand Operation (Type S Operating Stand Required for Type M):*

9.1.1 Care shall be exercised to minimize the exposure of the instrument to environmental conditions that are adverse to the performance of the instrument, or adversely affect test results.

9.1.2 Adjust the presser foot to support table parallelism as described in 5.1.2.1. It is necessary to make this adjustment each time the support table is moved to accommodate specimens of varying dimensions.

9.1.3 Prior to conducting a test, adjust the vertical distance from the presser foot to the contact surface of the test specimen to 25.4 ± 2.5 mm (1.00 ± 0.100 in.), unless it is known that identical results are obtained with presser foot at a greater or lesser vertical distance from the test specimen contact surface, or if otherwise stipulated by the manufacturer.

9.1.4 Place the specimen on the specimen support table, in a manner that the contact point of the indentor is in accordance with Section 6, unless it is known that identical results are obtained when measurements are made with the indentor at a lesser distance from the edge of the test specimen.

9.1.5 Actuate the release lever (Fig. 2) of the operating stand or activate the electromechanical device, allowing the durometer to descend at a controlled rate and apply the presser foot to the specimen in accordance with 5.1.2. In the case of "specimen to indentor" type operating stands, operate the lever or other mechanism to apply the specimen to the indentor in a manner that assures parallel contact of the specimen to the durometer presser foot without shock and with just sufficient force to overcome the calibrated spring force as shown in Table 1.

9.1.6 An operating stand that applies the mass at a controlled rate of descent, without shock is mandatory for Type M durometers. Hand-held application or the use of a Type 1 or Type 2 operating stand for the Type M durometer is not an acceptable practice, see 5.1.2.4.

9.1.7 For any material covered in 1.1, once the presser foot is in contact with the specimen, for example, when the initial indentor travel has ceased, the maximum indicated reading shall be recorded. The time interval of 1 s, between initial indentor travel cessation and the recording of the indicated reading, shall be considered standard. Other time intervals, when agreed upon among laboratories or between supplier and user, may be used and reported accordingly. The indicated hardness reading may change with time.

9.1.7.1 If the durometer is equipped with an electronic maximum indicator or timing device (refer to 5.1.1.9) the indicated reading shall be recorded within 1 ± 0.1 s of the cessation of indentor travel and reported (refer to 10.2.9 for reporting protocols), unless otherwise noted.

9.1.7.2 If the durometer is equipped with an analog type maximum indicator (refer to 5.1.1.10), the maximum indicated reading may be recorded and shall be reported (refer to 10.2.9), unless otherwise noted.

9.1.7.3 If the durometer is not equipped with the devices described in 5.1.1.9 or 5.1.1.10, the indicated reading shall be recorded within 1 s as is possible and reported (refer to 10.2.9), unless otherwise noted.

9.1.8 Make five determinations of hardness at different positions on the specimen at least 6.0 mm (0.24 in.) apart, 0.80 mm (0.030 in.) apart for Type M, and calculate the arithmetic mean, or alternatively calculate the median. The means of calculating the determinations shall be reported according to 10.2.8.

9.2 *Manual (Hand Held) Operation of Durometer:*

9.2.1 Care shall be exercised to minimize the exposure of the instrument to environmental conditions that are adverse to the performance of the instrument, or adversely affect test results.

9.2.2 Place the specimen on a flat, hard, horizontal surface. Hold the durometer in a vertical position with the indentor tip at a distance from any edge of the specimen as described in Section 6, unless it is known that identical results are obtained when measurements are made with the indentor at a lesser distance.

9.2.3 Apply the presser foot to the specimen, maintaining it in a vertical position keeping the presser foot parallel to the specimen, with a firm smooth downward action that will avoid shock, rolling of the presser foot over the specimen, or the application of lateral force. Apply sufficient pressure to assure firm contact between the presser foot and the specimen.

9.2.4 For any material covered in 1.1, after the presser foot is in contact with the specimen, the indicated reading shall be recorded within 1 ± 0.1 s, or after any period of time agreed upon among laboratories or between supplier and user. If the

TABLE 2 Type 1 Precision—Type M Durometer Method

Material	Average Level	Within Laboratories			Between Laboratories		
	MEAN	$(Sr)^A$	r^B	$(r)^C$	$(SR)^D$	R^E	$(R)^F$
1	31,8	1,36	3,78	11,94	3,16	10,63	33,41
2	48,8	1,14	3,23	7,00	2,47	7,00	17,13
3	64,0	0,975	2,76	5,11	2,39	6,73	12,46
4	82,8	0,792	2,21	3,53	2,24	6,34	10,16
5	76,9	0,788	2,21	3,83	0,874	2,76	3,69
6	80,6	1,686	4,77	5,92	1,61	4,58	5,61
7	87,7	1,15	3,25	3,71	2,63	7,45	8,50
8	32,4	0,947	2,68	8,26	3,84	10,79	31,73
9	41,8	0,797	2,26	5,48	2,13	6,01	15,11
10	53,9	0,669	1,89	3,55	2,29	6,48	12,17
11	63,9	0,495	1,37	2,17	2,19	6,20	9,80
12	63,6	0,737	2,09	3,68	0,99	2,80	4,62
13	78,3	0,794	2,23	2,84	1,04	2,94	3,75
14	87,6	1,121	3,17	3,62	2,65	7,48	8,55
15	34,1	0,95	2,69	7,85	1,94	5,50	15,55
16	42,3	0,535	1,49	4,25	1,70	3,30	8,01
17	64,6	0,55	1,53	2,80	3,15	8,89	11,15
18	63,8	1,13	3,17	5,04	1,47	4,16	6,61
19	76,3	0,589	1,65	2,77	0,944	2,67	3,60
20	81,7	0,483	1,37	1,67	1,10	3,10	3,80
21	87,9	0,673	1,49	1,69	2,67	5,86	6,67
AVERAGE	61,6						
POOLED VALUES		0,934	2,62	4,26	2,148	6,07	9,89

^{A} Sr = repeatability standard deviation, measurement units.
^{B} r = repeatability = 2,83 × Sr, measurement units.
^{C} (r) = repeatability, relative, (that is, in percent).
^{D} SR = reproducibility standard deviation, measurement units.
^{E} R = reproducibility = 2,83 × SR, measurement units.
^{F} (R) = reproducibility, relative, (that is, in percent).

TABLE 3 Type 1 Precision—Type A Durometer Method

Material	Average Level	Within Laboratories			Between Laboratories		
		$(Sr)^A$	r^B	$(r)^C$	$(SR)^D$	R^E	$(R)^F$
1	51,0	0,646	1,83	3,58	1,56	4,41	8,64
2	65,0	0,679	1,92	2,91	2,21	6,26	9,27
3	80,0	0,433	1,23	1,53	2,29	6,45	8,06
Pooled	67,0	0,677	1,92	3,11	2,018	5,72	8,54

^{A} Sr = repeatability standard deviation, measurement units.
^{B} r = repeatability = 2,83 × Sr, measurement units.
^{C} (r) = repeatability, relative, (that is, in percent).
^{D} SR = reproducibility standard deviation, measurement units.
^{E} R = reproducibility = 2,83 × SR, measurement units.
^{F} (R) = reproducibility, relative, (that is, in percent).

TABLE 4 Type 1 Precision—Type D Durometer Method

Material	Average Level	Within Laboratories			Between Laboratories		
		$(Sr)^A$	r^B	$(r)^C$	$(SR)^D$	R^E	$(R)^F$
1	40,8	0,316	0,894	2,19	2,62	7,39	18,2
2	54,5	0,791	2,24	4,11	3,54	10,0	18,4
3	80,3	1,01	2,86	3,47	3,54	10,0	12,2
Pooled	58,8	0,762	2,16	3,61	3,32	9,40	15,7

^{A} Sr = repeatability standard deviation, measurement units.
^{B} r = repeatability = 2,83 × Sr, measurement units.
^{C} (r) = repeatability, relative, (that is, in percent).
^{D} SR = reproducibility standard deviation, measurement units.
^{E} R = reproducibility = 2,83 × SR, measurement units.
^{F} (R) = reproducibility, relative, (that is, in percent).

durometer is equipped with a maximum indicator, the maximum indicated reading shall be recorded within 1 ± 0.1 s of the cessation of initial indenter travel. The indicated hardness reading may change with time.

9.2.5 Make five determinations of hardness at different positions on the specimen at least 6.0 mm (0.24 in.) apart and calculate the arithmetic mean, or alternatively calculate the median. The means of calculating the determinations shall be reported according to 10.2.8.

9.3 It is acknowledged that durometer readings below 20 or above 90 are not considered reliable. It is suggested that readings in these ranges not be recorded.

9.4 Manual operation (handheld) of a durometer will cause variations in the results attained. Improved repeatability may be obtained by using a mass, securely affixed to the durometer and centered on the axis of the indenter. Recommended masses are 1 kg for Type A, B, E, and O durometers, 5 kg for Type C, D, and DO durometers, and 400 g for Type OO, OOO, and OOO-S durometers. The introduction of an additional mass on Type M durometers is not permitted. Further improvement may be achieved by the use of a durometer operating stand that controls the rate of descent of the durometer presser foot to the test specimen and incorporates the masses described above.

10. Report

10.1 *Instrument Calibration Report (Durometer or Operating Stand):*

10.1.1 Date of calibration.

10.1.2 Date of last calibration.

10.1.3 Calibration due date (see Note 2).

10.1.4 Manufacturer, type, model, and serial number of the instrument, and a notation when a maximum indicator or timing device is present.

10.1.5 Values obtained (pre- and post-calibration results), including a notation of the effect of a maximum indicator, if present. The method of reporting the calibrated value shall be by attaining the arithmetic mean of the determinations.

10.1.6 Ambient temperature.

10.1.7 Relative humidity.

10.1.8 Technician identification.

10.1.9 Applicable standards to which the instrument is calibrated.

10.1.10 Calibrating instrument information to include type, serial number, manufacturer, date of last calibration, calibration due date (see Note 2), and a statement of traceability of standards used to NIST or other acceptable organization. See 1.4.

10.2 *Hardness Measurement Report:*

10.2.1 Date of test.

10.2.2 Relative humidity.

10.2.3 Ambient temperature.

10.2.4 Manufacturer, type, and serial number of the durometer or operating stand, or both, including a notation when a maximum indicator or timing device is present, date of last calibration, and calibration due date (see Note 2).

NOTE 2—The calibration interval (calibration due date) for a durometer is to be determined by the user, based upon frequency of use, severity of conditions, environmental factors, and other variables.

Periodic checking of the operation and state of durometer calibration using commercially available rubber test blocks (refer to 7.8), specifically designed for this purpose, is recommended.

An instrument that has been exposed to severe shock, is visibly damaged, produces test determinations more than 2 points different from calibrated rubber test blocks or other reference standard, or is otherwise

suspected of unreliability, should be removed from service and returned to a qualified calibration facility.

A calibration interval of one year is recommended for durometer test blocks and durometer instruments that are infrequently used, more often for others.

The calibration interval for instruments and peripheral devices employed in the calibration of durometers is to be determined by the calibration service provider. It is recommended that the protocols outlined in ISO/IEC 17025, as required by the manufacturer, and those to which the service is provided, be followed.

10.2.5 Means of testing, whether manual (hand held), Type 1 operating stand (specimen to indenter), Type 2 operating stand (indenter to specimen type), or Type 3 operating stand (electromechanical or hydraulically dampened).

10.2.6 Description of test specimen, including thickness, number of pieces piled if less than the thickness indicated in Section 6, including the vulcanization date.

10.2.7 Complete identification of material tested.

10.2.8 Hardness value obtained and method of calculation, either arithmetic mean or alternatively, the median.

10.2.9 Indentation hardness time interval at which determination was made. Readings may be reported in the form: M/60/1 where M is the type of durometer, 60 the reading, and 1 the time in seconds that the presser foot is in contact with the specimen or from an electronic timing device.

11. Precision and Bias

11.1 These precision and bias statements have been prepared in accordance with Practice D4483. Refer to this Practice for terminology and other testing and statistical concepts.

11.2 The Type 1 precision for the Type M method was determined from an interlaboratory program with 21 materials of varying hardness, with six participating laboratories. Tests were conducted on two separate days in each laboratory for the Type M testing program. All materials were supplied from a single source, being those commonly supplied as reference materials with the instruments from the manufacturer.

11.3 The precision results in this precision and bias section give an estimate of the precision of this test method with the materials (rubbers) used in the particular interlaboratory program as described above. The precision parameters should not be used for acceptance or rejection testing, or both, of any group of materials without documentation that they are applicable to those particular materials and the specific testing protocols that include this test method.

11.4 The Type 1 precision for both Type A and D methods was determined from an interlaboratory program with 3 materials of varying hardness, with six participating laboratories. Tests were conducted on two separate days in each laboratory for both A and D testing programs. All materials were supplied from a single source.

11.5 A test result for hardness, for Types A, D, and M, was the median of five individual hardness readings on each day in each laboratory.

11.6 Table 2 shows the precision results for Type M method.[4] Table 3 shows the precision results for Type A method,[5] and Table 4 gives the precision results for Type D method.[5]

11.7 *Precision*—The precision of this test method may be expressed in the format of the following statements which use as appropriate value *r*, *R*, *(r)*, or *(R)*, that is, that value to be used in decisions about test results (obtained with the test method). The appropriate value is that value of *r* or *R* associated with a mean level in Table 1 closest to the mean level under consideration (at any given time, for any given material) in routine testing operations.

NOTE 5—A Type 1 precision statement for Types B, OOO, OOO-S, and R have not yet been made available.

11.7.1 *Repeatability*—The repeatability, *r*, of these test methods has been established as the appropriate value tabulated in Tables 2–4. Two single test results, obtained under normal test method procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or non-identical sample populations.

11.7.2 *Reproducibility*—The reproducibility, *R*, of these test methods has been established as the appropriate value tabulated in Tables 2–4. Two single test results obtained in two different laboratories, under normal test method procedures, that differ by more than the tabulated *R* (for any given level) must be considered to have come from different or non-identical sample populations.

11.7.3 Repeatability and reproducibility are expressed as a percentage of the mean level, *(r)* and *(R)*, and have equivalent application statements as above for *r* and *R*. For the *(r)* and *(R)* statements, the difference in the two single test results is expressed as a percentage of the arithmetic mean of the two test results.

11.8 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since the value (of the test property) is exclusively defined by this test method. Bias, therefore cannot be determined.

12. Keywords

12.1 durometer; durometer hardness; hardness; indentation hardness; micro durometer hardness

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D11-1091.

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D11-1019.

APPENDIXES

(Nonmandatory Information)

X1. DUROMETER SELECTION GUIDE

X1.1 The durometer selection guide is designed to assist in the selection of the proper durometer type for various applications.

TABLE X1.1 Durometer Selection: Typical Uses

Type (Scale)	Typical Examples of Materials Tested	Durometer Hardness (Typical Use)
A	Soft vulcanized rubber, natural rubber, nitriles, thermoplastic elastomers, flexible polyvinyls and thermosets, wax, felt, and leathers	20–90 A
B	Moderately hard rubber, thermoplastic elastomers, paper products, and fibrous materials	Above 90 A Below 20 D
C	Medium-hard rubber, thermoplastic elastomers, medium-hard plastics, and thermoplastics	Above 50 B Below 20 D
D	Hard rubber, thermoplastic elastomers, harder plastics, and rigid thermoplastics	Above 40 A
DO	Moderately hard rubber, thermoplastic elastomers, and very dense textile windings	Above 90 C Below 20 D
M	Thin, irregularly shaped rubber, thermoplastic elastomer, and plastic specimens	Same as A
O	Soft rubber, thermoplastic elastomers, very soft plastics and thermoplastics, medium-density textile windings	Below 70 OO
OO	Extremely soft rubber, thermoplastic elastomers, sponge, extremely soft plastics and thermoplastics, foams, low-density textile windings, human and animal tissue	Below 20 O
CF	Composite foam materials, such as amusement ride safety cushions, vehicle seats, dashboards, headrests, armrests, and door panels	See Test Method F1957

X1.2 It is generally recognized that durometer hardness determination below 20 and above 90 are unreliable. It is recommended that the next lower or higher type (scale) be used in these situations.

X1.3 It is also recommended that, whenever possible, an operating stand be employed in performing durometer hardness tests.

X2. RELATED TEST METHODS[2]

C367 Test Methods for Strength Properties of Prefabricated Architectural Acoustical Tile or Lay-in Ceiling Panels

C473 Test Methods for Physical Testing of Gypsum Panel Products

C581 Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service

C661 Test Method for Indentation Hardness of Elastomeric-Type Sealants by Means of a Durometer

C836 Specification for High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane for Use with Separate Wearing Course

D461 Test Methods for Felt

D531 Test Method for Rubber Property—Pusey and Jones Indentation

D619 Test Methods for Vulcanized Fibre Used for Electrical Insulation

D1037 Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials

D1054 Test Method for Rubber Property—Resilience Using a Goodyear-Healey Rebound Pendulum

D1414 Test Methods for Rubber O-Rings

D1474 Test Methods for Indentation Hardness of Organic Coatings

D2134 Test Method for Determining the Hardness of Organic Coatings with a Sward-Type Hardness Rocker

D2287 Specification for Nonrigid Vinyl Chloride Polymer and Copolymer Molding and Extrusion Compounds

D2583 Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor

D2632 Test Method for Rubber Property—Resilience by Vertical Rebound

D4289 Test Method for Elastomer Compatibility of Lubricating Greases and Fluids

D5672 Test Method for Flexible Cellular Materials Measurement of Indentation Force Deflection Using a 25-mm (1-in.) Deflection Technique

D6546 Test Methods for and Suggested Limits for Determining Compatibility of Elastomer Seals for Industrial Hydraulic Fluid Applications

F1151 Test Method for Determining Variations in Hardness of Film Ribbon Pancakes

NOTE X2.1—The hardness testing of other nonmetallic materials may be under the jurisdiction of one or more ASTM committees; the respective committee should be contacted for specific information.

ANEXO No. 6: ASTM D6110: Standard test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics

Designation: D6110 – 10

Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics[1]

This standard is issued under the fixed designation D6110; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method is used to determine the resistance of plastics to breakage by flexural shock as indicated by the energy extracted from standardized (see Note 1) pendulum-type hammers, mounted in standardized machines, in breaking standard specimens with one pendulum swing. This test method requires specimens to be made with a milled notch (see Note 2). The notch produces a stress concentration which promotes a brittle, rather than a ductile, fracture. The results of this test method are reported in terms of energy absorbed per unit of specimen width (see Note 3).

Note 1—The machines with pendulum-type hammers have been standardized in that they must comply with certain requirements including a fixed height of hammer fall, which results in a substantially fixed velocity of the hammer at the moment of impact. Hammers of different initial energies (produced by varying their effective weights), however, are recommended for use with specimens of different impact resistance. Moreover, manufacturers of the equipment are permitted to use different lengths and constructions of pendulums with possible differences in pendulum rigidities resulting (see Section 5). Be aware that other differences in machine design do exist.

Note 2—The specimens are standardized in that they have a fixed length and fixed depth, however, the width of the specimens is permitted to vary between limits. One design of milled notch is allowed. The notch in the specimen serves to concentrate the stress, minimize plastic deformation, and direct the fracture to the part of the specimen behind the notch. Scatter in energy-to-break is thus reduced. Because of differences in the elastic and viscoelastic properties of plastics, however, response to a given notch varies among materials.

Note 3—Caution must be exercised in interpreting the results of this test method. The following testing parameters have been shown to affect test results significantly: method of specimen fabrication, including but not limited to processing technology, molding conditions, mold design, and thermal treatment; method of notching; speed of notching tool; design of notching apparatus; quality of the notch; time between notching and test; test specimen thickness; test specimen width under notch; and environmental conditioning.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Note 4—This standard resembles ISO 179 in title only. The content is significantly different.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing

D647 Practice for Design of Molds for Test Specimens of Plastic Molding Materials (Withdrawn 1994)[3]

D883 Terminology Relating to Plastics

D4000 Classification System for Specifying Plastic Materials

D4066 Classification System for Nylon Injection and Extrusion Materials (PA)

D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions*—For definitions related to plastics, see Terminology D883.

4. Summary of Test Method

4.1 A notched specimen is supported as a horizontal simple beam and is broken by a single swing of the pendulum with the impact line midway between the supports and directly opposite the notch.

5. Significance and Use

5.1 Before proceeding with this test method, refer to the material specification for the material being tested. Any test specimen preparation, conditioning, dimensions and testing parameters required by the materials specification shall take precedence over those required by this test method. Table 1 of

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.
Current edition approved April 1, 2010. Published April 2010. Originally approved in 1997. Last previous edition approved in 2000 as D6110–00. DOI: 10.1520/D6110-10.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

*A Summary of Changes section appears at the end of this standard

Classification D4000 lists the ASTM materials standards that currently exist. If there is no material specification, then the requirements of this test method apply.

5.2 The pendulum impact test indicates the energy to break standard test specimens of specified size under stipulated conditions of specimen mounting, notching (stress concentration), and pendulum velocity at impact.

5.3 For this test method, the energy lost by the pendulum during the breakage of the specimen is the sum of the energies required to initiate fracture of the specimen; to propagate the fracture across the specimen; to throw the free ends of the broken specimen (toss energy); to bend the specimen; to produce vibration in the pendulum arm; to produce vibration or horizontal movement of the machine frame or base; to overcome friction in the pendulum bearing and in the indicating mechanism, and to overcome windage (pendulum air drag); to indent or deform, plastically, the specimen at the line of impact; and to overcome the friction caused by the rubbing of the striking nose over the face of the bent specimen.

NOTE 5—The toss energy, or the energy used to throw the free ends of the broken specimen, is suspected to represent a very large fraction of the total energy absorbed when testing relatively dense and brittle materials. No procedure has been established for estimating the toss energy for the Charpy method.

5.4 For tough, ductile, fiber-filled, or cloth-laminated materials, the fracture propagation energy is usually large compared to the fracture initiation energy. When testing these materials, energy losses due to fracture propagation, vibration, friction between the striking nose and the specimen has the potential to become quite significant, even when the specimen is accurately machined and positioned, and the machine is in good condition with adequate capacity (see Note 6). Significant energy losses due to bending and indentation when testing soft materials have also been observed.

NOTE 6—Although the frame and the base of the machine must be sufficiently rigid and massive to handle the energies of tough specimens without motion or excessive vibration, the pendulum arm cannot be made very massive because the greater part of its mass must be concentrated near its center of percussion at its striking nose. Locating the striking nose precisely at the center of percussion reduces the vibration of the pendulum arm when used with brittle specimens. Some losses due to pendulum arm vibration (the amount varying with the design of the pendulum) will occur with tough specimens even when the striking nose is properly positioned.

5.5 In a well-designed machine of sufficient rigidity and mass, the losses due to vibration and friction in the pendulum bearing and in the indicating mechanism will be very small. Vibrational losses are observed when wide specimens of tough materials are tested in machines of insufficient mass, or in machines that are not securely fastened to a heavy base.

5.6 Since this test method permits a variation in the width of the specimens and since the width dictates, for many materials, whether a brittle, low-energy break (as evidenced by little or no drawing down or necking and by a relatively low energy absorption) or a ductile, high-energy break (as evidenced by considerable drawing or necking down in the region behind the notch and by a relatively high energy absorption) will occur, it is necessary that the width be stated in the specification covering that material and that the width be stated along with the impact value.

5.7 This test method requires that the specimen break completely. Results obtained when testing materials with a pendulum that does not have sufficient energy to complete the breaking of the extreme fibers and toss the broken pieces shall be considered a departure from standard and shall not be reported as a standard result. Impact values cannot be directly compared for any two materials that experience different types of failure.

5.8 The value of this impact test method lies mainly in the areas of quality control and materials specification. If two groups of specimens of supposedly the same material show significantly different energy absorptions, critical widths, or critical temperatures, it is permitted to assume that they were made of different materials or were exposed to different processing or conditioning environments. The fact that a material shows twice the energy absorption of another under these conditions of test does not indicate that this same relationship will exist under another set of test conditions.

6. Apparatus

6.1 *Pendulum Impact Machine*—The machine shall consist of a massive base on which are mounted a pair of supports for holding the specimen and to which is connected, through a rigid frame and bearings, one of a number of pendulum-type hammers having an initial energy suitable for use with the particular specimen to be tested (or one basic pendulum designed to accept add-on weights), plus a pendulum holding and releasing mechanism and a mechanism for indicating the breaking energy of the specimen. The specimen anvil, pendulum, and frame shall be sufficiently rigid to maintain correct alignment of the striking edge and specimen, both at the moment of impact and during the propagation of the fracture, and to minimize energy losses due to vibration. The base shall be sufficiently massive so that the impact will not cause it to move. The machine shall be designed, constructed, and maintained so that energy losses due to pendulum air drag (windage), friction in the pendulum bearings, and friction and inertia in the indicating mechanism are held to a minimum.

6.1.1 *Pendulum*—The simple pendulum shall consist of a single or multi-membered arm with a bearing on one end and a head, containing the striking nose, on the other. Although a large proportion of the mass of the simple pendulum is concentrated in the head, the arm must be sufficiently rigid to maintain the proper clearances and geometric relationships between the machine parts and the specimen and to minimize vibrational energy losses, which are always included in the measured impact value. A machine with a simple pendulum design is illustrated in Fig. 1. Instruments with a compound-pendulum design also have been found to be acceptable for use. A compound-pendulum design is illustrated in Fig. 2.

6.1.1.1 The machine shall be provided with a basic pendulum capable of delivering an energy of 2.7 ± 0.14 J (2.0 ± 0.10 ft-lbf). This pendulum shall be used for specimens that extract less than 85 % of this energy when breaking a specimen. Heavier pendulums or additional weights designed to attach to the basic pendulum shall be provided for specimens

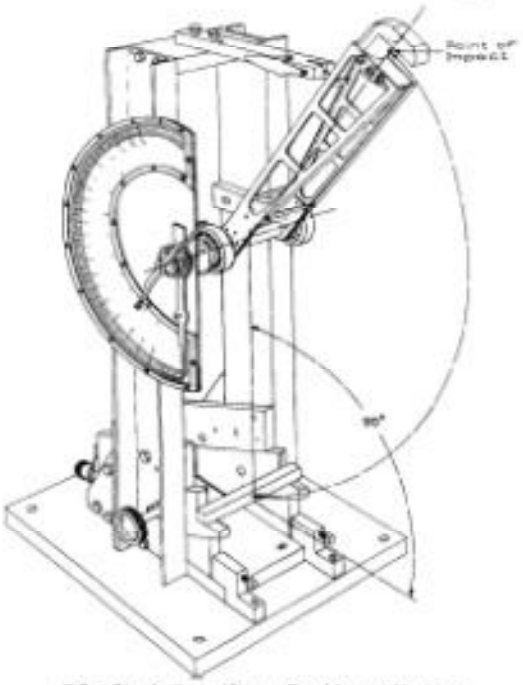


FIG. 1 Simple Beam (Charpy-Type) Impact Machine

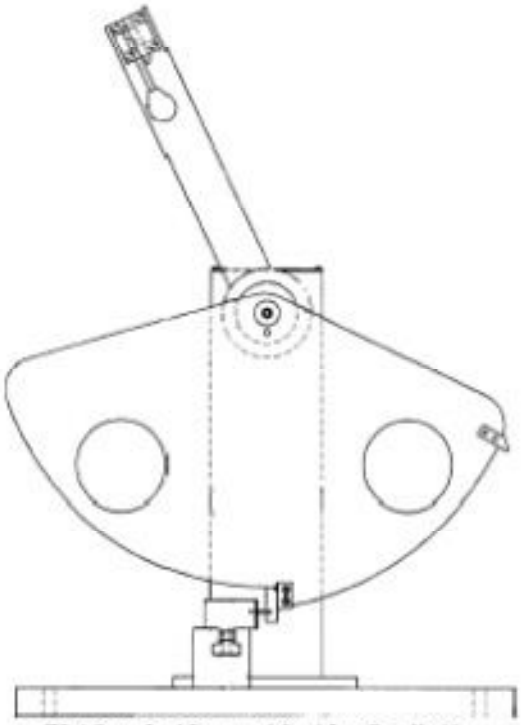


FIG. 2 Example of Compound-Pendulum-Type Machine

that require more energy to break. A series of pendulums such that each has twice the energy of the next lighter one has been found convenient.

6.1.1.2 The effective length of the pendulum shall be between 0.325 and 0.406 m (12.8 and 16.0 in.) so that the required elevation of the striking nose is obtained by raising the pendulum to an angle between 60 and 30° above the horizontal.

6.1.2 *Striking Edge*—The striking edge (nose) of the pendulum shall be made of hardened steel, tapered to have an included angle of 45 ± 2° and shall be rounded to a radius of 3.17 ± 0.12 mm (0.125 ± 0.005 in.). The pendulum shall be aligned in such a way that when it is in its free hanging position, the center of percussion of the pendulum shall lie within ±2.54 mm (0.10 in.) of the middle of the line of contact made by the striking nose upon the face of a standard specimen of square cross section. The distance from the axis of support to the center of percussion is determined experimentally from the period of motion of small amplitude oscillations of the pendulum by means of the following equation:

$$L = (g/4\pi^2)\,p^2 \qquad (1)$$

where:

L = distance from the axis of support to the center of percussion, m,
g = local gravitational acceleration (known to an accuracy of one part in one thousand), m/s^2,
π = 3.1416 ($4\pi^2$ = 39.48), and
p = period, in s, of a single complete swing (to and fro) determined from at least 20 consecutive and uninterrupted swings. The angle of swing shall be less than 5° each side of center.

6.1.3 *Pendulum Holding and Releasing Mechanism*—The mechanism shall be designed, constructed, and operated so that it will release the pendulum without imparting acceleration or vibration to the pendulum. The position of the pendulum holding and releasing mechanism shall be such that the vertical height of fall of the striking nose shall be 610 ± 2 mm (24.0 ± 0.005 in.). This will produce a velocity of the striking nose at the moment of impact of approximately 3.46 m (11.4 ft)/s as determined by the following equation:

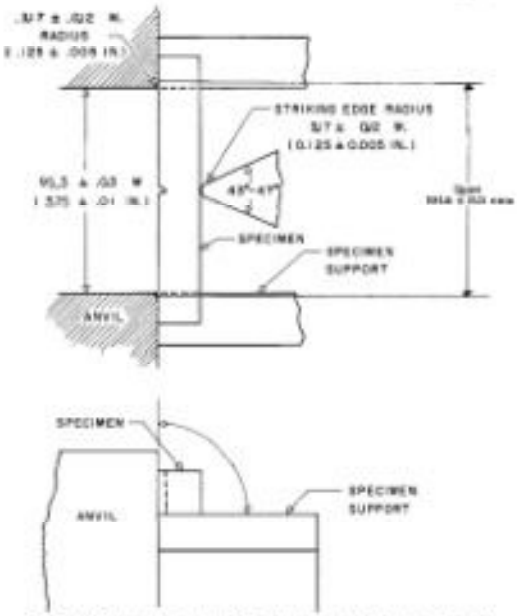


FIG. 3 Relationship of Anvil, Specimen, and Striking Edge to Each Other for Charpy Test Method

$$v = \sqrt{2gh} \tag{2}$$

where:

v = velocity of the striking nose at the moment of impact,
g = local gravitational acceleration, and
h = vertical height of fall of the striking nose.

This assumes no windage or friction.

6.1.4 *Specimen Supports*—The test specimen shall be supported against two rigid anvils in such a position that its center of gravity and the center of the notch shall lie on tangent to the arc of travel of the center of percussion of the pendulum drawn at the position of impact. The edges of the anvils shall be rounded to a radius of 3.17 ± 0.12 mm (0.125 ± 0.005 in.) and the anvils' lines of contact (span) with the specimen shall be 101.6 ± 0.5 mm (4.0 ± 0.02 in.) apart (see Fig. 3). Some machine manufacturers supply a jig for positioning the specimen on the supports.

NOTE 7—Old-style machines currently in use employ a 108.0-mm span. Data obtained under these conditions are valid.*

6.1.5 *Indicator*—Means shall be provided for determining the energy expended by the pendulum in breaking the specimen. This is accomplished using either a pointer and dial mechanism or an electronic system consisting of a digital indicator and sensor (typically an encoder or resolver). In either case, the indicated breaking energy is determined by detecting the height of rise of the pendulum beyond the point of impact in terms of energy removed from that specific pendulum. The indicated remaining energy must be corrected for pendulum bearing friction, pointer friction, pointer inertia, and pendulum windage. Some equipment manufacturers provide graphs or tables to aid in the calculation of the correction for friction and windage. Instructions for making these corrections are found in Annex A1 and Annex A2. Many digital indicating systems automatically correct for windage and friction. Consult the equipment manufacturer for information on how this is performed.

6.1.6 Appendix X2 describes a calibration procedure for establishing the accuracy of the equipment. A check of the calibration of an impact machine is difficult to make under dynamic conditions. The basic parameters normally are checked under static conditions. If the machine passes the static tests, then it is assumed to be accurate. Appendix X2, however, also describes a dynamic test for checking certain features of the machine and specimen. For some machine designs, it might be necessary to change the recommended method of obtaining the required calibration measurements. Contact the machine manufacturer to determine if additional instructions for adjusting a particular machine are available. Other methods of performing the required checks are acceptable provided that they are proven to result in an equivalent accuracy.

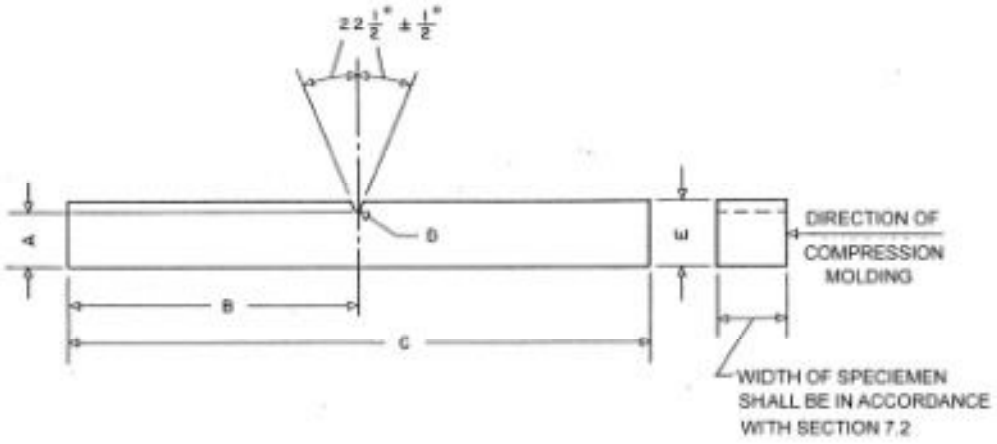
6.2 *Specimen Notching Machine*—Notching shall be done on a milling machine, engine lathe, or other suitable machine tool. A carbide-tipped or industrial diamond-tipped notching cutter is recommended. Both cutter speed and feed rate shall be controllable. Provision for cooling the specimen is recommended. Water and compressed air are suitable coolants for many plastics.

6.2.1 The profile of the cutting tooth or teeth shall be such as to produce a notch in the test specimen of the contour and depth specified in Fig. 4 and in the manner specified in Section 8.

6.2.2 A single-tooth cutter shall be used for notching the specimen, unless it is demonstrated that notches of an equivalent quality are produced with a multi-tooth cutter. Single-tooth cutters are preferred because of the ease of grinding the cutter to the specimen contour and because of the smoother cut on the specimen. The cutting edge shall be ground and honed carefully to ensure sharpness and freedom from nicks and burrs. Tools with no rake and a work relief angle of 15 to 20° have been found satisfactory.

6.3 *Micrometers*—Apparatus for measurement of the width of the specimen shall comply with the requirements of Test Methods D5947. Apparatus for the measurement of the depth of plastic material remaining in the specimen under the notch shall comply with requirements of Test Methods D5947, provided however that the one anvil or presser foot shall be a tapered blade conforming to the dimensions given in Fig. 5. The opposing anvil or presser foot shall be flat and conforming to Test Methods D5947.

* Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1011.



	mm	in.
A	12.70 ± 0.05	0.500 ± 0.002
B	63.5 max	2.50 max
	57.0 min	2.40 min
C	127.0 max	5.00 max
	124.5 min	4.90 min
D	0.250R ± 0.05	0.010R ± 0.002
E	10.79 ± 0.15	0.500 ± 0.006

FIG. 4 Dimensions of Simple Beam, Charpy Type, Impact Test Specimen

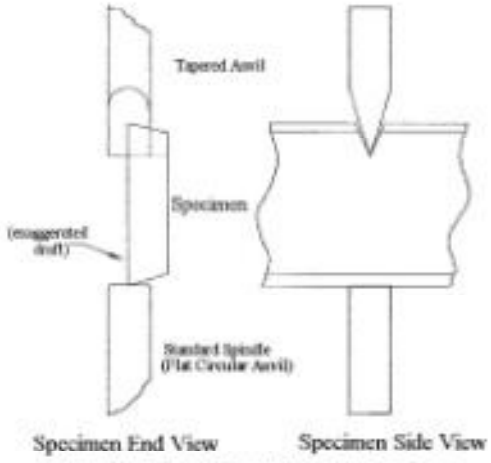


FIG. 5 Notch Depth Measurement on Test Specimens

7. Test Specimen

7.1 The test specimen shall conform to the dimensions and geometry of Fig. 4, except as modified in accordance with 7.2–7.5. To ensure the correct contour and cleanness of the specified notch, all specimens shall be notched in accordance with Section 8.

7.2 Molded specimens shall have a width between 3.00 and 12.7 mm (0.118 and 0.500 in.). Use the specimen width as specified in the material specification or as agreed upon between the supplier and the customer.

7.2.1 The type of mold and molding machine used and the flow behavior in the mold cavity will influence the strength obtained. It is possible that results from a specimen taken from one end of a molded bar will give different results than a specimen taken from the other end. It is therefore important that cooperating laboratories agree on standard molds conforming to Practice D647, and upon a standard molding procedure for the material under investigation.

