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APPENDIX A

List of Factories and Plastic Waste dealers Interviewed

1. นำสินพลาสติก
2. พลาสติกเจี่ยฮงเส็ง
3. พลาสติกคุ้งฮวด
4. มานะอุตสาหกรรม
5. คุณเขื่อน ช.อ่อนนุช
6. คุณอรรถกรณ์ ช.สน.ท่าข้าม
7. ปัญจพงษ์พลาสติก
8. บริษัทสยามพลาสติกรีไซคลิ่ง จำกัด
9. สินมั่นคง
10 ไทยเยี่ยมพลาสติก
11. พันธมิตร
12. ไท้ฮวดพลาสติก
13. สมชัย (กู่) พลาสติก
14. บริษัท ยิ่งกิจเจริญ พลาสติก 2 จำกัด
15. โชคชัยพลาสติก
16. เอเชียพลาสติก
17. บี เค เค พลาสติก
18. บริษัท เอสโซ่แสตนดาร์ด ประเทศไทย จำกัด
19. บริษัท คัสตอมแพค จำกัด
20. บริษัท เม่งเช้ง พลาสติก จำกัด
21. หจก.โสภณพลาสติก
22. คุณกิตตินันท์ ช.สุขใจ 1
23. หจก.เค ขจรรัตน์

24. หจก.ทรัสติค
25. บริษัท ตอมิเนก จำกัด
26. กรุงเทพน้ำกลั่นบริการ (1969) จำกัด
27. บริษัท ไทยเพ็ทอุตสาหกรรม จำกัด
28. บริษัท ไฮเทคพลาสติก จำกัด

APPENDIX B

Questionaire for Plastic Fabricators

งานวิจัยเรื่อง " การศึกษาการนำขยะพลาสติกประเภทภาชนะบรรจุกลับมาใช้ประโยชน์

คณะผู้วิจัย : รศ.ดร.เกริกชัย สุกาญจนัจที
น.ส.วรวดี เชียงทอง
น.ส.ณัฐกานต์ จินตพยุงกุล

โรงงาน .....
ที่อยู่ .....
โทรศัพท์ .....

สำนักงานใหญ่ .....
ที่อยู่ .....
.....
โทรศัพท์ .....
ผู้ที่สามารถติดต่อ .....

ท่านอยากได้รายงานผลงานวิจัยนี้หรือไม่ ? อยากได้ ( )
ไม่อยากได้ ( )

โรงงานเริ่มทำการผลิตเมื่อ พ.ศ. .....
กำลังการผลิต.....ตัน/วัน .....แรงม้า จำนวนเครื่องเป่า.....

โรงงานผลิตขวดบรรจุกี่ชนิด ? ..... ชนิด

โปรดระบุชนิดของขวดตามประเภทดังนี้ 1.น้ำดื่ม 2.นม 3.น้ำมันเครื่อง 4.เครื่องสำอาง 5.ยาและเคมีภัณฑ์ 6.น้ำมันพืช 7.ฝาขวด 8.ฯลฯ

ชนิดของขวด									
	ไม่ใส่สี	ขาวขุ่น	สี	ไม่ใส่สี	ขาวขุ่น	สี	ไม่ใส่สี	ขาวขุ่น	สี
1. Resin (โปรดใส่เครื่องหมาย)									
1. HDPE									
2. LDPE									
3. LLDPE									
4. PET									
5. PP									
6. PS									
7. PVC									
8. Resin เก่า (%)									
2. ปริมาณการผลิต (ตัน/ปี)									
3. ช่วงเดือนที่ผลิตมากที่สุด									
ปริมาณการผลิต (จำนวน/เดือน) ในช่วงเดือนนี้									
4. คาดว่าปีหน้าจะผลิตเพิ่มที่ %									

ชนิดของขวด

วัตถุดิบ

5. ชื้อเม็ดพลาสติกที่ผสมแล้ว

(compounded pellets) ใช่ (ไปตอบข้อ 7) ( ) ( ) ( )

ไม่ใช่ (ไปตอบข้อ 6) ( ) ( ) ( )

6. จากข้อ 5, กรณี : ไม่ใช่

ชื้อโพลิเมอร์จากบริษัท _____ _____ _____

เกรด (grade) _____ _____ _____

ข้อกำหนด (specification)

_____ _____ _____ _____

_____ _____ _____ _____

(ต่อข้อ 8)

7. จากข้อ 5, กรณี : ใช่

ชื้อเม็ดพลาสติกจากบริษัท _____ _____ _____

เกรด (grade) _____ _____ _____

ข้อกำหนด (specification)

_____ _____ _____ _____

_____ _____ _____ _____

ชนิดของขวด			
8. สีและสารเติมแต่ง			
สี : ผง (pigment)	( )	( )	( )
master batch	( )	( )	( )
% สีในผลิตภัณฑ์			
จากบริษัท			
สารเติมแต่ง (additive) ที่ 1			
% สารเติมแต่งในผลิตภัณฑ์			
จากบริษัท			
สารเติมแต่ง (additive) ที่ 2			
% สารเติมแต่งในผลิตภัณฑ์			
จากบริษัท			
9. สภาวะของการผลิต (operating-condition)			
อุณหภูมิสูงสุด (c)			
ความดันสูงสุด ( )			
10. %เศษพลาสติกที่นำกลับไปใช้ในวัตถุดิบ			
11. %เศษพลาสติกที่ทิ้ง			

ชนิดของขวด

---

12. มีการทดสอบคุณภาพผลิตภัณฑ์หรือไม่

มี (ไปตอบข้อ 13)	( )	( )	( )
ไม่มี (ไปตอบข้อ 14)	( )	( )	( )

13. คุณสมบัติของขวดที่ทดสอบ

14. มีการเปลี่ยนสูตรผสมของผลิตภัณฑ์หรือไม่ ?

มี	( )	( )	( )
ไม่มี	( )	( )	( )

15. ผลิตภัณฑ์นี้ผลิตให้กับบริษัท

ชนิดของขวด

16. พิมพ์สีเอง	ใช่	( )	( )	( )
	ไม่ใช่	( )	( )	( )

17. เดินเครื่องวันละกี่ชั่วโมง .....

18. จำนวนคนงาน .....

เงินเดือนต่อคน .....

19. ค่าซ่อมบำรุงรักษาเครื่อง .....

20. เฉลี่ยอายุเครื่องจักร .....

21. เครื่องจักรผลิตในประเทศใช่หรือไม่ใช่? .....

22. ปัญหาการผลิต .....

23. ข้อสังเกตุ : .....

Questionaire for Plastic Recycling Factories

งานวิจัยเรื่อง " การศึกษาการนำขยะพลาสติกประเภทภาชนะบรรจุกลับมาใช้ประโยชน์"

แบบสอบถามสำหรับโรงงานที่ใช้พลาสติกเก่าเป็นวัตถุดิบ

คณะผู้วิจัย : รศ.ดร.เกริกชัย สุกาญจนัจที
น.ส.วรวดี เชียงทอง
น.ส.ศิรกานต์ จินตพยุงกุล

โรงงาน .....
ที่อยู่ .....
.....
โทรศัพท์ .....

สำนักงานใหญ่ .....
ที่อยู่ .....
.....
โทรศัพท์ .....
ผู้ที่สามารถติดต่อ .....

ท่านอยากได้รายงานผลงานวิจัยนี้หรือไม่ ? อยากได้ ( )
ไม่อยากได้ ( )

โรงงานเริ่มทำการผลิตเมื่อ พ.ศ. .....
กำลังการผลิต.....ตัน/วัน

ผลิตภัณฑ์ชนิดที่

1. ผลิตภัณฑ์				
ชื่อผลิตภัณฑ์	_____	_____	_____	_____
น้ำหนัก (kg/ผลิตภัณฑ์)	_____	_____	_____	_____
ปริมาณการผลิต (จำนวน/ปี)	_____	_____	_____	_____
คาดว่าปีหน้าจะผลิตเพิ่มกี่ %	_____	_____	_____	_____
ราคา	_____	_____	_____	_____
ท่านพอใจในผลิตภัณฑ์นี้หรือไม่	( ) พอใจ เพราะ _____		( ) พอใจ เพราะ _____	
	( ) ไม่พอใจ เพราะ _____		( ) ไม่พอใจ เพราะ _____	
มีโครงการจะเปลี่ยนเป็นผลิตภัณฑ์อื่นหรือไม่	( ) มี ผลิตภัณฑ์คือ _____		( ) มี ผลิตภัณฑ์คือ _____	
	( ) ไม่มี		( ) ไม่มี	
มีการทดสอบคุณภาพของผลิตภัณฑ์หรือไม่	( ) มี		( ) มี	
	( ) ไม่มี		( ) ไม่มี	

ผลิตภัณฑ์ชนิดที่

---

2. วัตถุดิบ

ชนิดเม็ดพลาสติก (HDPE,PP,.....)

เม็ดพลาสติก	เก่า	ใหม่	เก่า	ใหม่	เก่า	ใหม่	เก่า	ใหม่
ซื้อเม็ดพลาสติกจาก								
ปริมาณที่ใช้ (kg/ปี)								
ราคา (บาท/kg)								
% ที่ใช้ในผลิตภัณฑ์								
มีการทดสอบคุณภาพของวัตถุดิบหรือไม่ มี	( )	( )	( )	( )	( )	( )	( )	( )
ไม่มี	( )	( )	( )	( )	( )	( )	( )	( )
มีปัญหาเกี่ยวกับวัตถุดิบไม่เพียงพอหรือไม่ มี	( )	( )	( )	( )	( )	( )	( )	( )
ไม่มี	( )	( )	( )	( )	( )	( )	( )	( )

ผลิตภัณฑ์ชนิดที่				
3. สารเติมแต่ง (additive) ที่ 1				
% สารเติมแต่งในผลิตภัณฑ์				
ราคา (บาท/kg)				
จากบริษัท				
สารเติมแต่ง (additive) ที่ 2				
% สารเติมแต่งในผลิตภัณฑ์				
ราคา (บาท/kg)				
จากบริษัท				
สี (pigment)				
% สีในผลิตภัณฑ์				
ราคา (บาท/kg)				
จากบริษัท				

ผลิตภัณฑ์ชนิดที่

4. สภาวะของการผลิต (operating-condition)				
อุณหภูมิสูงสุด (c)	_____	_____	_____	_____
ความดันสูงสุด ( )	_____	_____	_____	_____
5. xเศษพลาสติกที่นำกลับไปใช้ในวัตถุดิบ	_____	_____	_____	_____
6. xเศษพลาสติกที่ทิ้ง	_____	_____	_____	_____

7. อุปกรณ์การผลิต

( ) เครื่องบด .....เครื่อง ยี่ห้อ _____ รุ่น _____ ขนาด _____ แรงม้า

( ) เครื่องผสม .....เครื่อง ยี่ห้อ _____ รุ่น _____ ขนาด _____ แรงม้า

( ) เครื่องทำเม็ด .....เครื่อง ยี่ห้อ _____ รุ่น _____ ขนาด _____ แรงม้า

( ) เครื่องจักรขึ้นรูป .....เครื่อง

(โปรดระบุชนิด): _____

ยี่ห้อ _____ รุ่น _____ ขนาด _____ แรงม้า

ผลิตภัณฑ์ชนิดที่

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8. เดินเครื่องวันละกี่ชั่วโมง .....

9. จำนวนคนงาน .....

   เงินเดือนต่อคน .....

10. ค่าซ่อมบำรุงรักษาเครื่อง .....

11. เฉลี่ยอายุเครื่องจักร .....

12. เครื่องจักรผลิตในประเทศใช่หรือไม่ใช่? .....

13. ปัญหาการผลิต .....

14. ข้อสังเกตุ : .....

APPENDIX C

ASTM D 638M

Designation: D 638M – 91a
METRIC

An American National Standard

Standard Test Method for Tensile Properties of Plastics (Metric)[1]

This standard is issued under the fixed designation D 638M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

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

1.2 This test method can be used for testing materials of any thickness up to 10 mm. However, for testing specimens in the form of thin sheeting, including film less than 1.0 mm, Test Methods D 882 is the preferred test method. Materials with a thickness greater than 10 mm must be reduced by machining.

NOTE 1—This test method is the companion to inch-pound Test Method D 638.

NOTE 2—This test method may be used for testing phenolic resin molded or laminated materials. However, where these materials are used as electrical insulation, such materials should be tested in accordance with Methods D 229 and Test Method D 651.

NOTE 3—This test method is not intended to cover precise physical procedures. It is recognized that the constant-rate-of-crosshead-movement type of test leaves much to be desired from a theoretical standpoint, that wide differences may exist between rate of crosshead movement and rate of strain between gage marks on the specimen, and that the testing speeds specified disguise important effects characteristic of materials in the plastic state. Further, it is realized that variations in the thicknesses of test specimens, which are permitted by these procedures, produce variations in the surface-volume ratios of such specimens, and that these variations may influence the test results. Hence, where directly comparable results are desired, all samples should be of equal thickness. Special additional tests should be used where more precise physical data are needed.

NOTE 4—For tensile properties of resin-matrix composites reinforced with oriented continuous or discontinuous high modulus >20 GPa fibers, tests shall be made in accordance with Test Method D 3039.

1.3 *This standard does not purport to address all of the safety problems, 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:*

D 229 Methods of Testing Rigid Sheet and Plate Materials Used for Electrical Insulation[2]

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[3]

D 638 Test Method for Tensile Properties of Plastics[3]

D 651 Test Method for Tensile Strength of Molded Electrical Insulating Materials[2]

D 882 Test Methods for Tensile Properties of Thin Plastic Sheeting[3]

D 883 Terminology Relating to Plastics[3]

D 3039 Test Method for Tensile Properties of Fiber-Resin Composites[4]

D 4000 Classification System for Specifying Plastic Materials[5]

D 4066 Specification for Nylon Injection and Extrusion Materials[5]

E 4 Practices for Load Verification of Testing Machines[6]

E 83 Practice for Verification and Classification of Extensometers[6]

3. Terminology

3.1 *Definitions*—Definitions of terms applying to this test method appear in Terminology D 883 and Annex A1.

4. Significance and Use

4.1 This test method is designed to produce tensile property data for the control and specification of plastic materials. These data are also useful for qualitative characterization purposes and for research and development. For many materials, there may be a specification that requires the use of this test method, but with some procedural modifications that take precedence when adhering to the specification. Therefore, it is advisable to refer to that material specification before using this test method. Table 1 in Classification D 4000 lists the ASTM materials standards that currently exist.

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

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

4.3 Tensile properties may provide useful data for plastics

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[1] This test method is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

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[2] *Annual Book of ASTM Standards*, Vol 10.01.

[3] *Annual Book of ASTM Standards*, Vol 08.01.

[4] *Annual Book of ASTM Standards*, Vol 15.03.

[5] *Annual Book of ASTM Standards*, Vol 08.03.

[6] *Annual Book of ASTM Standards*, Vol 03.01.

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

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

5. Apparatus

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

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

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

5.1.3 *Grips*—Grips for holding the test specimen between the fixed member and the movable member. The grips shall be self-aligning, that is, they shall be attached to the fixed and movable member, respectively, in such a manner that they will move freely into alignment as soon as any load is applied, so that the long axis of the test specimen will coincide with the direction of the applied pull through the center line of the grip assembly. The specimens should be aligned as perfectly as possible with the direction of pull so that no rotary motion that may induce slippage will occur in the grips: there is a limit to the amount of misalignment self-aligning grips will accommodate.

5.1.3.1 The test specimen shall be held in such a way that slippage relative to the grips is prevented insofar as possible. Grip surfaces that are deeply scored or serrated with a pattern similar to those of a coarse single-cut file, serrations about 2.5 mm apart and about 1.5 mm deep, have been found satisfactory for most thermoplastics. Finer serrations have been found to be more satisfactory for harder plastics such as the thermosetting materials. The serrations should be kept clean and sharp. Breaking in the grips may occur at times, even when deep serrations or abraded specimen surfaces are used; other techniques must be used in these cases. Other techniques that have been found useful, particularly with smooth-faced grips, are abrading that portion of the surface of the specimen that will be in the grips, and interposing thin pieces of abrasive cloth, abrasive paper, or plastic or rubber-coated fabric, commonly called hospital sheeting, between the specimen and the grip surface. Number 80 double-sided abrasive paper has been found effective in many cases. An open-mesh fabric, in which the threads are coated with abrasive, has also been effective. Reducing the cross-sectional area of the specimen may also be effective. The use of special types of grips is sometimes necessary to eliminate slippage and breakage in the grips.

5.1.4 *Drive Mechanism*—A drive mechanism for imparting to the movable member a uniform, controlled velocity with respect to the stationary member, with this velocity to be regulated as specified in Section 9.

5.1.5 *Load Indicator*—A suitable load-indicating mechanism capable of showing the total tensile load carried by the test specimen when held by the grips. This mechanism shall be essentially free from inertia-lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the indicated value, or better. The accuracy of the testing machine shall be verified in accordance with Practices E 4.

NOTE 6—Experience has shown that many testing machines now in use are incapable of maintaining accuracy for as long as the periods between inspection recommended in Practices E 4. Hence, it is recommended that each machine be studied individually and verified as often as may be found necessary. It will frequently be necessary to perform this function daily.

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

5.2 *Extension Indicator* (extensometer)—A suitable instrument shall be used for determining the distance between two designated points within the gage length of the test specimen as the specimen is stretched. For referee purposes, the extensometer must be set at the full gage length of the specimen, as shown in Fig. 1. It is desirable, but not essential, that this instrument automatically record this distance, or any change in it, as a function of the load on the test specimen, or of the elapsed time from the start of the test, or both. If only the latter is obtained, load-time data must also be taken. This instrument shall be essentially free of inertia at the specified speed of testing. Extensometers shall be classified and their calibration periodically verified in accordance with Practice E 83.

5.2.1 *Modulus-of-Elasticity Measurements*—For modulus-of-elasticity measurements, an extensometer with a maximum strain error of 0.0002 mm/mm that automatically and continuously records shall be used. A Class B-2 extensometer (Practice E 83) meets this requirement.

5.2.2 *Low-Extension Measurements*—For elongation-at-yield and low-extension measurements (nominally 20 % or less), the same above extensometer, attenuated to 20 % extension, may be used. In any case, the extensometer system must meet at least Class C (Practice E 83) requirements, which include a fixed strain error of 0.001 strain or ±1.0 % of the indicated strain, whichever is greater.

