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Bahan Seminar oleh PT Jaya Fibrindo Karsa Pratama

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- **ASTM D638M**
- **ASTM D790M**

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 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 metric counterpart of 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 ASTM Method D 229, Testing Rigid Sheet and Plate Materials Used for Electrical Insulation,[2,3] and ASTM Method D 651, Test for Tensile Strength of Molded Electrical Insulating Materials.[3]

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 equal thickness. Special additional tests should be used where more precise physical data are needed.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 *ASTM Standards:*

D 618 Methods of Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 638 Test Method for Tensile Properties of Plastics[2]

D 882 Test Methods for Tensile Properties of Thin Plastic Sheeting[2]

D 883 Definitions of Terms Relating to Plastics[2]

D 4066 Specification for Nylon Injection and Extrusion Materials[4]

E 4 Practices for Load Verification of Testing Machines[4,5]

E 83 Practice for Verification and Classification of Extensometers[5]

3. Significance and Use

3.1 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.

3.2 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.

3.2.1 It is realized that a material cannot be

[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 08.01.

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

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

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

...ing the method of prepa-
ration of that material. Hence, when comparative
tests ... materials per se are desired, the greatest
care ...st be exercised to ensure that all samples
are p...ared in exactly the same way, unless the
test ... include the effects of sample prepara-
tion. ...ilarly, for referee or comparisons within
any g... series of specimens, care must be taken
to se... the maximum degree of uniformity in
detai... preparation, treatment, and handling.
3.... ...nsile properties may provide useful data
for p... ...cs engineering design purposes. How-
ever, ...ause of the high degree of sensitivity
exhib... by many plastics to rate of straining
and e... ...onmental conditions, data obtained by
this t... ...nethod cannot be considered valid for
applic... ...ns involving load-time scales or envi-
ronm... widely different from those of this test
meth... ...n cases of such dissimilarity, no reliable
estima... ...of the limit of usefulness can be made
for m... ...lastics. This sensitivity to rate of strain-
ing an... ...vironment necessitates testing over a
broad ... ...d-time scale (including impact and
creep) ... range of environmental conditions if
tensile ... ...perties are to suffice for engineering
design ... ...poses.

NOTE ... Since the existence of a true elastic limit
in plast... ...ing many other organic materials and in
many ... ...s is debatable, the propriety of applying
the term ...astic modulus" in its quoted generally ac-
cepted ... ...ition to describing the "stiffness" or "rigid-
ity" of ... ...stic has been seriously questioned. The
exact str... ...train characteristics of plastic materials are
highly d... ...dent on such factors as rate of application
of stress... ...perature, previous history of specimen,
etc. How... ...stress-strain curves for plastics, deter-
mined a... ...ribed in this test method, almost always
show a l... ...region at low stresses, and a straight line
drawn t... ...to this portion of the curve permits
calculati... ...an elastic modulus of the usually defined
type. Su... ...constant is useful if its arbitrary nature
and dependence on time, temperature, and similar
factors are realized.

Definitions

4.1 Definitions of terms applying to this test
method appear in Definitions D 883 and Annex ...

Apparatus

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

... 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, this velocity to be ...

... 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 5—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*—A suitable instrument for determining the distance between two designated points located within the gage length of the test specimen as the specimen is stretched. 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 lag at the specified speed of testing and shall be accurate to ±1 % of strain or better.

NOTE 6—Refer to Practice E 83.

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

preferred specimen and shall b...
sufficient material having a thick...
or less is available. The Type M...
shall be used where only limited...
ing a thickness of 4 mm or less i...
evaluation, or where a large nu...
mens are to be exposed in a ...
(thermal and environmental stabi...
The Type M-II specimen should...
direct comparisons are required...
terials in different rigidity cases...
rigid and semirigid).

6.1.2 *Nonrigid Plastics*—The ...
shall conform to the dimensions ...
1. The Type M-II specimen sha...
testing nonrigid plastics with a ...
mm or less. The Type M-I spec...
used for all materials with a thi...
than 4 mm but not more than 1...

6.1.3 *Preparation*—Test speci...
prepared by machining operatio...
ting, from materials in sheet, ...
similar form. Materials thicker ...
must be machined to 10 mm fo...
M-I specimens. Specimens can al...
by molding the material to be te...