7.2.2 A critical investigation of the mechanics of impact testing has shown that tests made upon specimens under 6.35 mm (0.250 in.) in width absorb more energy due to crushing, bending, and twisting than do wider specimens. Specimens 6.35 mm (0.250 in.) or over in width are therefore recommended. The responsibility for determining the minimum specimen width shall be the investigator's, with due reference to the specification for that material.

7.2.3 The impact resistance of a plastic material will be different if the notch is perpendicular to, rather than parallel to, the direction of molding.

7.3 For sheet materials, the specimens shall be cut from the sheet in both the lengthwise and crosswise directions unless otherwise specified. The width of the specimen shall be the thickness of the sheet if the sheet thickness is between 3.00 and 12.7 mm (0.118 and 0.500 in.). Sheet material thicker than 12.7 mm (0.500 in.) shall be machined down to 12.7 mm (0.500 in.).

It is acceptable to test specimens with a 12.7-mm (0.500-in.) square cross section either edgewise or flatwise as cut from the sheet. When specimens are tested flatwise, the notch shall be made on the machined surface if the specimen is machined on one face only. When the specimen is cut from a thick sheet, notation shall be made of the portion of the thickness of the sheet from which the specimen was cut, for example, center, top, or bottom surface.

7.3.1 The impact resistance of a plastic material will be different if the notch is perpendicular to, rather than parallel to, the grain of an anisotropic bar cut from a sheet. Specimens cut from sheets that are suspected of being anisotropic shall be prepared and tested both lengthwise and crosswise to the direction of the anisotropy.

7.4 The practice of cementing, bolting, clamping, or otherwise combining specimens of substandard width to form a composite test specimen is not recommended since test results will be seriously affected by interface effects or effects of solvents and cements on energy absorption of composite test specimens, or both. If Charpy test data on such thin materials are required, however, and if possible sources of error are recognized and acceptable, the following technique of preparing composites ought to be utilized. The test specimens shall be a composite of individual thin specimens totaling 6.35 to 12.7 mm (0.125 to 0.500 in.) in width. Individual members of the composite shall be aligned accurately with each other and clamped, bolted, or cemented together. Care must be taken to select a solvent or adhesive that will not affect the impact resistance of the material under test. If solvents or solvent-containing adhesives are employed, a conditioning procedure shall be established to ensure complete removal of the solvent prior to test. The composite specimens shall be machined to proper dimensions and then notched. In all such cases, the use of composite specimens shall be noted in the report of test results.

7.5 Each specimen shall be free of twist and shall be bounded by mutually perpendicular pairs of plane, parallel surfaces and free from scratches, pits, and sink marks. The specimens shall be checked for conformity with these requirements by visual observation against straight edges, squares or flat plates, and by measuring with micrometer calipers. Any specimen showing observable or measurable departure from one or more of these requirements shall be rejected or machined to the proper size and shape before testing. A specimen that has a slight twist to its notched face of 0.05 mm (0.002 in.) at the point of contact with the pendulum striking edge will be likely to have a characteristic fracture surface with considerable greater fracture area than for a normal break. In this case, the energy to break and toss the broken section will be considerably larger (20 to 30 %) than for a normal break.

8. Notching Test Specimens

Note 8—When testing a material for the first time, it is necessary to study the effect of all variations in the notching conditions, including cutter dimensions, notch depth, cutter speed, and feed rate. To establish that the notching parameters are suitable, it is advisable to notch several specimens of the material and inspect both the tool entrance and tool exit side of each notched specimen, in accordance with Appendix X1. Adjust the notching machine as required. The specimens used to determine notching conditions shall not be used to make determinations of impact resistance.

8.1 *Notch Dimensions*—The included angle of the notch shall be 45 ± 1° with a radius of curvature at the apex of 0.25 ± 0.05 mm (0.010 ± 0.002 in.). The plane bisecting the notch angle shall be perpendicular to the face of the test specimen within 2°.

8.1.1 The notch is a critical factor of this test. It is extremely important, therefore, that dimensions of the notch in the specimen are verified. There is evidence that the contour of notches cut in materials of widely differing physical properties by the same cutter will differ. It is sometimes necessary to alter the cutter dimensions in order to produce the required notch contour for certain materials.

8.1.2 A notching operation notches one or more specimens plus the "dummy bars". The specimen notch produced by each cutter will be examined after every 500 notching operations or less frequently if experience shows this to be acceptable. The specimen used to verify the notch shall be the same material that is being prepared for testing. Inspect and verify the notch in the specimen. If the angle or radius of the notch does not meet the requirements of 8.1, the cutter shall be replaced. One procedure for inspecting and verifying the notch is provided in Appendix X1.

Note 9—The contour of the notch made using multi-tooth cutters is checked by measuring the contour of the notch on a strip of soft metal that is inserted between two specimens during the notching process.

Note 10—When the same material is being tested on a repetitive basis, and it is demonstrated that the notch in the specimen takes the contour of the tip of the cutter and that the notch meets the contour requirements when checked in accordance with Appendix X1, then it is acceptable to check the contour of the tip of the cutter instead of the notch in the specimen.

8.2 *Notch Depth*—The depth of the plastic material remaining in the specimen under the notch shall be 10.16 ± 0.05 mm (0.400 ± 0.002 in.). This dimension shall be measured with apparatus in accordance with 6.3. The tapered blade will be fitted to the notch. The specimen will be approximately vertical between the anvils. Position the edge of the non-cavity (wider edge) surface centered on the micrometer's flat circular anvil.

8.3 *Cutter Speed and Feed Rate*—Select the cutter speed and feed speed based on the material being tested. The quality of the notch will be adversely affected by thermal deformations and stresses induced during the cutting operation if proper conditions are not selected.[5] The notching parameters used shall not alter the physical state of the material, such as by raising the temperature of a thermoplastic above its glass transition temperature.

8.3.1 In general, high cutter speeds, slow feed rates, and lack of coolant induce more thermal damage than a slow cutter speed, fast feed speed, and the use of a coolant. Too high a feed speed/cutter speed ratio, however, has been shown to cause impacting and cracking of the specimen. The range of cutter speed/feed ratios possible to produce acceptable notches has been shown to be extended by the use of a suitable coolant.

8.3.1.1 For some thermoplastics, suitable notches have been produced using cutter speeds from 54 to 150 m/min and a feed rate of 89 to 160 mm/min without a water coolant. Satisfactory

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1066.

notches also have been produced using the same cutter speeds at feed speeds of from 36 to 160 mm/min with water coolant.

8.3.1.2 Embedded thermocouples have been used to determine the temperature rise in the material near the apex of the notch during machining. Thermal stresses induced during the notching operation have been observed in transparent materials by viewing the specimen at low magnification between crossed polars in monochromatic light. The specimens used to determine temperature rise shall not be used to make determinations of impact resistance.

8.3.2 The feed rate and the cutter speed shall remain constant throughout the notching operation.

8.4 It is acceptable to notch specimens individually or in a group. In either case, however, an unnotched backup or dummy bar shall be placed behind the last specimen in the sample holder to prevent distortion and chipping by the cutter as it exits from the last test specimen.

8.5 All specimens having one dimension less than 12.7 mm (0.500 in.) shall have the notch cut on the shorter side. Compression molded specimens shall be notched on the side parallel to the direction of application of molding pressure. The impact resistance of a plastic material will be different if the notch is perpendicular to rather than parallel to the direction of molding, as with or across the grain of an anisotropic bar cut from a plate.

9. Conditioning

9.1 Check the materials specification for the material that is being tested. If there are no conditioning requirements stated by the materials specification, the test specimens shall be conditioned at 23 ± 2°C (73 ± 3.6°F) and 50 ± 10 % relative humidity for not less than 40 h after notching and prior to testing in accordance with Procedure A of Practice D618 unless documented (between supplier and customer) that shorter conditioning time is sufficient for a given material to reach equilibrium of impact resistance.

9.2 For hygroscopic materials, such as nylons, the material specifications (for example, Classification System D4066) call for testing dry-as-molded specimens. Such requirements take precedence over the above routine preconditioning to 50 % relative humidity. These specimens shall be sealed in water vapor-impermeable containers as soon as molded. When notching these specimens, minimize the exposure time during notching and return the specimens to a dry container after notching to allow for full cooling of the specimens prior to testing.

9.3 *Test Conditions*—Conduct tests in the standard laboratory atmosphere of 23 ± 2°C (73 ± 3.6°F) and 50 ± 10 % relative humidity, unless otherwise specified. In case of disagreement, the tolerances shall be ±1°C and ±5 % relative humidity.

10. Procedure

10.1 *Specimen Preparation:*

10.1.1 Prepare the test specimens in accordance with the procedures in Section 7. At least five and preferably ten or more individual determinations of impact resistance shall be made to determine the average impact resistance for a particular sample. The specimens shall be of nominal width only.

10.1.2 Notch the specimens in accordance with the procedure in Section 8.

10.1.3 Condition the specimens in accordance with the materials specification for the material that is being tested. If there are no conditioning requirements detailed in the materials specification, follow the conditioning requirements in Section 9.

10.2 *Machine Preparation:*

10.2.1 Estimate the breaking energy for the sample and select a pendulum of suitable energy. Select the lightest standard pendulum that is expected to break all specimens in the group with an energy loss of not more than 85 % of its capacity (see 6.1). If the breaking energy cannot be estimated, select the correct pendulum by performing trial runs. Use caution to avoid damaging the pendulum by selecting a pendulum that is too light for a particular sample.

NOTE 11—Ideally, an impact test would be conducted at a constant test velocity. In a pendulum-type test, however, the velocity decreases as the fracture progresses. For specimens that have an impact energy approaching the capacity of the pendulum, there is insufficient energy to complete the break and toss. By avoiding the higher 15 % scale energy readings, the velocity of the pendulum will not be reduced below 1.33 m/s. On the other hand, the use of a pendulum that is too heavy would reduce the sensitivity of the reading.

10.2.2 After installing the selected pendulum on the machine, check the machine for conformity with the requirements of Section 6 before starting the tests.

10.2.3 When using a machine equipped with a pointer and dial mechanism or an electronic indicator that does not automatically correct for windage and friction, determine the windage and friction correction factors for the machine before testing specimens. Windage and friction correction factors shall be determined on a daily basis and shall be calculated each time weights are added to the pendulum or the pendulum is changed. Refer to Annex A1 for information on constructing windage and friction correction charts or refer to Annex A2 for a procedure to calculate the windage and friction correction. If excessive friction is indicated (see X2.12 and X2.13) the machine shall be adjusted before testing specimens. Follow the machine manufacturer's instructions to correct for excessive windage and friction.

NOTE 12—The actual correction factors for windage and friction will be smaller than these factors in an actual test because the energy absorbed by the specimen prevents the pendulum from making a full swing. The indicated breaking energy of the specimen, therefore, must be included in the calculation of the machine correction.

10.2.4 Some machines equipped with an electronic digital display or computer automatically compensate for windage and friction.

10.3 *Specimen Testing:*

10.3.1 Check all of the specimens in the sample group for conformity with the requirements of Sections 7 and 8 and 10.1.

10.3.2 Measure and record the width of each specimen after notching to the nearest 0.025 mm (0.001 in). Measure the width in one location adjacent to the notch centered about the anticipated fracture plane.

10.3.3 Measure and record the depth of material remaining in the specimen under the notch of each specimen to the nearest 0.025 mm (0.001 in). The tapered blade will be fitted to the notch. The specimen will be approximately vertical between the anvils. Position the edge of the non-cavity (wider edge) surface so that it is centered on the micrometer's flat circular anvil. See Fig. 5.

10.3.4 Position a test specimen horizontally on the supports and against the anvils so that it will be impacted on the face opposite the notch (see Fig. 3). Center the notch between the anvils. A centering jig is useful for this purpose.

10.3.5 Raise and secure the pendulum in the release mechanism and reset the indicating mechanism.

10.3.6 Release the pendulum, allowing the striking edge of the pendulum to impact the specimen. Note the indicated breaking energy.

10.3.7 Calculate the net breaking energy (see 11.1). If the net breaking energy is greater than 85 % of the pendulum's nominal energy, the wrong pendulum was used. Discard the result. Select and install a pendulum with a greater available energy or add additional weight to the pendulum, determine the windage and friction correction factor, and repeat the test on a new specimen.

10.3.8 If the proper pendulum was used, test the remaining specimens as described in 10.3.1–10.3.6. Results from specimens that do not break shall be discarded. A specimen that does not break completely into two or more pieces is not considered to be broken.

10.3.9 After all of the specimens for the sample have been tested, calculate the impact resistance, in joules per metre, for each individual specimen (see 11.2).

10.3.10 Calculate the average impact resistance for the group of specimens (see 11.3). Values obtained from specimens that did not break completely shall not be included in the average.

10.3.11 Calculate the standard deviation for the group of specimens (see 11.4).

11. Calculation

11.1 *Net Breaking Energy*—Subtract the windage and friction loss energy from the indicated breaking energy.

11.2 *Impact Resistance*—Divide the net breaking energy by the measured width of each individual specimen.

11.3 Calculate the average impact resistance for a group of specimens by adding the individual impact resistance values for the group and dividing the sum by the total number of specimens in the group.

11.4 Calculate the standard deviation as follows and report it to two significant figures:

$$s = \sqrt{(\sum X^2 - n\,\bar{X}^2)/(n-1)} \quad (3)$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, and previous history.

12.1.2 A statement of how the specimens were prepared, the testing conditions used, the number of hours the specimens were conditioned after notching, and for sheet materials, the direction of testing with respect to anisotropy, if any.

12.1.3 The capacity of the pendulum, J.

12.1.4 The span.

12.1.5 The width and depth under the notch of each specimen tested.

12.1.6 The total number of specimens tested per sample of material (that is five, ten, or more).

12.1.7 The average impact resistance, J/m. Impact resistance is not to be reported for other than complete breaks. Reporting results in kJ/m^2 is optional (see Appendix X4).

12.1.8 The standard deviation of the values of the impact resistance of the specimens in 10.3.11.

TABLE 1 Precision for Charpy Test

Values in J/m$_n$ of Width

Material	Average	S_r [A]	S_R [B]	r [C]	R [D]	Number of Laboratories
Phenolic	0.65	0.059	0.068	0.29	0.34	7
Reinforced nylon	1.88	0.095	0.143	0.18	0.60	7
Polycarbonate	2.85	0.083	0.422	0.23	1.18	8
Polypropylene	4.06	0.151	0.422	0.42	1.18	9
ABS	10.3	0.115	0.529	0.32	1.78	9

[A] S_r = within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations of the test results from all of the participating laboratories.

$$S_r = [(S_1)^2 + (S_2)^2 \ldots + (S_n)^2)/n]^{1/2}$$

[B] S_R = between-laboratories reproducibility, expressed as standard deviation:

$$S_R = [S_r^2 + S_L^2]^{1/2}$$

where S_L = standard deviation of laboratory means.
[C] r = within-laboratory critical interval between two test results = $2.8 \times S_r$.
[D] R = between-laboratories critical interval between two test results = $2.8 \times S_R$.

13. Precision and Bias

13.1 Table 1 is based on a round robin[6] conducted in 1987 in accordance with Practice D691, involving five materials tested by nine laboratories. For each material, all samples were prepared at one source, but the individual specimens were notched and conditioned at the laboratories which tested them. Each laboratory tested an average of nine specimens for each material. (**Warning**—The explanations of r and R (13.2–13.2.3) are intended only to present a meaningful way of considering the approximate precision of this test method. The data presented in Table 1 are not to be applied to acceptance or rejection of materials, as these data apply only to the materials tested in the round robin and are unlikely to be rigorously

[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1134.

representative of other lots, formulations, conditions, materials, or laboratories. Users of this test method are advised to apply the principles outlined in Practice E691 to generate data specific to their materials and laboratory, or between specific laboratories. The principles of 13.2–13.2.3 would then be valid for such data.)

13.2 *Concept of r and R in* Table 1 —If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing nine specimens for each test result, then:

13.2.1 *Repeatability*—*r* is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory. Two tests results shall be judged not equivalent if they differ by more than the *r* value for that material.

13.2.2 *Reproducibility*—*R* is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories, not necessarily on the same day. Two test results shall be judged not equivalent if they differ by more than the *R* value for that material.

13.2.3 Any judgement in accordance with 13.2.1 or 13.2.2 would have an approximate 95 % (0.95) probability of being correct.

13.3 There are no recognized standards by which to estimate bias of this test method.

14. Keywords

14.1 Charpy impact; impact resistance; notch sensitivity; notched specimen

ANNEXES

(Mandatory Information)

A1. INSTRUCTIONS FOR THE CONSTRUCTION OF A WINDAGE AND FRICTION CORRECTION CHART

A1.1 The construction and use of the chart herein described is based upon the assumption that the friction and windage losses are proportional to the angle through which these loss torques are applied to the pendulum. Fig. A1.1 shows the assumed energy loss versus the angle of the pendulum position during the pendulum swing. The correction chart to be described is principally the left half of Fig. A1.1. Some manufacturers supply windage and friction correction charts for their equipment. The energy losses designated as A or B are described in 10.3.

A1.2 Start the construction of the correction chart (Fig. A1.2) by laying off to some convenient linear scale on the abscissa of a graph the angle of pendulum position for the portion of the swing beyond the free hanging position. For convenience, place the free hanging reference point on the right end of the abscissa with the angular displacement increasing linearly to the left. The abscissa is referred to as

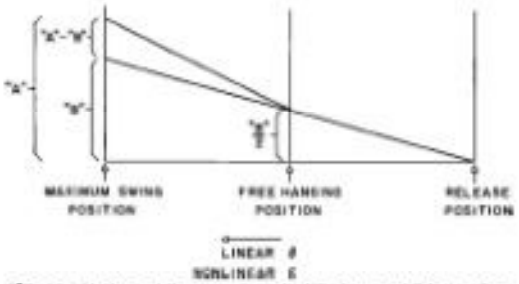


FIG. A1.1 Method of Construction of a Windage and Friction Correction Chart

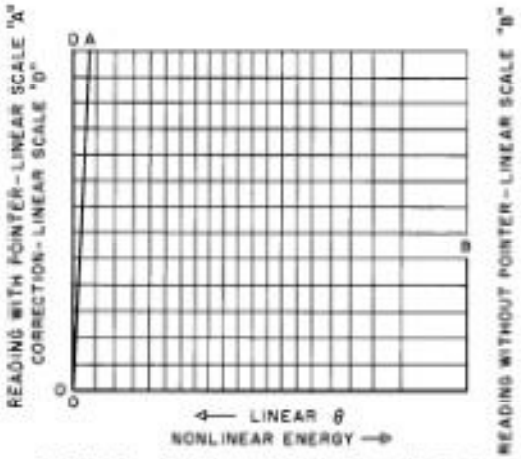


FIG. A1.2 Sample Windage and Friction Correction Chart

Scale C. Although angular displacement is the quantity to be represented linearly on the abscissa, this displacement is more conveniently expressed in terms of indicated energy read from the machine dial. This yields a nonlinear Scale C with indicated pendulum energy increasing to the right.

A1.3 On the right hand ordinate lay off a linear Scale B starting with zero at the bottom and stopping at the maximum expected pendulum friction and windage value at the top.

A1.4 On the left ordinate construct a linear Scale D ranging from zero at the bottom to 1.2 times the maximum ordinate

value appearing on Scale B, but make the scale twice the scale used in the construction of Scale B.

A1.5 Adjoining Scale D draw a curve OA which is the focus of points whose coordinates have equal values of energy correction on Scale D and indicated energy on Scale C. This curve is referred to as Scale A and utilizes the same divisions and numbering system as the adjoining Scale D.

A1.6 *Instructions for Using Chart:*

A1.6.1 Locate and mark on Scale A the reading A obtained from the free swing of the pendulum with the pointer prepositioned in the free hanging or maximum indicated energy position on the dial.

A1.6.2 Locate and mark on Scale B the reading B obtained after several free swings with the pointer pushed up close to zero indicated energy position of the dial by the pendulum in accordance with instructions in 10.3.

A1.6.3 Connect the two points thus obtained by a straight line.

A1.6.4 From the indicated impact energy on Scale C project up to the constructed line and across to the left to obtain the correction for windage and friction from Scale D.

A1.6.5 Subtract this correction from the indicated impact reading to obtain the energy delivered to the specimen.

A2. PROCEDURE FOR THE CALCULATION OF WINDAGE AND FRICTION CORRECTION

A2.1 The procedure for the calculation of the windage and friction correction in this annex is based on the equations developed by derivation in Appendix X3. This procedure is acceptable as a substitute for the graphical procedure described in Annex A1 and is applicable to small electronic calculator and computer analysis.

A2.2 Calculate L, the distance from the axis of support to the center of percussion as indicated in 6.3. It is assumed here that the center of percussion is approximately the same as the center of strike.

A2.3 Measure the maximum height, h_M, of the center of percussion (center of strike) of the pendulum at the start of the test as indicated in X2.11.

A2.4 Measure and record the energy correction, E_A, for windage of the pendulum plus friction in the dial, as determined with the first swing of the pendulum with no specimen in the testing device. This correction must be read on the energy scale, E_M, appropriate for the pendulum used.

A2.5 Without resetting the position of the indicator obtained in A2.4, measure the energy correction, E_B, for pendulum windage after two additional releases of the pendulum with no specimen in the testing device.

A2.6 Calculate β_{max} as follows:

$$\beta_{max} = \cos^{-1}\{1 - [(h_M/L)(1 - E_A/E_M)]\} \quad (A2.1)$$

where:

E_A = energy correction for windage of pendulum plus friction in dial, J (ft·lbf),
E_M = full-scale reading for pendulum used, J (ft·lbf),
L = distance from fulcrum to center of strike of pendulum, m (ft),
h_M = maximum height of center of strike of pendulum at start of test, m (ft), and
β_{max} = maximum angle pendulum will travel with one swing of the pendulum.

A2.7 Measure specimen breaking energy, E_s, J (ft·lbf).

A2.8 Calculate β for specimen measurement E_s as:

$$\beta = \cos^{-1}\{1 - [(h_M/L)(1 - E_d/E_M)]\} \quad (A2.2)$$

where:

β = angle pendulum travels for a given specimen, and
E_d = dial reading breaking energy for a specimen, J (ft·lbf).

A2.9 Calculate total correction energy, E_{TC} as:

$$E_{TC} = [E_A - (E_B/2)][\beta/\beta_{max}] + (E_B/2) \quad (A2.3)$$

where:

E_{TC} = total correction energy for the breaking energy, E_s, of a specimen, J (ft·lbf), and
E_B = energy correction for windage of the pendulum, J (ft·lbf).

A2.10 Calculate the impact resistance using the following formula:

$$I_s = (E_s - E_{TC})/t \quad (A2.4)$$

where:

I_s = impact resistance of specimen, J/m (ft·lbf/in.) of width, and
t = width of specimen or width of notch, m (in.)

APPENDIXES

(Nonmandatory Information)

X1. PROCEDURE FOR THE INSPECTION AND VERIFICATION OF NOTCH

X1.1 The purpose of this procedure is to describe the microscopic method to be used for determining the radius and angle of the notch. These measurements could also be made using a comparator if available.

NOTE X1.1—The notch shall have a radius of 0.25 ± 0.05 mm (0.010 ± 0.002 in.) and an angle of 45 ± 1°.

X1.2 *Apparatus*:

X1.2.1 *Optical Device*, with minimum magnification of 60×, Filar glass scale and camera attachment.

X1.2.2 *Transparent Template*, that will be developed in this procedure.

X1.2.3 *Ruler*.

X1.2.4 *Compass*.

X1.2.5 *Plastic Drafting Set Squares (Triangles)*, 45–45–90°.

X1.3 A transparent template must be developed for each magnification and for each microscope used. It is preferable that each laboratory standardize on one microscope and one magnification. It is not necessary for each laboratory to use the same magnification because each microscope and camera combination have somewhat different blowup ratios.

X1.3.1 Set the magnification of the optical device at a suitable magnification with a minimum magnification of 60×.

X1.3.2 Place the Filar glass slide on the microscope platform. Focus the microscope so the most distinct of the Filar scale is visible.

X1.3.3 Take a photograph of the Filar scale (see Fig. X1.1).

X1.3.4 Create a template similar to that shown in Fig. X1.2.

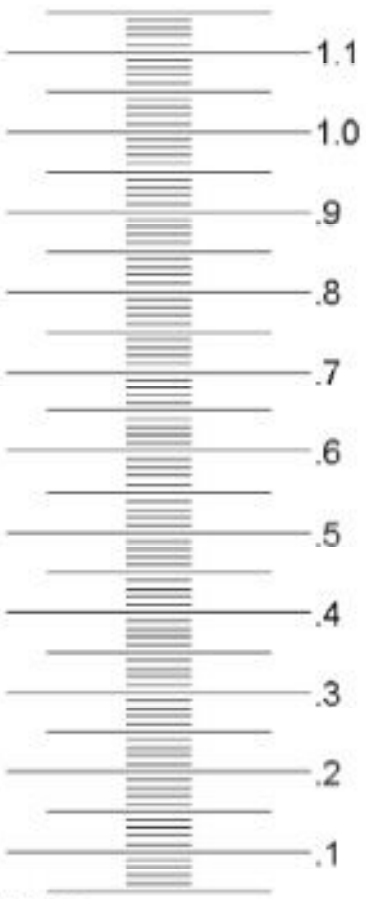
X1.3.4.1 Find the approximate center of the piece of paper.

X1.3.4.2 Draw a set of perpendicular coordinates through the center point.

X1.3.4.3 Draw a family of concentric circles that are spaced in accordance with the dimensions of the Filar scale. This task is accomplished by first setting a mechanical compass at a distance of 0.1 mm (0.004 in.) as referenced by the magnified photograph of the Filar eyepiece. Subsequent circles shall be spaced 0.02 mm apart (0.001 in.), as rings, with the outer ring being 0.4 mm (0.016 in.) from the center.

X1.3.5 Photocopy the paper with the concentric circles to make a transparent template of the concentric circles.

X1.3.6 Construct Fig. X1.3 by taking a second piece of paper, finding its approximate center, and marking this point. Draw one line through this center point. Label this line zero degree (0°). Draw a second line perpendicular to the first line through this center point. Label this line 90°. From the center draw a line that is 44° relative to the 0°. Label the line 44°. Draw another line at 46°. Label the line 46°.

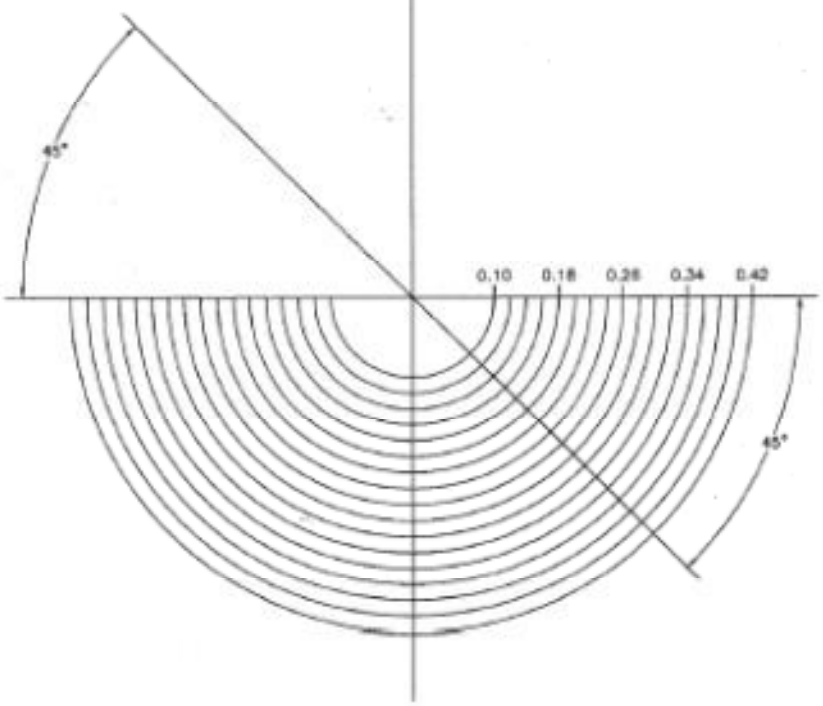


NOTE 1—100× Reference
NOTE 2—0.1 mm major scale; 0.01 mm minor scale

FIG. X1.1 Filar Scale

X1.4 Place a microscope glass slide on the microscope platform. Place the notched specimen on top of the slide. Focus the microscope. Move the specimen around using the platform adjusting knobs until the specimen's notch is centered and near the bottom of the viewing area. Take a picture of the notch.

X1.4.1 *Determination of Notching Radius* (Fig. X1.4):



Note 1—Magnification = 100×

FIG. X1.2 Example of Transparent Template for Determining Radius of Notch

X1.4.1.1 Place the picture on a sheet of paper. Position the picture so that bottom of the notch in the picture faces downwards and is about 64 mm (2.5 in.) from the bottom of the paper. Tape the picture down to the paper.

X1.4.1.2 Draw two lines along the sides of the notch projecting down to a point where they intersect below the notch Point I (see Fig. X1.4B).

X1.4.1.3 Open the compass to about 51 mm (2 in.). Using Point I as a reference, draw two arcs intersecting both sides of the notch (see Fig. X1.4C). These intersections are called 1a and 1b.

X1.4.1.4 Close the compass to about 38 mm (1.5 in.). Using Point 1a as the reference point, draw an arc (2a) above the notch, draw a second arc (2b) that intersects with arc 2a at Point J. Draw a line between I and J. This establishes the centerline of the notch (see Fig. X1.4D)

X1.4.1.5 Place the transparent template on top of the picture and align the center of the concentric circles with the drawn centerline of the notch (see Fig. X1.4E).

X1.4.1.6 Slide the template down the centerline of the notch until one concentric circle touches both sides of the notch. Record the radius of the notch and compare it against the limits of 0.2 to 0.3 mm (0.008 to 0.012 in.).

X1.4.1.7 Examine the notch to ensure that there are no flat spots along the measured radius.

X1.4.2 *Determination of Notch Angle*—Place transparent template for determining notch angle (Fig. X1.3) on top of the photograph attached to the sheet of paper. Rotate the picture so that the notch tip is pointed towards you. Position the center point of the template on top of the Point I established in 0° axis of the template with the right side straight portion of the notch. Check the left side straight portion of the notch to ensure that this portion falls between the 44° and 46° lines. If not, replace the blade.

X1.5 A picture of a notch shall be taken at least every 500 notches or if a control sample gives a value outside its 3-sigma limits for that test.

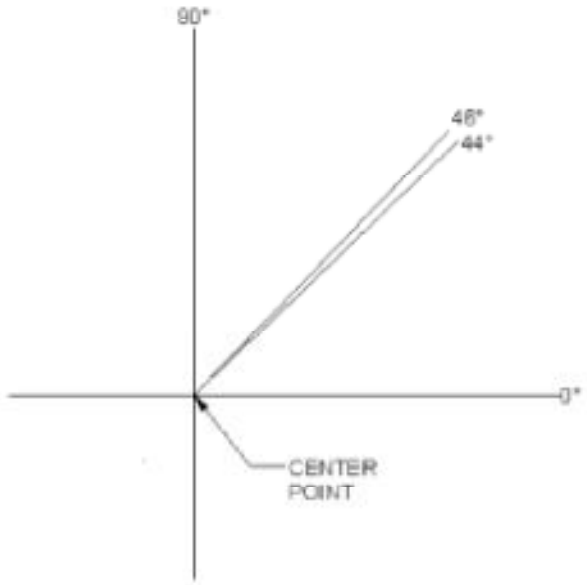


FIG. X1.3 Example of Transparent Template for Determining Angle of Notch

X1.6 If the notch in the control specimen is not within the requirements, take a picture of the notching blade and analyze it by the same procedure used for the specimen notch. If the notching blade does not meet ASTM requirements or shows damage, it shall be replaced with a new blade which has been checked for proper dimensions.

X1.7 If a cutter has the correct dimensions, but does not cut the correct notch in the specimen, it will be necessary to evaluate other conditions (cutter and feed speeds) to obtain the correct notch dimension for that material.

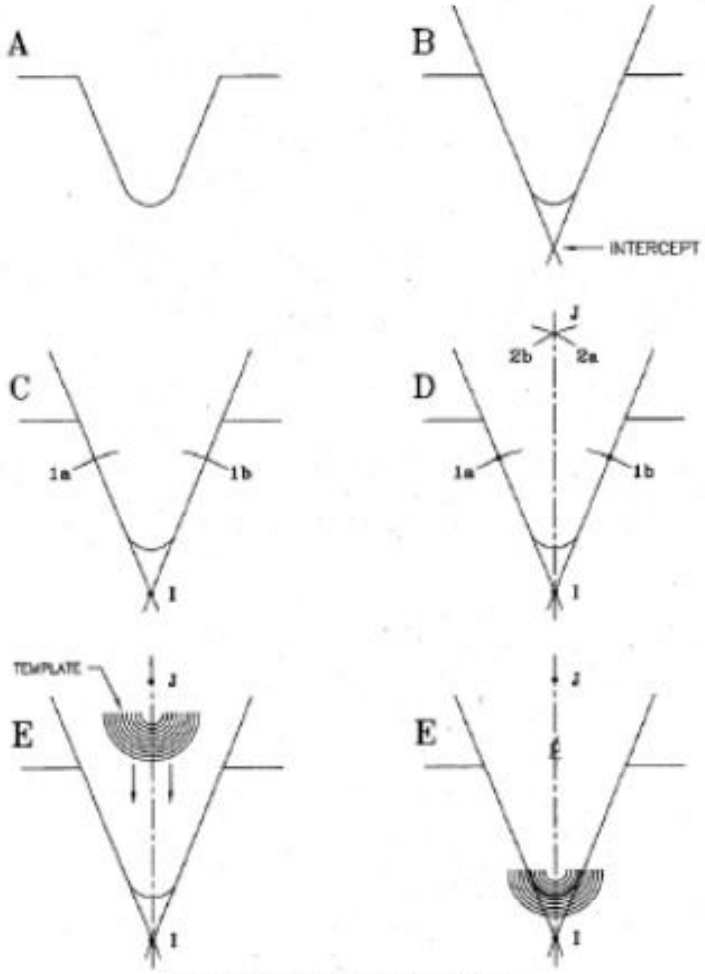


FIG. X1.4 Determination of Notching Radius

X2. CALIBRATION OF PENDULUM-TYPE HAMMER IMPACT MACHINES FOR USE WITH PLASTIC SPECIMENS

X2.1 This calibration procedure applies specifically to the Charpy impact machine.

X2.2 Locate the impact machine on a sturdy base. It shall not walk on the base and the base shall not vibrate appreciably. Loss of energy from vibrations will give high readings. It is recommended that the impact tester be bolted to a base having a mass of at least 23 kg if it is used at capacities higher than 2.7 J (2 ft-lbf).

X2.3 Check the level of the machine in both directions on the plane of the base with spirit levels mounted in the base, by a machinist's level if a satisfactory reference surface is available, or with a plumb bob. Level the machine to within $\tan^{-1}$ 0.001 in the plane of swing and to within $\tan^{-1}$ 0.002 in the plane perpendicular to the swing.

X2.4 Contact the machine manufacturer for a procedure to ensure the striker radius is in tolerance (3.17 ± 0.12 mm) (see 6.1.2).

X2.5 Check the transverse location of the center of the pendulum striking edge that shall be within 0.40 mm (0.016 in.) of the center of the anvil. Readjust the shaft bearings or relocate the anvil or straighten the pendulum shaft as necessary to attain the proper relationship between the two centers.

X2.6 Check the pendulum arm for straightness within 1.2 mm (0.05 in.) with a straightedge or by sighting down the shaft. This arm is sometimes bent by allowing the pendulum to slam against the catch when high-capacity weights are on the pendulum.

X2.7 Center a notched 12.7-mm square metal bar having opposite sides parallel within 0.025 mm and 125 mm long on the Charpy anvils. Place a thin oil film, ink or dye on the striking edge of the pendulum and let the striking edge rest gently against the bar. If the striking edge is correctly making contact with the specimen, a thin line of oil, ink, or dye will be transferred across the entire width of the bar.

X2.8 When the pendulum is hanging free in its lowest position, the energy reading must be within 0.2 % of full scale.

X2.9 Swing the pendulum to a horizontal position, and support it by the striking edge in this position with a vertical bar. Allow the other end of this bar to rest at the center of a load pan on a balanced scale. Subtract the weight of the bar from the total weight to find the effective weight of the pendulum. The effective pendulum weight shall be within 0.4 % of the required weight for that pendulum capacity. If weight must be added or removed, take care to balance the added or removed weight without affecting the center of percussion relative to the striking edge. It is not advisable to add weight to the opposite side of the bearing axis from the striking edge to decrease the effective weight of the pendulum since the distributed mass has the potential to result in large energy losses from vibration of the pendulum.

X2.10 Calculate the effective length of the pendulum arm or the distance to the center of percussion from the axis of rotation by the procedure in 6.1.2. The effective length must be within the tolerance stated in 6.1.1.2.

X2.11 Determine the vertical distance of fall of the pendulum striking edge from its latched height to its lowest point. This distance shall be 610 ± 2 mm. This measurement is made with a half-width specimen positioned on the anvils. Place a thin oil film on the specimen and bring the striking edge against it. The upper end of the oil line on the striking edge is the center of strike. Measure the change in vertical height of the center of strike from the latched to the free hang position (the lowest point). This vertical fall distance is adjusted by varying the position of the pendulum latch.

X2.12 If a pointer and dial mechanism is used to indicate the energy, the pointer friction shall be adjusted so that the pointer will just maintain its position anywhere on the scale. The striking pin of the pointer shall be securely fastened to the pointer. Friction washers with glazed surfaces shall be replaced with new washers. Friction washers shall be on either side of the pointer collar. The last friction washer installed shall be backed by a heavy metal washer. Pressure on this metal washer is produced by a thin bent spring washer and locknuts. If the spring washer is placed next to the fiber friction washer, the pointer will tend to vibrate during impact.

