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TEMA:

"CARACTERIZACIÓN TÉRMICA, MECÁNICA Y MICROESTRUCTURAL DE UN MATERIAL COMPUESTO DE MATRIZ POLIÉSTER REFORZADA CON FIBRA NATURAL DE BANANO Y SU POSIBLE APLICACIÓN INDUSTRIAL."

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AMBATO - ECUADOR
Septiembre - 2023

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En mi calidad de Tutor del Trabajo Experimental, previo a la obtención del Título de Ingeniero Mecánico, con el tema: "**CARACTERIZACIÓN TÉRMICA, MECÁNICA Y MICROESTRUCTURAL DE UN MATERIAL COMPUESTO DE MATRIZ POLIÉSTER REFORZADA CON FIBRA NATURAL DE BANANO Y SU POSIBLE APLICACIÓN INDUSTRIAL**", elaborado por el señor Erick Isaac López Martínez, portador de la cédula de ciudadanía 1805072657, estudiante de la carrera de Mecánica, de la Facultad de Ingeniería Civil y Mecánica.

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DEDICATORIA

A mi padre Hugo López y a mi madre Imelda Martínez, por brindarme todo su apoyo, esfuerzos y sacrificios realizados a lo largo de toda mi vida académica, por permitirme llegar a cumplir una meta más propuesta en mi vida ya que sin su apoyo no lo hubiese logrado.

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RESUMEN EJECUTIVO

Este estudio investigó la viabilidad de utilizar fibra natural de banano como refuerzo en un material polimérico compuesto de resina de poliéster. La fibra de banano se obtuvo a partir de residuos producidos de una plantación bananera en Ecuador, lo que la convierte en una opción atractiva debido a su fácil disponibilidad, bajo costo y su bajo impacto ambiental.

Se establecieron tres proporciones volumétricas diferentes (80 matriz - 20 fibra, 70 matriz - 30 refuerzo y 60 matriz - 40 refuerzo) para identificar el compuesto con el mejor comportamiento mecánico. Se llevó a cabo ensayos mecánicos de impacto, dureza y abrasión, siguiendo las normas ASTM D5628-10, ASTM D2240-15 y ASTM G0195-13a, respectivamente. Además, se realizó análisis de microestructura mediante un Microscopio Electrónico de Barrido (SEM) y de calorimetría con un Calorímetro Diferencial de Barrido (DSC).

Los resultados destacan que el material compuesto con una proporción del 70 por ciento de resina de poliéster y 30 por ciento de fibra mostró las mejores propiedades mecánicas, con valores de energía de impacto de 0.23J, dureza de 73.1 Shore D, índice de abrasión de 23.4 (mg/ciclo) y un pico de temperatura de 113.88 grados centígrados. La fibra de banano representa una alternativa prometedora como refuerzo en materiales compuestos de resina de poliéster, y el compuesto con la proporción del 70 por ciento de matriz y 30 por ciento de refuerzo demostró un comportamiento mecánico óptimo. Estos resultados tienen importantes aplicaciones potenciales en diversas industrias, como la construcción, la automoción y la aeronáutica.

Palabras clave: Resina poliéster, fibra de banano, ensayos mecánicos, SEM, DSC.

ABSTRACT

This study investigated the feasibility of using natural banana fiber as reinforcement in a polymeric material made up of polyester resin. The banana fiber was obtained from waste produced from a banana plantation in Ecuador, making it an attractive option due to its easy availability, low cost, and low environmental impact.

Three different volumetric proportions were established (80 matrix - 20 fiber, 70 matrix - 30 reinforcement and 60 matrix - 40 reinforcement) to identify the compound with the best mechanical behavior. Mechanical impact, hardness and abrasion tests were carried out, following the ASTM D5628-10, ASTM D2240-15 and ASTM G0195-13a standards, respectively. In addition, microstructure analysis was performed using a Scanning Electron Microscope (SEM) and calorimetry with a Differential Scanning Calorimeter (DSC).

The results highlight that the composite material with a proportion of 70 percent polyester resin and 30 percent fiber showed the best mechanical properties, with impact energy values of 0.23J, hardness of 73.1 Shore D, abrasion index of 23.4 (mg/cycle) and a peak temperature of 113.88 degrees Celsius. Banana fiber represents a promising alternative as reinforcement in polyester resin composites, and the composite with the ratio of 70 percent matrix and 30 percent reinforcement demonstrated optimal mechanical behavior. These results have important potential applications in various industries, such as construction, automotive, and aeronautics.

Keywords: Polyester resin, banana fiber, mechanical tests, SEM, DSC.

CAPÍTULO I

1. MARCO TEÓRICO:

1.1. Tema

“CARACTERIZACIÓN TÉRMICA, MECÁNICA Y MICROESTRUCTURAL DE UN MATERIAL COMPUESTO DE MATRIZ POLIÉSTER REFORZADA CON FIBRA NATURAL DE BANANO Y SU POSIBLE APLICACIÓN INDUSTRIAL.”

1.2. Antecedentes

Para llevar a cabo este proyecto, se han tenido en cuenta investigaciones previas que proporcionan la información requerida para el proceso de obtener materiales compuestos utilizando resina poliéster como matriz y fibra natural como refuerzo.

En el trabajo de investigación presentado por la revista internacional “MPDI Polymers “en el año 2022 con el título: “A Review on Natural Fiber Reinforced Polymer Composites (NFRPC) for Sustainable Industrial Applications” este estudio se hace hincapié de la importancia de la implementación de materiales compuestos a base de fibra natural dentro de la industria, para sustentar la investigación recalca la importancia de la aplicación de nuevas tecnologías, caracterizaciones de sus propiedades físicas o potenciales usos dentro de la industria. [1]

En la Facultad de Ingeniería Civil y Mecánica de la Universidad Técnica de Ambato en el año 2020, se desarrolló un trabajo de investigación con el tema: “ANÁLISIS DEL COMPORTAMIENTO MECÁNICO DE UN MATERIAL COMPUESTO DE MATRIZ POLIÉSTER REFORZADO CON FIBRA DE PELO DE RES Y SU POSIBLE APLICACIÓN INDUSTRIAL”, con autoría de Ángel Vinicio Tonato Porras, en este trabajo se investigación se determinó que las probetas fabricadas con una fracción volumétrica de 60% de matriz poliéster y 40% de refuerzo de fibra de pelo de res exhibieron las mejores propiedades mecánicas en términos de tracción, flexión e impacto. La densidad de la fibra de pelo de res se obtuvo mediante el método gravimétrico y se registró un valor de 1.03 g/cm³. El grupo de probetas con el 60% de resina poliéster y 40% de fibra de pelo de res en orientación a 0° demostró las propiedades mecánicas más idóneas a tracción, con un esfuerzo máximo promedio de 30.87 MPa y un módulo de elasticidad de 1843.17 MPa. Asimismo, las probetas del grupo 1, con el 40% de refuerzo y 60% de matriz en orientación a 0°, exhibieron las mejores propiedades mecánicas a flexión, con un esfuerzo máximo promedio de 55 MPa y un módulo de elasticidad de 1618.26 MPa. En cuanto a las propiedades mecánicas a impacto, el grupo 2, compuesto por una fracción volumétrica del 60% de resina poliéster y 40% de refuerzo en orientación a 45°, presentó el valor promedio más alto de energía absorbida, con 1.32 J, lo que indica una mayor resistencia a impacto en comparación con los otros grupos. En conclusión, el material compuesto de matriz poliéster reforzado con fibra de pelo de res muestra una mayor resistencia a tracción y flexión en comparación con la madera y el MDF, lo que lo hace aplicable en la industria de la construcción y en la industria carrocera. [2]

En el año 2020 en la Universidad Técnica de Ambato se llevó a cabo un trabajo de investigación con el título: "INFLUENCIA DE LA EXPOSICIÓN A LA INTEMPERIE EN LA RESISTENCIA A LA TRACCIÓN, FLEXIÓN E IMPACTO DE DOS MATERIALES COMPUESTOS DE MATRIZ POLIÉSTER REFORZADOS CON FIBRA DE ABACÁ Y PLÁTANO", con autoría de Francisco Javier Oquendo Lazo en donde se tras el análisis de la influencia de la exposición a la intemperie en la resistencia a la tracción, flexión e impacto de los materiales compuestos, se concluyó que hubo una afectación en las propiedades mecánicas de las probetas ensayadas. Se elaboraron dos materiales compuestos con una fracción volumétrica de 70% de matriz poliéster y 30% de refuerzo de fibra de abacá y fibra de plátano. A través de ensayos de tracción, flexión e impacto, se determinaron las propiedades mecánicas de las probetas, y se verificó mediante análisis estadísticos que las propiedades mecánicas de cada material, expuestas a la intemperie durante un lapso de seis meses, presentaron variaciones significativas. La resistencia a la tracción de las probetas de abacá disminuyó de 4715.12 N a 4039.9 N, mientras que las probetas de plátano pasaron de 3419.4 N a 2500.9 N. Además, se observaron cambios en el esfuerzo máximo de tracción, el módulo de elasticidad y el porcentaje de elongación. En los ensayos de flexión, se registraron valores diferentes en la fuerza máxima de flexión, la deflexión, el esfuerzo máximo de flexión y el módulo de elasticidad. Estos resultados demuestran que la exposición a la intemperie afecta las propiedades mecánicas de los materiales compuestos de matriz poliéster y refuerzo de fibra de abacá y fibra de plátano.[3]

En el año 2019 en la Facultad de Ingeniería Mecánica de la Escuela Politécnica Nacional se realizó un trabajo de titulación con el tema: "ESTUDIO DEL COMPORTAMIENTO MECÁNICO DE UN MATERIAL COMPUESTO CON MATRIZ DE POLIPROPILENO AL AÑADIR PARTÍCULAS DE CASCARILLA DE ORYZA SATIVA (ARROZ)" a cago del Sr. ORTIZ FLORES MICHAEL STALIN y de la Sra. OSORIO CAMACHO MIREYA CLEMENTINA. En este trabajo además de ensayos mecánicos se hace uso de un ensayo de calorimetría para caracterizar térmicamente al material y a partir de esto, se evidenció que el material compuesto exhibió un comportamiento frágil en contraste con el polipropileno, debido al endurecimiento ocasionado por el refuerzo, lo cual condujo a una menor deformación en el material. La presencia de partículas de cascarilla de arroz en el compuesto afectó los parámetros de moldeo, requiriendo ajustes en la temperatura y presión utilizadas. Los valores óptimos obtenidos fueron una temperatura de precalentamiento de 120 ºC, un tiempo de precalentamiento de 6 minutos, una temperatura de moldeo de 168 ºC y una presión de moldeo de 100 kgf/cm2 para las probetas de tracción, y de 40 kgf/cm2 para las de flexión. Además, se encontró que el porcentaje de refuerzo tuvo un impacto significativo en las propiedades mecánicas del material, siendo recomendable utilizar un máximo del 15% en peso. En particular, la composición PP_10CA_T100, con un 10% en peso de refuerzo y partículas de tamaño de 150 µm, exhibió las mejores propiedades en términos de tracción y flexión. Sin embargo, se observó que, al aumentar el porcentaje de refuerzo, las propiedades mecánicas disminuyeron debido a la falta de homogeneidad en el compuesto, identificándose la presencia de poros en la zona de fractura, los cuales debilitaron la resistencia del material. Las composiciones con un 5% y 10% en peso mostraron fracturas de tipo dúctil, mientras que la composición con un 15% en peso presentó una fractura frágil. Cabe mencionar que las propiedades del material desarrollado en este estudio fueron inferiores en comparación con investigaciones realizadas en otros países. Finalmente, el análisis estadístico ANOVA reveló que el porcentaje en peso del refuerzo tuvo una mayor influencia en las propiedades mecánicas a tracción y flexión. El aumento en dicho porcentaje resultó en un incremento de la densidad del material y una leve elevación en la temperatura de fusión. [4]

1.3. Objetivos

1.3.1. Objetivo General

Realizar la caracterización térmica, mecánica y microestructural de un material compuesto de matriz poliéster reforzada con fibra natural de banano y su posible aplicación en la industria.

1.3.2. Objetivos Específicos

- Determinar la orientación del refuerzo, fracción volumétrica y estratificación del material compuesto de matriz polimérica reforzado con fibra de banano.
- Realizar ensayos de Impacto, Dureza, Abrasión, calorimetria y Fractografía del material compuesto de matriz polimérica reforzado con fibra de banano.
- Determinar el material compuesto que presente la mejor combinación de propiedades mecánicas y su posible aplicación en la industria.

1.4. Fundamentación teórica

1.4.1. Ciencia e ingeniería en materiales

La disciplina de ciencia e ingeniería de materiales se divide en dos ámbitos: la ciencia de materiales y la ingeniería de materiales. La ciencia de materiales investiga las relaciones entre las estructuras y propiedades de los materiales, mientras que la ingeniería de materiales utiliza estas correlaciones para diseñar materiales con propiedades específicas. Los graduados en programas de materiales están capacitados en ambas áreas. La estructura de un material se refiere a la disposición de sus componentes internos, desde la estructura subatómica hasta la macroscópica. Las propiedades de los materiales se dividen en seis categorías: mecánicas, eléctricas, térmicas, magnéticas, ópticas y químicas. El procesamiento de los materiales y su rendimiento también son componentes importantes en la ciencia e ingeniería de materiales.[5] La inter relación entre el procesamiento, estructura, propiedades y el rendimiento se representa en la Figura 1.

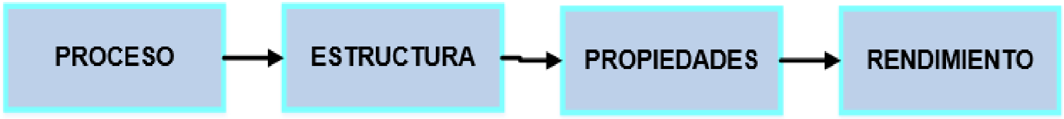


Figura 1. Secuencia de procesamiento de materiales.

1.4.2. Materiales Compuesto

Un material compuesto es la combinación de dos o más componentes que se unen sinérgicamente para formar un material con una mayor capacidad estructural que la de sus constituyentes cuando actúan por separado. El refuerzo es la fase más rígida y resistente, que se presenta en forma de partículas o fibras continuas o discontinuas y se encuentra embebido en un material continúo denominado matriz. Las propiedades mecánicas del material compuesto dependen de las propiedades de los materiales constituyentes, su geometría, distribución y fracción volumétrica. La distribución topológica del refuerzo determina el grado de uniformidad u homogeneidad del material compuesto, y su geometría y orientación afecta al grado de anisotropía del sistema. Los materiales compuestos ofrecen ventajas determinantes en comparación con los materiales estructurales convencionales, como la posibilidad de generar estructuras de geometrías complejas, debido a su alto módulo de rigidez y resistencia específica. Aunque pueden requerir un análisis más complejo que los materiales convencionales, proporcionan una mayor libertad para un diseño y una configuración óptima del material estructural. [6].

1.4.3. Clasificación de materiales compuestos

La clasificación de los compuestos se basa en la geometría del refuerzo, que puede ser particulado, en láminas o de fibras, o en el tipo de matriz, que puede ser de polímero, metal, cerámica o carbono. En resumen, los compuestos se clasifican según la forma del refuerzo y el tipo de matriz utilizado. A continuación, se detallan algunos tipos de compuestos mencionados anteriormente:

- Los compuestos particulados están compuestos por partículas sumergidas en matrices como aleaciones y cerámicas. Por lo general, son isotrópicos ya que las partículas se agregan al azar. Los compuestos particulados tienen ventajas como una mayor resistencia, temperatura de operación más alta, resistencia a la oxidación, etc. Algunos ejemplos típicos incluyen el uso de partículas de aluminio en caucho, partículas de carburo de silicio en aluminio, y grava, arena y cemento para hacer concreto. En resumen, los compuestos particulados consisten en partículas dentro de matrices y tienen varias ventajas, como mayor resistencia y resistencia a la oxidación.

- Los compuestos de laminados consisten en refuerzos planos de matrices. Los materiales compuestos típicos de lámina son vidrio, mica, aluminio y plata. Los compuestos de lámina ofrecen ventajas como un alto módulo de flexión fuera del plano, mayor resistencia y bajo costo. Sin embargo, las láminas no pueden orientarse fácilmente y solo un número limitado de materiales están disponibles para su uso. Dicho de otra forma, los compuestos de lámina se componen de refuerzos planos de matrices y ofrecen ventajas como alta resistencia y bajo costo, aunque su uso se ve limitado por la dificultad de orientación y la disponibilidad de materiales.
- Los compuestos de fibra consisten en matrices reforzadas por fibras cortas (discontinuas) o largas (continuas). Las fibras suelen ser anisotrópicas y los ejemplos incluyen carbono y aramidas. Ejemplos de matrices son resinas como el epoxi, metales como el aluminio y cerámicas como el silicato de calcio-aluminio. Este libro se enfoca en los compuestos de fibra continua, los cuales se discuten más a fondo en este capítulo por los tipos de matrices: polímero, metal, cerámica y carbono. Las unidades fundamentales de un compuesto de matriz continua y fibra son láminas de fibra unidireccionales o tejidas. Las láminas se apilan unas encima de otras en diversos ángulos para formar un laminado multidireccional. Los compuestos de fibra se componen de matrices reforzadas por fibras cortas o largas, y se dividen en compuestos de fibra continua y discontinua.
- Los nano compuestos están compuestos de materiales a escala de nanómetros (10^{-9}) m. Para ser considerado un nano compuesto, uno de los componentes debe tener un tamaño inferior a los 100 nm. Las propiedades de los materiales a esta escala son diferentes de las del material a granel. Los materiales compuestos

avanzados suelen tener componentes en la escala micrométrica (10^{-6}) m. Al tener materiales a escala nanométrica, la mayoría de las propiedades del material compuesto resultante son mejores que las del material a escala micro. Sin embargo, no todas las propiedades de los nano compuestos son mejores, ya que, en algunos casos, la resistencia al impacto puede disminuir. Los nanos compuestos tienen aplicaciones en el embalaje militar, en donde películas de nano compuestos demuestran mejoras en propiedades como el módulo elástico y la tasa de transmisión de vapor de agua, distorsión térmica y oxígeno. Dicho de otra forma, los nanos compuestos están compuestos de materiales a escala nanométrica y tienen propiedades superiores a los materiales a escala micro, sin embargo, algunas propiedades pueden disminuir, como la resistencia al impacto. [7]

1.4.4. Componentes de materiales compuestos

Los materiales compuestos están conformados por dos fases claramente diferenciadas: la fase de refuerzo y la matriz.

Refuerzo

El propósito de las fibras es reforzar la matriz del material compuesto, proporcionando una alta resistencia a la tracción y rigidez. La matriz, por otro lado, proporciona resistencia a la compresión y a la deformación. La combinación de la fibra y la matriz produce un material con una resistencia y rigidez excepcionales en comparación con los materiales convencionales.

Es importante tener en cuenta que la elección del tipo de fibra y matriz es crucial para obtener las propiedades deseadas del material compuesto. Las propiedades de la fibra, como la resistencia a la tracción y la rigidez, deben ser compatibles con las propiedades de la matriz para lograr una transferencia eficiente de carga entre las fibras y la matriz. [8]

Clasificación de tipo de fibra

Dentro de la ingeniería en materiales, la palabra "fibra" puede referirse a la aglomeración de células en las que la longitud es mucho mayor que el diámetro. Es importante destacar que existen dos categorías de fibras, las naturales y las químicas, y dentro de cada una de ellas hay una gran cantidad de subcategorías que permiten su clasificación más precisa.

Es posible clasificar las fibras en función de distintos criterios, como su longitud, su función o su origen. Por ejemplo, las fibras pueden ser cortas o largas dependiendo de la longitud que tengan después de ser procesadas. También se pueden clasificar como fibras estructurales o no estructurales según su función. Por último, según su origen, las fibras se clasifican en naturales o químicas.[9]

A. Fibras cortas

Es posible obtener partículas muy finas o fibras cortas mediante procesos industriales. Estos materiales se pueden utilizar para obtener perfiles extruidos. Asimismo, las fibras cortas pueden ser utilizadas para crear mantas de fibras no tejidas mediante un proceso de impregnación de termocompresión. De esta forma, se pueden obtener materiales con propiedades específicas para su uso en diversos campos de la ingeniería.[9]

B. Fibras largas

Las fibras largas pueden ser clasificadas en dos grupos: "roving" y "tejido". El roving se refiere al hilo de la fibra que ha sido sometido a un proceso de enrollamiento de los filamentos. Por otro lado, los tejidos pueden ser obtenidos mediante procesos manuales o mediante la transferencia de resinas. En cuanto a la forma en que se pueden añadir las fibras, existen varias opciones.[9]

C. Fibras estructurales

Existen fibras con propiedades que les permiten cumplir una función estructural en materiales como el cemento u hormigón una vez incorporadas, por lo que es necesario realizar un cálculo previo antes de su incorporación. La resistencia a esfuerzo cortante se ve significativamente mejorada con la presencia de fibras estructurales en la mezcla. Es importante destacar que las fibras estructurales no pueden tener una disposición aleatoria, y deben ser incorporadas siguiendo procesos específicos que garanticen su correcta ubicación para un funcionamiento óptimo.[9]

D. Fibras no estructurales

Existen fibras que al ser añadidas a materiales de construcción como el hormigón aportan ciertas cualidades sin afectar el cálculo estructural. Tal es el caso de las fibras naturales que se mencionaran a continuación, estás fibras mejoran las propiedades de materiales de construcción, pero no cumplen una función estructural, a diferencia de las barras de acero.[9]

E. Fibras según su origen

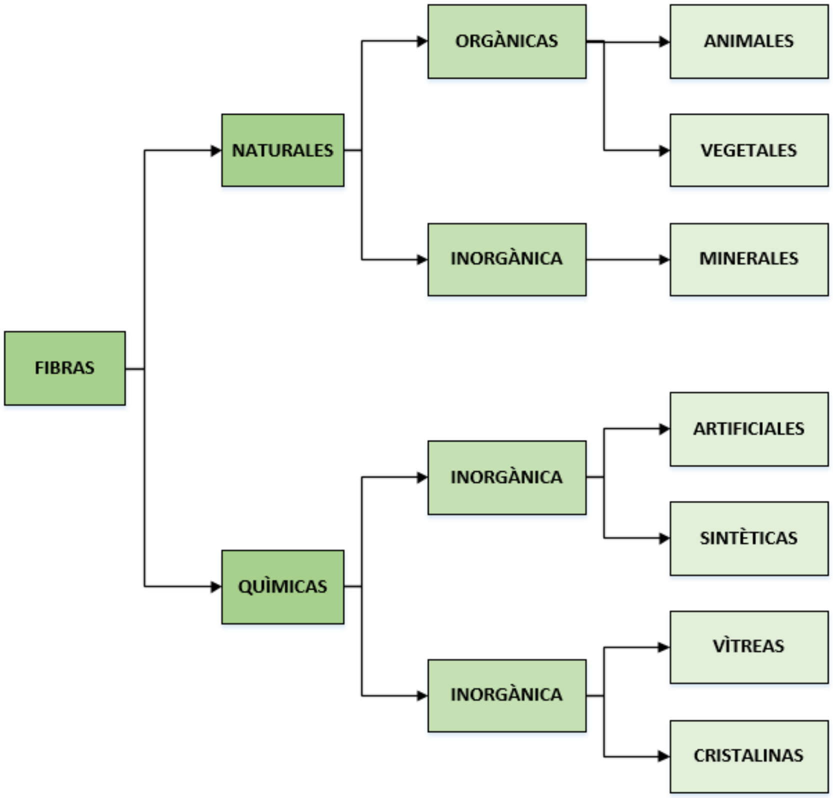


Figura 2. Clasificación de fibras según su origen.

Fibras naturales en materiales compuestos

En las últimas décadas, ha habido un aumento significativo en el uso de materiales poliméricos en diversas aplicaciones debido a su facilidad de procesamiento, productividad en la obtención, baja densidad y bajo costo en comparación con otros materiales. Una práctica común es mejorar las propiedades de los materiales poliméricos mediante la adición de partículas, tejidos o fibras de diferentes materiales para obtener compuestos de matriz polimérica termoplástica, elastomérica o termoestable.

Según diversos estudios, el uso de fibras naturales como cargas en compuestos de matriz polimérica ofrece numerosas ventajas. Estas fibras provienen de recursos renovables, lo que las hace fácilmente disponibles, son de bajo costo y biodegradables, reduciendo así su impacto ambiental. Además, presentan propiedades mecánicas comparables a los materiales de refuerzo sintéticos convencionales, como las fibras de vidrio o de carbono. Las fibras naturales se clasifican según su origen vegetal, animal o mineral. En particular, las fibras de origen vegetal se clasifican según la parte de la planta de la que se extraen, como se muestra en la Figura 3. [10]

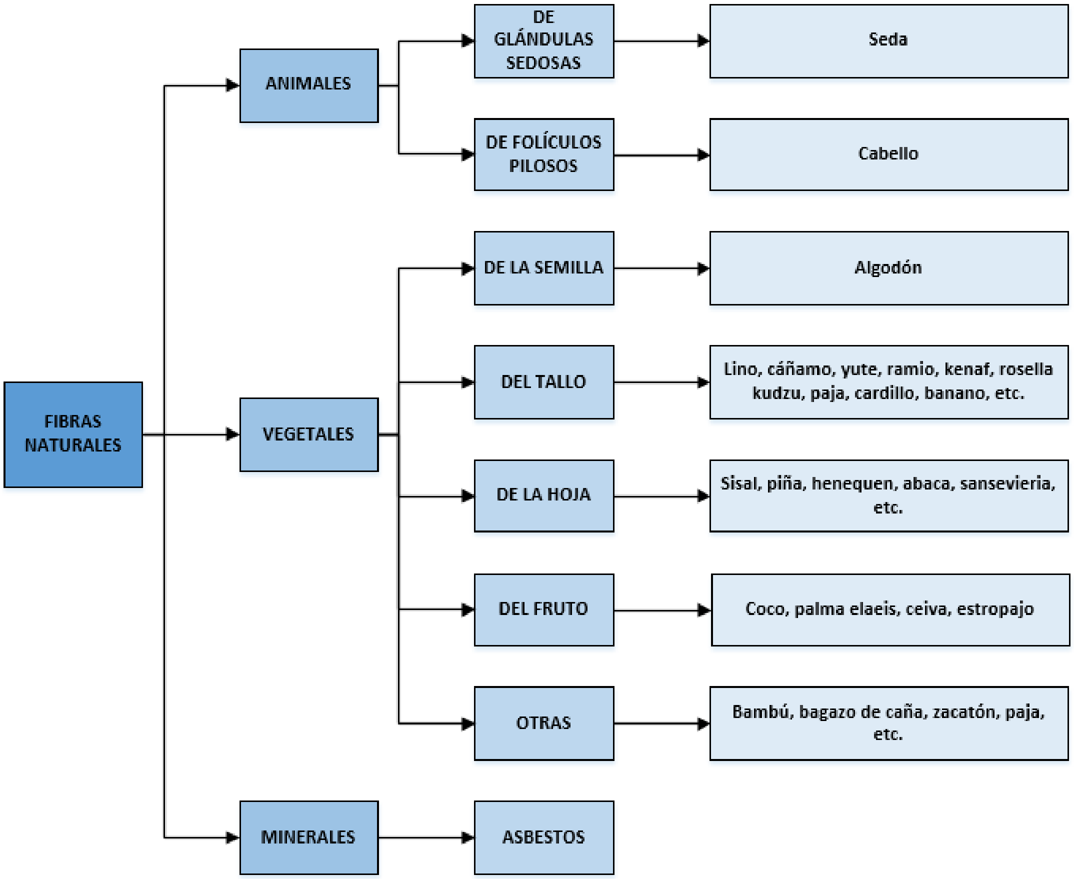


Figura 3. Clasificación de fibras naturales.

Matriz

En los materiales compuestos, la fase de matriz es el material que rodea y sostiene las fibras o partículas de refuerzo. La matriz es responsable de transferir las cargas entre las fibras o partículas de refuerzo y proporcionar protección contra el medio ambiente.

La selección de la fase de matriz es crítica para el rendimiento del material compuesto. La fase de matriz debe ser compatible con los materiales de refuerzo y debe tener propiedades mecánicas adecuadas para soportar las cargas aplicadas. Además, la fase de matriz debe ser resistente a los efectos ambientales, como la humedad y la temperatura.

Es importante tener en cuenta que la fase de matriz puede afectar significativamente las propiedades mecánicas del material compuesto. Por ejemplo, una matriz más rígida puede mejorar la resistencia a la fatiga del material compuesto, mientras que una matriz más flexible puede mejorar la resistencia al impacto.[11]

A. Matrices Poliméricas

En la fabricación de materiales compuestos, se utilizan comúnmente matrices poliméricas debido a su accesibilidad y bajo costo. Los polímeros se caracterizan por tener baja densidad y propiedades sobresalientes a temperatura ambiente, sin embargo, no son muy resistentes a altas temperaturas. Por esta razón, se emplean como matriz y se refuerzan con fibras orgánicas e inorgánicas para mejorar su resistencia y durabilidad. [12]

B. Matrices termoplásticas

Las matrices termoplásticas se distinguen por su capacidad de transformarse en estado líquido cuando se les aplica calor, lo que las hace altamente moldeables. Dentro de los termoplásticos, podemos encontrar ejemplos como el polietileno, polipropileno, policarbonatos y poliuretanos. De esta forma, su versatilidad permite una amplia gama de aplicaciones en diferentes industrias.[12]

C. Matrices termoestables

Las matrices termoestables se destacan por su incapacidad de transformarse en estado líquido al aplicarles altas temperaturas, lo que provoca que pasen directamente al estado gaseoso conocido como carbonización. Esto impide que sean remoldeados y se descomponen químicamente. Ejemplos de termoestables son las resinas poliéster, epóxicas y fenólicas, que se utilizan en una amplia variedad de aplicaciones, desde la fabricación de piezas estructurales hasta materiales de construcción. [12]

Resina poliéster

Las resinas poliéster son ampliamente utilizadas como matriz termoestable a nivel mundial. Debido a sus características, son empleadas en la fabricación materiales de construcción, partes de autos, embarcaciones, entre otros. Además, ofrecen una ventaja económica en comparación con otras matrices termoestables. Sin embargo, estas resinas son componentes inestables y tienden a polimerizarse y gelificarse. Para garantizar su correcta formación, se aplican inhibidores para prevenir estos procesos no deseados.[13] Las propiedades mecánicas de la resina se muestran en la tabla 1.

Tabla 1. Propiedades de resina poliéster.

PROPIEDADES DE RESINA POLIÉSTER	
Resistencia a la tracción	50 Mpa
Resistencia a la flexión	80 Mpa
Resistencia a la impacto	10 $\frac{kJ}{m^2}$
Resistencia a la compresión	70 Mpa
Densidad	1.2 $\frac{g}{cm^2}$
Módulo de Young	3.5 Gpa

Fuente: [13]

Tipos de resina poliéster

De acuerdo con la composición de los ácidos y alcoholes utilizados, se pueden obtener distintos tipos de resinas poliéster. Estas resinas se clasifican en tres categorías principales según la naturaleza de sus monómeros: orto-ftálicas, iso-ftálicas y bis-fenólicas. A continuación, se detallan cada una.

- Las resinas orto-ftálicas son las más utilizadas debido a su menor costo y son capaces de absorber hasta un 2.5% de agua en inmersiones prolongadas. [14]
- Las resinas iso-ftálicas, por otro lado, tienen mejores propiedades mecánicas y una menor absorción de agua, lo que las hace ideales para su uso en ambientes marinos. [14]
- Las resinas bis-fenólicas son las más resistentes a la corrosión y tienen excelentes propiedades mecánicas y químicas, pero también son las más costosas. Debido a esto, son las más adecuadas para su uso en ambientes corrosivos.[14]

1.4.5. Ensayos materiales compuestos

Para determinar las propiedades mecánicas de un material compuesto, como la resistencia al impacto, a la abrasión o su dureza; o las propiedades térmicas como ensayos de calorimetría diferencial de barrido (DSC) se requiere la realización deferentes ensayos.

Estos ensayos deben seguir las normas establecidas por organismos como ASTM, ISO y INEN, y se realizan en condiciones simuladas para obtener resultados precisos y confiables. En esta investigación se utilizarán las normas ASTM para los diferentes tipos de ensayos.

CAPÍTULO II

2. METODOLIGÍA

2.1. Diagrama de flujo

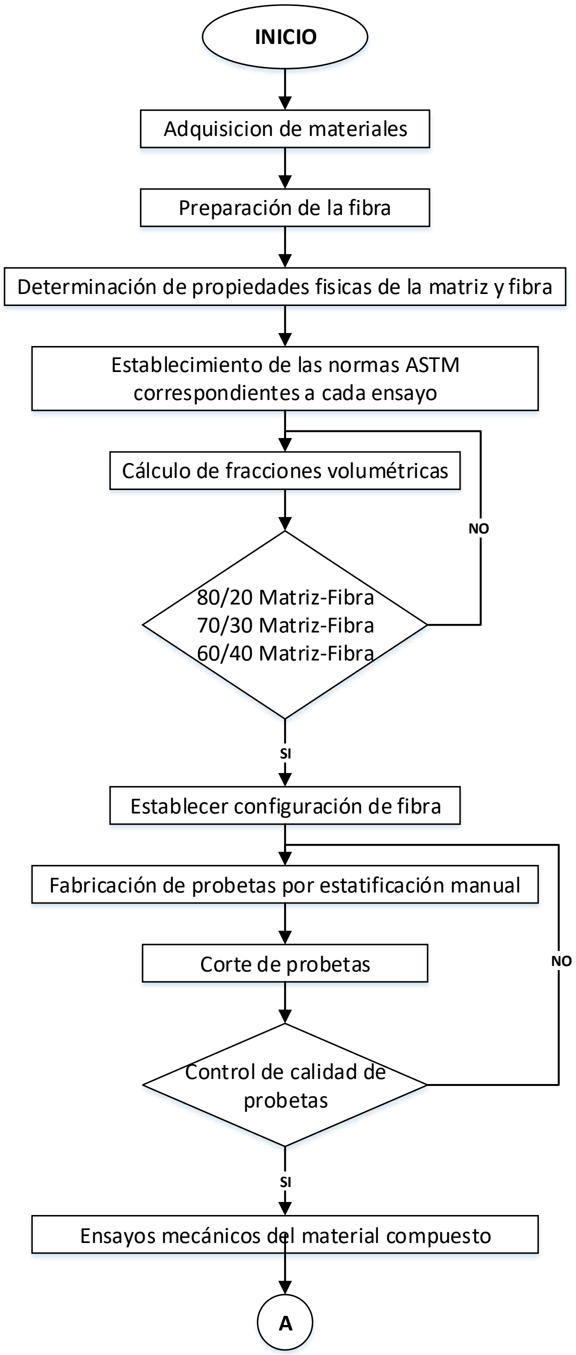


Figura 4. Diagrama de flujo del trabajo experimental.