NOTE 7—Specimens prepared by ...
ing may have different tensile prope...
mens prepared by machining or die-...
of the orientation induced. This effe...
pronounced in specimens with narro...

6.2 All surfaces of the specime...
of visible flaws, scratches, or ...
Marks left by coarse machining o...
be carefully removed with a fine ...
and the filed surfaces shall then ...
with abrasive paper (No. 00 ...
finishing sanding strokes shall ...
direction parallel to the long a...
specimen. All flash shall be re...
molded specimen, taking great c...
turb the molded surfaces. In mac...
imen, undercuts that would exce...
sional tolerances shown in Fig. 1...
pulously avoided. Care shall als...
avoid other common machining ...

6.3 If it is necessary to place g...
the specimen, this shall be don...
crayon or India ink that will ...

...shall be prepared having their long axes respect...y parallel with, and normal to, the suspect... direction of anisotropy.

7. Con...ning

7.1 ...litioning—Condition the test speci-mens at... ± 2°C and 50 ± 5 % relative humidity ...or not ... than 40 h prior to test in accordance with Pr... lure A of Methods D 618, for those ...sts wh... conditioning is required. In cases of ...sagree...it, the tolerances shall be ± 1°C and ...2 % r... ve humidity.

7.1.1 ...e that for some hygroscopic mate-...ls, su... s nylons, the material specifications ...or exa..., Specification D 4066) call for test-...g "dry ...molded specimens". Such require-...ents ta... precedence over the above routine ...condi...ing to 50 % RH and require sealing ...speci...is in water vapor-impermeable con-...ners as...n as molded and not removing them ...til rea...or testing.

7.2 T... Conditions—Conduct tests in the ...ndard...boratory Atmosphere of 23 ± 2°C ...1 50 ±... relative humidity, unless otherwise ...cified...the test methods. In cases of disa-...ement...the tolerances shall be ± 1°C and ± ...relati...umidity.

...ote 8... tensile properties of some plastics ...ge ra... with small changes in temperature. ...e heat... be generated as a result of straining the ...imen ...ates, conduct tests without forced ...ing to ... uniformity of test conditions. Mea-...the te... ature in the reduced section of the ...men a...ore it for materials where self-heating ...pected...

...umbe... Test Specimens

...1 Tes...least five specimens for each sam-...n the ... of isotropic materials.

...2 Tes... specimens, five normal to, and ...arallel with the principle axis of anisotropy, ...ch sample in case of anisotropic materials.

... Discard specimens that break at some ob-... fortuitous flaw, or that do not break be-... the predetermined gage marks, and make ..., unless such flaws constitute a variable to ...died.

...E 9—Before testing, all transparent specimens ...be inspected in a polariscope. Those which show ...l or concentrated strain patterns should be re-... unless the effects of these residual strains consti-...

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.

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 10—If it is desired to measure both modulus and failure properties (yield or break, or both), it may ... permanently damaged. A broad-range incremental extensometer or hand rule technique may be needed when such materials are taken to rupture.

11. Calculations

11.1 *Tensile Strength*—Calculate the tensile strength by dividing 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 (Annex Note A1.1).

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" (Annex 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 ...ular property in question.

11.5 Calculate the standard dev...mated) as follows and report it to ...cant 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 ...tions.

12. Report

12.1 The report shall include the...

12.1.1 Complete identification o...rial tested, including type, source...turer's code numbers, form, princi...sions, previous history, etc.,