X2.13 The free-swing reading of the pendulum (without specimen) from the latched height shall be less than 2.5 % of pendulum capacity on the first swing. If the reading is higher than this, the friction in the indicating mechanism is excessive or the bearings are dirty. To clean the bearings, dip them in grease solvent and spin dry in an air jet. Clean the bearings until they spin freely or replace them. Oil very lightly with instrument oil before replacing. A reproducible method of starting the pendulum from the proper height must be devised.

X2.14 The shaft about which the pendulum rotates shall have no detectable radial play, less than 0.05 mm (0.002 in.). An end play of 0.25 mm (0.010 in.) is permissible when a 9.8-N (2.2-lbf) axial force is applied in alternate directions.

X2.15 The machine shall not be used to indicate more than 85 % of the energy capacity of the pendulum. Extra weight added to the pendulum will increase available energy of the machine. This weight must be added so as to maintain the center of percussion within the tolerance stated in 6.1.2. Correct effective weight for any range is calculated as follows:

$$W = E_p/h \qquad \text{(X2.1)}$$

where:

W = the effective pendulum weight, N (lbf) (see X2.9),
E_p = potential or available energy of the machine, J (ft × lbf), and
h = the vertical distance of fall of the pendulum striking edge, m (ft) (see X2.11).

Each 4.5 N (1 lbf) of added effective weight increases the capacity of the machine by 2.7 J (2 ft × lbf).

NOTE X2.1—If the pendulum is designed for use with added weights, it is recommended that they be obtained through the equipment manufacturer.

X3. DERIVATION OF PENDULUM IMPACT CORRECTION EQUATIONS

X3.1 From right triangle distances in Fig. X3.1:

$$L - h = L\cos\beta \tag{X3.1}$$

X3.2 The potential energy gain of pendulum, E_p, is:

$$E_p = hW_p g \tag{X3.2}$$

X3.3 Combining Eq X3.1 and Eq X3.2 gives the following:

$$L - E_p/W_p g = L\cos\beta \tag{X3.3}$$

X3.4 The maximum energy of the pendulum is the potential energy at the start of the test, E_M, or

$$E_M = h_M W_p g \tag{X3.4}$$

X3.5 The potential energy gained by the pendulum, E_p, is related to the absorption of energy of a specimen, E_s, by the following equation:

$$E_M = E_s + E_p \tag{X3.5}$$

X3.6 Combining Eq X3.3–X3.5 gives the following:

$$(E_M - E_s)/E_M = L/h_M(1 - \cos\beta) \tag{X3.6}$$

X3.7 Solving Eq X3.6 for β gives the following:

$$\beta = \cos^{-1}\left(1 - [(h_M/L)(1 - E_s/E_M)]\right) \tag{X3.7}$$

X3.8 From Fig. X3.2, the total energy correction, E_{TC}, is given as:

$$E_{TC} = m\beta + b \tag{X3.8}$$

X3.9 At the zero point of the pendulum the potential energy is:

$$E_p/2 = m(0) + b \tag{X3.9}$$

or

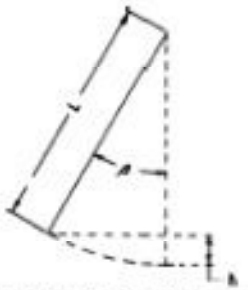


FIG. X3.1 Swing of Pendulum from the Rest Position

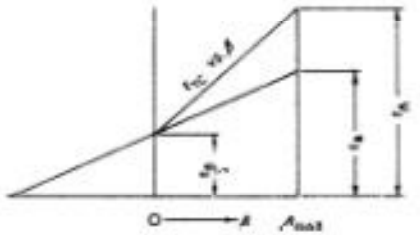


FIG. X3.2 Total Energy Correction for Pendulum Windage and Dial Friction as a Function of Pendulum Position

$$b = E_p/2$$

X3.10 The energy correction, E_A, on the first swing of the pendulum occurs at the maximum pendulum angle, β_{max}. Substituting in Eq X3.8 gives the following:

$$E_A = m\beta_{max} + (E_p/2) \tag{X3.10}$$

X3.11 Combining Eq X3.8 and Eq X3.11 gives the following:

$$E_{TC} = (E_s - (E_p/2))(\beta/\beta_{max}) + (E_p/2) \tag{X3.11}$$

X3.12 Nomenclature:

- b = intercept of total correction energy straight line,
- E_A = energy correction, including both pendulum windage plus dial friction, J,
- E_p = energy correction for pendulum windage only, J,
- E_M = maximum energy of the pendulum (at the start of test), J,
- E_p = potential energy gain of pendulum from the pendulum rest position, J,
- E_s = uncorrected breaking energy of specimen, J,
- E_{TC} = total energy correction for a given breaking energy, E_s, J,
- g = acceleration of gravity, m/s^2,
- h = distance center of gravity of pendulum rises vertically from the rest position of the pendulum, m,
- h_M = maximum height of the center of gravity of the pendulum, m,
- m = slope of total correction energy straight line,
- L = distance from fulcrum to center of gravity of pendulum, m,
- W_p = weight of pendulum, as determined in X2.13, kg, and
- β = angle of pendulum position from the pendulum rest position.

X4. UNIT CONVERSIONS

X4.1 Joules per metre cannot be converted directly into kilojoules per square metre.

NOTE X4.1—If the optional units of kJ/m² (ft·lbf/in.²) are required the cross-sectional area under the notch must be reported.

X4.2 The following examples are approximations:

19 J/m (0.37 ft·lbf/in.) = 1 kJ/m²
19 J/m (36.37) (1.358) J/m
19 J/m = 53.6 J/m
19 J/m = 0.0534 kJ/m

19 J/m (1000 in./ft) = 1 kJ/m²
19 J/m (1000) (1.358) J/m²
19 J/m = 2181 J/m²
19 J/m = 2.1 kJ/m²

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D6110 – 08) that may impact the use of this standard. (April 1, 2010)

(1) Revised Section 9.

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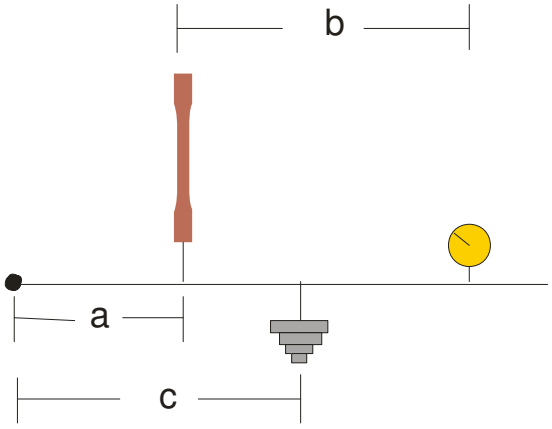
ANEXO No. 1: Procedimiento para calcular el módulo de Young

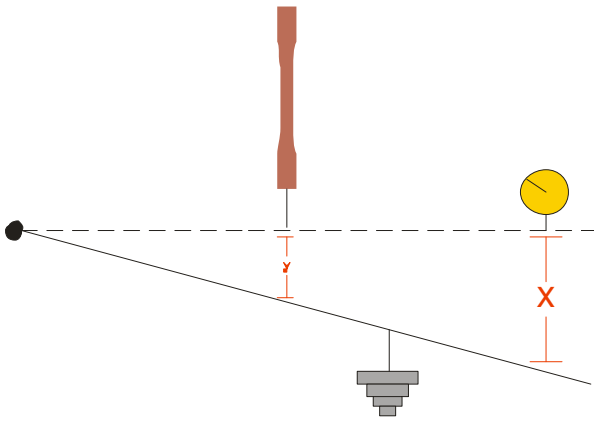
Por medio de análisis matemáticos y físicos, se obtienen los valores de fuerza y distancia necesarios para calcular el módulo de Young.

El módulo de elasticidad, o más comúnmente denominado módulo de Young, resulta de la relación, o el cociente, entre la tensión y la deformación del material. Por medio del análisis de los datos y las mediciones obtenidas del montaje se obtendrán las gráficas de tensión y deformación específicas para el material prototipo.

La Gráfica 1 muestra la posición inicial del montaje, indicando las distancias que deben tenerse en cuenta para la subsecuente cálculo de las distancias como se muestra en la Grafica 2.



Gráfica 1

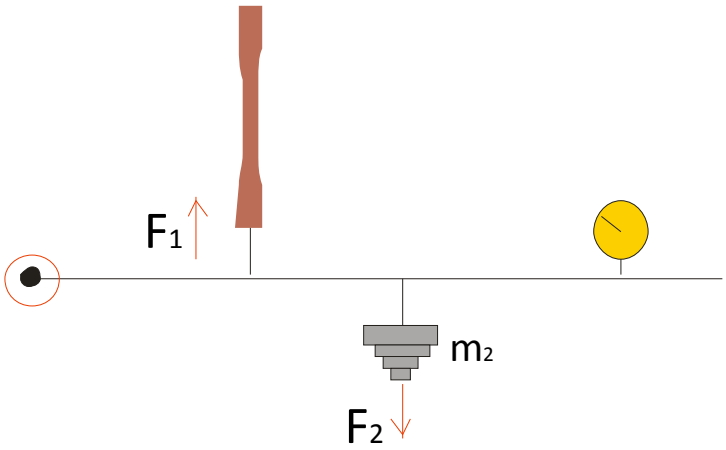


Gráfica 2

A medida que se añaden las cargas, el comparador de carátulas registra la elongación *x*, y por medio de una relación matemática se obtiene *y,* siendo *y* la elongación real del material*:*

$$\frac{x}{a+b} = \frac{y}{a}$$

Para hallar la carga ejercida sobre la probeta, se realiza un análisis de torque tal como se indica en la Gráfica 3:



Gráfica 3

El sistema funciona como una sumatoria de torques alrededor de un punto pivote:

$$0 = aF_1 - cF_2$$

Donde:

$$F_2 = gm_2 \qquad (g = gravedad)$$

$$F_2 = \frac{cF_1}{a}$$

Una vez se cuenta con la fuerza ejercida sobre la probeta se calcula la tensión sobre la misma teniendo en cuenta el área transversal *(A)*:

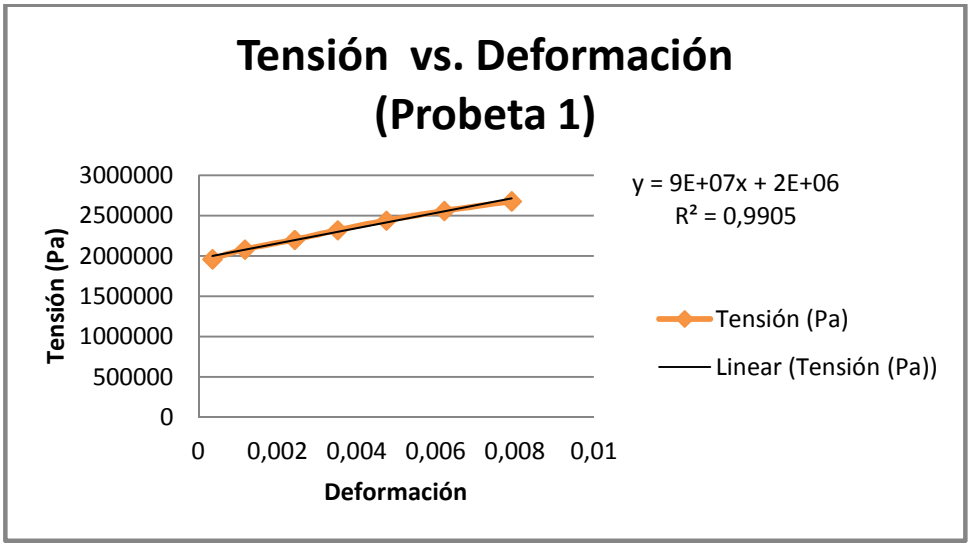
$$T = \frac{F}{A}$$

Utilizando Excel, se grafica los resultados de tensión vs. Deformación, incluyendo una línea de tendencia y su ecuación. El gráfica 4 a continuación ejemplifica la tabulación de resultados para la probeta 1:

Gage length (mm)	13.81	0.01381					
Espesor (mm)	1.08	0.00108					
a (mm)	55						
b (mm)	320						
c (mm)	200						
x (mm)	0.12	0.4	0.83	1.2	1.62	2.12	2.7
y	0.0176	0.0586667	0.1217333	0.176	0.2376	0.3109333	0.396
y en metros	0.0000176	5.867E-05	0.0001217	0.000176	0.0002376	0.0003109	0.000396
masa (gr)	820.97	870.97	920.97	970.97	1020.97	1070.97	1120.97
Peso (newton)	8.045506	8.535506	9.025506	9.515506	10.005506	10.495506	10.985506
Area (crossectional m)	1.49148E-05						
F2 (Newton)	29.25638545	31.038204	32.820022	34.60184	36.383658	38.165476	39.947295
Elongación	0.000352	0.0011733	0.0024347	0.00352	0.004752	0.0062187	0.00792
Tensión (Pa)	1961567.4	2081033.8	2200500.3	2319966.7	2439433.2	2558899.6	2678366.1

Gráfica 4

La gráfica resultante de la deformación y tensión obtenida resulta en la gráfica 5:



Gráfica 5

De la ecuación resultante de la línea de tendencia, se tiene la pendiente de dicha recta es el módulo de Young o módulo de elasticidad. Para este caso específico de la probeta 1, el módulo de Young es 90 MPa.

ANEXO No. 2: Norma ASTM D570: Standard Test Method for Water Absorption of Plastics

Designation: D570 – 98 (Reapproved 2010)$^{\varepsilon 1}$

Standard Test Method for Water Absorption of Plastics[1]

This standard is issued under the fixed designation D570; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

ε[1] NOTE—Removed ASTM D647 as a referenced document editorially in June 2010.

1. Scope

1.1 This test method covers the determination of the relative rate of absorption of water by plastics when immersed. This test method is intended to apply to the testing of all types of plastics, including cast, hot-molded, and cold-molded resinous products, and both homogeneous and laminated plastics in rod and tube form and in sheets 0.13 mm (0.005 in.) or greater in thickness.

1.2 The values given in SI units are to be regarded as standard. The values stated in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—This standard is equivalent to ISO 62.

2. Referenced Documents

2.1 *ISO Standard:*
ISO 62 Plastics—Determination of Water Absorption[2]

3. Significance and Use

3.1 This test method for rate of water absorption has two chief functions: first, as a guide to the proportion of water absorbed by a material and consequently, in those cases where the relationships between moisture and electrical or mechanical properties, dimensions, or appearance have been determined, as a guide to the effects of exposure to water or humid conditions on such properties; and second, as a control test on the uniformity of a product. This second function is particularly applicable to sheet, rod, and tube arms when the test is made on the finished product.

3.2 Comparison of water absorption values of various plastics can be made on the basis of values obtained in accordance with 7.1 and 7.4.

3.3 Ideal diffusion of liquids[3] into polymers is a function of the square root of immersion time. Time to saturation is strongly dependent on specimen thickness. For example, Table 1 shows the time to approximate time saturation for various thickness of nylon-6.

3.4 The moisture content of a plastic is very intimately related to such properties as electrical insulation resistance, dielectric losses, mechanical strength, appearance, and dimensions. The effect upon these properties of change in moisture content due to water absorption depends largely on the type of exposure (by immersion in water or by exposure to high humidity), shape of the part, and inherent properties of the plastic. With nonhomogeneous materials, such as laminated forms, the rate of water absorption may be widely different through each edge and surface. Even for otherwise homogeneous materials, it may be slightly greater through cut edges than through molded surfaces. Consequently, attempts to correlate water absorption with the surface area must generally be limited to closely related materials and to similarly shaped specimens: For materials of widely varying density, relation between water-absorption values on a volume as well as a weight basis may need to be considered.

4. Apparatus

4.1 *Balance*—An analytical balance capable of reading 0.0001 g.

4.2 *Oven*, capable of maintaining uniform temperatures of 50 ± 3°C (122 ± 5.4°F) and of 105 to 110°C (221 to 230°F).

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.50 on Durability of Plastics.
Current edition approved April 1, 2010. Published June 2010. Originally approved in 1940. Last previous edition approved in 2005 as D570 - 98 (2005). DOI: 10.1520/D0570-98R10E01.

[2] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[3] Additional information regarding diffusion of liquids in polymers can be found in the following references: (*1*) *Diffusion, Mass Transfer in Fluid Systems*, E. L. Cussler, Cambridge University Press, 1985, ISBN 0-521-29846-6, (*2*) *Diffusion in Polymers*, J. Crank and G. S. Park, Academic Press, 1968, and (*3*) "Permeation, Diffusion, and Sorption of Gases and Vapors," R. M. Felder and G. S. Huvard, in *Methods of Experimental Physics*, Vol 16C, 1980, Academic Press.

TABLE 1 Time to Saturation for Various Thickness of Nylon-6

Thickness, mm	Typical Time to 95 % Saturation, h
1	100
2	400
3.2	1 000
10	10 000
25	62 000

5. Test Specimen

5.1 The test specimen for molded plastics shall be in the form of a disk 50.8 mm (2 in.) in diameter and 3.2 mm (⅛ in.) in thickness. Permissible variations in thickness are ±0.18 mm (±0.007 in.) for hot-molded and ±0.30 mm (±0.012 in.) for cold-molded or cast materials.

5.2 *ISO Standard Specimen*—The test specimen for homogeneous plastics shall be 60 by 60 by 1 mm. Tolerance for the 60-mm dimension is ±2 mm and ±0.05 mm for the 1-mm thickness. This test method and ISO 62 are technically equivalent when the test specimen described in 5.2 is used.

5.3 The test specimen for sheets shall be in the form of a bar 76.2 mm (3 in.) long by 25.4 mm (1 in.) wide by the thickness of the material. When comparison of absorption values with molded plastics is desired, specimens 3.2-mm (⅛-in.) thick should be used. Permissible variations in thickness shall be 0.20 mm (±0.008 in.) except for materials which have greater standard commercial tolerances.

5.4 The test specimen for rods shall be 25.4-mm (1-in.) long for rods 25.4 mm in diameter or under and 12.7-mm (½-in.) long for larger-diameter rods. The diameter of the specimen shall be the diameter of the finished rod.

5.5 The test specimen for tubes less than 76 mm (3 in.) in inside diameter shall be the full section of the tube and 25.4-mm (1-in.) long. For tubes 76 mm (3 in.) or more in inside diameter, a rectangular specimen shall be cut 76 mm in length in the circumferential direction of the tube and 25.4 mm in width lengthwise of the tube.

5.6 The test specimens for sheets, rods, and tubes shall be machined, sawed, or sheared from the sample so as to have smooth edges free from cracks. The cut edges shall be made smooth by finishing with No. 0 or finer sandpaper or emery cloth. Sawing, machining, and sandpapering operations shall be slow enough so that the material is not heated appreciably.

NOTE 2—If there is any oil on the surface of the specimen when received or as a result of machining operations, wash the specimen with a cloth wet with gasoline to remove oil, wipe with a dry cloth, and allow to stand in air for 2 h to permit evaporation of the gasoline. If gasoline attacks the plastic, use some suitable solvent or detergent that will evaporate within the 2-h period.

5.7 The dimensions listed in the following table for the various specimens shall be measured to the nearest 0.025 mm (0.001 in.). Dimensions not listed shall be measured within 0.8 mm (±1/32 in.).

Type of Specimen	Dimensions to Be Measured to the Nearest 0.025 mm (0.001 in.)
Molded disk	thickness
Sheet	thickness
Rod	length and diameter
Tube	inside and outside diameter, and wall thickness

6. Conditioning

6.1 Three specimens shall be conditioned as follows:

6.1.1 Specimens of materials whose water-absorption value would be appreciably affected by temperatures in the neighborhood of 110°C (230°F), shall be dried in an oven for 24 h at 50 ± 3°C (122 ± 5.4°F), cooled in a desiccator, and immediately weighed to the nearest 0.001 g.

NOTE 3—If a static charge interferes with the weighing, lightly rub the surface of the specimens with a grounded conductor.

6.1.2 Specimens of materials, such as phenolic laminated plastics and other products whose water-absorption value has been shown not to be appreciably affected by temperatures up to 110°C (230°F), shall be dried in an oven for 1 h at 105 to 110°C (221 to 230°F).

6.1.3 When data for comparison with absorption values for other plastics are desired, the specimens shall be dried in an oven for 24 h at 50 ± 3°C (122 ± 5.4°F), cooled in a desiccator, and immediately weighed to the nearest 0.001 g.

7. Procedure

7.1 *Twenty-Four Hour Immersion*—The conditioned specimens shall be placed in a container of distilled water maintained at a temperature of 23 ± 1°C (73.4 ± 1.8°F), and shall rest on edge and be entirely immersed. At the end of 24, +½, −0 h, the specimens shall be removed from the water one at a time, all surface water wiped off with a dry cloth, and weighed to the nearest 0.001 g immediately. If the specimen is 1/16 in. or less in thickness, it shall be put in a weighing bottle immediately after wiping and weighed in the bottle.

7.2 *Two-Hour Immersion*—For all thicknesses of materials having a relatively high rate of absorption, and for thin specimens of other materials which may show a significant weight increase in 2 h, the specimens shall be tested as described in 7.1 except that the time of immersion shall be reduced to 120 ± 4 min.

7.3 *Repeated Immersion*—A specimen may be weighed to the nearest 0.001 g after 2-h immersion, replaced in the water, and weighed again after 24 h.

NOTE 4—In using this test method the amount of water absorbed in 24 h may be less than it would have been had the immersion not been interrupted.

7.4 *Long-Term Immersion*—To determine the total water absorbed when substantially saturated, the conditioned specimens shall be tested as described in 7.1 except that at the end of 24 h they shall be removed from the water, wiped free of surface moisture with a dry cloth, weighed to the nearest 0.001 g immediately, and then replaced in the water. The weighings shall be repeated at the end of the first week and every two weeks thereafter until the increase in weight per two-week period, as shown by three consecutive weighings, averages less

than 1 % of the total increase in weight or 5 mg, whichever is greater; the specimen shall then be considered substantially saturated. The difference between the substantially saturated weight and the dry weight shall be considered as the water absorbed when substantially saturated.

7.5 *Two-Hour Boiling Water Immersion*—The conditioned specimens shall be placed in a container of boiling distilled water, and shall be supported on edge and be entirely immersed. At the end of 120 ± 4 min, the specimens shall be removed from the water and cooled in distilled water maintained at room temperature. After 15 ± 1 min, the specimens shall be removed from the water, one at a time, all surface water removed with a dry cloth, and the specimens weighed to the nearest 0.001 g immediately. If the specimen is 1/16 in. or less in thickness, it shall be weighed in a weighing bottle.

7.6 *One-Half-Hour Boiling Water Immersion*—For all thicknesses of materials having a relatively high rate of absorption and for thin specimens of other materials which may show a significant weight increase in ½ h, the specimens shall be tested as described in 7.5, except that the time of immersion shall be reduced to 30 ± 1 min.

7.7 *Immersion at 50°C*—The conditioned specimens shall be tested as described in 7.5, except that the time and temperature of immersion shall be 48 ± 1 h and 50 ± 1°C (122.0 ± 1.8°F), respectively, and cooling in water before weighing shall be omitted.

7.8 When data for comparison with absorption values for other plastics are desired, the 24-h immersion procedure described in 7.1 and the equilibrium value determined in 7.4 shall be used.

8. Reconditioning

8.1 When materials are known or suspected to contain any appreciable amount of water-soluble ingredients, the specimens, after immersion, shall be weighed, and then reconditioned for the same time and temperature as used in the original drying period. They shall then be cooled in a desiccator and immediately reweighed. If the reconditioned weight is lower than the conditioned weight, the difference shall be considered as water-soluble matter lost during the immersion test. For such materials, the water-absorption value shall be taken as the sum of the increase in weight on immersion and of the weight of the water-soluble matter.

9. Calculation and Report

9.1 The report shall include the values for each specimen and the average for the three specimens as follows:

9.1.1 Dimensions of the specimens before test, measured in accordance with 5.6, and reported to the nearest 0.025 mm (0.001 in.),

9.1.2 Conditioning time and temperature,

9.1.3 Immersion procedure used,

9.1.4 Time of immersion (long-term immersion procedure only),

9.1.5 Percentage increase in weight during immersion, calculated to the nearest 0.01 % as follows:

$$\text{Increase in weight, \%} = \frac{\text{wet weight} - \text{conditioned weight}}{\text{conditioned weight}} \times 100$$

9.1.6 Percentage of soluble matter lost during immersion, if determined, calculated to the nearest 0.01 % as follows (see Note 5):

$$\text{Soluble matter lost, \%} = \frac{\text{conditioned weight} - \text{reconditioned weight}}{\text{conditioned weight}} \times 100$$

NOTE 5—When the weight on reconditioning the specimen after immersion in water exceeds the conditioned weight prior to immersion, report "none" under 9.1.6.

9.1.7 For long-term immersion procedure only, prepare a graph of the increase in weight as a function of the square root of each immersion time. The initial slope of this graph is proportional to the diffusion constant of water in the plastic. The plateau region with little or no change in weight as a function of the square root of immersion time represents the saturation water content of the plastic.

NOTE 6—Deviation from the initial slope and plateau model indicates that simple diffusion may be a poor model for determining water content. In such cases, additional studies are suggested to determine a better model for water absorption.

9.1.8 The percentage of water absorbed, which is the sum of the values in 9.1.5 and 9.1.6, and

9.1.9 Any observations as to warping, cracking, or change in appearance of the specimens.

10. Precision and Bias[4]

10.1 *Precision*—An interlaboratory test program was carried out using the procedure outlined in 7.1, involving three laboratories and three materials. Analysis of this data yields the following coefficients of variation (average of three replicates).

	Within Laboratories	Between Laboratories
Average absorption above 1 % (2 materials)	2.33 %	4.88 %
Average absorption below 0.2 % (1 material)	9.01 %	16.63 %

NOTE 7—A round robin is currently under way to more completely determine repeatability and reproducibility of this test method.

10.2 *Bias*—No justifiable statement on the bias of this test method can be made, since the true value of the property cannot be established by an accepted referee method.

11. Keywords

11.1 absorption; immersion; plastics; water

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1064.

D570 – 98 (2010)ε1

ANEXO No. 3: ASTM D635 Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position

Designation: D635 – 10

Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position[1]

This standard is issued under the fixed designation D635; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This fire-test-response test method covers a small-scale laboratory screening procedure for comparing the relative linear rate of burning or extent and time of burning, or both, of plastics in the form of bars, molded or cut from sheets, plates, or panels, and tested in the horizontal position.

NOTE 1—This test method, and test method A of IEC 60695-11-10 are technically equivalent.

NOTE 2—For additional information on materials which do not burn to the first reference mark by this test, see Test Method D3801.

1.2 This test method was developed for polymeric materials used for parts in devices and appliances. The results are intended to serve as a preliminary indication of their acceptability with respect to flammability for a particular application. The final acceptance of the material is dependent upon its use in complete equipment that conforms with the standard applicable to such equipment.

1.3 The classification system described in Appendix X1 is intended for quality assurance and the preselection of component materials for products.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazards or fire risk assessment of materials, products, or assemblies under actual fire conditions.*

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific hazards statements, see 9.2.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing
D648 Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position
D883 Terminology Relating to Plastics
D1929 Test Method for Determining Ignition Temperature of Plastics
D2843 Test Method for Density of Smoke from the Burning or Decomposition of Plastics
D3801 Test Method for Measuring the Comparative Burning Characteristics of Solid Plastics in a Vertical Position
D5025 Specification for Laboratory Burner Used for Small-Scale Burning Tests on Plastic Materials
D5207 Practice for Confirmation of 20–mm (50–W) and 125–mm (500–W) Test Flames for Small-Scale Burning Tests on Plastic Materials
E84 Test Method for Surface Burning Characteristics of Building Materials
E176 Terminology of Fire Standards
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *IEC Standards:*[3]

IEC 60695-11-10 Fire Hazard Testing—Part 11-10 Test Flames—50W Horizontal and Vertical Flame Test Methods

3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.30 on Thermal Properties (Section D20.30.03).

Current edition approved July 1, 2010. Published August 2010. Originally approved in 1941. Last previous edition approved in 2006 as D635 - 06. DOI: 10.1520/D0635-10.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Publications of the International Electrotechnical Commission (IEC) and International Organization for Standardization (ISO) are available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

*A Summary of Changes section appears at the end of this standard

3.1.1 Definitions used in this test method are in accordance with Terminology D883, unless otherwise specified. For terms relating to fire, the definitions used in this test method are in accordance with Terminology E176.

4. Summary of Test Method

4.1 A bar specimen of the material to be tested is supported horizontally at one end. The free end is exposed to a specified gas flame for 30 s. Time and extent of burning are measured and reported if the specimen does not burn 100 mm. An average burning rate is reported for a material if it burns to the 100 mm mark from the ignited end.

5. Significance and Use

5.1 Tests made on a material under conditions herein prescribed are of value in comparing the rate of burning or extent and time of burning characteristics, or both, of different materials, in controlling manufacturing processes, or as a measure of deterioration or change in these burning characteristics prior to or during use. Correlation with flammability under actual use conditions is not implied.

5.2 The rate of burning and other burning phenomena will be affected by such factors as density, pigments, any anisotropy of the material and the thickness of the specimen. Test data shall be compared only for specimens of similar thickness, whether comparisons are being made with the same or different materials. The rate of burning and other burning phenomena will vary with thickness.

5.3 It is feasible that sheet materials that have been stretched during processing will relax during burning and give erratic results unless they are first heated above their deflection temperature, in accordance with Test Method D648, for a time sufficient to permit complete relaxation.

5.4 Burning tests require that certain variables be arbitrarily fixed, for example, specimen size, energy source and application time, and end points. Materials will be found that are unusually sensitive to one or more of the conditions chosen for this method leading to highly variable results. Additional burning characterization by other methods is highly desirable in such cases (see Note 2).

5.5 In this procedure, the specimens are subjected to specific laboratory test conditions. If different test conditions are substituted or the end-use conditions are changed, it will not always be possible by or from this test to predict changes in the fire-test-response characteristics measured. Therefore, the results are valid only for the fire-test-exposure conditions described in this procedure.

6. Apparatus

6.1 *Test Chamber,* enclosed laboratory hood, or chamber free of induced or forced draft during test, having an inside volume of at least 0.5 m^3. An enclosed laboratory hood with a heat-resistant glass window for observing the test and an exhaust fan for removing the products of combustion after the tests is recommended. The atmosphere in and around the test chamber shall be maintained between 15 to 35°C and 45 to 75 % relative humidity.

NOTE 3—The amount of oxygen available to support combustion is naturally important for the conduct of these fire-test-response tests. For tests conducted by this test method where burning times are protracted, chamber sizes less than 1 m^3 may not provide accurate results.

NOTE 4—Some laboratory hoods have induced drafts even with the exhaust fan off. A positive-closing damper is recommended.

NOTE 5—A mirror in the chamber, to provide a rear view of the specimen, has been found useful in some enclosures.

6.2 *Test Fixture,* A laboratory ring stand or test fixture equipped with a means of holding a 125 mm^2 wire gauze horizontal and a small clamp permitting the specimen to be held with its longitudinal axis horizontal and its transverse axis inclined at 45 ± 2° angle as illustrated in Fig. 1.

NOTE 6—A pan of water may be placed on the floor of the hood in position to catch any burning particles that may drop during the test.

6.3 *Laboratory Burner,* constructed in accordance with Specification D5025.

6.4 *Gas Supply,* a supply of technical-grade methane gas with suitable regulator and meter for uniform gas flow. Natural gas mixtures having an energy density of approximately 37 MJ/m^3 have been found to provide similar results. However, technical-grade methane gas shall be used as the referee in cases of dispute.

6.5 *Wire Gauze,* 20-mesh (approximately 20 openings per 25 mm), made with 0.43 ± 0.03 mm diameter iron wire cut to approximately 125 mm^2, to sustain burning or glowing particles falling from the specimens.

6.6 *Timing Device,* accurate to 0.5 s.

6.7 *Scale,* graduated in millimetres.

6.8 *Micrometer,* accurate to 0.05 mm.

6.9 *Conditioning Room or Chamber,* capable of being maintained at 23 ± 2°C and 50 ± 5 % relative humidity.

6.10 *Flexible Specimen Support Fixture,* used to facilitate the testing of specimens that sag and touch the wire gauze. (See 9.4 and Fig. 2.)

7. Test Specimens

7.1 All test specimens shall be cut from a representative sample of the material (sheet or end products), or shall be cast or injection-, compression-, transfer- or pultrusion-molded to the necessary form. After any cutting operation, care shall be taken to remove all dust and any particles from the surface; cut edges shall be fine sanded to have a smooth finish. Unless otherwise agreed, fabrication of test specimens shall be in accordance with the specifications of the material being tested.

7.2 Specimens shall be 125 ± 5 mm long by 13.0 ± 0.5 mm wide, and provided in the minimum thickness and in the 3.0 (−0.0 +0.2) mm thickness. The 3.0 mm thick specimens are not necessary if the minimum thickness is greater than 3.0 mm, or the maximum thickness is less than 3.0 mm. The maximum thickness shall not exceed 13 mm. The maximum width shall not exceed 13.5 mm. The edges shall be smooth, and the radius on the corners shall not exceed 1.3 mm.

7.3 It is possible that the results of tests carried out on test specimens of different colors, thicknesses, densities, molecular

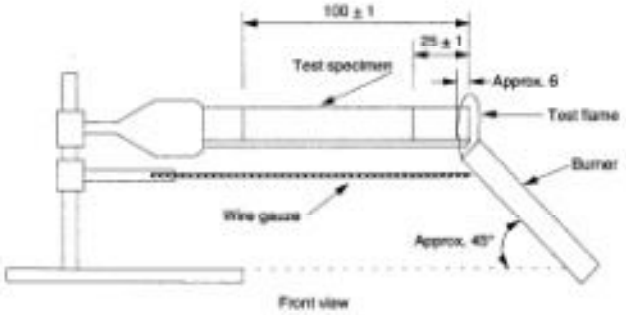


FIG. 1 Test Fixture

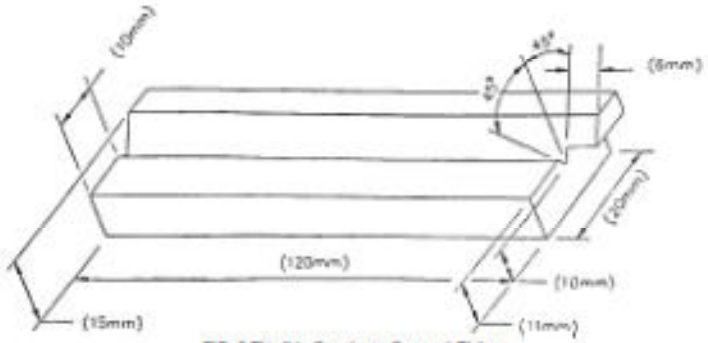


FIG. 2 Flexible Specimen Support Fixture

masses, directions of anisotropy and types, or with different additives, fillers/reinforcements will be different.

7.3.1 Test specimens in the minimum and maximum densities, melt flows and level of fillers/reinforcements contents shall be considered representative of the range, if the results yield the same flame test classification. If the burning characteristics are not essentially the same for all specimens representing the range, the evaluation is to be limited only to the materials in the densities, melt flows, and fillers/reinforcements contents tested. Additional specimens in the intermediate densities, melt flows, and fillers/reinforcements contents are to be tested.

7.3.2 Uncolored test specimens and test specimens with the highest level of organic and inorganic pigment loading by weight are considered representative of the color range, if the test results are essentially the same. When certain pigments are known to affect flammability characteristics, they are also to be tested. Specimens to be tested are those that:

(a) contain no coloring
(b) contain the highest level of organic pigments
(c) contain the highest level of inorganic pigments
(d) contain pigments which are known to adversely affect flammability characteristics

8. Conditioning

8.1 Condition ten bar specimens for each material and thickness to be tested in accordance with Procedure A of Practice D618 for a minimum of 48 hours. Once removed from the conditioning atmosphere test the specimens within 1 h. Temperature and humidity tolerances shall be in accordance with Section 7 of Practice D618.

8.2 Conduct testing in a laboratory atmosphere of 15 to 35°C and 45 to 75 % relative humidity.

9. Procedure

9.1 Prepare at least ten bar specimens. After measuring and recording the specimen thickness, mark each specimen with two lines perpendicular to the longitudinal axis of the bar, 25 ± 1 and 100 ± 1 mm from the end that is to be ignited.

9.2 Conduct the burning test in a chamber, enclosure, or laboratory hood free of induced or forced draft. (**Warning**—Products of combustion may be toxic. An enclosed laboratory hood and an exhaust fan for removing the products of combustion after the tests are recommended. The exhaust fan is turned off during the test and turned on immediately following the test in order to remove products of combustion.)

9.3 Clamp the specimen at the end farthest from the 25 mm reference mark, in a support with its longitudinal axis horizontal and its transverse axis inclined at 45 ± 2° as illustrated in Fig. 1. Clamp the wire gauze horizontally beneath the specimen, with a distance of 10 ± 1 mm between the lowest edge of the specimen and the wire gauze, and with the free end of the specimen even with the edge of the gauze. Any material remaining on the wire gauze from the previous test must be burned off or a new section of wire gauze used for each test.

9.4 If the specimen sags at its free end during the initial set up and is not able to maintain the distance of 10 ± 1 mm as specified in 9.2, the flexible specimen support fixture illustrated in Fig. 2 shall be used. Position the support fixture under the specimen with the small extending portion of the support fixture at least 20 mm from the free end of the specimen. Provide enough clearance at the clamped end of the specimen so that the support fixture can be moved freely sidewards. As the flame front progresses along the specimen, withdraw the support fixture at the same approximate rate, preventing the flame front from contacting the flexible specimen support fixture, so that there is no effect on the test flame or on the burning of the specimen.