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

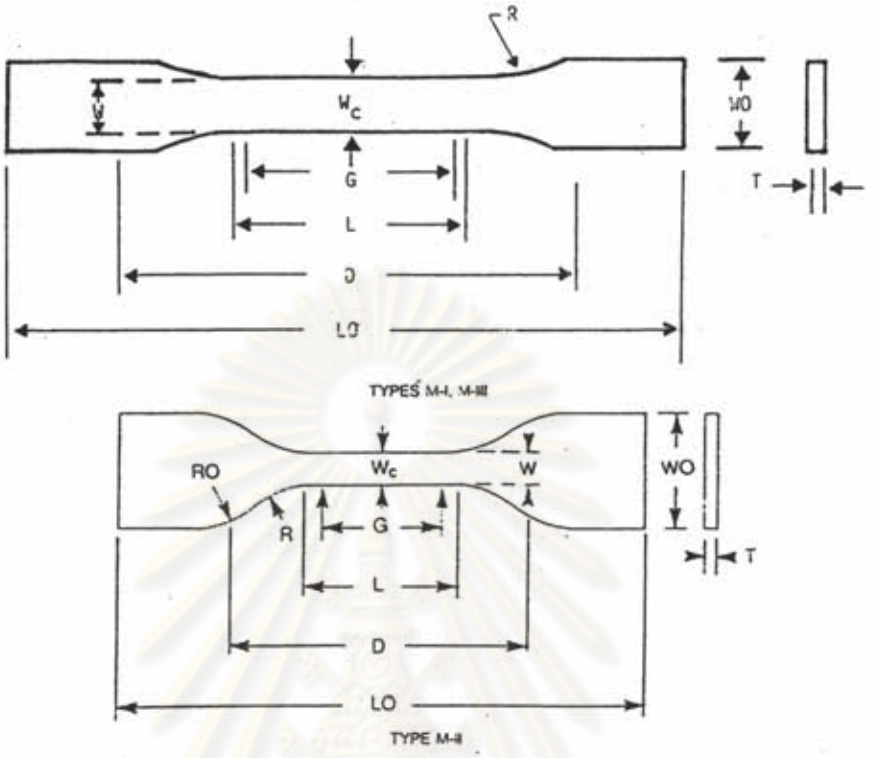


FIG. 1 Tension Test Specimens

5.3 *Micrometers*—Suitable micrometers, reading to at least 0.02 mm for measuring the width and thickness of the test specimens. The thickness of nonrigid plastics should be measured with a dial micrometer that exerts a pressure of 25 ± 5 kPa on the specimen and measures the thickness to within 0.02 mm. The anvil of the micrometer shall be at least 30 mm in diameter and parallel to the face of the contact foot.

6. Test Specimens

6.1 *Sheet, Plate, and Molded Plastics:*

6.1.1 *Rigid and Semirigid Plastics*—The test specimens shall conform to the dimensions shown in Fig. 1. The Type M-I specimen is the preferred specimen and shall be used where sufficient material having a thickness of 10 mm or less is available. The Type M-III specimen shall be used where only limited material having a thickness of 4 mm or less is available for evaluation, or where a large number of specimens are to be exposed in a limited space (thermal and environmental stability tests, etc.). The Type M-II specimen should be used when direct comparisons are required between materials in different rigidity cases (that is, nonrigid and semirigid).

6.1.2 *Nonrigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type M-II specimen shall be used for testing nonrigid plastics with a thickness of 4 mm or less. The Type M-I specimen must be used for all materials with a thickness greater than 4 mm but not more than 10 mm.

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

6.1.4 *Preparation*—Test specimens shall be prepared by machining operations, or die cutting, from materials in sheet, plate, slab, or similar form. Materials thicker than 10 mm must be machined to 10 mm for use as Type M-I specimens. Specimens can also be prepared by molding the material to be tested.

NOTE 7—Test results have shown that for some materials such as glass cloth, SMC, and BMC laminates, other specimen types should be considered to ensure breakage within the gage length of the specimen, as mandated by Section 8.3.

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

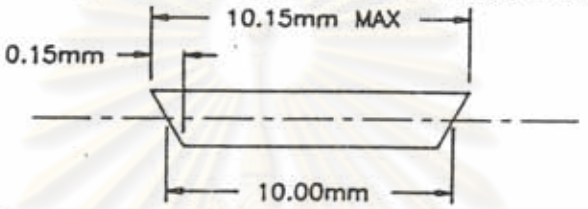
NOTE 9—Specimens prepared by injection molding may have different tensile properties than specimens prepared by machining or die-cutting because of the orientation induced. This effect may be more pronounced in specimens with narrow sections.

6.2 All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine file or abrasive and the filed surfaces shall then be smoothed with abrasive paper (No. 00 or finer). The finishing sanding strokes shall be made in a direction parallel to the long axis

Dimensions (see drawings)	Specimen Dimensions for Thickness, T, mm[B,C]			Tolerances
	10 or Under	4 or Under		
	Type M-I	Type M-II	Type M-III	
W—Width of narrow section[A,B]	10	6	2.5	±0.5[H]
L—Length of narrow section	60	33	10	±0.5
WO—Width of overall, min[E,F]	20	25	10	±0.5
LO—Length overall, min[E,G]	150	115	60	no max
G—Gage length[C]	50	—	7.5	±0.25
G—Gage length[C]	—	25	—	±0.5
D—Distance between grips	115	80	25	±5
R—Radius of fillet	60	14	15	±1
RO—Outer radius (Type II)	—	25	—	±1

[A] The width at the center W_o shall be plus 0.00 mm, minus 0.10 mm compared with width W at other parts of the reduced section. Any reduction in W at the center shall be gradual, equally on each side so that no abrupt changes in dimension result.

[B] For molded specimens, a draft of not over 0.15 mm may be allowed for Type M-1, 4 mm in thickness, and this should be taken into account when calculating width of the specimen. Thus a typical section of a molded Type M-I specimen, having the maximum allowable draft, could be as follows:



[C] Test marks or initial extensometer span.

[D] Thickness, T, shall be 4 ± 0.2 mm for all types of molded specimens where possible. If specimens are machined from sheets or plates, thickness, T, may be the thickness of the sheet or plate provided this does not exceed the range stated for the intended specimen type. For sheets of nominal thickness greater than 10 mm, the specimens shall be machined to 10 ± 0.2 mm in thickness, for use with the Type M-I specimen. For sheets of nominal thickness between 10 and 50 mm approximately equal amounts shall be machined from each surface. For thicker sheets both surfaces of the specimen shall be machined and the location of the specimen with reference to the original thickness of the sheet, shall be noted. Tolerances on thickness less than 10 mm shall be those standard for the grade of material tested.

[E] A Type M-I specimen, having an overall width of 20 mm and an overall length of 215 mm is the preferred specimen and shall be used whenever possible.

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

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

[H] The Type M-II specimen is intended for nonrigid plastics but may be used for rigid types where desirable.

FIG. 1 *Continued*

of the test specimen. All flash shall be removed from a molded specimen, taking great care not to disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shown in Fig. 1 shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors.

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

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

7. Conditioning

7.1 *Conditioning*—Condition the test specimens at 23 ± 2°C and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Practice D 618, for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1°C and ±2 % relative humidity.

7.1.1 Note that for some hygroscopic materials, such as nylons, the material specifications (for example, Specification D 4066) call for testing "dry as-molded specimens." Such requirements take precedence over the above routine preconditioning to 50 % relative humidity and require sealing the specimens in water vapor-impermeable containers as soon as molded and not removing them until ready for testing.

7.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2°C and 50 ± 5 % relative humidity, unless otherwise specified in the test methods. In cases of disagreement, the tolerances shall be ±1°C and ± 2 % relative humidity.

NOTE 10—The tensile properties of some plastics change rapidly with small changes in temperature. Since heat may be generated as a result of straining the specimen at high rates, conduct tests without forced cooling to ensure uniformity of test conditions. Measure the temperature in the reduced section of the specimen and record it for materials where self-heating is suspected.

8. Number of Test Specimens

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

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

8.3 Discard specimens that break at some obvious fortuitous flaw, or that do not break between the predetermined gage marks, and make retests, unless such flaws constitute a variable to be studied.

NOTE 11—Before testing, all transparent specimens should be inspected in a polariscope. Those which show atypical or concentrated strain patterns should be rejected, unless the effects of these residual strains constitute a variable to be studied.

TABLE 1 Designation for Speed of Testing[A]

Classification[B]	Specimen Type	Speed of Testing, mm/min	Nominal Strain[C] Rate at Start of Test, mm/mm·min
Rigid and semirigid	M-I	5 ± 25 %	0.1
		50 ± 10 %	1
		500 ± 10 %	10
	M-II	5 ± 25 %	0.15
		50 ± 10 %	1.5
		500 ± 10 %	15
	M-III	1 ± 25 %	0.1
		10 ± 25 %	1
		100 ± 25 %	10
Nonrigid	M-II	50 ± 10 %	1.5
		500 ± 10 %	15

[A] Select the lowest speed that produces rupture in ½ to 5 min for the specimen geometry being used (see 9.2).

[B] See Definitions D 883 for definitions.

[C] The initial rate of straining cannot be calculated exactly for dumbbell-shaped specimens because of extension, both in the reduced section outside the gage length and in the fillets. This initial strain rate can be measured from the initial slope of the tensile strain-versus-time diagram.

9. Speed of Testing

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

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

9.3 Modulus determinations may be made at the speed selected for the other tensile properties or as required by the specification.

10. Procedure

10.1 Measure the width and thickness of rigid flat specimens (Fig. 1) with a suitable micrometer to the nearest 0.02 mm at several points along their narrow sections. Measure the thickness of nonrigid specimens (produced by a Type M-II die) in the same manner with the required dial micrometer. Take the width of this specimen as the distance between the cutting edges of the die in the narrow section. Record the minimum values of cross-sectional area so determined.

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

10.3 Attach the extension indicator. When modulus is being determined, the extension indicator must continuously record the distance the specimen is stretched (elongated) within the gage length as a function of the load through the initial (linear) portion of the load-elongation curve.

NOTE 12—Modulus of materials is determined from the slope of the linear portion of the stress-strain curve. For most plastics, this linear portion is very small, occurs very rapidly, and must be recorded automatically. The change in jaw separation is never to be used for calculating modulus or elongation.

10.4 Set the speed of testing at the proper rate as required in Section 9, and start the machine.

10.5 Record load-extension curve of the specimen.

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

NOTE 13—If it is desired to measure both modulus and failure properties (yield or break, or both), it may be necessary, in the case of highly extensible materials to run two independent tests. The high-magnification extensometer, normally used to determine properties up to the yield point, may not be suitable for tests involving high extensibility. If allowed to remain attached to the specimen, the extensometer could be permanently damaged. A broad-range incremental extensometer or hand rule technique may be needed when such materials are taken to rupture.

11. Calculation

11.1 *Tensile Strength*—Calculate the tensile strength by diyiding the maximum load in newtons by the original minimum cross-sectional area of the specimen in square metres. Express the result in pascals and report it to three significant figures as tensile strength at yield or tensile strength at break, whichever term is applicable. When a nominal yield or break load less than the maximum is present and applicable, it may be desirable also to calculate, in a similar manner, the corresponding tensile stress at yield or tensile stress at break and report it to three significant figures (see Note A1.8).

11.2 *Percent Elongation*—If the specimen gives a yield load that is larger than the load at break, calculate percent elongation at yield. Otherwise, calculate percent elongation at break. Do this by reading the extension (change in gage length) at the moment the applicable load is reached. Divide that extension by the original gage length and multiply by 100. Report percent elongation at yield or percent elongation at break to two significant figures. When a yield or breaking load less than the maximum is present and of interest, it is desirable to calculate and report both percent elongation at yield and percent elongation at break (see Note A1.2).

11.3 *Modulus of Elasticity*—Calculate the modulus of elasticity by extending the initial linear portion of the load-extension curve and dividing the difference in stress corresponding to any segment of section on this straight line by the corresponding difference in strain. Compute all elastic modulus values using the average initial cross-sectional area of the test specimens in the calculations. Express the result in pascals and report to three significant figures.

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

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

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

where:

s = estimated standard deviation,

X = value of single observation,

n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

11.6 See Appendix X1 for information on toe compensation.

12. Report

12.1 Report the following information:

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

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimensions,

12.1.4 Conditioning procedure used,

12.1.5 Atmospheric conditions in test room,

12.1.6 Number of specimens tested,

12.1.7 Speed of testing,

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

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

12.1.10 Percent elongation at yield or break (or both as applicable), average value, and standard deviation,

12.1.11 Modulus of elasticity, average value, and standard deviation, and

12.1.12 Date of test.

13. Precision and Bias[7]

13.1 The precision and bias of this test method are under investigation by a task group of Section D20.10.22. Anyone wishing to participate in this work may contact the Chairman, Section D20.10.22, ASTM, 1916 Race Street, Philadelphia, PA 19103.

14. Keywords

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

[7] A report on a limited comparison between Methods D 638 and D 638M is available from ASTM Headquarters. Request RR:D20-1088.

ANNEX

(Mandatory Information)

A1. DEFINITIONS OF TERMS AND SYMBOLS RELATING TO TENSION TESTING OF PLASTICS

A1.1 *elastic limit*—the greatest stress which a material is capable of sustaining without any permanent strain remaining upon completed release of the stress. It is expressed in force per unit area, usually megapascals.

NOTE A1.1—Measured values of proportional limit and elastic limit vary greatly with the sensitivity and accuracy of the testing equipment, eccentricity of loading, the scale to which the stress-strain diagram is plotted, and other factors. Consequently, these values are usually replaced by yield strength.

A1.2 *elongation*—the increase in length produced in the gage length of the test specimen by a tensile load. It is expressed in units of length, usually millimetres. (Also known as *extension*.)

NOTE A1.2—Elongation and strain values are valid only in cases where uniformity of specimen behavior within the gage length is present. In the case of materials exhibiting necking phenomena, such values are only of qualitative utility after attainment of yield point. This is due to inability to assure that necking will encompass the entire length between the gage marks prior to specimen failure.

A1.3 *gage length*—the original length of that portion of the specimen over which strain or change in length is determined.

A1.4 *modulus of elasticity*—the ratio of stress (nominal) to corresponding strain below the proportional limit of a material. It is expressed in force per unit area, usually megapascals (also known as *elastic modulus* or *Young's modulus*).

NOTE A1.3—The stress-strain relations of many plastics do not conform to Hooke's law throughout the elastic range but deviate therefrom even at stresses well below the elastic limit. For such materials the slope of the tangent to the stress-strain curve at a low stress is usually taken as the modulus of elasticity. Since the existence of a true proportional limit in plastics is debatable, the propriety of applying the term "modulus of elasticity" to describe the stiffness or rigidity of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are very dependent on such factors as rate of stressing, temperature, previous specimen history, etc. However, such a value is useful if its arbitrary nature and dependence on time, temperature, and other factors are realized.

A1.5 *necking*—the localized reduction in cross section which may occur in a material under tensile stress.

A1.6 *offset yield strength*—the stress at which the strain exceeds by a specified amount (the offset) an extension of the initial proportional portion of the stress-strain curve. It is expressed in force per unit area, usually megapascals.

NOTE A1.4—This measurement is useful for materials whose stress-strain curve in the yield range is of gradual curvature. The offset yield strength can be derived from a stress-strain curve as follows (Fig. A1.1):

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

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

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

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

A1.7 *percent elongation*—the elongation of a test specimen expressed as a percent of the gage length.

A1.8 *percent elongation at break and yield:*

A1.8.1 *percent elongation at break*—the percent elongation at the moment of rupture of the test specimen.

A1.8.2 *percent elongation at yield*—the percent elonga-

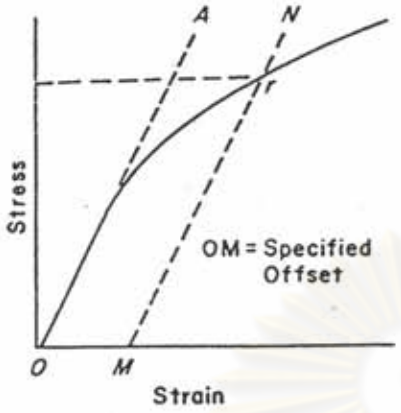


FIG. A1.1 Offset Yield Strength

tion at the moment the yield point (A1.21) is attained in the test specimen.

A1.9 *percent reduction of area (nominal)*—the difference between the original cross-sectional area measured at the point of rupture after breaking and after all retraction has ceased, expressed as a percent of the original area.

A1.10 *percent reduction of area (true)*—the difference between the original cross-sectional area of the test specimen and the minimum cross-sectional area within the gage boundaries prevailing at the moment of rupture, expressed as a percent of the original area.

A1.11 *proportional limit*—the greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). It is expressed in force per unit area, usually megapascals.

A1.12 *rate of loading*—the change in tensile load carried by the specimen per unit time. It is expressed in force per unit time, usually newtons per minute. The initial rate of loading can be calculated from the initial slope of the load versus time diagram.

A1.13 *rate of straining*—the change in tensile strain per unit time. It is expressed either as strain per unit time, usually metres per metre per minute, or percent elongation per unit time, usually percent elongation per minute. The initial rate of straining can be calculated from the initial slope of the tensile strain-versus-time diagram.

NOTE A1.5—The initial rate of straining is synonymous with the rate of crosshead movement divided by the initial distance between crossheads only in a machine with constant-rate-of-crosshead movement and when the specimen has a uniform original cross-section, does not "neck down" and does not slip in the jaws.

A1.14 *rate of stressing (nominal)*—the change in tensile stress (nominal) per unit time. It is expressed in force per unit area per unit time, usually megapascals per minute. The initial rate of stressing can be calculated from the initial slope of the tensile stress (nominal) versus time diagram.

NOTE A1.6—The initial rate of stressing as determined in this manner has only limited physical significance. It does, however, roughly describe the average rate at which the initial stress (nominal) carried by the test specimen is applied. It is affected by the elasticity and flow characteristics of the materials being tested. At the yield point, the rate of stressing (nominal) may become zero, but the rate of stressing (true) may continue to have a positive value if the cross-sectional area is decreasing.

A1.15 *secant modulus*—the ratio of stress (nominal) to corresponding strain at any specified point on the stress-strain curve. It is expressed in force per unit area, usually megapascals and reported together with the specified stress or strain.

NOTE A1.7—This measurement is usually employed in place of modulus of elasticity in the case of materials whose stress-strain diagram does not demonstrate proportionality of stress to strain.

A1.16 *strain*—the ratio of the elongation to the gage length of the test specimen, that is, the change in length per unit of original length. It is expressed as a dimensionless ratio.

A1.17 *tensile strength (nominal)*—the maximum tensile stress (nominal) sustained by the specimen during a tension test. When the maximum stress occurs at the yield point (A1.21), it shall be designated tensile strength at yield. When the maximum stress occurs at break, it shall be designated tensile strength at break.

A1.18 *tensile stress (nominal)*—the tensile load per unit area of minimum original cross section, within the gage boundaries, carried by the test specimen at any given moment. It is expressed in force per unit area, usually megapascals.

NOTE A1.8—The expression of tensile properties in terms of the minimum original cross-section is almost universally used in practice. In the case of materials exhibiting high extensibility, or necking, or both (A1.5), nominal stress calculations may not be meaningful beyond the yield point (A1.21) due to the extensive reduction in cross-sectional area that ensues. Under some circumstances it may be desirable to express the tensile properties per unit of minimum prevailing cross section. These properties are called true tensile properties (that is, true tensile stress, etc.).