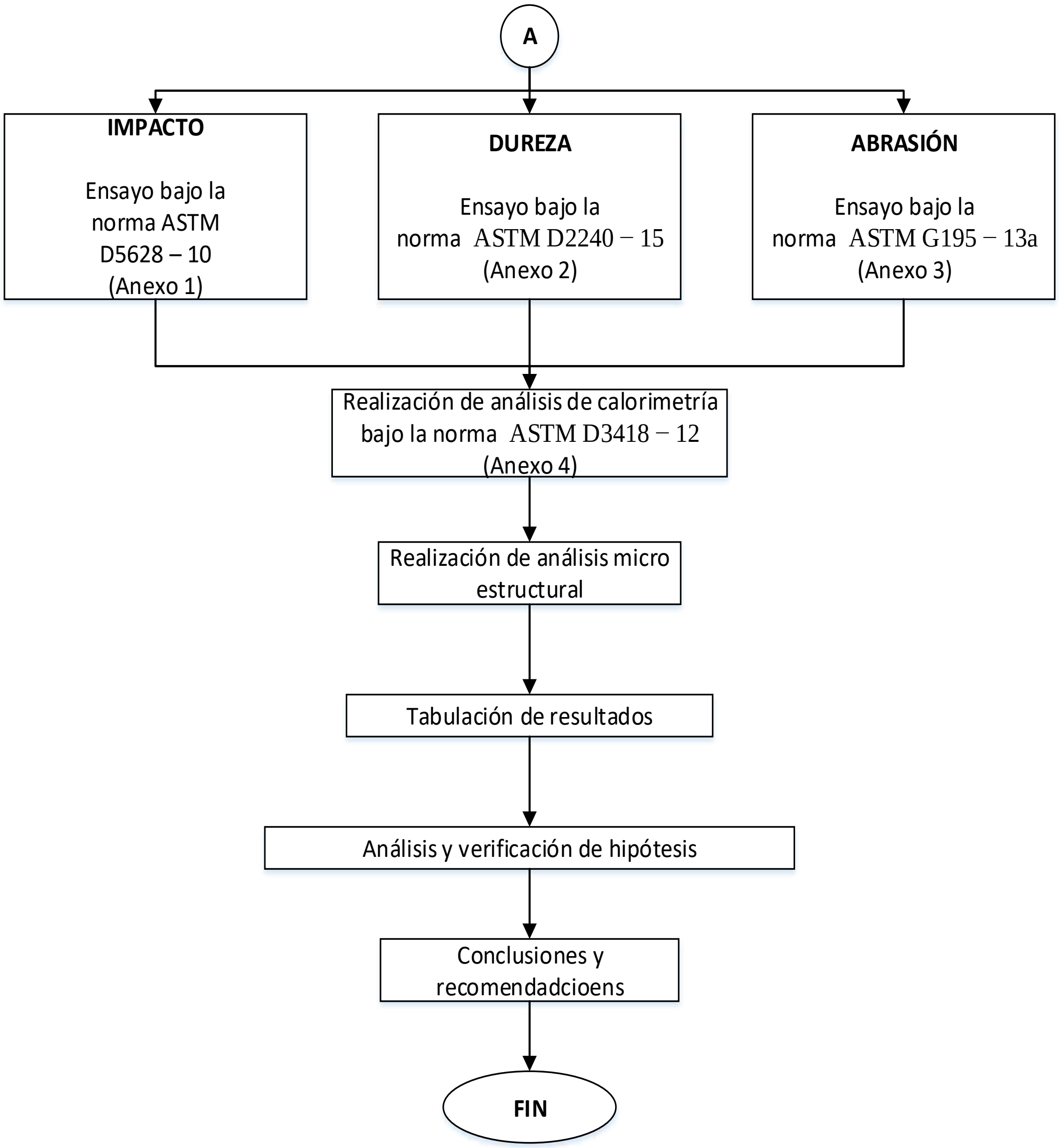


Figura 4. Continuación.

2.2. Materiales

En la tabla 2 se muestra y detallan los materiales, equipos y herramientas que fueron utilizados para la realización del presente trabajo experimental.

Tabla 2. Listado de equipos y materiales.

ELEMENTO	DETALLE	REPRESENTACIÓN GRÁFICA
Computador	Máquina utilizada para la generación del informe escrito y análisis de resultados	
Máquina de impacto por caída de dardo	Equipo utilizado para evaluar la resistencia al impacto de materiales y productos.	
Durómetro Shore	Dispositivo utilizado para medir la dureza de materiales como plásticos, elastómeros y materiales similares.	
Tabla de desgaste giratoria	Dispositivo utilizado para evaluar la resistencia al desgaste de materiales	

Tabla 2. Continuación

Calorímetro diferencial de barrido	Equipo utilizada para la caracterización térmica del material	
Microscopio de barrido	Equipo empleador para el análisis microestructura del material	
Resina Poliéster	Resina poliéster transparente en presentación de 1 kg.	
Acelerador de cobalto	Octato de Cobalto al 12 % de Co	

Tabla 2. Continuación

Catalizador MERK	Peróxido metil eltil cetonal al 9% de oxigeno activo	
Fibra de banano	Fibra extraída del tallo de la planta del banano	
Cera desmoldaste	Cera para pisos utilizado como desmoldaste marca Brillante en presentación de 600 ml	
Jeringas	Dos jeringas de 20 ml para el catalizador Mek y acelerarte, respectivamente y una de 50 ml para la resina poliéster	
Recipientes	Diferentes contenedores de plástico para preparar la resina poliéster	
Moldes	Tres diferentes moldes para ensayos de impacto, dureza y abrasión respectivamente.	

Tabla 2. Continuación

Balanza digital	Balanza digital gramera de hasta 10 kg	
Mandil	Indumentaria para protección	
Implementos de seguridad	Indumentaria para protección (Guantes y gafas)	

2.3. Métodos

En la elaboración y ensayos del material compuesto se emplearán los siguientes métodos:

Bibliográfico

En el ámbito de la investigación de ingeniería, el nivel bibliográfico cumple una función crucial al facilitar la recopilación de información, imágenes, datos y antecedentes investigativos relevantes para el trabajo en cuestión. Dicha información se encuentra disponible en distintas fuentes bibliográficas como libros, tesis, artículos y páginas web, siempre y cuando se mantenga una relación estrecha con el tema de interés, en este caso los materiales compuestos, fibras sintéticas y naturales, resinas epoxi y los procedimientos para la conformación de dichos materiales.

Descriptivo

En este estudio se ha empleado un método para la caracterización de las propiedades térmicas y mecánicas de la conformación de un determinado material. A través de este método, se han identificado las características que se obtienen en cada combinación volumétrica realizada, las cuales serán aplicadas en los correspondientes ensayos. Asimismo, se han generado fichas técnicas que permiten la identificación precisa de cada uno de los materiales y su variación.

Experimental

La presente investigación se enmarca dentro del tipo experimental, puesto que se llevarán a cabo ensayos cuyos resultados permitirán obtener datos estadísticos relevantes para la identificación y análisis de la resistencia al impacto, dureza, índice de abrasión y calorimetría del material señalado.

Exploratorio

En el marco de esta tesis de ingeniería, se ha decidido emplear el método exploratorio para la conformación de materiales compuestos mediante la utilización de resina poliéster reforzada con fibra de banano en diversas combinaciones volumétricas. El objetivo de este enfoque es determinar la combinación óptima que permita obtener las mejores propiedades mecánicas y térmicas en el compuesto final.

2.4. Población y muestra

2.4.1. Población

El presente trabajo en fase de prueba tiene como población la preparación de probetas a ensayar, para conocer las características mecánicas, térmicas y microestructurales de las mismas. Las probetas están conformadas por una combinación de resina poliéster + fibra natural de banano, se las fabricarán bajo las dimensiones y condiciones establecidas en las normas ASTM divididas acorde a la fracción volumétrica (80 / 20, 70 / 30, 60 / 40) porcentajes de matriz y refuerzo respectivamente.

2.4.2. Muestra

Las diferentes probetas se realizarán con un mínimo de cinco para el ensayo de impacto todo bajo las especificaciones de las normas correspondientes (Impacto ASTM D5628 - 10) en función de la fracción volumétrica del material compuesto (resina poliéster + fibra de banano) mediante moldes y probetas.

Para los ensayos de dureza se realizarán cinco mediciones por cada fracción volumétrica diferente acorde a la norma ASTM D2240−15, en cambio para los ensayos de abrasión se crearán 5 probetas de la configuración volumétrica que posea mejores propiedades frente a la resistencia al impacto y a la dureza.

Para el ensayo DSC se tomará una muestra aproximadamente de 50 mg representativa del material. Finalmente, tras su análisis correspondiente determinar el material que presente la mejor combinación de propiedades mecánicas y térmicas.

2.5. Hipótesis

El análisis calorimétrico (DSC), junto con los ensayos mecánicos impacto, dureza, abrasión y microestructural permitirá tener una mejor caracterización del material compuesto de matriz poliéster reforzado con fibra de banano.

La configuración de fibra entrecruzada presentará buenas condiciones frente a la resistencia al impacto, los ensayos de dureza ayudarán a delimitar la mejor configuración volumétrica, posterior los ensayos de abrasión brindarán una mejor caracterización mecánica del material. Finalmente, el análisis de calorimetría ayudará a delimitar el área de trabajo en donde el material es termoestable.

2.6. Señalamiento de variables

2.6.1. Variable independiente

Material compuesto de resina poliéster reforzado con fibra natural de banano.

Tabla 3. Variable independiente.

Tipo variable	**Conceptualización**	**Categoría**	**Indicadores**	**Ítems**	**Técnicas e instrumentación**
Independiente	Se puede definir un material compuesto como aquel que está compuesto por dos o más componentes que se han combinado para crear un nuevo material con mejores propiedades físicas y mecánicas que los materiales originales por separado.	Material compuesto	Fracción volumétrica	80% matriz y 20% refuerzo	-Observación directa. -Fichas de técnicas. -Normas ASTM. -Bibliografía.
				70% matriz y 20% refuerzo	
				60% matriz y 30% refuerzo	

2.6.2. Variable dependiente

Tabla 4. Variable dependiente.

Tipo variable	**Conceptualización**	**Categoría**	**Indicadores**	**Índice**	**Técnicas e instrumentación**
Dependiente	Las características de resistencia y comportamiento de un material ante fuerzas externas son propiedades mecánicas. Estas se pueden medir a través de pruebas específicas que se realizan de acuerdo a ciertas normativas, y proporcionan información sobre cómo el material se comporta cuando se le aplica una carga hasta un punto determinado en el tiempo.	Impacto	Cantidad de absorción de energía	Energía de impacto E=hwf [J]	-Ensayos de laboratorio. -Normas ASTM. -Fichas técnicas de resultados.
		Dureza	Resistencia del material a ser rayado	Shore D	
		Abrasión	Porcentaje de desgaste del material	Índice de abrasión $\frac{g}{ciclos}$	
		Calorimetría diferencial	Variación de capacidad calórica	Pico de calor, cristalinidad	
		Análisis microestructural	Adherencia ente la matriz y el refuerzo	Adherencia matriz-refuerzo	

2.7. Procedimientos para la elaboración de los compuestos

2.7.1. Determinación de las propiedades físicas de la fibra

Al construir un nuevo material compuesto, es importante considerar el cálculo o determinación de sus características físicas, especialmente su densidad. Durante la fase de prueba, el cálculo de la densidad se realiza mediante el procedimiento gravitatorio, que utiliza la relación entre la masa y el volumen del material. Los valores necesarios se pueden obtener midiendo las probetas y aplicando la fórmula 1. Este proceso es esencial para comprender las propiedades físicas del material y determinar si cumple con las especificaciones requeridas para su aplicación en un proyecto específico.

$$\rho = \frac{m}{v} \tag{1}$$

Donde:

$\rho = densidad\ \left[\frac{g}{cm^3}\right]$

$m = masa\ [g]$

$v = volumen\ [cm^3]$

La fibra de plátano presenta una amplia variabilidad en sus propiedades físicas. Por ejemplo, su densidad se encuentra en un rango de 950 a 750 kg/m³, mientras que su longitud oscila entre 2000 y 5000 mm. El diámetro de la fibra, por su parte, se encuentra en un rango de 0,080 a 0,250 mm y su capacidad de absorción de agua es del 60 %. Además, el índice de aspecto (l/d) de la fibra de plátano es de 1,5.[15]

Tabla 5. Determinación de la densidad de la fibra de banano.

	Universidad Técnica de Ambato **Facultad de Ingeniería Civil Y Mecánica** **Carrera de Mecánica**				
RECOLECCIÓN DE DATOS Y EVALUACIÓN DE DENSIDAD DE LA FIBRA NATURAL DE BANANO					
DATOS INFORMATIVOS					
Temperatura:	Ambiente 20°		Fecha:	05 de Mayo de 2023	
Fibra:	Banano		N° Muestras:	4	
Método:	Gravimétrico		Ciudad:	Ambato	
Revisado por:	Ing. Mg. Pablo Valle, Ph.D				
Realizado por:	Erick López Martínez				
RESULTADOS					
Iteración	m_{fibra} $[g]$	$V_o\ Agua$ $[cm^3]$	$V_i\ Agua$ $[cm^3]$	$\Delta V\ Agua$ $[cm^3]$	ρ $\left[\frac{g}{cm^3}\right]$
1	3	60	64.5	4.5	0.667
2	6	60	68.5	8.5	0.706
3	9	60	72	12	0.750
4	12	60	75.5	16	0.750
PROMEDIO					0.714
IMÁGENES ENSAYO					
Pesado de fibra			Variación Volumétrica		

Tabla 5. Continuación

	
Densidad de la fibra de banano $0.714 \frac{g}{cm^3}$	

2.7.2. Adquisición de materia prima

La fibra natural de banano proviene de la palma de banano (Musa × paradisiaca), la misma que puede ser encontrada en su mayoría en la región Costa del país, siendo las provincias de Manabí, Santo Domingo y los Ríos las mayores productoras de banano. La adquisición de la fibra se lo realizó por medio de la empresa “Impadesa” Fig. 5.

Figura 5. Fibra de banano

Fuente: [16]

Por otra parte, la resina poliéster con marca "Disther" y el catalizador marca "Curox" se lo adquirió por medio del almacén Pintura. El resto de materiales se los fueron adquiriendo en diferentes almacenes

2.7.3. Determinación de la cantidad de resina y catalizador.

Se emplearán las ecuaciones "a" y "b" para calcular la cantidad necesaria de resina y endurecedor (catalizador) respectivamente, ecuación 2 y 3. Estas medidas son de gran importancia, debido a que la cantidad de matriz requerida varía según cada caso, y se debe seguir las instrucciones del fabricante para determinar la cantidad adecuada.

$$RE = \frac{100}{127}\ Fibra_P \tag{2}$$

$$CA = \frac{27}{127}\ Fibra_P \tag{3}$$

Donde:

$RE = Cantidad\ resiana\ [g]$

$CA = Cantidad\ catalizador\ [g]$

$Fibra_P = Peso\ de\ fibra\ [g]$

2.7.4. Cálculos para la elaboración de probetas

Probetas de impacto

Calculo (Fracción volumétrica 80% matriz y 20% refuerzo)

Datos:

$\rho_{fibra} = 0.71 \frac{g}{cm^3}$

$\rho_{matriz} = 1.21 \frac{g}{cm^3}$

$P_{fibra} = 20\ \%$

$P_{matriz} = 80\,\%$

Donde:

ρ_{fibra} = densidad de fibra

ρ_{matriz} = densidad de matriz

P_{fibra} = porcentaje fibra

P_{matriz} = porcentaje matriz

Cálculo de la densidad del material compuesto resina poliéster y fibra natural de banano.

$$\rho_{compuesto} = (\rho_{matriz}\, P_{matriz}) + (\rho_{fibra} P_{fibra})$$

$$\rho_{compuesto} = \left(\frac{80}{100}\right)(1.21)\frac{g}{cm^3} + \left(\frac{20}{100}\right)(0.71)\frac{g}{cm^3}$$

$$\rho_{compuesto} = 0.968\frac{g}{cm^3} + 0.142\frac{g}{cm^3}$$

$$\rho_{compuesto} = 1.111\frac{g}{cm^3}$$

Calculo volumen de molde

$Largo$: $300\ mm$

$Ancho$: $60\ mm$

$Profundidad$: $8\ mm$

$$V_{molde} = Largo\ Ancho\ Profundidad$$

$$V_{molde} = (\ 300\ )(60)(8)\ mm$$

$$V_{molde} = 144000\ mm^3 \ \rightarrow\ 144\ cm^3$$

Una vez conocida las fracciones volumétricas y el volumen del molde, se calcular el volumen de la matriz y el peso del refuerzo

Cálculo volumen de la matriz

$\boldsymbol{V_{molde}} = 144\, cm^3$

$P_{matriz} = 80\, \%$

$\rho_{matriz} = 1.21 \frac{g}{cm^3}$

$$100\ \% \rightarrow 144\, cm^3$$
$$80\ \% \rightarrow V_{m1}$$

$$\boldsymbol{V_{m1} = 115.2\ cm^3}$$

$$\boldsymbol{V_{matriz} = V_{m1}\ \rho_{matriz}}$$
$$V_{matriz} = (115.2\ )(1.21)\ cm^3$$
$$V_{matriz} = 139.392\ cm^3$$

Cálculo de la masa del refuerzo

$\boldsymbol{V_{molde}} = 144\, cm^3$

$P_{fibra} = 20\, \%$

$$100\ \% \rightarrow 144\, cm^3$$
$$20\ \% \rightarrow V_{f1}$$

$$V_{f1} = 28.8\ cm^3$$

Masa de fibra requerida

$$m_{f1} = \rho\ V_{f1}$$

$$m_{f1} = \left(0.71 \frac{g}{cm^3}\right)(28.8\ cm^3)$$

$$\boldsymbol{m_{f1} = 20.448\ g}$$

Cálculos volumétricos de 70% resina y 30% fibra

Datos:

$\rho_{fibra} = 0.71 \frac{g}{cm^3}$

$\rho_{matriz} = 1.21 \frac{g}{cm^3}$

$P_{fibra} = 30\ \%$

$P_{matriz} = 70\ \%$

Cálculo de la densidad del material compuesto resina poliéster y fibra natural de banano.

$$\rho_{compuesto} = (\rho_{matriz}\ P_{matriz}) + (\rho_{fibra}\ P_{fibra})$$

$$\rho_{compuesto} = \left(\frac{70}{100}\right)(1.21)\frac{g}{cm^3} + \left(\frac{30}{100}\right)(0.71)\frac{g}{cm^3}$$

$$\rho_{compuesto} = 0.847\frac{g}{cm^3} + 0.213\frac{g}{cm^3}$$

$$\rho_{compuesto} = 1.06\frac{g}{cm^3}$$

$$V_{molde} = 144000\ mm^3 \ \rightarrow\ 144\ cm^3$$

Una vez conocida las fracciones volumétricas y el volumen del molde, se calcular el volumen de la matriz y el peso del refuerzo

Cálculo volumen de la matriz

$\boldsymbol{V_{molde}} = 144\,cm^3$

$P_{matriz} = 70\%$

$$100\ \% \rightarrow 144\,cm^3$$

$$70\ \% \rightarrow V_{m2}$$

$$\boldsymbol{V_{m2} = 100.8\ cm^3}$$

$$\boldsymbol{V_{matriz} = V_{m2}\ \rho_{matriz}}$$

$$V_{matriz} = (100.8)(1.21)\ cm^3$$

$$V_{matriz} = 121.668\ cm^3$$

Cálculo de la masa del refuerzo

$\boldsymbol{V_{molde}} = 90\,cm^3$

$P_{fibra} = 30\ \%$

$$100\ \% \rightarrow 144\,cm^3$$

$$30\ \% \rightarrow V_{f1}$$

$$V_{f1} = 43.2\ cm^3$$

Masa de fibra requerida

$$m_{f1} = \rho\ V_{f1}$$

$$m_{f1} = \left(0.71\frac{g}{cm^3}\right)(43.2\ cm^3)$$

$$\boldsymbol{m_{f1} = 30.672\ g}$$

Cálculos volumétricos de 60% resina y 40% fibra

Datos:

$\rho_{fibra} = 0.71 \frac{g}{cm^3}$

$\rho_{matriz} = 1.21 \frac{g}{cm^3}$

$P_{fibra} = 40\ \%$

$P_{matriz} = 60\%$

Cálculo de la densidad del material compuesto resina poliéster y fibra natural de banano.

$$\rho_{compuesto} = (\rho_{matriz}\ P_{matriz}) + (\rho_{fibra}\ P_{fibra})$$

$$\rho_{compuesto} = \left(\frac{60}{100}\right)(1.21)\frac{g}{cm^3} + \left(\frac{40}{100}\right)(0.71)\frac{g}{cm^3}$$

$$\rho_{compuesto} = 0.726\frac{g}{cm^3} + 0.28\frac{g}{cm^3}$$

$$\rho_{compuesto} = 1.01\frac{g}{cm^3}$$

$$V_{molde} = 108000\ mm^3 \ \rightarrow \ 108\ cm^3$$

Una vez conocida las fracciones volumétricas y el volumen del molde, se calcular el volumen de la matriz y el peso del refuerzo.

Cálculo volumen de la matriz

$\boldsymbol{V_{molde}} = 144\ cm^3$

$P_{matriz} = 60\ \%$

$$100\ \% \rightarrow 144\ cm^3$$

$$60\ \% \rightarrow V_{m1}$$

$$\boldsymbol{V_{m3} = 86.4\ cm^3}$$

$$\boldsymbol{V_{matriz} = V_{m3}\ \rho_{matriz}}$$
$$V_{matriz} = (86.4)(1.21)\ cm^3$$
$$V_{matriz} = 104.544\ cm^3$$

Cálculo de la masa del refuerzo

$\boldsymbol{V_{molde}} = 144\ cm^3$

$P_{fibra} = 40\ \%$

$$100\ \% \rightarrow 144\ cm^3$$
$$40\ \% \rightarrow V_{f1}$$

$$V_{f1} = 57.6\ cm^3$$

Masa de fibra requerida

$$m_{f1} = \rho\ V_{f1}$$

$$m_{f1} = \left(0.71 \frac{g}{cm^3}\right)(57.6\ cm^3)$$

$$\boldsymbol{m_{f1} = 40.896\ g}$$

A continuación, se muestra en la tabla 6 los resultados de los cálculos de la densidad, volumen de la resina y cantidad de refuerzo requerido para cada fracción volumétrica correspondientes las probetas a ser ensayadas a impacto.

Tabla 6. Resumen de medidas de probetas de impacto.

CONFIGURACION DE REFUERZO	FACCION VOLUMÉTRICA	DENSIDAD MATERIAL COMPUESTO $\left[\frac{g}{cm^3}\right]$	VOLUMEN DE MATRIZ $[cm^3]$	MASA DE LA FIBRA $[g]$
Fibra entrecruzada	80% matriz 20% refuerzo	1.111	139.392	20.448
	70% matriz 30% refuerzo	1.06	121.668	30.672
	60% matriz 40% refuerzo	1.01	104.54	40.896

PROBETAS DE DUREZA

Calculo (Fracción volumétrica 80% matriz y 20% refuerzo)

Datos:

$\rho_{fibra} = 0.71 \frac{g}{cm^3}$

$\rho_{matriz} = 1.21 \frac{g}{cm^3}$

$P_{fibra} = 20\ \%$

$P_{matriz} = 80\ \%$

Calculo volumen de molde

$Largo$: 80 mm

$Ancho$: 80 mm

$Profundidad$: 10 mm

$$V_{molde} = Largo\ Ancho\ Profundidad$$

$$V_{molde} = (80)(80)(10)mm$$

$$V_{molde} = 64000\ mm^3 \ \rightarrow \ 64\ cm^3$$

Una vez conocida las fracciones volumétricas y el volumen del molde, se calcular el volumen de la matriz y el peso del refuerzo

Cálculo volumen de la matriz

$\boldsymbol{V_{molde}} = 64\, cm^3$

$P_{matriz} = 80\,\%$

$\rho_{matriz} = 1.21 \frac{g}{cm^3}$

$$100\,\% \rightarrow 64\, cm^3$$

$$80\,\% \rightarrow V_{m1}$$

$$V_{m1} = 51.2\, cm^3$$

$$\boldsymbol{V_{matriz} = V_{m1}\, \rho_{matriz}}$$

$$V_{matriz} = (51.2)(1.21)\ cm^3$$

$$\boldsymbol{V_{matriz} = 61.95\, cm^3}$$

Cálculo de la masa del refuerzo

$\boldsymbol{V_{molde}} = 64\, cm^3$

$P_{fibra} = 20\,\%$

$$100\,\% \rightarrow 64\, cm^3$$

$$20\,\% \rightarrow V_{f1}$$

$$V_{f1} = 12.8\, cm^3$$

Masa de fibra requerida

$$m_{f1} = \rho\, V_{f1}$$

$$m_{f1} = \left(0.71 \frac{g}{cm^3}\right)(12.8\, cm^3)$$

$$\boldsymbol{m_{f1} = 9.088\ g}$$

Cálculos volumétricos de 70% resina y 30% fibra

$\rho_{fibra} = 0.71\ \frac{g}{cm^3}$

$\rho_{matriz} = 1.21 \frac{g}{cm^3}$

$$V_{molde} = 64000\ mm^3 \ \rightarrow \ 64\ cm^3$$

Una vez conocida las fracciones volumétricas y el volumen del molde, se calcular el volumen de la matriz y el peso del refuerzo

Cálculo volumen de la matriz

$\boldsymbol{V_{molde}} = 64\ cm^3$

$P_{matriz} = 70\ \%$

$$100\ \% \rightarrow 64\ cm^3$$
$$70\ \% \rightarrow V_{m2}$$
$$V_{m2} = 44.8\ cm^3$$
$$\boldsymbol{V_{matriz} = V_{m2}\rho_{matriz}}$$
$$V_{matriz} = (44.8)(1.21)\ cm^3$$
$$\boldsymbol{V_{matriz} = 54.028\ cm^3}$$

Cálculo de la masa del refuerzo

$\boldsymbol{V_{molde}} = 64\ cm^3$

$P_{fibra} = 30\ \%$

$$100\ \% \rightarrow 64\ cm^3$$
$$30\ \% \rightarrow V_{f1}$$
$$V_{f1} = 19.2\ cm^3$$

Masa de fibra requerida

$$m_{f1} = \rho \; V_{f1}$$

$$m_{f1} = \left(0.71 \frac{g}{cm^3}\right)(19.2 \; cm^3)$$

$$\boldsymbol{m_{f1} = 13.632 \; g}$$

Cálculos volumétricos de 60% resina y 40% fibra

$\rho_{fibra} = \; 0.71 \frac{g}{cm^3}$

$\rho_{matriz} = 1.21 \frac{g}{cm^3}$

$$V_{molde} \; = 64000 \; mm^3 \; \rightarrow \; 64 \; cm^3$$

Una vez conocida las fracciones volumétricas y el volumen del molde, se calcular el volumen de la matriz y el peso del refuerzo

Cálculo volumen de la matriz

$\boldsymbol{V_{molde}} = \; 64 \, cm^3$

$P_{matriz} = 60 \, \%$

$$100 \, \% \rightarrow \; 64 \; cm^3$$

$$60 \, \% \; \rightarrow \; V_{m1}$$

$$V_{m3} \; = \; 38.40 \; cm^3$$

$$\boldsymbol{V_{matriz} \; = \; V_{m3} \; \rho_{matriz}}$$

$$V_{matriz} \; = \; (38.40)(1.21) \; cm^3$$

$$\boldsymbol{V_{matriz} \; = 46.464 \; cm^3}$$

Cálculo de la masa del refuerzo

$\boldsymbol{V_{molde}} = \ 108\, cm^3$

$P_{fibra} = 40\,\%$

$$100\ \% \ \rightarrow \ 64\ cm^3$$

$$40\ \% \ \rightarrow \ V_{f1}$$

$$V_{f1} = 25.6\ cm^3$$

Masa de fibra requerida

$$m_{f1} = \rho\ V_{f1}$$

$$m_{f1} = \left(0.71 \frac{g}{cm^3}\right)(25.6\ cm^3)$$

$$\boldsymbol{m_{f1} = 18.176\ g}$$

A continuación, se muestra en la tabla 7 los resultados de los cálculos de la densidad, volumen de la resina y cantidad de refuerzo requerido para cada fracción volumétrica correspondientes las probetas a ser ensayadas de dureza

Tabla 7. Resumen de medidas de probetas de dureza.

CONFIGURACIÓN DE REFUERZO	FACCIÓN VOLUMÉTRICA	DENSIDAD MATERIAL COMPUESTO $\left[\frac{g}{cm^3}\right]$	VOLUMEN DE MATRIZ $[cm^3]$	MASA DE LA FIBRA $[g]$
Fibra entrecruzada	80% matriz 20% refuerzo	1.111	61.95	9.088
	70% matriz 30% refuerzo	1.06	54.028	13.632
	60% matriz 40% refuerzo	1.01	46.464	18.176

PROBETAS DE DESGASTE

Calculo volumen de molde

$Largo$: $500\ mm$

$Ancho$: $100\ mm$

$Profundidad$: $6\ mm$

$$V_{molde} = Largo\ Ancho\ Profundidad$$
$$V_{molde} = (500)(100)(6)mm$$
$$V_{molde} = 300000\ mm^3 \rightarrow 3000\ cm^3$$

Una vez conocida las fracciones volumétricas y el volumen del molde, se calcular el volumen de la matriz y el peso del refuerzo

Cálculos volumétricos de 70% resina y 30% fibra

$\rho_{fibra} = 0.71 \frac{g}{cm^3}$

$\rho_{matriz} = 1.21 \frac{g}{cm^3}$

$P_{fibra} = 30\ \%$

$P_{matriz} = 70\,\%$

Cálculo de la densidad del material compuesto resina poliéster y fibra natural de banano.

$$\rho_{compuesto} = (\rho_{matriz}\ P_{matriz}) + (\rho_{fibra} P_{fibra})$$

$$\rho_{compuesto} = \left(\frac{70}{100}\right)(1.21)\frac{g}{cm^3} + \left(\frac{30}{100}\right)(0.71)\frac{g}{cm^3}$$

$$\rho_{compuesto} = 0.847\frac{g}{cm^3} + 0.213\frac{g}{cm^3}$$

$$\rho_{compuesto} = 1.06\frac{g}{cm^3}$$

$$V_{molde} = 300000\ mm^3\ \rightarrow\ 300\ cm^3$$

Una vez conocida las fracciones volumétricas y el volumen del molde, se calcular el volumen de la matriz y el peso del refuerzo

Cálculo volumen de la matriz

$\boldsymbol{V_{molde}} = 108\ cm^3$

$P_{matriz} = 70\,\%$

$$100\ \% \rightarrow 300\ cm^3$$

$$70\ \% \rightarrow V_{m2}$$

$$\boldsymbol{V_{m2} = 210\ cm^3}$$

$$\boldsymbol{V_{matriz} = V_{m2}\ \rho_{matriz}}$$

$$V_{matriz} = (210\ )(1.21\ )cm^3$$
$$V_{matriz} = 254.1\ cm^3$$

Cálculo de la masa del refuerzo

$\boldsymbol{V_{molde}} = \ 300\ cm^3$

$P_{fibra} = 30\ \%$

$$100\ \% \ \rightarrow \ 300\ cm^3$$
$$30\ \% \ \rightarrow \ V_{f1}$$
$$V_{f1} = 90\ cm^3$$

Masa de fibra requerida

$$m_{f1} = \rho\ V_{f1}$$
$$m_{f1} = \left(0.71 \frac{g}{cm^3}\right)(90\ cm^3)$$
$$\boldsymbol{m_{f1} = 63.9\ g}$$

A continuación, se muestra en la tabla 8 los resultados de los cálculos de la densidad, volumen de la resina y cantidad de refuerzo requerido para la fracción volumétrica de 70/30 correspondiente a las probetas a ser ensayadas a desgaste por abrasión.

Tabla 8. Resumen de medidas de probetas de abrasión.

CONFIGURACIÓN DE REFUERZO	FACCIÓN VOLUMÉTRICA	DENSIDAD MATERIAL COMPUESTO $\left[\frac{g}{cm^3}\right]$	VOLUMEN DE MATRIZ $[cm^3]$	MASA DE LA FIBRA [g]
Fibra entrecruzada al azar	70% matriz 30% refuerzo	1.06	91.47	23

2.7.5. Elaboración de probetas

Tabla 9. Elaboración de probetas

PROCEDIMIENTO PARA LA ELABORACIÓN DE PROBETAS PARA ENSAYOS MECÁNICOS			
Ítem	Actividad	Definición	Gráfico
Preparación de la fibra			
1	Separar de fibra	Se procede a separar la fibra acorde a su longitud y a descartar aquellas que no puedan ser utilizadas	
2	Establecer la cantidad	Se establece que cantidad de fibra se va a utilizar para la probetas	

Tabla 9. Continuación

3	Deshilar	Se procede a desenredad cada hebra de la fibra y a colocarlos de manera longitudinal	
4	Pesar	Se toma la porción necesaria de fibra acorde a los cálculos	
5	Tejido de fibra	Se realiza un tejido entrecruzado con los hilos de la fibra de banano	
Preparación del molde			
6	Limpiar	Se procura tener limpia toda la superficie interior de los moldes	
7	Lubricar	Se aplica cera desmoldaste en las paredes interiores del molde	

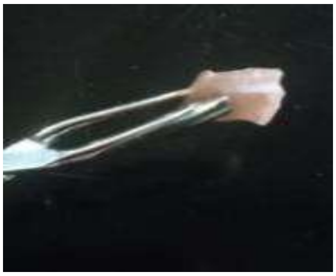
Tabla 9. Continuación

Preparación de la resina			
8	Medición	Se miden y preparan las porciones de volumen requeridos de la resina poliéster.	
9	Mezclar	Se coloca las porciones de volumen calculados en el siguiente orden: resina poliéster, catalizador y acelerador de cobalto	
Montaje			
10	Vertido	Se colocar una porción de la mezcla en el molde posterior se procede a colocar la fibra en la posición predestinada y posterior se coloca el resto de la resina poliéster	
11	Aplanado	Se pasa una brocha con un poco de presión con el propósito de sacar posibles burbujas de aire	

Tabla 9. Continuación

12	Tapado y curado	Se coloca la tapa del molde, se aplica una pequeña cantidad de peso y se lo deja reposar por 24 hora en un ambiente seco	
Acabado			
13	Desmolde	Una vez cerciorado de un correcto secado de las probeta se la desmolda	
14	Corte	Finalmente una vez desmoldada las probetas se procede con el corte mediante cierra acorde a las medidas de las normativas ya preestablecida.	

Tabla 10. Toma de muestras para análisis DSC y microestructural.

PROCEDIMIENTO PARA LA ELABORACIÓN DE MUESTRAS PARA ENSAYOS TÉRMICOS Y MICROESTRUCTURALES			
Ítem	Actividad	Definición	Gráfico
1	Extraer muestra	Se toma un pequeña muestra aproximadamente de 50 mg de una probeta y 1 cm^3 Para los ensayos de calorimetría y microestructural	 
2	Encapsulado para análisis de calorimetría	Se debe colocar la muestra dentro de un crisol diseñado para el DSC	

2.7.6. Control de calidad de probetas

Se realiza el control de calidad de las probetas mediante una inspección visual. Se verifica que no exista porosidad o posibles incrustaciones en el material compuesto. Como se muestra en la tabla 11.

Tabla 11. Probetas y muestras.

INSPECCIÓN DE PROBETAS		
ENSAYOS	**IMÁGENES**	**OBSERVACIONES**
Probetas		
Impacto		Acabado superficial liso y plano, Se muestra pequeñas porosidades que no representan ningún problema
Dureza		Acabado superficial liso y plano, sin presencia de porosidades a simple vista
Desgaste		Superficie lisa, no presencia de porosidades ni rugosidades
Muestras:		
DSC		Peso aproximado de la muestra 3,7 mg
SEM		Dimensión de la muestra 10x10x10 mm

Se verificó mediante la inspección visual que el material compuesto no presenta imperfecciones que puedan afectar los resultados de los ensayos mecánicos.

2.8. Parámetro para el ensayo de materiales

Ya realizadas las probetas, es imprescindible obtener las propiedades térmicas y mecánicas del material, el mismo que es sometido a ensayos destructivos para determinar dichos valores como es la cantidad de energía absorbida, calor especifico, entre otros.

2.8.1. Ensayos de Impacto

El ensayo descrito en la norma ASTM D5628_10 (ANEXO 1) implica el uso de una máquina estándar para soltar dardos fig 6 desde alturas específicas con el fin de evaluar la resistencia del material a través de la energía media necesaria para que falle.

Figura 6. Máquina estándar para ensayos de impacto.

En las siguientes líneas se detallan la ecuación .4 necesaria para realizar el cálculo de las características mecánicas durante la realización del ensayo de impacto.

Esfuerzo máximo

$$MEF = hwf \tag{4}$$

Donde:

$h = Altura\ \ maxima\ de\ la\ ruptura\ [mm]$

$w = Masa\ [Kg]$

$f = Factor\ de\ conversion\ [Joules]$

2.8.2. Ensayo de dureza

Las pruebas de dureza se realizan en materiales compuestos para medir su resistencia a la indentación. La prueba de dureza más común para los materiales compuestos es la prueba de dureza Rockwell, que utiliza un indentador de diamante para hacer una pequeña muesca en el material y mide la profundidad de la muesca. Cuanto mayor sea el número de dureza Rockwell, más duro será el material.

La norma ASTM G195-13 (ANEXO 2) es un estándar que proporciona un procedimiento detallado para realizar pruebas de dureza Rockwell en materiales compuestos. La norma específica el tipo de penetrador, la carga y la duración de la prueba para diferentes tipos de materiales compuestos. Además, es un recurso valioso para cualquiera que necesite realizar pruebas de dureza en materiales compuestos. El estándar proporciona procedimientos e instrucciones detallados que pueden ayudar a garantizar resultados precisos y repetibles. Ensayos de durómetros pueden ser realizados con instrumentos de medición como Durómetro digital Shore D 0-100 HD. Fig 7.

Figura 7. Durómetro Shore D.