12.1.2 Method of preparing test ...

12.1.3 Type of test specimen a...sions,

12.1.4 Conditioning procedure u...

12.1.5 Atmospheric conditions in...

12.1.6 Number of specimens test...

12.1.7 Speed of testing,

12.1.8 Tensile strength at yield o...erage value, and standard deviation,

12.1.9 Tensile stress at yield or b...plicable, average value, and standard...

12.1.10 Percent elongation at yie...(or both as applicable), average value...ard deviation,

12.1.11 Modulus of elasticity, av...and standard deviation, and

12.1.12 Date of test.

13. Precision and Bias[6]

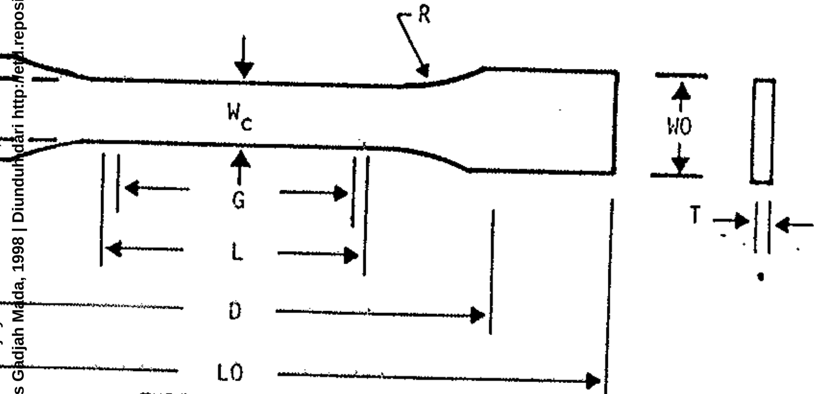
13.1 A task group has been forme... the precision and bias statement f... method.

[6] A report on a limited comparison between ... and D 638M are available on loan from ASTM ... Request RR:D20-1088.

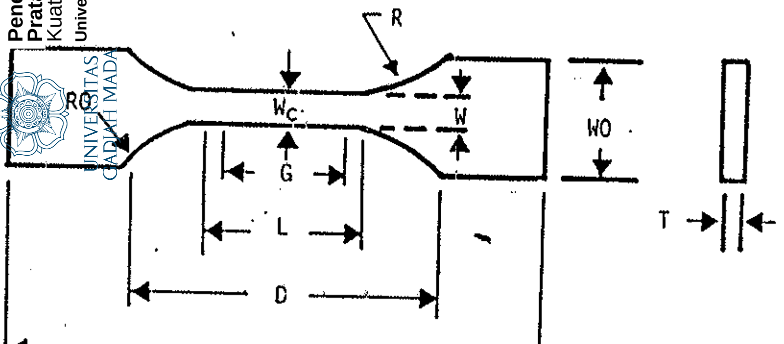
TABLE 1 Designation for Speed of Testing[A]

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.



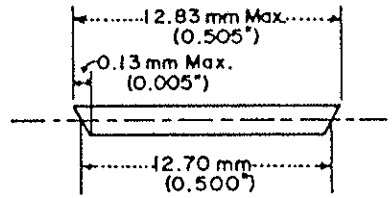
TYPES M-I, M-III



Dimensions (see drawings)	10 or Under	4 or Under		Toler[illegible]
	Type M-I	Type M-II	Type M-III	
W—Width of narrow section[A,B]	10	6	2.5	±0.[illegible]
L—Length of narrow section	60	33	10	±0.[illegible]
WO—Width of overall, min[F]	20	25	10	±0.[illegible]
LO—Length overall, min[G]	150	115	60	no [illegible]
G—Gage length[C]	50	—	7.5	±0.[illegible]
G—Gage length[C]	—	25	—	±0.[illegible]
D—Distance between grips	115	80	25	±5
R—Radius of fillet	60	14	15	±1
RO—Outer radius (Type II)	—	25	—	±1

Specimen Dimensions for Thickness, *T*, mm[D]

[A] The width at the center W_c shall be plus 0.00 mm, minus 0.10 mm compared with width *W* at other parts of [illegible] section. Any reduction in *W* at the center shall be gradual, equally on each side so that no abrupt changes in dime[illegible]
[B] For molded specimens, a draft of not over 0.15 mm may be allowed for Type M-I, 3 mm in thickness, and [illegible] be taken into account when calculating width of the specimen. Thus a typical section of a molded Type M-I speci[illegible] the maximum allowable draft, could be as follows:



[C] Test marks or initial extensometer span.
[D] Thickness, *T*, shall be 3 ± 0.4 mm for all types of molded specimens where possible. If specimens are ma[illegible] sheets or plates, thickness, *T*, may be the thickness of the sheet or plate provided this does not exceed the range s[illegible] intended specimen type. For sheets of nominal thickness greater than 10 mm, the specimens shall be machined [illegible] mm in thickness, for use with the Type M-I specimen. For sheets of nominal thickness between 10 and 50 mm ap[illegible] equal amounts shall be machined from each surface. For thicker sheets both surfaces of the specimen shall be m[illegible] the location of the specimen with reference to the original thickness of the sheet, shall be noted. Tolerances on t[illegible] 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 sp[illegible] shall be used whenever possible.
[F] Overall widths greater than the minimum indicated may be desirable for some materials in order to avoid bre[illegible] grips.
[G] Overall lengths greater than the minimum indicated may be desirable either to avoid breaking in the grips [illegible] 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*.