9.5 With the central axis of the burner tube in the vertical position, place the burner remote from the specimen, ignite, and adjust it to produce a blue flame 20 mm high. Adjust the gas supply and the air ports of the burner until a 20-mm yellow-tipped blue flame is produced, and then increase the air supply until the yellow tip just disappears. Measure the height of the flame. If the flame height is not 20 ± 2 mm, adjust the burner gas supply to give the proper flame height. Once the flame has been properly set to a height of 20 ± 2 mm wait for at least 5 min to allow the burner conditions to reach equilibrium.

NOTE 7—See Practice D5207 for recommended back pressure and flow rate for the gas supply and calibration procedure for the 20 mm flame.

9.6 Place the burner so that the test flame impinges on the free end of the test specimen to a depth of approximately 6 mm starting the timing device simultaneously. The central axis of the burner tube is to be in the same vertical plane as the longitudinal bottom edge of the specimen and inclined toward the end of the specimen at an angle of approximately 45 ± 2 degrees to the horizontal. See Fig. 1. Apply the flame for 30 ± 1 s without changing its position. If the test specimen shrinks from the applied flame without ignition, the material is not suitable for evaluation by these test methods. Excessive distortion of the specimen during the test will invalidate the results. Withdraw the test flame sufficiently from the specimen (see Note 8) so that there is no effect on the specimen after 30 ± 1 s or as soon as the flame front of the specimen reaches the 25 mm mark (if less than 30 s). Restart the timing device when the flame front reaches the 25 mm reference mark.

NOTE 8—Withdrawing the burner a distance of 150 mm from the specimen has been found satisfactory.

9.7 If the specimen continues to burn, with a flame or glowing combustion (visible glow without flame), after removal of the test flame, record the elapsed time (t), in seconds, for the flame front to travel from the 25 mm reference mark to the 100 mm reference mark and record the burned length (L), as 75 mm. If the flame front passes the 25 mm reference mark but does not reach the 100 mm reference mark, record the elapsed time (t), in seconds, and the burned length (L), in millimetres between the 25 mm reference mark and where the flame front stopped.

9.8 Repeat the test procedure (9.1-9.7) until three specimens have burned to or beyond the 100 mm reference mark, or ten specimens have been tested.

NOTE 9—For classification purposes, if only one specimen does not comply with the criteria, test an additional set of specimens. See X1.3.

10. Calculation

10.1 Calculate the linear burning rate (V), in millimetres per minute, for each specimen where the flame front reaches the 100 mm reference mark using the equation:

$$V = 60L/t$$

where:

L = the burned length, in millimetres, as defined in 9.7; and

t = the time, in seconds, as defined in 9.7.

NOTE 10—If the flame front reached the 100-mm reference mark, $L = 75$.

NOTE 11—The SI units of the linear burning rate is metre per second. In practice, the unit millimetre per minute is used.

NOTE 12—It is acceptable to report the results in cm/min by using the method prescribed in 10.1 and then dividing the obtained rate by ten.

10.2 Calculate the average linear burning rate or classify the material in accordance with the appendix.

TABLE 1 Average Linear Burning Rate for Specimens Tested Without Flexible Specimen Support Fixture

Material	Nominal Specimen Thickness, mm	Rate of Linear Burning, mm/min: Average	S_r[A]	S_R[B]	r[C]	R[D]
Polyethylene (PE)	3.0	15.2	0.7	1.3	1.9	3.7
ABS	3.2	27.9	2.1	4.1	5.7	11.5
Acrylic	3.0	29.7	1.7	2.2	4.8	6.1

[A] S_r is the within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations of the test results from all of the participating laboratories:

$$S_r = [(s_1)^2 + (s_2)^2 \ldots + (s_n)^2 / n]^{1/2}$$

[B] S_R is the between-laboratories reproducibility, expressed as stated deviation:

$$S_R = [S_r^2 + S_L^2]^{1/2}$$

where: S_L = the standard deviation of laboratory means.
[C] r is the within-laboratory critical interval between two test results = $2.8 \times S_r$.
[D] R is the between-laboratories critical interval between two test results = $2.8 \times S_R$.

11. Report

11.1 Include the following in the complete report:

11.1.1 *Material Identification*—Include generic description, manufacturer, commercial designation, lot number, and color.

11.1.2 The thickness, as measured with a micrometer to the nearest 0.1 mm, of the test specimen.

11.1.3 The nominal apparent density (rigid cellular materials only).

11.1.4 The direction of any anisotropy relative to the test specimen dimensions.

11.1.5 Conditioning treatment.

11.1.6 Any prior treatment before testing, other than cutting, trimming and conditioning.

11.1.7 Whether or not the specimen continued to burn (with or without visible flame) after application of test flame.

11.1.8 Whether or not the flame front reached the 25 and 100 mm reference marks.

11.1.9 For specimens with which the flame front does not reach or pass the 25 mm reference mark, a statement that indicates the flame front did not reach or pass the 25 mm reference mark. Do not report an elapsed time (t) and burned length (L).

11.1.10 For specimens with which the flame front passed the 25 mm reference mark but did not reach the 100 mm reference mark, the elapsed time (t) and burned length (L).

11.1.11 If a specimen does not burn to the 100 mm mark because of dripping, flowing, or falling burning particles, the report must so indicate.

11.1.12 If a specimen is reignited by burning material on the gauze, the report must so state.

11.1.13 For specimens with which the flame front reached the 100 mm reference mark, the average linear burning rate, (V).

11.1.14 Whether the flexible specimen support fixture was used.

11.1.15 The caveat contained in 1.5 herein shall be incorporated in its entirety in the test report issued.

11.1.16 *Optional*—Flame classification as determined from the appendix.

12. Precision and Bias

12.1 Table 1 is based on a round robin completed in 1987[4] in accordance with Practice E691, involving three self-supporting materials tested by eleven laboratories. Each laboratory conditioned, at 23°C and 50 % relative humidity, the specimens that it tested. Each laboratory conducted the tests in a laboratory hood with the hood exhaust essentially turned off. All three materials were classified by the test as possessing an average burning rate. Each test result consisted of an average linear burning rate determined from three specimens. Each laboratory obtained three test results for each material.

12.2 Table 2 is based on a round robin completed in 1986[5] in accordance with Practice 691, involving four materials that required use of the flexible specimen support fixture and tested by six different laboratories. For each material, all samples were provided by one source. The individual specimens were cut and distributed by one laboratory. Each laboratory conditioned, at 23°C and 50 % relative humidity, the specimens that it tested. Each test result consisted of an average linear burning rate determined from three specimens. Each laboratory obtained two average linear burning rates from a total six individual specimen test results for each material.

12.3 This test method does not contain a numerical precision and bias statement for the time of burning and extent of burning for specimens where the flame front passes the 25-mm reference mark, but does not reach the 100-mm reference mark, and therefore shall not be used as a referee test method for these two characteristics in case of dispute. Due to the rarity of materials which consistently produce this result, a numerical precision and bias statement for this type of test result is not being actively pursued at this time. (**Warning**—The explanations of "r" and "R" given in 12.4-12.4.3 are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Tables 1 and 2 shall

[4] Supporting data for Table 1 are available from ASTM Headquarters. Request RR:D20-1149.
[5] Supporting data for Table 2 are available from ASTM Headquarters. Request RR:D20-1146.

TABLE 2 Average Linear Burning Rate for Specimens Tested With Flexible Specimen Support Fixture

Material	Nominal Specimen Thickness, mm	Rate of Linear Burning, mm/min				
		Average	S_r[A]	S_R[B]	r[C]	R[D]
Polyurethane (PUR)	1.3	41.6	1.0	[E]	2.9	[E]
Polyurethane (PUR)	0.8	60.9	10.9	14.4	30.6	40.4
Polyurethane (PUR)	0.4	82.3	10.6	26.6	29.8	74.4
Polyethylene terephthalate (PET)	0.1	102.0	32.2	[E]	123.7	[E]

[A] S_r = within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations of the test results from all of the participating laboratories, as follows:

$$S_r = [(s_1)^2 + (s_2)^2 \ldots + (s_n)^2/n]^{1/2}$$

[B] S_R = between-laboratories reproducibility, expressed as stated deviation, as follows:

$$S_R = [S_L^2 + S_r^2]^{1/2}$$

where S_L = the standard deviation of laboratory means.
[C] r = within-laboratory critical interval between two test results = $2.8 \times S_r$.
[D] R = between-laboratories critical interval between two test results = $2.8 \times S_R$.
[E] The number of laboratories in the interlaboratory study reporting a linear burning rate was too small to establish a between-laboratory standard deviation.

not be rigorously applied to acceptance or rejection of material, as these data apply only to the materials tested in the round robin and are unlikely to be rigorously representative of other lots, formulations, conditions, materials or laboratories. Users of this test method shall apply the principles outlined in Practice E691 to generate data specific to their materials and laboratory (or between specific laboratories). The principles of 12.4-12.4.3 would then be valid for such data.)

12.4 *Concept of "r" and "R"*—If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing three specimens for each test result, then:

12.4.1 *Repeatability, r*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "r" value for the material. "r" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

12.4.2 *Reproducibility, R*—Two test results obtained from different laboratories shall be judged not equivalent if they differ by more than the "R" value for the material. "R" is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

12.4.3 Judgments in accordance with 12.4.1 and 12.4.2 have an approximate 95 % (0.95) probability of being correct.

12.5 *Bias*—There are no recognized standards on which to base an estimate of bias for this test method.

13. Keywords

13.1 burning characteristics; combustion; extent of burning; flammability; HB; horizontal burning rate; plastics; rate of burning; small-scale burning test burning; time of burning

APPENDIXES

(Nonmandatory Information)

X1. CLASSIFICATION SYSTEM FOR DETERMINING THE RELATIVE LINEAR RATE OF BURNING AND/OR EXTENT AND TIME OF BURNING OF PLASTICS

X1.1 General

X1.1.1 This appendix covers a classification system for characterizing the burning behavior of plastic materials, supported in a horizontal position, in response to a small-flame ignition source. The use of a category designation code is optional and is determined by examining the test results of materials tested by this method. Each category code represents a preferred range of performance levels that simplifies description in material designations or specifications and may assist certification bodies to determine compliance with applicable requirements.

X1.2 *Category Designation*—The behavior of specimens shall be classified HB (HB = horizontal burning) if,

X1.2.1 There are no visible signs of combustion after the ignition source is removed, or

X1.2.2 The flame front does not pass the 25 mm reference mark, or

X1.2.3 The flame front passes the 25 mm reference mark but does not reach the 100 mm reference mark, or

X1.2.4 The flame front reaches the 100 mm reference mark and the linear burning rate does not exceed 40 mm/min for

specimens having a thickness between 3 and 13 mm or 75 mm/min for specimens having a thickness less than 3 mm.

X1.3 If only one specimen from the first set of specimens does not comply with the criteria indicated, another set of specimens is to be tested. All specimens from this second set shall comply with the criteria indicated in order for the material, of that thickness, to be classified as HB.

X1.4 If the linear burning rate does not exceed 40 mm/min when tested in the 3.0 mm ± 0.2 mm thickness, the HB category designation shall be extended to a 1.5 mm minimum thickness.

X1.5 Recording the category designation in the test report is optional.

X2. IBC REFERENCE TO TEST METHOD D635

INTRODUCTION

In the *International Building Code* (2003 Edition), this test method is referenced in section 2606.4 for LIGHT-TRANSMITTING PLASTICS. Classifications are established based on the extent of burning using this test method. The IBC states as follows:

X2.1 **2606.4 Specifications** Light-transmitting plastics, including thermoplastic, thermosetting or reinforced thermosetting plastic material, shall have a self-ignition temperature of 650°F [343°C] or greater where tested in accordance with Test Method D1929; a smoke-developed index not greater than 450 where tested in the manner intended for use in accordance with Test Method E84, or not greater than 75 where tested in the thickness intended for use in accordance with Test Method D2843 and shall conform to one of the following combustibility classifications:

X2.1.1 *Class CC1:* Plastic materials that have a burning extent of 1 in. [25 mm] or less where tested at a nominal thickness of 0.060 in. [1.5 mm], or in the thickness intended for use, in accordance with this test method,

X2.1.2 *Class CC2:* Plastic materials that have a burning rate of 2.5 inches per minute [1.06 mm/s] or less where tested at a nominal thickness of 0.060 in. [1.5 mm], or in the thickness intended for use, in accordance with this test method.

X2.2 The classification scheme shown above is limited within the *International Building Code* to light-transmitting plastics only. It is not applicable to plastics used in other construction applications. In addition, the flammability requirements given here are not the only requirements for light-transmitting plastics.

X2.3 Test Method D2843 reports values as a Smoke Density Rating.

X2.4 These classifications are not part of this test method and are not under the jurisdiction of ASTM committee D20. However, they are in common usage and are presented here for information only.

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue, D635 - 06, that may impact the use of this standard. (July 1, 2010)

(1) Revised 8.1 for consistency with Practice D618.

ANEXO No. 4: ASTM D638 – 10: Standard Test Method for Tensile Properties of Plastics

Designation: D638 – 10

Standard Test Method for Tensile Properties of Plastics[1]

This standard is issued under the fixed designation D638; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This test method covers the determination of the tensile properties of unreinforced and reinforced plastics in the form of standard dumbbell-shaped test specimens when tested under defined conditions of pretreatment, temperature, humidity, and testing machine speed.

1.2 This test method can be used for testing materials of any thickness up to 14 mm (0.55 in.). However, for testing specimens in the form of thin sheeting, including film less than 1.0 mm (0.04 in.) in thickness, Test Methods D882 is the preferred test method. Materials with a thickness greater than 14 mm (0.55 in.) must be reduced by machining.

1.3 This test method includes the option of determining Poisson's ratio at room temperature.

NOTE 1—This test method and ISO 527-1 are technically equivalent.

NOTE 2—This test method is not intended to cover precise physical procedures. It is recognized that the constant rate of crosshead movement type of test leaves much to be desired from a theoretical standpoint, that wide differences may exist between rate of crosshead movement and rate of strain between gage marks on the specimen, and that the testing speeds specified disguise important effects characteristic of materials in the plastic state. Further, it is realized that variations in the thicknesses of test specimens, which are permitted by these procedures, produce variations in the surface-volume ratios of such specimens, and that these variations may influence the test results. Hence, where directly comparable results are desired, all samples should be of equal thickness. Special additional tests should be used where more precise physical data are needed.

NOTE 3—This test method may be used for testing phenolic molded resin or laminated materials. However, where these materials are used as electrical insulation, such materials should be tested in accordance with Test Methods D229 and Test Method D651.

NOTE 4—For tensile properties of resin-matrix composites reinforced with oriented continuous or discontinuous high modulus >20-GPa (>3.0 × 10^6-psi) fibers, tests shall be made in accordance with Test Method D3039/D3039M.

1.4 Test data obtained by this test method are relevant and appropriate for use in engineering design.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D229 Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation

D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension

D618 Practice for Conditioning Plastics for Testing

D651 Test Method for Test for Tensile Strength of Molded Electrical Insulating Materials (Withdrawn 1989)[3]

D882 Test Method for Tensile Properties of Thin Plastic Sheeting

D883 Terminology Relating to Plastics

D1822 Test Method for Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials

D3039/D3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials

D4000 Classification System for Specifying Plastic Materials

D4066 Classification System for Nylon Injection and Extrusion Materials (PA) (Withdrawn 2012)[3]

D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

E4 Practices for Force Verification of Testing Machines

E83 Practice for Verification and Classification of Extensometer Systems

E132 Test Method for Poisson's Ratio at Room Temperature

E691 Practice for Conducting an Interlaboratory Study to

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.
Current edition approved May 15, 2010. Published June 2010. Originally approved in 1941. Last previous edition approved in 2008 as D638 - 08. DOI: 10.1520/D0638-10.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

*A Summary of Changes section appears at the end of this standard

Determine the Precision of a Test Method
2.2 *ISO Standard:*[4]
ISO 527-1 Determination of Tensile Properties

3. Terminology

3.1 *Definitions*—Definitions of terms applying to this test method appear in Terminology D883 and Annex A2.

4. Significance and Use

4.1 This test method is designed to produce tensile property data for the control and specification of plastic materials. These data are also useful for qualitative characterization and for research and development. For many materials, there may be a specification that requires the use of this test method, but with some procedural modifications that take precedence when adhering to the specification. Therefore, it is advisable to refer to that material specification before using this test method. Table 1 in Classification D4000 lists the ASTM materials standards that currently exist.

4.2 Tensile properties may vary with specimen preparation and with speed and environment of testing. Consequently, where precise comparative results are desired, these factors must be carefully controlled.

4.2.1 It is realized that a material cannot be tested without also testing the method of preparation of that material. Hence, when comparative tests of materials per se are desired, the greatest care must be exercised to ensure that all samples are prepared in exactly the same way, unless the test is to include the effects of sample preparation. Similarly, for referee purposes or comparisons within any given series of specimens, care must be taken to secure the maximum degree of uniformity in details of preparation, treatment, and handling.

4.3 Tensile properties may provide useful data for plastics engineering design purposes. However, because of the high degree of sensitivity exhibited by many plastics to rate of straining and environmental conditions, data obtained by this test method cannot be considered valid for applications involving load-time scales or environments widely different from those of this test method. In cases of such dissimilarity, no reliable estimation of the limit of usefulness can be made for most plastics. This sensitivity to rate of straining and environment necessitates testing over a broad load-time scale (including impact and creep) and range of environmental conditions if tensile properties are to suffice for engineering design purposes.

NOTE 5—Since the existence of a true elastic limit in plastics (as in many other organic materials and in many metals) is debatable, the propriety of applying the term "elastic modulus" in its quoted, generally accepted definition to describe the "stiffness" or "rigidity" of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are highly dependent on such factors as rate of application of stress, temperature, previous history of specimen, etc. However, stress-strain curves for plastics, determined as described in this test method, almost always show a linear region at low stresses, and a straight line drawn tangent to this portion of the curve permits calculation of an elastic modulus of the usually defined type. Such a constant is useful if its arbitrary nature and dependence on time, temperature, and similar factors are realized.

5. Apparatus

5.1 *Testing Machine*—A testing machine of the constant-rate-of-crosshead-movement type and comprising essentially the following:

5.1.1 *Fixed Member*—A fixed or essentially stationary member carrying one grip.

5.1.2 *Movable Member*—A movable member carrying a second grip.

5.1.3 *Grips*—Grips for holding the test specimen between the fixed member and the movable member of the testing machine can be either the fixed or self-aligning type.

5.1.3.1 Fixed grips are rigidly attached to the fixed and movable members of the testing machine. When this type of grip is used extreme care should be taken to ensure that the test specimen is inserted and clamped so that the long axis of the test specimen coincides with the direction of pull through the center line of the grip assembly.

5.1.3.2 Self-aligning grips are attached to the fixed and movable members of the testing machine in such a manner that they will move freely into alignment as soon as any load is applied so that the long axis of the test specimen will coincide with the direction of the applied pull through the center line of the grip assembly. The specimens should be aligned as perfectly as possible with the direction of pull so that no rotary motion that may induce slippage will occur in the grips; there is a limit to the amount of misalignment self-aligning grips will accommodate.

5.1.3.3 The test specimen shall be held in such a way that slippage relative to the grips is prevented insofar as possible. Grip surfaces that are deeply scored or serrated with a pattern similar to those of a coarse single-cut file, serrations about 2.4 mm (0.09 in.) apart and about 1.6 mm (0.06 in.) deep, have been found satisfactory for most thermoplastics. Finer serrations have been found to be more satisfactory for harder plastics, such as the thermosetting materials. The serrations should be kept clean and sharp. Breaking in the grips may occur at times, even when deep serrations or abraded specimen surfaces are used; other techniques must be used in these cases. Other techniques that have been found useful, particularly with smooth-faced grips, are abrading that portion of the surface of the specimen that will be in the grips, and interposing thin pieces of abrasive cloth, abrasive paper, or plastic, or rubber-coated fabric, commonly called hospital sheeting, between the specimen and the grip surface. No. 80 double-sided abrasive paper has been found effective in many cases. An open-mesh fabric, in which the threads are coated with abrasive, has also been effective. Reducing the cross-sectional area of the specimen may also be effective. The use of special types of grips is sometimes necessary to eliminate slippage and breakage in the grips.

5.1.4 *Drive Mechanism*—A drive mechanism for imparting to the movable member a uniform, controlled velocity with respect to the stationary member, with this velocity to be regulated as specified in Section 8.

5.1.5 *Load Indicator*—A suitable load-indicating mechanism capable of showing the total tensile load carried by the

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

test specimen when held by the grips. This mechanism shall be essentially free of inertia lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the indicated value, or better. The accuracy of the testing machine shall be verified in accordance with Practices E4.

NOTE 6—Experience has shown that many testing machines now in use are incapable of maintaining accuracy for as long as the periods between inspection recommended in Practices E4. Hence, it is recommended that each machine be studied individually and verified as often as may be found necessary. It frequently will be necessary to perform this function daily.

5.1.6 The fixed member, movable member, drive mechanism, and grips shall be constructed of such materials and in such proportions that the total elastic longitudinal strain of the system constituted by these parts does not exceed 1 % of the total longitudinal strain between the two gage marks on the test specimen at any time during the test and at any load up to the rated capacity of the machine.

5.1.7 *Crosshead Extension Indicator*—A suitable extension indicating mechanism capable of showing the amount of change in the separation of the grips, that is, crosshead movement. This mechanism shall be essentially free of inertial lag at the specified rate of testing and shall indicate the crosshead movement with an accuracy of ±10 % of the indicated value.

5.2 *Extension Indicator* (extensometer)—A suitable instrument shall be used for determining the distance between two designated points within the gage length of the test specimen as the specimen is stretched. For referee purposes, the extensometer must be set at the full gage length of the specimen, as shown in Fig. 1. It is desirable, but not essential, that this instrument automatically record this distance, or any change in it, as a function of the load on the test specimen or of the elapsed time from the start of the test, or both. If only the latter is obtained, load-time data must also be taken. This instrument shall be essentially free of inertia at the specified speed of testing. Extensometers shall be classified and their calibration periodically verified in accordance with Practice E83.

5.2.1 *Modulus-of-Elasticity Measurements*—For modulus-of-elasticity measurements, an extensometer with a maximum strain error of 0.0002 mm/mm (in./in.) that automatically and continuously records shall be used. An extensometer classified by Practice E83 as fulfilling the requirements of a B-2 classification within the range of use for modulus measurements meets this requirement.

5.2.2 *Low-Extension Measurements*—For elongation-at-yield and low-extension measurements (nominally 20 % or less), the same above extensometer, attenuated to 20 % extension, may be used. In any case, the extensometer system must meet at least Class C (Practice E83) requirements, which include a fixed strain error of 0.001 strain or ±1.0 % of the indicated strain, whichever is greater.

5.2.3 *High-Extension Measurements*—For making measurements at elongations greater than 20 %, measuring techniques with error no greater than ±10 % of the measured value are acceptable.

5.3 *Micrometers*—Apparatus for measuring the width and thickness of the test specimen shall comply with the requirements of Test Method D5947.

6. Test Specimens

6.1 *Sheet, Plate, and Molded Plastics:*

6.1.1 *Rigid and Semirigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type I specimen is the preferred specimen and shall be used where sufficient material having a thickness of 7 mm (0.28 in.) or less is available. The Type II specimen may be used when a material does not break in the narrow section with the preferred Type I specimen. The Type V specimen shall be used where only limited material having a thickness of 4 mm (0.16 in.) or less is available for evaluation, or where a large number of specimens are to be exposed in a limited space (thermal and environmental stability tests, etc.). The Type IV specimen should be used when direct comparisons are required between materials in different rigidity cases (that is, nonrigid and semirigid). The Type III specimen must be used for all materials with a thickness of greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.).

6.1.2 *Nonrigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type IV specimen shall be used for testing nonrigid plastics with a thickness of 4 mm (0.16 in.) or less. The Type III specimen must be used for all materials with a thickness greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.).

6.1.3 *Reinforced Composites*—The test specimen for reinforced composites, including highly orthotropic laminates, shall conform to the dimensions of the Type I specimen shown in Fig. 1.

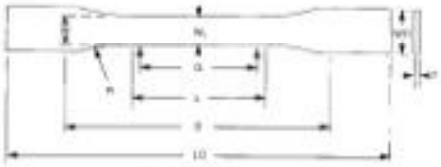
6.1.4 *Preparation*—Test specimens shall be prepared by machining operations, or die cutting, from materials in sheet, plate, slab, or similar form. Materials thicker than 14 mm (0.55 in.) must be machined to 14 mm (0.55 in.) for use as Type III specimens. Specimens can also be prepared by molding the material to be tested.

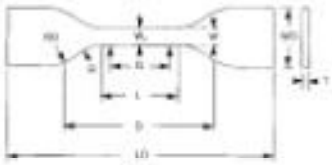
NOTE 7—Test results have shown that for some materials such as glass cloth, SMC, and BMC laminates, other specimen types should be considered to ensure breakage within the gage length of the specimen, as mandated by 7.3.

NOTE 8—When preparing specimens from certain composite laminates such as woven roving, or glass cloth, care must be exercised in cutting the specimens parallel to the reinforcement. The reinforcement will be significantly weakened by cutting on a bias, resulting in lower laminate properties, unless testing of specimens in a direction other than parallel with the reinforcement constitutes a variable being studied.

NOTE 9—Specimens prepared by injection molding may have different tensile properties than specimens prepared by machining or die-cutting because of the orientation induced. This effect may be more pronounced in specimens with narrow sections.

6.2 *Rigid Tubes*—The test specimen for rigid tubes shall be as shown in Fig. 2. The length, *L*, shall be as shown in the table in Fig. 2. A groove shall be machined around the outside of the specimen at the center of its length so that the wall section after machining shall be 60 % of the original nominal wall thickness. This groove shall consist of a straight section 57.2 mm (2.25 in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter. Steel or brass plugs having





Specimen Dimensions for Thickness, *T*, mm [in.][A]

Dimensions (see drawings)	*T* (0.28) or under		Over *T* to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 [0.50]	6 [0.25]	19 [0.75]	6 [0.25]	3.18 [0.125]	±0.5 [±0.02][E,G]
L—Length of narrow section	57 [2.25]	57 [2.25]	57 [2.25]	33 [1.30]	9.53 [0.375]	±0.5 [±0.02][G]
WO—Width overall, min[H]	19 [0.75]	19 [0.75]	29 [1.13]	19 [0.75]	...	+ 6.4 [+ 0.25]
WO—Width overall, min[H]	...	...	...	...	9.53 [0.375]	+ 3.18 [+ 0.125]
LO—Length overall, min[H]	165 [6.5]	183 [7.2]	246 [9.7]	115 [4.5]	63.5 [2.5]	no max [no max]
G—Gage length[I]	50 [2.00]	50 [2.00]	50 [2.00]	...	7.62 [0.300]	±0.25 [±0.010][G]
G—Gage length[I]	...	...	...	25 [1.00]	...	±0.13 [±0.005]
D—Distance between grips	115 [4.5]	135 [5.5]	115 [4.5]	65 [2.5][J]	25.4 [1.0]	±5 [±0.2]
R—Radius of fillet	76 [3.00]	76 [3.00]	76 [3.00]	14 [0.56]	12.7 [0.5]	±1 [±0.04][G]
RO—Outer radius (Type IV)	...	...	...	25 [1.00]	...	±1 [±0.04]

[A] Thickness, *T*, shall be 3.2 ± 0.4 mm [0.13 ± 0.02 in.] for all types of molded specimens, and for other Types I and II specimens where possible. If specimens are machined from sheets or plates, thickness, *T*, may be the thickness of the sheet or plate provided this does not exceed the range stated for the intended specimen type. For sheets of nominal thickness greater than 14 mm [0.55 in.] the specimens shall be machined to 14 ± 0.4 mm [0.55 ± 0.02 in.] in thickness, for use with the Type III specimen. For sheets of nominal thickness between 14 and 51 mm [0.55 and 2 in.] approximately equal amounts shall be machined from each surface. For thicker sheets both surfaces of the specimen shall be machined, and the location of the specimen with reference to the original thickness of the sheet shall be noted. Tolerances on thickness less than 14 mm [0.55 in.] shall be those standard for the grade of material tested.

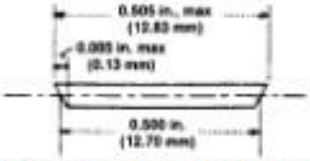
[B] For the Type IV specimen, the internal width of the narrow section of the die shall be 6.00 ± 0.05 mm [0.250 ± 0.002 in.]. The dimensions are essentially those of Die C in Test Methods D412.

[C] The Type V specimen shall be machined or die cut to the dimensions shown, or molded in a mold whose cavity has these dimensions. The dimensions shall be:
W = 3.18 ± 0.05 mm [0.125 ± 0.001 in.],
L = 9.53 ± 0.05 mm [0.375 ± 0.003 in.],
G = 7.62 ± 0.02 mm [0.300 ± 0.001 in.], and
R = 12.7 ± 0.05 mm [0.500 ± 0.003 in.].
The other tolerances are those in the table.

[D] Supporting data on the introduction of the L specimen of Test Method D1822 as the Type V specimen are available from ASTM Headquarters. Request RR:D20-1008.

[E] The width at the center *W*, shall be +0.00 mm, −0.10 mm [+0.000 in., −0.004 in.] compared with width *W* at other parts of the reduced section. Any reduction in *W* at the center shall be gradual, equally on each side so that no abrupt changes in dimension result.

[F] For molded specimens, a draft of not over 0.13 mm [0.005 in.] may be allowed for either Type I or II specimens 3.2 mm [0.13 in.] in thickness, and this should be taken into account when calculating width of the specimen. Thus a typical section of a molded Type I specimen, having the maximum allowable draft, could be as follows:



[G] Overall widths greater than the minimum indicated may be desirable for some materials in order to avoid breaking in the grips.

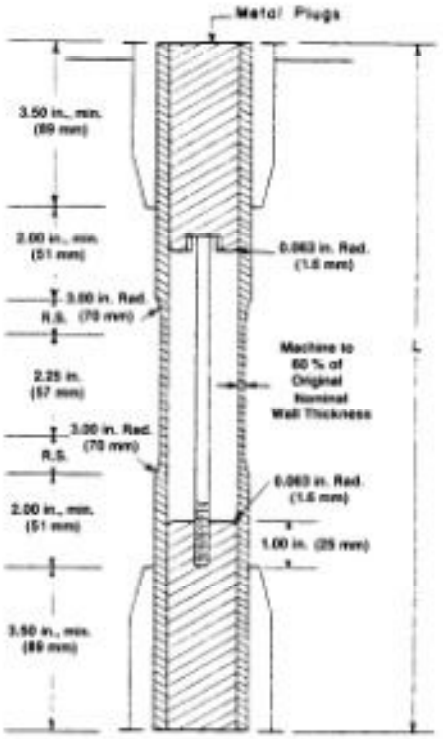
[H] Overall lengths greater than the minimum indicated may be desirable either to avoid breaking in the grips or to satisfy special test requirements.

[I] Test marks or initial extensometer span.

[J] When self-tightening grips are used, for highly extensible polymers, the distance between grips will depend upon the types of grips used and may not be critical if maintained uniform once chosen.

FIG. 1 Tension Test Specimens for Sheet, Plate, and Molded Plastics

diameters such that they will fit snugly inside the tube and having a length equal to the full jaw length plus 25 mm (1 in.) shall be placed in the ends of the specimens to prevent crushing. They can be located conveniently in the tube by separating and supporting them on a threaded metal rod. Details of plugs and test assembly are shown in Fig. 2.

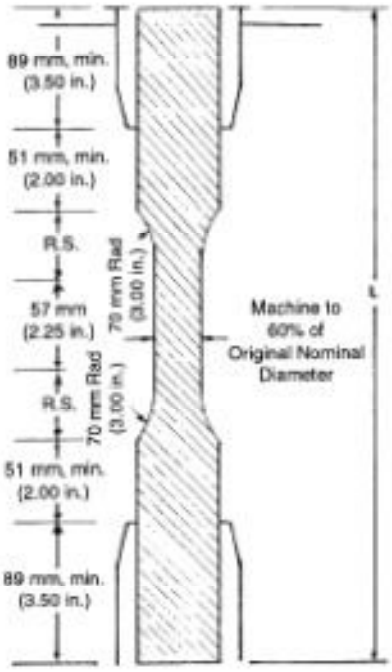


DIMENSIONS OF TUBE SPECIMENS

Nominal Wall Thickness	Length of Radial Sections, ±0.5	Total Calculated Minimum Length of Specimen	Standard Length, L, of Specimen to Be Used for 89-mm (3.5-in.) Jaws[A]
mm (in.)			
0.79 (1/32)	13.9 (0.547)	350 (13.80)	381 (15)
1.2 (3/64)	17.0 (0.670)	354 (13.92)	381 (15)
1.6 (1/16)	19.6 (0.773)	356 (14.02)	381 (15)
2.4 (3/32)	24.0 (0.946)	361 (14.20)	381 (15)
3.2 (1/8)	27.7 (1.091)	364 (14.34)	381 (15)
4.8 (3/16)	33.9 (1.333)	370 (14.58)	381 (15)
6.4 (1/4)	39.0 (1.536)	376 (14.79)	400 (15.75)
7.9 (5/16)	43.5 (1.714)	380 (14.96)	400 (15.75)
9.5 (3/8)	47.6 (1.873)	384 (15.12)	400 (15.75)
11.1 (7/16)	51.3 (2.019)	388 (15.27)	400 (15.75)
12.7 (1/2)	54.7 (2.154)	391 (15.40)	419 (16.5)

[A] For other jaws greater than 89 mm (3.5 in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (0.25 to 0.50 in.) in each jaw while maintaining the maximum length of the jaw grip.

FIG. 2 Diagram Showing Location of Tube Tension Test Specimens in Testing Machine



DIMENSIONS OF ROD SPECIMENS

Nominal Diameter	Length of Radial Sections, ±0.5	Total Calculated Minimum Length of Specimen	Standard Length, L, of Specimen to Be Used for 89-mm (3½-in.) Jaws[A]
mm (in.)			
3.2 (1/8)	19.6 (0.775)	356 (14.02)	381 (15)
4.7 (3/16)	24.0 (0.946)	361 (14.20)	381 (15)
6.4 (1/4)	27.7 (1.091)	364 (14.34)	381 (15)
8.5 (5/16)	33.9 (1.333)	370 (14.58)	381 (15)
12.7 (1/2)	39.0 (1.536)	376 (14.79)	400 (15.75)
15.9 (5/8)	43.5 (1.714)	380 (14.96)	400 (15.75)
19.0 (3/4)	47.6 (1.873)	384 (15.12)	400 (15.75)
22.2 (7/8)	51.3 (2.019)	388 (15.27)	400 (15.75)
25.4 (1)	54.7 (2.154)	391 (15.40)	419 (16.5)
31.8 (1¼)	60.9 (2.398)	398 (15.65)	419 (16.5)
38.1 (1½)	66.4 (2.615)	403 (15.87)	419 (16.5)
44.5 (1¾)	71.4 (2.812)	408 (16.06)	419 (16.5)
50.8 (2)	76.0 (2.990)	412 (16.24)	432 (17)

[A] For other jaws greater than 89 mm (3.5 in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (0.25 to 0.50 in.) in each jaw while maintaining the maximum length of the jaw grip.

FIG. 3 Diagram Showing Location of Rod Tension Test Specimen in Testing Machine

6.3 *Rigid Rods*—The test specimen for rigid rods shall be as shown in Fig. 3. The length, *L*, shall be as shown in the table in Fig. 3. A groove shall be machined around the specimen at the center of its length so that the diameter of the machined portion shall be 60 % of the original nominal diameter. This groove shall consist of a straight section 57.2 mm (2.25 in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter.

6.4 All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine file or abrasive, and the filed surfaces shall then be smoothed with abrasive paper (No. 00 or finer). The finishing sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not to disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shown in Fig. 1 shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors.

6.5 If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon or India ink that will not affect the material being tested. Gage marks shall not be scratched, punched, or impressed on the specimen.

6.6 When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.

7. Number of Test Specimens

7.1 Test at least five specimens for each sample in the case of isotropic materials.

7.2 Test ten specimens, five normal to, and five parallel with, the principle axis of anisotropy, for each sample in the case of anisotropic materials.

7.3 Discard specimens that break at some flaw, or that break outside of the narrow cross-sectional test section (Fig. 1, dimension "L"), and make retests, unless such flaws constitute a variable to be studied.

NOTE 10—Before testing, all transparent specimens should be inspected in a polariscope. Those which show atypical or concentrated strain patterns should be rejected, unless the effects of these residual strains constitute a variable to be studied.

8. Speed of Testing

8.1 Speed of testing shall be the relative rate of motion of the grips or test fixtures during the test. The rate of motion of the driven grip or fixture when the testing machine is running idle may be used, if it can be shown that the resulting speed of testing is within the limits of variation allowed.

8.2 Choose the speed of testing from Table 1. Determine this chosen speed of testing by the specification for the material being tested, or by agreement between those concerned. When the speed is not specified, use the lowest speed shown in Table 1 for the specimen geometry being used, which gives rupture within ½ to 5-min testing time.

8.3 Modulus determinations may be made at the speed selected for the other tensile properties when the recorder response and resolution are adequate.

9. Conditioning

9.1 *Conditioning*—Condition the test specimens in accordance with Procedure A of Practice D618, unless otherwise specified by contract or the relevant ASTM material specification. Conditioning time is specified as a minimum. Temperature and humidity tolerances shall be in accordance with Section 7 of Practice D618 unless specified differently by contract or material specification.

9.2 *Test Conditions*—Conduct the tests at the same temperature and humidity used for conditioning with tolerances in accordance with Section 7 of Practice D618, unless otherwise specified by contract or the relevant ASTM material specification.