2.8.3. Ensayo de desgaste por abrasión

La prueba de abrasión es un método para determinar la resistencia de un material al desgaste. A menudo se utiliza para evaluar el rendimiento de los materiales compuestos, que se componen de dos o más materiales diferentes que se unen entre sí. estas pruebas se pueden realizar de varias maneras, pero todas implican someter el material a alguna forma de acción abrasiva. Esto se puede hacer frotando el material contra una superficie rugosa, puliéndolo con chorro de arena o usando una rueda giratoria con partículas abrasivas. Los resultados de las pruebas de abrasión se pueden utilizar para comparar la resistencia al desgaste de diferentes materiales o para determinar cómo cambia la resistencia al desgaste de un material con el tiempo. Esta información se puede utilizar para mejorar el diseño y el rendimiento de los materiales compuestos.

Aquí hay algunos ejemplos de pruebas de abrasión que se usan comúnmente para evaluar materiales compuestos:

- Prueba de desgaste “Pin-on-Disk”: esta prueba consiste en frotar un pasador cilíndrico hecho del material que se va a probar contra un disco giratorio hecho de un material diferente. Luego se mide la cantidad de desgaste en el pasador.

- Prueba de abrasión de la rueda de goma: esta prueba consiste en frotar una muestra rectangular del material que se va a probar contra una rueda giratoria cubierta de partículas abrasivas. Luego se mide la cantidad de desgaste en la muestra.
- Prueba de abrasión con papel de lija: esta prueba consiste en frotar una muestra del material que se va a probar contra un trozo de papel de lija de un tamaño de grano específico. Luego se mide la cantidad de desgaste en la muestra.
- Prueba de desgaste con un abrasador de plataforma rotatoria: Este ensayo emplea una abrasadora de plataforma giratoria es una máquina que utiliza una rueda giratoria con partículas abrasivas para desgastar la superficie de un material. Es una herramienta común para realizar pruebas de desgaste en materiales Fig 8. La Guía estándar para realizar pruebas de desgaste con un abrasador de plataforma rotatoria ASTM G0195 (ANEXO 3) es un documento que brinda orientación sobre cómo realizar estas pruebas.[17]

Figura 8. Probador de abrasión tipo Taber

Los resultados de las pruebas de abrasión se pueden utilizar para determinar las siguientes propiedades de los materiales compuestos:

- Resistencia al desgaste: esta es la capacidad de un material para resistir el desgaste.
- Tasa de abrasión: esta es la tasa a la que se desgasta un material.
- Tenacidad a la abrasión: esta es la capacidad de un material para absorber energía durante la abrasión.

2.8.4. Calorimetría diferencial de barrido (DSC)

La calorimetría diferencial de barrido (DSC) es una técnica de análisis térmico que mide el flujo de calor en función de la temperatura o el tiempo para una muestra y un material de referencia. La diferencia en el flujo de calor entre la muestra y el material de referencia se utiliza para determinar las propiedades térmicas de la muestra, como el punto de fusión, la temperatura de transición vítrea y la temperatura de cristalización.

DSC se puede utilizar para caracterizar una variedad de materiales, incluidos polímeros, plásticos, compuestos y productos farmacéuticos.

En materiales compuestos, DSC se puede utilizar para determinar las siguientes propiedades:[18]

- Punto de fusión: El punto de fusión de un material compuesto es la temperatura a la que se funde la matriz polimérica. Esta propiedad es importante para determinar las condiciones de procesamiento del material compuesto.
- Temperatura de transición vítrea: La temperatura de transición vítrea es la temperatura a la que la matriz polimérica cambia de un estado duro y vítreo a un estado blando y gomoso. Esta propiedad es importante para determinar las propiedades mecánicas del material compuesto.
- Temperatura de cristalización: La temperatura de cristalización es la temperatura a la que la matriz polimérica comienza a cristalizar. Esta propiedad es importante para determinar las propiedades de la fase cristalina del material compuesto.

Figura 9. Calorímetro diferencial de barrido DSC AT03.

DSC es una técnica versátil que se puede utilizar para caracterizar una amplia gama de materiales. Es una herramienta valiosa para comprender las propiedades térmicas de los materiales compuestos y para optimizar su rendimiento.[18]

2.8.5. Microscopía Electrónica de Barrido (SEM)

Este análisis emplea un microscopio electrónico de barrido (SEM) que es un tipo de microscopio electrónico que produce imágenes de una muestra escaneando la superficie con un haz de electrones enfocado. Fig. 10. Los electrones interactúan con los átomos de la muestra, produciendo varias señales que contienen información sobre la topografía de la superficie y la composición de la muestra. El haz de electrones se escanea en un patrón de barrido de trama y la posición del haz se combina con la intensidad de la señal detectada para producir una imagen.

Los SEM se utilizan para estudiar una amplia variedad de materiales, incluidos metales, plásticos, cerámicas y tejidos biológicos. Son particularmente útiles para estudiar la morfología superficial de los materiales, así como su composición química. Los SEM también se pueden usar para medir el espesor de películas delgadas y para estudiar la distribución de fases en materiales heterogéneos.

Estas son algunas de las ventajas de usar SEM:[20]

- Alta resolución: los SEM pueden producir imágenes con resoluciones de hasta 1 nanómetro, que es aproximadamente el tamaño de un átomo.

- Profundidad de campo: los SEM tienen una gran profundidad de campo, lo que significa que toda la imagen está enfocada, incluso si la muestra no es perfectamente plana.
- Variedad de señales: los SEM pueden detectar una variedad de señales, incluidos electrones secundarios, electrones retrodispersados y rayos X característicos. Esto permite el estudio tanto de la morfología superficial como de la composición química de la muestra.

El empleo de SEM son una herramienta poderosa para estudiar la morfología superficial y la composición química de los materiales. Se utilizan en una amplia variedad de campos, incluida la ciencia de los materiales, la biología y la medicina.[20]

Figura 10. Microscopio electrónico de barrido.

Fuente: [21]

CAPITULO III

3. RESULTADOS Y DISCUSIONES

3.1. Interpretación y tabulación de resultados

Los valores de los resultados que se lograron constatar y recolectar en la realización de los ensayos de impacto, abrasión, DSC y microscopia, se detallan a continuación.

3.1.1. Tabulación de los resultados obtenidos en ensayos de impacto

Tipo de falla

Las fallas que se pueden presentar en la probeta a ensayar se presentan en la tabla 12.

Tabla 12. Fallas en ensayos de impacto.

FALLA	DESCRIPCIÓN	CONSIDERACIÓN
A	Gritas o fisuras en una sola cara de la probeta	No falla
B	Gritas que se extiende por toda la probeta	No falla
C	Quebradizo	Falla
D	Probeta destrozada totalmente	Falla

Tabulación de datos

Los resultados de los ensayos de impacto presentados a continuación se los obtuvo del informe técnico CTT-2023 – 148 (ANEXO 5).

Tabla 13. Ficha técnica de recolección de datos de ensayo de impacto, resina 80% y Fibra de banano 20%. Orientación de fibra entrecruzada.

	UNIVERSIDAD TÉCNICA DE AMBATO FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA CARRERA DE MECÁNICA		
FICHA DE RECOLECCIÓN DE DATOS			
DATOS INFORMATIVOS			
Fecha:	15/06/2023	Ciudad:	Ambato
Tipo de ensayo;	**IMPACTO**	Norma:	ASTM D5628-10
Laboratorio:	Laboratorio de Materiales de la Facultad de Ingeniería Mecánica. FICM-UTA		
Realizador por:	Erick Isaac López Martinez	Revisado por:	Ing. Mg. Pablo Valle, Ph.D.
PARÁMETROS DE ENSAYO			
Máquina:	Máquina tipo caída de masas de Impacto		
Matriz:	Resina transparente poliéster	Facción volumétrica:	80%
Refuerzo:	Fibra natural de banano	Facción volumétrica:	20%
Configuración de refuerzo:	Tejido entrecruzado	Estratificación:	Manual
Temperatura de curado:	Ambiente	Número de probetas:	5
Dimensiones:	58·58·e	Espesor promedio:	8 mm
RESULTADOS			

Tabla 13. Continuación.

# de Probeta (80/20)	Incremento de masa (kg)	Masa aplicada (Kg)	Altura media de fallo (mm)	Energía media de fallo (J)	Tipo de falla
1	0,192	0,287	200	0,9398	No falla
2	0,192	0,287	300	1,4097	No falla
3	0,192	0,287	400	1,8796	No falla
4	0,192	0,287	500	2,3495	Falla
5	0,192	0,287	600	2,8194	Falla
PROMEDIO	-	-	400	2.3495	-

IMÁGENES DE PROBETAS ENSAYADAS

Tabla 13. Continuación.

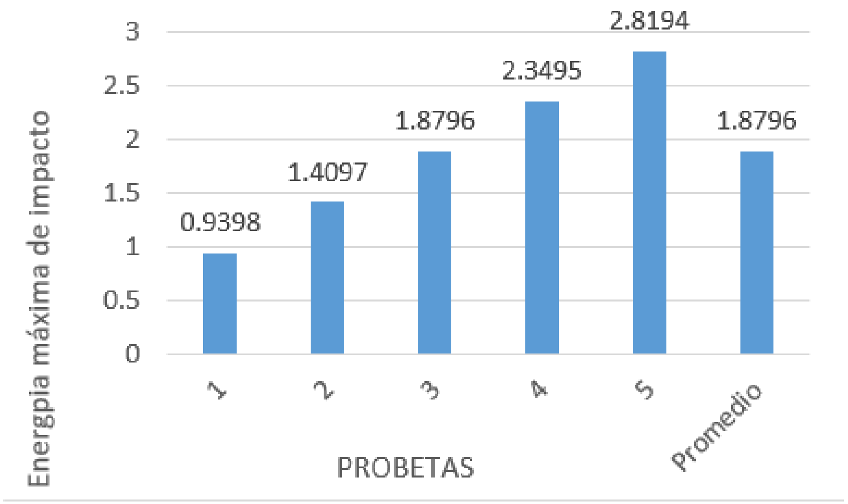
<table>
<tr><th colspan="4">GRÁFICA DE RESULTADOS</th></tr>
<tr><td colspan="4">
</td></tr>
<tr><th colspan="2">OBSERVACIONES</th><th colspan="2">ENERGÍA MEDIA DE FALLO</th></tr>
<tr><td colspan="2">La probetas 1, 2 y 4 presentan grietas en una sola cara por lo tanto son fallas de tipo A, mientras que las probetas 3 y 5 están quebradizas presentas fallas de tipo C</td><td colspan="2">2,3495 J</td></tr>
<tr><td>Elaborado por:</td><td>Erick López M.</td><td>Aprobado por:</td><td>Ing. Mg. Pablo Valle, Ph.D.</td></tr>
</table>

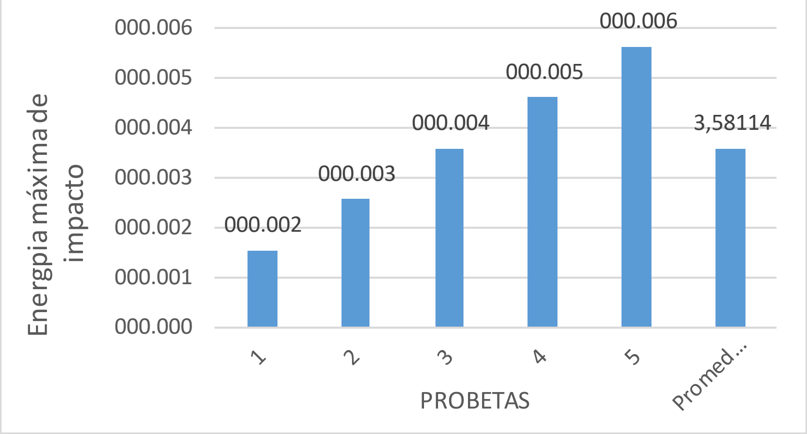
Tabla 14. Ficha técnica de recolección de datos de ensayo de impacto, resina 70% y Fibra de banano 30%. Orientación de fibra entrecruzada.

	UNIVERSIDAD TÉCNICA DE AMBATO FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA CARRERA DE MECÁNICA		
FICHA DE RECOLECCIÓN DE DATOS			
DATOS INFORMATIVOS			
Fecha:	15/06/2023	Ciudad:	Ambato
Tipo de ensayo;	**IMPACTO**	Norma:	ASTM D5628-10
Laboratorio:	Laboratorio de Materiales de la Facultad de Ingeniería Mecánica. FICM-UTA		
Realizador por:	Erick Isaac López Martinez	Revisado por:	Ing. Mg. Pablo Valle, Ph.D.
PARÁMETROS DE ENSAYO			
Máquina:	Máquina tipo caída de masas de Impacto		
Matriz:	Resina transparente poliéster	Facción volumétrica:	70%
Refuerzo:	Fibra natural de banano	Facción volumétrica:	30%
Configuración de refuerzo:	Tejido entrecruzado	Estratificación:	Manual
Temperatura de curado:	Ambiente	Número de probetas:	5
Dimensiones:	58·58·e	Espesor promedio:	8 mm

Tabla 14. Continuación.

RESULTADOS					
# de Probeta (70/30)	Incremento de masa (kg)	Masa aplicada (Kg)	Altura media de fallo (mm)	Energía media de fallo (J)	Tipo de falla
1	0,756	0,287	150	1.5348	No falla
2	0,756	0,287	250	2.5580	No falla
3	0,756	0,287	350	3,5811	Falla
4	0,756	0,287	450	4.6043	Falla
5	0,756	0,287	550	5.6275	Falla
PROMEDIO	-	-	350	3.58114	-
IMÁGENES DE PROBETAS ENSAYADAS					
					

Tabla 14. Continuación.

<table>
<tr><th colspan="4">GRÁFICAS DE RESULTADOS</th></tr>
<tr><td colspan="4">


</td></tr>
<tr><th colspan="2">OBSERVACIONES</th><th colspan="2">ENERGÍA MEDIA DE FALLO</th></tr>
<tr><td colspan="2">La probetas 1 y 2 presentan grietas en una sola cara por lo tanto son fallas de tipo A, mientras que las probetas 3 y 5 están quebradizas presentas fallas de tipo C y por último la probeta 4 pose una falla de tipo D</td><td colspan="2">3,5811 J</td></tr>
<tr><td>Elaborado por:</td><td>Erick López M.</td><td>Aprobado por:</td><td>Ing. Mg. Pablo Valle, Ph.D.</td></tr>
</table>

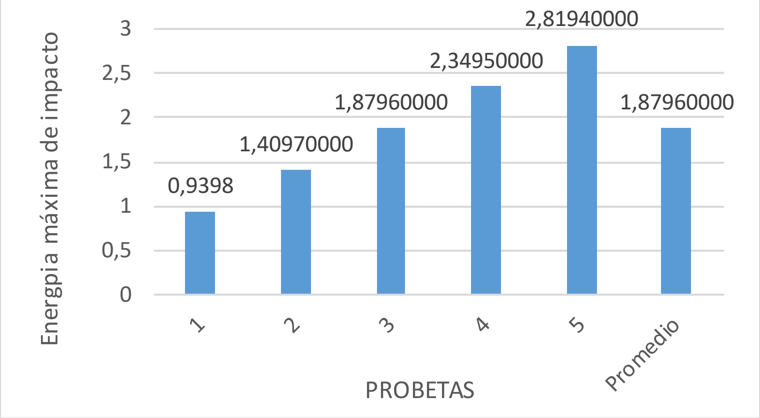
Tabla 15. Ficha técnica de recolección de datos de ensayo de impacto, resina 60% y Fibra de banano 40%. Orientación de fibra entrecruzada.

	UNIVERSIDAD TÉCNICA DE AMBATO FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA CARRERA DE MECÁNICA		
FICHA DE RECOLECCIÓN DE DATOS			
DATOS INFORMATIVOS			
Fecha:	15/06/2023	Ciudad:	Ambato
Tipo de ensayo;	**IMPACTO**	Norma:	ASTM D5628-10
Laboratorio:	Laboratorio de Materiales de la Facultad de Ingeniería Mecánica. FICM-UTA		
Realizador por:	Erick Isaac López Martinez	Revisado por:	Ing. Mg. Pablo Valle, Ph.D.
PARÁMETROS DE ENSAYO			
Máquina:	Máquina tipo caída de masas de Impacto		
Matriz:	Resina transparente poliéster	Facción volumétrica:	60%
Refuerzo:	Fibra natural de banano	Facción volumétrica:	40%
Configuración de refuerzo:	Tejido entrecruzado	Estratificación:	Manual
Temperatura de curado:	Ambiente	Número de probetas:	5
Dimensiones:	58·58·e	Espesor promedio:	8 mm

Tabla 15. Continuación

<table>
<tr><th colspan="6">RESULTADOS</th></tr>
<tr><th># de Probeta (60/40)</th><th>Incremento de masa (kg)</th><th>Masa aplicada (Kg)</th><th>Altura media de fallo (mm)</th><th>Energía media de fallo (J)</th><th>Tipo de falla</th></tr>
<tr><td>1</td><td>0,192</td><td>0,287</td><td>200</td><td>0,9398</td><td>No falla</td></tr>
<tr><td>2</td><td>0,192</td><td>0,287</td><td>300</td><td>1,4097</td><td>No falla</td></tr>
<tr><td>3</td><td>0,192</td><td>0,287</td><td>400</td><td>1,8796</td><td>No falla</td></tr>
<tr><td>4</td><td>0,192</td><td>0,287</td><td>500</td><td>2,3495</td><td>No falla</td></tr>
<tr><td>5</td><td>0,192</td><td>0,287</td><td>600</td><td>2,8194</td><td>Falla</td></tr>
<tr><td>PROMEDIO</td><td>-</td><td>-</td><td>400</td><td>2.8194</td><td>-</td></tr>
<tr><th colspan="6">IMÁGENES DE PROBETAS ENSAYADAS</th></tr>
<tr><td colspan="6"> </td></tr>
</table>

Tabla 15. Continuación

<table>
<tr><th colspan="4">GRÁFICAS DE RESULTADOS</th></tr>
<tr><td colspan="4">


</td></tr>
<tr><th colspan="2">OBSERVACIONES</th><th colspan="2">ENERGÍA MEDIA DE FALLO</th></tr>
<tr><td colspan="2">La probetas 1, 2, 3 y 4 presentan grietas en una sola cara por lo tanto son fallas de tipo A, mientras que la probeta 5 pose una falla de tipo C</td><td colspan="2">2,8194 J.</td></tr>
<tr><td>Elaborado por:</td><td>Erick López</td><td>Aprobado por:</td><td>Ing. Mg. Pablo Valle, Ph.D.</td></tr>
</table>

3.1.2. Tabulación de los resultados obtenidos en ensayos de dureza

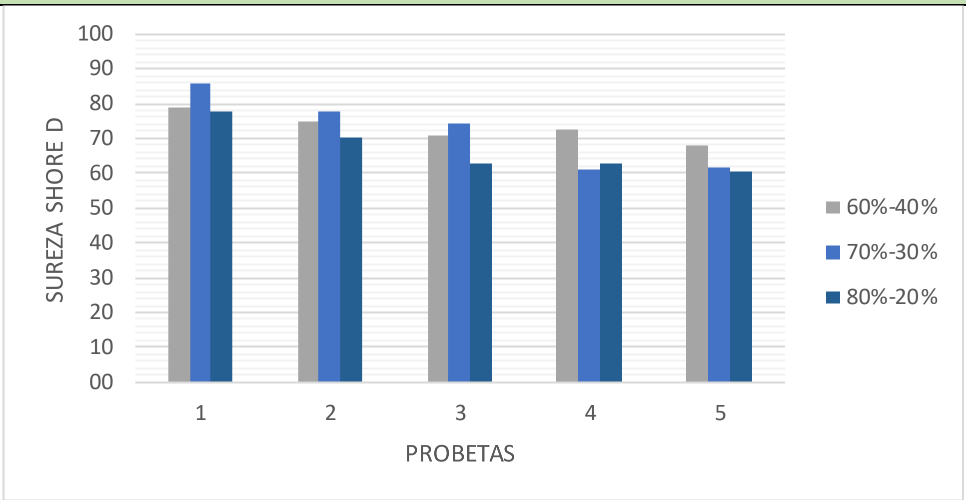
Tabla 16. Ficha técnica de recolección de datos de ensayos de dureza. Orientación de fibra entrecruzada.

	UNIVERSIDAD TÉCNICA DE AMBATO FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA CARRERA DE MECÁNICA		
FICHA DE RECOLECCIÓN DE DATOS			
DATOS INFORMATIVOS			
Fecha:	29/06/2023	Ciudad:	Ambato
Tipo de ensayo;	**DUREZA**	Norma:	ASTM D2240−15
Laboratorio:	Laboratorio de Materiales de la Facultad de Ingeniería Mecánica. FICM-UTA		
Realizador por:	Erick Isaac López Martinez	Revisado por:	Ing. Mg. Pablo Valle, Ph.D.
PARÁMETROS DE ENSAYO			
Máquina:	Durómetro digital Shore D 0-100 HD		
Matriz:	Resina transparente poliéster	Temperatura:	15 °C
Refuerzo:	Fibra natural de banano	Iluminación:	Luz natural
Configuración de refuerzo:	Tejido entrecruzado	Estratificación:	Manual
Temperatura de curado:	Ambiente	Número de probetas:	3
Dimensiones:	80·80·e	Espesor promedio:	8 mm

Tabla 16. Continuación.

RESULTADOS				
N° de medición	DUREZA SHORE D			Promedio de mediciones
	Fracción resina-fibra (60/40)	Fracción resina-fibra (70/30)	Fracción resina-fibra (80/20)	
1	79.0	86.0	77.5	80.8
2	75.0	78.0	70.5	74.5
3	71.0	74.5	63.0	69.5
4	72.5	61.0	62.5	65.3
5	68	61.5	60.5	63.3
PROMEDIO	73.1	72.2	66.8	70.7
IMÁGENES DE PROBETAS ENSAYADAS				
				

Tabla 16. Continuación.

<table>
<tr><th colspan="4">GRÁFICA DE RESULTADOS</th></tr>
<tr><td colspan="4">
</td></tr>
<tr><th colspan="4">OBSERVACIONES</th></tr>
<tr><td colspan="4">La distribución de los resultados de las mediciones entre las diferentes probetas no varía demasiado entre las diferentes fracciones volumétricas. No obstante, la facción volumétrica 60/40 matriz-fibra posee una media de mediciones un poco más alta.</td></tr>
<tr><td>Elaborado por:</td><td>Erick López M.</td><td>Aprobado por:</td><td>Ing. Mg. Pablo Valle, Ph.D.</td></tr>
</table>

3.1.3. Tabulación de los resultados obtenidos en ensayos de abrasión

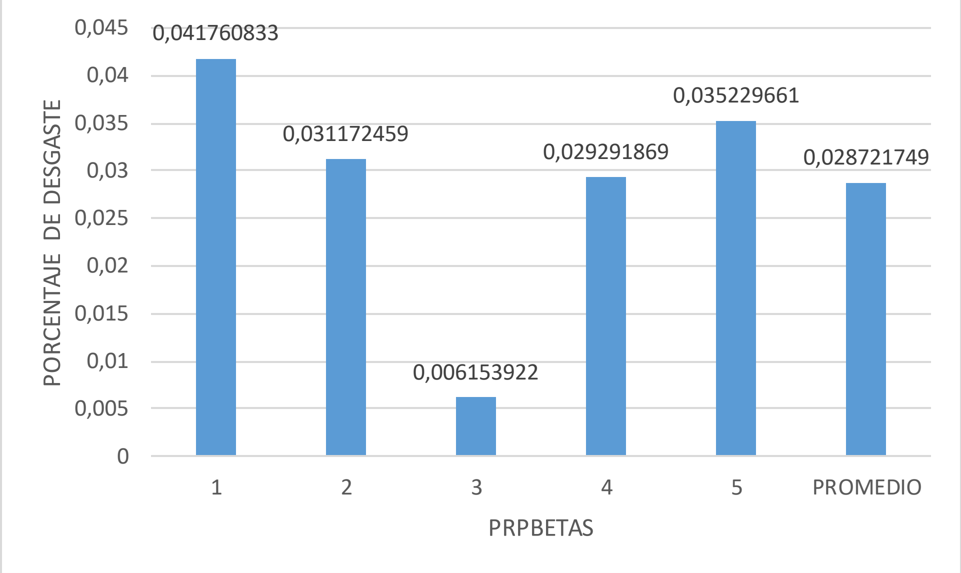
Tabla 17. Ficha técnica de recolección de datos de ensayo de abrasión, resina 70% y Fibra de banano 30%. Orientación de fibra entrecruzada.

	UNIVERSIDAD TÉCNICA DE AMBATO FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA CARRERA DE MECÁNICA		
FICHA DE RECOLECCIÓN DE DATOS			
DATOS INFORMATIVOS			
Fecha:	06/07/2023	Ciudad:	Ambato
Tipo de ensayo;	**ABRASIÓN**	Norma:	ASTM G195 − 13
Laboratorio:	Laboratorio de Materiales de la Facultad de Ingeniería Mecánica. FICM-UTA		
Realizador por:	Erick Isaac López Martinez	Revisado por:	Ing. Mg. Pablo Valle, Ph.D.
PARÁMETROS DE ENSAYO			
Máquina:	Taber Type Abrasion Tester		
Tipo de ruedas de abrasamiento:	CS-17	Velocidad de rotación:	70 RPM
Matriz:	Resina transparente poliéster	Facción volumétrica:	70%
Refuerzo:	Fibra natural de banano	Facción volumétrica:	30%
Configuración de refuerzo:	Tejido entrecruzado	Estratificación:	Manual
Temperatura de curado:	Ambiente	Número de probetas:	5

Tabla 17. Continuación

<table>
<tr><td>Dimensiones:</td><td colspan="2">10·10·6 mm</td><td>Numero de ciclos:</td><td colspan="2">1000</td></tr>
<tr><td colspan="6">RESULTADOS</td></tr>
<tr><td># de Probeta (70/30)</td><td>Carga aplicada (g)</td><td>Masa Inicial (g)</td><td>Masa final (g)</td><td>Diferencia de masa (g)</td><td>Porcentaje %</td></tr>
<tr><td>1</td><td>1000</td><td>81.416</td><td>81.382</td><td>0.034</td><td>0.04176083</td></tr>
<tr><td>2</td><td>1000</td><td>80.199</td><td>80.174</td><td>0.025</td><td>0.03117246</td></tr>
<tr><td>3</td><td>1000</td><td>81.249</td><td>81.244</td><td>0.005</td><td>0.00615392</td></tr>
<tr><td>4</td><td>1000</td><td>81.934</td><td>81.91</td><td>0.024</td><td>0.02929187</td></tr>
<tr><td>5</td><td>1000</td><td>82.317</td><td>82.288</td><td>0.029</td><td>0.03522966</td></tr>
<tr><td>PROMEDIO</td><td>-</td><td>81.423</td><td>81.3996</td><td>0.0234</td><td>0.02872175</td></tr>
<tr><td colspan="6">IMÁGENES DE PROBETAS ENSAYADAS</td></tr>
<tr><td colspan="6">
</td></tr>
</table>

Tabla 17. Continuación

<table>
<tr><th colspan="4">PORCENTAJE DE DESGASTE</th></tr>
<tr><td colspan="4">
</td></tr>
<tr><th colspan="4">OBSERVACIONES</th></tr>
<tr><td colspan="4">El desgaste por abrasión en todas las probetas se a simple vista se presentan en iguales proporciones</td></tr>
<tr><td>Elaborado por:</td><td>Erick López</td><td>Aprobado por:</td><td>Ing. Mg. Pablo Valle, Ph.D.</td></tr>
</table>

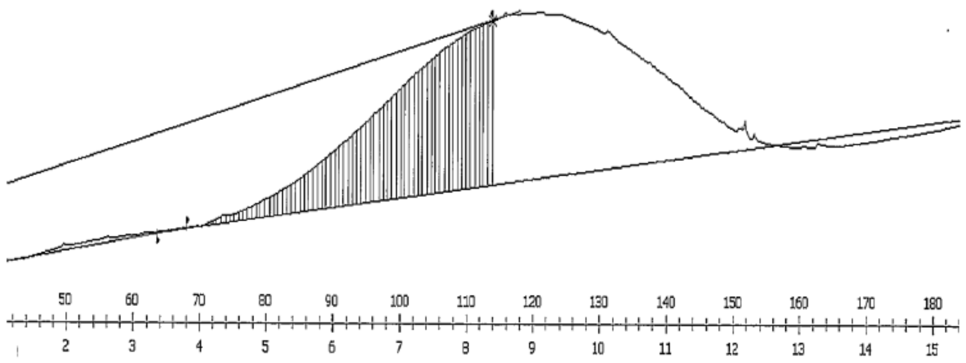
3.1.4. Tabulación de los resultados obtenidos en análisis DSC

Los resultados análisis de calorimetría presentados a continuación se los obtuvo del LABORATORIO DE CONTROL Y ANALISIS DE ALIMENTOS (LACONAL) De Le Facultad De Ciencia e Ingeniería en Alimentos y Biotecnología de la Universidad Técnica de Ambato (ANEXO 6)

Tabla 18. Ficha técnica análisis de calorimetría Resina poliéster + Fibra de banano.

	UNIVERSIDAD TÉCNICA DE AMBATO FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA CARRERA DE MECÁNICA		
FICHA DE RECOLECCIÓN DE DATOS			
DATOS INFORMATIVOS			
Fecha:	14/07/2023	Ciudad:	Ambato
Análisis;	**CALORIMETRÍA**	Norma:	ASTM D3418 − 12
Laboratorio:	Laboratorio de Control y Análisis de Alimentos (LACONAL) Facultad De Ciencia e Ingeniería en Alimentos y Biotecnología		
Realizador por:	Erick Isaac López Martinez	Revisado por:	Ing. Mg. Pablo Valle, Ph.D.
PARÁMETROS DEL ANÁLISIS			
Máquina:	Calorímetro diferencial de barrido		
Matriz:	Resina transparente poliéster	Facción volumétrica:	70%
Refuerzo:	Fibra natural de banano	Número de intervalos	2
Temperatura inicial de análisis:	30 °C	Taza de calentamiento	10 °Cmin-1
Temperatura final de análisis:	200 °C	Peso de muestra:	3.7 mg

Tabla 18. Continuación.

<table>
<tr><th colspan="4">RESULTADOS</th></tr>
<tr><td>Integral</td><td>37.35 mJ</td><td>Onset</td><td>68.2 °C</td></tr>
<tr><td>Peak Width</td><td>44. 98 °C</td><td>Endset</td><td>116,77 °C</td></tr>
<tr><td>Peak Heat</td><td>0,32 mW</td><td>Peak temperature</td><td>113.88 °C</td></tr>
<tr><td>Left Limit</td><td>63.41 °C</td><td>Rigth Limit</td><td>113.88 °C</td></tr>
<tr><td>Result Mode</td><td>Simple</td><td>Partial area</td><td>44.99 %</td></tr>
<tr><th colspan="4">TERMOGRAMA</th></tr>
<tr><td colspan="4">
</td></tr>
<tr><th colspan="4">OBSERVACIONES</th></tr>
<tr><td colspan="4">El material compuesto muestra su pico de calor a 113.88 °C, punto en el cual la absorción de energía calórica llega a su máximo nivel. Además el área parcial del material durante el análisis es de 49.99%</td></tr>
<tr><td>Elaborado por:</td><td>Erick López</td><td>Aprobado por:</td><td>Ing. Mg. Pablo Valle, Ph.D.</td></tr>
</table>

3.1.5. Tabulación de los resultados obtenidos en el SEM

Tabla 19. Análisis de fractografia, dimensiones de fibra de banano e interfaz.

	UNIVERSIDAD TÉCNICA DE AMBATO FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA CARRERA DE MECÁNICA		
FICHA DE RECOLECCIÓN DE DATOS			
DATOS INFORMATIVOS			
Fecha:	21/06/2023	Ciudad:	Ambato
Equipo;	Microscopio Electrónico de Barrido	Modelo:	TESCAN VEGA 3 SBU
Laboratorio:	Laboratorio de Materiales de la Facultad de Ingeniería Mecánica. FICM-UTA		
Realizador por:	Erick Isaac López Martinez	Revisado por:	Ing. Mg. Pablo Valle, Ph.D.
PARÁMETROS DE ENSAYO			
Matriz:	Resina transparente poliéster	Facción volumétrica:	70%
Refuerzo:	Fibra natural de banano	Facción volumétrica:	30%
Configuración de refuerzo:	Tejido entrecruzado	Estratificación:	Manual
Dimensiones:	10·10·10 (mm)	Número muestras:	3
Resultados: Imágenes del Material Compuesto Resina Poliéster + Fibra de banano.			

Tabla 19. Continuación.

IMÁGENES DE PROBETAS ENSAYADAS
VISTA DE LA MUESTRA

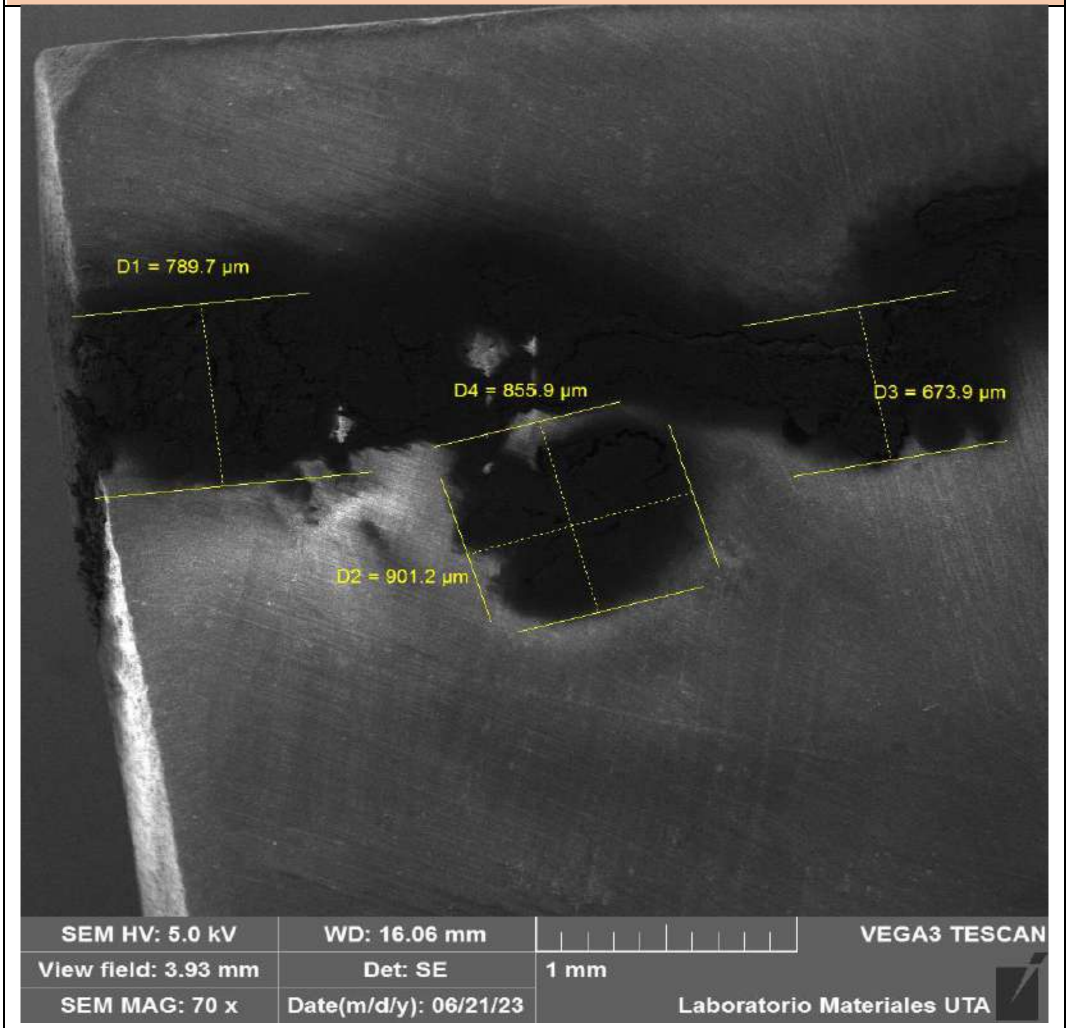
MEDIDAS DE LA FIBRA (70x)

MEDIDAS DE LA INTERFAZ (RESINA) (73x) VISTA TRANSVERSAL

Tabla 19. Continuación.