ANNEX

(Mandatory Information)

A1. DEFINITIONS OF TERMS AND SYMBOLS RELATING TO TENSION TESTIN[illegible] PLASTICS

A1.1 *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

or both (A1.11) nominal stress calculatio[illegible] be meaningful beyond the yield point (A1[illegible] the extensive reduction in cross-sectiona[illegible] ensues. Under some circumstances it may [illegible] ble to express the tensile properties per u[illegible] sile stress (nominal) sustained by the specimen ing a … on test. When the maximum stress urs at th… ld point (A1.10), it shall be designated ensile S… gth at Yield." When the maximum ss occu… break, it shall be designated "Tensile ength at … ak."

A1.3 ga… ngth—the original length of that por- of the … imen over which strain or change in th is de… ined.

1.4 elo… ion—the increase in length produced e gage… gth of the test specimen by a tensile . It is e… ssed in units of length, usually milli- es. (Al… own as *extension*.)

OTE A… -Elongation and strain values are only … ases where uniformity of specimen vior wi… the gage length is present. In the case aterial… ibiting "necking phenomena," such es are … of qualitative utility after attainment ield" p… This is due to inability to assure that ing wil… ompass the entire length between the marks … r to specimen failure.

1.5 *per… elongation*—the elongation of a test men ex… sed as a percent of the gage length.

1.6 *per… elongation at yield and break:*

1.6.1 *p… t elongation at yield*—the percent ation … e moment the yield point (A1.10) is ed in … est specimen.

1.6.2 *p… t elongation at break*—the percent ation … e moment of rupture of the test men.

.7 *stra…* the ratio of the elongation to the length … test specimen, that is, the change gth per … of original length. It is expressed as ension … ratio.

.8 *true … in* (see Fig. A1.1) is defined by the ving eq… n for ϵ_T:

$$\int dL/L = \ln L/L_o$$

= th… ment of elongation when the dis- ta… between the gage marks is L,
= th… ginal distance between gage marks, an…
= th… tance between gage marks at any time.

) *tensile stress - strain curve*—a diagram in values of tensile stress are plotted as ordinates t corresponding values of tensile strain as abs-

10 *yield point*—the first point on the stress - curve at which an increase in strain occurs t an increase in stress (Fig. A1.2).

E A1.3—Only materials whose stress - strain exhibit a point of zero slope may be considered ing a yield point.

E A1.4—Some materials exhibit a distinct " or discontinuity in the stress - strain curve in tic region. This break …

section which may occur in a material under tensile stress.

A1.12 *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 A1.2 (Fig. A1.2). (See *offset yield strength*.)

A1.13 *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 A1.5—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. A1.3):

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.

A1.14 *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.

A1.15 *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 A1.6—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.

A1.16 *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 A1.7—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 mate-

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.

A1.17 *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 A1.8—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.

A1.18 *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.

A1.19 *percent reduction of area (true)*—the difference between the original cross-sectional area of the test specimen and the minimum cross-sectional area within the gage boundaries prevailing at the moment of rupture, expressed as a percentage of the original area.

A1.20 *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.

A1.21 *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 A1.9—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.

A1.22 *rate of straining*—the change in tensile strain per unit time. It is expressed either as strain per unit time, usually metres per metre 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 A1.10—The initial rate of straining is syn-

cross-section, does not "neck down" and slip in the jaws.