TABLE 1 Designations for Speed of Testing[A]

Classification[B]	Specimen Type	Speed of Testing, mm/min [in./min]	Nominal Strain[C] Rate at Start of Test, mm/mm·min [in./in.·min]
Rigid and Semirigid	I, II, III rods and tubes	5 [0.2] ± 25 %	0.1
		50 [2] ± 10 %	1
		500 [20] ± 10 %	10
	IV	5 [0.2] ± 25 %	0.15
		50 [2] ± 10 %	1.5
		500 [20] ± 10 %	15
	V	1 [0.05] ± 25 %	0.1
		10 [0.5] ± 25 %	1
		100 [5] ± 25 %	10
Nonrigid	III	50 [2] ± 10 %	1
		500 [20] ± 10 %	10
	IV	50 [2] ± 10 %	1.5
		500 [20] ± 10 %	15

[A] Select the lowest speed that produces rupture in ½ to 5 min for the specimen geometry being used (see 8.2).
[B] See Terminology D883 for definitions.
[C] The initial rate of straining cannot be calculated exactly for dumbbell-shaped specimens because of extension, both in the reduced section outside the gage length and in the fillets. This initial strain rate can be measured from the initial slope of the tensile strain-versus-time diagram.

10. Procedure

10.1 Measure the width and thickness of each specimen to the nearest 0.025 mm (0.001 in.) using the applicable test methods in D5947.

TABLE 2 Modulus, 10^3 psi, for Eight Laboratories, Five Materials

	Mean	S_r	$S_{(r)}$	I_r	$I_{(r)}$
Polypropylene	0.210	0.0089	0.071	0.025	0.201
Cellulose acetate butyrate	0.248	0.0179	0.035	0.051	0.144
Acrylic	0.481	0.0179	0.063	0.051	0.144
Glass-reinforced nylon	1.17	0.0537	0.217	0.152	0.614
Glass-reinforced polyester	1.39	0.0894	0.266	0.253	0.753

10.1.1 Measure the width and thickness of flat specimens at the center of each specimen and within 5 mm of each end of the gage length.

10.1.2 Injection molded specimen dimensions may be determined by actual measurement of only one specimen from each sample when it has previously been demonstrated that the specimen-to-specimen variation in width and thickness is less than 1 %.

10.1.3 Take the width of specimens produced by a Type IV die as the distance between the cutting edges of the die in the narrow section.

10.1.4 Measure the diameter of rod specimens, and the inside and outside diameters of tube specimens, to the nearest 0.025 mm (0.001 in.) at a minimum of two points 90° apart; make these measurements along the groove for specimens so constructed. Use plugs in testing tube specimens, as shown in Fig. 2.

10.2 Place the specimen in the grips of the testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. The distance between the ends of the gripping surfaces, when using flat specimens, shall be as indicated in Fig. 1. On tube and rod specimens, the location for the grips shall be as shown in Fig. 2 and Fig. 3. Tighten the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test, but not to the point where the specimen would be crushed.

10.3 Attach the extension indicator. When modulus is being determined, a Class B-2 or better extensometer is required (see 5.2.1).

NOTE 11—Modulus of materials is determined from the slope of the linear portion of the stress-strain curve. For most plastics, this linear portion is very small, occurs very rapidly, and must be recorded automatically. The change in jaw separation is never to be used for calculating modulus or elongation.

10.4 Set the speed of testing at the proper rate as required in Section 8, and start the machine.

10.5 Record the load-extension curve of the specimen.

10.6 Record the load and extension at the yield point (if one exists) and the load and extension at the moment of rupture.

NOTE 12—If it is desired to measure both modulus and failure properties (yield or break, or both), it may be necessary, in the case of highly extensible materials, to run two independent tests. The high magnification extensometer normally used to determine properties up to the yield point may not be suitable for tests involving high extensibility. If allowed to remain attached to the specimen, the extensometer could be permanently damaged. A broad-range incremental extensometer or hand-rule technique may be needed when such materials are taken to rupture.

11. Calculation

11.1 Toe compensation shall be made in accordance with Annex A1, unless it can be shown that the toe region of the curve is not due to the take-up of slack, seating of the specimen, or other artifact, but rather is an authentic material response.

11.2 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load in newtons (pounds-force) by the average original cross-sectional area in the gage length segment of the specimen in square metres (square inches). Express the result in pascals (pounds-force per square inch) and report it to three significant figures as tensile strength at yield or tensile strength at break, whichever term is applicable. When a nominal yield or break load less than the maximum is present and applicable, it may be desirable also to calculate, in a similar manner, the corresponding tensile stress at yield or tensile stress at break and report it to three significant figures (see Note A2.8).

11.3 Elongation values are valid and are reported in cases where uniformity of deformation within the specimen gage length is present. Elongation values are quantitatively relevant and appropriate for engineering design. When non-uniform deformation (such as necking) occurs within the specimen gage length nominal strain values are reported. Nominal strain values are of qualitative utility only.

11.3.1 *Percent Elongation*—Percent elongation is the change in gage length relative to the original specimen gage length, expressed as a percent. Percent elongation is calculated using the apparatus described in 5.2.

11.3.1.1 *Percent Elongation at Yield*—Calculate the percent elongation at yield by reading the extension (change in gage length) at the yield point. Divide that extension by the original gage length and multiply by 100.

11.3.1.2 *Percent Elongation at Break*—Calculate the percent elongation at break by reading the extension (change in gage length) at the point of specimen rupture. Divide that extension by the original gage length and multiply by 100.

11.3.2 *Nominal Strain*—Nominal strain is the change in grip separation relative to the original grip separation expressed as a percent. Nominal strain is calculated using the apparatus described in 5.1.7.

11.3.2.1 *Nominal strain at break*—Calculate the nominal strain at break by reading the extension (change in grip separation) at the point of rupture. Divide that extension by the original grip separation and multiply by 100.

11.4 *Modulus of Elasticity*—Calculate the modulus of elasticity by extending the initial linear portion of the load-extension curve and dividing the difference in stress corresponding to any segment of section on this straight line by the corresponding difference in strain. All elastic modulus values shall be computed using the average original cross-sectional area in the gage length segment of the specimen in the calculations. The result shall be expressed in pascals (pounds-force per square inch) and reported to three significant figures.

11.5 *Secant Modulus*—At a designated strain, this shall be calculated by dividing the corresponding stress (nominal) by the designated strain. Elastic modulus values are preferable and shall be calculated whenever possible. However, for materials where no proportionality is evident, the secant value shall be calculated. Draw the tangent as directed in A1.3 and Fig. A1.2, and mark off the designated strain from the yield point where the tangent line goes through zero stress. The stress to be used in the calculation is then determined by dividing the load-extension curve by the original average cross-sectional area of the specimen.

11.6 For each series of tests, calculate the arithmetic mean of all values obtained and report it as the "average value" for the particular property in question.

11.7 Calculate the standard deviation (estimated) as follows and report it to two significant figures:

$$s = \sqrt{(\sum X^2 - n\bar{X}^2)/(n-1)} \quad (1)$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

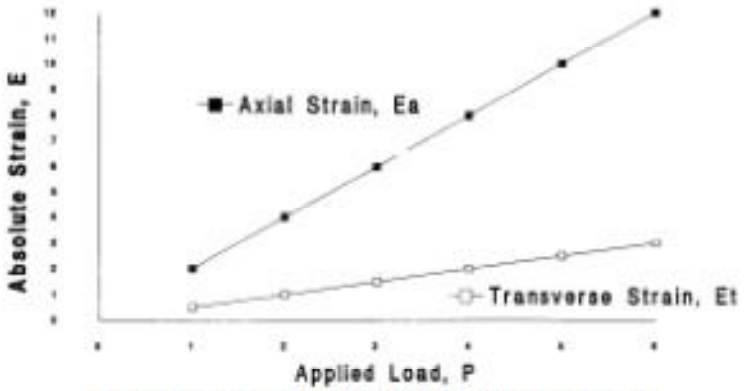


FIG. 4 Plot of Strains Versus Load for Determination of Poisson's Ratio

11.8 See Annex A1 for information on toe compensation.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code numbers, form, principal dimensions, previous history, etc.,

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimensions,

12.1.4 Conditioning procedure used,

12.1.5 Atmospheric conditions in test room,

12.1.6 Number of specimens tested,

12.1.7 Speed of testing,

12.1.8 Classification of extensometers used. A description of measuring technique and calculations employed instead of a minimum Class-C extensometer system,

12.1.9 Tensile strength at yield or break, average value, and standard deviation,

12.1.10 Tensile stress at yield or break, if applicable, average value, and standard deviation,

12.1.11 Percent elongation at yield, or break, or nominal strain at break, or all three, as applicable, average value, and standard deviation,

12.1.12 Modulus of elasticity or secant modulus, average value, and standard deviation,

TABLE 3 Tensile Strength at Break, 10^3 psi, for Eight Laboratories, Five Materials[A]

	Mean	S_r	S_R	I_r	I_R
Polypropylene	3.97	1.54	1.65	4.37	4.66
Cellulose acetate butyrate	4.82	0.058	0.180	0.164	0.509
Acrylic	8.09	0.452	0.751	1.27	2.13
Glass-reinforced polyester	20.8	0.235	0.437	0.659	1.24
Glass-reinforced nylon	23.6	0.277	0.696	0.784	1.98

[A] Tensile strength and elongation at break values obtained for unreinforced propylene plastics generally are highly variable due to inconsistencies in necking or "drawing" of the center section of the test bar. Since tensile strength and elongation at yield are more reproducible and relate in most cases to the practical usefulness of a molded part, they are generally recommended for specification purposes.

12.1.13 If measured, Poisson's ratio, average value, standard deviation, and statement of whether there was proportionality within the strain range,

12.1.14 Date of test, and

12.1.15 Revision date of Test Method D638.

13. Precision and Bias[5]

13.1 *Precision*—Tables 2-4 are based on a round-robin test conducted in 1984, involving five materials tested by eight laboratories using the Type I specimen, all of nominal 0.125-in. thickness. Each test result was based on five individual determinations. Each laboratory obtained two test results for each material.

13.1.1 Tables 5-10 are based on a round-robin test conducted by the polyolefin subcommittee in 1988, involving eight polyethylene materials tested in ten laboratories. For each material, all samples were molded at one source, but the individual specimens were prepared at the laboratories that tested them. Each test result was the average of five individual determinations. Each laboratory obtained three test results for each material. Data from some laboratories could not be used for various reasons, and this is noted in each table.

13.1.2 Table 11 is based on a repeatability study involving a single laboratory. The two materials used were unfilled polypropylene types. Measurements were performed by a single technician on a single day. Each test result is an individual determination. Testing was run using two Type B-1 extensometers for transverse and axial measurements at a test speed of 5 mm/min.

13.1.3 In Tables 2-11, for the materials indicated, and for test results that derived from testing five specimens:

13.1.3.1 S_r is the within-laboratory standard deviation of the average; $I_r = 2.83\ S_r$. (See 13.1.3.3 for application of I_r.)

13.1.3.2 S_R is the between-laboratory standard deviation of the average; $I_R = 2.83\ S_R$. (See 13.1.3.4 for application of I_R.)

[5] Supporting data are available from ASTM Headquarters. Request RR:D20-1125 for the 1984 round robin and RR:D20-1170 for the 1988 round robin.

TABLE 4 Elongation at Break, %, for Eight Laboratories, Five Materials[A]

	Mean	S_r	S_R	I_r	I_R
Glass-reinforced polyester	3.68	0.20	2.33	0.570	6.59
Glass-reinforced nylon	3.87	0.10	2.13	0.285	6.03
Acrylic	13.2	2.05	3.65	5.80	10.3
Cellulose acetate butyrate	14.1	1.87	6.62	5.29	18.7
Polypropylene	293.0	50.9	119.0	144.0	337.0

[A] Tensile strength and elongation at break values obtained for unreinforced propylene plastics generally are highly variable due to inconsistencies in necking or "drawing" of the center section of the test bar. Since tensile strength and elongation at yield are more reproducible and relate in most cases to the practical usefulness of a molded part, they are generally recommended for specification purposes.

TABLE 5 Tensile Yield Strength, for Ten Laboratories, Eight Materials

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1544	52.4	84.0	146.6	179.3
LDPE	20	1594	53.1	61.2	148.7	171.3
LLDPE	20	1879	74.2	99.9	207.6	279.7
LLDPE	20	1791	49.2	75.8	137.9	212.3
LLDPE	20	2900	55.5	87.9	155.4	246.1
LLDPE	20	1730	63.9	96.0	178.9	268.7
HDPE	2	4101	186.1	371.9	549.1	1041.3
HDPE	2	3523	175.9	479.0	492.4	1366.5

TABLE 6 Tensile Stress at Yield, 10^3 psi, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
Polypropylene	3.65	0.022	0.161	0.062	0.456
Cellulose acetate butyrate	5.01	0.058	0.227	0.164	0.642
Acrylic	10.4	0.067	0.317	0.190	0.897

TABLE 7 Elongation at Yield, %, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
Cellulose acetate butyrate	3.65	0.27	0.62	0.76	1.75
Acrylic	4.89	0.21	0.55	0.59	1.56
Polypropylene	8.79	0.45	5.86	1.27	16.5

13.1.3.3 *Repeatability*—In comparing two test results for the same material, obtained by the same operator using the same equipment on the same day, those test results should be judged not equivalent if they differ by more than the I_r value for that material and condition.

13.1.3.4 *Reproducibility*—In comparing two test results for the same material, obtained by different operators using different equipment on different days, those test results should be judged not equivalent if they differ by more than the I_R value for that material and condition. (This applies between different laboratories or between different equipment within the same laboratory.)

13.1.3.5 Any judgment in accordance with 13.1.3.3 and 13.1.3.4 will have an approximate 95 % (0.95) probability of being correct.

13.1.3.6 Other formulations may give somewhat different results.

TABLE 8 Tensile Yield Elongation, for Eight Laboratories, Eight Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	17.0	1.26	3.16	3.52	8.84
LDPE	20	14.6	1.02	2.38	2.86	6.67
LLDPE	20	15.7	1.37	2.65	3.85	7.37
LLDPE	20	16.6	1.59	3.30	4.46	9.24
LLDPE	20	11.7	1.27	2.86	3.56	8.08
LLDPE	20	15.3	1.27	2.59	3.55	7.25
HDPE	2	9.27	1.40	2.84	3.91	7.94
HDPE	2	9.63	1.23	2.75	3.45	7.71

TABLE 9 Tensile Break Strength, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1592	52.5	74.9	146.4	209.7
LDPE	20	1750	66.6	102.9	186.4	288.1
LLDPE	20	4379	127.1	219.0	355.8	613.3
LLDPE	20	2940	78.6	143.5	220.2	401.8
LLDPE	20	1679	34.3	47.0	95.96	131.6
LLDPE	20	2990	119.1	166.3	333.6	465.6

TABLE 10 Tensile Break Elongation, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	567	31.5	59.5	88.2	166.6
LDPE	20	569	61.5	89.2	172.3	249.7
LLDPE	20	590	25.7	113.6	71.9	318.7
LLDPE	20	64.4	6.66	11.7	18.7	32.8
LLDPE	20	603	25.7	104.4	71.9	292.5
LLDPE	20	782	41.6	96.7	116.6	270.8

TABLE 11 Poisson's Ratio Repeatability Data for One Laboratory and Two Polypropylene Materials

Materials	Values Expressed as a Dimensionless Ratio		
	Average	S_r	r
PP #1 Chord	0.412	0.009	0.026
PP #1 Least Squares	0.413	0.011	0.032
PP #2 Chord	0.391	0.009	0.026
PP #2 Least Squares	0.392	0.010	0.028

13.1.3.7 For further information on the methodology used in this section, see Practice E691.

13.1.3.8 The precision of this test method is very dependent upon the uniformity of specimen preparation, standard practices for which are covered in other documents.

13.2 *Bias*—There are no recognized standards on which to base an estimate of bias for this test method.

14. Keywords

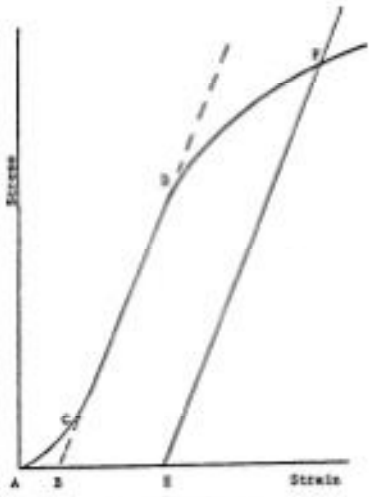
14.1 modulus of elasticity; percent elongation; plastics; tensile properties; tensile strength

ANNEXES

(Mandatory Information)

A1. TOE COMPENSATION

A1.1 In a typical stress-strain curve (Fig. A1.1) there is a toe region, *AC*, that does not represent a property of the material. It is an artifact caused by a takeup of slack and alignment or seating of the specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

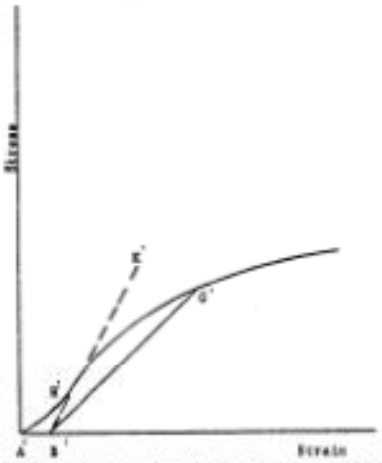


NOTE 1—
Some chart recorders plot the mirror image of this graph.

FIG. A1.1 Material with Hookean Region

A1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. A1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured, including the yield offset (*BE*), if applicable. The elastic modulus can be determined by dividing the stress at any point along the line *CD* (or its extension) by the strain at the same point (measured from Point *B*, defined as zero-strain).

A1.3 In the case of a material that does not exhibit any linear region (Fig. A1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection point (*H*). This is extended to intersect the strain axis at Point *B'*, the corrected zero-strain point. Using Point *B'* as zero strain, the stress at any point (*G*) on the curve can be divided by the strain at that point to obtain a secant modulus (slope of Line *B'G*). For those materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.



NOTE 1—Some chart recorders plot the mirror image of this graph.

FIG. A1.2 Material with No Hookean Region

A2. DEFINITIONS OF TERMS AND SYMBOLS RELATING TO TENSION TESTING OF PLASTICS

A2.1 *elastic limit*—the greatest stress which a material is capable of sustaining without any permanent strain remaining upon complete release of the stress. It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

NOTE A2.1—Measured values of proportional limit and elastic limit vary greatly with the sensitivity and accuracy of the testing equipment, eccentricity of loading, the scale to which the stress-strain diagram is plotted, and other factors. Consequently, these values are usually replaced by yield strength.

A2.2 *elongation*—the increase in length produced in the gage length of the test specimen by a tensile load. It is expressed in units of length, usually millimetres (inches). (Also known as *extension*.)

NOTE A2.2—Elongation and strain values are valid only in cases where uniformity of specimen behavior within the gage length is present. In the case of materials exhibiting necking phenomena, such values are only of qualitative utility after attainment of yield point. This is due to inability to ensure that necking will encompass the entire length between the gage marks prior to specimen failure.

A2.3 *gage length*—the original length of that portion of the specimen over which strain or change in length is determined.

A2.4 *modulus of elasticity*—the ratio of stress (nominal) to corresponding strain below the proportional limit of a material. It is expressed in force per unit area, usually megapascals (pounds-force per square inch). (Also known as *elastic modulus* or *Young's modulus*).

NOTE A2.3—The stress-strain relations of many plastics do not conform to Hooke's law throughout the elastic range but deviate therefrom even at stresses well below the elastic limit. For such materials the slope of the tangent to the stress-strain curve at a low stress is usually taken as the modulus of elasticity. Since the existence of a true proportional limit in plastics is debatable, the propriety of applying the term "modulus of elasticity" to describe the stiffness or rigidity of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are very dependent on such factors as rate of stressing, temperature, previous specimen history, etc. However, such a value is useful if its arbitrary nature and dependence on time, temperature, and other factors are realized.

A2.5 *necking*—the localized reduction in cross section which may occur in a material under tensile stress.

A2.6 *offset yield strength*—the stress at which the strain exceeds by a specified amount (the offset) an extension of the initial proportional portion of the stress-strain curve. It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

NOTE A2.4—This measurement is useful for materials whose stress-strain curve in the yield range is of gradual curvature. The offset yield strength can be derived from a stress-strain curve as follows (Fig. A2.1):

On the strain axis lay off *OM* equal to the specified offset.

Draw *OA* tangent to the initial straight-line portion of the stress-strain curve.

Through *M* draw a line *MN* parallel to *OA* and locate the intersection of *MN* with the stress-strain curve.

The stress at the point of intersection *t* is the "offset yield strength." The specified value of the offset must be stated as a percent of the original gage length in conjunction with the strength value. *Example:* 0.1 % offset yield strength = ... MPa (psi), or yield strength at 0.1 % offset ... MPa (psi).

A2.7 *percent elongation*—the elongation of a test specimen expressed as a percent of the gage length.

A2.8 *percent elongation at break and yield:*

A2.8.1 *percent elongation at break*—the percent elongation at the moment of rupture of the test specimen.

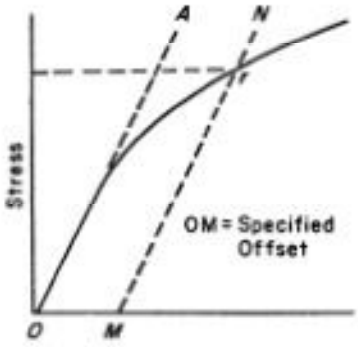


FIG. A2.1 Offset Yield Strength

A2.8.2 *percent elongation at yield*—the percent elongation at the moment the yield point (A2.22) is attained in the test specimen.

A2.9 *percent reduction of area (nominal)*—the difference between the original cross-sectional area measured at the point of rupture after breaking and after all retraction has ceased, expressed as a percent of the original area.

A2.10 *percent reduction of area (true)*—the difference between the original cross-sectional area of the test specimen and the minimum cross-sectional area within the gage boundaries prevailing at the moment of rupture, expressed as a percentage of the original area.

A2.11 *Poisson's Ratio*—The absolute value of the ratio of transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material.

A2.12 *proportional limit*—the greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

A2.13 *rate of loading*—the change in tensile load carried by the specimen per unit time. It is expressed in force per unit time, usually newtons (pounds-force) per minute. The initial rate of loading can be calculated from the initial slope of the load versus time diagram.

A2.14 *rate of straining*—the change in tensile strain per unit time. It is expressed either as strain per unit time, usually metres per metre (inches per inch) per minute, or percent elongation per unit time, usually percent elongation per minute. The initial rate of straining can be calculated from the initial slope of the tensile strain versus time diagram.

NOTE A2.5—The initial rate of straining is synonymous with the rate of crosshead movement divided by the initial distance between crossheads only in a machine with constant rate of crosshead movement and when the specimen has a uniform original cross section, does not "neck down," and does not slip in the jaws.

A2.15 *rate of stressing (nominal)*—the change in tensile stress (nominal) per unit time. It is expressed in force per unit area per unit time, usually megapascals (pounds-force per square inch) per minute. The initial rate of stressing can be calculated from the initial slope of the tensile stress (nominal) versus time diagram.

NOTE A2.6—The initial rate of stressing as determined in this manner has only limited physical significance. It does, however, roughly describe the average rate at which the initial stress (nominal) carried by the test specimen is applied. It is affected by the elasticity and flow characteristics of the materials being tested. At the yield point, the rate of stressing (true) may continue to have a positive value if the cross-sectional area is decreasing.

A2.16 *secant modulus*—the ratio of stress (nominal) to corresponding strain at any specified point on the stress-strain curve. It is expressed in force per unit area, usually megapascals (pounds-force per square inch), and reported together with the specified stress or strain.

NOTE A2.7—This measurement is usually employed in place of modulus of elasticity in the case of materials whose stress-strain diagram does not demonstrate proportionality of stress to strain.

A2.17 *strain*—the ratio of the elongation to the gage length of the test specimen, that is, the change in length per unit of original length. It is expressed as a dimensionless ratio.

A2.17.1 *nominal strain at break*—the strain at the moment of rupture relative to the original grip separation.

A2.18 *tensile strength (nominal)*—the maximum tensile stress (nominal) sustained by the specimen during a tension test. When the maximum stress occurs at the yield point (A2.22), it shall be designated tensile strength at yield. When the maximum stress occurs at break, it shall be designated tensile strength at break.

A2.19 *tensile stress (nominal)*—the tensile load per unit area of minimum original cross section, within the gage boundaries, carried by the test specimen at any given moment. It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

NOTE A2.8—The expression of tensile properties in terms of the minimum original cross section is almost universally used in practice. In the case of materials exhibiting high extensibility or necking, or both (A2.16), nominal stress calculations may not be meaningful beyond the yield point (A2.22) due to the extensive reduction in cross-sectional area that ensues. Under some circumstances it may be desirable to express the tensile properties per unit of minimum prevailing cross section. These properties are called true tensile properties (that is, true tensile stress, etc.).

A2.20 *tensile stress-strain curve*—a diagram in which values of tensile stress are plotted as ordinates against corresponding values of tensile strain as abscissas.

A2.21 *true strain* (see Fig. A2.2) is defined by the following equation for ε_v:

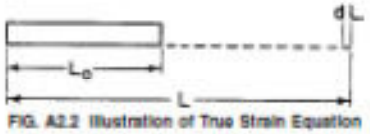


FIG. A2.2 Illustration of True Strain Equation

$$\varepsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o \qquad (A2.1)$$

where:

dL = increment of elongation when the distance between the gage marks is L,
L_o = original distance between gage marks, and
L = distance between gage marks at any time.

A2.22 *yield point*—the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress (Fig. A2.2).

NOTE A2.9—Only materials whose stress-strain curves exhibit a point of zero slope may be considered as having a yield point.

NOTE A2.10—Some materials exhibit a distinct "break" or discontinuity in the stress-strain curve in the elastic region. This break is not a yield point by definition. However, this point may prove useful for material characterization in some cases.

A2.23 *yield strength*—the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. Unless otherwise specified, this stress will be the stress at the yield point and when expressed in relation to the tensile strength shall be designated either tensile strength at yield or tensile stress at yield as required in A2.18 (Fig. A2.3). (See *offset yield strength*.)

A2.24 *Symbols*—The following symbols may be used for the above terms:

Symbol	Term
W	Load
ΔW	Increment of load
L	Distance between gage marks at any time
L_o	Original distance between gage marks
L_u	Distance between gage marks at moment of rupture
ΔL	Increment of distance between gage marks = elongation
A	Minimum cross-sectional area at any time
A_o	Original cross-sectional area
ΔA	Increment of cross-sectional area
A_u	Cross-sectional area at point of rupture measured after breaking specimen
A_T	Cross-sectional area at point of rupture, measured at the moment of rupture
t	Time
Δt	Increment of time
σ	Tensile stress
$\Delta\sigma$	Increment of stress
σ_T	True tensile stress
σ_u	Tensile strength at break (nominal)
σ_{uT}	Tensile strength at break (true)
ε	Strain
$\Delta\varepsilon$	Increment of strain
ε_u	Total strain, at break
ε_T	True strain
$\%E$	Percentage elongation
YP	Yield point
E	Modulus of elasticity

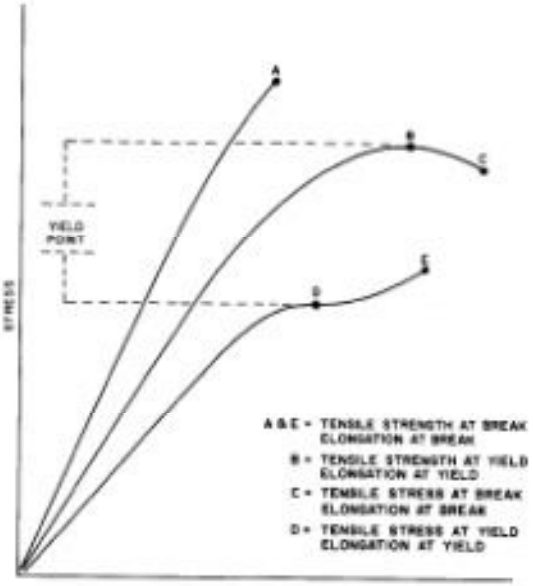


FIG. A2.3 Tensile Designations

A2.25 Relations between these various terms may be defined as follows:

$$\sigma = W/A_o$$
$$\sigma_T = W/A$$
$$\sigma_u = W/A_o \text{ (where } W \text{ is breaking load)}$$
$$\sigma_{uT} = W/A_T \text{ (where } W \text{ is breaking load)}$$
$$\varepsilon = \Delta L/L_o = (L - L_o)/L_o$$
$$\varepsilon_u = (L_u - L_o)/L_o$$
$$\varepsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o$$
$$\%E = [(L - L_o)/L_o] \times 100 = \varepsilon \times 100$$

Percent reduction of area (nominal) = $[(A_o - A_u)/A_o] \times 100$
Percent reduction of area (true) = $[(A_o - A_T)/A_o] \times 100$
Rate of loading = $\Delta W/\Delta t$
Rate of stressing (nominal) = $\Delta\sigma/\Delta = (\Delta W)/(A_o)/\Delta t$
Rate of straining = $\Delta\varepsilon/\Delta t = (\Delta L/L_o)/\Delta t$

For the case where the volume of the test specimen does not change during the test, the following three relations hold:

$$\sigma_T = \sigma(1 + \varepsilon) = \sigma L/L_o \qquad (A2.2)$$

$$\sigma_{uT} = \sigma_u(1 + \varepsilon_u) = \sigma_u L_u/L_o$$

$$A = A_o/(1 + \varepsilon)$$

A3. MEASUREMENT OF POISSON'S RATIO

A3.1. Scope

A3.1.1 This test method covers the determination of Poisson's ratio obtained from strains resulting from uniaxial stress only.

A3.1.2 Test data obtained by this test method are relevant and appropriate for use in engineering design.

A3.1.3 The values stated in SI units are regarded as the standard. The values given in parentheses are for information only.

NOTE A3.1—This standard is not equivalent to ISO 527-1.

A3.2. Referenced Documents

A3.2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing

D883 Terminology Relating to Plastics

D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

E83 Practice for Verification and Classification of Extensometer Systems

E132 Test Method for Poisson's Ratio at Room Temperature

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

A3.2.2 *ISO Standard:*[4]

ISO 527-1 Determination of Tensile Properties

A3.3. Terminology

A3.3.1 *Definitions*—Definitions of terms applying to this test method appear in Terminology D883 and Annex A2 of this standard.

A3.4. Significance and Use

A3.4.1 When uniaxial tensile force is applied to a solid, the solid stretches in the direction of the applied force (axially), but it also contracts in both dimensions perpendicular to the applied force. If the solid is homogeneous and isotropic, and the material remains elastic under the action of the applied force, the transverse strain bears a constant relationship to the axial strain. This constant, called Poisson's ratio, is defined as the negative ratio of the transverse (negative) to axial strain under uniaxial stress.

A3.4.2 Poisson's ratio is used for the design of structures in which all dimensional changes resulting from the application of force need to be taken into account and in the application of the generalized theory of elasticity to structural analysis.

NOTE A3.2—The accuracy of the determination of Poisson's ratio is usually limited by the accuracy of the transverse strain measurements because the percentage errors in these measurements are usually greater than in the axial strain measurements. Since a ratio rather than an absolute quantity is measured, it is only necessary to know accurately the relative value of the calibration factors of the extensometers. Also, in general, the value of the applied loads need not be known accurately.

A3.5. Apparatus

A3.5.1 Refer to 5.1 and 5.3 of this standard for the requirements of the testing machine and micrometers.

A3.5.2 For measurement of Poisson's Ratio use either a bi-axial extensometer or an axial extensometer in combination with a transverse extensometer. They must be capable of recording axial strain and transverse strain simultaneously. The extensometers shall be capable of measuring the change in strains with an accuracy of 1 % of the relevant value or better.

NOTE A3.3—Strain gages are used as an alternative method to measure axial and transverse strain; however, proper techniques for mounting strain gages are crucial to obtaining accurate data. Consult strain gage suppliers for instruction and training in these special techniques.

A3.6. Test Specimen

A3.6.1 *Specimen*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type I specimen is the preferred specimen and shall be used where sufficient material having a thickness of 7 mm (0.28 in.) or less is available.

A3.6.2 *Preparation*—Test specimens shall be prepared by machining operations, or die cutting, from materials in sheet, plate, slab, or similar form or be prepared by molding the material into the specimen shape to be tested.

NOTE A3.4—When preparing specimens from certain composite laminates such as woven roving, or glass cloth, care must be exercised in cutting the specimens parallel to the reinforcement, unless testing of specimens in a direction other than parallel with the reinforcement constitutes a variable being studied.

NOTE A3.5—Specimens prepared by injection molding have different tensile properties than specimens prepared by machining or die-cutting because of the orientation induced. This effect is more pronounced in specimens with narrow sections.

A3.6.3 All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine file or abrasive, and the filed surfaces shall then be smoothed with abrasive paper (No. 00 or finer). The finishing sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not to disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shown in Fig. 1 shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors.

A3.6.4 If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon or India ink that will not affect the material being tested. Gauge marks shall not be scratched, punched, or impressed on the specimen.

A3.6.5 When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.

A3.7 Number of Test Specimens

A3.7.1 Test at least five specimens for each sample in the case of isotropic materials.

A3.7.2 Test ten specimens, five normal to, and five parallel with, the principle axis of anisotropy, for each sample in the case of anisotropic materials.

A3.8. Conditioning

A3.8.1 Specimens shall be conditioned and tested in accordance with the requirement shown in Section 9 of this standard.

A3.9. Procedure

A3.9.1 Measure the width and thickness of each specimen to the nearest 0.025 mm (0.001 in.) using the applicable test methods in D5947. Follow the guidelines specified in 10.1.1 and 10.1.2 of this standard.

A3.9.2 Poisson's Ratio shall be determined at a speed of 5 mm/min.

A3.9.3 Place the specimen in the grips of the testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. The distance between the ends of the gripping surfaces, when using flat specimens, shall be as indicated in Fig. 1. Tighten the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test, but not to the point where the specimen would be crushed.

A3.9.4 Attach the biaxial extensometer or the axial and transverse extensometer combination to the specimen. The transverse extensometer should be attached to the width of the specimen.

A3.9.5 Apply a small preload (less than 5 N) to the specimen at a crosshead speed of 0.1 mm/min. This preload will eliminate any bending in the specimens.

A3.9.6 Rebalance the extensometers to zero.

A3.9.7 Run the test at 5 mm/min out to a minimum of 0.5 % strain before removing the extensometers, simultaneously recording the strain readings from the extensometers at the same applied force. The precision of the value of Poisson's Ratio will depend on the number of data points of axial and transverse strain taken. It is recommended that the data collection rate for the test be a minimum of 20 points per second (but preferably higher). This is particularly important for materials having a non linear stress to strain curve.

A3.9.8 Make the toe compensation in accordance with Annex A1. Determine the maximum strain (proportional limit) at which the curve is linear. If this strain is greater than 0.25 % the Poisson's Ratio is to be determined anywhere in this linear portion of the curve below the proportional limit. If the material does not exhibit a linear stress to strain relationship the Poisson's Ratio shall be determined within the axial strain range of 0.0005 to 0.0025 mm/mm (0.05 to 0.25 %). If the ratio is determined in this manner it shall be noted in the report that a region of proportionality of stress to strain was not evident.

NOTE A3.6—A suitable method for determination of linearity of the stress to strain curve is by making a series of tangent modulus measurements at different axial strain levels. Values equivalent at each strain level indicate linearity. Values showing a downward trend with increasing strain level indicate non linearity.

A3.10. Calculation

A3.10.1 *Poisson's Ratio*—The axial strain, ε_a, indicated by the axial extensometer, and the transverse strain, ε_t, indicated by the transverse extensometers, are plotted against the applied load, P, as shown in Fig. 4.

A3.10.1.1 For those materials where there is proportionality of stress to strain and it is possible to determine a modulus of elasticity, a straight line is drawn through each set of points within the load range used for determination of modulus, and the slopes $d\varepsilon_a / dP$ and $d\varepsilon_t / dP$, of those lines are determined. The use of a least squares method of calculation will reduce errors resulting from drawing lines. Poisson's Ratio, $|\mu|$, is then calculated as follows:

$$|\mu| = (d\varepsilon_t/dP)/(d\varepsilon_a/dP) \quad \text{(A3.1)}$$

where:

$d\varepsilon_t$ = change in transverse strain,
$d\varepsilon_a$ = change in axial strain, and
dP = change in applied load;

$$|\mu| = (d\varepsilon_t)/(d\varepsilon_a) \quad \text{(A3.2)}$$

A3.10.1.2 The errors that are introduced by drawing a straight line through the points are reduced by applying the least squares method.

A3.10.1.3 For those materials where there is no proportionality of stress to strain evident determine the ratio of $d\varepsilon_t / d\varepsilon_a$ when $d\varepsilon_a = 0.002$ (based on axial strain range of 0.0005 to 0.0025 mm/mm) and after toe compensation has been made.

$$|\mu| = d\varepsilon_t/0.002 \quad \text{(A3.3)}$$

A3.11. Report

A3.11.1 Report the following information:

A3.11.1.1 Complete identification of the material tested, including type, source, manufacturer's code numbers, form, principal dimensions, previous history, etc.,

A3.11.1.2 Method of preparing test specimens,

A3.11.1.3 Type of test specimen and dimensions,

A3.11.1.4 Conditioning procedure used,

A3.11.1.5 Atmospheric conditions in test room,

A3.11.1.6 Number of specimens tested,

A3.11.1.7 Speed of testing,

A3.11.1.8 Classification of extensometers used. A description of measuring technique and calculations employed,

A3.11.1.9 Poisson's ratio, average value, standard deviation, and statement of whether there was proportionality within the strain range,

A3.11.1.10 Date of test, and

A3.11.1.11 Revision date of Test Method D618.