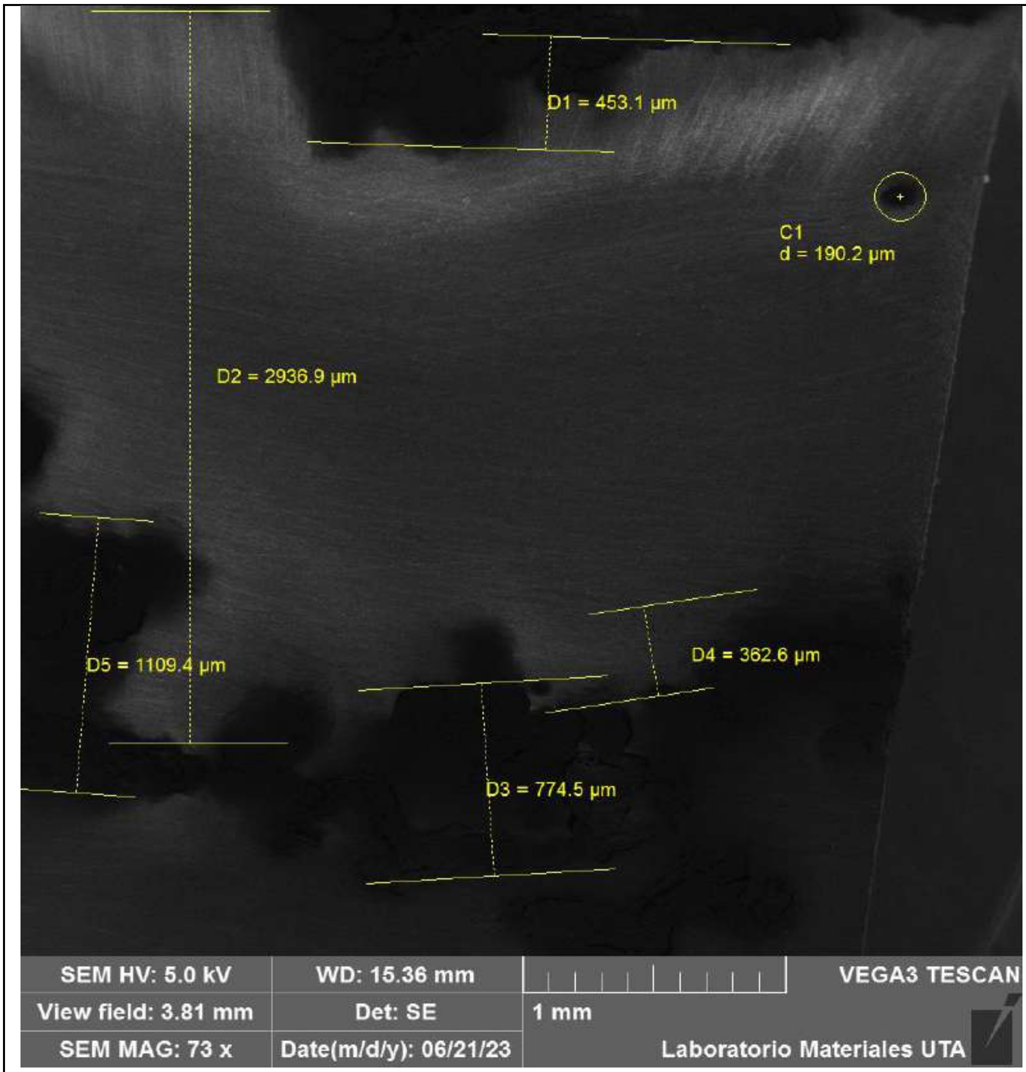
<table>
<tr><td colspan="4">
</td></tr>
<tr><td colspan="4">Observaciones:</td></tr>
<tr><td colspan="4">Acorde a las imágenes se puede observar que las dimensiones del grosor de la fibra fluctúan entre 901.02 µm y 673.9 µm; siendo los valores como 789.7 µm los más cercanos al promedio.
En cambio los valores de la interfaz incrustada en la fibra van desde 362.6 µm y 453.1 µm.</td></tr>
<tr><td>Elaborado por:</td><td>Erick López.</td><td>Supervisado por:</td><td>Ing. Christian Pérez</td></tr>
<tr><td>Revisado por:</td><td>Ing. Mg. Pablo Valle, Ph.D.</td><td>Aprobado por:</td><td>Ing. Mg. Pablo Valle, Ph.D.</td></tr>
</table>

Tabla 20. Análisis de fractografia, imperfecciones y defectos.

	UNIVERSIDAD TÉCNICA DE AMBATO FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA CARRERA DE MECÁNICA		
FICHA DE RECOLECCIÓN DE DATOS			
DATOS INFORMATIVOS			
Fecha:	21/06/2023	Ciudad:	Ambato
Equipo;	Microscopio Electrónico de Barrido	Modelo:	TESCAN VEGA 3 SBU
Laboratorio:	Laboratorio de Materiales de la Facultad de Ingeniería Mecánica. FICM-UTA		
Realizador por:	Erick Isaac López Martinez	Revisado por:	Ing. Mg. Pablo Valle, Ph.D.
PARÁMETROS DE ENSAYO			
Matriz:	Resina transparente poliéster	Facción volumétrica:	70%
Refuerzo:	Fibra natural de banano	Facción volumétrica:	30%
Configuración de refuerzo:	Tejido entrecruzado	Estratificación:	Manual
Dimensiones:	5·5·5 (mm)	Número muestras:	3
Resultados: Imágenes del Material Compuesto Resina Poliéster + Fibra de banano.			
IMÁGENES DE PROBETAS ENSAYADAS VISTA TRANSAVERSAL			
DISTANCIA ENTRE CAPAZ (32x)			

Tabla 20. Continuación

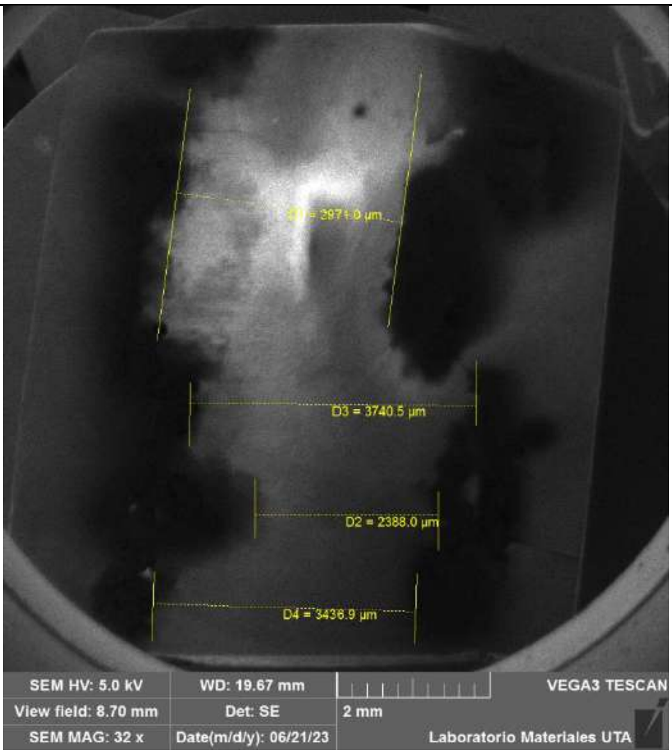
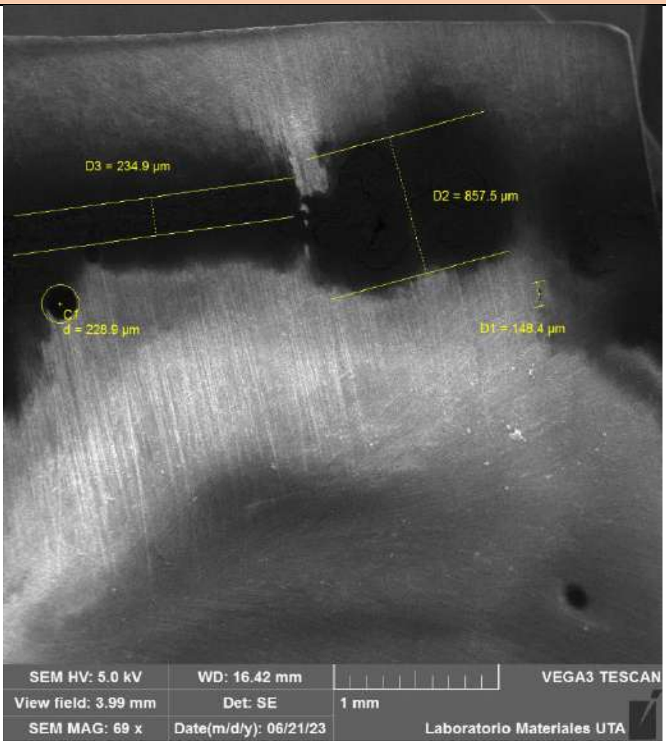
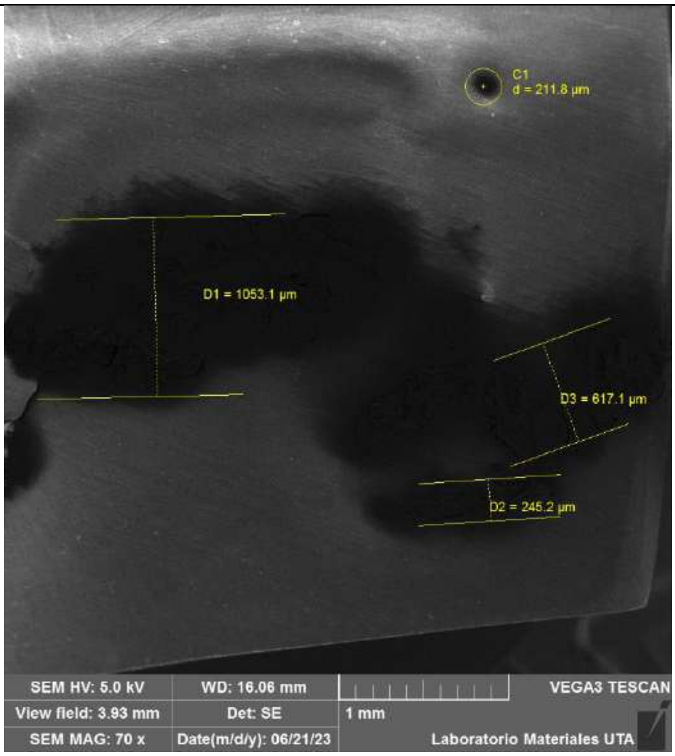

IMPERFECCIONES Y DEFECTOS (70X)


Tabla 20. Continuación



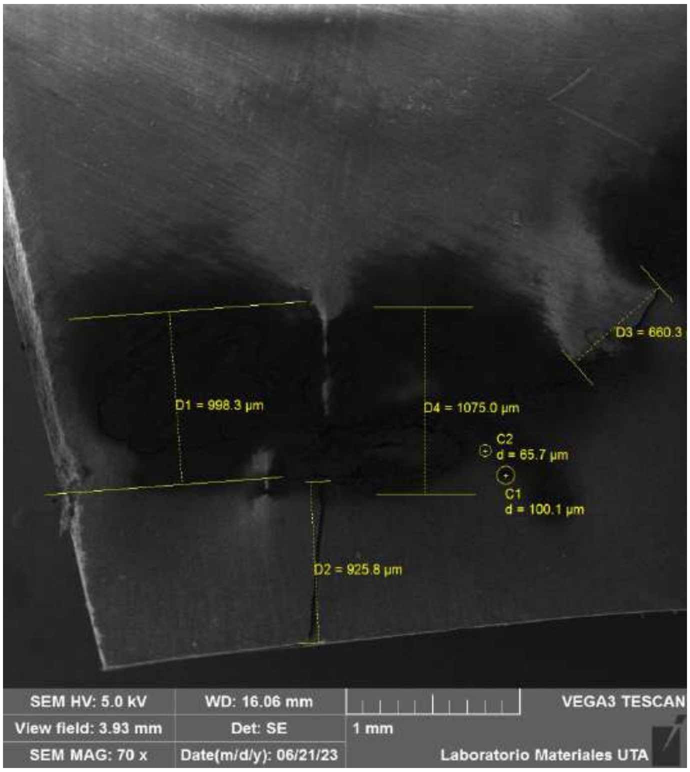


Tabla 20. Continuación

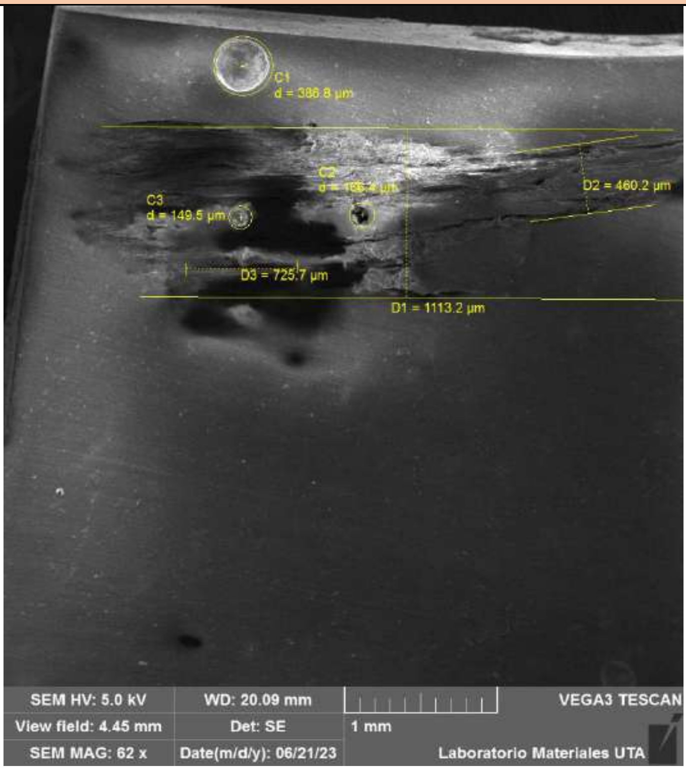
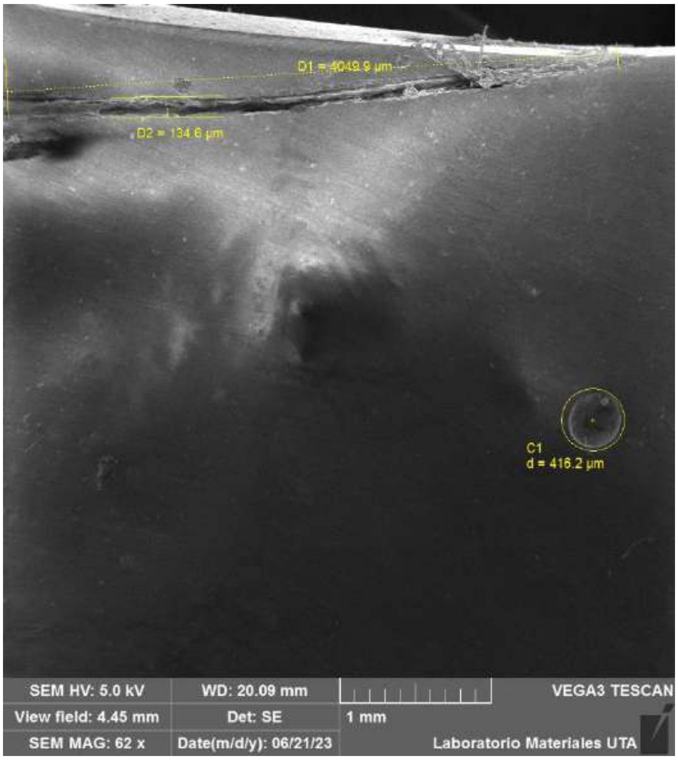
TOPOGRAFÍA DE LA SUPERFICIE (62x) VISTA SUPERFICIAL
 

Tabla 20. Continuación

<table>
<tr><th colspan="4">Observaciones:</th></tr>
<tr><td colspan="4">La distancia entre capas de la matriz tiene una distribución más promedia con valores de 3436.8 µm.
En las diferentes imágenes se presenta porosidades de diferentes diámetros: 228.8, 211.8 y 100.1 µm. Mismas que son producidas en la estratificación del material. Además, se presentan diferentes fisuras producidas en la manufactura de la muestra.
En la topografía de la superficie del material muestran porosidades de 388.8 y 41.2 µm. También muestra una grieta con una apertura de 14.6 µm, que seguramente fue producida en la conformación de la muestra. Además, se puede apreciar diferentes rugosidades que abarcan una extensión aproximadamente de 1113.2 µm, por otra parte, tomando en cuenta el resto de la superficie no se encuentras más irregularidades superficiales</td></tr>
<tr><td>Elaborado por:</td><td>Erick López M.</td><td>Supervisado por:</td><td>Ing. Christian Pérez</td></tr>
<tr><td>Revisado por:</td><td>Ing. Mg. Pablo Valle, Ph.D.</td><td>Aprobado por:</td><td>Ing. Mg. Pablo Valle, Ph.D.</td></tr>
</table>

3.2. Análisis y discusión de resultados

En la tabla 21 describen los resultados obtenidos en cada ensayo realizados a impacto, abrasión, dureza y análisis DSC; mismos que serán sirven para la caracterización del material compuesto.

Tabla 21. Resumen de resultados.

RESULTADOS OBTENIDOS				
MEDICIONES	ENSAYOS			
	IMPACTO (J)	DUREZA SHORE D	DESGASTE (%)	DSC (Pico calor)
A1 80/20	0.9398	63.0		113.88 °C
A2 80/20	1.4097	77.5		
A3 80/20	1.8796	62.5		
A4 80/20	2.3495	60.5		
A5 80/20	2.8194	70.5		
B1 70/30	1.5348	86.0	0.11177164	
B2 70/30	2.5580	74.5	0.03117246	
B3 70/30	3.5811	78.0	0.00615392	
B4 70/30	4.6043	61.0	0.02929187	
B5 70/30	5.6275	61.5	0.03522966	
C1 60/40	0.9398	71.0		
C2 60/40	1.4097	68.0		
C3 60/40	1.8796	75.0		
C4 60/40	2.3495	72.5		
C5 60/40	2.8194	79.0		

3.2.1. Verificación de hipótesis

Se empleó el método T-Student, el cual es una técnica estadística utilizada para evaluar la hipótesis planteada. Este método se aplicó con el objetivo de comparar los resultados de los ensayos de tracción, flexión e impacto entre dos muestras diferentes. Para llevar a cabo esta metodología, se seleccionó un nivel de confianza del 95%, lo que implica un margen de error del 5%, considerado apropiado para proyectos de investigación. Además, se utiliza los siguientes términos:

Ha = Hipótesis alternativa

Ho = Hipótesis nula

α = Margen de error

X = Resultados de los ensayos de muestra 1.

Y=Resultados de los ensayos de muestra 2.

METODO T-STUDENT PARA EL ENSAYO DE IMPACTO

Hipótesis nula (Ho)

El material compuesto de 70% matriz poliéster y 30% de fibra entrecruzada de banano, no presentará mejores resultados a ensayos de impacto que el material compuesto de 80% matriz poliéster y 20% de fibra entrecruzada de banano.

Hipótesis alternativa (Ha)

El material compuesto de 70% matriz poliéster y 30% de fibra entrecruzada de banano, presentará mejores resultados a ensayos de impacto que el material compuesto de 80% matriz poliéster y 20% de fibra entrecruzada de banano.

Solución

Calculo de la distribución t

A continuación, en la tabla 22, los resultados obtenidos de los ensayos a impacto del material compuesto con fracción volumétrica (70% matriz poliéster + 30% vibra de banano) y (80% matriz poliéster + 20% fibra de banano).

Tabla 22. Resultado ensayos impacto

Número de probetas	ESFUERZO MÁXIMO A IMPACTO (Joules)	
	70% resina poliéster 30% fibra de banano	80% resina poliéster 20% fibra de banano
1	1.5348	0,9398
2	2.5580	1,4097
3	3,5811	1,8796
4	4.6043	2,3495
5	5.6275	2,8194
Media	3.58114	2.3495

Cálculo de la varianza

$$S_1^2 = \frac{\sum(xi - \bar{x})^2}{n - 1}$$

$$S_1^2 = \frac{2.208060228}{4}$$

$$S_1^2 = 0.55202$$

$$S_2^2 = \frac{\sum(yi - \bar{y})^2}{n - 1}$$

$$S_2^2 = \frac{10.468768492}{4}$$

$$S_2^2 = 2.61719$$

$$S_p = \sqrt{\frac{S_1^2(n_1 - 1) + S_2^2(n_2 - 1)}{n_1 + n_2 - 2}}$$

$$S_p = \sqrt{\frac{0.55202(5-1) + 2.61719(5-1)}{5+5-2}}$$

$$S_p = 1.25881$$

$$t_c = \frac{\overline{x1} - \overline{x2}}{S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$$t_c = \frac{3.58114 - 2.3495}{1.25881\sqrt{\frac{1}{5} + \frac{1}{5}}}$$

$$t_c = 2.3411$$

La regla de decisión es: aceptar Ho si, t-calculado > t-tabulado

Nivel de confianza 95%

Margen de error 5%.

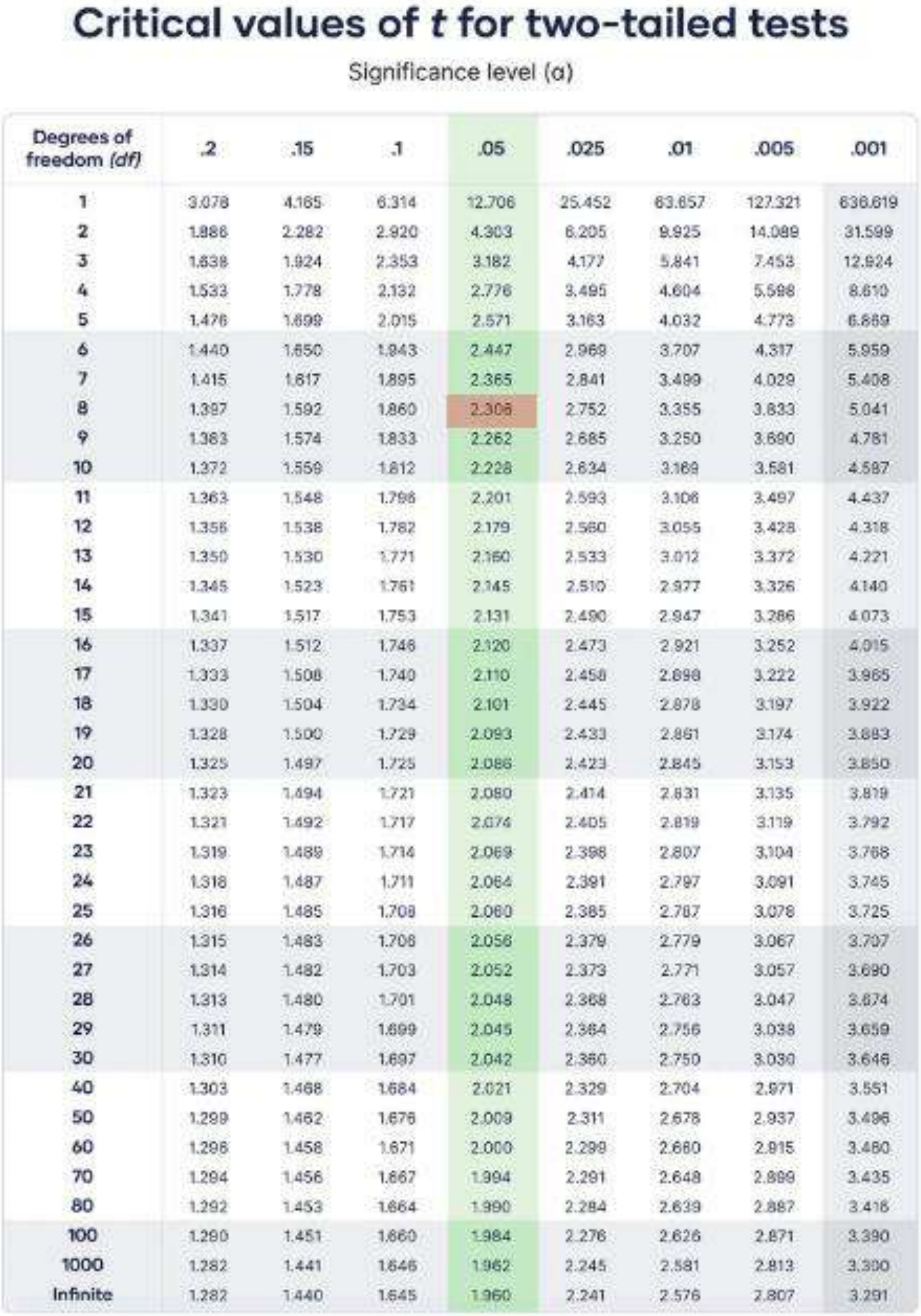
Nivel de significancia o potencia de la prueba $\alpha = 0.05/2 = 0.025$.

Grados de libertad

$$V = n1 + n2 - 2$$

$$V = 5 + 5 - 2$$

$$V = 8$$



Critical values of *t* for two-tailed tests

Significance level (α)

Degrees of freedom *(df)*	.2	.15	.1	.05	.025	.01	.005	.001
1	3.078	4.165	6.314	12.706	25.452	63.657	127.321	636.619
2	1.886	2.282	2.920	4.303	6.205	9.925	14.089	31.599
3	1.638	1.924	2.353	3.182	4.177	5.841	7.453	12.924
4	1.533	1.778	2.132	2.776	3.495	4.604	5.598	8.610
5	1.476	1.699	2.015	2.571	3.163	4.032	4.773	6.869
6	1.440	1.650	1.943	2.447	2.969	3.707	4.317	5.959
7	1.415	1.617	1.895	2.365	2.841	3.499	4.029	5.408
8	1.397	1.592	1.860	2.306	2.752	3.355	3.833	5.041
9	1.383	1.574	1.833	2.262	2.685	3.250	3.690	4.781
10	1.372	1.559	1.812	2.228	2.634	3.169	3.581	4.587
11	1.363	1.548	1.796	2.201	2.593	3.106	3.497	4.437
12	1.356	1.538	1.782	2.179	2.560	3.055	3.428	4.318
13	1.350	1.530	1.771	2.160	2.533	3.012	3.372	4.221
14	1.345	1.523	1.761	2.145	2.510	2.977	3.326	4.140
15	1.341	1.517	1.753	2.131	2.490	2.947	3.286	4.073
16	1.337	1.512	1.746	2.120	2.473	2.921	3.252	4.015
17	1.333	1.508	1.740	2.110	2.458	2.898	3.222	3.965
18	1.330	1.504	1.734	2.101	2.445	2.878	3.197	3.922
19	1.328	1.500	1.729	2.093	2.433	2.861	3.174	3.883
20	1.325	1.497	1.725	2.086	2.423	2.845	3.153	3.850
21	1.323	1.494	1.721	2.080	2.414	2.831	3.135	3.819
22	1.321	1.492	1.717	2.074	2.405	2.819	3.119	3.792
23	1.319	1.489	1.714	2.069	2.398	2.807	3.104	3.768
24	1.318	1.487	1.711	2.064	2.391	2.797	3.091	3.745
25	1.316	1.485	1.708	2.060	2.385	2.787	3.078	3.725
26	1.315	1.483	1.706	2.056	2.379	2.779	3.067	3.707
27	1.314	1.482	1.703	2.052	2.373	2.771	3.057	3.690
28	1.313	1.480	1.701	2.048	2.368	2.763	3.047	3.674
29	1.311	1.479	1.699	2.045	2.364	2.756	3.038	3.659
30	1.310	1.477	1.697	2.042	2.360	2.750	3.030	3.646
40	1.303	1.468	1.684	2.021	2.329	2.704	2.971	3.551
50	1.299	1.462	1.676	2.009	2.311	2.678	2.937	3.496
60	1.296	1.458	1.671	2.000	2.299	2.660	2.915	3.460
70	1.294	1.456	1.667	1.994	2.291	2.648	2.899	3.435
80	1.292	1.453	1.664	1.990	2.284	2.639	2.887	3.416
100	1.290	1.451	1.660	1.984	2.276	2.626	2.871	3.390
1000	1.282	1.441	1.646	1.962	2.245	2.581	2.813	3.300
Infinite	1.282	1.440	1.645	1.960	2.241	2.576	2.807	3.291

Figura 11. T- Student. 95% confianza y 8 grados de libertad

Fuente: [22]

t-calculado = 2.3411 > t-tabulado = 2.308

Como el t-calculado está afuera del rango del t-tabulado se aceptado la hipótesis alterna de trabajo la mismo que dice: El material compuesto de 70% matriz poliéster y 30% de fibra entrecruzada de banano, presentara mejores resultados a ensayos de impacto que el material compuesto de 80% matriz poliéster y 20% de fibra entrecruzada de banano

METODO T-STUDENT PARA EL ENSAYO DE DUREZA

Hipótesis nula (Ho)

El material compuesto de 70% matriz poliéster y 30% de fibra entrecruzada de banano, no presentará mejores resultados a ensayos de dureza que el material compuesto de 60% matriz poliéster y 40% de fibra entrecruzada de banano.

Hipótesis alternativa (Ha)

El material compuesto de 70% matriz poliéster y 30% de fibra entrecruzada de banano, presentará mejores resultados a ensayos de dureza que el material compuesto de 60% matriz poliéster y 40% de fibra entrecruzada de banano.

Solución

Calculo de la distribución t.

A continuación, en la tabla 23, los resultados obtenidos de los ensayos de dureza del material compuesto con fracción volumétrica (70% matriz poliéster + 30% vibra de banano) y (80% matriz poliéster + 20% fibra de banano).

Tabla 23. Resultados ensayo dureza

Número de probetas	**ENSAYO DE DUREZA SHORE A**	
	70% resina poliéster 30% fibra de banano	60% resina poliéster 40% fibra de banano
1	86.0	79.0
2	78.0	75.0
3	74.5	71.0
4	61.0	72.5
5	61.5	68
Media	72.2	73.1

Cálculo de la varianza

$$S_1^2 = \frac{\sum(xi - \bar{x})^2}{n-1}$$

$$S_1^2 = \frac{69.2}{4}$$

$$S_1^2 = 17.3$$

$$S_2^2 = \frac{\sum(yi - \bar{y})^2}{n-1}$$

$$S_2^2 = \frac{469.3}{4}$$

$$S_2^2 = 117.325$$

$$S_p = \sqrt{\frac{S_1^2(n_1 - 1) + S_2^2(n_2 - 1)}{n_1 + n_2 - 2}}$$

$$S_p = \sqrt{\frac{17.3(5 - 1) + 117.325(5 - 1)}{5 + 5 - 2}}$$

$$S_p = 8.2044$$

$$t_c = \frac{\overline{x1} - \overline{x2}}{S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$$t_c = \frac{72.2 - 73.1}{8.2044\sqrt{\frac{1}{5} + \frac{1}{5}}}$$

$$t_c = -0.17345$$

La regla de decisión es: aceptar Ho si, t-calculado > t-tabulado

Nivel de confianza 95%

Margen de error 5%.

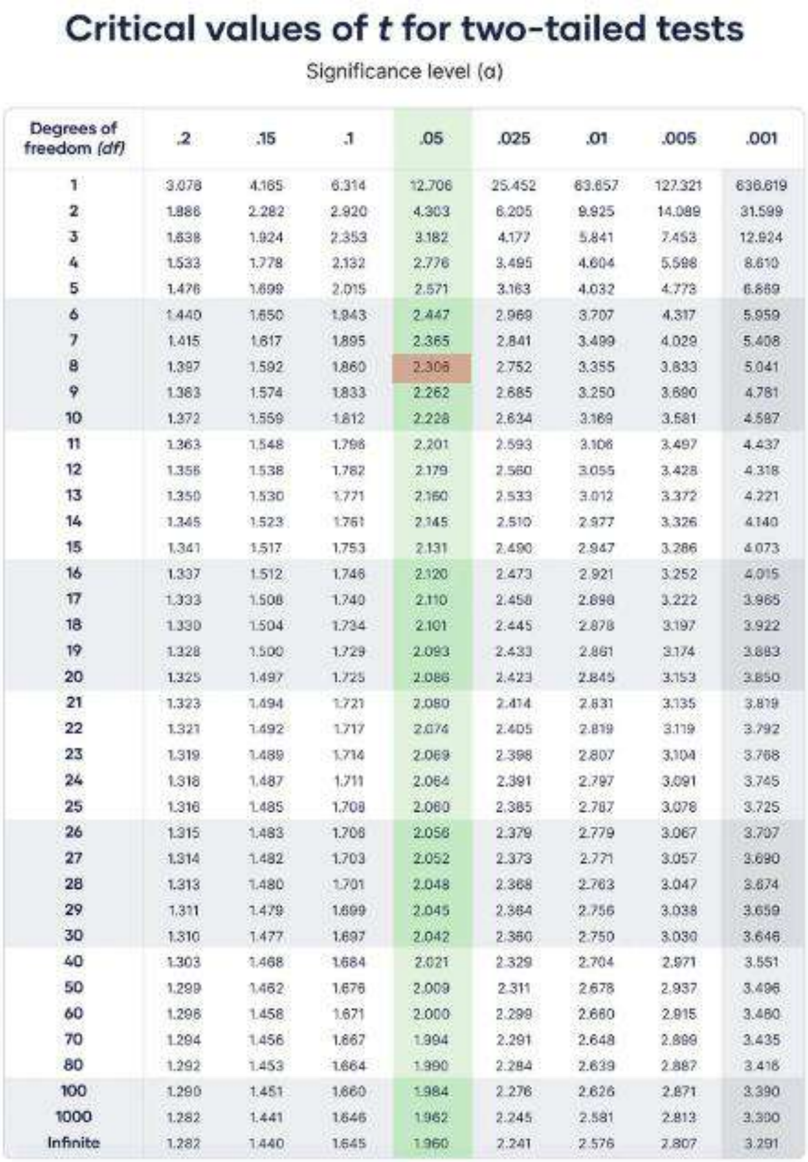
Nivel de significancia o potencia de la prueba α = 0.05/2 = 0.025.

Grados de libertad

$$V = n1 + n2 - 2$$

$$V = 5 + 5 - 2$$

$$V = 8$$



Critical values of *t* for two-tailed tests

Significance level (α)

Degrees of freedom *(df)*	.2	.15	.1	.05	.025	.01	.005	.001
1	3.078	4.165	6.314	12.706	25.452	63.657	127.321	636.619
2	1.886	2.282	2.920	4.303	6.205	9.925	14.089	31.599
3	1.638	1.924	2.353	3.182	4.177	5.841	7.453	12.924
4	1.533	1.778	2.132	2.776	3.495	4.604	5.598	8.610
5	1.476	1.699	2.015	2.571	3.163	4.032	4.773	6.869
6	1.440	1.650	1.943	2.447	2.969	3.707	4.317	5.959
7	1.415	1.617	1.895	2.365	2.841	3.499	4.029	5.408
8	1.397	1.592	1.860	2.306	2.752	3.355	3.833	5.041
9	1.383	1.574	1.833	2.262	2.685	3.250	3.690	4.781
10	1.372	1.559	1.812	2.228	2.634	3.169	3.581	4.587
11	1.363	1.548	1.796	2.201	2.593	3.106	3.497	4.437
12	1.356	1.538	1.782	2.179	2.560	3.055	3.428	4.318
13	1.350	1.530	1.771	2.160	2.533	3.012	3.372	4.221
14	1.345	1.523	1.761	2.145	2.510	2.977	3.326	4.140
15	1.341	1.517	1.753	2.131	2.490	2.947	3.286	4.073
16	1.337	1.512	1.746	2.120	2.473	2.921	3.252	4.015
17	1.333	1.508	1.740	2.110	2.458	2.898	3.222	3.965
18	1.330	1.504	1.734	2.101	2.445	2.878	3.197	3.922
19	1.328	1.500	1.729	2.093	2.433	2.861	3.174	3.883
20	1.325	1.497	1.725	2.086	2.423	2.845	3.153	3.850
21	1.323	1.494	1.721	2.080	2.414	2.831	3.135	3.819
22	1.321	1.492	1.717	2.074	2.405	2.819	3.119	3.792
23	1.319	1.489	1.714	2.069	2.398	2.807	3.104	3.768
24	1.318	1.487	1.711	2.064	2.391	2.797	3.091	3.745
25	1.316	1.485	1.708	2.060	2.385	2.787	3.078	3.725
26	1.315	1.483	1.706	2.056	2.379	2.779	3.067	3.707
27	1.314	1.482	1.703	2.052	2.373	2.771	3.057	3.690
28	1.313	1.480	1.701	2.048	2.368	2.763	3.047	3.674
29	1.311	1.479	1.699	2.045	2.364	2.756	3.038	3.659
30	1.310	1.477	1.697	2.042	2.360	2.750	3.030	3.646
40	1.303	1.468	1.684	2.021	2.329	2.704	2.971	3.551
50	1.299	1.462	1.676	2.009	2.311	2.678	2.937	3.496
60	1.296	1.458	1.671	2.000	2.299	2.660	2.915	3.460
70	1.294	1.456	1.667	1.994	2.291	2.648	2.899	3.435
80	1.292	1.453	1.664	1.990	2.284	2.639	2.887	3.416
100	1.290	1.451	1.660	1.984	2.276	2.626	2.871	3.390
1000	1.282	1.441	1.646	1.962	2.245	2.581	2.813	3.300
Infinite	1.282	1.440	1.645	1.960	2.241	2.576	2.807	3.291

Figura 12. T- Student. 95% confianza y 8 grados de libertad.