A1.19 *tensile stress-strain curve*—a diagram in which values of tensile stress are plotted as ordinates against corresponding values of tensile strain as abscissas.

A1.20 *true strain* (see Fig. A1.2) is defined by the following equation for ϵ_T:

$$\epsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o$$

where:

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

A1.21 *yield point*—the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress (Fig. A1.3).

NOTE A1.9—Only materials whose stress-strain curves exhibit a point of zero slope may be considered as having a yield point.

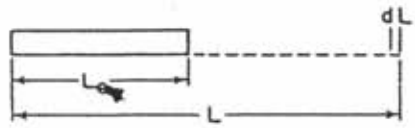


FIG. A1.2 Illustration of True Strain Equation

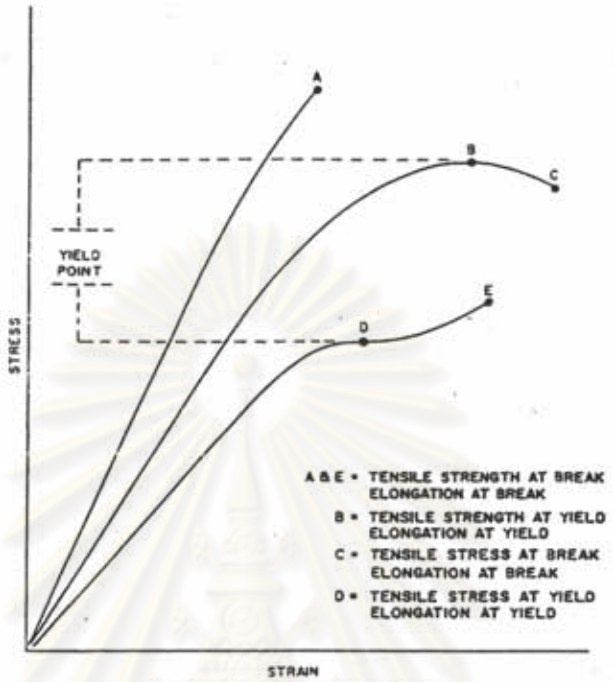


FIG. A1.3 Tensile Designations

NOTE A1.10—Some materials exhibit a distinct "break" or discontinuity in the stress-strain curve in the elastic region. This break is not a yield point by definition. However, this point may prove useful for material characterization in some cases.

A1.22 *yield strength*—the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. Unless otherwise specified, this stress will be the stress at the yield point and when expressed in relation to the tensile strength shall be designated either tensile strength at yield or tensile stress at yield as required under A1.17 (Fig. A1.3). (See *offset yield strength.*)

A1.23 *Symbols*—The following symbols may be used for the above terms:

SYMBOL	TERM
W	Load
ΔW	Increment of load
L	Distance between gage marks at any time
L_o	Original distance between gage marks
L_u	Distance between gage marks at moment of rupture
ΔL	Increment of distance between gage marks = elongation
A	Minimum cross-sectional area at any time
A_o	Original cross-sectional area
ΔA	Increment of cross-sectional area
A_u	Cross-sectional area at point of rupture measured after breaking specimen
A_T	Cross-sectional area at point of rupture, measured at the moment of rupture
t	Time
Δt	Increment of time
σ	Tensile stress
$\Delta\sigma$	Increment of stress
σ_T	True tensile stress
σ_r	Tensile strength at break (nominal)
σ_{UT}	Tensile strength at break (true)
ϵ	Strain
$\Delta\epsilon$	Increment of strain
ϵ_U	Total strain at break
ϵ_T	True strain
% El	Percent elongation
Y.P.	Yield point
E	Modulus of elasticity

A1.23.1 Relations between these various terms may be defined as follows:

$$\sigma = W/A_o$$
$$\sigma_T = W/A$$
$$\sigma_U = W/A_o \text{ (where } W \text{ is breaking load)}$$
$$\sigma_{UT} = W/A_T \text{ (where } W \text{ is breaking load)}$$
$$\epsilon = \Delta L/L_o = (L - L_o)/L_o$$
$$\epsilon_U = (L_u - L_o)/L_o$$
$$\epsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o$$
$$\% El = [(L - L_o)/L_o] \times 100 = \epsilon \times 100$$

Percent reduction of area (nominal) = $[(A_o - A_u)/A_o] \times 100$

Percent reduction of area (true) = $[(A_o - A_T)/A_o] \times 100$

Rate of loading = $\Delta W/\Delta t$

Rate of stressing (nominal) = $\Delta\sigma/\Delta t = (\Delta W/A_o)/\Delta t$

Rate of straining = $\Delta\epsilon/\Delta t = (\Delta L/L_o)/\Delta t$

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

$$\sigma_T = \sigma(1 + \epsilon) = \sigma L/L_o$$
$$\sigma_{UT} = \sigma_U(1 + \epsilon_U) = \sigma_U L_u/L_o$$
$$A = A_o/(1 + \epsilon)$$

APPENDIX

(Nonmandatory Information)

X1. TOE COMPENSATION

X1.1 In a typical stress-strain curve (Fig. X1.1) there is a toe region, *AC*, which does not represent a property of the material. It is an artifact caused by a takeup of slack, and alignment or seating of the specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

X1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. X1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured, including the yield offset (*BE*), if applicable. The elastic modulus can be determined by dividing the stress at any point along the line *CD* (or its extension) by the strain at the same point (measured from point *B*, defined as zero-strain).

X1.3 In the case of a material which does not exhibit any linear region (Fig. X1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection point (*H'*). This is extended to intersect the strain axis at point *B'*, the corrected zero-strain point. Using point *B'* as zero strain, the stress at any point (*G'*) on the curve can be divided by the strain at that point to obtain a secant modulus (slope of line *B' G'*). For these materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.

FIG. X1.1 Material with Hookean Region

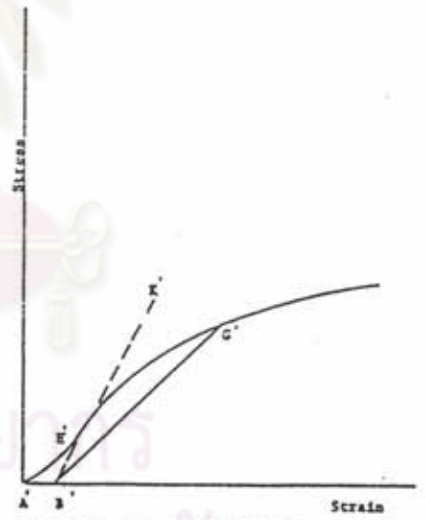


FIG. X1.2 Material with No Hookean Region
(Note that some chart recorders plot the mirror image of these graphs.)

ASTM D 256

Designation: D 256 – 90b

An American National Standard

Standard Test Methods for Impact Resistance of Plastics and Electrical Insulating Materials[1]

This standard is issued under the fixed designation D 256; 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.

These test methods have been approved for use by agencies of the Department of Defense to replace Methods 11221 (part) and 11231 (part) of Federal Test Method Standard No. 601, and to replace Method 107.1 of Federal Test Method Standard 406. These test methods are also approved for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 These test methods cover the determination of the resistance to breakage by flexural shock of plastics and electrical insulating materials, as indicated by the energy extracted from "standardized" (Note 1) pendulum-type hammers, mounted in "standardized" machines, in breaking standard specimens with one pendulum swing. The standard tests for these test methods require specimens made with a milled notch (Note 2). In the Charpy (Test Method B) and Izod (Test Methods A, C, and D) tests, the notch produces a stress concentration which promotes a brittle, rather than a ductile, fracture. In Test Method E, the unnotched impact strength is obtained by reversing the position in the vise of a notched specimen (Note 20). The results of all tests are reported in terms of energy absorbed per unit of specimen width.

NOTE 1—The machines with their pendulum-type hammers have been "standardized" in that they must comply with certain requirements, including a fixed height of hammer fall which results in a substantially fixed velocity of the hammer at the moment of impact. However, besides the fact that the designs of machines for use with Test Methods A and B (see Section 3) must be somewhat different, hammers of different initial energies (produced by varying their effective weights) are recommended for use with specimens of different impact strengths. Moreover, manufacturers of the equipment are permitted to use different lengths and constructions of pendulums (with resulting possible differences in pendulum rigidities (see Section 4), plus other differences in machine design. The specimens are "standardized" in that they are required to have either one of two fixed lengths (Test Methods A and B), one fixed depth and one particular design of milled notch. The width of the specimens is permitted to vary between limits.

NOTE 2—The notch in the Izod specimen serves to concentrate the stress, minimize plastic deformation, and direct the fracture to the part of the specimen behind the notch. Scatter in energy-to-break is thus reduced. However, because of differences in the elastic and visco-elastic properties of plastics, response to a given notch varies among materials. A measure of a plastic's "notch sensitivity" may be obtained with Test Method D by comparing the energies to break specimens with identical notches, except for the radius at the base of the notch.

NOTE 3—Caution must be exercised in interpreting the results of these standard test methods. The following testing parameters may affect test results significantly:

method of fabrication, including but not limited to processing technology, molding conditions, mold design, and thermal treatments;
method of notching;
speed of notching tool;
design of notching apparatus;
quality of the notch;
time between notching and test;
test specimen thickness, and
environmental conditioning

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

1.3 *This standard does not purport to address the safety problems 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:*

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[2]
D 647 Practice for Design of Molds for Test Specimens of Plastic Molding Materials[2]
D 4066 Specification for Nylon Injection and Extrusion Materials[3]
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[4]

3. Types of Tests

3.1 Two basically different test methods, A and B, are described. These differ as to design of machine and specimen and method of holding and striking the latter. A third test method, Test Method C, is Test Method A modified by the addition of the determination of toss correction. Test Method D provides a measure of notch sensitivity of plastics, while Test Method E gives an indication of the unnotched strength of a material. Each test method has characteristics that may dictate its use. There is no known means for correlating the results of tests made by the different test methods.

3.2 In Test Method A (Izod type) the specimen is held as a vertical cantilever beam and is broken by a single swing of the pendulum with the line of initial contact at a fixed distance from the specimen clamp and from the centerline of the notch and on the same face as the notch.

3.3 In Test Method B (Charpy type) the specimen is

[1] These test methods are under the jurisdiction of ASTM Committee D-20 on Plastics and are the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

Current edition approved Dec. 28, 1990. Published February 1991. Originally published as D 256 – 26 T. Last previous edition D 256 – 90a.

[2] *Annual Book of ASTM Standards*, Vol 08.01.
[3] *Annual Book of ASTM Standards*, Vol 08.03.
[4] *Annual Book of ASTM Standards*, Vol. 14.02.

supported as a horizontal simple beam and is broken by a single swing of the pendulum with the impact line midway between the supports and directly opposite the notch.

3.4 Test Method C is the same as Test Method A but includes a determination of the energy expended in tossing a portion of the specimen. The value reported is called the "estimated net Izod impact strength." Test Method C is preferred over Test Method A for materials that have an Izod impact strength of less than 27 J/m of notch (0.5 ft·lbf/in. of notch). The differences between Test Methods A and C become unimportant for materials that have an Izod impact strength higher than this value.

3.5 Test Method D provides a measure of the notch sensitivity of a material. The stress-concentration at the notch increases with decreasing radius. For a given system, greater stress concentration results in higher local rates-of-strain. Since the effect of strain-rate on energy-to-break varies among materials, a measure of this effect may be obtained by testing specimens with different notch radii. In the Izod-type test it has been demonstrated[5] that the function, energy-to-break versus notch radius, is reasonably linear from a radius of 0.03 to 2.5 mm (0.001 to 0.100 in.), provided that all specimens have the same type of break (4.7 and 25.2). For the purpose of this test, the slope, b, (26.1) of the line between radii of 0.25 and 1.0 mm (0.010 and 0.040 in.) is used unless tests with the 1.0-mm radius give "non-break" results. In that case, 0.25 and 0.50 mm (0.010 and 0.020 in.) radii may be used. The effect of notch radius on the impact energy to break a specimen under the conditions of this test is measured by the value b. Materials with low values of b, whether high or low energy to break with the standard notch, are relatively insensitive to differences in notch radius; while the energy to break materials with high values of b is highly dependent on notch radius. The parameter b cannot be used in design calculations but may serve as a guide to the designer and in selection of materials.

3.6 Test Method E is the reversed notch test and is used to give an indication of the unnotched impact strength of plastics.[6] It is similar to Test Method A, except that the specimen is reversed in the vise of the machine 180° to the usual striking position, such that the striker of the apparatus impacts the specimen on the face opposite the notch (Fig. 1).

4. Significance and Use

4.1 The excess energy pendulum impact test indicates the energy to break standard test specimens of specified size under stipulated conditions of specimen mounting, notching (stress concentration), and pendulum velocity at impact.

4.2 The energy lost by the pendulum during the breakage of the specimen is the sum of the energies required (*1*) to initiate fracture of the specimen, (*2*) to propagate the fracture across the specimen, (*3*) to throw the free end (or ends) of the broken specimen ("toss correction"), (*4*) to bend the specimen, (*5*) to produce vibration in the pendulum arm, (*6*) to produce vibration or horizontal movement of the machine frame or base, (*7*) to overcome friction in the pendulum bearing and in the excess energy indicating mechanism, and to overcome windage (pendulum air drag), (*8*) to indent or deform plastically the specimen at the line of impact, and (*9*) to overcome the friction caused by the rubbing of the striking nose (or other part of the pendulum) over the face of the bent specimen.

4.3 For relatively brittle materials for which fracture propagation energy is small in comparison with the fracture initiation energy, the indicated impact energy absorbed is, for all practical purposes, the sum of items (*1*) and (*3*) of 4.2. The toss correction (*3*) may represent a very large fraction of the total energy absorbed when testing relatively dense and brittle materials. Test Method C shall be used for materials that have an Izod impact strength of less than 27 J/m of notch (0.5 ft·lbf/in. of notch). The toss correction obtained in Test Method C is only an approximation of the toss error, since the rotational and rectillinear velocities may not be the same during the retoss of the specimen as for the original toss, and because stored stresses in the specimen may have been released as kinetic energy during the specimen fracture.

4.4 For tough, ductile, fiber filled, or cloth laminated materials, the fracture propagation energy (*2*) may be large compared to the fracture initiation energy (*1*). When testing these materials, factors (*2*), (*5*), and (*9*) can become quite significant, even when the specimen is accurately machined and positioned and the machine is in good condition with adequate capacity (Note 3). Bending (*4*) and indentation losses (*8*) may be appreciable when testing soft materials.

NOTE 3—Although the frame and base of the machine should be sufficiently rigid and massive to handle the energies of tough specimens without motion or excessive vibration, the pendulum arm can not be made very massive because the greater part of its mass must be concentrated near its center of percussion at the striking nose. Locating the striking nose precisely at the center of percussion reduces vibration of the pendulum arm when used with brittle specimens. However, some losses due to pendulum arm vibration, the amount varying with the design of the pendulum, will occur with tough specimens even when the striking nose is properly positioned.

4.5 In a well-designed machine of sufficient rigidity and mass the losses due to (*6*) and (*7*) should be very small. Vibrational losses (*6*) can be quite large when wide specimens of tough materials are tested in machines of insufficient mass, not securely fastened to a heavy base.

4.6 With some materials, a critical width of specimen may be found below which specimens will appear ductile, as evidenced by considerable drawing or necking down in the region behind the notch and by a relatively high energy absorption, and above which they will appear brittle as evidenced by little or no drawing down or necking and by a relatively low energy absorption. Since these test methods permit a variation in the width of the specimens and since the width dictates for many materials whether a brittle, low energy break or ductile, high energy, break will occur, it is necessary that the width be stated in the ASTM specification covering that material and that the width be stated along with the impact value.

4.7 The standard Test Methods A, C, D, and E require that the type of failure for each specimen be recorded as one of the four coded categories defined as follows:

C *complete break*—a break in which the specimen separates into two or more pieces.

H *hinge break*—an incomplete break such that one part of

[5] Supporting data giving results of the interlaboratory tests are available from ASTM Headquarters. Request RR:D20-1021.

[6] Supporting data giving results of the interlaboratory tests are available from ASTM Headquarters. Request RR:D20-1026.

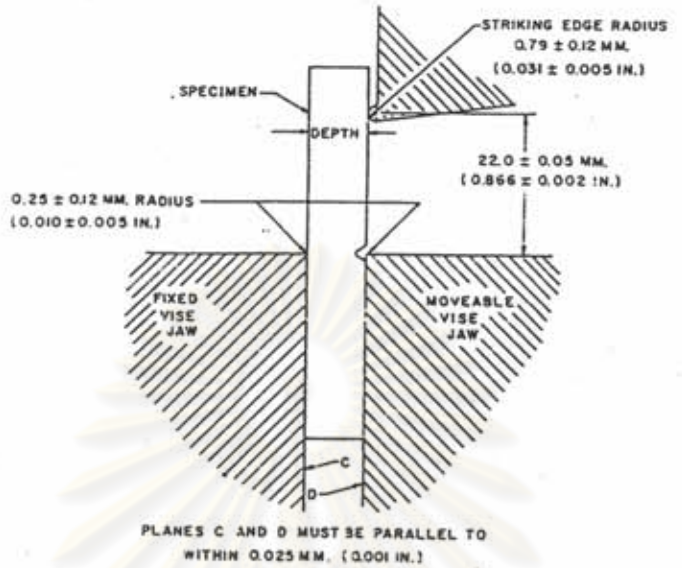


FIG. 1A Relationship of Vise, Specimen, and Striking Edge to Each Other for Izod Test Methods A and C

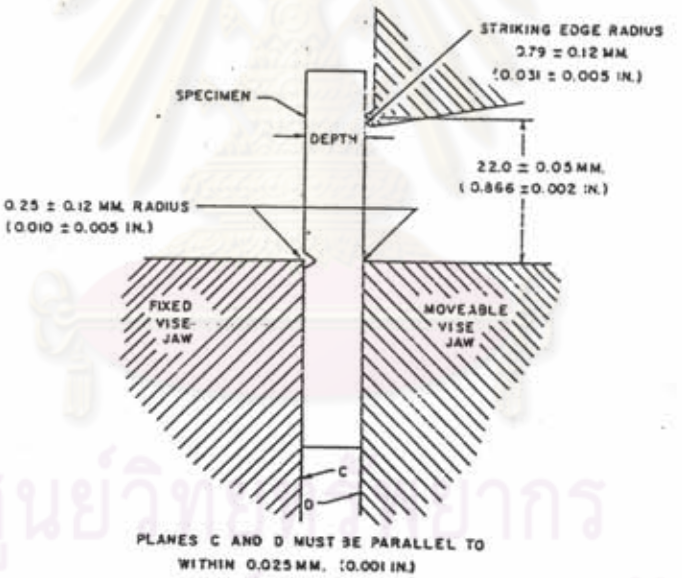


FIG. 1B Relationship of Vise, Specimen, and Striking Edge to Each Other for Test Method E

the specimen cannot support itself above the horizontal when the other part is held vertically (less than 90° included angle).