A3.12. Precision and Bias

A3.12.1 *Precision*—The repeatability standard deviation has been determined to be the following (see Table A3.1.) An attempt to develop a full precision and bias statement for this test method will be made at a later date. For this reason, data on precision and bias cannot be given. Because this test method does not contain a round-robin based numerical precision and bias statement, it shall not be used as a referee test method in

TABLE A3.1 Poisson's Ratio Based on One Laboratory

Material	Extensometer Type	Average	V_x[A]	V_R[B]	r[C]	R[D]
PP Copolymer	2-point	0.406	0.011		0.031	
PP Copolymer	4-point	0.392	0.010		0.028	
PP Homopolymer with 20 % Glass	2-point	0.426	0.013		0.036	
PP Homopolymer with 20 % Glass	4-point	0.410	0.015		0.042	

[A] S_r = within-laboratory standard deviation for the indicated material. It is obtained by first pooling the within-laboratory standard deviations of the test results from all the participating laboratories:

$$S_r = [(S_1)^2 + (S_2)^2 + \ldots + (S_n)^2]/n]^{1/2}$$

[B] S_R = between-laboratories reproducibility, expressed as standard deviation: $S_R = [S_r^2 + S_L^2]^{1/2}$

[C] r = within-laboratory critical interval between two test results = $2.8 \times S_r$

[D] R = between-laboratories critical interval between two test results = $2.8 \times S_R$

case of dispute. Anyone wishing to participate in the development of precision and bias data should contact the Chairman, Subcommittee D20.10 Mechanical Properties, ASTM International, 100 Barr Harbor, West Conshohocken, PA 19428.

A3.13 Keywords

A3.13.1 axial strain; Poisson's ratio; transverse strain

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D638 - 08) that may impact the use of this standard. (May 15, 2010)

(1) Edited conditioning and test condition clauses.

ANEXO No. 5: ASTM D2240: Standard test Method for Rubber Property – Durometer Hardness

Designation: D2240 – 05 (Reapproved 2010)

Standard Test Method for Rubber Property—Durometer Hardness[1]

This standard is issued under the fixed designation D2240; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers twelve types of rubber hardness measurement devices known as durometers: Types A, B, C, D, DO, E, M, O, OO, OOO, OOO-S, and R. The procedure for determining indentation hardness of substances classified as thermoplastic elastomers, vulcanized (thermoset) rubber, elastomeric materials, cellular materials, gel-like materials, and some plastics is also described.

1.2 This test method is not equivalent to other indentation hardness methods and instrument types, specifically those described in Test Method D1415.

1.3 This test method is not applicable to the testing of coated fabrics.

1.4 All materials, instruments, or equipment used for the determination of mass, force, or dimension shall have traceability to the National Institute for Standards and Technology, or other internationally recognized organizations parallel in nature.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only. Many of the stated dimensions in SI are direct conversions from the U. S. Customary System to accommodate the instrumentation, practices, and procedures that existed prior to the Metric Conversion Act of 1975.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D374 Test Methods for Thickness of Solid Electrical Insulation

D618 Practice for Conditioning Plastics for Testing

D785 Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials

D1349 Practice for Rubber—Standard Temperatures for Testing

D1415 Test Method for Rubber Property—International Hardness

D4483 Practice for Evaluating Precision for Test Method Standards in the Rubber and Carbon Black Manufacturing Industries

F1957 Test Method for Composite Foam Hardness-Durometer Hardness

2.2 *ISO Standard:*[3]

ISO/IEC 17025: 1999 General Requirements for the Competence of Testing and Calibration Laboratories

3. Summary of Test Method

3.1 This test method permits hardness measurements based on either initial indentation or indentation after a specified period of time, or both. Durometers with maximum reading indicators used to determine maximum hardness values of a material may yield lower hardness when the maximum indicator is used.

3.2 The procedures for Type M, or micro hardness durometers, accommodate specimens that are, by their dimensions or configuration, ordinarily unable to have their durometer hardness determined by the other durometer types described. Type M durometers are intended for the testing of specimens having a thickness or cross-sectional diameter of 1.25 mm (0.050 in.) or greater, although specimens of lesser dimensions may be successfully accommodated under the conditions specified in Section 6, and have a Type M durometer hardness range between 20 and 90. Those specimens which have a durometer hardness range other than specified shall use another suitable procedure for determining durometer hardness.

[1] This test method is under the jurisdiction of ASTM Committee D11 on Rubber and is the direct responsibility of Subcommittee D11.10 on Physical Testing.

Current edition approved Jan. 1, 2010. Published April 2010. Originally approved in 1964. Last previous edition approved in 2005 as D2240–05. DOI: 10.1520/D2240-05R10.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland.

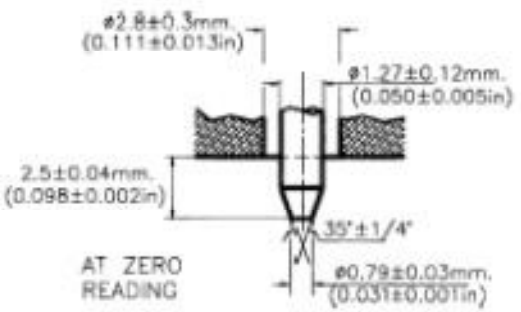


FIG. 1 (a) Type A and C Indentor

4. Significance and Use

4.1 This test method is based on the penetration of a specific type of indentor when forced into the material under specified conditions. The indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material. *The geometry of the indentor and the applied force influence the measurements such that no simple relationship exists between the measurements obtained with one type of durometer and those obtained with another type of durometer or other instruments used for measuring hardness.* This test method is an empirical test intended primarily for control purposes. No simple relationship exists between indentation hardness determined by this test method and any fundamental property of the material tested. For specification purposes, it is recommended that Test Method D785 be used for materials other than those described in 1.1.

5. Apparatus

5.1 *Hardness Measuring Apparatus, or Durometer, and an Operating Stand*, Type 1, Type 2, or Type 3 (see 5.1.2) consisting of the following components:

5.1.1 *Durometer:*

5.1.1.1 *Presser Foot*, the configuration and the total area of a durometer presser foot may produce varying results when there are significant differences between them. It is recommended that when comparing durometer hardness determinations of the same type (see 4.1), that the comparisons be between durometers of similar presser foot configurations and total area, and that the presser foot configuration and size be noted in the Hardness Measurement Report (see 10.2.4 and 5.1.1.3).

5.1.1.2 *Presser Foot*, Types A, B, C, D, DO, E, O, OO, OOO, and OOO-S, with an orifice (to allow for the protrusion of the indentor) having a diameter as specified in Fig. 1 (a, b, c, d, e, f, and g), with the center a minimum of 6.0 mm (0.24 in.) from any edge of the foot. When the presser feet is not of a flat circular design, the area shall not be less than 500 mm^2 (19.7 $in.^2$).

NOTE 1—The Type OOO and the Type OOO-S, designated herein, differ in their indentor configuration, spring force, and the results obtained. See Table 1 and Fig. 1 (e and g).

5.1.1.3 *Presser Foot*—flat circular designs designated as Type *xR*, where *x* is the standard durometer designation and *R* indicates the flat circular press foot described herein, for example, Type *aR*, *dR*, and the like. The presser foot, having a centrally located orifice (to allow for the protrusion of the indentor) of a diameter as specified in Fig. 1 (a through g). The flat circular presser feet shall be 18 ± 0.5 mm (0.71 ± 0.02 in.) in diameter. These durometer types shall be used in an operating stand (see 5.1.2).

(a) Durometers having a presser feet configuration other than that indicated in 5.1.1.3 shall not use the Type *xR* designation, and it is recommended that their presser foot configuration and size be stated in the Hardness Measurement Report (see 10.2.4).

5.1.1.4 *Presser Foot, Type M*, with a centrally located orifice (to allow for the protrusion of the indentor), having a diameter as specified in Fig. 1 (d), with the center a minimum of 1.60 mm (0.063 in.) from any edge of the flat circular presser foot. The Type M durometer shall be used in a Type 3 operating stand (see 5.1.2.4).

5.1.1.5 *Indentor*, formed from steel rod and hardened to 500 HV10 and shaped in accordance with Fig. 1 (a, b, c, d, e, or g), polished over the contact area so that no flaws are visible under 20× magnification, with an indentor extension of 2.50 ± 0.04 mm (0.098 ± 0.002 in.).

5.1.1.6 *Indentor, Type OOO-S*, formed from steel rod and hardened to 500 HV10, shaped in accordance with Fig. 1 (f), polished over the contact area so that no flaws are visible under 20× magnification, with an indentor extension of 5.00 ± 0.04 mm (0.198 ± 0.002 in.).

5.1.1.7 *Indentor, Type M*, formed from steel rod and hardened to 500 HV10 and shaped in accordance with Fig. 1 (d), polished over the contact area so that no flaws are visible under 50× magnification, with an indentor extension of 1.25 ± 0.02 mm (0.049 ± 0.001 in.).

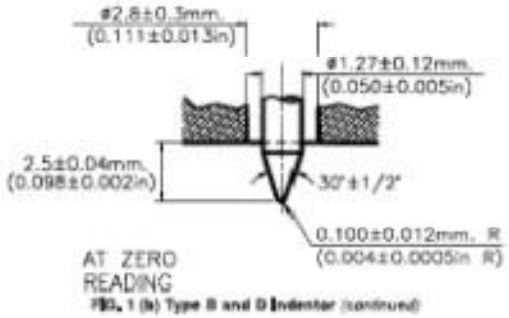


FIG. 1 (b) Type B and B Indentor (continued)

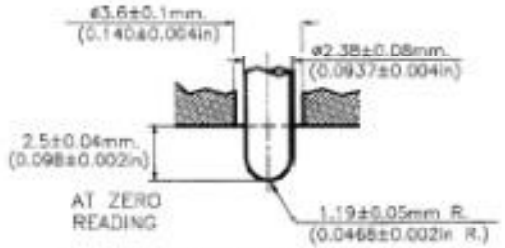


FIG. 1 (c) Type O, OO, and OO Indentor (continued)

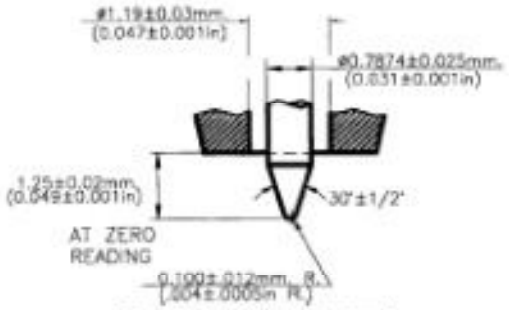


FIG. 1 (d) Type M Indentor (continued)

5.1.1.8 *Indentor Extension Indicator*, analog or digital electronic, having a display that is an inverse function of the indentor extension so that:

(1) The display shall indicate from 0 to 100 with no less than 100 equal divisions throughout the range at a rate of one hardness point for each 0.025 mm (0.001 in.) of indentor movement,

(2) The display for Type OOO-S durometers shall indicate from 0 to 100 with no less than 100 equal divisions throughout the range at a rate of one hardness point for each 0.050 mm (0.002 in.) of indentor movement,

(3) The display for Type M durometers shall indicate from 0 to 100 with no less than 100 equal divisions at a rate of one hardness point for each 0.0125 mm (0.0005 in.) of indentor movement, and

(4) In the case of analog dial indicators having a display of 360°, the points indicating 0 and 100 may be at the same point on the dial and indicate 0, 100, or both.

5.1.1.9 *Timing Device (optional)*, capable of being set to a desired elapsed time, signaling the operator or holding the hardness reading when the desired elapsed time has been reached. The timer shall be automatically activated when the presser foot is in contact with the specimen being tested, for example, the initial indentor travel has ceased. Digital electronic durometers may be equipped with electronic timing devices that shall not affect the indicated reading or determinations attained by more than one-half of the calibration tolerance stated in Table 1.

5.1.1.10 *Maximum Indicators (optional)*, maximum indicating pointers are auxiliary analog indicating hands designed to

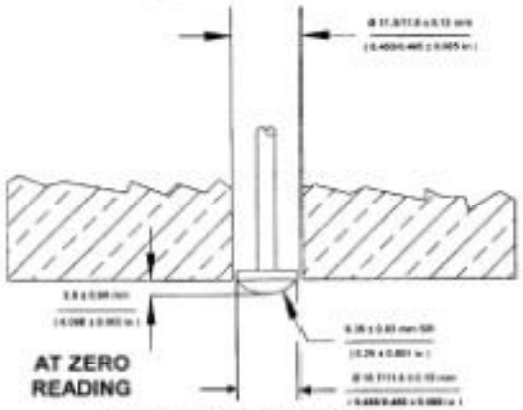


FIG. 1 (e) Type OOO Indenter (continued)

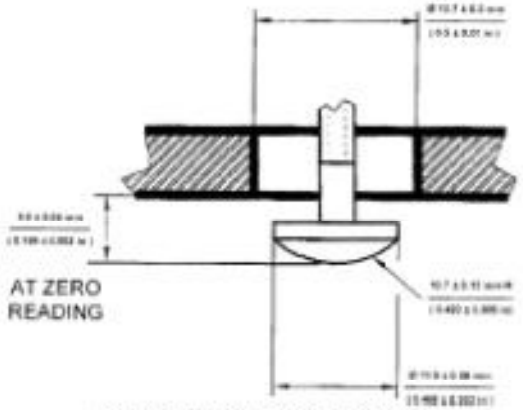


FIG. 1 (f) Type OOO-S Indenter (continued)

remain at the maximum hardness value attained until reset by the operator. Electronic maximum indicators are digital displays electronically indicating and maintaining the maximum value hardness valued achieved until reset by the operator.

5.1.1.11 Analog maximum indicating pointers have been shown to have a nominal effect on the values attained, however, this effect is greater on durometers of lesser total mainspring loads; for example, the effect of a maximum indicating pointer on Type D durometer determinations will be less than those determinations achieved using a Type A durometer. Analog style durometers may be equipped with maximum indicating pointers. The effect of a maximum indicating pointer shall be noted at the time of calibration in the calibration report (see 10.1.5), and when reporting hardness determinations (see 10.2.4). Analog Type M, OO, OOO, and Type OOO-S durometers shall not be equipped with maximum indicating pointers.

5.1.1.12 Digital electronic durometers may be equipped with electronic maximum indicators that shall not affect the indicated reading or determinations attained by more than one half of the spring calibration tolerance stated in Table 1.

5.1.1.13 *Calibrated Spring*, for applying force to the indentor, in accordance with Fig. 1 (a through g) and capable of applying the forces as specified in Table 1.

5.1.2 *Operating Stand* (Fig. 2):

5.1.2.1 Type 1, Type 2, and Type 3 shall be capable of supporting the durometer presser foot surface parallel to the specimen support table (Fig. 3) throughout the travel of each. The durometer presser foot to specimen support table parallelism shall be verified each time the test specimen support table is adjusted to accommodate specimens of varying dimensions. This may be accomplished by applying the durometer presser foot to the point of contact with the specimen support table and making adjustments by way of the durometer mounting assembly or as specified by the manufacturer.

5.1.2.2 *Operating Stand, Type 1* (specimen to indentor type), shall be capable of applying the specimen to the indentor in a manner that minimizes shock.

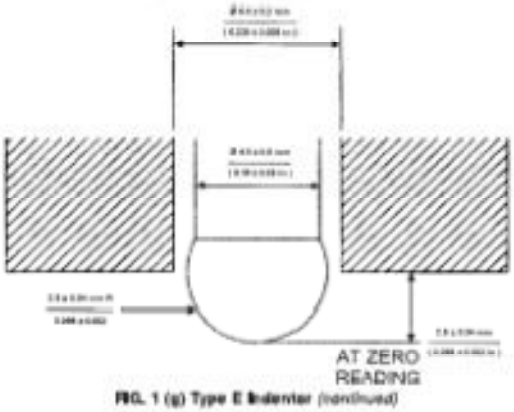


FIG. 1 (g) Type E Indenter (continued)

TABLE 1 Durometer Spring Force Calibration[A]
All Values are in N

Indicated Value	Type A, B, E, O	Type C, O, OO	Type M	Type OO, OOO	Type OOO-S
0	0,55	0	0,324	0,053	0,147
10	1,3	0,445	0,368	0,244	0,343
20	3,05	0,89	0,412	0,385	0,520
30	5,8	13,335	0,456	0,476	0,698
40	8,55	17,78	0,5	0,566	0,875
50	12,3	22,225	0,544	0,657	1,049
60	16,05	26,67	0,589	0,748	1,226
70	20,8	31,115	0,633	0,839	1,402
80	26,55	35,56	0,677	0,93	1,579
90	33,3	40,005	0,721	1,02	1,756
100	44,45	44,45	0,765	1,111	1,932
Nidurometer unit	0,075	0,4445	0,0044	0,00108	0,01765
Spring Calibration Tolerance	± 0,075 N	± 0,4445 N	± 0,0178 N	± 0,0100 N	± 0,0353 N

[A] Refer to 5.1.1.3 for the Type of designation.

5.1.2.3 *Operating Stand, Type 2* (indentor to specimen type), shall be capable of controlling the rate of descent of the indentor to the specimen at a maximum of 3.20 mm/s (0.125 in./s) and applying a force sufficient to overcome the calibrated spring force as shown in Table 1.

5.1.2.4 *Operating Stand, Type 3* (indentor to specimen type), hydraulic dampening, pneumatic dampening, or electromechanical (required for the operation of Type M durometers) shall be capable of controlling the rate of descent of the indentor to the specimen at a maximum of 3.2 mm/s (0.125 in./s) and applying a force sufficient to overcome the calibrated spring force as shown in Table 1. Manual application, Type 1 or Type 2 operating stands are not acceptable for Type M durometer operation.

5.1.2.5 The entire instrument should be plumb and level, and resting on a surface that will minimize vibration. Operating the instrument under adverse conditions will negatively affect the determinations attained.

5.1.2.6 *Specimen Support Table*, (Fig. 3) integral to the operating stand, and having a solid flat surface. The specimen support platform may have orifices designed to accept various inserts or support fixtures (Fig. 3) to provide for the support of irregularly configured specimens. When inserts are used to support test specimens, care must be taken to align the indentor to the center of the insert, or the point at which the indentor is to contact the specimen. Care should be exercised to assure that the indentor does not abruptly contact the specimen support table as damage to the indentor may result.

6. Test Specimen

6.1 The test specimens, herein referred to as "specimen" or "test specimen" interchangeably, shall be at least 6.0 mm (0.24 in.) in thickness unless it is known that results equivalent to the 6.0-mm (0.24-in.) values are obtained with a thinner specimen.

6.1.1 A specimen may be composed of plied pieces to obtain the necessary thickness, but determinations made on such specimens may not agree with those made on solid specimens, as the surfaces of the plied specimens may not be in complete contact. The lateral dimensions of the specimen shall be sufficient to permit measurements at least 12.0 mm (0.48 in.) from any edge, unless it is known that identical results are obtained when measurements are made at a lesser distance from an edge.

6.1.2 The surfaces of the specimen shall be flat and parallel over an area to permit the presser foot to contact the specimen over an area having a radius of at least 6.0 mm (0.24 in.) from

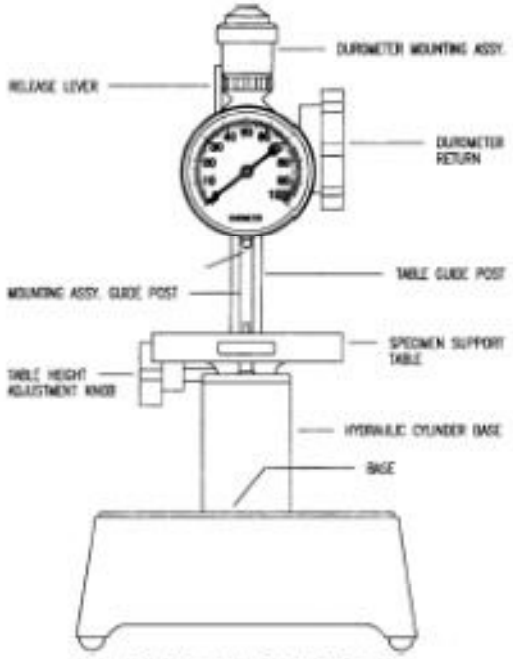
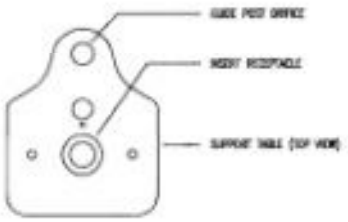


FIG. 2 Durometer Operating Stand



TYPICAL TABLE INSERTS USED FOR POSITIONING TUBING, O-RINGS AND SMALL SPECIMENS

FIG. 3 Small Specimen Support Table

the indentor point. The specimen shall be suitably supported to provide for positioning and stability. *A suitable hardness determination cannot be made on an uneven or rough point of contact with the indentor.*

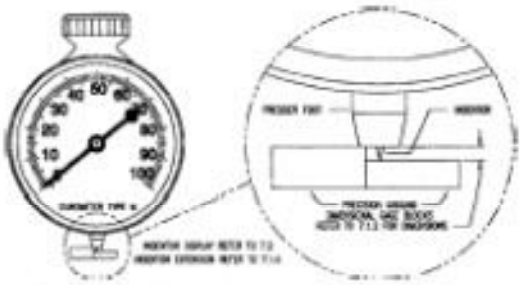


FIG. 4 Detail of Indentor Extension and Display Adjustment

6.2 Type OOO, OOO-S, and M test specimens should be at least 1.25 mm (0.05 in.) in thickness, unless it is known that results equivalent to the 1.25-mm (0.05-in.) values are obtained with a thinner specimen.

6.2.1 A Type M specimen that is not of a configuration described in 6.2.2 may be composed of plied pieces to obtain the necessary thickness, but determinations made on such specimens may not agree with those made on solid specimens because the surfaces of the plied specimens may not be in complete contact. The lateral dimensions of the specimen should be sufficient to permit measurements at least 2.50 mm (0.10 in.) from any edge unless it is known that identical results are obtained when measurements are made at lesser distance from an edge. *A suitable hardness determination cannot be made on an uneven or rough point of contact with the indentor.*

6.2.2 The Type M specimen, when configured as an o-ring, circular band, or other irregular shape shall be at least 1.25 mm (0.05 in.) in cross-sectional diameter, unless it is known that results equivalent to the 1.25-mm (0.05-in.) values are obtained with a thinner specimen. The specimen shall be suitably supported in a fixture (Fig. 3) to provide for positioning and stability.

6.3 The minimum requirement for the thickness of the specimen is dependent on the extent of penetration of the indentor into the specimen; for example, thinner specimens may be used for materials having higher hardness values. The minimum distance from the edge at which measurements may be made likewise decreases as the hardness increases.

7. Calibration

7.1 *Indentor Extension Adjustment Procedure:*

7.1.1 Place precision ground dimensional blocks (Grade B or better) on the support table and beneath the durometer presser foot and indentor. Arrange the blocks so that the durometer presser foot contacts the larger block(s) and the indentor tip just contacts the smaller block (Fig. 4). It is necessary to observe the arrangement of the blocks and the presser foot/indentor under a minimum of 20× magnification to assure proper alignment.

7.1.2 Indentor extension and shape shall be in accordance with 5.1.1.5, 5.1.1.6, or 5.1.1.7, respective to durometer type. See Fig. 1 (a through g). Examination of the indentor under 20× magnification, 50× for Type M indentors, is required to examine the indentor condition. Misshapen or damaged indentors shall be replaced.

7.1.3 A combination of dimensional gage blocks shall be used to achieve a difference of 2.54 + 0.00/−0.0254 mm (0.100 + 0.00/−0.001 in.) between them. For Type OOO-S durometers, the gage block dimensions are 5.08 + 0.00/−0.0508 mm (0.200 + 0.00/−0.002 in.). For Type M durometers, the gage block dimensions are 1.27 + 0.00/−0.0127 mm (0.050 + 0.00/−0.0005 in.) between them (Fig. 4).

7.1.4 Carefully lower the durometer presser foot until it contacts the largest dimensional block(s), the indentor tip should just contact the smaller block, verifying full indentor extension.

7.1.5 Adjust the indentor extension to 2.50 ± 0.04 mm (0.098 ± 0.002 in.). For Type OOO-S durometers, adjust the indentor extension to 5.0 ± 0.04 mm (0.196 ± 0.002 in.). For Type M durometers, adjust the indentor extension to 1.25 ± 0.02 mm (0.049 ± 0.001 in.), following the manufacturer's recommended procedure.

7.1.5.1 When performing the procedures in 7.1, care should be used so as not to cause damage to the indentor tip. Fig. 4 depicts a suitable arrangement for gaging indentor extension.

7.1.6 Parallelism of the durometer presser foot to the support surface, and hence the dimensional gage blocks, at the time of instrument calibration, may be in accordance with Test Methods D374, Machinist's Micrometers, or otherwise accomplished in accordance with the procedures specified by the manufacturer.

7.2 *Indentor Display Adjustment:*

7.2.1 After adjusting the indentor extension as indicated in 7.1, use a similar arrangement of dimensional gage blocks to verify the linear relationship between indentor travel and indicated display at two points: 0 and 100. Following the manufacturer's recommendations, make adjustments so that:

7.2.2 The indicator displays a value equal to the indentor travel measured to within:

−0.0 +1.0 durometer units measured at 0;

±0.50 durometer units measured at 100;

±1 durometer units at all other points delineated in 7.4.

7.2.3 Each durometer point indicated is equal to 0.025 mm (0.001 in.) of indentor travel, except for:

7.2.3.1 Type M Durometers, each indicated point is equal to 0.0125 mm (0.0005 in.) of indentor travel;

7.2.3.2 Type OOO-S Durometers, each indicated point is equal to 0.050 mm (0.002 in.) of indentor travel.

7.2.4 The indicator shall not display a value greater than 100 or less than 0 at the time of calibration.

7.2.5 Other means of determining indentor extension or indentor travel, such as optical or laser measurement methods, are acceptable. The instrumentation used shall have traceability as described in 1.4.

7.2.6 The durometer shall be supported in a suitable fashion when performing the procedures described in 7.1 and 7.2.

7.3 *Calibration Device:*

7.3.1 The durometer spring shall be calibrated by supporting the durometer in a calibrating device, see Fig. 5, in a vertical position and applying a measurable force to the indentor tip. The force may be measured by means of a balance

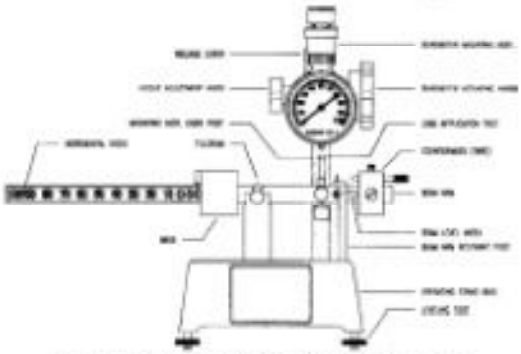


FIG. 5 Example of Durometer Calibration Apparatus

as depicted in Fig. 5, or an electronic force cell. The calibrating device shall be capable of measuring applied force to within 0.5 % of the maximum spring force necessary to achieve 100 durometer units.

7.3.2 Care should be taken to ensure that the force is applied vertically to the indentor tip, as lateral force will cause errors in calibration. See 7.1.5.1 and 7.1.6.

7.4 *Spring Calibration*—The durometer spring shall be calibrated at displayed readings of 10, 20, 30, 40, 50, 60, 70, 80, and 90. The measured force (9.8× mass in kilograms) shall be within the spring calibration tolerance specified in Table 1. Table 1 identifies the measured force applied to the indenter for the entire range of the instrument, although it is necessary only to verify the spring calibration at points listed herein.

7.5 *Spring Calibration Procedure:*

7.5.1 Ensure that the indentor extension has been adjusted in accordance with 7.1, and the linear relationship between indentor travel and display is as specified in 7.2.

7.5.2 Place the durometer in the calibration device as depicted in Fig. 5. Apply the forces indicated in Table 1 so that forces applied are aligned with the centerline of the indenter in a fashion that eliminates shock or vibration and adjust the durometer according to manufacturers' recommendations so that:

7.5.3 At the points enumerated in 7.4, the display shall indicate a value equal to 0.025 mm (0.001 in.) of indentor travel. For Type OOO-S durometers, the display shall indicate a value equal to 0.05 mm (0.002 in.) of indentor travel. For Type M durometers, the display shall indicate a value equal to 0.0125 mm (0.0005 in.) of indentor travel within the spring calibration tolerances specified in 7.6.

7.6 Spring calibration tolerances are ±1.0 durometer units for Types A, B, C, D, E, O, and DO, ±2.0 durometer units for Types OO, OOO, and OOO-S, and ±4.0 durometer units for Type M, while not indicating below 0 or above 100 at the time of calibration (see Table 1).

7.7 *Spring Force Combinations:*

7.7.1 For Type A, B, E, and O durometers:
Force, N = 0.55 + 0.075 HA
Where HA = hardness reading on Type A, B, E, and O durometers.

7.7.2 For Type C, D, and DO durometers:
Force, N = 0.4445 HD
Where HD = hardness reading on Type C, D, and DO durometers.

7.7.3 For Type M durometers:
Force, N = 0.324 + 0.0044 HM
Where HM = hardness reading on Type M durometers.

7.7.4 For Type OO and OOO durometers:
Force, N = 0.203 + 0.00908 HOO
Where HOO = hardness reading on Type OO durometers.

7.7.5 For Type OOO-S durometers:
Force, N = 0.167 + 0.01765 HOOO-S
Where HOOO-S = hardness reading on Type OOO-S durometers.

7.8 The rubber reference block(s) provided for verifying durometer operation and state of calibration are not to be relied upon as calibration standards. The calibration procedures outlined in Section 7 are the only valid calibration procedures.

7.8.1 The use of metal reference blocks is no longer recommended (see Note 2).

7.9 Verifying the state of durometer calibration, *during routine use*, may be accomplished by:

7.9.1 Verifying that the zero reading is no more than 1 indicated point above zero, and not below zero (on durometers so equipped), when the durometer is positioned so that no external force is placed upon the indentor.

7.9.2 Verifying that the 100 reading is no more than 100 and no less than 99 when the durometer is positioned on a flat surface of a non-metallic material so that the presser foot is in complete contact, causing the indentor to be fully retracted.

7.9.2.1 It is important that when performing the verification of 100, as described in 7.9.2, that extreme care be taken so as to not cause damage to the indentor. Verification of the 100 value is not recommended for durometers having a spring force greater than 10 N (Types C, D, and DO).

7.9.2.2 When performing the verification of 100, as described in 7.9.2, the non-metallic material shall be of a hardness value greater than 100 of the type (scale) of the durometer being employed. Tempered glass of a thickness greater than 6.35 mm (0.25 in.) has been found satisfactory for this application.

7.9.3 Verifying the displayed reading at any other point using commercially available rubber reference blocks which are certified to a stated value of the type (scale) of the durometer being employed. The displayed value of the durometer should be within ±2 durometer points of the reference block's stated value.

7.9.4 Verification of the zero and 100 readings of a durometer provide reasonable assurance that the linear relationship between the indicated display and the durometer mechanism remain valid.

7.9.5 Verification of points between zero and 100 provide reasonable assurance that the curvilinear relationship between the indicated display and the durometer mechanism remain valid.

7.9.6 *This is not a calibration procedure, it is a means by which a user may routinely verify that the durometer may be functioning correctly.* (See Note 2.)

8. Laboratory Atmosphere and Test Specimen Conditioning

8.1 Tests shall be conducted in the standard laboratory atmosphere, as defined in Practice D618, Section 4.2.

8.2 The instrument shall be maintained in the standard laboratory atmosphere, as defined in Practice D618, Section 4.1, for 12 h prior to performing a test.

8.3 The specimen shall be conditioned in accordance with condition 40/23 exclusive of humidity control, as described in Practice D618, Section 8.1, Procedure A and tested under the same conditions, exclusive of humidity control.

8.4 These procedures may be modified if agreed upon between laboratories or between supplier and user and are in accordance with alternative procedures identified in Practice D618.

8.5 No conclusive evaluation has been made on durometers at temperatures other than 23.0 ± 2.0°C (73.4 ± 3.6°F). Conditioning at temperatures other than the above may show changes in calibration. Durometer use at temperatures other than the above should be decided locally (see Practice D1349).

9. Procedure

9.1 *Operating Stand Operation (Type S Operating Stand Required for Type M):*

9.1.1 Care shall be exercised to minimize the exposure of the instrument to environmental conditions that are adverse to the performance of the instrument, or adversely affect test results.

9.1.2 Adjust the presser foot to support table parallelism as described in 5.1.2.1. It is necessary to make this adjustment each time the support table is moved to accommodate specimens of varying dimensions.

9.1.3 Prior to conducting a test, adjust the vertical distance from the presser foot to the contact surface of the test specimen to 25.4 ± 2.5 mm (1.00 ± 0.100 in.), unless it is known that identical results are obtained with presser foot at a greater or lesser vertical distance from the test specimen contact surface, or if otherwise stipulated by the manufacturer.

9.1.4 Place the specimen on the specimen support table, in a manner that the contact point of the indentor is in accordance with Section 6, unless it is known that identical results are obtained when measurements are made with the indentor at a lesser distance from the edge of the test specimen.

9.1.5 Actuate the release lever (Fig. 2) of the operating stand or activate the electromechanical device, allowing the durometer to descend at a controlled rate and apply the presser foot to the specimen in accordance with 5.1.2. In the case of "specimen to indentor" type operating stands, operate the lever or other mechanism to apply the specimen to the indentor in a manner that assures parallel contact of the specimen to the durometer presser foot without shock and with just sufficient force to overcome the calibrated spring force as shown in Table 1.

9.1.6 An operating stand that applies the mass at a controlled rate of descent, without shock is mandatory for Type M durometers. Hand-held application or the use of a Type 1 or Type 2 operating stand for the Type M durometer is not an acceptable practice, see 5.1.2.4.

9.1.7 For any material covered in 1.1, once the presser foot is in contact with the specimen, for example, when the initial indentor travel has ceased, the maximum indicated reading shall be recorded. The time interval of 1 s, between initial indentor travel cessation and the recording of the indicated reading, shall be considered standard. Other time intervals, when agreed upon among laboratories or between supplier and user, may be used and reported accordingly. The indicated hardness reading may change with time.

9.1.7.1 If the durometer is equipped with an electronic maximum indicator or timing device (refer to 5.1.1.9) the indicated reading shall be recorded within 1 ± 0.1 s of the cessation of indentor travel and reported (refer to 10.2.9 for reporting protocols), unless otherwise noted.

9.1.7.2 If the durometer is equipped with an analog type maximum indicator (refer to 5.1.1.10), the maximum indicated reading may be recorded and shall be reported (refer to 10.2.9), unless otherwise noted.

9.1.7.3 If the durometer is not equipped with the devices described in 5.1.1.9 or 5.1.1.10, the indicated reading shall be recorded within 1 s as is possible and reported (refer to 10.2.9), unless otherwise noted.

9.1.8 Make five determinations of hardness at different positions on the specimen at least 6.0 mm (0.24 in.) apart, 0.80 mm (0.030 in.) apart for Type M, and calculate the arithmetic mean, or alternatively calculate the median. The means of calculating the determinations shall be reported according to 10.2.8.

9.2 *Manual (Hand Held) Operation of Durometer:*

9.2.1 Care shall be exercised to minimize the exposure of the instrument to environmental conditions that are adverse to the performance of the instrument, or adversely affect test results.

9.2.2 Place the specimen on a flat, hard, horizontal surface. Hold the durometer in a vertical position with the indentor tip at a distance from any edge of the specimen as described in Section 6, unless it is known that identical results are obtained when measurements are made with the indentor at a lesser distance.

9.2.3 Apply the presser foot to the specimen, maintaining it in a vertical position keeping the presser foot parallel to the specimen, with a firm smooth downward action that will avoid shock, rolling of the presser foot over the specimen, or the application of lateral force. Apply sufficient pressure to assure firm contact between the presser foot and the specimen.

9.2.4 For any material covered in 1.1, after the presser foot is in contact with the specimen, the indicated reading shall be recorded within 1 ± 0.1 s, or after any period of time agreed upon among laboratories or between supplier and user. If the

TABLE 2 Type 1 Precision—Type M Durometer Method

Material	Average Level	Within Laboratories			Between Laboratories		
	MEAN	$(Sr)^A$	r^B	$(r)^C$	$(SR)^D$	R^E	$(R)^F$
1	31,8	1,36	3,78	11,94	3,16	10,63	33,41
2	48,8	1,14	3,23	7,00	2,47	7,00	17,13
3	64,0	0,975	2,76	5,11	2,39	6,73	12,46
4	82,8	0,792	2,21	3,53	2,24	6,34	10,16
5	76,9	0,788	2,21	3,83	0,874	2,76	3,69
6	80,6	1,686	4,77	5,92	1,61	4,58	5,61
7	87,7	1,15	3,25	3,71	2,63	7,45	8,50
8	32,4	0,947	2,68	8,26	3,84	10,79	31,73
9	41,8	0,797	2,26	5,48	2,13	6,01	15,11
10	53,9	0,669	1,89	3,55	2,29	6,48	12,17
11	63,9	0,495	1,37	2,17	2,19	6,20	9,80
12	63,6	0,737	2,09	3,68	0,99	2,80	4,62
13	78,3	0,794	2,23	2,84	1,04	2,94	3,75
14	87,6	1,121	3,17	3,62	2,65	7,48	8,55
15	34,1	0,95	2,69	7,85	1,94	5,50	15,55
16	42,3	0,535	1,49	4,25	1,70	3,30	8,01
17	64,6	0,55	1,53	2,80	3,15	8,89	11,15
18	63,8	1,13	3,17	5,04	1,47	4,16	6,61
19	76,3	0,589	1,65	2,77	0,944	2,67	3,60
20	81,7	0,483	1,37	1,67	1,10	3,10	3,80
21	87,9	0,673	1,49	1,69	2,67	5,86	6,67
AVERAGE	61,6						
POOLED VALUES		0,934	2,62	4,26	2,148	6,07	9,89

^{A} Sr = repeatability standard deviation, measurement units.
^{B} r = repeatability = 2,83 × Sr, measurement units.
^{C} (r) = repeatability, relative, (that is, in percent).
^{D} SR = reproducibility standard deviation, measurement units.
^{E} R = reproducibility = 2,83 × SR, measurement units.
^{F} (R) = reproducibility, relative, (that is, in percent).