Fuente: [22]

t-calculado $= -0.17345 <$ t-tabulado $= 2.304$

Como el t-calculado se encuentra dentro de los valores del t-tabulado, aceptado la hipótesis nula de trabajo la mismo que dice: El material compuesto de 70% matriz poliéster y 30% de fibra entrecruzada de banano, no presentara mejores resultados a ensayos de dureza que el material compuesto de 60% matriz poliéster y 40% de fibra entrecruzada de banano

3.2.2. Análisis de resultados de ensayos de abrasión

La pérdida de masa por abrasión este dado acorde la siguiente ecuación 6

$$L = A - B \tag{6}$$

Donde:

A= masas de la muestra antes de la abrasión

B= masa de la muestra después de la abrasión

Índice de desgaste

Ese índice se calcula a parir de la pérdida de masa en miligramos por mil ciclos de abrasión. Ecuación 7.

$$I = \frac{(A - B)1000}{C} \tag{7}$$

Donde:

A= masas de la muestra antes de la abrasión [mg]

B= masa de la muestra después de la abrasión [mg]

C= número de ciclos recorridos

Tabla 24. Resultados ensayo de abrasión.

RESULTADOS					
# de Probeta	Carga aplicada (g)	Masa Inicial (g)	Masa final (g)	Diferencia de masa (g)	Porcentaje %
1	1000	81.416	81.382	0.034	0.04176083
2	1000	80.199	80.174	0.025	0.03117246
3	1000	81.249	81.244	0.005	0.00615392
4	1000	81.934	81.91	0.024	0.02929187
5	1000	82.317	82.288	0.029	0.03522966
PROMEDIO	-	81.423	81.3996	0.0234	0.02872175

Para el cálculo del índice de desgaste se empleará los valores promedios arrojados en los ensayos de desgaste realizados. Ecuación 8.

$$I = \frac{(A - B)1000}{C} \tag{8}$$

$A = 81.423\,g \rightarrow 81423\,mg$

$B = 81.3996\,g \rightarrow 81399.6\,mg$

$C = 1000\,ciclos$

$$I = \frac{(81423\,mg - 81399.6\,mg)1000}{1000\,ciclos}$$

$$I = 23.4\frac{mg}{ciclos}$$

3.3. Posibles aplicaciones industriales

En los últimos años, ha habido un notorio crecimiento en la utilización de materiales compuestos, los cuales han reemplazado a los metales y plásticos convencionales. En particular, el material compuesto generado por una matriz de poliéster reforzada con fibra de banano presenta propiedades decentes en términos de dureza, resistencia al impacto y desgaste. Su bajo costo y peso ligero lo hacen muy atractivo en la industria de fabricación de carrocerías, donde se busca reducir el peso de los componentes y partes para mejorar el rendimiento de los vehículos y ahorrar energía. Además de sus ventajas económicas, este material es ambientalmente amigable y facilita el moldeo de piezas. En cuanto a posibles aplicaciones adicionales, también podría encontrar utilidad en sectores como la construcción, la fabricación de muebles y la producción de artículos deportivos, donde se valora la combinación de resistencia y ligereza.

La tabla 25 se muestra los resultados de ensayos de impacto de diferentes materiales compuestos caracterizados por distintos autores, estos materiales pueden ser sustituidos por el material compuestos caracterizado en el presente trabajo

Tabla 25. Comparación de resultados de ensayos de impacto

Autor	Material	Energía en Joules
Erick Isaac López Martínez	**Material compuesto 70% matriz poliéster y 30% de fibra de banano**	**3.5811**
Edisson Fernando Lalaleo Galarza	Material compuesto 83% matriz poliéster y 17% de cascarilla de arroz. [23]	1.4
Ángel Vinicio Tonato Porras	Material compuesto 60% matriz poliéster y 40% de fibra de pelo de res. [2]	1.32
Darwin Iván Alomaliza Masaquiza	Material compuesto 70% matriz poliéster y 30% 1 capa de fibra de vidrio + 1capa de acero inoxidable + 1 capa de fibra de vidrio. [13]	0.910
José Luis Pico Vaca	Material compuesto 70% matriz poliéster y 30% de fibra larga de totora. [24]	0.23

En la tabla 26 se muestra valores de diversos materiales compuestos que pueden ser sustituidos por el presente trabajo de investigación.

Tabla 26. Comparación de resultados de ensayos de dureza Shore D

Autor	Material	Dureza Shore D
Erick Isaac López Martínez	**Material compuesto de matriz poliéster reforzado con fibra de banano**	**73**
Ángel Vinicio Tonato Porras	Material compuesto de matriz elastomérica reforzado con fibra de cabuya. [26]	48,667

Tabla 26. Continuación.

Franco Giovanny Palacios Pérez	Material compuesto a partir de matriz elastomérica de látex reforzado con gránulo de caucho [25]	14,94

Sector del mobiliario

El aspecto estético del material compuesto resulta beneficioso para la decoración. Dado que es un polímero capaz de absorber impactos en caso de caídas, se puede emplear en marcos de fotografías, cuadros y para resaltar estanterías, evitando así un mayor uso de madera. También se puede utilizar en forma de tableros para proporcionar acabados a mesas, escritorios y estanterías en oficinas o viviendas.

Industria automotriz

En el ámbito de la industria automotriz, se han desarrollado materiales compuestos con el objetivo de reducir el peso de los vehículos. En este campo, se ha investigado el uso de fibra de banano, por ejemplo, en la fabricación de accesorios que no estén sometidos a esfuerzos significativos como puede ser en la creación de alerones o recubrimientos de guardafangos

Deportes y material de protección

Este material compuesto puede ser probado para la fabricación de equipos deportivos, como raquetas, cascos, rodilleras o coderas. Son más ligeros que los materiales tradicionales, como la madera y el metal, y también son más resistentes a los impactos y corrosión. Además, en caso de ser sometidos a un alza de temperatura por abrasión este material alcanza un holgado rango de trabajo térmicamente estable.

CAPITULO IV

4. CONCLUSIONES Y RECOMENDACIONES

4.1. Conclusiones

- Para la conformación del material compuesto se estableció diferentes fracciones volumétricas: 80% resina poliéster 20% fibra de banano, 70% resina poliéster 30% fibra banano, 60% resina poliéster 40% fibra banano, con una distribución de la fibra entrecruzada. De las cuales se determinó que la mejor combinación volumétrica frente a ensayos mecánicos resulto ser la de 70% resina poliéster y 30% fibra banano.
- Para la caracterización del material compuesto se determinó que las siguientes normativas cumplen los requerimientos necesarios para llevar a cabo los diferentes tipos de ensayos: ASTM D5628-10 para el ensayo de impacto, ASTM D2240-15 para el ensayo de dureza y ASTM G0195-13a para el de abrasión.
- Se determinó que el material compuesto con mejor comportamiento mecánico es el de (70% Matriz poliéster – 30% Refuerzo, fibra de banano). Los valores encontrados son las siguientes:
  - Energía de impacto: 3.5811 J
  - Dureza: 73.1 Shore D
  - Índice de abrasión: $23.4\frac{mg}{ciclos}$
  - Pico calor térmico: 113.88 °C
- Se realizó la caracterización, térmica, mecánica y microestructura de un material compuesto de matriz poliéster reforzada con fibra natural de banano, a partir de esta caracterización el material mostró una mayor resistencia al impacto que la madera y otros materiales compuestos de matriz poliéster y fibra natural, por lo cual puede ser empleado en la industria maderera o en ciertas aplicaciones dentro de la construcción. De igual forma

por su relativo bajo costo y ligereza también puede ser probada en la industria automotriz y en indumentaria de protección.

4.2. Recomendaciones

- Realizar un trabajo experimental utilizando diferentes tipos de resinas para buscar aumentar sus propiedades mecánicas.
- Realizar un trabajo experimental de este material utilizando una distribución de la fibra al azar.
- Encontrar más aplicaciones en las que se pueda utilizar este material compuesto (resina poliéster + fibra de banano).
- Realizar una caracterización de inflamabilidad del material para conocer de mejor forma su comportamiento frente a altas temperaturas.

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ANEXOS

ANEXO 1

Designation: D5628 – 10

INTERNATIONAL

Standard Test Method for Impact Resistance of Flat, Rigid Plastic Specimens by Means of a Falling Dart (Tup or Falling Mass)[1]

This standard is issued under the fixed designation D5628; 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 (s) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the determination of the threshold value of impact-failure energy required to crack or break flat, rigid plastic specimens under various specified conditions of impact of a free-falling dart (tup), based on testing many specimens.

1.2 The values stated in SI units are to be regarded as the standard. The values 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.* Specific hazard statements are given in Section 8.

NOTE 1—This test method and ISO 6603-1 are technically equivalent only when the test conditions and specimen geometry required for Geometry FE and the Bruceton Staircase method of calculation are used.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing
D883 Terminology Relating to Plastics
D1600 Terminology for Abbreviated Terms Relating to Plastics
D1709 Test Methods for Impact Resistance of Plastic Film by the Free-Falling Dart Method
D2444 Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
D3763 Test Method for High Speed Puncture Properties of Plastics Using Load and Displacement Sensors
D4000 Classification System for Specifying Plastic Materials
D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens
D6779 Classification System for Polyamide Molding and Extrusion Materials (PA)
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *ISO Standards:*[3]

ISO 291 Standard Atmospheres for Conditioning and Testing
ISO 6603-1 Plastics—Determination of Multiaxial Impact Behavior of Rigid Plastics—Part 1: Falling Dart Method

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of plastic terms used in this test method, see Terminologies D883 and D1600.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *failure (of test specimen)*—the presence of any crack or split, created by the impact of the falling tup, that can be seen by the naked eye under normal laboratory lighting conditions.

3.2.2 *mean-failure energy (mean-impact resistance)*—the energy required to produce 50 % failures, equal to the product of the constant drop height and the mean-failure mass, or, to the product of the constant mass and the mean-failure height.

3.2.3 *mean-failure height (impact-failure height)*—the height at which a standard mass, when dropped on test specimens, will cause 50 % failures.

NOTE 2—Cracks usually start at the surface opposite the one that is struck. Occasionally incipient cracking in glass-reinforced products, for example, is difficult to differentiate from the reinforcing fibers. In such cases, a penetrating dye can confirm the onset of crack formation.

3.2.4 *mean-failure mass (impact-failure mass)*—the mass of the dart (tup) that, when dropped on the test specimens from a standard height, will cause 50 % failures.

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

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[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 July 1, 2010. Published July 2010. Originally approved in 1994. Last previous edition approved in 2007 as D5628 - 07. DOI: 10.1520/D5628-10.

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

3.2.5 *tup*—a dart with a hemispherical nose. See 7.2 and Fig. 1.

4. Summary of Test Method

4.1 A free-falling dart (tup) is allowed to strike a supported specimen directly. Either a dart having a fixed mass is dropped from various heights, or a dart having an adjustable mass is dropped from a fixed height. (See Fig. 2).

4.2 The procedure determines the energy (mass 3 height) that will cause 50 % of the specimens tested to fail (mean failure energy).

4.3 The technique used to determine mean failure energy is commonly called the Bruceton Staircase Method or the Up-and-Down Method **(1)**.[4] Testing is concentrated near the mean, reducing the number of specimens required to obtain a reasonably precise estimate of the impact resistance.

4.4 Each test method permits the use of different tup and test specimen geometries to obtain different modes of failure, permit easier sampling, or test limited amounts of material. There is no known means for correlating the results of tests made by different impact methods or procedures.

5. Significance and Use

5.1 Plastics are viscoelastic and therefore are likely to be sensitive to changes in velocity of the mass falling on their surfaces. However, the velocity of a free-falling object is a function of the square root of the drop height. A change of a factor of two in the drop height will cause a change of only 1.4 in velocity. Hagan et al **(2)** found that the mean-failure energy of sheeting was constant at drop heights between 0.30 and 1.4 m. This suggests that a constant mass-variable height method will give the same results as the constant height-variable mass technique. On the other hand, different materials respond differently to changes in the velocity of impact. Equivalence of these methods should not be taken for granted. While both constant-mass and constant-height techniques are permitted by these methods, the constant-height method should be used for those materials that are found to be rate-sensitive in the range of velocities encountered in falling-weight types of impact tests.

5.2 The test geometry FA causes a moderate level of stress concentration and can be used for most plastics.

5.3 Geometry FB causes a greater stress concentration and results in failure of tough or thick specimens that do not fail with Geometry FA **(3)**. This approach can produce a punch shear failure on thick sheet. If that type of failure is undesirable, Geometry FC should be used. Geometry FB is suitable for research and development because of the smaller test area required.

5.3.1 The conical configuration of the 12.7-mm diameter tup used in Geometry FB minimizes problems with tup penetration and sticking in failed specimens of some ductile materials.

5.4 The test conditions of Geometry FC are the same as those of Test Method A of Test Method D1709. They have been used in specifications for extruded sheeting. A limitation of this geometry is that considerable material is required.

5.5 The test conditions of Geometry FD are the same as for Test Method D3763.

5.6 The test conditions of Geometry FE are the same as for ISO 6603-1.

5.7 Because of the nature of impact testing, the selection of a test method and tup must be somewhat arbitrary. Although a choice of tup geometries is available, knowledge of the final or intended end-use application shall be considered.

5.8 Clamping of the test specimen will improve the precision of the data. Therefore, clamping is recommended. However, with rigid specimens, valid determinations can be made without clamping. Unclamped specimens tend to exhibit greater impact resistance.

5.9 Before proceeding with this test method, reference should be made to the specification of the material being tested. Table 1 of Classification System D4000 lists the ASTM materials standards that currently exist. Any test specimens preparation, conditioning, dimensions, or testing parameters or combination thereof covered in the relevant ASTM materials specification shall take precedence over those mentioned in this test method. If there are no relevant ASTM material specifications, then the default conditions apply.

6. Interferences

6.1 Falling-mass-impact-test results are dependent on the geometry of both the falling mass and the support. Thus, impact tests should be used only to obtain relative rankings of materials. Impact values cannot be considered absolute unless the geometry of the test equipment and specimen conform to the end-use requirement. Data obtained by different procedures within this test method, or with different geometries, cannot, in general, be compared directly with each other. However, the relative ranking of materials is expected to be the same between two test methods if the mode of failure and the impact velocities are the same.

6.1.1 Falling-mass-impact types of tests are not suitable for predicting the relative ranking of materials at impact velocities differing greatly from those imposed by these test methods.

6.2 As cracks usually start at the surface opposite the one that is struck, the results can be greatly influenced by the quality of the surface of test specimens. Therefore, the composition of this surface layer, its smoothness or texture, levels of and type of texture, and the degree of orientation introduced during the formation of the specimen (such as during injection molding) are very important variables. Flaws in this surface will also affect results.

6.3 Impact properties of plastic materials can be very sensitive to temperature. This test can be carried out at any reasonable temperature and humidity, thus representing actual use environments. However, this test method is intended primarily for rating materials under specific impact conditions.

7. Apparatus

7.1 *Testing Machine*—The apparatus shall be constructed essentially as is shown in Fig. 2. The geometry of the specimen clamp and tup shall conform to the dimensions given in 7.1.1 and 7.2.

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[4] The boldface numbers in parentheses refer to a list of references at the end of the text.

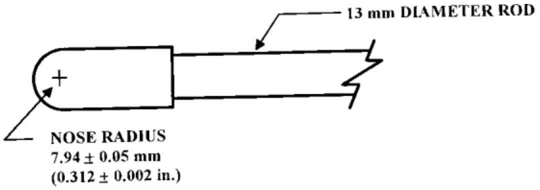

FIG. 1 (a)

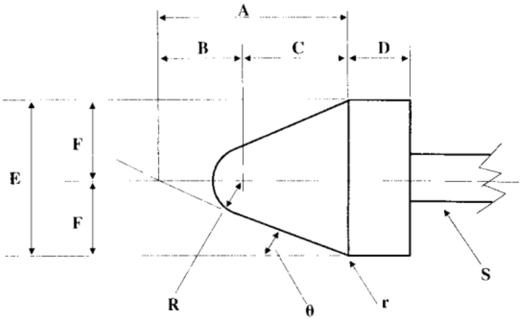

FIG. 1 (b)

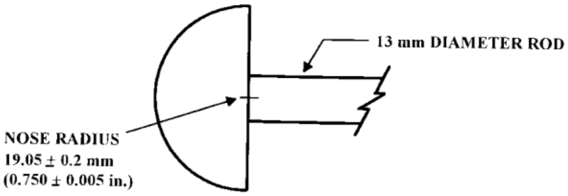

FIG. 1 (c)

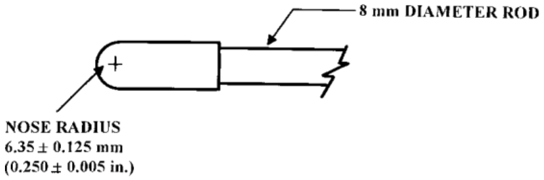

FIG. 1 (d)

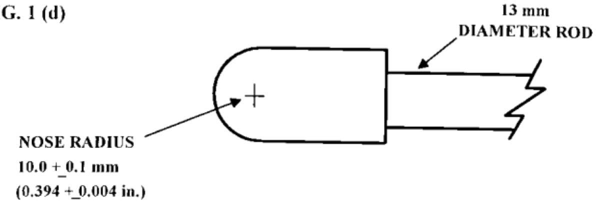

FIG. 1 (e)

Dimensions of Conical Dart (Not to scale.)—Fig. 1(*b*)

NOTE 1—Unless specified, the tolerance on all dimensions shall be ±2 %.

Position	Dimension, mm	Dimension, in.
A	27.2	1.07
B	15	0.59
C	12.2	0.48
D	6.4	0.25
E	25.4	1
F	12.7	0.5
R (nose radius)	6.35 ± 0.05	0.250 ± 0.002
r (radius)	0.8	0.03
S (diameter)[A]	6.4	0.25
θ	25 ± 1°	25 ± 1°

[A] Larger diameter shafts shall be used.

FIG. 1 Tup Geometries for Geometries FA (1*a*), FB (1*b*), FC (1*c*), FD (1*d*), and FE (1*e*)

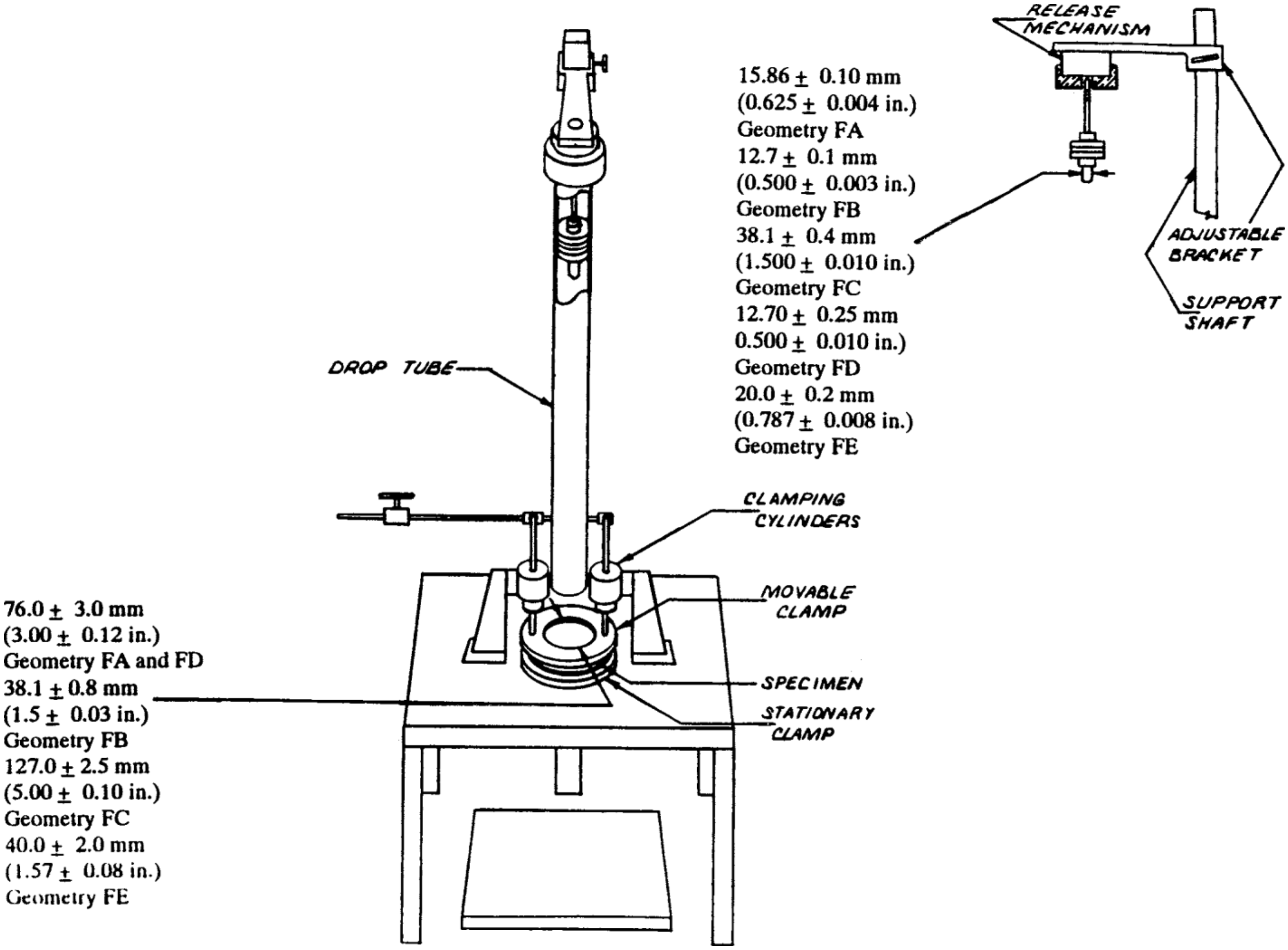

FIG. 2 One Type of Falling Mass Impact Tester

7.1.1 *Specimen Clamp*—For flat specimens, a two-piece annular specimen clamp similar to that shown in Fig. 3 is recommended. For Geometries FA and FD, the inside diameter should be 76.0 6 3.0 mm (3.00 6 0.12 in.). For Geometry FB, the inside diameter should be 38.1 6 0.80 mm (1.5 6 0.03 in.). For Geometry FC, the inside diameter should be 127.0 6 2.5 mm (5.00 6 0.10 in.). For Geometry FE an annular specimen clamp similar to that shown in Fig. 4 is required. The inside diameter should be 40 6 2 mm (1.57 6 0.08 in.) (see Table 1). For Geometries FA, FB, FC, and FD, the inside edge of the upper or supporting surface of the lower clamp should be rounded slightly; a radius of 0.8 mm (0.03 in.) has been found to be satisfactory. For Geometry FE this radius should be 1 mm (0.04 in.).

7.1.1.1 Contoured specimens shall be firmly held in a jig so that the point of impact will be the same for each specimen.

7.1.2 *Tup Support*, capable of supporting a 13.5-kg (30-lb) mass, with a release mechanism and a centering device to ensure uniform, reproducible drops.

NOTE 3—Reproducible drops are ensured through the use of a tube or cage within which the tup falls. In this event, care should be exercised so that any friction that develops will not reduce the velocity of the tup appreciably.

7.1.3 *Positioning Device*—Means shall be provided for positioning the tup so that the distance from the impinging surface of the tup head to the test specimen is as specified.

7.2 *Tup*:

7.2.1 The tup used in Geometry FA shall have a 15.86 6 0.10-mm (0.625 6 0.004-in.) diameter hemispherical head of tool steel hardened to 54 HRC or harder. A steel shaft about 13 mm (0.5 in.) in diameter shall be attached to the center of the flat surface of the head with its longitudinal axis at 90° to that surface. The length of the shaft shall be great enough to accommodate the maximum mass required (see Fig. 1(*a*) and Table 1).

7.2.2 The tup used in Geometry FB shall be made of tool steel hardened to 54 HRC or harder. The head shall have a diameter of 12.76 0.1 mm (0.500 6 0.003 in.) with a conical (50° included angle) configuration such that the conical surface is tangent to the hemispherical nose. A 6.4-mm (0.25-in.) diameter shaft is satisfactory (see Fig. 1(*b*) and Table 1).

7.2.3 The tup used for Geometry FC shall be made of tool steel hardened to 54 HRC or harder. The hemispherical head shall have a diameter of 38.1 6 0.4 mm (1.5 6 0.015 in.). A steel shaft about 13 mm (0.5 in.) in diameter shall be attached to the center of the flat surface of the head with its longitudinal

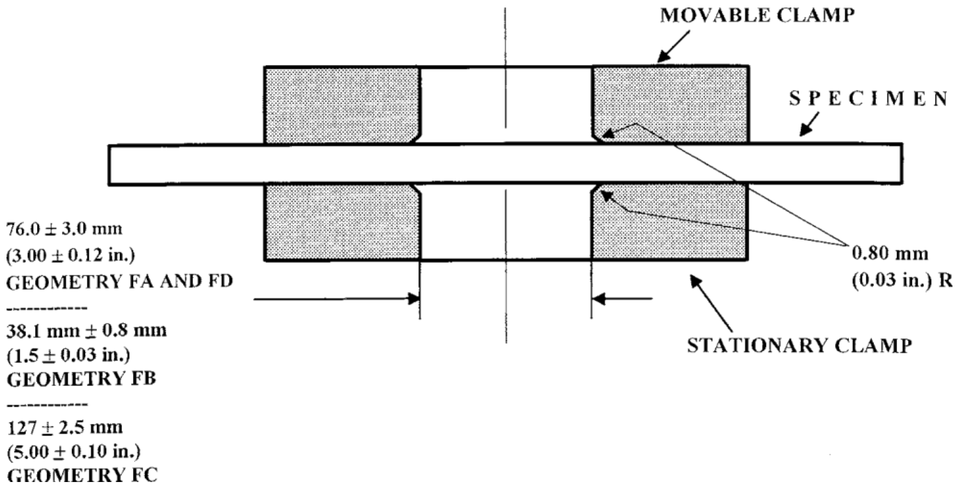

FIG. 3 Support Plate/Specimen/Clamp Configuration for Geometries FA, FB, FC, and FD

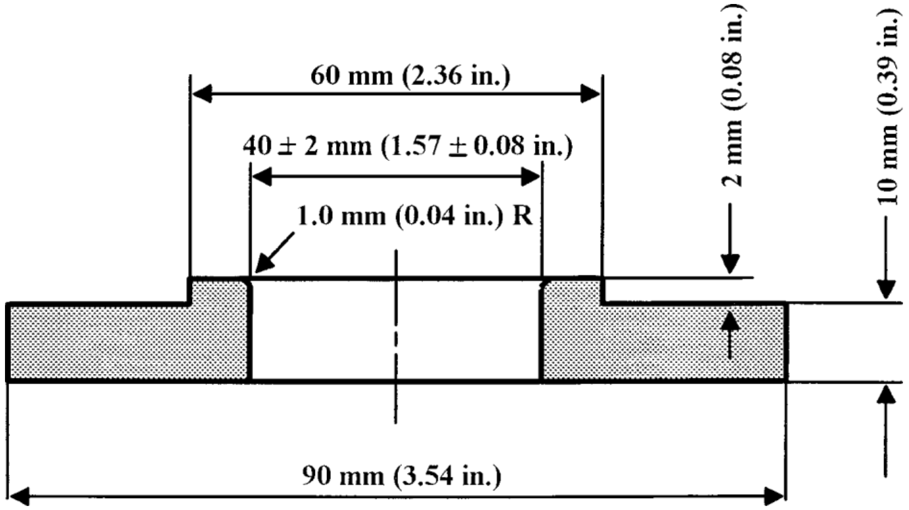

FIG. 4 Test-Specimen Support for Geometry FE

TABLE 1 Tup and Support Ring Dimensions

Geometry	Dimensions, mm (in.)	
	Tup Diameter	Inside Diameter Support Ring
FA	15.86 6 0.10 (0.625 6 0.004)	76.0 6 3.0 (3.00 6 0.12)
FB	12.7 6 0.1 (0.500 6 0.003)	38.1 6 0.8 (1.5 6 0.03)
FC	38.1 6 0.4 (1.5 6 0.010)	127.0 6 2.5 (5.00 6 0.10)
FD	12.70 6 0.25 (0.500 6 0.010)	76.0 6 3.0 (3.00 6 0.12)
FE	20.0 6 0.2 (0.787 6 0.008)	40.0 6 2.0 (1.57 6 0.08)

axis at 90° to that surface. The length of the shaft shall be great enough to accommodate the maximum mass (see Fig. 1(*c*) and Table 1).

7.2.4 The tup used in Geometry FD shall have a 12.70 6 0.25-mm (0.500 6 0.010-in.) diameter hemispherical head of tool steel hardened to 54 HRC or harder. A steel shaft about 8 mm (0.31 in.) in diameter shall be attached to the center of the flat surface of the head with its longitudinal axis at 90° to the surface. The length of the shaft shall be great enough to accommodate the maximum mass required (see Fig. 1(*d*) and Table 1).

7.2.5 The tup used in Geometry FE shall have a 20.0 6 0.2-mm (0.787 6 0.008-in.) diameter hemispherical head of tool steel hardened to 54 HRC or harder. A steel shaft about 13 mm (0.5 in.) in diameter shall be attached to the center of the flat surface of the head with its longitudinal axis at 90° to the surface. The length of the shaft shall be great enough to accommodate the maximum mass required (see Fig. 1(*e*) and Table 1).

7.2.6 The tup head shall be free of nicks, scratches, or other surface irregularities.

7.3 *Masses*—Cylindrical steel masses are required that have a center hole into which the tup shaft will fit. A variety of masses are needed if different materials or thicknesses are to be

TABLE 2 Minimum Size of Specimen

Geometry	Specimen Diameter, mm (in.)	Square Specimen, mm (in.)
FA	89 (3.5)	89 by 89 (3.5 by 3.5)
FB	51 (2.0)	51 by 51 (2.0 by 2.0)
FC	140 (5.5)	140 by 140 (5.5 by 5.5)
FD	89 (3.5)	89 by 89 (3.5 by 3.5)
FE	58 (2.3)	58 by 58 (2.3 by 2.3)

tested. The optimal increments in tup mass range from 10 g or less for materials of low impact resistance, to 1 kg or higher for materials of high impact resistance.

7.4 *Micrometer*, for measurement of specimen thickness. It should be accurate to within 1 % of the average thickness of the specimens being tested. See Test Methods D5947 for descriptions of suitable micrometers.

7.5 The mass of the tup head and shaft assembly and the additional mass required must be known to within an accuracy of 61 %.

8. Hazards

8.1 *Safety Precautions*:

8.1.1 Cushioning and shielding devices shall be provided to protect personnel and to avoid damage to the impinging surface of the tup. A tube or cage can contain the tup if it rebounds after striking a specimen.

8.1.2 When heavy weights are used, it is hazardous for an operator to attempt to catch a rebounding tup. Figure 2 of Test Method D2444 shows an effective mechanical "rebound catcher" employed in conjunction with a drop tube.

9. Sampling

9.1 Sample the material to meet the requirements of Section 14.

10. Test Specimens

10.1 Flat test specimens shall be large enough so that they can be clamped firmly if clamping is desirable. See Table 2 for the minimum size of specimen that can be used for each test geometry.

10.2 The thickness of any specimen in a sample shall not differ by more than 5 % from the average specimen thickness of that sample. However, if variations greater than 5 % are unavoidable in a sample that is obtained from parts, the data shall not be used for referee purposes. For compliance with ISO 6603-1 the test specimen shall be 60 6 2 mm (2.4 6 0.08 in.) in diameter or 60 6 2 mm (2.4 6 0.08 in.) square with a thickness of 2 6 0.1 mm (0.08 6 0.004 in.). Machining specimens to reduce thickness variation is not permissible.

10.3 When the approximate mean failure mass for a given sample is known, 20 specimens will usually yield sufficiently precise results. If the approximate mean failure mass is unknown, six or more additional specimens should be used to determine the appropriate starting point of the test. For compliance with ISO 6603-1 a minimum of 30 specimens must be tested.

10.4 Carefully examine the specimen visually to ensure that samples are free of cracks or other obvious imperfections or damages, unless these imperfections constitute variables under study. Samples known to be defective should not be tested for specification purposes. Production parts, however, should be tested in the as-received condition to determine conformance to specified standards.

10.5 Select a suitable method for making the specimen that will not affect the impact resistance of the material.

10.6 Specimens range from having flat smooth surfaces on both sides, being textured on one side and smooth on the other side, or be textured on both surfaces. When testing, special attention must be paid to how the specimen is positioned on the support.

NOTE 4—As few as ten specimens often yield sufficiently reliable estimates of the mean-failure mass. However, in such cases the estimated standard deviation will be relatively large (**1**).

11. Conditioning

11.1 Unless otherwise specified, by contract or relevant ASTM material specification, condition the test specimens in accordance with Procedure A of Practice D618, for those tests where conditioning is required. Temperature and humidity tolerances shall be in accordance with Section 7 of Practice D618, unless otherwise specified by contract or relevant ASTM material specification. For compliance with ISO requirements, the specimens must be conditioned for a minimum of 16 h prior to testing or post conditioning in accordance with ISO 291, unless the period of conditioning is stated in the relevant ISO specification for the material.

11.1.1 Note that for some hygroscopic materials, such as polyamides, the material specifications (for example, Classification System D6779) call for testing "dry as-molded specimens". Such requirements take precedence over the above routine preconditioning to 50 % RH and require sealing the specimens in water vapor-impermeable containers as soon as molded and not removing them until ready for testing.

11.2 Conduct 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 relevant ASTM material specification.

11.3 When testing is desired at temperatures other than 23°C, transfer the materials to the desired test temperature within 30 min, preferably immediately, after completion of the preconditioning. Hold the specimens at the test temperature for no more than 5 h prior to test, and, in no case, for less than the time required to ensure thermal equilibrium in accordance with Section 10 of Test Method D618.

12. Procedure

12.1 Determine the number of specimens for each sample to be tested, as specified in 10.3.

12.2 Mark the specimens and condition as specified in 11.1.

12.3 Prepare the test apparatus for the geometry (FA, FB, FC, FD, FE) selected.

12.4 Measure and record the thickness of each specimen in the area of impact. In the case of injection molded specimens, it is not necessary to measure each specimen. It is sufficient to measure and record thickness for one specimen when it has been previously demonstrated that the thickness does not vary by more than 5 %.

12.5 Choose a specimen at random from the sample.

12.6 Clamp or position the specimen. The same surface or area should be the target each time (see 6.2). When clamping is employed, the force should be sufficient to prevent motion of the clamped portion of the specimen when the tup strikes.

12.7 Unless otherwise specified, initially position the tup 0.660 ± 0.008 m (26.0 ± 0.3 in.) from the surface of the specimen.

12.8 Adjust the total mass of the tup or the height of the tup, or both, to that amount expected to cause half the specimens to fail.

NOTE 5—If failures cannot be produced with the maximum available missile mass, the drop height can be increased. The test temperature could be reduced by (*a*) use of an ice-water mixture, or (*b*) by air-conditioned environment to provide one of the temperatures given in 3.3 of Test Methods D618. Conversely, if the unloaded tup causes failures when dropped 0.660 m, the drop height can be decreased. A moderate change in dart velocity will not usually affect the mean-failure energy appreciably. Refer to 5.1.

12.9 Release the tup. Be sure that it hits the center of the specimen. If the tup bounces, catch it to prevent multiple impact damage to the specimen's surface (see 8.1.2).

12.10 Remove the specimen and examine it to determine whether or not it has failed. Permanent deformation alone is not considered failure, but note the extent of such deformation (depth, area). For some polymers, for example, glass-reinforced polyester, incipient cracking is difficult to determine with the naked eye. Exposure of the stressed surface to a penetrating dye, such as gentian violet, confirms the onset of cracking. As a result of the wide range of failure types observed with different materials, the definition of failure defined in the material specification, or a definition agreed upon by supplier and user, shall take precedence over the definition stated in 3.2.1.