P *partial break*—an incomplete break that does not meet the definition for a hinge break but has fractured at least 90 % of the distance between the vertex of the notch and the opposite side.

NB *non-break*—an incomplete break where the fracture extends less than 90 % of the distance between the vertex of the notch and the opposite side.

NOTE 4—In both the Izod (except Test Method E) and Charpy type tests the fibers on the side of the specimen opposite the notch are stressed in compression during the fracture and can only be subjected to tension at the termination of the break when the momentum of one specimen half relative to the other tends to break the remaining fibers.

Test Method B requires that the specimen break completely. For tough materials the pendulum may not have the energy necessary to complete the breaking of the extreme fibers and toss the broken piece or pieces. Results obtained from unbroken specimens or other types of partially broken specimens shall be considered a departure from standard and

shall not be reported as a standard result. Results obtained from "non-break" specimens in Test Methods A, C, and E and for other than "complete breaks" in Test Method B shall be considered a departure from standard and shall not be reported as a standard result. Impact values cannot be directly compared for any two materials that experience different types of failure as defined in the method by this code. Averages reported must likewise be derived from specimens contained within a single failure category. This letter code will suffix the reported impact identifying the types of failure associated with the reported value. If more than one type of failure is observed for a sample material, then the report will indicate the average impact value for each type of failure, followed by the percent of the specimens failing in that manner and suffixed by the letter code.

4.8 The value of these impact test methods lies mainly in the areas of quality control and materials specification. If two groups of specimens of supposedly the same material show significantly different energy absorptions, types of breaks, critical widths, or critical temperatures, it may be assumed that they were made of different materials or were exposed to different processing or conditioning environments. The fact that a material shows twice the energy absorption of another under these conditions of test does not indicate that this same relationship will exist under another set of test conditions. The order of toughness may even be reversed under different testing conditions.

TEST METHOD A—CANTILEVER BEAM (IZOD-TYPE) TEST

5. Apparatus

5.1 The machine shall consist of a massive base on which is mounted a vise for holding the specimen and to which is connected, through a rigid frame and anti-friction bearings, one of a number of pendulum-type hammers (or one basic hammer to which extra weights may be attached) having an initial energy suitable for use with the particular specimen to be tested, plus a pendulum holding and releasing mechanism and a pointer and dial mechanism for indicating the excess energy remaining in the pendulum after breaking the specimen. A jig for positioning the specimen in the vise and graphs or tables to aid in the calculation of the correction for friction and windage also should be included. One type of machine is shown in Fig. 2. One design of specimen-positioning jig is illustrated in Fig. 3. Detailed requirements are given in subsequent paragraphs. General methods for checking and calibrating the machine are given in Appendix X1. Additional instructions for adjusting a particular machine should be supplied by the manufacturer.

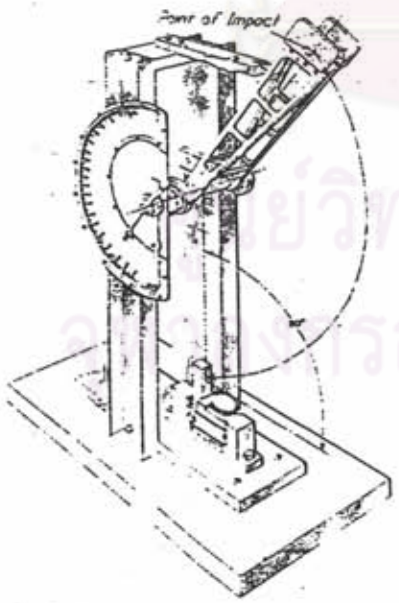


FIG. 2 Cantilever Beam (Izod-Type) Impact Machine

FIG. 3 A Jig for Positioning Specimen for Clamping

5.2 The pendulum shall consist of a single or multimembered arm with a bearing on one end and a head, containing the striking nose, on the other. Although a large proportion of the mass of the pendulum should be concentrated in the head, the arm must be sufficiently rigid to maintain the proper clearances and geometric relationships between the machine parts and the specimen and to minimize vibrational energy losses which are always included in the measured impact value.

5.3 The striking nose of the pendulum shall be hardened steel and shall be a cylindrical surface having a radius of curvature of 0.79 ± 0.12 mm (0.031 ± 0.005 in.) with its axis horizontal and perpendicular to the plane of swing of the pendulum. The line of contact of the striking nose shall be located at the center of percussion of the pendulum within ±2.54 mm (0.100 in.) (Note 5). Those portions of the pendulum adjacent to the cylindrical striking edge shall be recessed or inclined at a suitable angle so that there will be no chance for other than this cylindrical surface coming in contact with the specimen during the break.

NOTE 5—The distance from the axis of support to the center of percussion may be determined experimentally from the period of small amplitude oscillations of the pendulum by means of the following equation:

$$L = (g/4\pi^2)\, p^2$$

where:

L = distance from the axis of support to the center of percussion, m (or ft),

g = local gravitational acceleration (known to an accuracy of one part in one thousand), m/s^2 (or ft/s^2),

π = 3.1416 ($4\pi^2$ = 39.48), and

p = period, in seconds, of a single complete swing (to and fro) determined from at least 50 consecutive and uninterrupted swings (known to one part in two thousand). The angle of swing shall be less than 5° each side of center.

5.4 The position of the pendulum holding and releasing mechanism shall be such that the vertical height of fall of the striking nose shall be 610 ± 2 mm (24.0 ± 0.1 in.). This will produce a velocity of the striking nose at the moment of impact of approximately 3.46 m (11.35 ft)/s. The mechanism shall be so constructed and operated that it will release the pendulum without imparting acceleration or vibration to it.

NOTE 6—

$$V = \sqrt{2gh}$$

where:

V = velocity of the striking nose at the moment of impact,

g = local gravitational acceleration, and

h = vertical height of fall of the striking nose.

This assumes no windage or friction.

5.5 The effective length of the pendulum shall be between 0.325 and 0.406 m (12.8 and 16.0 in.) so that the above required elevation of the striking nose may be obtained by raising the pendulum to an angle between 60 and 30° above the horizontal.

5.6 The machine shall be provided with a basic pendulum capable of delivering an energy of 2.710 ± 0.135 J (2.00 ± 0.10 ft·lbf). This pendulum shall be used with all specimens that extract less than 85 % of this energy. Heavier pendulums shall be provided for specimens that require more energy to break. These may be separate interchangeable pendulums or one basic pendulum to which extra pairs of equal calibrated weights may be attached rigidly to opposite sides of the pendulum at its center of percussion. It is imperative that the extra weights shall not change the position of the center of percussion or the free-hanging rest point of the pendulum. A range of pendulums having energies from 2.710 to 21.680 J (2 to 16 ft·lbf) has been found to be sufficient for use with most plastic specimens and may be used with most machines. A series of pendulums such that each has twice the energy of the next lighter one will be found convenient. Each pendulum shall have an energy within ±0.5 % of its nominal capacity.

5.7 A vise shall be provided for clamping the specimen rigidly in position so that the long axis of the specimen is vertical and at right angles to the top plane of the vise (Fig. 1). This top plane shall bisect the angle of the notch with a tolerance of 0.12 mm (0.005 in.). This correct positioning of the specimen is generally done with a jig furnished with the machine. The top edge at the fixed jaw of the vise shall have a radius of 0.25 ± 0.12 mm (0.010 ± 0.005 in.). For specimens whose thickness approaches the lower limiting value of 3.17 mm (0.125 in.), means shall be provided to prevent the lower half of the specimen from moving during the clamping or testing operations (Fig. 3).

NOTE 7—Some plastics are sensitive to clamping pressure; therefore, cooperating laboratories should agree upon some means of standardizing the clamping force, such as with a torque wrench on the screw of the specimen vise. If the faces of the vise or specimen are not flat and parallel, a greater sensitivity to clamping pressure may be evident. See the calibration procedure in Appendix X1 for adjustment and correction instructions for faulty instruments.

5.8 When the pendulum is free hanging, the striking surface shall come within 0.5 % of scale of touching the front face of a standard specimen. During an actual swing this element shall make initial contact with the specimen on a line 22.00 ± 0.05 mm (0.866 ± 0.002 in.) above the top surface of the vise.

5.9 Means shall be provided for determining energy remaining in the pendulum after breaking the specimen. Usually this will consist of a pointer and dial mechanism which indicate the height of rise of the pendulum beyond the point of impact in terms of energy removed from that specific pendulum. Since the indicated remaining energy must be corrected for pendulum bearing friction, pointer friction, pointer inertia, and pendulum windage, instructions for making these corrections are included in 9.3 and Appendix X2.

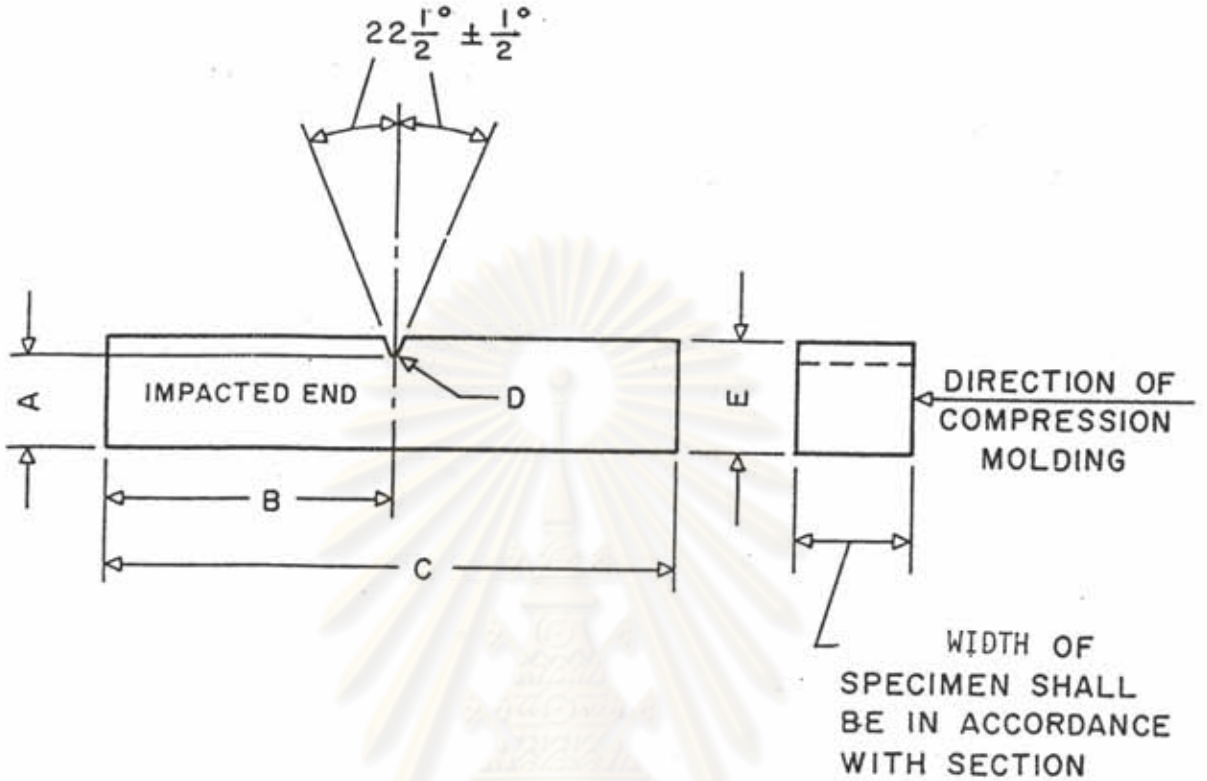
5.10 The vise, pendulum, and frame shall be sufficiently rigid to assure correct alignment of the hammer and specimen, both at the moment of impact and during the propagation of the fracture, and to minimize energy losses due to vibration. The base shall be sufficiently massive that the impact will not cause it to move. The machine shall be so designed, constructed, and maintained that energy losses due to pendulum air drag (windage), friction in the pendulum bearings, and friction and inertia in the excess energy-indicating mechanism, are held to a minimum.

5.11 A check of the calibration of an impact machine is difficult to make under dynamic conditions. The basic parameters are normally checked under static conditions: if the machine passes the static tests, then it is assumed to be accurate. The calibration procedure in Appendix X1 shall be used to establish the accuracy of the equipment. However, for some machine designs it might be necessary to change the recommended method of obtaining the required calibration measurements. Other methods of performing the required checks may be substituted provided that they can be shown to result in an equivalent accuracy. Appendix X1 also describes a dynamic test for checking certain features of the machine and specimen.

6. Test Specimens

6.1 The test specimens shall conform to the dimensions and geometry of Fig. 4, except as modified in accordance with 6.2, 6.3, 6.4, and 6.5. To ensure the correct contour and conditions of the specified notch, all specimens shall be notched as directed in Section 7.

6.2 Molded specimens shall have a width between 3.17 and 12.7 mm (0.125 and 0.500 in.) as specified in the ASTM material specification or as agreed as representative of the cross section in which the particular material may be used (Notes 8 and 9). All specimens having one dimension less than 12.7 mm (0.500 in.) shall have the notch cut on the shorter side (Note 10). Otherwise, all compression molded specimens shall be notched on the side parallel to the direction of application of molding pressure (Note 11). The notched surface and the opposite surface may not be parallel in molded specimens due to the draft of the mold, and, therefore,



	mm	in.
A	10.16 ± 0.05	0.400 ± 0.002
B	32.00 max	1.250 max
	31.50 min	1.240 min
C	63.50 max	2.500 max
	60.30 min	2.375 min
D	0.25R ± 0.05	0.010R ± 0.002
E	12.70 ± 0.15	0.500 ± 0.006

FIG. 4 Dimensions of Izod Type Test Specimen

it is essential that the notched surface be machined parallel to its opposite surface within 0.025 mm (0.001 in.), removing a minimum of material in the process, so as to remain within the allowable tolerance for the specimen depth (see Fig. 4).

NOTE 8—Extreme care must be used in handling specimens less than 6.35 mm (0.250 in.) wide. Such specimens must be accurately positioned and supported to prevent twist or lateral buckling during the test. Some materials, furthermore, are very sensitive to clamping pressure (see Note 7).

NOTE 9—The type of mold and molding machine used and the flow behavior in the mold cavity will influence the strength obtained. A specimen taken from one end of a molded bar may give different results from a specimen taken from the other end. Cooperating laboratories should, therefore agree on standard molds conforming to Practice D 647, and upon a standard molding procedure for the material under investigation.

NOTE 10—A critical investigation of the mechanics of impact testing has shown that tests made upon specimens under 6.36 mm (0.250 in.) wide absorb more energy due to crushing, bending, and twisting than do wider specimens. Therefore, specimens 6.36 mm (0.250 in.) or over in width are recommended. The responsibility for determining the minimum specimen width shall be the investigator's with due reference to the ASTM specification for that material.

NOTE 11—The impact strength of a plastic material may be different if the notch be perpendicular to rather than parallel to the direction of molding, as with or across the grain of an anisotropic bar cut from a plate.

6.3 For sheet materials, the specimens shall be cut from the sheet in both the lengthwise and crosswise directions unless otherwise specified. The width of the specimen shall be the thickness of the sheet if the sheet thickness is between 3.17 and 12.7 mm (0.125 and 0.500 in.). Sheet material thicker than 12.7 mm (0.500 in.) shall be machined down to 12.7 mm (0.500 in.). Specimens with a 12.7-mm (0.500 in.) square cross section may be tested either edgewise or flatwise as cut from the sheet. When specimens are tested flatwise, the notch shall be made on the machined surface if the specimen be machined on one face only. When the specimen is cut from a thick sheet, notation shall be made of the portion of the thickness of the sheet from which the specimen was cut, for example, center, top, or bottom surface.

6.4 The practice of cementing, bolting, clamping, or otherwise combining specimens of substandard width to form a composite test specimen is not recommended and

should be avoided since test results may be seriously affected by interface effects or effects of solvents and cements on energy absorption of composite test specimens, or both. However, if Izod test data on such thin materials are required when no other means of preparing specimens are available, and if possible sources of error are recognized and acceptable, the following technique of preparing composites may be utilized. The test specimen shall be a composite of individual thin specimens totaling 6.35 to 12.7 mm (0.250 to 0.500 in.) in width. Individual members of the composite shall be accurately aligned with each other and clamped, bolted or cemented (Note 12) together. The composite shall be machined to proper dimensions and then notched. In all such cases the use of composite specimens shall be noted in the report of test results.

NOTE 12—Care must be taken to select a solvent or adhesive that will not affect the impact resistance of the material under test. If solvents or solvent-containing adhesives are employed, a conditioning procedure shall be established to ensure complete removal of the solvent prior to test.

6.5 Each specimen shall be free of twist (Note 13) and shall be bounded by mutually perpendicular pairs of plane parallel surfaces, free from scratches, pits, and sink marks. The specimens shall be checked for conformity with these requirements by visual observation against straightedges, squares, and flat plates, and by measuring with micrometer calipers. Any specimen showing observable or measurable departure from one or more of these requirements shall be rejected or machined to the proper size and shape before testing.

NOTE 13—A specimen that has a slight twist to its notched face of 0.05 mm (0.002 in.) at the point of contact with the pendulum striking edge will be likely to have a characteristic fracture surface with considerable greater fracture area than for a normal break. In this case the energy to break and toss the broken section may be considerably larger (20 to 30 %) than for a normal break. A tapered specimen may require more energy to bend it in the vise before fracture.

7. Notching Test Specimens

7.1 Notching shall be done on a milling machine, engine lathe, or other suitable machine tool, accurate to 0.025 mm (0.001 in.). Both the feed speed and the cutter speed shall be constant throughout the notching operation (Note 16). Provision for cooling the specimen with either a liquid or gas coolant is recommended. A single-tooth cutter shall be used for notching the specimen, unless notches of an equivalent quality can be produced with a multitooth cutter. Single-tooth cutters are preferred because of the ease of grinding the cutter to the specimen contour and because of the smoother cut on the specimen. The cutting edge shall be carefully ground and honed to ensure sharpness and freedom from nicks and burrs. Tools with no rake and a work relief angle of 15 to 20° have been found satisfactory.

7.2 Specimens may be notched separately or in a group. However, in either case an unnotched back-up or "dummy" bar shall be placed behind the last specimen in the sample holder to prevent distortion and chipping by the cutter as it exits from the last test specimen.

7.3 The profile of the cutting tooth or teeth shall be such as to produce a notch of the contour and depth in the test specimen as specified in Fig. 4 (Note 14). The included angle of the notch shall be 45 ± 1° with a radius of curvature at the apex of 0.25 ± 0.05 mm (0.010 ± 0.002 in.). The plane bisecting the notch angle shall be perpendicular to the face of the test specimen within 2°.