TABLE 3 Type 1 Precision—Type A Durometer Method

Material	Average Level	Within Laboratories			Between Laboratories		
		$(Sr)^A$	r^B	$(r)^C$	$(SR)^D$	R^E	$(R)^F$
1	51,0	0,646	1,83	3,58	1,56	4,41	8,64
2	65,0	0,679	1,92	2,91	2,21	6,26	9,27
3	80,0	0,433	1,23	1,53	2,29	6,45	8,06
Pooled	67,0	0,677	1,92	3,11	2,018	5,72	8,54

^{A} Sr = repeatability standard deviation, measurement units.
^{B} r = repeatability = 2,83 × Sr, measurement units.
^{C} (r) = repeatability, relative, (that is, in percent).
^{D} SR = reproducibility standard deviation, measurement units.
^{E} R = reproducibility = 2,83 × SR, measurement units.
^{F} (R) = reproducibility, relative, (that is, in percent).

TABLE 4 Type 1 Precision—Type D Durometer Method

Material	Average Level	Within Laboratories			Between Laboratories		
		$(Sr)^A$	r^B	$(r)^C$	$(SR)^D$	R^E	$(R)^F$
1	40,8	0,316	0,894	2,19	2,62	7,39	18,2
2	54,5	0,791	2,24	4,11	3,54	10,0	18,4
3	80,3	1,01	2,86	3,47	3,54	10,0	12,2
Pooled	58,8	0,762	2,16	3,61	3,32	9,40	15,7

^{A} Sr = repeatability standard deviation, measurement units.
^{B} r = repeatability = 2,83 × Sr, measurement units.
^{C} (r) = repeatability, relative, (that is, in percent).
^{D} SR = reproducibility standard deviation, measurement units.
^{E} R = reproducibility = 2,83 × SR, measurement units.
^{F} (R) = reproducibility, relative, (that is, in percent).

durometer is equipped with a maximum indicator, the maximum indicated reading shall be recorded within 1 ± 0.1 s of the cessation of initial indenter travel. The indicated hardness reading may change with time.

9.2.5 Make five determinations of hardness at different positions on the specimen at least 6.0 mm (0.24 in.) apart and calculate the arithmetic mean, or alternatively calculate the median. The means of calculating the determinations shall be reported according to 10.2.8.

9.3 It is acknowledged that durometer readings below 20 or above 90 are not considered reliable. It is suggested that readings in these ranges not be recorded.

9.4 Manual operation (handheld) of a durometer will cause variations in the results attained. Improved repeatability may be obtained by using a mass, securely affixed to the durometer and centered on the axis of the indenter. Recommended masses are 1 kg for Type A, B, E, and O durometers, 5 kg for Type C, D, and DO durometers, and 400 g for Type OO, OOO, and OOO-S durometers. The introduction of an additional mass on Type M durometers is not permitted. Further improvement may be achieved by the use of a durometer operating stand that controls the rate of descent of the durometer presser foot to the test specimen and incorporates the masses described above.

10. Report

10.1 *Instrument Calibration Report (Durometer or Operating Stand):*

10.1.1 Date of calibration.

10.1.2 Date of last calibration.

10.1.3 Calibration due date (see Note 2).

10.1.4 Manufacturer, type, model, and serial number of the instrument, and a notation when a maximum indicator or timing device is present.

10.1.5 Values obtained (pre- and post-calibration results), including a notation of the effect of a maximum indicator, if present. The method of reporting the calibrated value shall be by attaining the arithmetic mean of the determinations.

10.1.6 Ambient temperature.

10.1.7 Relative humidity.

10.1.8 Technician identification.

10.1.9 Applicable standards to which the instrument is calibrated.

10.1.10 Calibrating instrument information to include type, serial number, manufacturer, date of last calibration, calibration due date (see Note 2), and a statement of traceability of standards used to NIST or other acceptable organization. See 1.4.

10.2 *Hardness Measurement Report:*

10.2.1 Date of test.

10.2.2 Relative humidity.

10.2.3 Ambient temperature.

10.2.4 Manufacturer, type, and serial number of the durometer or operating stand, or both, including a notation when a maximum indicator or timing device is present, date of last calibration, and calibration due date (see Note 2).

NOTE 2—The calibration interval (calibration due date) for a durometer is to be determined by the user, based upon frequency of use, severity of conditions, environmental factors, and other variables.

Periodic checking of the operation and state of durometer calibration using commercially available rubber test blocks (refer to 7.8), specifically designed for this purpose, is recommended.

An instrument that has been exposed to severe shock, is visibly damaged, produces test determinations more than 2 points different from calibrated rubber test blocks or other reference standard, or is otherwise

suspected of unreliability, should be removed from service and returned to a qualified calibration facility.

A calibration interval of one year is recommended for durometer test blocks and durometer instruments that are infrequently used, more often for others.

The calibration interval for instruments and peripheral devices employed in the calibration of durometers is to be determined by the calibration service provider. It is recommended that the protocols outlined in ISO/IEC 17025, as required by the manufacturer, and those to which the service is provided, be followed.

10.2.5 Means of testing, whether manual (hand held), Type 1 operating stand (specimen to indenter), Type 2 operating stand (indenter to specimen type), or Type 3 operating stand (electromechanical or hydraulically dampened).

10.2.6 Description of test specimen, including thickness, number of pieces piled if less than the thickness indicated in Section 6, including the vulcanization date.

10.2.7 Complete identification of material tested.

10.2.8 Hardness value obtained and method of calculation, either arithmetic mean or alternatively, the median.

10.2.9 Indentation hardness time interval at which determination was made. Readings may be reported in the form: M/60/1 where M is the type of durometer, 60 the reading, and 1 the time in seconds that the presser foot is in contact with the specimen or from an electronic timing device.

11. Precision and Bias

11.1 These precision and bias statements have been prepared in accordance with Practice D4483. Refer to this Practice for terminology and other testing and statistical concepts.

11.2 The Type 1 precision for the Type M method was determined from an interlaboratory program with 21 materials of varying hardness, with six participating laboratories. Tests were conducted on two separate days in each laboratory for the Type M testing program. All materials were supplied from a single source, being those commonly supplied as reference materials with the instruments from the manufacturer.

11.3 The precision results in this precision and bias section give an estimate of the precision of this test method with the materials (rubbers) used in the particular interlaboratory program as described above. The precision parameters should not be used for acceptance or rejection testing, or both, of any group of materials without documentation that they are applicable to those particular materials and the specific testing protocols that include this test method.

11.4 The Type 1 precision for both Type A and D methods was determined from an interlaboratory program with 3 materials of varying hardness, with six participating laboratories. Tests were conducted on two separate days in each laboratory for both A and D testing programs. All materials were supplied from a single source.

11.5 A test result for hardness, for Types A, D, and M, was the median of five individual hardness readings on each day in each laboratory.

11.6 Table 2 shows the precision results for Type M method.[4] Table 3 shows the precision results for Type A method,[5] and Table 4 gives the precision results for Type D method.[5]

11.7 *Precision*—The precision of this test method may be expressed in the format of the following statements which use as appropriate value *r*, *R*, *(r)*, or *(R)*, that is, that value to be used in decisions about test results (obtained with the test method). The appropriate value is that value of *r* or *R* associated with a mean level in Table 1 closest to the mean level under consideration (at any given time, for any given material) in routine testing operations.

NOTE 5—A Type 1 precision statement for Types B, OOO, OOO-S, and R have not yet been made available.

11.7.1 *Repeatability*—The repeatability, *r*, of these test methods has been established as the appropriate value tabulated in Tables 2–4. Two single test results, obtained under normal test method procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or non-identical sample populations.

11.7.2 *Reproducibility*—The reproducibility, *R*, of these test methods has been established as the appropriate value tabulated in Tables 2–4. Two single test results obtained in two different laboratories, under normal test method procedures, that differ by more than the tabulated *R* (for any given level) must be considered to have come from different or non-identical sample populations.

11.7.3 Repeatability and reproducibility are expressed as a percentage of the mean level, *(r)* and *(R)*, and have equivalent application statements as above for *r* and *R*. For the *(r)* and *(R)* statements, the difference in the two single test results is expressed as a percentage of the arithmetic mean of the two test results.

11.8 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since the value (of the test property) is exclusively defined by this test method. Bias, therefore cannot be determined.

12. Keywords

12.1 durometer; durometer hardness; hardness; indentation hardness; micro durometer hardness

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D11-1091.

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D11-1019.

APPENDIXES

(Nonmandatory Information)

X1. DUROMETER SELECTION GUIDE

X1.1 The durometer selection guide is designed to assist in the selection of the proper durometer type for various applications.

TABLE X1.1 Durometer Selection: Typical Uses

Type (Scale)	Typical Examples of Materials Tested	Durometer Hardness (Typical Use)
A	Soft vulcanized rubber, natural rubber, nitriles, thermoplastic elastomers, flexible polyvinyls and thermosets, wax, felt, and leathers	20–90 A
B	Moderately hard rubber, thermoplastic elastomers, paper products, and fibrous materials	Above 90 A Below 20 D
C	Medium-hard rubber, thermoplastic elastomers, medium-hard plastics, and thermoplastics	Above 50 B Below 20 D
D	Hard rubber, thermoplastic elastomers, harder plastics, and rigid thermoplastics	Above 40 A
DO	Moderately hard rubber, thermoplastic elastomers, and very dense textile windings	Above 90 C Below 20 D
M	Thin, irregularly shaped rubber, thermoplastic elastomer, and plastic specimens	Same as A
O	Soft rubber, thermoplastic elastomers, very soft plastics and thermoplastics, medium-density textile windings	Below 70 OO
OO	Extremely soft rubber, thermoplastic elastomers, sponge, extremely soft plastics and thermoplastics, foams, low-density textile windings, human and animal tissue	Below 20 O
CF	Composite foam materials, such as amusement ride safety cushions, vehicle seats, dashboards, headrests, armrests, and door panels	See Test Method F1957

X1.2 It is generally recognized that durometer hardness determination below 20 and above 90 are unreliable. It is recommended that the next lower or higher type (scale) be used in these situations.

X1.3 It is also recommended that, whenever possible, an operating stand be employed in performing durometer hardness tests.

X2. RELATED TEST METHODS[2]

C367 Test Methods for Strength Properties of Prefabricated Architectural Acoustical Tile or Lay-in Ceiling Panels

C473 Test Methods for Physical Testing of Gypsum Panel Products

C581 Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service

C661 Test Method for Indentation Hardness of Elastomeric-Type Sealants by Means of a Durometer

C836 Specification for High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane for Use with Separate Wearing Course

D461 Test Methods for Felt

D531 Test Method for Rubber Property—Pusey and Jones Indentation

D619 Test Methods for Vulcanized Fibre Used for Electrical Insulation

D1037 Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials

D1054 Test Method for Rubber Property—Resilience Using a Goodyear-Healey Rebound Pendulum

D1414 Test Methods for Rubber O-Rings

D1474 Test Methods for Indentation Hardness of Organic Coatings

D2134 Test Method for Determining the Hardness of Organic Coatings with a Sward-Type Hardness Rocker

D2287 Specification for Nonrigid Vinyl Chloride Polymer and Copolymer Molding and Extrusion Compounds

D2583 Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor

D2632 Test Method for Rubber Property—Resilience by Vertical Rebound

D4289 Test Method for Elastomer Compatibility of Lubricating Greases and Fluids

D5672 Test Method for Flexible Cellular Materials Measurement of Indentation Force Deflection Using a 25-mm (1-in.) Deflection Technique

D6546 Test Methods for and Suggested Limits for Determining Compatibility of Elastomer Seals for Industrial Hydraulic Fluid Applications

F1151 Test Method for Determining Variations in Hardness of Film Ribbon Pancakes

NOTE X2.1—The hardness testing of other nonmetallic materials may be under the jurisdiction of one or more ASTM committees; the respective committee should be contacted for specific information.

ANEXO No. 6: ASTM D6110: Standard test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics

Designation: D6110 – 10

Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics[1]

This standard is issued under the fixed designation D6110; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method is used to determine the resistance of plastics to breakage by flexural shock as indicated by the energy extracted from standardized (see Note 1) pendulum-type hammers, mounted in standardized machines, in breaking standard specimens with one pendulum swing. This test method requires specimens to be made with a milled notch (see Note 2). The notch produces a stress concentration which promotes a brittle, rather than a ductile, fracture. The results of this test method are reported in terms of energy absorbed per unit of specimen width (see Note 3).

Note 1—The machines with pendulum-type hammers have been standardized in that they must comply with certain requirements including a fixed height of hammer fall, which results in a substantially fixed velocity of the hammer at the moment of impact. Hammers of different initial energies (produced by varying their effective weights), however, are recommended for use with specimens of different impact resistance. Moreover, manufacturers of the equipment are permitted to use different lengths and constructions of pendulums with possible differences in pendulum rigidities resulting (see Section 5). Be aware that other differences in machine design do exist.

Note 2—The specimens are standardized in that they have a fixed length and fixed depth, however, the width of the specimens is permitted to vary between limits. One design of milled notch is allowed. The notch in the specimen serves to concentrate the stress, minimize plastic deformation, and direct the fracture to the part of the specimen behind the notch. Scatter in energy-to-break is thus reduced. Because of differences in the elastic and viscoelastic properties of plastics, however, response to a given notch varies among materials.

Note 3—Caution must be exercised in interpreting the results of this test method. The following testing parameters have been shown to affect test results significantly: method of specimen fabrication, including but not limited to processing technology, molding conditions, mold design, and thermal treatment; method of notching; speed of notching tool; design of notching apparatus; quality of the notch; time between notching and test; test specimen thickness; test specimen width under notch; and environmental conditioning.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Note 4—This standard resembles ISO 179 in title only. The content is significantly different.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing

D647 Practice for Design of Molds for Test Specimens of Plastic Molding Materials (Withdrawn 1994)[3]

D883 Terminology Relating to Plastics

D4000 Classification System for Specifying Plastic Materials

D4066 Classification System for Nylon Injection and Extrusion Materials (PA)

D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions*—For definitions related to plastics, see Terminology D883.

4. Summary of Test Method

4.1 A notched specimen is supported as a horizontal simple beam and is broken by a single swing of the pendulum with the impact line midway between the supports and directly opposite the notch.

5. Significance and Use

5.1 Before proceeding with this test method, refer to the material specification for the material being tested. Any test specimen preparation, conditioning, dimensions and testing parameters required by the materials specification shall take precedence over those required by this test method. Table 1 of

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.
Current edition approved April 1, 2010. Published April 2010. Originally approved in 1997. Last previous edition approved in 2000 as D6110–00. DOI: 10.1520/D6110-10.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

*A Summary of Changes section appears at the end of this standard

Classification D4000 lists the ASTM materials standards that currently exist. If there is no material specification, then the requirements of this test method apply.

5.2 The pendulum impact test indicates the energy to break standard test specimens of specified size under stipulated conditions of specimen mounting, notching (stress concentration), and pendulum velocity at impact.

5.3 For this test method, the energy lost by the pendulum during the breakage of the specimen is the sum of the energies required to initiate fracture of the specimen; to propagate the fracture across the specimen; to throw the free ends of the broken specimen (toss energy); to bend the specimen; to produce vibration in the pendulum arm; to produce vibration or horizontal movement of the machine frame or base; to overcome friction in the pendulum bearing and in the indicating mechanism, and to overcome windage (pendulum air drag); to indent or deform, plastically, the specimen at the line of impact; and to overcome the friction caused by the rubbing of the striking nose over the face of the bent specimen.

NOTE 5—The toss energy, or the energy used to throw the free ends of the broken specimen, is suspected to represent a very large fraction of the total energy absorbed when testing relatively dense and brittle materials. No procedure has been established for estimating the toss energy for the Charpy method.

5.4 For tough, ductile, fiber-filled, or cloth-laminated materials, the fracture propagation energy is usually large compared to the fracture initiation energy. When testing these materials, energy losses due to fracture propagation, vibration, friction between the striking nose and the specimen has the potential to become quite significant, even when the specimen is accurately machined and positioned, and the machine is in good condition with adequate capacity (see Note 6). Significant energy losses due to bending and indentation when testing soft materials have also been observed.

NOTE 6—Although the frame and the base of the machine must be sufficiently rigid and massive to handle the energies of tough specimens without motion or excessive vibration, the pendulum arm cannot be made very massive because the greater part of its mass must be concentrated near its center of percussion at its striking nose. Locating the striking nose precisely at the center of percussion reduces the vibration of the pendulum arm when used with brittle specimens. Some losses due to pendulum arm vibration (the amount varying with the design of the pendulum) will occur with tough specimens even when the striking nose is properly positioned.

5.5 In a well-designed machine of sufficient rigidity and mass, the losses due to vibration and friction in the pendulum bearing and in the indicating mechanism will be very small. Vibrational losses are observed when wide specimens of tough materials are tested in machines of insufficient mass, or in machines that are not securely fastened to a heavy base.

5.6 Since this test method permits a variation in the width of the specimens and since the width dictates, for many materials, whether a brittle, low-energy break (as evidenced by little or no drawing down or necking and by a relatively low energy absorption) or a ductile, high-energy break (as evidenced by considerable drawing or necking down in the region behind the notch and by a relatively high energy absorption) will occur, it is necessary that the width be stated in the specification covering that material and that the width be stated along with the impact value.

5.7 This test method requires that the specimen break completely. Results obtained when testing materials with a pendulum that does not have sufficient energy to complete the breaking of the extreme fibers and toss the broken pieces shall be considered a departure from standard and shall not be reported as a standard result. Impact values cannot be directly compared for any two materials that experience different types of failure.

5.8 The value of this impact test method lies mainly in the areas of quality control and materials specification. If two groups of specimens of supposedly the same material show significantly different energy absorptions, critical widths, or critical temperatures, it is permitted to assume that they were made of different materials or were exposed to different processing or conditioning environments. The fact that a material shows twice the energy absorption of another under these conditions of test does not indicate that this same relationship will exist under another set of test conditions.

6. Apparatus

6.1 *Pendulum Impact Machine*—The machine shall consist of a massive base on which are mounted a pair of supports for holding the specimen and to which is connected, through a rigid frame and bearings, one of a number of pendulum-type hammers having an initial energy suitable for use with the particular specimen to be tested (or one basic pendulum designed to accept add-on weights), plus a pendulum holding and releasing mechanism and a mechanism for indicating the breaking energy of the specimen. The specimen anvil, pendulum, and frame shall be sufficiently rigid to maintain correct alignment of the striking edge and specimen, both at the moment of impact and during the propagation of the fracture, and to minimize energy losses due to vibration. The base shall be sufficiently massive so that the impact will not cause it to move. The machine shall be designed, constructed, and maintained so that energy losses due to pendulum air drag (windage), friction in the pendulum bearings, and friction and inertia in the indicating mechanism are held to a minimum.

6.1.1 *Pendulum*—The simple pendulum shall consist of a single or multi-membered arm with a bearing on one end and a head, containing the striking nose, on the other. Although a large proportion of the mass of the simple pendulum is concentrated in the head, the arm must be sufficiently rigid to maintain the proper clearances and geometric relationships between the machine parts and the specimen and to minimize vibrational energy losses, which are always included in the measured impact value. A machine with a simple pendulum design is illustrated in Fig. 1. Instruments with a compound-pendulum design also have been found to be acceptable for use. A compound-pendulum design is illustrated in Fig. 2.

6.1.1.1 The machine shall be provided with a basic pendulum capable of delivering an energy of 2.7 ± 0.14 J (2.0 ± 0.10 ft-lbf). This pendulum shall be used for specimens that extract less than 85 % of this energy when breaking a specimen. Heavier pendulums or additional weights designed to attach to the basic pendulum shall be provided for specimens

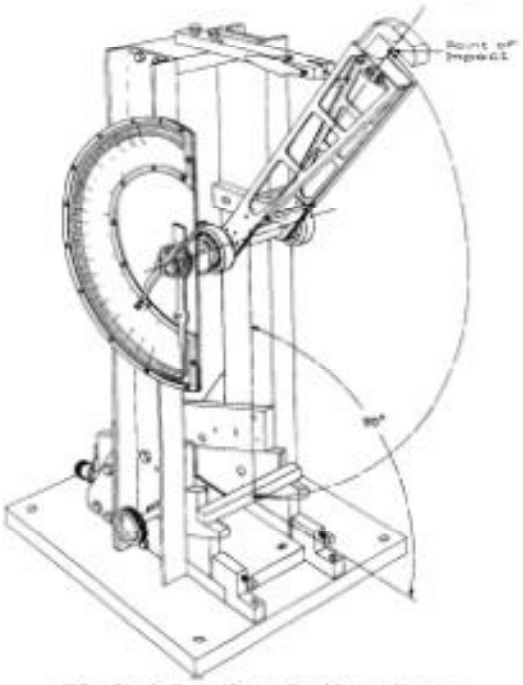


FIG. 1 Simple Beam (Charpy-Type) Impact Machine

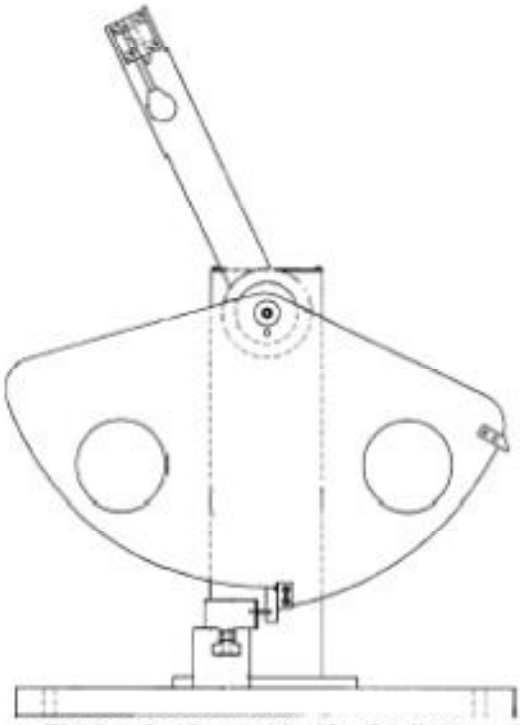


FIG. 2 Example of Compound-Pendulum-Type Machine

that require more energy to break. A series of pendulums such that each has twice the energy of the next lighter one has been found convenient.

6.1.1.2 The effective length of the pendulum shall be between 0.325 and 0.406 m (12.8 and 16.0 in.) so that the required elevation of the striking nose is obtained by raising the pendulum to an angle between 60 and 30° above the horizontal.

6.1.2 *Striking Edge*—The striking edge (nose) of the pendulum shall be made of hardened steel, tapered to have an included angle of 45 ± 2° and shall be rounded to a radius of 3.17 ± 0.12 mm (0.125 ± 0.005 in.). The pendulum shall be aligned in such a way that when it is in its free hanging position, the center of percussion of the pendulum shall lie within ±2.54 mm (0.10 in.) of the middle of the line of contact made by the striking nose upon the face of a standard specimen of square cross section. The distance from the axis of support to the center of percussion is determined experimentally from the period of motion of small amplitude oscillations of the pendulum by means of the following equation:

$$L = (g/4\pi^2)\,p^2 \qquad (1)$$

where:

L = distance from the axis of support to the center of percussion, m,
g = local gravitational acceleration (known to an accuracy of one part in one thousand), m/s^2,
π = 3.1416 ($4\pi^2$ = 39.48), and
p = period, in s, of a single complete swing (to and fro) determined from at least 20 consecutive and uninterrupted swings. The angle of swing shall be less than 5° each side of center.

6.1.3 *Pendulum Holding and Releasing Mechanism*—The mechanism shall be designed, constructed, and operated so that it will release the pendulum without imparting acceleration or vibration to the pendulum. The position of the pendulum holding and releasing mechanism shall be such that the vertical height of fall of the striking nose shall be 610 ± 2 mm (24.0 ± 0.005 in.). This will produce a velocity of the striking nose at the moment of impact of approximately 3.46 m (11.4 ft)/s as determined by the following equation:

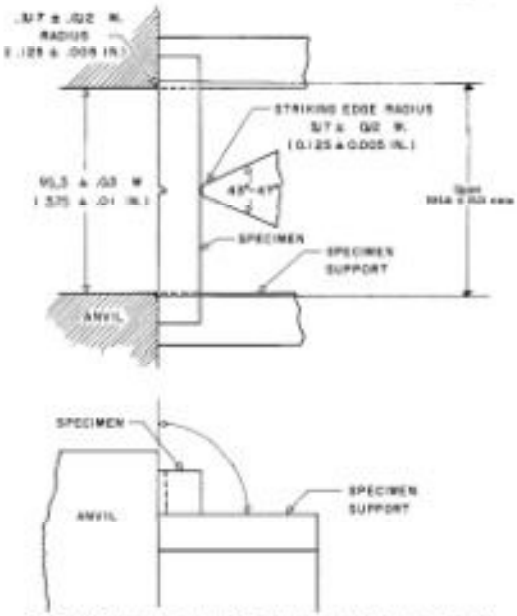


FIG. 3 Relationship of Anvil, Specimen, and Striking Edge to Each Other for Charpy Test Method

$$v = \sqrt{2gh} \tag{2}$$

where:

v = velocity of the striking nose at the moment of impact,
g = local gravitational acceleration, and
h = vertical height of fall of the striking nose.

This assumes no windage or friction.

6.1.4 *Specimen Supports*—The test specimen shall be supported against two rigid anvils in such a position that its center of gravity and the center of the notch shall lie on tangent to the arc of travel of the center of percussion of the pendulum drawn at the position of impact. The edges of the anvils shall be rounded to a radius of 3.17 ± 0.12 mm (0.125 ± 0.005 in.) and the anvils' lines of contact (span) with the specimen shall be 101.6 ± 0.5 mm (4.0 ± 0.02 in.) apart (see Fig. 3). Some machine manufacturers supply a jig for positioning the specimen on the supports.

NOTE 7—Old-style machines currently in use employ a 108.0-mm span. Data obtained under these conditions are valid.*

6.1.5 *Indicator*—Means shall be provided for determining the energy expended by the pendulum in breaking the specimen. This is accomplished using either a pointer and dial mechanism or an electronic system consisting of a digital indicator and sensor (typically an encoder or resolver). In either case, the indicated breaking energy is determined by detecting the height of rise of the pendulum beyond the point of impact in terms of energy removed from that specific pendulum. The indicated remaining energy must be corrected for pendulum bearing friction, pointer friction, pointer inertia, and pendulum windage. Some equipment manufacturers provide graphs or tables to aid in the calculation of the correction for friction and windage. Instructions for making these corrections are found in Annex A1 and Annex A2. Many digital indicating systems automatically correct for windage and friction. Consult the equipment manufacturer for information on how this is performed.

6.1.6 Appendix X2 describes a calibration procedure for establishing the accuracy of the equipment. A check of the calibration of an impact machine is difficult to make under dynamic conditions. The basic parameters normally are checked under static conditions. If the machine passes the static tests, then it is assumed to be accurate. Appendix X2, however, also describes a dynamic test for checking certain features of the machine and specimen. For some machine designs, it might be necessary to change the recommended method of obtaining the required calibration measurements. Contact the machine manufacturer to determine if additional instructions for adjusting a particular machine are available. Other methods of performing the required checks are acceptable provided that they are proven to result in an equivalent accuracy.

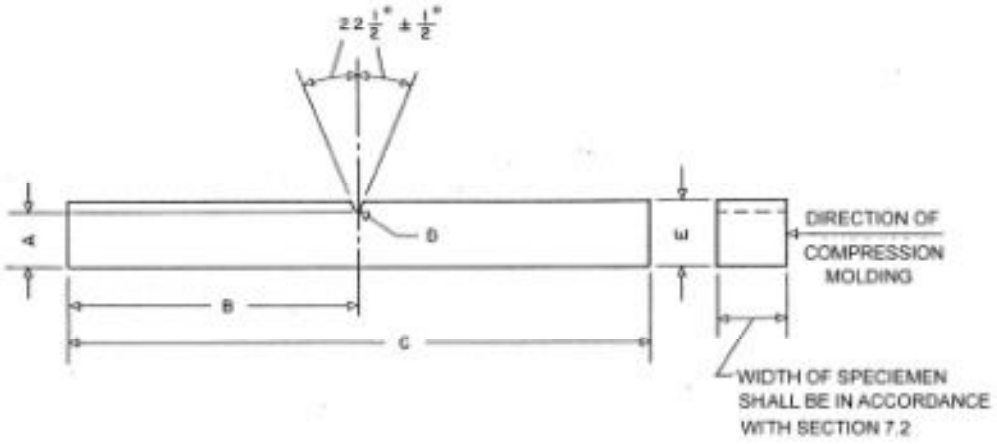
6.2 *Specimen Notching Machine*—Notching shall be done on a milling machine, engine lathe, or other suitable machine tool. A carbide-tipped or industrial diamond-tipped notching cutter is recommended. Both cutter speed and feed rate shall be controllable. Provision for cooling the specimen is recommended. Water and compressed air are suitable coolants for many plastics.

6.2.1 The profile of the cutting tooth or teeth shall be such as to produce a notch in the test specimen of the contour and depth specified in Fig. 4 and in the manner specified in Section 8.

6.2.2 A single-tooth cutter shall be used for notching the specimen, unless it is demonstrated that notches of an equivalent quality are produced with a multi-tooth cutter. Single-tooth cutters are preferred because of the ease of grinding the cutter to the specimen contour and because of the smoother cut on the specimen. The cutting edge shall be ground and honed carefully to ensure sharpness and freedom from nicks and burrs. Tools with no rake and a work relief angle of 15 to 20° have been found satisfactory.

6.3 *Micrometers*—Apparatus for measurement of the width of the specimen shall comply with the requirements of Test Methods D5947. Apparatus for the measurement of the depth of plastic material remaining in the specimen under the notch shall comply with requirements of Test Methods D5947, provided however that the one anvil or presser foot shall be a tapered blade conforming to the dimensions given in Fig. 5. The opposing anvil or presser foot shall be flat and conforming to Test Methods D5947.

* Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1011.



	mm	in.
A	12.70 ± 0.05	0.500 ± 0.002
B	63.5 max	2.50 max
	57.0 min	2.40 min
C	127.0 max	5.00 max
	124.5 min	4.90 min
D	0.250R ± 0.05	0.010R ± 0.002
E	10.79 ± 0.15	0.500 ± 0.006

FIG. 4 Dimensions of Simple Beam, Charpy Type, Impact Test Specimen

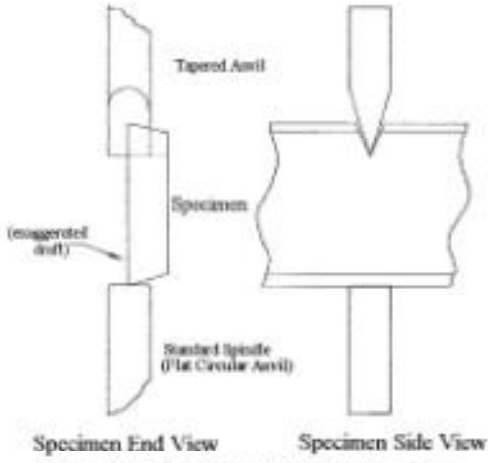


FIG. 5 Notch Depth Measurement on Test Specimens

7. Test Specimen

7.1 The test specimen shall conform to the dimensions and geometry of Fig. 4, except as modified in accordance with 7.2–7.5. To ensure the correct contour and cleanness of the specified notch, all specimens shall be notched in accordance with Section 8.

7.2 Molded specimens shall have a width between 3.00 and 12.7 mm (0.118 and 0.500 in.). Use the specimen width as specified in the material specification or as agreed upon between the supplier and the customer.

7.2.1 The type of mold and molding machine used and the flow behavior in the mold cavity will influence the strength obtained. It is possible that results from a specimen taken from one end of a molded bar will give different results than a specimen taken from the other end. It is therefore important that cooperating laboratories agree on standard molds conforming to Practice D647, and upon a standard molding procedure for the material under investigation.

7.2.2 A critical investigation of the mechanics of impact testing has shown that tests made upon specimens under 6.35 mm (0.250 in.) in width absorb more energy due to crushing, bending, and twisting than do wider specimens. Specimens 6.35 mm (0.250 in.) or over in width are therefore recommended. The responsibility for determining the minimum specimen width shall be the investigator's, with due reference to the specification for that material.

7.2.3 The impact resistance of a plastic material will be different if the notch is perpendicular to, rather than parallel to, the direction of molding.

7.3 For sheet materials, the specimens shall be cut from the sheet in both the lengthwise and crosswise directions unless otherwise specified. The width of the specimen shall be the thickness of the sheet if the sheet thickness is between 3.00 and 12.7 mm (0.118 and 0.500 in.). Sheet material thicker than 12.7 mm (0.500 in.) shall be machined down to 12.7 mm (0.500 in.).

It is acceptable to test specimens with a 12.7-mm (0.500-in.) square cross section either edgewise or flatwise as cut from the sheet. When specimens are tested flatwise, the notch shall be made on the machined surface if the specimen is machined on one face only. When the specimen is cut from a thick sheet, notation shall be made of the portion of the thickness of the sheet from which the specimen was cut, for example, center, top, or bottom surface.

7.3.1 The impact resistance of a plastic material will be different if the notch is perpendicular to, rather than parallel to, the grain of an anisotropic bar cut from a sheet. Specimens cut from sheets that are suspected of being anisotropic shall be prepared and tested both lengthwise and crosswise to the direction of the anisotropy.

7.4 The practice of cementing, bolting, clamping, or otherwise combining specimens of substandard width to form a composite test specimen is not recommended since test results will be seriously affected by interface effects or effects of solvents and cements on energy absorption of composite test specimens, or both. If Charpy test data on such thin materials are required, however, and if possible sources of error are recognized and acceptable, the following technique of preparing composites ought to be utilized. The test specimens shall be a composite of individual thin specimens totaling 6.35 to 12.7 mm (0.125 to 0.500 in.) in width. Individual members of the composite shall be aligned accurately with each other and clamped, bolted, or cemented together. Care must be taken to select a solvent or adhesive that will not affect the impact resistance of the material under test. If solvents or solvent-containing adhesives are employed, a conditioning procedure shall be established to ensure complete removal of the solvent prior to test. The composite specimens shall be machined to proper dimensions and then notched. In all such cases, the use of composite specimens shall be noted in the report of test results.

7.5 Each specimen shall be free of twist and shall be bounded by mutually perpendicular pairs of plane, parallel surfaces and free from scratches, pits, and sink marks. The specimens shall be checked for conformity with these requirements by visual observation against straight edges, squares or flat plates, and by measuring with micrometer calipers. Any specimen showing observable or measurable departure from one or more of these requirements shall be rejected or machined to the proper size and shape before testing. A specimen that has a slight twist to its notched face of 0.05 mm (0.002 in.) at the point of contact with the pendulum striking edge will be likely to have a characteristic fracture surface with considerable greater fracture area than for a normal break. In this case, the energy to break and toss the broken section will be considerably larger (20 to 30 %) than for a normal break.

8. Notching Test Specimens

Note 8—When testing a material for the first time, it is necessary to study the effect of all variations in the notching conditions, including cutter dimensions, notch depth, cutter speed, and feed rate. To establish that the notching parameters are suitable, it is advisable to notch several specimens of the material and inspect both the tool entrance and tool exit side of each notched specimen, in accordance with Appendix X1. Adjust the notching machine as required. The specimens used to determine notching conditions shall not be used to make determinations of impact resistance.

8.1 *Notch Dimensions*—The included angle of the notch shall be 45 ± 1° with a radius of curvature at the apex of 0.25 ± 0.05 mm (0.010 ± 0.002 in.). The plane bisecting the notch angle shall be perpendicular to the face of the test specimen within 2°.

8.1.1 The notch is a critical factor of this test. It is extremely important, therefore, that dimensions of the notch in the specimen are verified. There is evidence that the contour of notches cut in materials of widely differing physical properties by the same cutter will differ. It is sometimes necessary to alter the cutter dimensions in order to produce the required notch contour for certain materials.

8.1.2 A notching operation notches one or more specimens plus the "dummy bars". The specimen notch produced by each cutter will be examined after every 500 notching operations or less frequently if experience shows this to be acceptable. The specimen used to verify the notch shall be the same material that is being prepared for testing. Inspect and verify the notch in the specimen. If the angle or radius of the notch does not meet the requirements of 8.1, the cutter shall be replaced. One procedure for inspecting and verifying the notch is provided in Appendix X1.

Note 9—The contour of the notch made using multi-tooth cutters is checked by measuring the contour of the notch on a strip of soft metal that is inserted between two specimens during the notching process.

Note 10—When the same material is being tested on a repetitive basis, and it is demonstrated that the notch in the specimen takes the contour of the tip of the cutter and that the notch meets the contour requirements when checked in accordance with Appendix X1, then it is acceptable to check the contour of the tip of the cutter instead of the notch in the specimen.

8.2 *Notch Depth*—The depth of the plastic material remaining in the specimen under the notch shall be 10.16 ± 0.05 mm (0.400 ± 0.002 in.). This dimension shall be measured with apparatus in accordance with 6.3. The tapered blade will be fitted to the notch. The specimen will be approximately vertical between the anvils. Position the edge of the non-cavity (wider edge) surface centered on the micrometer's flat circular anvil.

8.3 *Cutter Speed and Feed Rate*—Select the cutter speed and feed speed based on the material being tested. The quality of the notch will be adversely affected by thermal deformations and stresses induced during the cutting operation if proper conditions are not selected.[5] The notching parameters used shall not alter the physical state of the material, such as by raising the temperature of a thermoplastic above its glass transition temperature.