12.11 If the first specimen fails, remove one increment of mass from the tup while keeping the drop height constant, or decrease the drop height while keeping the mass constant (see 12.12). If the first specimen does not fail, add one increment of mass to the tup or increase the drop height one increment, as above. Then test the second specimen.

12.12 In this manner, select the impact height or mass for each test from the results observed with the specimen just previously tested. Test each specimen only once.

12.13 For best results, the mass or height increment used should be approximately equivalent to *s*, the estimated standard deviation of the test for that sample. An increment of 0.5 to 2 times *s* is satisfactory (see section 13.4).

NOTE 6—An increment of 10 % of the estimated mean-failure mass or mean-failure height has been found to be acceptable in most instances.

12.14 Keep a running plot of the data, as shown in Appendix X1. Use one symbol, such as *X*, to indicate a failure and a different symbol, such as *O*, to indicate a non-failure at each mass or height level.

12.15 For any specimen that gives a break behavior that appears to be an outlier, the conditions of that impact shall be examined. The specimen shall be discarded only if a unique cause for the anomaly can be found, such as an internal flaw visible in the broken specimen. Note that break behavior can vary widely within a set of specimens. Data from specimens that show atypical behavior shall not be discarded simply on the basis of such behavior.

13. Calculation

13.1 *Mean-Failure Mass*—If a constant-height procedure was used, calculate the mean-failure mass from the test data obtained, as follows:

$$w = w_o + d_w\,(A/N \pm 0.5) \qquad (1)$$

13.2 *Mean-Failure Height*—If a constant-mass procedure was used, calculate the mean-failure height from the test data obtained, as follows:

$$h = h_o + d_h\,(A/N \pm 0.5) \qquad (2)$$

where:

w = mean-failure mass, kg,
h = mean-failure height, mm,
d_w = increment of tup weight, kg,
d_h = increment of tup height, mm,
N = total number of failures or non-failures, whichever is smaller. For ease of notation, call whichever are used events,
w_o = smallest mass at which an event occurred, kg
h_o = lowest height at which an event occurred, mm (or in.),

A = $\sum_{i=0}^{k} in_i$,
i = 0, 1, 2... k (counting index, starts at h_o or w_o),
n_i = number of events that occurred at h_i or w_i,
w_i = $w_o + id_w$, and
h_i = $h_o + id_h$.

In calculating w or h, the negative sign is used when the events are failures. The positive sign is used when the events are non-failures. Refer to the example in Appendix X1.

13.3 *Mean-Failure Energy*—Compute the mean-failure energy as follows: MFE = hwf

where:

MFE = mean-failure energy, J,
h = mean-failure height or constant height as applicable, mm
w = mean-failure mass or constant mass as applicable, kg, and
f = factor for conversion to joules.
Use f = 9.80665×10^{-3} if h = mm and w = kg.

13.4 *Estimated Standard Deviation of the Sample*—If desired for record purposes, the estimated standard deviation of the sample for either variable mass or variable height can be calculated as follows:

$$s_w = 1.62d_w[B/N — (A/N)^2] + 0.047d_w \textit{ or} \qquad (3)$$

$$s_h = 1.62d_h[B/N — (A/N)^2] + 0.047d_h \qquad (4)$$

where:

s_w = estimated standard deviation, mass, kg
s_h = estimated standard deviation, height, mm, and

$$B = \sum_{i=0}^{k} i^2 n_i \quad (5)$$

The above calculation is valid for $[B/N - (A/N)^2] > 0.3$. If the value is <0.3, use Table I from Ref **(3)**.

13.5 *Estimated Standard Deviation of the Sample Mean*—Calculate the estimated standard deviation of the sample mean-failure height or weight as follows:

$$S_{\bar{w}} = G s_w / \sqrt{N} \quad (6)$$

or

$$S_{\bar{h}} = G s_h / \sqrt{N} \quad (7)$$

where:

$s_{\bar{h}}$ = estimated standard deviation of the mean height, mm,
$s_{\bar{w}}$ = estimated standard deviation of the mean mass, kg, and
G = factor that is a function of s/d (see Appendix X2).

A sample computation of s_w is found in Appendix X1.

NOTE 7—For values of G at other levels of s/d, see Fig. 22 in Ref **(4)**.

13.6 *Estimated Standard Deviation of the Mean-Failure Energy*—Calculate the estimated standard deviation of the mean-failure energy as follows:

$$S_{MFE} = s_{\bar{h}}\, w f \quad (8)$$

or

$$S_{MFE} = S_{\bar{w}}\, h f\text{, as applicable} \quad (9)$$

where:

S_{MFE} = estimated standard deviation of the mean-failure energy.

14. Report

14.1 Report the following information:

14.1.1 Complete identification of the sample tested, including type of material, source, manufacturer's code, form, principal dimensions, and previous history,

14.1.2 Method of preparation of specimens,

14.1.3 Whether surface of the specimen is smooth or textured, the level of and type of texture if known, and whether texture is on only one or both surfaces,

14.1.4 If the specimen is textured, report whether textured surface faces upward towards the dart or downward away from the dart,

14.1.5 Means of clamping, if any,

14.1.6 Statement of geometry (FA, FB, FC, FD, FE) and procedure used—constant mass or constant height,

14.1.7 Thickness of specimens tested (average and range).

14.1.8 Number of test specimens employed to determine the mean failure height or mass,

14.1.9 Mean-failure energy,

14.1.10 Types of failure, for example: (*a*) crack or cracks on one surface only (the plaque could still hold water), (*b*) cracks that penetrate the entire thickness (water would probably penetrate through the plaque), (*c*) brittle shatter (the plaque is in several pieces after impact), or (*d*) ductile failure (the plaque is penetrated by a blunt tear). Report other observed deformation due to impact, whether the specimens fail or not,

TABLE 3 Precision, Method FB

Material	Mean, *J*	Values Expressed as Percent of the Mean	
		V_r	*r*
Poly methyl Methacrylate (PMMA)	0.35	12.6	35.7
Styrene–Butadiene (SB)[A]	9.26	18.7	52.9
Acrylonitrile–Butadiene–Styrene (ABS)[A]	11.8	14.9	42.2

[A] Data generated in three laboratories.
V_r = within-laboratory coefficient of variation of the mean.
$r = 2.83\ V_r$.

14.1.11 If atypical deformation for any specimen within a sample for that material is observed, note the assignable cause, if known,

14.1.12 Date of test and operator's identification,

14.1.13 Test temperature,

14.1.14 In no case shall results obtained with arbitrary geometries differing from those contained in these test methods be reported as values obtained by this test method (D5628), and

14.1.15 The test method number and published/revision date.

15. Precision and Bias

15.1 Tables 3 and 4 are based on a round robin[5] conducted in 1972 involving three materials tested by six laboratories. Data from only four laboratories were used in calculating the values in these tables. Each test result was the mean of multiple individual determinations (Bruceton Staircase Procedure). Each laboratory obtained one test result for a material.

NOTE 8—The number of laboratories participating in the 1972 round robin and the number of results collected do not meet the minimum requirements of Practice E691. Data in Tables 3 and 4 should be used only for guidance, and not as a referee when there is a dispute between users of this test method.

15.1.1 *Polymethylmethacrylate (PMMA)*—Specimens were cut from samples of 3.18-mm (0.125-in.) thickness extruded sheet.

15.1.2 *Styrene-Butadiene (SB)*—Specimens were cut from samples of 2.54-mm (0.100-in.) thickness extruded sheet.

15.1.3 *Acrylonitrile-Butadiene-Styrene (ABS)*—Specimens were cut from samples of 2.64-mm (0.104-in.) thickness extruded sheet. (**Warning—**The following explanations of *r* and *R* (15.2-15.2.3) are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Tables 3 and 4 should not be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and not necessarily representative of other lots, conditions, materials, or laboratories. Users of this test method should apply the principles outlined in Practice E691 to generate data specific to their laboratory and materials, or between specific laboratories. The principles of 15.2-15.2.3 would then be valid for such data.)

15.2 *Concept of r and R*—If V_r and V_R have been calculated from a large enough body of data, and for test results that were

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[5] Supporting data are available from ASTM Headquarters. Request RR:D20-1030.

TABLE 4 Precision, Method FC

Material	Mean, J	Values Expressed as Percent of the Mean	
		V_r	r
Polymethyl Methacrylate (PMMA)	1.33	4.13	11.7
Styrene–Butadiene (SB)	48.3	18.3	51.8

V_r = within-laboratory coefficient of variation of the mean.
$r = 2.83\ V_r$.

means from testing multiple individual specimens (Bruceton Staircase Procedure), the following applies:

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

15.2.2 *Reproducibility, R*—In comparing two test results for the same material obtained by different operators using different equipment in different laboratories, reproducibility statistics were not calculated because data from only four and three laboratories do not justify making these calculations.

15.2.3 Any judgment in accordance with 15.2.1 would have an approximate 95 % (0.95) probability of being correct.

15.3 *Bias*—There are no recognized standards by which to estimate bias of this test method.

15.4 Efforts to form a task group to address between laboratory reproducibility of this test method has been unsuccessful. Persons interested in participating in such a task group should contact ASTM Headquarters.

16. Keywords

16.1 dart impact; falling-mass impact; impact; impact resistance; mean-failure energy; mean-failure height; mean-failure mass; rigid plastic; tup

APPENDIX

(Nonmandatory Information)

X1. SAMPLE CALCULATIONS

X1.1 See below.

Total Dart Mass, kg	Outcome of Test (X = failure; O = non-failure)																				n_x	n_o	i	n_i	in_1	i^2n_1
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20						
9.00						X															1	0	2	1	2	4
8.00					O		X		X				X		X						4	1	1	4	4	4
7.00		X		O				O		X		O		O		X		X		O	4	5	0	4	0	0
6.00	O		O								O						O		O		0	5				
																				Totals	9 (N_g)	11 (N_o)		9 (N)	6 (A)	8 (B)

w_o = 7.00; $N = N_x = 9$; d =1.00
w = $w_o + d(A/N - 0.5)$
= 7.00 + 1.00 (6/9 − 0.5)
= 7.17 kg
s = $1.620\ d[((NB - A^2)/9^2) + 0.029]$
= $1.620\ (1.00)[((9.8 - 6^2)/9^2) + 0.029]$
0.77 kg
s/d = 0.77/1.00 = 0.77; G = 1.035 (from Table X1.1)
s_w = $Gs/\sqrt{N} = 1.035\ (0.77)/\sqrt{9} = 0.27$ kg

TABLE X1.1 Values of G for Obtaining the Estimated Standard Deviation of the Mean

s/d	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.40						1.18	1.175	1.17	1.16	1.155
0.50	1.15	1.145	1.14	1.135	1.13	1.125	1.12	1.11	1.105	1.10
0.60	1.095	1.09	1.085	1.08	1.075	1.07	1.07	1.065	1.06	1.06
0.70	1.055	1.055	1.05	1.05	1.045	1.04	1.04	1.035	1.035	1.03
0.80	1.03	1.025	1.025	1.02	1.02	1.02	1.015	1.015	1.015	1.01
0.90	1.01	1.01	1.005	1.005	1.005	1.00	1.00	1.00	0.995	0.995
1.00	0.995	0.99	0.99	0.99	0.985	0.985	0.985	0.985	0.98	0.98
1.10	0.98	0.98	0.98	0.975	0.975	0.975	0.975	0.975	0.975	0.97
1.20	0.97	0.97	0.97	0.97	0.97	0.97	0.965	0.965	0.965	0.965
1.30	0.965	0.965	0.965	0.965	0.96	0.96	0.96	0.96	0.96	0.96
1.40	0.96	0.96	0.96	0.955	0.955	0.955	0.955	0.955	0.955	0.955
1.50	0.955	0.955	0.955	0.95	0.95	0.95	0.95	0.95	0.95	0.95
1.60	0.95	0.95	0.95	0.95	0.945	0.945	0.945	0.945	0.945	0.945
1.70	0.945	0.945	0.945	0.945	0.945	0.945	0.94	0.94	0.94	0.94
1.80	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.935
1.90	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935
2.00	0.935	0.935	0.935	0.93	0.93	0.93	0.93	0.93	0.93	0.93

REFERENCES

(1) Brownlee, K. A., Hodgest, J. L., Jr., and Rosenblatt, Murray, "The Up-and-Down Method with Small Samples," *American Statistical Association Journal*, Vol 48, 1953, pp. 262–277.

(2) Hagan, R. S., Schmitz, J. V., and Davis, D. A., "Impact Testing of High Impact Thermoplastic Sheet," *Technical Papers, 17th Annual Technical Conference of SPE, SPPPB*, Vol VIII, January 1961.

(3) "Test Method A—Falling Dart Impact, Proposed Method of Test for Impact Resistance of Fabricated Plastics Parts," *Proposed Test Methods for Plastics Parts Used in Appliances*, the Society of the Plastics Industry, New York, NY, January 1965.

(4) Weaver, O. R., "Using Attributes to Measure a Continuous Variable in Impact Testing Plastic Bottles," *Materials Research and Standards, MR & S*, Vol 6, No. 6, June 1966, pp. 285–291.

(5) Natrella, M. G., *Experimental Statistics*, National Bureau of Standards Handbook 91, October 1966, pp. 10–22 and 10–23.

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D5628 - 07) that may impact the use of this standard. (July 1, 2010)

(1) Revised 11.1 and 11.2 for consistency with Practice D618.

(2) Revised 12.4 to allow measurement of only one specimen for injection molded specimens.

ANEXO 2

Designation: D2240 – 15

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 U.S. 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 (Withdrawn 2013)[3]
D618 Practice for Conditioning Plastics for Testing
D785 Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials
D1349 Practice for Rubber—Standard Conditions 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:*[4]

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.

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[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 Aug. 1, 2015. Published January 2016. Originally approved in 1964. Last previous edition approved in 2010 as D2240 – 05 (2010). DOI: 10.1520/D2240-15.

[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.

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

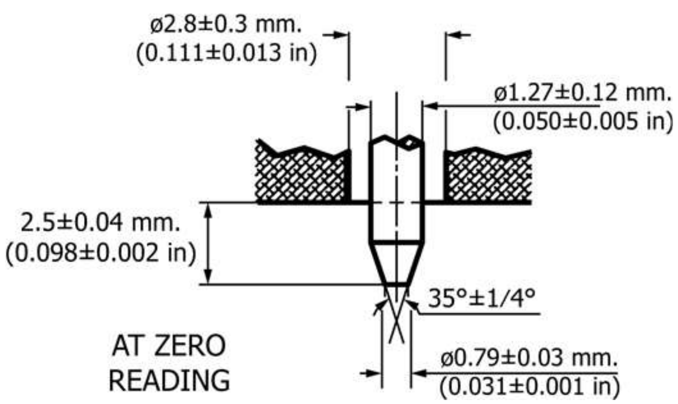


FIG. 1 (a) Type A and C Indentor

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 foot 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 foot 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 foot 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.).

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:

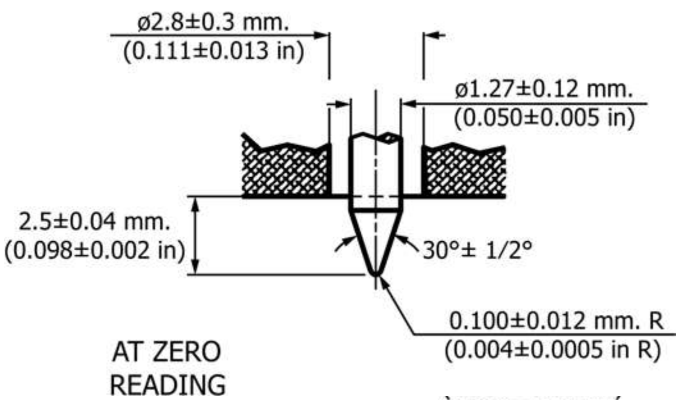


FIG. 1 (b) Type B and D Indentor *(continued)*

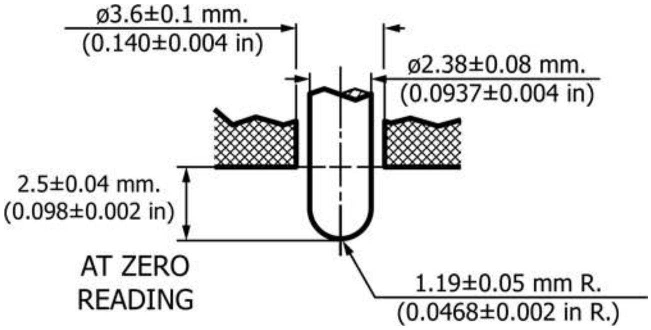


FIG. 1 (c) Type O, DO, and OO Indentor *(continued)*

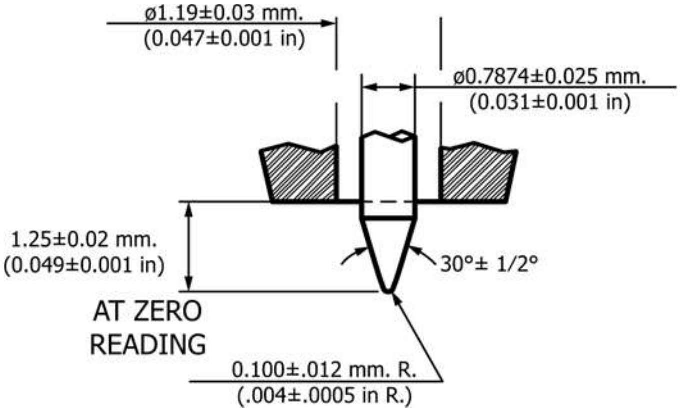


FIG. 1 (d) Type M Indentor *(continued)*

(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

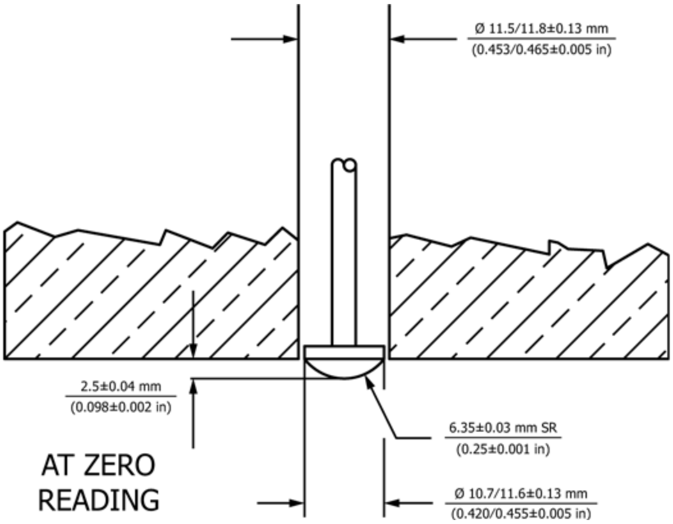


FIG. 1 (e) Type OOO Indentor *(continued)*

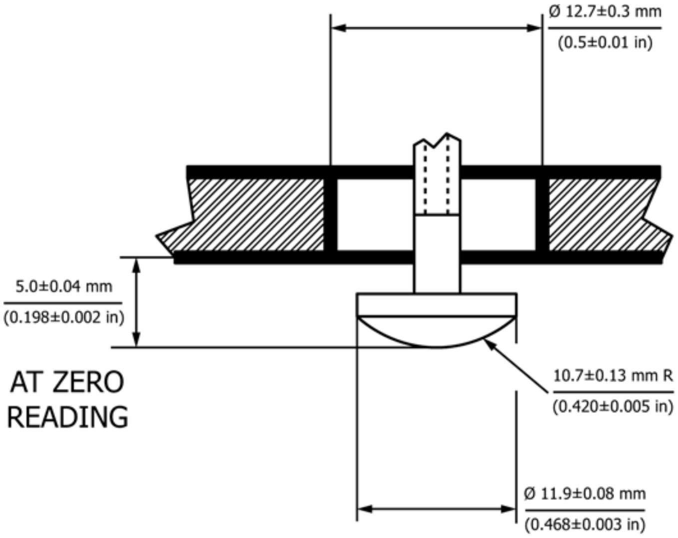


FIG. 1 (f) Type OOO-S Indentor *(continued)*

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 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

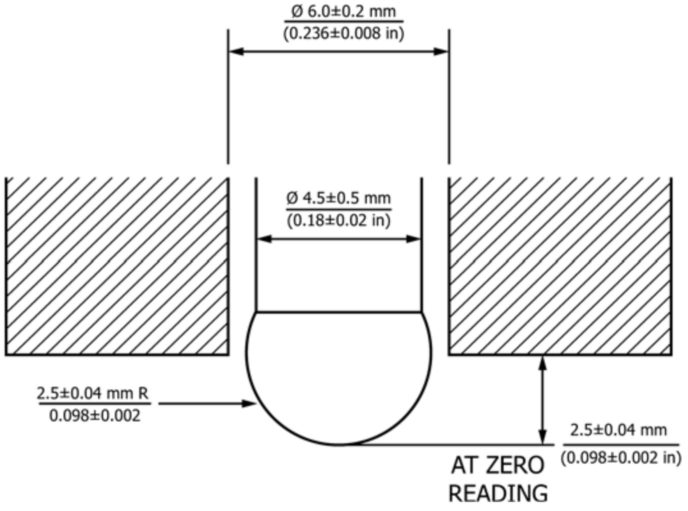


FIG. 1 (g) Type E Indentor *(continued)*

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

Indicated Value	Type A, B, E, O	Type C, D, DO	Type M	Type OO, OOO	Type OOO-S
0	0.55	0	0.324	0.203	0.167
10	1.3	4.445	0.368	0.294	0.343
20	2.05	8.89	0.412	0.385	0.520
30	2.8	13.335	0.456	0.476	0.696
40	3.55	17.78	0.5	0.566	0.873
50	4.3	22.225	0.544	0.657	1.049
60	5.05	26.67	0.589	0.748	1.226
70	5.8	31.115	0.633	0.839	1.402
80	6.55	35.56	0.677	0.93	1.579
90	7.3	40.005	0.721	1.02	1.755
100	8.05	44.45	0.765	1.111	1.932
N/durometer unit	0.075	0.4445	0.0044	0.00908	0.01765
Spring Calibration Tolerance	± 0.075 N	± 0.4445 N	± 0.0176 N	± 0.0182 N	± 0.0353 N

[A] Refer to 5.1.1.3 for the Type *xR* designation.

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.

5.1.2.3 *Operating Stand, Type 2* (indentor to specimen type), shall be capable of applying the indentor to the specimen in a manner that minimizes shock.

5.1.2.4 *Operating Stand, Type 3* (indentor to specimen type), hydraulic dampening, pneumatic dampening, or electro-mechanical (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 specimen, 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.

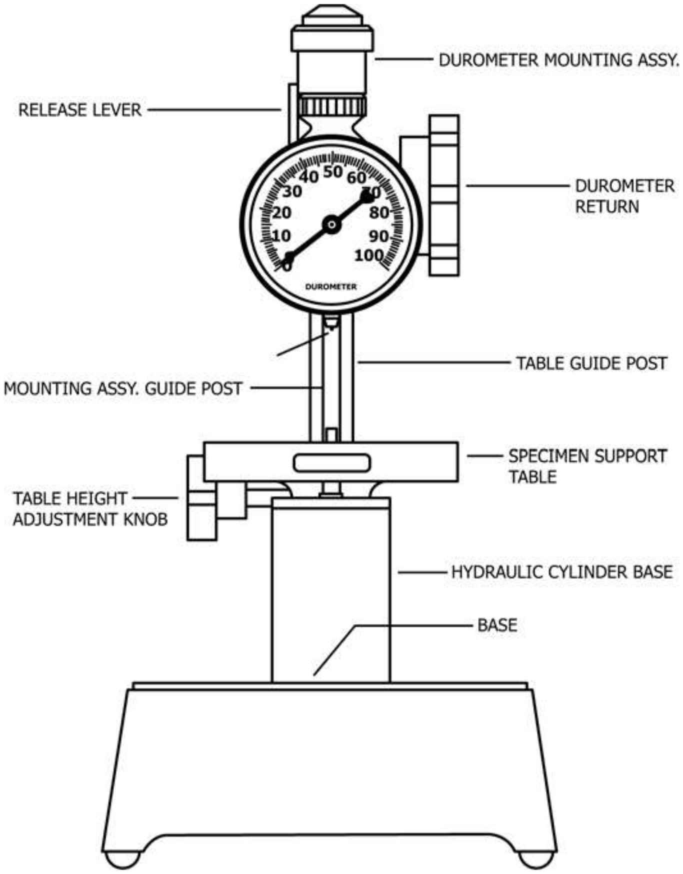


FIG. 2 Durometer Operating Stand

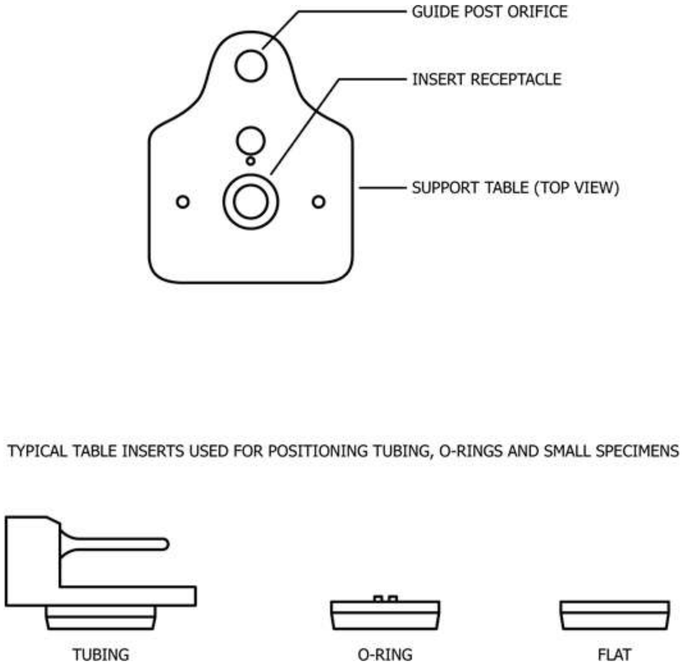


FIG. 3 Small Specimen Support Table

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 the indentor point. The specimen shall be suitably supported to

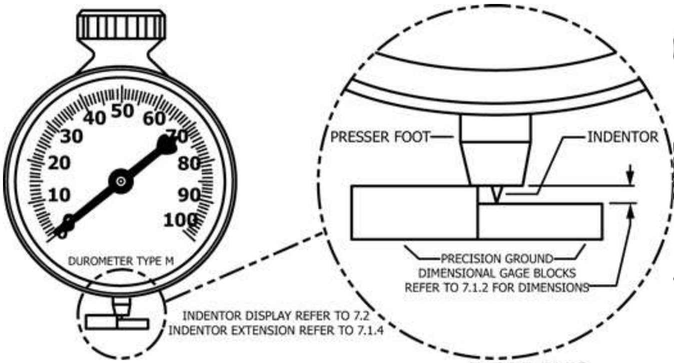
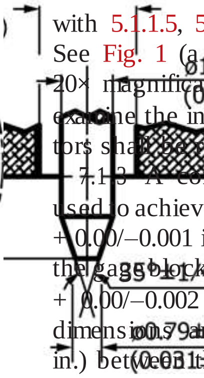


FIG. 4 Detail of Indentor Extension and Display Adjustment



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

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 mm + 0.0/–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 (0.198 ± 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:

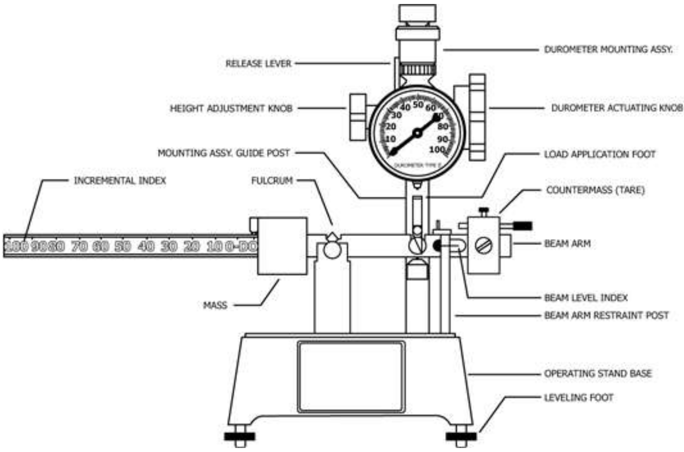


FIG. 5 Example of Durometer Calibration Apparatus

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 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 indentor for the entire range of the instrument, although it is necessary only to verify the spring calibration at points listed herein.

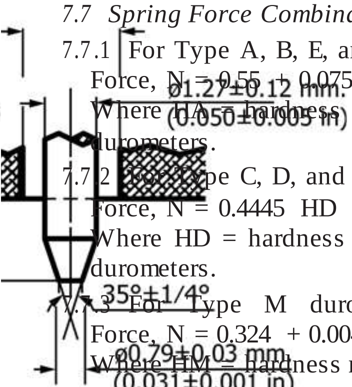
7.5 *Spring Calibration Procedure:*

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 indentor 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).

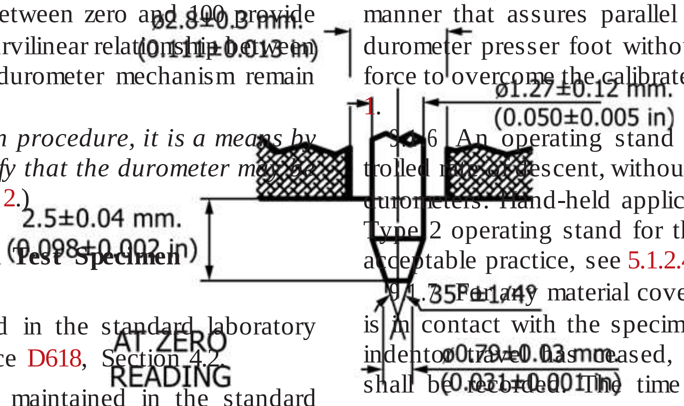
7.9.2.2 When performing the verification of 100, as described in 7.9.2, the non-metallic material shall be of a hardness value greater than 100 of the type (scale) of the durometer being employed. Tempered glass of a thickness greater than 6.35 mm (0.25 in.) has been found satisfactory for this application.

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 3 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 ± 0.3 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	MEAN	Within Laboratories Sr[A]	r[B]	(r)[C]	Between Laboratories SR[D]	R[E]	(R)[F]
1	31.8	1.26	3.58	11.24	3.76	10.63	33.41
2	40.8	1.14	3.23	7.90	2.47	7.00	17.13
3	54.0	0.975	2.76	5.11	2.38	6.73	12.46
4	62.8	0.782	2.21	3.52	2.24	6.34	10.10
5	70.9	0.709	2.01	2.83	0.974	2.76	3.89
6	80.6	1.686	4.77	5.92	1.61	4.56	5.65
7	87.7	1.15	3.25	3.71	2.63	7.45	8.50
8	32.4	0.947	2.68	8.26	3.64	10.29	31.73
9	41.8	0.797	2.26	5.40	2.23	6.31	15.11
10	53.3	0.669	1.89	3.55	2.29	6.49	12.17
11	63.2	0.485	1.37	2.17	2.19	6.20	9.80
12	69.6	0.737	2.09	3.00	0.99	2.80	4.02
13	78.3	0.784	2.22	2.84	1.04	2.94	3.75
14	87.6	1.121	3.17	3.62	2.65	7.49	8.55
15	34.1	0.85	2.40	7.05	1.84	5.20	15.25
16	42.3	0.635	1.80	4.25	1.20	3.39	8.01
17	54.6	0.56	1.59	2.90	2.15	6.09	11.15
18	62.9	1.12	3.17	5.04	1.47	4.16	6.61
19	70.3	0.689	1.95	2.77	0.944	2.67	3.80
20	81.7	0.483	1.37	1.67	1.10	3.10	3.80
21	87.9	0.879	2.49	2.83	2.07	5.86	6.67
AVERAGE	61.4						
POOLED VALUES		0.924	2.62	4.26	2.146	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 Sr[A]	r[B]	(r)[C]	Between Laboratories SR[D]	R[E]	(R)[F]
1	51.4	0.646	1.83	3.56	1.56	4.41	8.59
2	65.3	0.878	2.48	3.81	2.21	6.06	9.27
3	68.0	0.433	1.23	1.80	2.28	6.45	9.49
Pooled	61.6	0.677	1.92	3.11	2.018	5.72	9.28

[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 Sr[A]	r[B]	(r)[C]	Between Laboratories SR[D]	R[E]	(R)[F]
1	42.6	0.316	0.894	2.10	2.82	7.98	18.7
2	54.5	0.791	2.24	4.11	3.54	10.0	18.4
3	82.3	1.01	2.86	3.47	3.54	10.0	12.2
Pooled	59.8	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 indentor 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 indentor. 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 indentor), Type 2 operating stand (indentor to specimen type), or Type 3 operating stand (electromechanical or hydraulically dampened).

10.2.6 Description of test specimen, including thickness, number of pieces plied 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,[5] Table 3 shows the precision results for Type A method,[6] and Table 4 gives the precision results for Type D method.[6]

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 3—A Type 1 precision statement for Types E, 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

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[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D11-1091.

[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D11-1029.

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.

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.

TABLE X1.1 Durometer Selection: Typical Uses

Type (Scale)	Typical Examples of Materials Tested	Durometer Hardness (Typical Uses)
A	Soft vulcanized rubber, natural rubber, nitriles, thermoplastic elastomers, flexible polyacrylics 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 90 B Below 20 D
D	Hard rubber, thermoplastic elastomers, harder plastics, and rigid thermoplastics	Above 90 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	20–85 A
O	Soft rubber, thermoplastic elastomers, very soft plastics and thermoplastics, medium-density textile windings	Below 20 DO
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

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 3

Designation: G195 – 13a

Standard Guide for
Conducting Wear Tests Using a Rotary Platform Abraser[1]

This standard is issued under the fixed designation G195; 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 guide covers and is intended to assist in establishing procedures for conducting wear tests of rigid or flexible materials utilizing the rotary platform abraser.

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

1.2.1 *Exception*—Inch-pound units are used when stating rotational speed and determining coating thickness.

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.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C501 Test Method for Relative Resistance to Wear of Unglazed Ceramic Tile by the Taber Abraser
C1353 Test Method for Abrasion Resistance of Dimension Stone Subjected to Foot Traffic Using a Rotary Platform, Double-Head Abraser
D1044 Test Method for Resistance of Transparent Plastics to Surface Abrasion
D3389 Test Method for Coated Fabrics Abrasion Resistance (Rotary Platform Abrader)
D3451 Guide for Testing Coating Powders and Powder Coatings
D3730 Guide for Testing High-Performance Interior Architectural Wall Coatings
D3884 Test Method for Abrasion Resistance of Textile Fabrics (Rotary Platform, Double-Head Method)
D4060 Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
D4685 Test Method for Pile Fabric Abrasion
D4712 Guide for Testing Industrial Water-Reducible Coatings
D5034 Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test)
D5035 Test Method for Breaking Force and Elongation of Textile Fabrics (Strip Method)
D5144 Guide for Use of Protective Coating Standards in Nuclear Power Plants
D5146 Guide to Testing Solvent-Borne Architectural Coatings
D5324 Guide for Testing Water-Borne Architectural Coatings
D6037 Test Methods for Dry Abrasion Mar Resistance of High Gloss Coatings
D7255 Test Method for Abrasion Resistance of Leather (Rotary Platform, Double-Head Method)
F362 Test Method for Determining the Erasability of Inked Ribbons
F510 Test Method for Resistance to Abrasion of Resilient Floor Coverings Using an Abrader with a Grit Feed Method
F1344 Specification for Rubber Floor Tile
F1478 Test Method for Determination of Abrasion Resistance of Images Produced from Copiers and Printers (Taber Method)
F1978 Test Method for Measuring Abrasion Resistance of Metallic Thermal Spray Coatings by Using the Taber Abraser
G40 Terminology Relating to Wear and Erosion

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *abraser*—wear testing instrument to evaluate abrasion resistance, also referred to as an abrader.

3.1.2 *abrasion cycle*—in abrasion testing, one or more movements of the abradant across a material surface, or the material surface across the abradant, that permits a return to its starting position. In the case of the rotary platform abraser test method, it consists of one complete rotation of the turntable specimen platform.

3.1.3 *mil*—a U.S. term referring to the imperial unit of measure of one one-thousandth of an inch (0.001 in.) referred to elsewhere in the world as "one thou;" 1 mil = 25.4 microns.