NOTE 14—There is evidence that notches cut in materials of widely differing physical properties by the same cutter may differ in contour. If the notch in the specimen should take the contour of the cutter, then the contour of the tip of the cutter may be checked instead of the notch in the specimen for single-tooth cutters. Under the same condition, multi-tooth cutters may be checked by measuring the contour of a strip of soft metal shim inserted between two bars for notching.

7.4 The depth of the plastic material remaining in the bar under the notch shall be 10.16 ± 0.05 mm (0.400 ± 0.002 in.). This dimension shall be measured, on a random selection of at least 20 % of each group of specimens notched at the same time, with a special micrometer[7] having a contour anvil of 42 ± 2° with a radius of curvature at the apex of 0.13 ± 0.07 mm (0.005 ± 0.003 in.). In the case of referee testing, each specimen shall be measured.

7.5 Cutter speed and feed speed should be chosen appropriate for the material being tested since the quality of the notch may be adversely affected by thermal deformations and stresses induced during the cutting operation if proper conditions are not selected.[8] The notching parameters used shall not alter the physical state of the material such as by raising the temperature of a thermoplastic above its glass transition temperature. In general, high cutter speeds, slow feed rates, and lack of coolant induce more thermal damage than a slow cutter speed, fast feed speed, and the use of a coolant. Too high a feed speed/cutter speed ratio, however, may cause impacting and cracking of the specimen. The range of cutter speed/feed ratios possible to produce acceptable notches can be extended by the use of a suitable coolant (Note 15). In the case of new types of plastics and electrical insulating materials, it is necessary to study the effect of variations in the notching conditions (Note 17).

NOTE 15—Water or compressed gas is a suitable coolant for many plastics.

NOTE 16—To establish that the notching parameters are suitable, the quality of the notch can be checked with a metallograph or suitable microscope using at least a 60× magnification. The notch should be checked on both the tool entrance and tool exit side of the specimen. Embedded thermocouples can be used to determine the temperature rise in the material near the apex of the notch during machining. Thermal stresses induced during the notching operation can be observed in transparent materials by viewing the specimen at low magnification between crossed polars in monochromatic light.

NOTE 17—For some thermoplastics, cutter speeds from 53.3 to 150 m/min (160 to 450 ft/min) at a feed speed of 88.9 to 160 mm/min (3.5 to 6.3 in./min) without a water coolant or the same cutter speeds at feed of from 35.6 to 160 mm/min (1.4 to 6.3 in./min) with water coolant produced suitable notches.

7.6 After an individual cutter has been used to produce 300 notches, or more often as circumstances may indicate, the notch in a specimen (Note 18) shall be inspected for a clean, sharp cut, freedom from nicks, thermal deformation, correct radius of tip, and notch angle. If the angle or radius should not fall within the specified limits for materials of satisfactory machining characteristics, then the cutter shall be replaced with a newly sharpened and honed one.

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[7] Available from Custom Scientific Instruments, Inc., P.O. Box A, Whippany, NJ 07981, and Testing Machines, Inc., 400 Bayview Ave., Amityville, NY 11701.

[8] Supporting data are available from ASTM Headquarters. Request RR:D20-1066.

NOTE 18—PMMA (3.17 mm (⅛ in.)) has been found useful for checking the sharpness of a cutter. Dull cutters tend to form cracks at the apex of the notch. A microscope with a camera lucida attachment (60× magnification) is suitable for checking the radius and angle of notch.

NOTE 19—A carbide-tipped notching cutter is recommended for longer service life.

8. Conditioning

8.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h after notching and prior to testing in accordance with Procedure A of Methods D 618, unless it can be documented (between supplier and customer) that shorter conditioning time is sufficient for a given material to reach equilibrium of impact strength.

8.1.1 Note that for some hygroscopic materials, such as nylons, the material specifications (for example, Specification D 4066) 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.

8.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified in the test methods. In cases of disagreement, the tolerances shall be ±1°C (±1.8°F) and ±2 % relative humidity.

9. Procedure

9.1 At least five and preferably ten or more individual determinations of impact value must be made on each sample to be tested under the conditions prescribed in Section 8. Each group shall consist of specimens of one nominal width only. In the case of specimens cut from sheets that are suspected of being anisotropic, prepare and test specimens from each principal direction (lengthwise and crosswise to the direction of anisotropy).

9.2 Estimate the breaking energy for the specimen and select a pendulum of suitable energy. Use the lightest standard pendulum that is expected to break each specimen in the group with a loss of not more than 85 % of its energy (Note 20). Check the machine with the proper pendulum in place for conformity with the requirements of Section 5 before starting the tests (see Appendix X1).

NOTE 20—Ideally an impact test would be conducted at a constant test velocity. In a pendulum-type test the velocity decreases as the fracture progresses. For specimens that have an impact energy approaching the capacity of the pendulum there is insufficient energy to complete the break and toss. By avoiding the higher 15 % scale energy readings the velocity of the pendulum will not be reduced below 1.33 m/s (4.4 ft/s). On the other hand, the use of too heavy a pendulum would reduce the sensitivity of the reading.

9.3 Before testing the specimens, perform the following operations on the machine:

9.3.1 With the excess energy indicating pointer in its normal starting position but without a specimen in the vise, release the pendulum from its normal starting position and note the position the pointer attains after the swing as one reading of factor *A*.

9.3.2 Without resetting the pointer, raise the pendulum and release again. The pointer should move up the scale an additional amount. Repeat (*2*) until a swing causes no additional movement of the pointer and note the final reading as one reading of factor *B*.

9.3.3 Repeat the above two operations several times and calculate and record the average *A* and *B* readings.

NOTE 21—Factor *B* is an indication of the energy lost by the pendulum to friction in the pendulum bearings and to windage. The difference *A*−*B* is an indication of the energy lost to friction and inertia in the excess energy indicating mechanism. However, the actual corrections will be smaller than these factors, since in an actual test the energy absorbed by the specimen prevents the pendulum from making a full swing. Therefore, the indicated breaking strength of the specimen must be included in the calculation of the machine correction before using it in 9.6. These *A* and *B* values also provide an indication of the condition of the machine. If they indicate excessive friction, the machine shall be adjusted before starting a test.

9.4 Check the specimens for conformity with the requirements of Sections 6 and 7. Measure the width of each specimen in the region of the notch with a micrometer caliper to the nearest 0.025 mm (0.001 in.) and record its average width along with its identifying markings.

9.5 Position the specimen precisely (5.7) and rigidly but not too tightly (Note 7) clamped in the vise. Pay special attention to assure that the "impacted end" of the specimen as shown and dimensioned in Fig. 4 be the end projecting above the vise. Release the pendulum and note and record the excess energy remaining in the pendulum after breaking the specimen, together with a description of the appearance of the broken specimen (see failure categories in 4.7).

9.6 Calculate the machine correction from the indicating breaking strength of the specimen and factors *A* and *B* using tables or the graph described in Appendix X2. Subtract the correction so calculated from the indicated breaking strength of the specimen. Compare the net value so found with the energy requirement of the hammer specified in 9.2. If a hammer of improper energy was used, discard the result and make additional tests on new specimens with the proper hammer. If the proper hammer was used, divide the net value so found by the measured width of the particular specimen to obtain its impact strength in joules per metre (foot-pounds-force per inch) of width.

9.7 Calculate the average impact strength of the group of specimens. However, only values of specimens having the same nominal width and type of break may be averaged. Values obtained from specimens that did not break in the manner specified in 4.7 shall not be included in the average. When required, also calculate the standard deviation of the group of values.

10. Report

10.1 The report shall include the following:

10.1.1 Complete identification of the material tested, including type source, manufacturer's code number, and previous history.

10.1.2 A statement of how the specimens were prepared, the testing conditions used, the number of hours the specimens were conditioned after notching, and, for sheet materials, the direction of testing with respect to anisotropy, if any.

10.1.3 The capacity of the pendulum in joules, or foot-pounds-force, or inch-pounds-force.

10.1.4 The nominal width of the specimen.

NOTE 22—All abbreviated or tabulated reports shall include after the Izod impact strength value the nominal specimen width in millimetres or inches in brackets (see 4.6).

10.1.5 The total number of specimens tested per sample of material (that is, five, ten, or more).

10.1.6 The number of those specimens that resulted in failures conforming to each of the categories requirements of 4.7.

10.1.7 The average impact strength in joules per metre, or foot-pounds-force per inch, of width of the specimens of 10.1.6 for each failure category except non-break.

10.1.8 If required, the standard deviation of the values of the impact strengths of the specimens of 10.1.6.

10.1.9 The percent of specimens failing in each category suffixed by the corresponding letter code from 4.7.

TEST METHOD B—SIMPLE BEAM (CHARPY-TYPE) TEST

11. Apparatus

11.1 The machine shall consist of a massive base on which are mounted a pair of supports for holding the specimen and to which is connected, through a rigid frame and anti-friction bearings, one of a number of pendulum-type hammers having an initial energy suitable for use with the particular specimen to be tested, plus a pendulum holding and releasing mechanism and a pointer and dial mechanism for indicating the excess energy remaining in the pendulum after breaking the specimen. A jig for positioning the specimen on the supports and graphs or tables to aid in the calculation of the correction for friction and windage also should be included. One design of machine is illustrated in Fig. 5. Specific requirements are given in subsequent paragraphs. General methods for checking and calibrating the machine are given in Appendix X1. Additional instructions for adjusting a particular machine should be supplied by the manufacturer.

11.2 Same as 5.2.

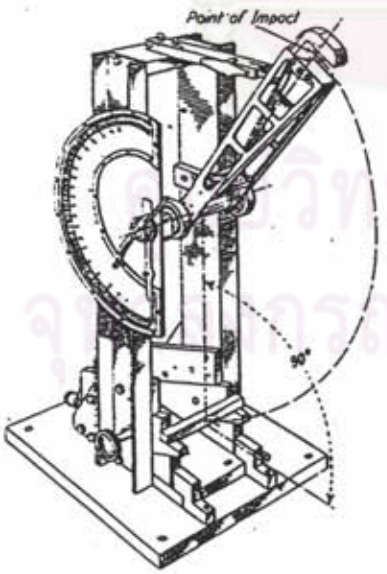
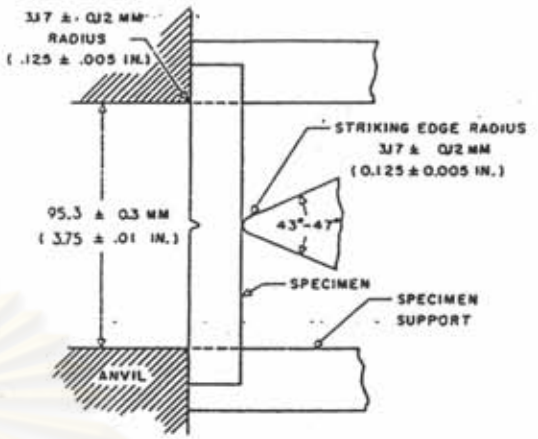


FIG. 5 Simple Beam (Charpy-Type) Impact Machine



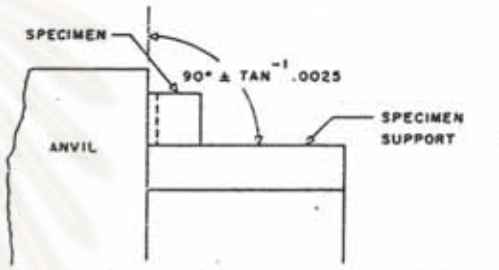


FIG. 6 Relationship of Anvil, Specimen and Striking Edge to Each Other for Charpy Test Method

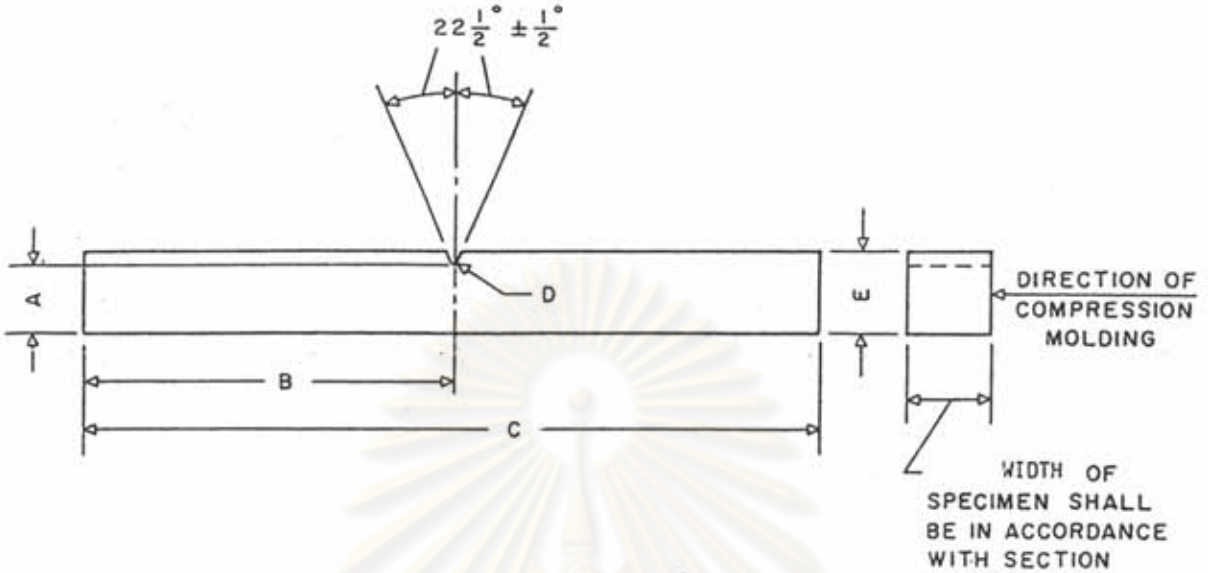
11.3 The striking edge of the pendulum shall be made of hardened steel, tapered to have an included angle of 45 ± 2° and shall be rounded to a radius of 3.17 ± 0.12 mm (0.125 ± 0.005 in.). It shall be so aligned that when the pendulum is free hanging the cylindrical impacting surface shall have a vertical axis and be tangent to the front face of a rectangular standard specimen to within 0.025 mm (0.001 in.). In the free hanging position the center of percussion of the pendulum shall lie within 2.54 mm (0.100 in.) of the middle of the line of contact made by the striking nose upon the face of a standard specimen of square cross section (Note 5).

11.4 Same as 5.4.

11.5 Same as 5.5.

11.6 The machine shall be provided with a basic pendulum capable of delivering an energy of 2.710 ± 0.135 J (2.00 ± 0.10 ft·lbf). This pendulum shall be used with all specimens that extract less than 85 % of this energy. Heavier pendulums shall be provided for specimens that require more energy to break. Each pendulum shall have an energy within 0.5 % of its nominal capacity.

11.7 The test specimen shall be supported against two rigid anvils in such a position that its center of gravity and the center of the notch shall lie on tangent to the arc of travel of the center of percussion of the pendulum drawn at the position of impact. The edges of the anvils shall be rounded to a radius of 3.17 ± 0.12 mm (0.125 ± 0.005 in.) and the anvils' lines of contact with the specimen shall be 101.6 ± 0.5 mm (4.000 ± 0.020 in.) apart (Fig. 6).



	mm	in.
A	10.16 ± 0.05	0.400 ± 0.002
B	63.50 max	2.500 max
	61.00 min	2.400 min
C	127.00 max	5.000 max
	124.50 min	4.900 min
D	0.25R ± 0.05	0.010R ± 0.002
E	12.70 ± 0.15	0.500 ± 0.006

FIG. 7 Dimensions of Simple Beam, Charpy Type, Impact Test Specimen

11.8 Same as 5.9.

NOTE 23—Some machines currently in use employ a 108.0-mm (4.25-in.) span. Data obtained under these conditions are valid.*

11.9 Same as 5.10.

11.10 Same as 5.11.

12. Test Specimen

12.1 The test specimen shall conform to the dimensions and geometry of Fig. 7, except as modified in accordance with 12.2, 12.3, 12.4, and 12.5. To ensure the correct contour and conditions of the specified notch, all specimens shall be notched as directed in Section 7.

12.2 Same as 6.2.

12.3 Same as 6.3.

12.4 Same as 6.4.

12.5 Same as 6.5.

13. Conditioning

13.1 *Conditioning*—See 8.1.

13.2 *Test Conditions*—See 8.2.

14. Procedure

14.1 Same as 9.1.

14.2 Same as 9.2.

14.3 Same as 9.3.

14.4 Check the specimen for conformity with the requirements of Section 12. Measure the width of each specimen in the region of the notch with a micrometre caliper to the nearest 0.025 mm (0.001 in.) and record its average width along with its identifying markings.

14.5 Position the test specimen precisely on the supports in a horizontal position so that it will be impacted edgewise at its center on the face opposite the notch for notched specimens. Release the pendulum and note and record the excess energy remaining in the pendulum after breaking the specimen, together with a description of the appearance of a broken specimen.

14.6 Same as 9.6.

14.7 Same as 9.7.

15. Report

15.1 The report shall include the following:

15.1.1 Same as 10.1.1.

15.1.2 Same as 10.1.2.

15.1.3 Same as 10.1.3.

15.1.4 The nominal width of the specimens.

15.1.5 Same as 10.1.5.

15.1.6 The number of those specimens that resulted in a complete break.

15.1.7 The average impact strength in joules per metre, or foot-pounds-force per inch, of width for the specimens of 15.1.6 above that resulted in a complete break (Note 24). Impact strengths are not to be reported for other than complete breaks.

* Supporting round-robin data are available from ASTM Headquarters. Request RR:D20-1033.

NOTE 24—All abbreviated or tabulated reports shall affix behind the Charpy impact strength value the nominal specimen thickness in millimetres (or inches) in brackets (see 4.6).

15.1.8 Same as 10.1.8.

15.1.9 The percent of specimens failing with a complete break.

15.1.10 Span (see Note 23).

TEST METHOD C—CANTILEVER BEAM (IZOD-TYPE) TEST FOR MATERIALS OF LESS THAN 27 J/m (0.5 ft·lbf/in.) OF NOTCH

16. Apparatus

16.1 The apparatus shall be the same as specified in Section 5.

17. Test Specimen

17.1 The test specimen shall be the same as specified in Section 6.

18. Conditioning

18.1 *Conditioning*—See 8.1.

18.2 *Test Conditions*—See 8.2.

19. Procedure

19.1 The procedure shall be the same as in Section 9 with the addition of a procedure for estimating the energy to toss the broken specimen part. Make an estimate of the magnitude of the energy to toss each different type of material and each different specimen size (width). This is done by repositioning the free end of the broken specimen on the clamped portion and striking it a second time with the pendulum released in such a way as to impart to the specimen approximately the same velocity it had attained during the test. This is done by releasing the pendulum from a height corresponding to that to which it rose following the breakage of the test specimen. The energy to toss is then considered to be the difference between the reading described above and the free swing reading obtained from this height. A reproducible method of starting the pendulum from the proper height must be devised.