8.3.1 In general, high cutter speeds, slow feed rates, and lack of coolant induce more thermal damage than a slow cutter speed, fast feed speed, and the use of a coolant. Too high a feed speed/cutter speed ratio, however, has been shown to cause impacting and cracking of the specimen. The range of cutter speed/feed ratios possible to produce acceptable notches has been shown to be extended by the use of a suitable coolant.

8.3.1.1 For some thermoplastics, suitable notches have been produced using cutter speeds from 54 to 150 m/min and a feed rate of 89 to 160 mm/min without a water coolant. Satisfactory

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1066.

notches also have been produced using the same cutter speeds at feed speeds of from 36 to 160 mm/min with water coolant.

8.3.1.2 Embedded thermocouples have been used to determine the temperature rise in the material near the apex of the notch during machining. Thermal stresses induced during the notching operation have been observed in transparent materials by viewing the specimen at low magnification between crossed polars in monochromatic light. The specimens used to determine temperature rise shall not be used to make determinations of impact resistance.

8.3.2 The feed rate and the cutter speed shall remain constant throughout the notching operation.

8.4 It is acceptable to notch specimens individually or in a group. In either case, however, an unnotched backup or dummy bar shall be placed behind the last specimen in the sample holder to prevent distortion and chipping by the cutter as it exits from the last test specimen.

8.5 All specimens having one dimension less than 12.7 mm (0.500 in.) shall have the notch cut on the shorter side. Compression molded specimens shall be notched on the side parallel to the direction of application of molding pressure. The impact resistance of a plastic material will be different if the notch is perpendicular to rather than parallel to the direction of molding, as with or across the grain of an anisotropic bar cut from a plate.

9. Conditioning

9.1 Check the materials specification for the material that is being tested. If there are no conditioning requirements stated by the materials specification, the test specimens shall be conditioned at 23 ± 2°C (73 ± 3.6°F) and 50 ± 10 % relative humidity for not less than 40 h after notching and prior to testing in accordance with Procedure A of Practice D618 unless documented (between supplier and customer) that shorter conditioning time is sufficient for a given material to reach equilibrium of impact resistance.

9.2 For hygroscopic materials, such as nylons, the material specifications (for example, Classification System D4066) call for testing dry-as-molded specimens. Such requirements take precedence over the above routine preconditioning to 50 % relative humidity. These specimens shall be sealed in water vapor-impermeable containers as soon as molded. When notching these specimens, minimize the exposure time during notching and return the specimens to a dry container after notching to allow for full cooling of the specimens prior to testing.

9.3 *Test Conditions*—Conduct tests in the standard laboratory atmosphere of 23 ± 2°C (73 ± 3.6°F) and 50 ± 10 % relative humidity, unless otherwise specified. In case of disagreement, the tolerances shall be ±1°C and ±5 % relative humidity.

10. Procedure

10.1 *Specimen Preparation:*

10.1.1 Prepare the test specimens in accordance with the procedures in Section 7. At least five and preferably ten or more individual determinations of impact resistance shall be made to determine the average impact resistance for a particular sample. The specimens shall be of nominal width only.

10.1.2 Notch the specimens in accordance with the procedure in Section 8.

10.1.3 Condition the specimens in accordance with the materials specification for the material that is being tested. If there are no conditioning requirements detailed in the materials specification, follow the conditioning requirements in Section 9.

10.2 *Machine Preparation:*

10.2.1 Estimate the breaking energy for the sample and select a pendulum of suitable energy. Select the lightest standard pendulum that is expected to break all specimens in the group with an energy loss of not more than 85 % of its capacity (see 6.1). If the breaking energy cannot be estimated, select the correct pendulum by performing trial runs. Use caution to avoid damaging the pendulum by selecting a pendulum that is too light for a particular sample.

NOTE 11—Ideally, an impact test would be conducted at a constant test velocity. In a pendulum-type test, however, the velocity decreases as the fracture progresses. For specimens that have an impact energy approaching the capacity of the pendulum, there is insufficient energy to complete the break and toss. By avoiding the higher 15 % scale energy readings, the velocity of the pendulum will not be reduced below 1.33 m/s. On the other hand, the use of a pendulum that is too heavy would reduce the sensitivity of the reading.

10.2.2 After installing the selected pendulum on the machine, check the machine for conformity with the requirements of Section 6 before starting the tests.

10.2.3 When using a machine equipped with a pointer and dial mechanism or an electronic indicator that does not automatically correct for windage and friction, determine the windage and friction correction factors for the machine before testing specimens. Windage and friction correction factors shall be determined on a daily basis and shall be calculated each time weights are added to the pendulum or the pendulum is changed. Refer to Annex A1 for information on constructing windage and friction correction charts or refer to Annex A2 for a procedure to calculate the windage and friction correction. If excessive friction is indicated (see X2.12 and X2.13) the machine shall be adjusted before testing specimens. Follow the machine manufacturer's instructions to correct for excessive windage and friction.

NOTE 12—The actual correction factors for windage and friction will be smaller than these factors in an actual test because the energy absorbed by the specimen prevents the pendulum from making a full swing. The indicated breaking energy of the specimen, therefore, must be included in the calculation of the machine correction.

10.2.4 Some machines equipped with an electronic digital display or computer automatically compensate for windage and friction.

10.3 *Specimen Testing:*

10.3.1 Check all of the specimens in the sample group for conformity with the requirements of Sections 7 and 8 and 10.1.

10.3.2 Measure and record the width of each specimen after notching to the nearest 0.025 mm (0.001 in). Measure the width in one location adjacent to the notch centered about the anticipated fracture plane.

10.3.3 Measure and record the depth of material remaining in the specimen under the notch of each specimen to the nearest 0.025 mm (0.001 in). The tapered blade will be fitted to the notch. The specimen will be approximately vertical between the anvils. Position the edge of the non-cavity (wider edge) surface so that it is centered on the micrometer's flat circular anvil. See Fig. 5.

10.3.4 Position a test specimen horizontally on the supports and against the anvils so that it will be impacted on the face opposite the notch (see Fig. 3). Center the notch between the anvils. A centering jig is useful for this purpose.

10.3.5 Raise and secure the pendulum in the release mechanism and reset the indicating mechanism.

10.3.6 Release the pendulum, allowing the striking edge of the pendulum to impact the specimen. Note the indicated breaking energy.

10.3.7 Calculate the net breaking energy (see 11.1). If the net breaking energy is greater than 85 % of the pendulum's nominal energy, the wrong pendulum was used. Discard the result. Select and install a pendulum with a greater available energy or add additional weight to the pendulum, determine the windage and friction correction factor, and repeat the test on a new specimen.

10.3.8 If the proper pendulum was used, test the remaining specimens as described in 10.3.1–10.3.6. Results from specimens that do not break shall be discarded. A specimen that does not break completely into two or more pieces is not considered to be broken.

10.3.9 After all of the specimens for the sample have been tested, calculate the impact resistance, in joules per metre, for each individual specimen (see 11.2).

10.3.10 Calculate the average impact resistance for the group of specimens (see 11.3). Values obtained from specimens that did not break completely shall not be included in the average.

10.3.11 Calculate the standard deviation for the group of specimens (see 11.4).

11. Calculation

11.1 *Net Breaking Energy*—Subtract the windage and friction loss energy from the indicated breaking energy.

11.2 *Impact Resistance*—Divide the net breaking energy by the measured width of each individual specimen.

11.3 Calculate the average impact resistance for a group of specimens by adding the individual impact resistance values for the group and dividing the sum by the total number of specimens in the group.

11.4 Calculate the standard deviation as follows and report it to two significant figures:

$$s = \sqrt{(\sum X^2 - n\,\bar{X}^2)/(n-1)} \quad (3)$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, and previous history.

12.1.2 A statement of how the specimens were prepared, the testing conditions used, the number of hours the specimens were conditioned after notching, and for sheet materials, the direction of testing with respect to anisotropy, if any.

12.1.3 The capacity of the pendulum, J.

12.1.4 The span.

12.1.5 The width and depth under the notch of each specimen tested.

12.1.6 The total number of specimens tested per sample of material (that is five, ten, or more).

12.1.7 The average impact resistance, J/m. Impact resistance is not to be reported for other than complete breaks. Reporting results in kJ/m^2 is optional (see Appendix X4).

12.1.8 The standard deviation of the values of the impact resistance of the specimens in 10.3.11.

TABLE 1 Precision for Charpy Test

Values in J/m$_n$ of Width

Material	Average	S_r [A]	S_R [B]	r [C]	R [D]	Number of Laboratories
Phenolic	0.65	0.059	0.068	0.29	0.34	7
Reinforced nylon	1.88	0.095	0.143	0.18	0.60	7
Polycarbonate	2.85	0.083	0.422	0.23	1.18	8
Polypropylene	4.06	0.151	0.422	0.42	1.18	9
ABS	10.3	0.115	0.529	0.32	1.78	9

[A] S_r = within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations of the test results from all of the participating laboratories.

$$S_r = [(S_1)^2 + (S_2)^2 \ldots + (S_n)^2)/n]^{1/2}$$

[B] S_R = between-laboratories reproducibility, expressed as standard deviation:

$$S_R = [S_r^2 + S_L^2]^{1/2}$$

where S_L = standard deviation of laboratory means.
[C] r = within-laboratory critical interval between two test results = $2.8 \times S_r$.
[D] R = between-laboratories critical interval between two test results = $2.8 \times S_R$.

13. Precision and Bias

13.1 Table 1 is based on a round robin[6] conducted in 1987 in accordance with Practice D691, involving five materials tested by nine laboratories. For each material, all samples were prepared at one source, but the individual specimens were notched and conditioned at the laboratories which tested them. Each laboratory tested an average of nine specimens for each material. (**Warning**—The explanations of r and R (13.2–13.2.3) are intended only to present a meaningful way of considering the approximate precision of this test method. The data presented in Table 1 are not to be applied to acceptance or rejection of materials, as these data apply only to the materials tested in the round robin and are unlikely to be rigorously

[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1134.

representative of other lots, formulations, conditions, materials, or laboratories. Users of this test method are advised to apply the principles outlined in Practice E691 to generate data specific to their materials and laboratory, or between specific laboratories. The principles of 13.2–13.2.3 would then be valid for such data.)

13.2 *Concept of r and R in* Table 1 —If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing nine specimens for each test result, then:

13.2.1 *Repeatability*—*r* is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory. Two tests results shall be judged not equivalent if they differ by more than the *r* value for that material.

13.2.2 *Reproducibility*—*R* is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories, not necessarily on the same day. Two test results shall be judged not equivalent if they differ by more than the *R* value for that material.

13.2.3 Any judgement in accordance with 13.2.1 or 13.2.2 would have an approximate 95 % (0.95) probability of being correct.

13.3 There are no recognized standards by which to estimate bias of this test method.

14. Keywords

14.1 Charpy impact; impact resistance; notch sensitivity; notched specimen

ANNEXES

(Mandatory Information)

A1. INSTRUCTIONS FOR THE CONSTRUCTION OF A WINDAGE AND FRICTION CORRECTION CHART

A1.1 The construction and use of the chart herein described is based upon the assumption that the friction and windage losses are proportional to the angle through which these loss torques are applied to the pendulum. Fig. A1.1 shows the assumed energy loss versus the angle of the pendulum position during the pendulum swing. The correction chart to be described is principally the left half of Fig. A1.1. Some manufacturers supply windage and friction correction charts for their equipment. The energy losses designated as A or B are described in 10.3.

A1.2 Start the construction of the correction chart (Fig. A1.2) by laying off to some convenient linear scale on the abscissa of a graph the angle of pendulum position for the portion of the swing beyond the free hanging position. For convenience, place the free hanging reference point on the right end of the abscissa with the angular displacement increasing linearly to the left. The abscissa is referred to as

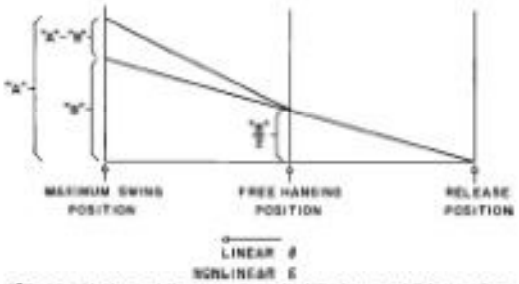


FIG. A1.1 Method of Construction of a Windage and Friction Correction Chart

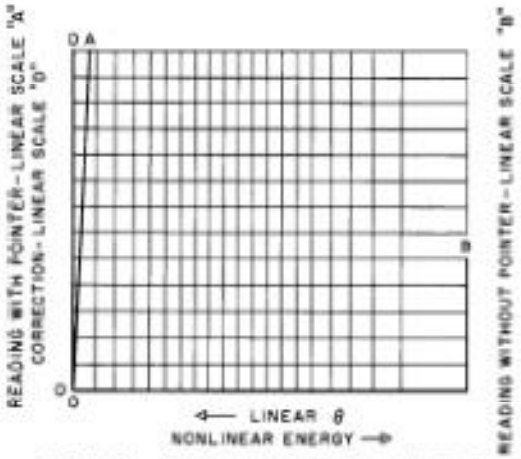


FIG. A1.2 Sample Windage and Friction Correction Chart

Scale C. Although angular displacement is the quantity to be represented linearly on the abscissa, this displacement is more conveniently expressed in terms of indicated energy read from the machine dial. This yields a nonlinear Scale C with indicated pendulum energy increasing to the right.

A1.3 On the right hand ordinate lay off a linear Scale B starting with zero at the bottom and stopping at the maximum expected pendulum friction and windage value at the top.

A1.4 On the left ordinate construct a linear Scale D ranging from zero at the bottom to 1.2 times the maximum ordinate

value appearing on Scale B, but make the scale twice the scale used in the construction of Scale B.

A1.5 Adjoining Scale D draw a curve OA which is the focus of points whose coordinates have equal values of energy correction on Scale D and indicated energy on Scale C. This curve is referred to as Scale A and utilizes the same divisions and numbering system as the adjoining Scale D.

A1.6 *Instructions for Using Chart:*

A1.6.1 Locate and mark on Scale A the reading A obtained from the free swing of the pendulum with the pointer prepositioned in the free hanging or maximum indicated energy position on the dial.

A1.6.2 Locate and mark on Scale B the reading B obtained after several free swings with the pointer pushed up close to zero indicated energy position of the dial by the pendulum in accordance with instructions in 10.3.

A1.6.3 Connect the two points thus obtained by a straight line.

A1.6.4 From the indicated impact energy on Scale C project up to the constructed line and across to the left to obtain the correction for windage and friction from Scale D.

A1.6.5 Subtract this correction from the indicated impact reading to obtain the energy delivered to the specimen.

A2. PROCEDURE FOR THE CALCULATION OF WINDAGE AND FRICTION CORRECTION

A2.1 The procedure for the calculation of the windage and friction correction in this annex is based on the equations developed by derivation in Appendix X3. This procedure is acceptable as a substitute for the graphical procedure described in Annex A1 and is applicable to small electronic calculator and computer analysis.

A2.2 Calculate L, the distance from the axis of support to the center of percussion as indicated in 6.3. It is assumed here that the center of percussion is approximately the same as the center of strike.

A2.3 Measure the maximum height, h_M, of the center of percussion (center of strike) of the pendulum at the start of the test as indicated in X2.11.

A2.4 Measure and record the energy correction, E_A, for windage of the pendulum plus friction in the dial, as determined with the first swing of the pendulum with no specimen in the testing device. This correction must be read on the energy scale, E_M, appropriate for the pendulum used.

A2.5 Without resetting the position of the indicator obtained in A2.4, measure the energy correction, E_B, for pendulum windage after two additional releases of the pendulum with no specimen in the testing device.

A2.6 Calculate β_{max} as follows:

$$\beta_{max} = \cos^{-1}\{1 - [(h_M/L)(1 - E_A/E_M)]\} \quad (A2.1)$$

where:

E_A = energy correction for windage of pendulum plus friction in dial, J (ft·lbf),
E_M = full-scale reading for pendulum used, J (ft·lbf),
L = distance from fulcrum to center of strike of pendulum, m (ft),
h_M = maximum height of center of strike of pendulum at start of test, m (ft), and
β_{max} = maximum angle pendulum will travel with one swing of the pendulum.

A2.7 Measure specimen breaking energy, E_s, J (ft·lbf).

A2.8 Calculate β for specimen measurement E_s as:

$$\beta = \cos^{-1}\{1 - [(h_M/L)(1 - E_d/E_M)]\} \quad (A2.2)$$

where:

β = angle pendulum travels for a given specimen, and
E_d = dial reading breaking energy for a specimen, J (ft·lbf).

A2.9 Calculate total correction energy, E_{TC} as:

$$E_{TC} = [E_A - (E_B/2)][\beta/\beta_{max}] + (E_B/2) \quad (A2.3)$$

where:

E_{TC} = total correction energy for the breaking energy, E_s, of a specimen, J (ft·lbf), and
E_B = energy correction for windage of the pendulum, J (ft·lbf).

A2.10 Calculate the impact resistance using the following formula:

$$I_s = (E_s - E_{TC})/t \quad (A2.4)$$

where:

I_s = impact resistance of specimen, J/m (ft·lbf/in.) of width, and
t = width of specimen or width of notch, m (in.)

APPENDIXES

(Nonmandatory Information)

X1. PROCEDURE FOR THE INSPECTION AND VERIFICATION OF NOTCH

X1.1 The purpose of this procedure is to describe the microscopic method to be used for determining the radius and angle of the notch. These measurements could also be made using a comparator if available.

NOTE X1.1—The notch shall have a radius of 0.25 ± 0.05 mm (0.010 ± 0.002 in.) and an angle of 45 ± 1°.

X1.2 *Apparatus*:

X1.2.1 *Optical Device*, with minimum magnification of 60×, Filar glass scale and camera attachment.

X1.2.2 *Transparent Template*, that will be developed in this procedure.

X1.2.3 *Ruler*.

X1.2.4 *Compass*.

X1.2.5 *Plastic Drafting Set Squares (Triangles)*, 45–45–90°.

X1.3 A transparent template must be developed for each magnification and for each microscope used. It is preferable that each laboratory standardize on one microscope and one magnification. It is not necessary for each laboratory to use the same magnification because each microscope and camera combination have somewhat different blowup ratios.

X1.3.1 Set the magnification of the optical device at a suitable magnification with a minimum magnification of 60×.

X1.3.2 Place the Filar glass slide on the microscope platform. Focus the microscope so the most distinct of the Filar scale is visible.

X1.3.3 Take a photograph of the Filar scale (see Fig. X1.1).

X1.3.4 Create a template similar to that shown in Fig. X1.2.

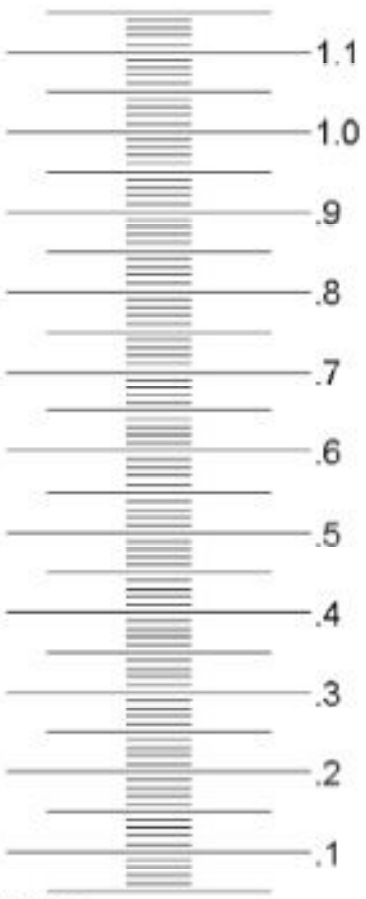
X1.3.4.1 Find the approximate center of the piece of paper.

X1.3.4.2 Draw a set of perpendicular coordinates through the center point.

X1.3.4.3 Draw a family of concentric circles that are spaced in accordance with the dimensions of the Filar scale. This task is accomplished by first setting a mechanical compass at a distance of 0.1 mm (0.004 in.) as referenced by the magnified photograph of the Filar eyepiece. Subsequent circles shall be spaced 0.02 mm apart (0.001 in.), as rings, with the outer ring being 0.4 mm (0.016 in.) from the center.

X1.3.5 Photocopy the paper with the concentric circles to make a transparent template of the concentric circles.

X1.3.6 Construct Fig. X1.3 by taking a second piece of paper, finding its approximate center, and marking this point. Draw one line through this center point. Label this line zero degree (0°). Draw a second line perpendicular to the first line through this center point. Label this line 90°. From the center draw a line that is 44° relative to the 0°. Label the line 44°. Draw another line at 46°. Label the line 46°.

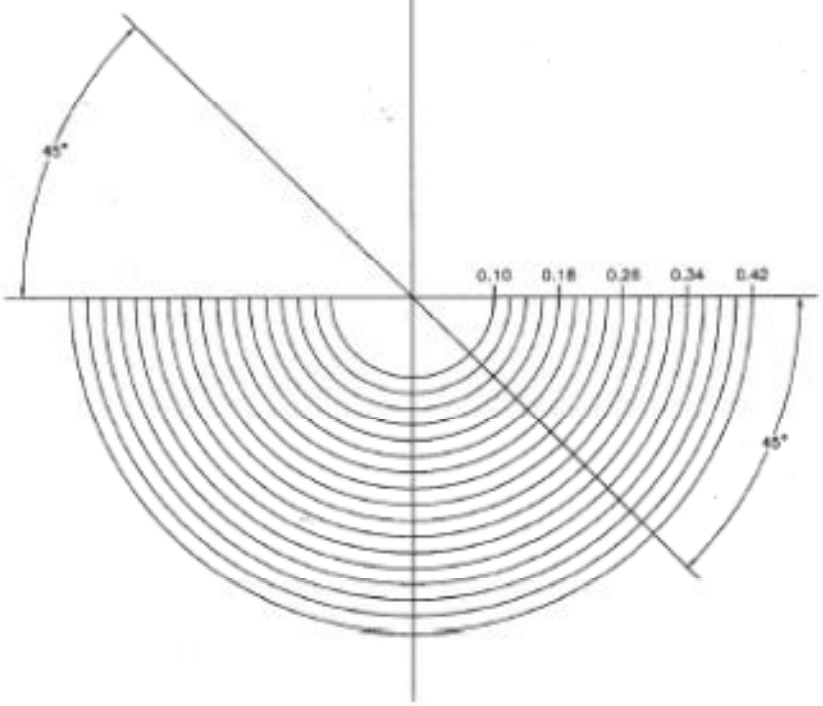


NOTE 1—100× Reference
NOTE 2—0.1 mm major scale; 0.01 mm minor scale

FIG. X1.1 Filar Scale

X1.4 Place a microscope glass slide on the microscope platform. Place the notched specimen on top of the slide. Focus the microscope. Move the specimen around using the platform adjusting knobs until the specimen's notch is centered and near the bottom of the viewing area. Take a picture of the notch.

X1.4.1 *Determination of Notching Radius* (Fig. X1.4):



Note 1—Magnification = 100×

FIG. X1.2 Example of Transparent Template for Determining Radius of Notch

X1.4.1.1 Place the picture on a sheet of paper. Position the picture so that bottom of the notch in the picture faces downwards and is about 64 mm (2.5 in.) from the bottom of the paper. Tape the picture down to the paper.

X1.4.1.2 Draw two lines along the sides of the notch projecting down to a point where they intersect below the notch Point I (see Fig. X1.4B).

X1.4.1.3 Open the compass to about 51 mm (2 in.). Using Point I as a reference, draw two arcs intersecting both sides of the notch (see Fig. X1.4C). These intersections are called 1a and 1b.

X1.4.1.4 Close the compass to about 38 mm (1.5 in.). Using Point 1a as the reference point, draw an arc (2a) above the notch, draw a second arc (2b) that intersects with arc 2a at Point J. Draw a line between I and J. This establishes the centerline of the notch (see Fig. X1.4D)

X1.4.1.5 Place the transparent template on top of the picture and align the center of the concentric circles with the drawn centerline of the notch (see Fig. X1.4E).

X1.4.1.6 Slide the template down the centerline of the notch until one concentric circle touches both sides of the notch. Record the radius of the notch and compare it against the limits of 0.2 to 0.3 mm (0.008 to 0.012 in.).

X1.4.1.7 Examine the notch to ensure that there are no flat spots along the measured radius.

X1.4.2 *Determination of Notch Angle*—Place transparent template for determining notch angle (Fig. X1.3) on top of the photograph attached to the sheet of paper. Rotate the picture so that the notch tip is pointed towards you. Position the center point of the template on top of the Point I established in 0° axis of the template with the right side straight portion of the notch. Check the left side straight portion of the notch to ensure that this portion falls between the 44° and 46° lines. If not, replace the blade.

X1.5 A picture of a notch shall be taken at least every 500 notches or if a control sample gives a value outside its 3-sigma limits for that test.

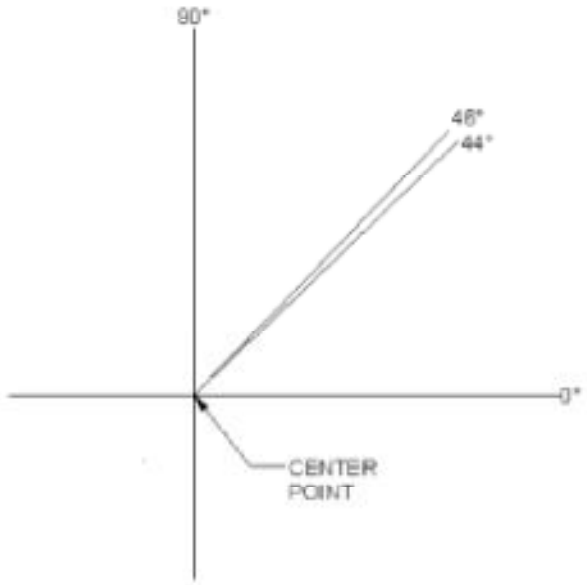


FIG. X1.3 Example of Transparent Template for Determining Angle of Notch

X1.6 If the notch in the control specimen is not within the requirements, take a picture of the notching blade and analyze it by the same procedure used for the specimen notch. If the notching blade does not meet ASTM requirements or shows damage, it shall be replaced with a new blade which has been checked for proper dimensions.

X1.7 If a cutter has the correct dimensions, but does not cut the correct notch in the specimen, it will be necessary to evaluate other conditions (cutter and feed speeds) to obtain the correct notch dimension for that material.

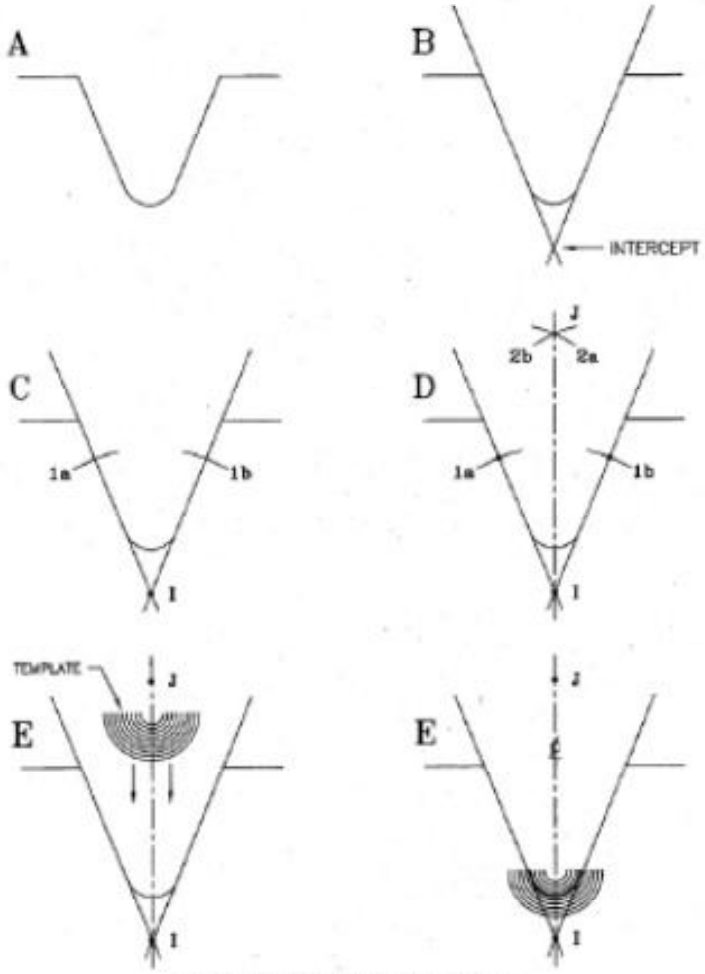


FIG. X1.4 Determination of Notching Radius

X2. CALIBRATION OF PENDULUM-TYPE HAMMER IMPACT MACHINES FOR USE WITH PLASTIC SPECIMENS

X2.1 This calibration procedure applies specifically to the Charpy impact machine.

X2.2 Locate the impact machine on a sturdy base. It shall not walk on the base and the base shall not vibrate appreciably. Loss of energy from vibrations will give high readings. It is recommended that the impact tester be bolted to a base having a mass of at least 23 kg if it is used at capacities higher than 2.7 J (2 ft-lbf).

X2.3 Check the level of the machine in both directions on the plane of the base with spirit levels mounted in the base, by a machinist's level if a satisfactory reference surface is available, or with a plumb bob. Level the machine to within $\tan^{-1}$ 0.001 in the plane of swing and to within $\tan^{-1}$ 0.002 in the plane perpendicular to the swing.

X2.4 Contact the machine manufacturer for a procedure to ensure the striker radius is in tolerance (3.17 ± 0.12 mm) (see 6.1.2).

X2.5 Check the transverse location of the center of the pendulum striking edge that shall be within 0.40 mm (0.016 in.) of the center of the anvil. Readjust the shaft bearings or relocate the anvil or straighten the pendulum shaft as necessary to attain the proper relationship between the two centers.

X2.6 Check the pendulum arm for straightness within 1.2 mm (0.05 in.) with a straightedge or by sighting down the shaft. This arm is sometimes bent by allowing the pendulum to slam against the catch when high-capacity weights are on the pendulum.

X2.7 Center a notched 12.7-mm square metal bar having opposite sides parallel within 0.025 mm and 125 mm long on the Charpy anvils. Place a thin oil film, ink or dye on the striking edge of the pendulum and let the striking edge rest gently against the bar. If the striking edge is correctly making contact with the specimen, a thin line of oil, ink, or dye will be transferred across the entire width of the bar.

X2.8 When the pendulum is hanging free in its lowest position, the energy reading must be within 0.2 % of full scale.

X2.9 Swing the pendulum to a horizontal position, and support it by the striking edge in this position with a vertical bar. Allow the other end of this bar to rest at the center of a load pan on a balanced scale. Subtract the weight of the bar from the total weight to find the effective weight of the pendulum. The effective pendulum weight shall be within 0.4 % of the required weight for that pendulum capacity. If weight must be added or removed, take care to balance the added or removed weight without affecting the center of percussion relative to the striking edge. It is not advisable to add weight to the opposite side of the bearing axis from the striking edge to decrease the effective weight of the pendulum since the distributed mass has the potential to result in large energy losses from vibration of the pendulum.

X2.10 Calculate the effective length of the pendulum arm or the distance to the center of percussion from the axis of rotation by the procedure in 6.1.2. The effective length must be within the tolerance stated in 6.1.1.2.

X2.11 Determine the vertical distance of fall of the pendulum striking edge from its latched height to its lowest point. This distance shall be 610 ± 2 mm. This measurement is made with a half-width specimen positioned on the anvils. Place a thin oil film on the specimen and bring the striking edge against it. The upper end of the oil line on the striking edge is the center of strike. Measure the change in vertical height of the center of strike from the latched to the free hang position (the lowest point). This vertical fall distance is adjusted by varying the position of the pendulum latch.

X2.12 If a pointer and dial mechanism is used to indicate the energy, the pointer friction shall be adjusted so that the pointer will just maintain its position anywhere on the scale. The striking pin of the pointer shall be securely fastened to the pointer. Friction washers with glazed surfaces shall be replaced with new washers. Friction washers shall be on either side of the pointer collar. The last friction washer installed shall be backed by a heavy metal washer. Pressure on this metal washer is produced by a thin bent spring washer and locknuts. If the spring washer is placed next to the fiber friction washer, the pointer will tend to vibrate during impact.

X2.13 The free-swing reading of the pendulum (without specimen) from the latched height shall be less than 2.5 % of pendulum capacity on the first swing. If the reading is higher than this, the friction in the indicating mechanism is excessive or the bearings are dirty. To clean the bearings, dip them in grease solvent and spin dry in an air jet. Clean the bearings until they spin freely or replace them. Oil very lightly with instrument oil before replacing. A reproducible method of starting the pendulum from the proper height must be devised.

X2.14 The shaft about which the pendulum rotates shall have no detectable radial play, less than 0.05 mm (0.002 in.). An end play of 0.25 mm (0.010 in.) is permissible when a 9.8-N (2.2-lbf) axial force is applied in alternate directions.

X2.15 The machine shall not be used to indicate more than 85 % of the energy capacity of the pendulum. Extra weight added to the pendulum will increase available energy of the machine. This weight must be added so as to maintain the center of percussion within the tolerance stated in 6.1.2. Correct effective weight for any range is calculated as follows:

$$W = E_p/h \qquad \text{(X2.1)}$$

where:

W = the effective pendulum weight, N (lbf) (see X2.9),
E_p = potential or available energy of the machine, J (ft × lbf), and
h = the vertical distance of fall of the pendulum striking edge, m (ft) (see X2.11).

Each 4.5 N (1 lbf) of added effective weight increases the capacity of the machine by 2.7 J (2 ft × lbf).

NOTE X2.1—If the pendulum is designed for use with added weights, it is recommended that they be obtained through the equipment manufacturer.

X3. DERIVATION OF PENDULUM IMPACT CORRECTION EQUATIONS

X3.1 From right triangle distances in Fig. X3.1:

$$L - h = L\cos\beta \tag{X3.1}$$

X3.2 The potential energy gain of pendulum, E_p, is:

$$E_p = hW_p g \tag{X3.2}$$

X3.3 Combining Eq X3.1 and Eq X3.2 gives the following:

$$L - E_p/W_p g = L\cos\beta \tag{X3.3}$$

X3.4 The maximum energy of the pendulum is the potential energy at the start of the test, E_M, or

$$E_M = h_M W_p g \tag{X3.4}$$

X3.5 The potential energy gained by the pendulum, E_p, is related to the absorption of energy of a specimen, E_s, by the following equation:

$$E_M = E_s + E_p \tag{X3.5}$$

X3.6 Combining Eq X3.3–X3.5 gives the following:

$$(E_M - E_s)/E_M = L/h_M(1 - \cos\beta) \tag{X3.6}$$

X3.7 Solving Eq X3.6 for β gives the following:

$$\beta = \cos^{-1}\left(1 - [(h_M/L)(1 - E_s/E_M)]\right) \tag{X3.7}$$

X3.8 From Fig. X3.2, the total energy correction, E_{TC}, is given as:

$$E_{TC} = m\beta + b \tag{X3.8}$$

X3.9 At the zero point of the pendulum the potential energy is:

$$E_p/2 = m(0) + b \tag{X3.9}$$

or

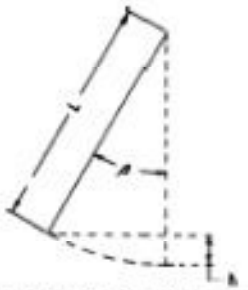


FIG. X3.1 Swing of Pendulum from the Rest Position

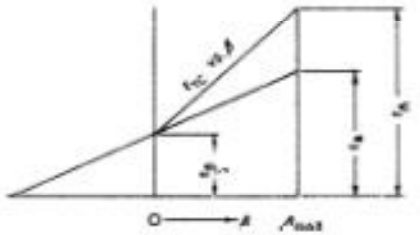


FIG. X3.2 Total Energy Correction for Pendulum Windage and Dial Friction as a Function of Pendulum Position

$$b = E_p/2$$

X3.10 The energy correction, E_A, on the first swing of the pendulum occurs at the maximum pendulum angle, β_{max}. Substituting in Eq X3.8 gives the following:

$$E_A = m\beta_{max} + (E_p/2) \tag{X3.10}$$

X3.11 Combining Eq X3.8 and Eq X3.11 gives the following:

$$E_{TC} = (E_s - (E_p/2))(\beta/\beta_{max}) + (E_p/2) \tag{X3.11}$$

X3.12 Nomenclature:

- b = intercept of total correction energy straight line,
- E_A = energy correction, including both pendulum windage plus dial friction, J,
- E_p = energy correction for pendulum windage only, J,
- E_M = maximum energy of the pendulum (at the start of test), J,
- E_p = potential energy gain of pendulum from the pendulum rest position, J,
- E_s = uncorrected breaking energy of specimen, J,
- E_{TC} = total energy correction for a given breaking energy, E_s, J,
- g = acceleration of gravity, m/s^2,
- h = distance center of gravity of pendulum rises vertically from the rest position of the pendulum, m,
- h_M = maximum height of the center of gravity of the pendulum, m,
- m = slope of total correction energy straight line,
- L = distance from fulcrum to center of gravity of pendulum, m,
- W_p = weight of pendulum, as determined in X2.13, kg, and
- β = angle of pendulum position from the pendulum rest position.

X4. UNIT CONVERSIONS

X4.1 Joules per metre cannot be converted directly into kilojoules per square metre.

NOTE X4.1—If the optional units of kJ/m² (ft·lbf/in.²) are required the cross-sectional area under the notch must be reported.

X4.2 The following examples are approximations:

19 J/m (0.37 ft·lbf/in.) = 1 kJ/m²
19 J/m (36.37) (1.358) J/m
19 J/m = 53.6 J/m
19 J/m = 0.0534 kJ/m

19 J/m (1000 in./ft) = 1 kJ/m²
19 J/m (1000) (1.358) J/m²
19 J/m = 2181 J/m²
19 J/m = 2.1 kJ/m²

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D6110 – 08) that may impact the use of this standard. (April 1, 2010)

(1) Revised Section 9.

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