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[1] This guide is under the jurisdiction of ASTM Committee G02 on Wear and Erosion and is the direct responsibility of Subcommittee G02.30 on Abrasive Wear.

Current edition approved Nov. 1, 2013. Published November 2013. Originally approved in 2008. Last previous edition approved in 2013 as G195–13. DOI: 10.1520/G0195-13A.

[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.

ANEXO 3

3.1.4 *resurface*—procedure of cleaning and refreshing the running surface of an abrasive wheel prior to use or during testing.

3.2 For definitions of other wear terms used in this guide, refer to Terminology G40.

4. Summary of Practice

4.1 A specimen is abraded using rotary rubbing action under controlled conditions of pressure and abrasive action. The test specimen, mounted on a turntable platform, turns on a vertical axis, against the sliding rotation of two abrading wheels. One abrading wheel rubs the specimen outward toward the periphery and the other, inward toward the center while a vacuum system removes wear debris generated during the test. The resulting abrasion marks form a pattern of crossed arcs over an area of approximately 30 cm^2. Resistance to abrasion is evaluated by various means which are described in Section 12.

5. Significance and Use

5.1 This test guide provides a means to quantify the abrasion resistance of material surfaces, and may be related to end-use performance, or used to comparatively rank material performance, or both. The resistance of material surfaces to abrasion, as measured on a testing machine in the laboratory, is generally only one of several factors contributing to wear performance as experienced in the actual use of the material. Other factors may need to be considered in any calculation of predicted life from specific abrasion data.

5.2 The resistance of material surfaces to abrasion may be affected by factors including test conditions; type of abradant; pressure between the specimen and abradant; mounting or tension of the specimen; and type, kind, or amount of finishing materials.

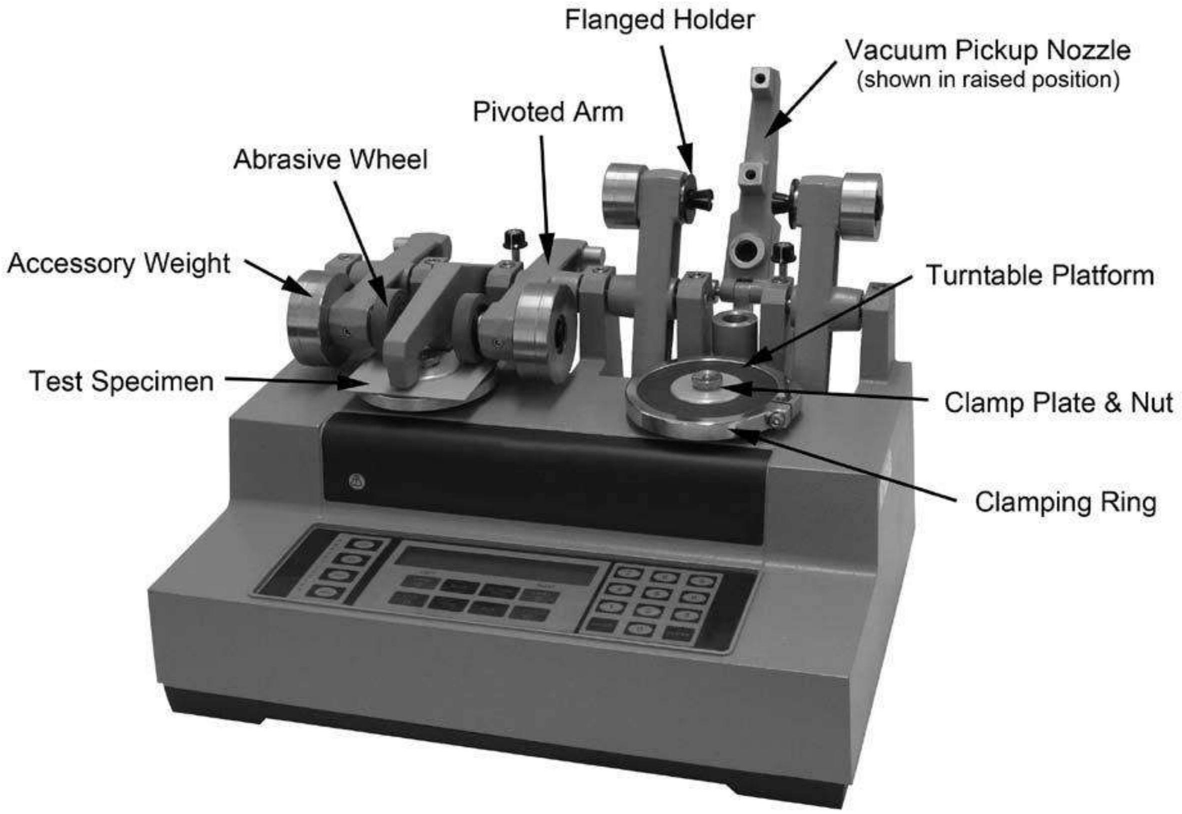
5.3 Abrasion tests utilizing the rotary platform abraser may be subject to variation due to changes in the abradant during the course of specific tests. Depending on abradant type and test specimen, the abrading wheel surface may change (that is, become clogged) due to the pick-up of finishing or other materials from test specimens. To reduce this variation, the abrading wheels should be resurfaced at regularly defined intervals. See Appendix X2.

5.4 The measurement of the relative amount of abrasion may be affected by the method of evaluation and influenced by the judgment of the operator.

6. Apparatus

6.1 *Rotary Platform Abraser,* consisting of the elements described in 6.1.1 to 6.1.5 (see Fig. 1). Also referred to as a rotary platform, double head (RPDH) abraser.

6.1.1 A turntable specimen platform, which is removable, that includes a rubber pad, clamp plate, centrally located



Note: Vacuum Suction System not shown

FIG. 1 Rotary Platform Abraser

threaded post and nut. When testing flexible specimens, the specimen platform will also include a clamping ring. The turntable shall be motor driven, and mounted so as to produce a circular surface travel of a flat specimen in the plane of its surface. The specimen platform should rotate with no visible wobble. This can be checked with a dial indicator at the top outer edge of the platform to make sure it runs true within 0.5 mm.

6.1.2 A motor capable of rotating the turntable platform at a speed of either 72 ± 2 rpm or 60 ± 2 rpm.

6.1.3 A pair of pivoted arms to which the abrasive wheels and accessory weights or counterweights are attached.

6.1.4 A vacuum suction system and vacuum pickup nozzle to remove debris and abrasive particles from the specimen surface during testing. The vacuum suction force shall be 13.7 kPa (139.7 cm of water column) or greater, as measured by a vacuum gauge at the vacuum pick-up nozzle port. The height of the vacuum pickup nozzle shall be adjustable, and the nozzle will have two 8 mm openings except in the case of D1044 when 11 mm openings are specified. One opening shall be positioned between the two wheels and over the wear path and the other placed diametrically opposite, with the distance between the axes of the two openings 76.0 ± 1.0 mm.

6.1.5 A counter to record the number of abrasion cycles (revolutions) made by the turntable platform.

6.2 *Abrasive Wheels,*[3] which are attached to the free end of the pivoted arms and are able to rotate freely about horizontal spindles.

6.2.1 The wheels shall be 12.7 ± 0.3 mm thick and have an external diameter of 51.9 ± 0.5 mm when new, and in no case less than 44.4 mm. The abrasive wheels are either resilient or vitrified based, with both types of wheels consisting of hard particles embedded in a binder material and manufactured in different grades of abrasive quality. Other types of wheels, which do not include hard particles embedded in a binder material, may also be used (see X1.4).

6.2.2 The internal faces of the abrasive wheels shall be 52.4 ± 1.0 mm apart and the hypothetical line through the two spindles shall be 19.05 ± 0.3 mm away from the central axis of the turntable (see Fig. 2). The wheels should be spaced equally on both sides from the wheel-mounting flange to the center of the specimen holder. The distance from the inside of the wheel mounting flange to the center of the specimen holder shall be 38.9 ± 0.5 mm.

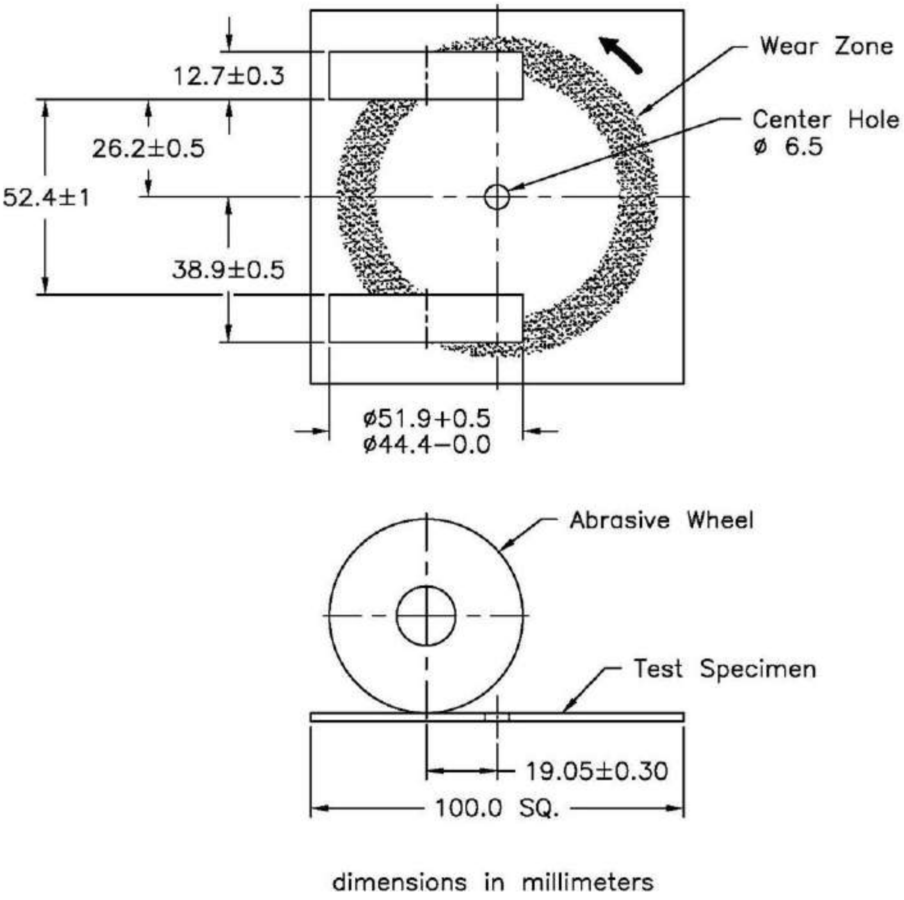


FIG. 2 Central Axis of the Turntable

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[3] The sole source of supply of the apparatus known to the committee at this time is Taber Industries, 455 Bryant Street, North Tonawanda, NY 14120. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

6.2.3 When resting on the specimen, the wheels will have a peripheral engagement with the surface of the specimen, the direction of travel of the periphery of the wheels and of the specimen at the contacting portions being at acute angles, and the angles of travel of one wheel periphery being opposite to that of the other. Motion of the abrasive wheels, in opposite directions, is provided by rotation of the specimen and the associated friction therefrom.

6.2.4 Prior to testing, ensure the expiration date has not passed for resilient wheels.

6.3 *Accessory Weights*, can be attached to the pivoted arms to increase or decrease the force at which the wheel is pressed against the specimen, exclusive of the mass of the wheel itself. Commonly used masses are 250 ± 1 g, 500 ± 1 g, and 1000 ± 1 g. Accessory weight references are per arm (not combined), and include the mass of the pivoted arm.

6.4 *Auxiliary Apparatus:*

6.4.1 Refacing disc, for resurfacing of resilient wheels. The refacing disc shall be 150 grit silicon carbide coated abrasive product, approximately 102 mm diameter with a 7-mm center hole, such as type S-11 or equivalent.

6.4.2 Refacing stone (for example, fine side of ST-11[3]), for resurfacing of CS-10F[3] resilient wheels when testing transparent materials.

6.4.3 Wheel refacer, with a diamond tool for resurfacing vitrified wheels or correcting out of round wheels.

6.4.4 A soft bristle brush, to remove loose particles from the surface of the specimen after testing.

6.4.5 Specimen mounting cards, approximately 108 mm round or square with a 7-mm center hole and one side coated with pressure sensitive adhesive to secure specimens.

7. Specimen Preparation

7.1 *Materials*—It is the intent of this test guide to allow for the abrasion testing of any material form, provided it is essentially flat. The field of application is varied and includes solid materials, metals, plastics, coated surfaces (for example, paint, lacquer, electroplated), textiles (ranging from sheer silks to heavy upholstery), leather, rubber, linoleum, and the rest.

7.1.1 Accepted industry practice should be employed for specimen preparation. Specific recommendations for specimen preparation may be available from the ASTM subcommittee responsible for that material. Selection and use should be agreed upon between the interested parties.

7.2 *Specimen Thickness*—The standard material thickness that can be evaluated with the rotary platform abraser is 6.35 mm or less.

NOTE 1—For materials thicker than 6.35 mm but less than 12.7 mm, an extension nut such as type S-21[3] or equivalent may be used. Alternatively, an arm height extension kit[3] will permit testing of specimens up to 40 mm.

7.3 *Specimen Size*—The width of the resulting wear path is 12.7 mm, and is located 31.75 mm from the center of the specimen. The size of the specimen may vary depending on the material being evaluated:

7.3.1 For most rigid materials, a sample approximately 100 mm square is recommended with a 6.5 mm diameter center hole.

7.3.2 Flexible specimens are typically circular and require the use of the clamp ring. If a mounting card is used, the specimen should be approximately 105 mm in diameter with a 6.5 mm diameter center hole. If no mounting card is used, an approximately 135 mm specimen is required such that the clamp ring will grip overlapped material. The specimen should include a 6.5 mm diameter hole in the center of the specimen. A sample cutter or die has been found useful for preparing flexible specimens.

7.4 *Mounting Card*—Certain flexible specimens may wrinkle or shift during testing. To prevent this, a mounting card with a pressure sensitive adhesive may be used. Prior to adhering, clean the back of the specimen with a soft bristle brush to remove any loose debris. Position the specimen on the card such that the specimen is free of folds, creases, or wrinkles and the center holes align.

8. Preparation and Set-Up of Apparatus

8.1 The following set-up parameters are dependent on the type of material being evaluated and shall be agreed upon by the interested parties. See Appendix X1 for guidance.

8.1.1 *Selection of Wheels*—Abrasive wheels manufactured in different grades are commercially available.[3]

8.1.2 *Vacuum Suction*—The vacuum suction force should be adjusted to lift the abraded particles, but not lift the specimen.

8.1.3 *Vacuum Pickup Nozzle*—The gap between the vacuum pickup nozzle and the specimen surface should be adjusted after the specimen has been mounted. A gap of 7 ± 1 mm has been found to be sufficient for most materials. On certain rigid materials, a setting of 3 ± 1 mm has been found to be more effective.

8.1.4 *Abrading Wheel Loading*—The mass selected should permit a minimum number of abrasion cycles (for example, 150) before the end of the test occurs. A mass of 500 g or 1000 g applied per wheel has been found to be sufficient for materials that are considered to be durable. A mass of 250 g or 500 g applied per wheel has been found to be sufficient for less durable materials.

9. Standardization of Abrasive Wheels

9.1 *Preparation of Resilient Abrading Wheels*—To ensure that the abrading function of the wheels is maintained at a constant level, prepare the resilient wheels according to the manufacturer's recommendations. See Appendix X2.

9.2 *Preparation of Vitrified Abrading Wheels*—Vitrified wheels do not require resurfacing unless the abrading surface becomes clogged, chipped, or out of round. A wheel refacer should be used to correct any of these conditions.

10. Conditioning

10.1 Prior to testing, condition all specimens according to established procedures specific to the material being evaluated or as agreed upon by the interested parties.

11. Procedure

11.1 Mount the wheels on their respective flanged holders, taking care not to handle them by their abrasive surfaces. Prior to testing, ensure that the wheels have been resurfaced according to Section 9 if necessary.

11.2 Depending on the type of evaluation criteria being utilized (see Section 12), it may be necessary to measure and record specific parameters of the unabraded specimen prior to conducting the test:

11.2.1 Mass loss method, weigh the specimen to the nearest mg. If using a mounting card, weigh after the specimen has been affixed to the card and conditioned in the standard testing environment.

11.2.2 Wear cycles per mil or depth of wear method, use a thickness gauge or other appropriate device to measure the specimen thickness on four points along the path to be abraded, approximately 38 mm from the center hole and 90° apart. Calculate the average of the readings.

11.3 *Mounting of Specimen*—Place the test specimen face up over the rubber mat on the turntable platform, unless otherwise specified. If the turntable platform was previously removed, ensure it is properly replaced on the motor drive shaft of the abraser prior to testing.

11.3.1 For rigid materials, secure the clamp plate and nut in place to hold the specimen.

11.3.2 For textile and other flexible materials, lightly secure the clamp plate and nut in place to hold the center of the specimen. Place the clamping ring over the turntable platform with the screw of the clamping ring at one end of the warp. Partially tighten the screw, and push the clamping ring half way down the edge of the turntable platform. Draw the specimen taut over the turntable platform by pulling on the corners and edges of the specimen. Tighten the clamping ring ¼ turn and push the ring all the way down, thus putting tension on the specimen as it is secured on holder. Finish tightening the nut and clamping ring. Avoid buckling the fabric when tightening. Trim off excess fabric around the edges. It is recommended not to remove the specimen from the specimen holder until the entire test is completed.

11.4 *Abrading Wheel Loading*—Select the mass to be used and affix it to the rotary platform abraser (see 8.1.4).

11.5 *Number of Abrasion Cycles*—The number of rotations of the turntable platform to which the specimen is to be subjected will depend on the type of material being tested, the type of abrading wheels used, the abrading wheel loading, and the type of test employed. The number of cycles should be predetermined by mutual agreement by the interested parties.

11.6 Lower the abrading heads carefully onto the surface of the specimen.

11.7 *Cleaning of Specimen*—The vacuum system is used to clean the specimen of debris and abrasive particles during the test. Position the nozzle above the specimen surface as determined in 8.1.3 and adjust the vacuum suction as outlined in 8.1.2. For some materials, it may be necessary to use a soft bristle brush to clean the specimen surface at set intervals during the test.

11.8 Start the rotary platform abraser and subject the test specimen to abrasion for the specified number of cycles as established in 11.5.

11.8.1 Depending on the type of evaluation criteria being utilized (see Section 12), the rate of wear may be calculated or plotted on a graph, or both. If required, take measurements periodically during testing with the frequency to be determined by the interested parties.

NOTE 2—In calculating Wear Index (see 12.3) or Wear Cycles Per Mil (see 12.4) of surface coatings and similar materials, it may be advisable to discard the final reading if results are affected by abrasion of the exposed substrate.

11.8.2 If cycles to a specific end point is used as the evaluation criteria (see 12.7), it may be necessary to stop the instrument at intervals during the test to examine the test specimen.

11.9 *Resurfacing of Wheels*—Due to uneven wear and clogging of the surface crevices with abraded debris (for example, fiber particles, finishing materials, and the like), the abrading wheels should be resurfaced at established intervals during tests, the frequency depending on the type of material being tested and the type of wheel used (see Appendix X2).

11.10 *Cleaning of Specimen After Test*—After the test is complete, a soft bristle brush may be used to remove any loose debris and abraded material remaining on the test specimen.

11.11 After testing, raise the abrader arms and vacuum nozzle then remove the specimen for evaluation. If desired, the turntable platform may be removed from the abraser by lifting straight up. This will permit a closer inspection of the specimen prior to removal from the turntable platform. Use a soft bristle brush or cloth to clean the rubber pad after each test.

12. Calculation or Interpretation of Results

NOTE 3—This guide does not recommend any specific interpretation of results but does provide procedures commonly used by industry.

12.1 After the specimens have been abraded to the set number of cycles or other specified endpoint, evaluate as directed in 12.2 – 12.10 as appropriate. If a mounting card was used and any evaluation technique described in 12.8 – 12.10 is employed, carefully remove the specimen from the mounting card.

12.2 *Mass Loss*—Change in mass caused by abrasion. Weigh the specimen after abrasion and compute mass loss, *L*, of the test specimen as follows:

$$L = A - B \tag{1}$$

where:

A = mass of test specimen before abrasion, mg, and
B = mass of test specimen after abrasion, mg.

12.3 *Wear Index*—Loss in mass in milligrams per thousand cycles of abrasion. Weigh the specimen after abrasion and compute the wear index, *I*, of a test specimen as follows:

$$I = \frac{(A - B)\,1000}{C} \tag{2}$$

where:

A = mass of test specimen before abrasion, mg,
B = mass of test specimen after abrasion, mg, and
C = number of cycles of abrasion recorded.

12.4 *Wear Cycles per mil (0.001 in.)*—Abrasion cycles required to wear through a coating of a known thickness. Compute the wear cycles per mil, *W*, of the test specimen as follows:

$$W = \frac{D}{T} \tag{3}$$

where:

D = number of cycles of abrasion required to wear coating through to substrate, and
T = thickness of coating, mils.

12.5 *Volume Loss*—In comparing the wear resistance of materials having different specific gravities, a correction for the specific gravity of each material should be applied to the mass loss to give a true measure of the comparative wear resistance. Calculate the wear index as shown in 12.3 and divide the result by the material's specific gravity. The use of this correction factor provides a wear index related to the loss in volume of the material to which it is applied. When comparing materials of different specific gravities, test parameters shall be the same including wheel selection and abrading wheel loading.

12.6 *Depth of Wear Method (Thickness)*—Repeat the measurements taken in 11.2.2 and record the difference. Calculate the average of the four readings. Alternatively, an instrument such as an optical micrometer may be used to measure the depth of wear.

12.7 *Cycles to a Specific End-Point*—The number of cycles required to reach a predetermined end point, or the appearance or condition of the specimen after a fixed number of cycles. The evaluation criteria may include: loss in breaking strength, yarn breakage, loss in coating, change in gloss, color loss, or other changes in appearance. In these cases, the abraded sample is usually compared to a known standard of the material tested. Aesthetic evaluations can be made using an agreed upon rating system such as a visual grading scale (for example, five-step) or pass/fail criteria.

12.8 *Residual Breaking Force*—The effective strength of the fabric or force required to break a specific width of fabric. If residual breaking force is required, calculate the individual breaking force of the individual abraded specimens and the unabraded specimens to the nearest 0.5 kg significant digits. Use Test Method D5034 and D5035, as appropriate, except that the distance between clamps shall be 25 mm and path of the abrasion on the abraded specimen is horizontally placed midway between the clamps of the machine.

12.9 *Average Breaking Strength*—If average breaking strength is required, calculate the average breaking strength of the abraded specimens and the unabraded specimens separately to the nearest 0.5 kg for the laboratory sampling unit and for the lot using the procedure described in 12.8.

12.10 *Percent Loss in Breaking Strength*—If percent breaking strength is required, calculate the percentage loss in breaking strength to the nearest 1 % of the abrasion resistance separately for each the lengthwise and widthwise directions using Eq 4, for the laboratory sampling unit and for the lot.

$$AR = \frac{100(A - B)}{A} \tag{4}$$

where:

AR = abrasion resistance, %,
A = average breaking force of the unabraded specimens, g (lb), and
B = average breaking force of the abraded specimen, g (lb).

13. Report

13.1 State that the specimens were tested as directed in Guide G195. Describe the product and the method used for sample collection.

13.2 Report the following information:

13.2.1 Temperature and humidity during conditioning and at time of testing.

13.2.2 Type of wheel used and manufacturing lot number.

13.2.3 Abrading wheel loading.

13.2.4 Vacuum suction level.

13.2.5 Height of vacuum pickup nozzle above specimen surface.

13.2.6 Specimen mounting card (only when used).

13.2.7 Evaluation criteria used to obtain failure or other end point, and results as determined in Section 12. If any other means of evaluating the effect of abrasion are used, describe evaluation criteria used to obtain failure or other end point.

13.3 Any deviation from the procedure described in this guide.

14. Keywords

14.1 abraser; abrasion; abrasion resistance; rotary platform; Taber; wear

APPENDIXES

(Nonmandatory Information)

X1. ABRADING WHEEL AND LOAD SELECTION

X1.1 Material specifications and test methods have been developed for many different types of specimens. If you are following a particular material specification, please refer to it for the appropriate wheel and load combination.

X1.2 The following information is intended to serve as a guideline only, when an abrasive wheel is not specified. Deciding which abrading wheel and load combination is appropriate for your application is best determined with preliminary testing on the actual material. The ideal outcome using this selection criterion is to reproduce the resulting wear that occurs in actual use. A correction factor may be necessary if there is no absolute fit between lab test results and field results. It is important to recognize that abrasive wheels represent a limited subset of actual contact conditions that material surfaces will be subjected to while in service.

X1.3 The following standardized abrasive wheels are commercially available:[3]

X1.3.1 *Resilient Wheels:*

CS-10F	Light abrasive action
CS-10	Medium abrasive action
CS-17	Medium to coarse abrasive action

X1.3.2 *Vitrified (Clay) Wheels:*

H-38	Light abrasive action (requires multi-point diamond tool for refacing)
H-10	Light to medium abrasive action
H-18	Medium abrasive action
H-22	Coarse abrasive action

X1.4 Specialty wheels may also be used for unique applications:

CS-0	Resilient material, containing no abrasive grain. Used when a very mild abrasive action is required. Alternatively, sandpaper strips (for example, S-33 or S-42) may be adhered to outer periphery for aggressive abrasive action.
CS-5	Densely, compacted wool felt. Suggested when the service wear of textile fabrics involves one fibrous material rubbing against another.
S-35	Tungsten Carbide with sharp, helical teeth cut in its periphery (25 per inch set at 45° spiral pitch). Intended for use on resilient materials only (for example, rubber, linoleum, and leather) when a cutting and tearing action / severe abrasion is required.
S-39	Leather strip adhered to a brass hub.

X1.5 *Abrading Wheel and Load Selection Chart*—See Table X1.1.

TABLE X1.1 Abrading Wheel and Load Selection Chart[A]

	Ref.	CS-10F	CS-10	CS-17	H-38	H-10	H-18	H-22	Mass (g) per Wheel	Vacuum Nozzle Gap
Carpet, Automotive	D3884		x						1000	7 ± 1 mm
Carpet, Broadloom	D3884				x		x	x	500 or 1000	7 ± 1 mm
Ceramic, Unglazed Tile	C501							x	1000	1⁄16 – 1⁄8 in.
Ceramic, Whitewares & related	C501							x	1000	1⁄16 – 1⁄8 in.
Coatings, High Gloss	D6037		x[B]						500	Not specified
Coatings, High Perf. Interior Architectural Wall (ref. D4060)	D3730		x	x					1000	6.5 mm (1⁄4 in.)
Coatings, Industrial Water-Reducible (ref. D4060)	D4712		x	x					1000	6.5 mm (1⁄4 in.)
Coatings, Metallic Thermal Spray	F1978							x	250	Not specified
Coatings, Organic	D4060		x	x					1000	6.5 mm (1⁄4 in.)
Coatings, Powder (ref. D4060)	D3451		x	x					1000	6.5 mm (1⁄4 in.)
Coatings, Protective (ref. D4060)	D5144		x	x					1000	6.5 mm (1⁄4 in.)
Coatings, Solvent-Borne Architectural (ref. D4060)	D5146		x	x					1000	6.5 mm (1⁄4 in.)
Coatings, Water-Borne Architectural (ref. D4060)	D5324		x	x					1000	6.5 mm (1⁄4 in.)
Dimension Stone	C1353							x	1000	1⁄16 – 1⁄8 in.
Inked Ribbons, Erasibility of	F362	x							500	Not specified
Leather, Dyed	D3884		x	x					500 or 1000	7 ± 1 mm
Leather, Durable	D3884						x	x	1000	7 ± 1 mm
Leather, Upholstery	D7255		x	x			x		1000[B]	7 ± 1 mm
Nonwovens	D3884					x			250	7 ± 1 mm
Plastic, Transparent	D1044	x							500	1⁄32 – 1⁄16 in.
Printing, Images Produced by Copiers and Printers	F1478	x							250	Not specified
Resilient Floor Coverings (w/Grit Feeder Attachment)	F510								1000	# 1⁄4 in.
Rubber Floor Tile (ref. D3389)	F1344						x		500	1⁄4 in.[B]
Textile Fabrics	D3884						x	x	1000	7 ± 1 mm
Textile Fabrics, Coated	D3389						x[B]		1000[B]	1⁄4 in.[B]
Textile Fabrics, Delicate	D3884		x		x				250 or 500	7 ± 1 mm
Textile Fabrics, Medium Wgt.	D3884		x	x					500 or 1000	7 ± 1 mm
Textile Fabrics, Automotive	D3884		x				x		1000	7 ± 1 mm
Textile Fabrics, Pile	D4685		x						250 or 500	6.35 mm
Upholstery	D3884				x		x	x	500 or 1000	7 ± 1 mm

[A] This table describes the results of using a particular test apparatus with a specific vendor's abrasive wheels. Users of this guide may find this information useful for comparison with their own conditions.

[B] Or other as agreed upon by interested parties.

X2. RESILIENT WHEEL REFACING PROCEDURE

X2.1 Mount the selected resilient wheels on their respective flange holders, taking care not to handle them by their abrasive surfaces. Adjust the mass on the abrading wheels to the load agreed upon between the interested parties for testing (see 8.1.4).

X2.2 Mount the refacing disc on the specimen platform and secure using the clamp plate and nut, and clamp ring. Lower the abrading heads until the wheels rest on the refacing disc. Place the vacuum pick-up nozzle in position and adjust it to the appropriate distance above the surface of the disc (see 8.1.3).

NOTE X2.1—When using CS-10F[3] wheels to evaluate transparent materials, resurface using the fine side of the ST-11[3] refacing stone in place of the refacing disc. No clamp plate or clamp ring is required.

X2.3 Set the counter to 'zero' and adjust the vacuum suction force to 100.

X2.4 Ensure the vacuum system is operating, and resurface the wheels by running them for the appropriate number of cycles against the refacing disc as shown in Table X2.1. Each refacing disc is good for one 25 or 50 cycle resurfacing operation, after which it shall be discarded.

X2.4.1 *New Set of Wheels (Break-In Procedure)*—Before placing a new set of resilient wheels in service they shall be subjected to two (2) resurfacings of 50 cycles to ensure perfect contact of the abrading faces with the specimen surface.

X2.4.2 *Starting a Test with Previously Used Wheels*—Before testing a specimen with previously used wheels, resurface on a new refacing disc. When the previous test was short in duration (<1000 cycles), resurfacing of 25 cycles is usually sufficient. When the previous test was 1000 cycles or more, a resurfacing of 50 cycles is recommended. Wheels that have not been used for an extended period of time may require a break-in resurfacing like a new set of wheels.

X2.4.3 *Resurfacing During Testing*—To maintain consistency and avoid clogging of wheel faces, the wheels may need to be resurfaced periodically during the test (see 5.3). For tests of 1000 cycles or more, resurfacing every 500 cycle interval has been found to be sufficient for most materials. Remove the specimen and resurface the wheels for 50 cycles with a new refacing disc. The sample should be carefully replaced on the specimen holder after resurfacing of the wheels. To prevent the integrity of the test from being jeopardized when removing and replacing flexible samples, specimens may be affixed to a mounting card.

NOTE X2.2—To determine if more frequent resurfacing is required, plot the total mass loss every 50 cycles. If a significant negative change in slope is observed prior to 500 cycles, the point at which the slope changes determines the resurfacing frequency.

TABLE X2.1 Preparation of Abrasive Wheels

Wheel Status	Resurfacing Cycles
New	2 resurfacings of 50 cycles
Used	25 or 50 cycles
During Test	50 cycles

ANEXO 4

Designation: D3418 − 12$^{\varepsilon1}$

Standard Test Method for
Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry[1]

This standard is issued under the fixed designation D3418; 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—Editorially corrected Figure 2 in December 2012.

1. Scope*

1.1 This test method covers determination of transition temperatures and enthalpies of fusion and crystallization of polymers by differential scanning calorimetry.

NOTE 1—True heats of fusion are to be determined in conjunction with structure investigation, and frequently, specialized crystallization techniques are needed.

1.2 This test method is applicable to polymers in granular form or to any fabricated shape from which it is possible to cut appropriate specimens.

1.3 The normal operating temperature range is from the cryogenic region to 600°C. Certain equipment allows the temperature range to be extended.

1.4 The values stated in SI units are the standard.

NOTE 2—This test method does not apply to all types of polymers as written (see 6.8).

1.5 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 3—This standard is similar but not equivalent to ISO 11357-1, -2, -3. The ISO procedures provide additional information not supplied by this test method.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E473 Terminology Relating to Thermal Analysis and Rheology

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

E967 Test Method for Temperature Calibration of Differential Scanning Calorimeters and Differential Thermal Analyzers

E968 Practice for Heat Flow Calibration of Differential Scanning Calorimeters

E1142 Terminology Relating to Thermophysical Properties

E1953 Practice for Description of Thermal Analysis and Rheology Apparatus

2.2 *ISO Standards:*[3]

ISO 11357-1 Plastics—Differential Scanning Calorimetry (DSC)—Part 1: General Principles

ISO 11357-2 Plastics—Differential Scanning Calorimetry (DSC)—Part 2: Determination of Glass Transition Temperature

ISO 11357-3 Plastics—Differential Scanning Calorimetry (DSC)—Part 3: Determination of Temperature and Enthalpy of Melting and Crystallization

3. Terminology

3.1 Specialized terms used in this test method are defined in Terminologies E473 and E1142.

4. Summary of Test Method

4.1 This test method consists of heating or cooling the test material at a controlled rate under a specified purge gas at a

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[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 D20.30.07).

Current edition approved Aug. 1, 2012. Published September 2012. Originally approved in 1975. Last previous edition approved in 2008 as D3418 - 08. DOI: 10.1520/D3418-12E01.

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

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

ANEXO 4

controlled flow rate and continuously monitoring with a suitable sensing device the difference in heat input between a reference material and a test material due to energy changes in the material. A transition is marked by absorption or release of energy by the specimen resulting in a corresponding endothermic or exothermic peak or baseline shift in the heating or cooling curve. Areas under the crystallization exotherm or fusion endotherm of the test materials are compared against the respective areas obtained by the treatment of a well-characterized standard.

5. Significance and Use

5.1 Thermal analysis provides a rapid method for measuring transitions due to morphological or chemical changes, in a polymer as it is heated/cooled through a specified temperature range. Change in specific heat capacity, heat flow and temperature values are determined for these transitions. Differential scanning calorimetry is used to assist in identifying specific polymers, polymer alloys, and certain polymer additives, which exhibit thermal transitions. Chemical reactions that cause or affect certain transitions have been measured with the aid of this technique; such reactions include oxidation, curing of thermosetting resins, and thermal decomposition.

5.2 This test method is useful for specification acceptance, process control, and research.

6. Interferences

6.1 Differences in heating or cooling rate as well as the final heating and cooling temperature have an effect on the measured results, especially on the enthalpy of fusion or crystallization. Therefore, departure from conditions specified for a given polymer is not permitted.

6.2 The presence of impurities is known to affect the transition temperature, particularly if an impurity tends to form solid solutions, or to be miscible in the melt phase.

6.3 Uncertain radiation losses at temperatures higher than 400°C have been known to affect the accuracy of results at times.

6.4 Since particle size has an effect upon detected transition temperatures, the specimens to be compared shall be approximately the same particle size **(1-5)**.[4]

6.5 In cases that specimens react with air during the temperature cycle, provision shall be made for running the test under an inert gas blanket to avoid any incorrect measurement. Since some materials degrade near the melting region, care must be used to distinguish between degradation and transition.

6.6 Since milligram quantities of a specimen are used, it is essential to ensure that specimens are homogeneous and representative.

6.7 It is possible that toxic or corrosive effluents are released when heating the material, and be harmful to the personnel or to the apparatus.

6.8 Not all polymers lend themselves to the exact terms of this test method. For some polymers such as polyarylamides, crystallization is only possible from solution. For other polymers such as crystallizable polystyrene, annealing is only possible above their glass transition temperatures. When this test method is used for polymers of this type, carefully annealed samples must be tested without conditioning.

7. Apparatus

7.1 *Differential Scanning Calorimeter (DSC)*—The essential instrumentation required to provide the minimum differential scanning calorimetric capability for this test method includes:

7.1.1 *DSC Test Chamber*—This chamber is composed of the following:

7.1.1.1 *Furnace(s),* to provide uniform controlled heating (cooling) of a specimen and reference to a constant temperature or at a constant rate within the applicable cryogenic to 600°C temperature range of this test method.