20. Report

20.1 The report shall be the same as in Section 10 with the addition of the following:

20.1.1 The estimated toss correction expressed in joules per metre of notch or foot-pounds-force per inch of notch, obtained by dividing the energy to toss in joules or foot-pounds-force by the specimen width in metres or inches, and

20.1.2 The difference between the Izod impact strength and the toss correction reported as the estimated net Izod impact strength.

TEST METHOD D—NOTCH RADIUS SENSITIVITY TEST

21. Apparatus

21.1 The apparatus shall be the same as specified in Section 5.

22. Test Specimen

22.1 The specimens shall be the same as specified in Section 6. All specimens must be of the same nominal width, preferably 6.35 mm (0.25 in.).

23. Notching

23.1 Notching shall be done as specified in Section 7 and Fig. 4, except that 10 specimens shall be notched with a radius of 0.25 mm (0.010 in.) and 10 specimens with a radius of 1.0 mm (0.040 in.).

24. Conditioning

24.1 Condition specimens in accordance with Section 8.

25. Procedure

25.1 Proceed in accordance with Section 9, testing a minimum of 5 (preferably 10) specimens of each notch radius.

25.2 The average impact strength of each group shall be calculated, except that within each group the type of break must be homogeneously C, H, C & H, or P.

25.3 If the specimens with the 0.25-mm (0.010-in.) radius notch do not break, the test is not applicable.

25.4 If any of 10 specimens tested with the 1.0 mm (0.040 in.) notch fail as in category NB, nonbreak, the notch sensitivity procedure cannot be used without obtaining additional data. A new set of specimens should be prepared from the same sample, using a 0.50-mm (0.020-in.) notch radius and the procedure of 25.1 and 25.2 repeated.

26. Calculation

26.1 The slope of the line connecting the values for impact energy-to-break for 0.254 and 1.012-mm (0.010 and 0.040-in.) notch radius (or 0.508-mm (0.020-in.) notch radius if applicable) should be calculated as follows:

$$b = E_A - E_B/R_2 - R_1$$

where:

E_A, E_B = average energy to break for the larger and smaller notch radii respectively, J/m (ft·lbf/in.) of notch,

R_2 = radius of the larger notch, m (in.), and

R_1 = radius of the smaller notch, m (in.).

Example: $E_{.50} = 6.2$ ft·lbf/in. $E_{.10} = 2.6$ ft·lbf/in.

$b = 6.2 - 2.6/0.040 - 0.010 = 3.6/0.03 = 120$ ft·lbf/in. of notch/in. (radius)

27. Report

27.1 The average value of b with its units, and the average Izod impact energy, 0.254 mm (0.010 in.) notch, shall be reported.

TEST METHOD E—CANTILEVER BEAM REVERSED NOTCH TEST

28. Apparatus

28.1 The apparatus shall be the same as specified in Section 5.

29. Test Specimen

29.1 The test specimen shall be the same as specified in Section 6.

30. Notching Test Specimens

30.1 Notch the test specimens in accordance with Section 7.

31. Conditioning

31.1 See 8.1.

31.2 *Test Conditions*—See 8.2.

32. Procedure

32.1 Proceed in accordance with Section 9, except clamp the specimen so that the striker impacts it on the face opposite the notch, hence subjecting the notch to compressive, rather than tensile stresses during impact (see Fig. 1*b* and Notes 25, 26, and 27.

NOTE 25—The reversed notch test employs a standard 0.25-mm (0.010-in.) notch specimen to provide an indication of unnotched impact strength. Use of the reversed notch test obviates the need for machining unnotched bars to the required 10.16 ± 0.05-mm (0.400 ± 0.002-in.) depth before testing and provides the same convenience of specimen mounting as the standard notch tests (Test Methods A and C).

NOTE 26—Where materials are suspected of anisotropy, due to molding or other fabricating influences, notch reversed notch specimens on the face opposite to that used for the standard Izod test; that is, present the same face to the impact blow.

NOTE 27—Results obtained by the reversed notch test may not always agree with those obtained on unnotched bars that have been machined to the 10.16-mm (0.400-in.) depth requirement. For some materials, the effects arising from the difference in the clamped masses of the two specimen types during test, and those attributable to a possible difference in toss energies ascribed to the broken ends of the respective specimens, may contribute significantly to a disparity in test results.

33. Report

33.1 The report shall include the following:

33.1.1 Same as 10.1.1,

33.1.2 Same as 10.1.2,

33.1.3 Same as 10.1.3,

33.1.4 Same as 10.1.4,

33.1.5 Same as 10.1.5,

33.1.6 Same as 10.1.6,

33.1.7 The average reversed notch impact strength, in joules per metre, or foot-pounds-force per inch, of width of the specimens of 10.1.6 for each category except non-break,

33.1.8 Same as 10.1.8, and

33.1.9 Same as 10.1.9.

34. Precision and Bias

34.1 Tables 1, 2, and 3 are based on a round robin[10] in accordance with Practice E 691. For each material, all the test bars were prepared at one source, except for notching. Each participating laboratory notched the bars that they tested. Tables 1, 2, and 3 are presented on the basis of a test result being the average for five specimens. In the round robin each laboratory tested, on average, nine specimens of each material.

34.2 Table 4 is based on a round robin[6] involving five materials tested by seven laboratories. For each material, all the samples were prepared at one source, and the individual specimens were all notched at the same laboratory. Table 4 is presented on the basis of a test result being the average for five specimens. In the round robin, each laboratory tested ten specimens of each material.

NOTE 28—Caution: The following explanations of I_r and I_R (34.3 through 34.3.3) are only intended to present a meaningful way of considering the *approximate* precision of this test method. The data in Tables 1 through 4 should not be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and may not be representative of other lots, conditions, materials, or laboratories. Users of this test method should apply the principles outlined in Practice E 691 to generate data specific to their laboratory and materials, or between specific laboratories. The principles of 34.3 through 34.3.3 would then be valid for such data.

34.3 *Concept of* I_r *and* I_R—If S_r and S_R have been calculated from a *large enough body of data*, and for test results that were averages from testing 5 specimens.

[10] Supporting data are available from ASTM Headquarters. Request RR: D-20-1134.

TABLE 1 Precision, Test Method A (Izod)

Material	Values in ft-lbf/in. of width					No. of Laboratories
	Avg	S_r[A]	S_R[B]	I_r[C]	I_R[D]	
Phenolic	0.57	0.024	0.076	0.06	0.21	19
Acetal	1.45	0.075	0.504	0.21	1.70	9
Reinforced nylon	1.98	0.083	0.245	0.23	0.69	15
Polypropylene	2.66	0.154	0.573	0.43	1.62	24
ABS	10.8	0.136	0.585	0.38	1.65	25
Polycarbonate	16.4	0.295	1.056	0.83	2.98	25

[A] S_r = within-laboratory standard deviation of the average.
[B] S_R = between-laboratories standard deviation of the average.
[C] $I_r = 2.83\ S_r$, and
[D] $I_R = 2.83\ S_R$.

TABLE 2 Precision, Test Method B (Charpy)

Material	Values in ft-lbf/in. of width					No. of Laboratories
	Avg	S_r[A]	S_R[B]	I_r[C]	I_R[D]	
Phenolic	0.55	0.029	0.050	0.08	0.14	7
Reinforced nylon	1.98	0.065	0.143	0.18	0.40	7
Polycarbonate	2.85	0.083	0.422	0.23	1.19	8
Polypropylene	4.06	0.151	0.422	0.42	1.19	9
ABS	10.3	0.115	0.629	0.32	1.78	9

[A] S_r = within-laboratory standard deviation of the average.
[B] S_R = between-laboratories standard deviation of the average.
[C] $I_r = 2.83\ S_r$, and
[D] $I_R = 2.83\ S_R$.

TABLE 3 Precision, Test Method C (Izod with Toss Correction)

Material	Values in ft-lbf/in. of width					No. of Laboratories
	Avg	S_r	S_w	I_r	I_w	
Phenolic	0.45	0.038	0.129	0.10	0.36	15

[A] S_r = within-laboratory standard deviation of the average.
[B] S_w = between-laboratories standard deviation of the average.
[C] $I_r = 2.83\ S_r$, and
[D] $I_w = 2.83\ S_w$.

TABLE 4 Precision, Test Method E (Reversed Notch Izod)

Material	Values in ft-lbf/in. of width				
	Avg	S_r[A]	S_w[B]	I_r[C]	I_w[D]
Acrylic sheet, unmodified	3.02	0.243	0.252	0.68	0.71
Premix molding compounds laminate	6.11	0.767	0.786	2.17	2.22
Rubber modified acrylic, injection molded	10.33	0.878	1.276	2.49	3.61
Sheet molding compound (SMC) laminate	11.00	0.719	0.785	2.03	2.22
Preformed mat laminate	19.43	0.960	1.618	2.72	4.58

[A] S_r = within-laboratory standard deviation of the average.
[B] S_w = between-laboratories standard deviation of the average.
[C] $I_r = 2.83\ S_r$, and
[D] $I_w = 2.83\ S_w$.

34.3.1 *Repeatability*, I_r (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 I_r value for that material.

34.3.2 *Reproducibility*, I_R (Comparing two test results for the same material, obtained by different operators using different equipment on different days)—The two test results should be judged not equivalent if they differ by more than the I_R value for that material.

34.3.3 Any judgment in accordance with 34.3.1 and 34.3.2 would have an approximate 95 % (0.95) probability of being correct.

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

APPENDIXES

(Nonmandatory Information)

X1. CALIBRATION OF LOW-CAPACITY (1.36 TO 21.68-J OR 1 TO 16-FT•LBF) IMPACT MACHINES FOR USE WITH PLASTIC SPECIMENS

X1.1 This calibration procedure applies specifically to the Izod impact machine. However, much of this procedure can be applied to the Charpy impact machine as well.

X1.2 Locate the impact machine on a sturdy base. It shall not "walk" on the base and the base shall not vibrate appreciably. Loss of energy from vibrations will give high readings. It is recommended that the impact tester be bolted to a base weighing at least 23 kg (50 lb) if it is used at capacities higher than 2.71 J (2 ft·lbf).

X1.3 Check the levelness of the machine in both directions in the plane of the base with spirit levels mounted in the base, by a machinist's level if a satisfactory reference surface is available, or with a plumb bob. The machine should be level to within $\tan^{-1}$ 0.001 in the plane of swing and to within $\tan^{-2}$ 0.002 in the plane perpendicular to the swing.

X1.4 With a straightedge check the height of the specimen clamping block relative to the vise. It must match the height of the vise within 0.08 mm (0.003 in.).

X1.5 Check the transverse location of the center of the pendulum striking edge which shall be within 0.40 mm (0.016 in.) of the center of the vise. Readjust the shaft bearings or relocate the vise, or straighten the pendulum shaft as necessary to attain the proper relationship between the two centers.

X1.6 Check the pendulum arm for straightness within 1.2 mm (0.05 in.) with a straightedge or by sighting down the shaft. This arm is sometimes bent by allowing the pendulum to slam against the catch when high capacity weights are on the pendulum.

X1.7 Insert vertically and center with a locating jig in the vise a straight machined bar 12.7 mm (0.500 in.) square and 25.4 mm (1 in.) long. Check the bar for vertical alignment within $\tan^{-1}$ 0.005 in both directions with a small machinist's level. Shim up the vise if necessary to correct for errors in the plane of pendulum swing, using care to preserve solid support for the vise. For errors in the plane perpendicular to the plane of pendulum swing, machine the inside face of the clamp type locating jig for correct alignment. If a blade-type jig is used, grind the shims or the base of the vise to bring the top surface level.

X1.8 Place a 60-mm (2.5-in.) length of unnotched metal bar ground flat and parallel within 0.025 mm (0.001 in.) in the center of the vise in the vertical position. Place a thin film of oil on the striking edge of the pendulum with an oiled tissue and let the striking edge rest gently against the specimen. The striking edge should make uniform contact

across the surface of the bar. If partial contact is made, examine the vise or pendulum for the cause of the misalignment. If no cause is apparent, remove the striking edges and shim up the low side or grind the striker back face for good contact of the striking edge with the specimen.

X1.9 Check oil line on face of bar for horizontal setting of striking edge within $\tan^{-1}$ 0.002 with a machinist's square.

X1.10 Without taking the bar of X1.8 from the vise of the machine, scratch a thin line on the face opposite the striking face of the bar at the top edge of the vise. Remove the bar from the vise and transfer this line to the striking face, using a machinist's square. The distance from the striking oil line to the top edge of the vise should be 21.95 to 22.05 mm (0.864 to 0.868 in.). Correct with shims or grinding as necessary at the bottom of the vise.

X1.11 Insert the bar of X1.8 again in the vise and clamp it tightly in the vertical position. When the pendulum is hanging free in its lowest position, the striking edge should come within 0.5 % of scale on either side of the position of contact with the specimen.

X1.12 Swing the pendulum to a horizontal position and support it by the striking edge in this position with a 6.3 mm (¼-in.) diameter vertical bar. Allow the other end of this bar to rest at the center of a load pan on a balanced scale. Subtract the weight of the bar from the total weight to find the effective weight of the pendulum. The effective pendulum weight should be within 0.4 % of the required weight for that pendulum capacity. If weight must be added or removed, care must be taken to balance the added or removed weight about the center of percussion (striking edge). It is not advisable to add weight to the opposite side of the bearing axis from the striking edge to increase the effective length of the pendulum since the distributed mass will lead to large energy losses from vibration of the pendulum.

X1.13 Calculate the effective length of the pendulum arm, or the distance to the center of percussion from the axis of rotation, by the procedure of Note 5. The effective length must be within the tolerance stated in 5.3.

X1.14 Measure the vertical distance of fall of the pendulum striking edge from the trip height to its lowest point. This distance should be 610 ± 2.0 mm (24 ± 0.1 in.). This measurement may be made by blocking up a level on the top of the vise and measuring the vertical distance from the loading nose to the bottom of the level and subtracting 22.0 mm (0.866 in.). The vertical falling distance may be adjusted by varying the position of the pendulum latch.

X1.15 Notch a standard specimen on one side, parallel to the molding pressure, at 32 mm (1.25 in.) from one end. The depth of the plastic material remaining in the specimen under the notch shall be 10.16 ± 0.05 mm (0.400 ± 0.002 in.). Use a jig to position the specimen correctly in the vise. When the specimen is clamped in place, the center of the notch should be within 1.2 mm (0.005 in.) of being in line with the top of the fixed surface of the vise and the specimen should be centered midway within 0.40 mm (0.015 in.) between the ends of the clamping faces. The notched face should be the striking face of the specimen for the Izod test. Under no circumstances during the breaking of the specimen should the top of the specimen touch the pendulum except at the striking edge.

X1.16 If a clamping-type locating jig is used, examine the clamping screw in the locating jig. If the thread has a loose fit the specimen may not be correctly positioned and may tend to creep as the screw is tightened. A burred or bent point on the screw may also have the same effect.

X1.17 When the pendulum is in position to just touch the test specimen the pointer should be at the full scale index within 0.2 % of scale.

X1.18 The pointer friction should be adjusted so that the pointer will just maintain its position anywhere on the scale. The striking pin of the pointer should be securely fastened to the pointer. Friction washers with glazed surfaces should be replaced with new washers. Friction washers should be on either side of the pointer collar. The last friction washer installed should be backed by a heavy metal washer. Pressure on this metal washer is produced by a thin bent spring washer and locknuts. If the spring washer is placed next to the fiber friction washer the pointer will tend to vibrate during impact.

X1.19 The free swing reading of the pendulum (without specimen) from the tripping height should be less than 2.5 % of pendulum capacity on the first swing. If the reading is higher than this then the pointer friction is excessive or the bearings are dirty. To clean the bearings dip them in grease solvent and spin dry in an air jet. Clean the bearings until they spin freely, or replace them. Oil very lightly with instrument oil before replacing. A reproducible method of starting the pendulum from the proper height must be devised.

X1.20 The position of the pointer after three swings of the pendulum, each from the starting position, without manual readjustment of the pointer should be 1 % or less of the pendulum capacity. If the readings differ from this, then the machine is out of plumb, the calibration dial is out of alignment, or the pendulum finger is out of calibration position.

X1.21 The shaft about which the pendulum rotates shall have no detectable radial play (less than 0.05 mm (0.002 in.)). An end play of 0.25 mm (0.010 in.) is permissible when a 9.8-N (2.2-lbf) axial force is applied in alternate directions. This shaft shall be horizontal within $\tan^{-1}$ 0.003 as checked with a level.

X1.22 The vise faces should be parallel in the horizontal and vertical directions within 0.025 mm (0.001 in.). This may be checked by inserting the machined square metal bar of X1.8 into the vise in a vertical position and clamping until the jaws begin to bind. Any freedom between the metal bar and the clamping surfaces of the jaws of the vise must not exceed the specified tolerance.

X1.23 The top edge of the fixed jaw of the vise shall have a radius of 0.25 ± 0.12 mm (0.010 ± 0.005 in.). This is the edge of stress concentration as the specimen breaks and should be examined carefully.

X1.24 If a brittle unfilled or granular filled plastic bar such as a general-purpose wood-flour-filled phenolic material is available, notch and break a set of bars in accordance with these test methods. Examine the surface of the break of each bar in the vise. If the break is flat and smooth across the top surface of the vise the condition of the machine is excellent. Considerable information regarding the condition of an impact machine can be obtained by examining the broken

sections of specimens. No weights should be added to the pendulum for the above tests.

X1.25 The machine should not be used to indicate more than 85 % of the energy capacity of the pendulum. Extra weights added in pairs on opposite sides of the pendulum at the center of percussion will increase available energy of the machine. Correct weights for any range can be calculated as follows:

$$W = E_p/h$$

where:

W = the effective pendulum weight (see X1.12),
E_p = potential or available energy of the machine, and
h = the vertical distance of fall of the pendulum striking edge (see X1.14).

Each lb of added weight increases the capacity of the machine by 2.710 J (2 ft-lbf).

X2. INSTRUCTIONS FOR THE CONSTRUCTION OF A WINDAGE AND FRICTION CORRECTION CHART

X2.1 The construction and use of the chart herein described is based upon the assumption that the friction and windage losses are proportional to the angle through which these loss torques are applied to the pendulum. Figure X2.1 shows the assumed energy loss versus the angle of the pendulum position during the pendulum swing. The correction chart to be described is principally the left half of Fig. X2.1. The windage and friction correction charts should be available from commercial testing machine manufacturers. The energy losses designated as A and B are described in 9.3 of the main body of the method.

X2.2 Start the construction of the correction chart (Fig. X2.2) by laying off to some convenient linear scale on the abscissa of a graph the angle of pendulum position for the portion of the swing beyond the free hanging position. For convenience place the free hanging reference point on the right end of the abscissa with the angular displacement increasing linearly to the left. The abscissa is referred to as Scale C. Although angular displacement is the quantity to be represented linearly on the abscissa, this displacement is more conveniently expressed in terms of indicated energy read from the machine dial. This yields a nonlinear Scale C

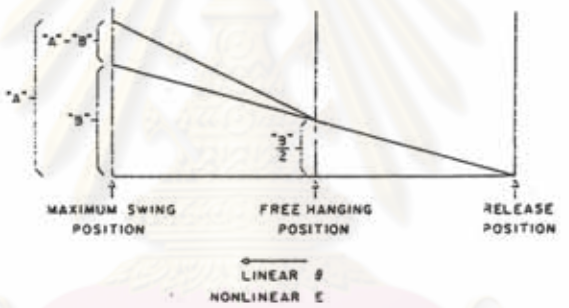


FIG. X2.1 Method of Construction of a Windage and Friction Correction Chart

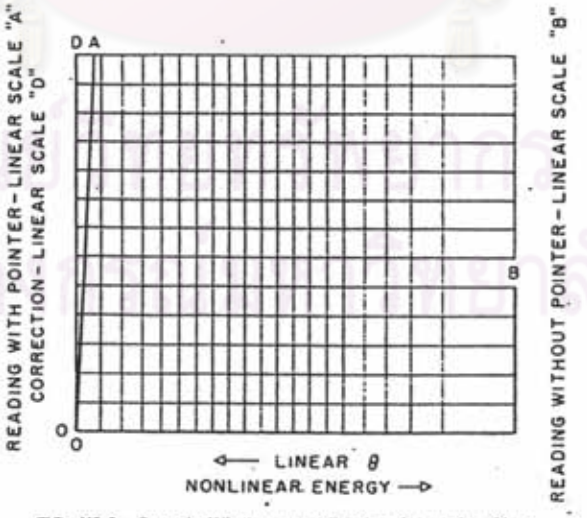


FIG. X2.2 Sample Windage and Friction Correction Chart

with indicated pendulum energy increasing to the right.

X2.3 On the right hand ordinate lay off a linear Scale *B* starting with zero at the bottom and stopping at the maximum expected pendulum friction and windage value at the top.

X2.4 On the left ordinate construct a linear Scale *D* ranging from zero at the bottom to 1.2 times the maximum ordinate value appearing on Scale *B*, but make the scale twice the scale used in the construction of Scale *B*.

X2.5 Adjoining Scale *D* draw a curve *OA* which is the focus of points whose coordinates have equal values of energy correction on Scale *D* and indicated energy on Scale *C*. This curve is referred to as Scale *A* and utilizes the same divisions and numbering system as the adjoining Scale *D*.

X2.6 *Instructions for Using Chart:*

X2.6.1 Locate and mark on Scale *A* the reading *A* obtained from the free swing of the pendulum with the pointer prepositioned in the free hanging or maximum indicated energy position on the dial.

X2.6.2 Locate and mark on Scale *B* the reading *B* obtained after several free swings with the pointer pushed up close to the zero indicated energy position of the dial by the pendulum in accordance with instructions in 9.3.

X2.6.3 Connect the two points thus obtained by a straight line.

X2.6.4 From the indicated impact energy on Scale *C* project up to the constructed line and across to the left to obtain the correction for windage and friction from Scale *D*.

X2.6.5 Subtract this correction from the indicated impact reading to obtain the energy delivered to the specimen.

X3. PROCEDURE FOR THE CALCULATION OF WINDAGE AND FRICTION CORRECTION

X3.1 The procedure for the calculation of the windage and friction correction in this appendix is based on the equations developed by derivation in Appendix X4. This procedure can be used as a substitute for the graphical procedure described in Appendix X2 and is applicable to small electronic calculator and computer analysis.

X3.2 Calculate L, the distance from the axis of support to the center of percussion as indicated in 5.3. (It is assumed here that the center of percussion is approximately the same as the center of gravity.)

X3.3 Measure the maximum height, h_M, of the center of percussion (center of gravity) of the pendulum at the start of the test as indicated in X1.14.

X3.4 Measure and record the energy correction, E_A, for windage of the pendulum plus friction in the dial, as determined with the first swing of the pendulum with *no* specimen in the testing device. This correction must be read on the energy scale, E_M, appropriate for the pendulum used.

X3.5 Without resetting the position of the indicator obtained in X3.4, measure the energy correction, E_B, for pendulum windage after two additional releases of the pendulum with *no* specimen in the testing device.

X3.6 Calculate β_{max} as follows:

$$\beta_{max} = \cos^{-1}\{1 - [(h_M/L)(1 - E_A/E_M)]\}$$

where:

E_A = energy correction for windage of pendulum plus friction in dial, J (or ft·lbf),

E_M = full-scale reading for pendulum used, J (or ft·lbf),

L = distance from fulcrum to center of gravity of pendulum, m (or ft),

h_M = maximum height of center of gravity of pendulum at start of test, m (or ft), and

β_{max} = maximum angle pendulum will travel with one swing of the pendulum.

X3.7 Measure specimen breaking energy, E_s, J (or ft·lbf).

X3.8 Calculate β for specimen measurement E_s as:

$$\beta = \cos^{-1}\{1 - [(h_M/L)(1 - E_s/E_M)]\}$$

where:

β = angle pendulum travels for a given specimen and

E_s = dial reading breaking energy for a specimen, J (or ft·lbf).

X3.9 Calculate total correction energy, E_{TC}, as:

$$E_{TC} = (E_A - (E_B/2))(\beta/\beta_{max}) + (E_B/2)$$

where:

E_{TC} = total correction energy for the breaking energy, E_s, of a specimen, J (or ft·lbf), and

E_B = energy correction for windage of the pendulum, J (or ft·lbf).

X3.10 Calculate the impact strength using the following formula:

$$I_s = (E_s - E_{TC})/t$$

where:

I_s = impact strength of specimen, J/m (or ft·lbf/in.) of width, and

t = width of specimen or width of notch, m (or in.).

X4. DERIVATION OF PENDULUM IMPACT CORRECTION EQUATIONS

X4.1 From right triangle distances in Fig. X4.1:

$$L - h = L\cos\beta \quad (1)$$

X4.2 But the potential energy gain of pendulum E_p is:

$$E_p = hW_pg \quad (2)$$

X4.3 Combining Eqs 1 and 2 gives the following:

$$L - E_p/W_pg = L\cos\beta \quad (3)$$

X4.4 The maximum energy of the pendulum is the potential energy at the start of the test, E_M, or

$$E_M = h_M W_p g \quad (4)$$

X4.5 The potential energy gained by the pendulum, E_p, is related to the absorption of energy of a specimen, E_s, by the following equation:

$$E_M - E_s = E_p \quad (5)$$

X4.6 Combining Eqs 3, 4, and 5 gives the following:

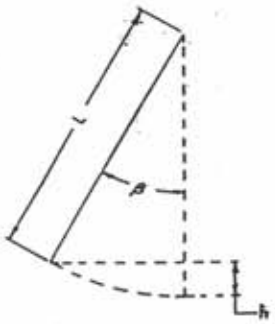


FIG. X4.1 Swing of Pendulum from Its Rest Position

X4.7 Solving Eq 6 for β gives the following:

$$\beta = \cos^{-1}\{1 - [(h_M/L)(1 - E_s/E_M)]\} \quad (7)$$

X4.8 From Fig. X4.2, the total energy correction E_{TC} is given as:

$$E_{TC} = m\beta + b \quad (8)$$

X4.9 But at the zero point of the pendulum potential energy

$$E_B/2 = m(0) + b \quad (9)$$

or

$$b = E_B/2 \quad (10)$$

X4.10 The energy correction, E_A, on the first swing of the pendulum occurs at the maximum pendulum angle, β_{max}. Substituting in Eq 8 gives the following:

$$E_A = m\beta_{max} + (E_B/2) \quad (11)$$

X4.11 Combining Eqs 8 and 11 gives the following:

$$E_{TC} = (E_A - (E_B/2))(\beta/\beta_{max}) + (E_B/2) \quad (12)$$

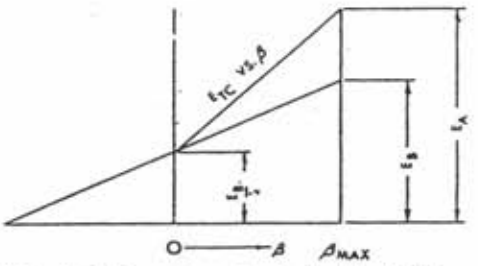


FIG. X4.2 Total Energy Correction for Pendulum Windage and Dial Friction as a Function of Pendulum Position

X4.12 *Nomenclature:*

- b = intercept of total correction energy straight line,
- E_A = energy correction including both pendulum windage plus dial friction, J,
- E_B = energy correction for pendulum windage only, J,
- E_M = maximum energy of the pendulum (at the start of test), J,
- E_p = potential energy gain of pendulum from the pendulum rest position, J,
- E_s = uncorrected breaking energy of specimen, J,
- E_{TC} = total energy correction for a given breaking energy, E_s, J,
- g = acceleration of gravity, m/s^2,
- h = distance center of gravity of pendulum rises vertically from the rest position of the pendulum, m,
- h_M = maximum height of the center of gravity of the pendulum, m,
- m = slope of total correction energy straight line,
- L = distance from fulcrum to center of gravity of pendulum, m,
- W_p = weight of pendulum, as determined in X1.12, kg, and
- β = angle of pendulum position from the pendulum rest position.

APPENDIX D

Table D Dimension of Samples for Tensile Strength Testing

Sample	Specimen No.	Width (mm)	Thickness (mm)	Sample	Specimen No.	Width (mm)	Thickness (mm)
PS11-001	1	5.95	2.95	PP15-001	1	6.10	2.80
	2	6.05	3.05		2	6.30	2.85
	3	5.95	3.05		3	5.70	2.95
	4	5.95	3.00		4	6.35	2.90
	5	5.55	2.95		5	6.55	2.95
PS21-001	1	5.65	3.05	PP25-001	1	6.50	2.85
	2	5.95	3.05		2	6.30	2.85
	3	6.10	3.00		3	6.75	2.90
	4	5.75	3.00		4	6.65	2.90
	5	5.85	3.00		5	6.85	2.95
PE12-001	1	6.40	2.70	PS15-001	1	5.90	2.85
	2	6.05	2.75		2	5.55	2.90
	3	5.95	2.85		3	6.10	2.80
	4	6.20	2.60		4	5.80	2.95
	5	6.25	2.80		5	5.90	2.85
PE22-001	1	5.45	2.70	PS25-001	1	6.05	2.85
	2	6.15	2.75		2	5.60	2.85
	3	5.50	2.70		3	6.15	2.85
	4	5.50	2.70		4	5.65	2.85
	5	6.20	2.70		5	6.20	2.85
PE13-001	1	6.30	2.80	PP16-001	1	5.90	2.45
	2	6.10	2.80		2	6.35	2.60
	3	6.50	2.80		3	6.25	2.55
	4	6.55	2.80		4	6.20	2.45
	5	6.50	2.80		5	6.20	2.45
PE13-002	1	6.35	2.80	PP16-101	1	6.00	2.60
	2	6.00	2.80		2	5.80	2.55
	3	6.15	2.80		3	5.90	2.55
	4	6.05	2.80		4	5.80	2.60
	5	6.10	2.80		5	5.95	2.55
PE13002	1	6.15	2.60	PP16-002	1	6.00	2.45
	2	6.30	2.60		2	6.20	2.60
	3	6.10	2.60		3	6.40	2.60
	4	6.30	2.60		4	6.20	2.55
	5	6.25	2.60		5	5.85	2.50
PE13-102	1	6.30	2.75	PP16-102	1	6.00	2.50
	2	6.45	2.75		2	6.10	2.50
	3	6.30	2.80		3	5.95	2.45
	4	6.40	2.80		4	6.25	2.60
	5	6.10	2.80		5	6.20	2.60
PE23-001	1	6.30	2.75	PE17-001	1	6.00	2.75
	2	6.70	2.80		2	6.30	2.80
	3	6.25	2.80		3	6.35	2.75
	4	6.25	2.75		4	6.40	2.75
	5	6.35	2.80		5	6.40	2.75
PE43-001	1	6.20	2.80	PE17-101	1	6.25	2.60
	2	6.00	2.85		2	6.30	2.60
	3	6.20	2.85		3	5.75	2.60
	4	6.20	2.90		4	6.20	2.60
	5	6.10	2.80		5	6.10	2.60
PE53-001	1	6.60	2.75	PE17-002	1	5.70	2.50
	2	6.45	2.75		2	5.65	2.55
	3	5.75	2.80		3	5.40	2.50
	4	5.95	2.70		4	5.80	2.50
	5	6.55	2.80		5	5.80	2.50
PE63-001	1	6.45	2.75	PE17-102	1	5.85	2.60
	2	6.25	2.75		2	6.10	2.55
	3	6.90	2.85		3	5.90	2.50
	4	6.95	2.80		4	5.70	2.55
	5	6.90	2.80		5	5.90	2.55

Table D Continued

Sample	Specimen No.	Width (mm)	Thickness (mm)
PE73-001	1	6.55	2.85
	2	6.10	2.85
	3	6.70	2.55
	4	6.75	2.85
	5	6.55	2.85
PP13-001	1	6.15	2.80
	2	6.10	2.70
	3	6.10	2.85
	4	6.05	2.85
	5	6.50	2.85
PE14-001	1	6.75	2.75
	2	6.85	2.70
	3	6.75	2.75
	4	6.80	2.75
	5	6.35	2.80
PE14-002	1	6.50	2.75
	2	6.55	2.80
	3	6.35	2.80
	4	6.50	2.75
	5	6.50	2.80
PE14002	1	5.85	2.60
	2	5.95	2.60
	3	6.25	2.55
	4	5.85	2.55
	5	5.55	2.60
PE14-102	1	6.70	2.75
	2	6.35	2.75
	3	6.80	2.80
	4	6.05	2.80
	5	6.30	2.75
PE14-003	1	5.80	2.80
	2	6.25	2.80
	3	6.50	2.90
	4	6.30	2.75
	5	6.10	2.70
PE14003	1	6.50	2.85
	2	6.50	2.85
	3	6.25	2.85
	4	6.55	2.85
	5	6.30	2.90
PE14-103	1	6.45	2.85
	2	6.25	2.70
	3	6.20	2.85
	4	6.30	2.75
	5	6.70	2.80
PE15-001	1	6.20	2.75
	2	6.20	2.70
	3	5.95	2.75
	4	6.00	2.70
	5	5.50	2.75
PE25-001	1	6.00	2.85
	2	6.50	2.95
	3	6.10	2.90
	4	6.30	2.90
	5	6.35	2.85
PE35-001	1	6.20	2.80
	2	6.10	2.70
	3	6.20	2.75
	4	5.75	2.90
	5	6.30	2.75

Sample	Specimen No.	Width (mm)	Thickness (mm)
PP17-001	1	6.15	2.80
	2	5.90	2.60
	3	6.30	2.50
	4	6.40	2.50
	5	6.00	2.50
PP17-101	1	6.25	2.45
	2	6.00	2.55
	3	6.55	2.55
	4	6.30	2.55
	5	6.55	2.55
PP17-002	1	6.20	2.60
	2	6.45	2.60
	3	5.85	2.70
	4	6.40	2.70
	5	6.45	2.60
PP17-102	1	6.20	2.70
	2	6.25	2.70
	3	6.35	2.70
	4	6.35	2.70
	5	6.10	2.70
PS18-001	1	6.55	2.75
	2	7.00	2.80
	3	6.30	2.80
	4	6.85	2.80
	5	6.65	2.80
PS18-101	1	6.55	2.80
	2	6.85	2.80
	3	6.45	2.75
	4	6.85	2.75
	5	6.50	2.75
PS18-002	1	6.80	2.80
	2	5.90	2.80
	3	6.35	2.80
	4	6.20	2.80
	5	7.00	2.80
PS18-102	1	6.60	2.75
	2	6.55	2.80
	3	6.65	2.80
	4	6.25	2.80
	5	6.25	2.80
PE19-001	1	6.00	2.75
	2	6.30	2.85
	3	6.35	2.75
	4	5.95	2.95
	5	6.15	2.75
PE19-101	1	6.20	2.60
	2	6.30	2.60
	3	6.15	2.60
	4	6.20	2.55
	5	6.25	2.55
PE110-001	1	6.10	2.55
	2	6.40	2.55
	3	5.85	2.50
	4	6.00	2.55
	5	6.40	2.50
PE110-101	1	6.10	2.55
	2	6.15	2.55
	3	6.05	2.55
	4	6.20	2.55
	5	6.00	2.50

APPENDIX E

Table E Dimension of Samples for Impact Strength Testing

Sample	Specimen No.	Width (mm)	Thickness (mm)	Sample	Specimen No.	Width (mm)	Thickness (mm)
PS11-001	1	10.10	3.10	PP15-001	1	9.70	2.85
	2	10.20	3.10		2	9.55	2.85
	3	10.15	3.10		3	9.30	2.85
	4	10.35	3.10		4	9.65	2.80
	5	10.40	3.10		5	9.80	2.80
PS21-001	1	10.25	3.20	PP25-001	1	8.90	2.85
	2	10.05	3.20		2	9.00	2.85
	3	10.15	3.10		3	9.35	2.85
	4	10.30	3.10		4	9.80	2.80
	5	10.00	3.20		5	9.50	2.85
PE12-001	1	9.75	2.45	PS15-001	1	9.95	2.80
	2	10.00	2.35		2	9.95	2.80
	3	10.05	2.45		3	9.95	2.80
	4	9.95	2.45		4	9.95	2.80
	5	9.95	2.40		5	–	–
PE22-001	1	10.10	2.70	PS25-001	1	9.95	2.85
	2	10.30	2.70		2	9.95	2.85
	3	9.95	2.75		3	9.90	2.85
	4	10.10	2.75		4	9.95	2.85
	5	9.85	2.75		5	9.95	2.85
PE13-001	1	9.85	2.80	PP18-001	1	9.90	2.50
	2	9.85	2.85		2	10.05	2.45
	3	9.80	2.75		3	10.05	2.60
	4	9.85	2.75		4	9.85	2.45
	5	9.70	2.75		5	9.85	2.45
PE13-002	1	9.95	2.75	PP16-101	1	10.10	2.55
	2	9.85	2.80		2	10.05	2.55
	3	9.75	2.80		3	9.95	2.65
	4	9.85	2.80		4	10.05	2.70
	5	9.55	2.75		5	9.95	2.60
PE13002	1	10.00	2.80	PP16-002	1	10.00	2.50
	2	9.95	2.60		2	9.95	2.65
	3	9.95	2.60		3	9.95	2.55
	4	10.00	2.60		4	9.85	2.55
	5	9.80	2.60		5	9.90	2.60
PE15-102	1	9.70	2.80	PP16-102	1	9.95	2.55
	2	10.05	2.80		2	9.95	2.50
	3	9.95	2.85		3	9.95	2.65
	4	9.85	2.85		4	10.00	2.50
	5	9.95	2.85		5	9.95	2.55
PE23-001	1	10.00	2.80	PE17-001	1	10.10	2.70
	2	10.10	2.80		2	10.45	2.75
	3	10.05	2.80		3	10.05	2.75
	4	10.05	2.80		4	10.45	2.80
	5	10.00	2.80		5	10.00	2.75
PE43-001	1	9.45	2.75	PE17-101	1	10.00	2.55
	2	9.65	2.75		2	9.80	2.60
	3	9.85	2.75		3	9.95	2.55
	4	9.85	2.75		4	9.95	2.55
	5	10.00	2.75		5	9.90	2.55
PE53-001	1	9.85	2.80	PE17-002	1	10.05	2.60
	2	9.85	2.80		2	10.00	2.50
	3	9.90	2.80		3	9.95	2.50
	4	10.00	2.80		4	10.00	2.50
	5	9.85	2.75		5	9.90	2.50
PE53-001	1	9.70	2.80	PE17-102	1	10.00	2.60
	2	9.55	2.75		2	9.90	2.55
	3	9.80	2.75		3	10.05	2.60
	4	9.50	2.75		4	9.95	2.55
	5	10.00	2.85		5	10.00	2.55