7.1.1.2 *Temperature Sensor,* to provide an indication of the specimen temperature to ±0.01°C.

7.1.1.3 *Differential Sensor,* to detect heat flow difference between the specimen and reference equivalent to 1 mW.

7.1.1.4 *Means of Sustaining a Test Chamber Environment* of purge gas at a purge flow rate of 10 to 50 ± 5 mL/min.

NOTE 4—Typically, 99+ % pure nitrogen, argon or helium are employed when oxidation in air is a concern. Unless effects of moisture are to be studied, use of dry purge gas is recommended and is essential for operation at sub-ambient temperatures.

7.1.2 *Temperature Controller,* Temperature Controller, capable of executing a specific temperature program by operating the furnace(s) between selected temperature limits at a rate of temperature change of 0.5 to 20°C/min constant to ±0.1°C/min or at an isothermal temperature constant to ±0.1°C.

7.1.3 *Recording Device,* capable of recording and displaying any fraction of the heat flow signal (DSC curve) including the signal noise as a function of temperature.

7.1.4 *Software,* for integrating areas under endothermic valleys or exothermic peaks, or both.

7.1.5 *Containers* (pans, crucibles, and so forth) that are inert to the specimen and reference materials; and that are of suitable structural shape and integrity to contain the specimen and reference in accordance with the specific requirements of this test method.

7.1.6 Cooling capability to hasten cool down from elevated temperatures, to provide constant cooling rates of 0.5 - 20 ºC/min to obtain repeatable crystallization temperatures, to achieve sub-ambient operation, or to sustain an isothermal sub-ambient temperature, or combination thereof.

7.2 *Balance,* capable of weighing to ±0.0001 grams for transition temperatures and to ±0.00001 grams for determining enthalpies.

8. Sample

8.1 *Powdered or Granular Specimens*—Avoid grinding if the preliminary thermal cycle as outlined in 10.1.3 is not performed. Grinding or similar techniques for size reduction

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[4] The boldface numbers in parentheses refer to the list of references at the end of this test method.

often introduce thermal effects because of friction or orientation, or both, and thereby change the thermal history of the specimen.

8.2 *Molded or Pelleted Specimens*—Cut the specimens with a microtome, razor blade, hypodermic punch, paper punch, or cork borer (Size No. 2 or 3) or other appropriate means to appropriate size, in thickness or diameter and length that will best fit the specimen containers as in 7.1.5 and will approximately meet the desired weight in the subsequent procedure.

8.3 *Film or Sheet Specimens*—For films thicker than 40 µm, see 8.2. For thinner films, cut slivers to fit in the specimen capsules or punch disks, if the circular specimen capsules are used.

8.4 Use any shape or form listed in 8.1-8.3 except when conducting referee tests that shall be performed on films as specified in 8.3.

9. Calibration

9.1 The purge gas shall be used during calibration.

9.2 Calibrate the DSC temperature signal using Practice E967 and the same heating rate to be used in this test method preferably 10°C/min or 20°C/min (see Note 5). (See Section 10 for details.)

9.3 Calibrate the DSC heat flow signal using Practice E968 and the same heating rate as in 9.2 (see Note 5).

9.4 Some instruments allow for the temperature and heat flow calibration to be performed simultaneously. In such cases, use the same heating rate for this method and follow the manufacturer's instruction. Report the heating rate. (See 12.1.3.)

Note 5—Use of other heating rates is permitted. However, test results are affected by the heating rate. It is the responsibility of the user of other rates to demonstrate equivalency to this test method.

10. Procedure

10.1 *For First-Order Transition (melting and crystallization):*

10.1.1 The purge gas shall be used during testing. The flow rate of the gas shall be the same as used in the calibration (9.1).

10.1.2 Use a specimen mass appropriate for the material to be tested. In most cases a 5-mg specimen mass is satisfactory. Avoid overloading. Weigh the specimen to an accuracy of 610 µg.

10.1.2.1 Intimate thermal contact between the pan and specimen is essential for reproducible results. Crimp a metal cover against the pan with the sample sandwiched in between to ensure good heat transfer. Take care to ensure flat pan bottoms.

10.1.3 Perform and record a preliminary thermal cycle by heating the sample at the same rate used for testing from at least 50°C below to 30°C above the melting temperature to erase previous thermal history.

10.1.4 When the effect of annealing is studied, selection of temperature and time are critical. Minimize the time of exposure to high temperature to avoid sublimation or decomposition. In some cases it is possible that the preliminary thermal cycle will interfere with the transition of interest, causing an incorrect transition or eliminating a transition. Where it has been shown that this effect is present, omit the preliminary thermal cycle.

10.1.5 Hold the temperature for 5 min (10.1.3).

Note 6—In cases that high-temperature annealing cause polymer degradation, the use of shorter annealing times is permitted but shall be reported.

10.1.6 Cool to at least 50°C below the peak crystallization temperature using the same rate that was used for heating and record the cooling curve.

10.1.7 Hold the temperature for 5 min.

10.1.8 Repeat heating at the same rate used in 10.1.3 (10°C/min or 20°C/min) and record the heating curve. Use this curve to calculate the enthalpies of transition.

10.1.9 Measure the temperatures for the desired points on the curves: T_{eim}, T_{pm}, T_{efm} , T_{eic}, T_{pc}, and T_{eic} (see Fig. 1). Report two T_{pm}'s or T_{pc}'s if observed.

10.1.10 In case of dispute determine T_m and T_c at a heating rate of 10°C/min.

where:

T_{eim} = melting extrapolated onset temperature, °C,
T_{efm} = melting extrapolated end temperature, °C,
T_{pm} = melting peak temperature,° C,
T_{eic} = crystallization extrapolated onset temperature, °C,
T_{pc} = crystallization peak temperature, °C, and
T_{efc} = crystallization extrapolated end temperature, °C.

Note 7—The actual temperature displayed on the temperature axis depends upon the instrument type (for example, specimen temperature, program temperature, or specimen-program temperature average). Follow any recommended procedures or guidelines of the instrument manufacturer to obtain specimen temperature at the point of interest.

10.2 *For Glass Transition:*

10.2.1 The purge gas shall be used during testing. The flow rate of the gas shall be the same as used in the calibration (9.1).

10.2.2 Use a specimen mass appropriate for the material to be tested. In most cases, a 10-mg specimen mass is satisfactory. Weigh the specimen to an accuracy of 610 µg.

10.2.3 Perform and record a preliminary thermal cycle by heating the sample at a rate of 20°C/min from at least 50°C below to 30°C above the melting temperature to erase previous thermal history.

10.2.4 Hold the temperature for 5 min. (See Note 6.)

10.2.5 Quench cool to at least 50°C below the transition temperature of interest.

10.2.6 Hold the temperature for 5 min.

10.2.7 Repeat heating at a rate of 20°C/min, and record the heating curve until all desired transitions have been completed. (See Note 5.)

10.2.8 The glass transition is more pronounced at faster heating rates. A heating rate of 20°C/min is the preferred heating rate for T_g measurements. The instrument shall be calibrated at the same heating rate used for testing. If both first- and second-order transitions (T_m and T_g, respectively) are to be determined in the same run, use the same heating rate as used in 10.1.8 for both transitions and determine results from the second heating step (10.1.8). Report the heating rate. (See 12.1.3.)

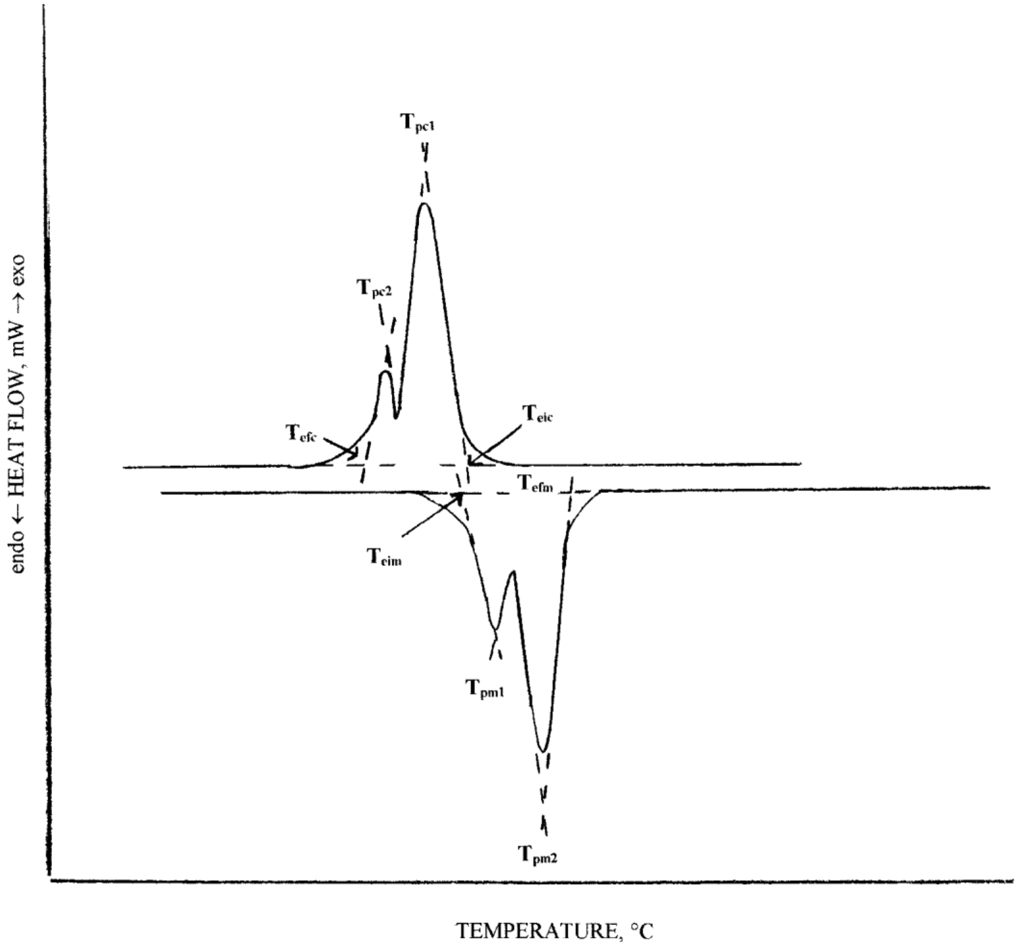

FIG. 1 First-Order Transition of Nylon

NOTE 8—T_g obtained using Procedure 10.1 will be different from T_g measured using procedures 10.2.3-10.2.7. Therefore, the heating rate must be reported as described in 12.1.3.

10.2.9 In case of dispute determine T_g at a heating rate of 20°C/min.

10.2.10 Measure temperatures T_{eig} , T_{mg}, and T_{efg} (see Fig. 2):

where:

T_{eig} = extrapolated onset temperature, °C,
T_{mg} = midpoint temperature, °C, and
T_{efg} = extrapolated end temperature, °C.

A new baseline will likely be established after the transition, rather than a peak (see Note 9). For most applications, the T_{mg} temperature is more meaningful. In those cases, designate T_{mg} as the glass transition temperature (T_g) in place of the extrapolated onset for the glass transition curve.

NOTE 9—Stress relaxation peaks, caused by annealing, that appear in some polymers above the glass transition are normally eliminated by the preliminary thermal cycle and a new baseline will be established after the transition.

11. Calculation for Heat of Fusion and Crystallization

11.1 Construct a baseline by connecting the two points at which the melting endotherm or freezing exotherm deviate from the relatively straight baseline, caused by a signal that is proportional to the difference in heat flow between the reference and specimen capsules (Fig. 3 and Fig. 4).

11.2 The method described in 11.1 is not applicable for certain materials. In such cases, other graphical means must be developed for enclosing the peak areas as agreed upon between the manufacturer and the purchaser **(4-8)**.

11.3 Integrate the area under the fusion heat flow endotherm or crystallization exotherm as a function of time to yield enthalpy or heat (mJ) of the transition.

11.4 Calculate the mass normalized enthalpy or heat of transition by dividing the enthalpy obtained in 11.3 by the mass of the test specimen. Report this mass normalized enthalpy of transition (J/g).

12. Report

12.1 Report the following information:

12.1.1 Complete identification and description of the material tested, including source, manufacturer's code,

12.1.2 Description of instrument used for the test,

12.1.3 Statement of the mass, dimensions, geometry, and materials of the specimen container, and the heating rate.

12.1.4 Description of temperature calibration procedure,

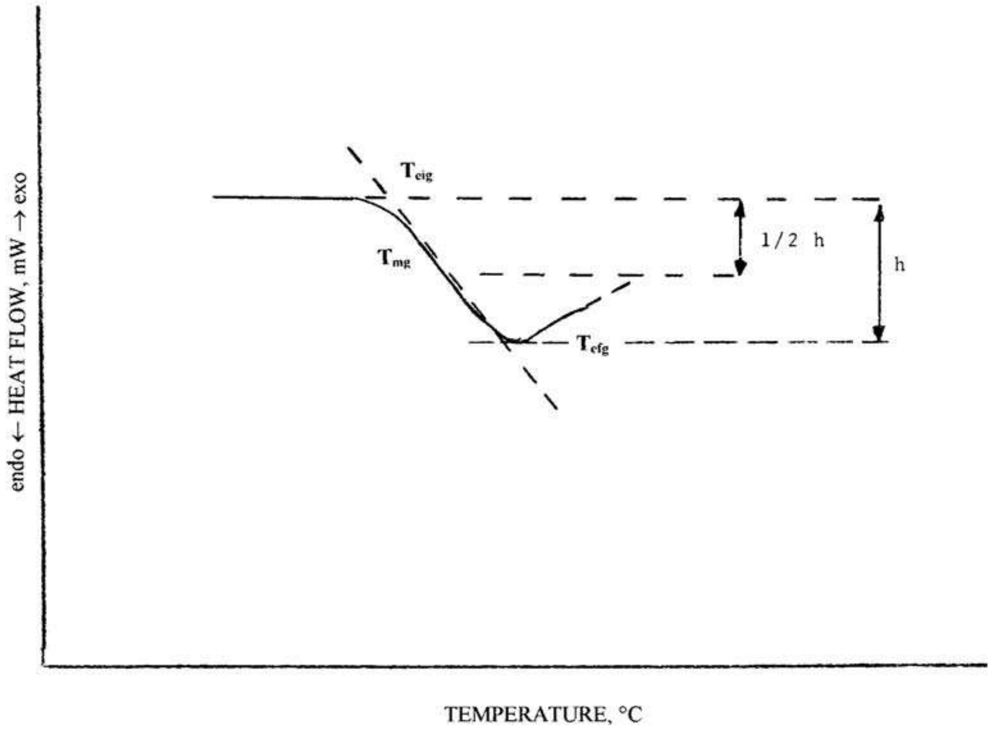

FIG. 2 Assignment of Glass Transition of Poly(Methyl Methacrylate) (PMMA)

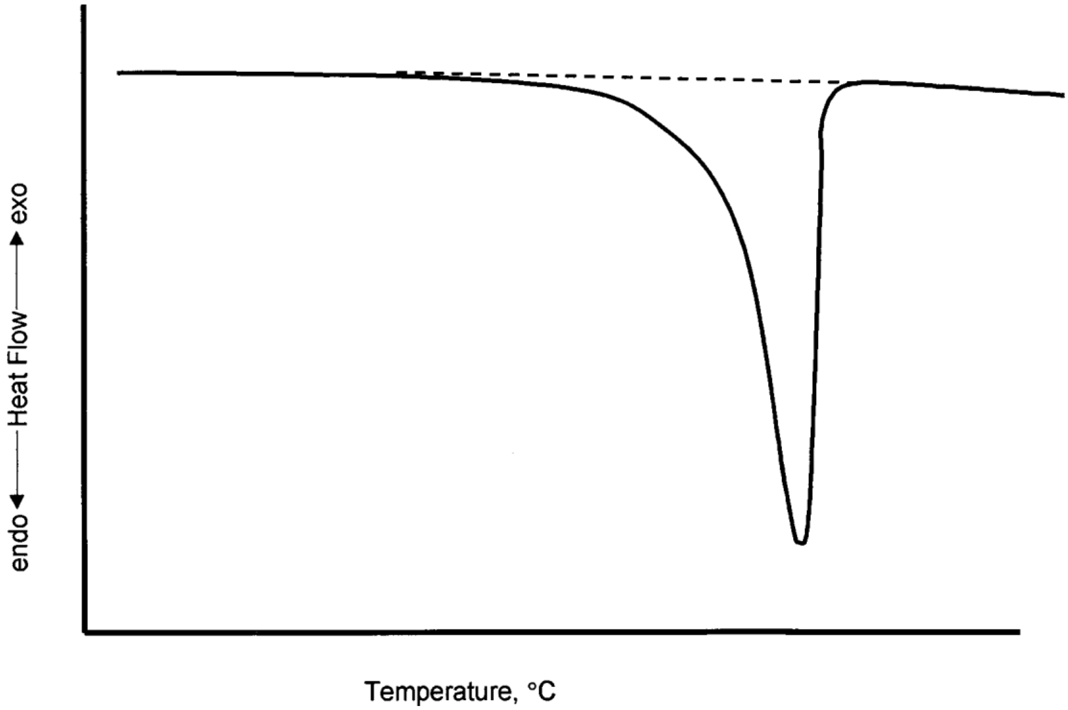

FIG. 3 Typical Heating Curve for Polyethylene

12.1.5 Identification of the sample atmosphere by purge gas flow rate, purity, and composition, including humidity, if applicable,

12.1.6 Results of the transition measurements using the temperature parameters cited in Fig. 1, or any combination of parameters suitable for the purpose in hand. T_{pm} and T_{eic} that

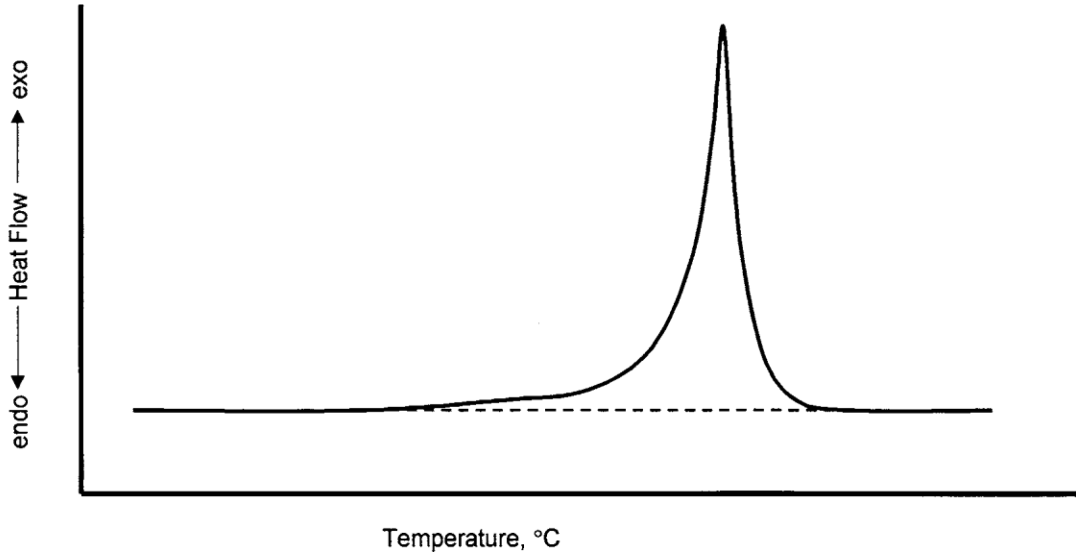

FIG. 4 Typical Freezing Curve for Polyethylene

are commonly used as single characteristic temperatures for the first-order transition of semicrystalline polymers but must be identified by including the subscript.

12.1.7 Heat of fusion or crystallization, or both, and,

12.1.8 Any side reaction (for example, crosslinking, thermal degradation, or oxidation), and the reaction identified if possible.

13. Precision and Bias[5]

13.1 Tables 1-5 are based on a round robin study conducted in 2007 in accordance with Practice E691, involving five materials tested by seven laboratories. Not all materials and tests were performed by every lab, due to the limitation of individual lab. All the samples were prepared at one source, but the individual test specimens were prepared at the laboratories that tested them. Each laboratory obtained two test results for each material.

NOTE 10—A program is being set up to re-evaluate the repeatability and reproducibility of this method at heating rates of 10°C/min and 20°C/min. The effect of the different heating rates on the transition temperatures and enthalpies will also be evaluated.

13.2 *Concept of "r" and "R":* If S_r and S_R have been calculated from a large enough body of data, then:

13.2.1 *Repeatability:* Two results obtained within one laboratory shall be judged not equivalent if they differ by more than the "*r*" value for that 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.

13.2.2 *Reproducibility:* Two test results obtained by different laboratories shall be judged not equivalent if they differ by more than the "*R*" value for that 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.

TABLE 1 Glass Transition Temperature, °C

Materials	Average	S_r^A	S_R^B	r^C	R^D
PET	76.2	0.19	1.12	0.55	3.18
PC	149.3	0.24	0.66	0.69	1.88

[A] S_r = the within-laboratory standard deviation of the average.
[B] S_R = the between-laboratories standard deviation of the average.
[C] r = repeatability limit = 2.83 × S_r
[D] R = reproducibility limit = 2.83 × S_R

TABLE 2 Melting Peak Temperature, °C

Materials	Average	S_r^A	S_R^B	r^C	R^D
PE	123.0	0.28	0.62	0.79	1.75
PP	160.6	0.29	1.55	0.83	4.38
PET	249.2	0.18	0.58	0.51	1.65
PA-6	220.3	0.30	0.81	0.84	2.29

[A] S_r = the within-laboratory standard deviation of the average.
[B] S_R = the between-laboratories standard deviation of the average.
[C] r = repeatability limit = 2.83 × S_r.
[D] R = reproducibility limit = 2.83 × S_R.

TABLE 3 Crystallization Peak Temperature, °C

Materials	Average	S^A	S_R^B	r^C	R^D
PE	109.8	0.08	1.73	0.21	4.90
PP	111.7	0.80	1.94	2.28	5.50
PET	194.9	0.54	1.52	1.52	4.29
PA-6	183.4	0.62	1.07	1.74	3.02

[A] S_r = the within-laboratory standard deviation of the average.
[B] S_R = the between-laboratories standard deviation of the average.
[C] r = repeatability limit = 2.83 × S_r.
[D] R = reproducibility limit = 2.83 × S_R.

13.2.3 Any judgment in accordance with 13.2.1 or 13.2.2 would have an approximate 95 % (0.95) probability of being correct. (**Warning**—The explanation of "*r*" and " *R*" are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Tables 1-5 are not intended 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 representative of other lots, formulations, conditions, materials, or laboratories.

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[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1249.

TABLE 4 Heat of Fusion, J/g

Materials	Average	S_r [A]	S_R [B]	r [C]	R [D]
PE	86.0	2.79	16.1	7.90	45.6
PP	89.6	1.24	12.9	3.50	36.4
PET	41.1	1.13	5.01	3.20	14.2
PA-6	62.0	1.40	9.00	3.97	25.5

[A] S_r = the within-laboratory standard deviation of the average.

[B] S_R = the between-laboratories standard deviation of the average.

[C] r = repeatability limit = 2.83 × S_r.

[D] R = reproducibility limit = 2.83 × S_R.

TABLE 5 Heat of Crystallization, J/g

Materials	Average	S_r [A]	S_R [B]	r [C]	R [D]
PE	64.6	1.70	17.4	4.82	49.3
PP	95.6	1.03	5.21	2.90	14.7
PET	45.9	0.99	1.93	2.81	5.46
PA-6	63.8	1.46	2.93	4.12	8.30

[A] S_r = the within-laboratory standard deviation of the average.

[B] S_R = the between-laboratories standard deviation of the average.

[C] r = repeatability limit = 2.83 × S_r.

[D] R = reproducibility limit = 2.83 × S_R.

When using this test method apply the principles outlined in Practice E691 to generate data specific to other materials and laboratories (or between specific laboratories). The principles of 13.2 through 13.2.3 would then be valid for such data.)

13.3 There are no recognized standards by which to estimate the bias of this method.

14. Keywords

14.1 crystallization; crystallization temperature; differential scanning calorimetry (DSC); enthalpy; first-order transition; glass transition; heat of crystallization; heat of fusion; heat of transition; melting; melting temperature; polymer; transition temperature

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SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D3418 - 08) that may impact the use of this standard. (August 1, 2012)

(1) All sections in which the rate of temperature rise are mentioned were revised. This includes subsections 9.2, 9.3, 10.1.3, 10.1.6, 10.1.8, 10.2.8, and 12.1.3.

(2) Permissive language was removed from 13.2.3.

(3) Old Note 6 is now section 10.1.4.

(4) Heating rates to be used in case of disputes are included in 10.1.10 and 10.2.9.

(5) Note 10 was added.

ANEXO 5

CTT - FICM

CENTRO DE TRANSFERENCIA Y TECNOLOGÍA FACULTAD INGENIERIA CIVIL Y MECÁNICA - UTA

UNIVERSIDAD TÉCNICA DE AMBATO

FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA

INGENIERÍA MECÁNICA

RESISTENCIA DE IMPACTO SEGÚN ASTM D 5628-10

JUNIO 2023

AMBATO - ECUADOR

ANEXO 5

INFORME TÉCNICO

CTT-2023 – 148

OBJETIVO

Establecer y mantener un método para evaluar la energía media de impacto en polímeros**.**

ALCANCE

Determinación de energía necesaria para el fallo de polímeros por impacto de dardo según las especificaciones señaladas en la norma ASTM D 5628-10.

ANTECEDENTES:

Con fecha 15 de junio de 2023, López Martínez Erick Isaac, solicita al Centro de Transferencia y Tecnología dela Facultad de Ingeniería Civil y Mecánica de la Universidad Técnica de Ambato, realizar ensayosde laboratorio para medir la energía media de impacto en muestras de material compuesto.

Se reciben 15 muestras o probetas, en 3 grupos de 5 probetas, bajo las designaciones:

- 80/20 - 1
- 80/20 - 2
- 80/20 - 3
- 80/20 - 4
- 80/20 - 5
- 70/30 – 1
- 70/30 – 2
- 70/30 – 3
- 70/30 – 4
- 70/30 – 5
- 60/40 – 1
- 60/40 – 2
- 60/40 – 3
- 60/40 – 4
- 60/40 – 5

Con la numeración de 1 a 5 en tres grupos (Probetas para Ensayo de Impacto en Material Compuesto de Resina poliéster reforzado con Fibra natural de banano); se realizó el ensayo de un total de 15 probetas, de dimensiones de 58 x 58 mm. Todas las probetas presentan superficies lisas.

ANEXO 5

PROBETAS PARA ENSAYO DE IMPACTO
80/20 
70/30 

60/40

PROCESO GENERAL:

- Determinación de número de especímenes para cada muestra.
- Mantener hermetizadas las muestras hasta el ensayo y marcarlas para su identificación.
- Preparación de la máquina de ensayos para la geometría preestablecida (FA, FB, FC, FD, FE) en este caso para el tipo FE dadas las dimensiones de la probeta.

Geometría	Diámetro de la Probeta mm	Probeta Cuadrada mm
FA	89	89
FB	51	51
FC	140	140
FD	89	89
FE	58	58

- Medición y registro del espesor de cada muestra, el cual se muestra en los resultados del ensayo.
- Realizar la prueba de impacto con probetas de calibración, fuera de los grupos mostrados anteriormente y localizamos el rango de falla del material.

- Se colocan las mordazas utilizando una fuerza que permita la inmovilidad de la probeta al momento del impacto.

- Colocar la masa a la altura preestablecida, según el método de prueba seleccionado.
- Se libera el dardo asegurándonos que golpee justo en el centro de la muestra, impidiendo cualquier rebote del dardo.

- Retirar la muestra y revisar si ha fallado o no. Considerando que una falla es cualquier grieta o ruptura generado por el impacto el cual pueda ser distinguido por el ojo humano bajo luz normal en condiciones normales.

UNIVERSIDAD TÉCNICA DE AMBATO

FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA

Centro de Transferencia y Tecnología

FICHA DE RECOLECCIÓN DE DATOS

DATOS INFORMATIVOS:

Fecha:	15/06/2023	**Ciudad:**	Ambato
Lugar:	Laboratorios de Materiales		**Campus Huachi**
Equipo:	Máquina tipo caída de masas de Impacto		
Realizado por: Ing. Christian Pérez		**Supervisado por:** Ing. Sebastián Villegas S.	
Tipo de material:	Material compuesto 80/20		**Orden:** 2023-148
Composición	Resina poliéster reforzado con Fibra natural de banano		

PARÁMETROS DE ENSAYO

Tipo de Medición:	Energía Media de impacto (J)	**Norma:**	ASTM D5628-10
Dimensiones (mm):	58mm x 58mm	**N^0 de probetas:**	5

CODIFICACIÓN (%fibra)	**Ancho (mm)**	**Largo(mm)**	**Espesor (mm)**	**Masa aplicada (kg)**	**Incremento de masa (kg)**	**Altura media de fallo (mm)**	**Energía media de fallo (J)**	**Criteriode falla**
80/20 - 1	58	58	8	0,287	0,192	200	0,9398	No falla
80/20 - 2	58	58	8	0,287	0,192	300	1,4097	No falla
80/20 - 3	58	58	8	0,287	0,192	400	1,8796	No falla
80/20 - 4	58	58	8	0,287	0,192	500	2,3495	Falla
80/20 - 5	58	58	8	0,287	0,192	600	2,8194	Falla

UNIVERSIDAD TÉCNICA DE AMBATO

FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA

Centro de Transferencia y Tecnología

FICHA DE RECOLECCIÓN DE DATOS

DATOS INFORMATIVOS:

Fecha:	15/06/2023	**Ciudad:**	Ambato
Lugar:	Laboratorios de Materiales		**Campus Huachi**
Equipo:	Máquina tipo caída de masas de Impacto		
Realizado por: Ing. Christian Pérez		**Supervisado por:** Ing. Sebastián Villegas S.	
Tipo de material:	Material compuesto 70/30		**Orden:** 2023-148
Composición	Resina poliéster reforzado con Fibra natural de banano		

PARÁMETROS DE ENSAYO

Tipo de Medición:	Energía Media de impacto (J)	**Norma:** -	ASTM D5628-10
Dimensiones (mm):	58mm x 58mm	**N^0 de probetas:**	5

CODIFICACIÓN (%fibra)	**Ancho (mm)**	**Largo(mm)**	**Espesor (mm)**	**Masa aplicada (kg)**	**Incremento de masa (kg)**	**Altura media de fallo (mm)**	**Energía media de fallo (J)**	**Criteriode falla**
80/20 - 1	58	58	8	0,287	0,756	150	1,5348	No falla
80/20 - 2	58	58	8	0,287	0,756	250	2,5580	No falla
80/20 - 3	58	58	8	0,287	0,756	350	3,5811	Falla
80/20 - 4	58	58	8	0,287	0,756	450	4,6043	Falla
80/20 - 5	58	58	8	0,287	0,756	550	5,6275	Falla

UNIVERSIDAD TÉCNICA DE AMBATO

FACULTAD DE INGENIERÍA CIVIL Y MECÁNICA

Centro de Transferencia y Tecnología

FICHA DE RECOLECCIÓN DE DATOS

DATOS INFORMATIVOS:

Fecha:	15/06/2023	**Ciudad:**	Ambato
Lugar:	Laboratorios de Materiales		**Campus Huachi**
Equipo:	Máquina tipo caída de masas de Impacto		
Realizado por: Ing. Christian Pérez		**Supervisado por:** Ing. Sebastián Villegas S.	
Tipo de material:	Material compuesto 60/40		**Orden:** 2023-148
Composición	Resina poliéster reforzado con Fibra natural de banano		

PARÁMETROS DE ENSAYO

Tipo de Medición:	Energía Media de impacto (J)	**Norma:**	ASTM D5628-10
Dimensiones (mm):	58mm x 58mm	**N^0 de probetas:**	5

CODIFICACIÓN (%fibra)	**Ancho (mm)**	**Largo(mm)**	**Espesor (mm)**	**Masa aplicada (kg)**	**Incremento de masa (kg)**	**Altura media de fallo (mm)**	**Energía media de fallo (J)**	**Criteriode falla**
60/40 - 1	58	58	8	0,287	0,192	200	0,9398	No falla
60/40 - 2	58	58	8	0,287	0,192	300	1,4097	No falla
60/40 - 3	58	58	8	0,287	0,192	400	1,8796	No Falla
60/40 - 4	58	58	8	0,287	0,192	500	2,3495	No Falla
60/40 - 5	58	58	8	0,287	0,192	600	2,8194	Falla

CoNCLUSIONES

- Las probetas 80/20 tienen una energía de fallo de 2,3495J.
- Las probetas 70/30 tienen una energía de fallo de 3,5811 J.
- Las probetas 60/40 tienen una energía de fallo de 2,8194 J.
- Todas las probetas se las ensayó con el método de prueba FE y fueron impactadas con un dardo de 0,287 Kg.

Firmado electrónicamente por:
CHRISTIAN SAUL
PÉREZ GAVILANES

REALIZADO POR:
Ing. Christian Pérez
LABORATORIO DE MATERIALES

Firmado electrónicamente por:
EDMUNDO SEBASTIAN
VILLEGAS SUAREZ

SUPERVISADO POR:
Ing. Sebastián Villegas S.
TÉCNICO DE LABORATORIO

ANEXO 6

LACONAL
LABORATORIO DE CONTROL Y ANÁLISIS DE ALIMENTOS

UNIVERSIDAD TÉCNICA DE AMBATO
FACULTAD DE CIENCIAS E INGENIERÍA EN ALIMENTOS Y BIOTECNOLOGÍA
LABORATORIO DE CONTROL Y ANÁLISIS DE ALIMENTOS

CERTIFICADO DE ANALISIS DE LABORATORIO

Certificado No: 23-144 R01-7.8 03 01084

Solicitud Nº: 23-144 Pág.:1 de 1

Fecha recepción: 05 de julio de 2023 Fecha de ejecución de ensayos: 13 de julio de 2023

Información del cliente:

Empresa: C.I./RUC: 1805072657
Representante: Erick López Tlf: 0979006421
Dirección: Ambato Email: elopez2657@uta.edu.ec
Ciudad: Ambato

Descripción de las muestras:

Producto: Resina Polister reforzada con fibra de banano Peso / Volumen: 4.9 g
Marca comercial: n/a Tipo de envase: envase de plástico
Lote: n/a No de muestras: una
F. Elb.: n/a F. Exp.: n/a
Conservación: Ambiente: X Refrigeración: Congelación: Almac. en Lab: 30 días
Cierres seguridad: Ninguno: X Intactos: Rotos: Muestreo por el cliente: 04 de julio de 2023

RESULTADOS OBTENIDOS

Muestras	Código del laboratorio	Código cliente	Ensayos solicitados/Técnica	Métodos utilizados	Unidades	Resultados
Resina Polister reforzada con fibra de banano	**14423296**	**Ninguno**	DSC (Calorimetro Diferencial de Barrido)	Método Interno	Ver Adjunto	

Conds. Ambientales: 21.9°C; 50.1%HR
Nota:
Se anexa 1 hoja

DIRECCIÓN DE CALIDAD
LACONAL

Ing. Gladys Risueño
Directora de Calidad

Autorización para transferencia electrónica de resultados: Si

Fecha de emisión del certificado: 17 de julio de 2023 MGFR

Nota: La muestra fue suministrada por el cliente y los resultados se aplican a la muestra en las condiciones recibidas. El Laboratorio se responsabiliza exclusivamente de los resultados emitidos en base a la muestra entregada por el cliente.

El Laboratorio no es responsable por el uso incorrecto de este certificado. No es un documento negociable. Solo se permite su reproducción sin fines de lucro y haciendo referencia a la fuente.

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☎ (593) 32400987 ext. 5517; 5518 http://laconal.uta.edu.ec laconal@uta.edu.ec

Integral	37,35 mJ
normalized	10,10 Jg^-1
Onset	68,62 °C
Peak Height	0,32 mW
Peak	113,88 °C
Extrapol. Peak	30,00 °C
Endset	116,77 °C
Peak Width	44,98 °C
Left Limit	67,99 °C
Right Limit	113,88 °C
Left bl Limit	63,41 °C
Right bl Limit	199,99 °C
Heating Rate	10,00 °Cmin^-1
Baseline Type	line
Result Mode	Sample Temp
Left Area	100,00 %
Right Area	0,00 %
Partial Area	43,99 %

liester reforzada con F banano, 13.07.2023 12:22:20
liester reforzada con F banano, 3,7000 mg