Table E Continued

Sample	Specimen No.	Width (mm)	Thickness (mm)
PE73–001	1	10.40	2.85
	2	10.30	2.85
	3	10.10	2.80
	4	10.10	2.85
	5	10.35	2.90
PP13–001	1	10.15	2.70
	2	10.20	2.80
	3	10.05	2.90
	4	10.15	2.75
	5	10.00	2.95
PE14–001	1	9.80	2.75
	2	9.85	2.80
	3	9.50	2.75
	4	9.30	2.75
	5	9.45	2.75
PE14–002	1	9.70	2.80
	2	9.55	2.75
	3	9.95	2.75
	4	9.80	2.80
	5	9.80	2.80
PE14002	1	9.85	2.80
	2	10.10	2.80
	3	10.10	2.80
	4	10.00	2.80
	5	9.95	2.80
PE14–102	1	10.35	2.80
	2	10.35	2.80
	3	10.25	2.80
	4	10.50	2.80
	5	10.10	2.85
PE14–003	1	10.00	2.80
	2	10.00	2.90
	3	9.95	2.80
	4	10.05	2.90
	5	10.05	2.90
PE14003	1	10.25	2.85
	2	10.10	2.90
	3	9.95	2.85
	4	10.10	2.85
	5	10.20	2.85
PE14–103	1	10.00	2.75
	2	9.80	2.75
	3	10.05	2.95
	4	10.15	2.90
	5	9.35	2.80
PE15–001	1	9.55	2.80
	2	9.35	2.80
	3	9.75	2.75
	4	9.80	2.75
	5	9.40	2.75
PE25–001	1	9.40	2.90
	2	9.35	2.95
	3	9.40	2.90
	4	9.75	2.95
	5	9.50	2.90
PE35–001	1	9.70	2.85
	2	10.00	2.95
	3	9.95	2.75
	4	9.55	2.70
	5	9.85	2.80

Sample	Specimen No.	Width (mm)	Thickness (mm)
PP17–001	1	9.95	2.55
	2	10.00	2.55
	3	9.95	2.60
	4	9.90	2.60
	5	9.95	2.70
PP17–101	1	10.00	2.70
	2	9.95	2.55
	3	9.00	2.50
	4	10.00	2.50
	5	9.90	2.60
PP17–002	1	9.90	2.60
	2	10.05	2.70
	3	9.85	2.65
	4	9.90	2.60
	5	–	–
PP17–102	1	10.05	2.70
	2	9.90	2.65
	3	9.95	2.70
	4	9.80	2.70
	5	9.95	2.70
PS18–001	1	9.95	2.80
	2	9.95	2.85
	3	9.90	2.80
	4	9.95	2.80
	5	9.95	2.80
PS18–101	1	10.00	2.80
	2	10.05	2.80
	3	10.00	2.80
	4	9.95	2.80
	5	9.95	2.80
PS18–002	1	10.00	2.80
	2	10.00	2.80
	3	9.95	2.80
	4	10.00	2.80
	5	10.00	2.80
PS18–102	1	10.00	2.80
	2	10.00	2.80
	3	10.05	2.80
	4	10.00	2.80
	5	9.95	2.80
PE19–001	1	10.25	2.70
	2	10.05	2.90
	3	10.15	2.80
	4	10.20	2.85
	5	10.30	2.75
PE19–101	1	9.80	2.60
	2	9.70	2.65
	3	9.70	2.55
	4	10.05	2.55
	5	10.00	2.60
PE110–001	1	9.95	2.50
	2	9.65	2.50
	3	9.95	2.55
	4	10.15	2.50
	5	9.95	2.55
PE110–101	1	9.90	2.55
	2	9.95	2.55
	3	9.95	2.50
	4	10.10	2.50
	5	9.85	2.50

APPENDIX F

Table F Tensile Stress and Impact Strength of Samples

Sample	Specimen Number	Tensile Stress (MPa)	Impact Strength J/m	Modulus (MPa)
PS11–001	1	–	30.00	3025.00
	2	31.36	30.97	3169.00
	3	29.63	31.94	2621.00
	4	30.01	43.23	2825.00
	5	30.70	22.58	–
Average		30.43	31.74	2910
S.D.		0.76	7.39	238.78
PS21–001	1	32.72	18.10	3330.00
	2	34.62	15.80	3277.00
	3	30.37	14.20	3538.00
	4	31.28	10.30	2754.00
	5	31.36	–	3268.00
Average		32.07	14.60	3233.00
S.D.		1.65	3.28	290.00
PE12–001	1	26.41	48.60	1685.00
	2	24.69	49.40	1295.00
	3	25.20	44.90	1343.00
	4	24.98	49.80	1794.00
	5	25.61	45.80	1538.00
Average		25.38	47.70	1531.00
S.D.		0.67	2.55	215.00
PE22–001	1	11.31	no break	598.20
	2	11.11	no break	404.70
	3	11.21	no break	968.50
	4	11.21	no break	318.40
	5	10.59	no break	526.70
Average		11.08	–	563.30
S.D.		0.29	–	250.94
PE13–001	1	25.11	107.10	1389.00
	2	24.99	105.30	1094.00
	3	24.35	120.40	1178.00
	4	24.01	109.80	1113.00
	5	24.63	127.30	1359.00
Average		24.62	113.98	1226.00
S.D.		0.45	9.47	139.00
PE13–002	1	24.00	214.90	1059.00
	2	23.97	133.20	1108.00
	3	24.01	141.10	1237.00
	4	24.09	206.40	1767.00
	5	23.89	180.40	1736.00
Average		23.99	175.20	1381.00
S.D.		0.07	37.09	344.00
PE13002	1	24.18	100.00	846.00
	2	24.58	173.10	1015.00
	3	24.55	114.20	1189.00
	4	23.93	167.70	1106.00
	5	23.46	161.50	1057.00
Average		24.14	143.30	1043.00
S.D.		0.47	33.68	127.30

Table F Continued

Sample	Specimen Number	Tensile Stress (MPa)	Impact Strength 10 J/m	Modulus (MPa)
PE13–102	1	24.17	111.07	1206.00
	2	23.92	93.93	1425.00
	3	24.35	80.35	1047.00
	4	22.32	110.18	1024.00
	5	23.74	96.14	1136.00
Average		23.70	98.33	1168.00
S.D.		0.81	1.27	161.00
PE23–001	1	20.61	42.50	824.30
	2	21.75	50.70	1110.00
	3	21.17	48.60	830.60
	4	22.02	48.60	925.30
	5	21.29	48.60	841.80
Average		21.37	47.80	906.30
S.D.		0.55	3.10	1804.00
PE43–001	1	24.28	71.64	1023.00
	2	23.39	90.55	1023.00
	3	22.79	57.09	1151.00
	4	22.99	60.00	1532.00
	5	23.42	68.36	1297.00
Average		23.37	69.53	1361.00
S.D.		0.57	13.16	311.00
PE53–001	1	23.66	80.71	1545.00
	2	23.15	73.57	1130.00
	3	22.17	67.14	1591.00
	4	23.73	83.57	1309.00
	5	20.93	74.91	1411.00
Average		22.73	75.98	1397.00
S.D.		1.18	6.42	186.00
PE63–001	1	24.06	49.64	1409.00
	2	23.27	95.64	1324.00
	3	22.66	65.45	1059.00
	4	22.76	85.09	1723.00
	5	22.79	70.18	1099.00
Average		23.11	73.20	1323.00
S.D.		0.58	17.81	268.00
PE73–001	1	9.637	no break	349.40
	2	9.727	no break	608.10
	3	9.421	no break	227.20
	4	9.352	no break	315.50
	5	9.348	no break	475.10
Average		9.497	–	395.10
S.D.		0.174	–	148.60
PP13–001	1	23.07	19.30	1537.00
	2	23.31	18.60	1511.00
	3	22.08	20.00	1336.00
	4	23.62	18.90	1258.00
	5	23.77	21.07	1576.00
Average		23.17	19.57	1444.00
S.D.		0.67	0.99	144.00

Table F Continued

Sample	Specimen Number	Tensile Stress (MPa)	Impact Strength 10 J/m	Modulus (MPa)
PE14–001	1	25.99	127.27	1580.25
	2	25.74	124.29	1271.25
	3	25.44	80.00	1389.50
	4	25.65	81.09	1170.00
	5	24.91	78.91	1093.00
Average		25.55	98.31	1300.80
S.D.		0.41	25.11	191.78
PE14–002	1	24.33	96.80	1592.00
	2	23.86	108.00	1620.00
	3	23.55	118.20	1147.00
	4	23.88	102.10	1381.00
	5	24.63	106.10	1468.00
Average		24.05	106.24	1442.00
S.D.		0.43	7.93	191.00
PE14002	1	24.88	82.31	1171.00
	2	25.68	80.00	1409.00
	3	24.76	122.69	1106.00
	4	–	101.15	1363.00
	5	24.56	–	1185.00
Average		24.97	96.54	1247.00
S.D.		0.60	19.84	132.00
PE14–102	1	23.90	83.57	1571.00
	2	23.52	139.93	1638.00
	3	23.12	115.00	1032.00
	4	22.50	94.55	1033.00
	5	22.93	–	1369.00
Average		23.19	108.26	1328.60
S.D.		0.60	24.81	287.87
PE14–003	1	24.80	128.20	1299.00
	2	23.47	128.60	1200.00
	3	23.36	127.10	1420.00
	4	24.17	120.00	1213.00
	5	24.61	116.10	1306.00
Average		24.08	124.00	1287.80
S.D.		0.65	5.63	88.00
PE14003	1	24.22	101.05	1114.00
	2	23.77	81.72	1403.00
	3	24.11	98.25	1676.00
	4	23.87	107.02	1227.00
	5	23.95	95.09	1301.00
Average		23.98	96.63	1344.00
S.D.		0.18	9.42	213.00
PE14–103	1	24.39	98.60	1097.00
	2	23.86	100.70	1203.00
	3	24.46	81.70	1375.00
	4	23.55	86.80	1497.00
	5	23.61	–	1492.00
Average		23.97	91.95	1333.80
S.D.		0.43	9.17	178.00

Table F Continued

Sample	Specimen Number	Tensile Stress (MPa)	Impact Strength 10 J/m	Modulus (MPa)
PE15–001	1	26.29	95.00	1642.00
	2	26.30	100.00	1765.00
	3	26.41	97.45	1200.00
	4	25.02	99.64	1146.00
	5	25.91	93.45	1259.00
Average		25.99	97.11	1402.40
S.D.		0.57	2.86	281.14
PE25–001	1	24.65	283.45	923.20
	2	19.60	241.69	739.50
	3	20.03	349.31	1096.00
	4	23.66	244.07	1127.00
	5	20.02	340.00	935.40
Average		21.59	291.70	964.22
S.D.		2.37	51.21	155.62
PE35–001	1	26.13	196.50	1407.00
	2	27.22	162.70	1422.00
	3	26.77	167.60	1962.00
	4	26.08	146.30	1130.00
	5	26.03	212.90	1529.00
Average		26.45	177.20	1490.00
S.D.		0.53	26.95	302.00
PP15–001	1	22.16	364.21	1238.30
	2	21.68	291.58	1307.00
	3	21.87	294.74	1227.00
	4	21.57	237.50	1177.00
	5	21.67	328.21	1166.00
Average		21.79	303.25	1223.00
S.D.		0.23	47.09	56.26
PP25–001	1	32.46	18.30	1268.00
	2	32.89	36.80	1621.00
	3	31.95	32.60	1225.00
	4	32.15	20.70	1759.00
	5	31.48	31.60	1276.00
Average		32.19	28.00	1430.00
S.D.		0.53	8.05	243.00
PS15–001	1	33.88	28.57	–
	2	33.27	28.57	–
	3	33.31	35.71	–
	4	29.77	28.57	–
	5	34.46	–	–
Average		32.94	30.36	–
S.D.		1.84	3.57	–
PS25–001	1	37.45	35.09	–
	2	37.51	35.09	–
	3	30.76	35.09	–
	4	37.38	42.11	–
	5	35.07	35.09	–
Average		35.63	36.49	–
S.D.		2.91	3.14	–

Table F Continued

Sample	Specimen Number	Tensile Stress (MPa)	Impact Strength 10 J/m	Modulus (MPa)
PP16–001	1	24.33	8.00	1452.00
	2	21.30	13.47	1335.00
	3	20.72	13.08	1687.00
	4	22.98	15.51	2963.00
	5	22.44	8.16	1447.00
Average		22.35	11.64	1777.00
S.D.		1.42	3.38	675.00
PP16–101	1	31.49	26.67	1345.00
	2	31.04	18.04	1439.00
	3	28.91	18.49	1465.00
	4	30.60	25.19	1368.00
	5	30.08	16.92	1388.00
Average		30.43	21.06	1401.00
S.D.		1.00	4.51	50.00
PP16–002	1	29.69	56.00	1403.29
	2	29.70	60.38	1258.27
	3	29.49	47.06	1352.38
	4	28.52	54.90	1375.93
	5	29.95	48.00	1359.19
Average		29.47	53.27	1349.81
S.D.		0.56	5.63	54.81
PP16–102	1	29.75	–	1375.22
	2	28.52	–	1426.46
	3	29.08	45.28	1440.81
	4	–	48.00	1338.68
	5	–	47.06	1223.14
Average		29.12	46.78	1360.86
S.D.		0.62	1.38	87.12
PE17–001	1	22.61	56.86	2057.00
	2	21.76	53.58	1367.00
	3	22.14	62.31	2151.00
	4	22.57	52.31	3457.00
	5	22.12	53.46	2969.00
Average		22.24	55.70	2396.00
S.D.		0.35	4.06	814.00
PE17–101	1	22.14	79.61	1038.00
	2	22.45	73.46	973.50
	3	22.80	78.43	1206.00
	4	22.31	86.27	1126.00
	5	22.01	92.94	991.80
Average		22.34	82.14	1067.00
S.D.		0.31	7.57	97.40
PE17–002	1	18.86	30.77	1210.72
	2	16.55	48.00	1249.55
	3	18.33	32.00	1044.80
	4	16.81	32.00	1128.65
	5	16.90	40.00	1073.52
Average		17.49	36.55	1141.45
S.D.		1.03	7.38	87.47

Table F Continued

Sample	Specimen Number	Tensile Stress (MPa)	Impact Strength 10 J/m	Modulus (MPa)
PE17–102	1	23.17	169.23	1232.94
	2	22.94	180.39	1157.37
	3	23.33	184.62	1220.53
	4	23.66	196.08	1135.37
	5	23.23	180.39	1221.53
Average		23.27	182.14	1193.55
S.D.		0.26	9.66	44.03
PP17–001	1	25.06	47.06	1641.91
	2	23.03	47.06	1466.99
	3	26.01	–	1547.87
	4	25.52	46.15	1406.48
	5	26.25	51.85	1540.23
Average		25.17	48.03	1502.70
S.D.		1.28	2.58	89.08
PP17–101	1	18.55	–	1420.64
	2	19.45	39.22	1348.26
	3	22.76	40.00	1347.32
	4	19.40	48.00	1284.05
	5	18.79	38.46	1414.69
Average		19.79	41.42	1362.99
S.D.		1.70	4.43	56.33
PP17–002	1	20.64	46.15	1349.47
	2	20.95	44.44	1185.34
	3	19.06	45.28	1329.75
	4	19.36	46.15	1193.77
	5	20.30	–	1408.99
Average		20.06	45.51	1293.46
S.D.		0.82	0.82	99.28
PP17–102	1	15.00	37.04	1380.89
	2	17.85	37.74	1446.71
	3	15.34	–	1449.38
	4	16.67	–	1367.61
	5	15.46	44.44	1371.11
Average		16.06	39.74	1403.14
S.D.		1.18	4.09	41.29
PS18–001	1	29.40	21.43	–
	2	22.02	28.07	–
	3	31.34	28.57	–
	4	29.28	21.43	–
	5	27.80	28.57	–
Average		27.97	25.61	–
S.D.		3.55	3.82	–
PS18–101	1	25.11	28.57	–
	2	26.22	–	–
	3	29.81	28.57	–
	4	–	21.42	–
	5	28.28	28.57	–
Average		27.36	26.78	–
S.D.		2.10	3.58	–

Table F Continued

Sample	Specimen Number	Tensile Stress (MPa)	Impact Strength 10 J/m	Modulus (MPa)
PS18–002	1	29.58	35.71	–
	2	18.91	35.71	–
	3	26.93	35.71	–
	4	23.39	28.57	–
	5	13.16	28.57	–
Average		22.39	32.85	–
S.D.		6.53	3.91	–
PS18–102	1	23.59	35.71	–
	2	22.08	35.71	–
	3	23.35	28.57	–
	4	23.53	35.71	–
	5	20.81	35.71	–
Average		22.67	34.28	–
S.D.		1.21	3.19	–
PE19–001	1	28.15	392.59	1515.00
	2	28.71	337.93	1410.00
	3	26.59	481.07	1421.00
	4	27.22	358.25	1511.00
	5	27.15	369.82	1319.00
Average		27.56	387.93	1435.00
S.D.		0.85	55.69	81.00
PE19–101	1	26.98	166.54	1373.00
	2	26.55	283.40	1335.00
	3	26.86	159.22	1340.00
	4	27.00	192.55	1608.00
	5	26.45	239.23	1490.00
Average		26.77	208.19	1429.00
S.D.		0.25	52.43	118.00
PE110–001	1	27.27	163.60	2049.00
	2	26.32	171.20	1955.00
	3	26.43	129.80	2735.00
	4	26.14	144.40	1867.00
	5	26.51	153.73	1681.00
Average		26.54	152.55	2057.00
S.D.		0.43	16.24	402.00
PE110–101	1	25.54	76.10	1595.00
	2	26.02	79.60	2051.00
	3	26.28	82.40	2007.00
	4	24.96	81.20	1423.00
	5	25.41	73.20	1726.00
Average		25.64	78.50	1760.00
S.D.		0.52	3.79	268.00

VITA

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