A1.23 *Symbols*—The following symbol used for the above terms:

SYMBOL	TERM
W	Load
ΔW	Increment of load
L	Distance between gage marks at any
L_o	Original distance between gage mark
L_u	Distance between gage marks at rupture
ΔL	Increment of distance between gag elongation
A	Minimum cross-sectional area at any
A_o	Original cross-sectional area
ΔA	Increment of cross-sectional area
A_u	Cross-sectional area at point of ru sured after breaking specimen
A_T	Cross-sectional area at point of ru sured 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_y	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 vari may be defined as follows:

$\sigma = W/A_o$

$\sigma_T = W/A$

$\sigma_U = W/A_o$ (where W is breaking loa

$\sigma_{UT} = W/A_T$ (where W is breaking loa

$\epsilon = \Delta L/L_o = (L - L_o)/L_o$

$\epsilon_U = (L_u - L_o)/L_o$

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

$\% El = [(L - L_o)/L_o] \times 100 = \epsilon \times 100$

Percent reduction of area (nominal)
$= [(A_o - A_u)/$

Percent reduction of area (true)
$= [(A_o - A_T)/$

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

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

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

For the case where the volume of the tes does not change during the test, the follo

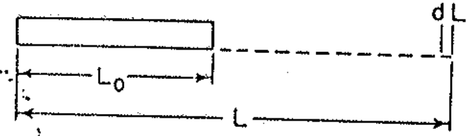


FIG. A1.1 Illustration of True Strain Equation

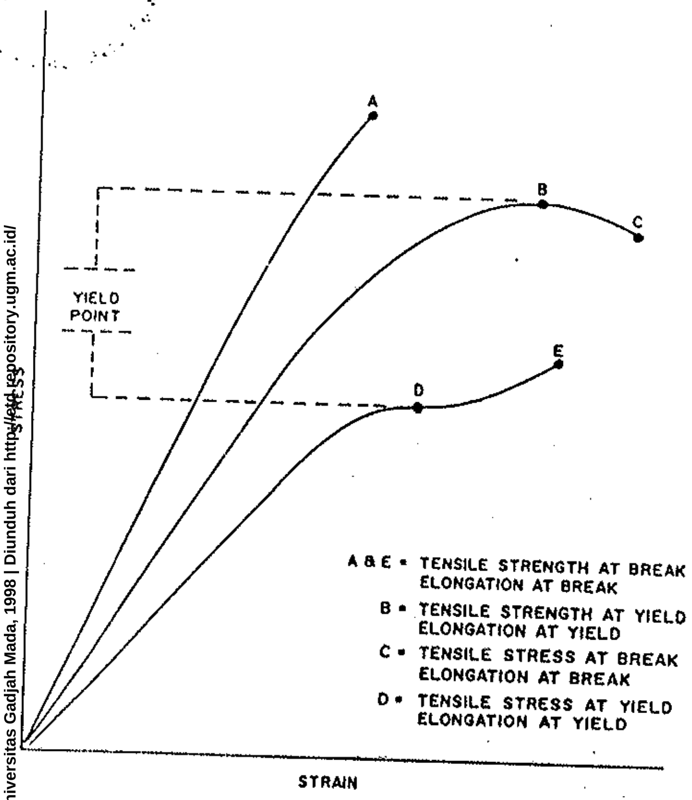


FIG. A1.2 Tensile Designations

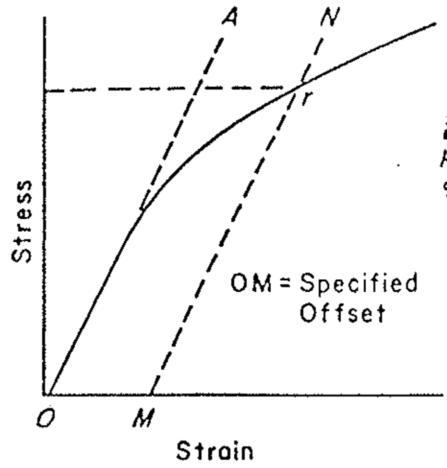


FIG. A1.3 Offset Yield Strength

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 same point (measured from point *I* zero-strain).

X1.3 In the case of a material whi exhibit any linear region (Fig. X1.2), th of toe correction of the zero-strain point by constructing a tangent to the maxim the inflection point (*H'*). This is extende the strain axis at point *B'*, the correcte point. Using point *B'* as zero strain, the point (*G'*) on the curve can be divided at that point to obtain a secant modulus *B' G'*). For these materials with no linea attempt to use the tangent through th point as a basis for determination of ar point may result in unacceptable error.

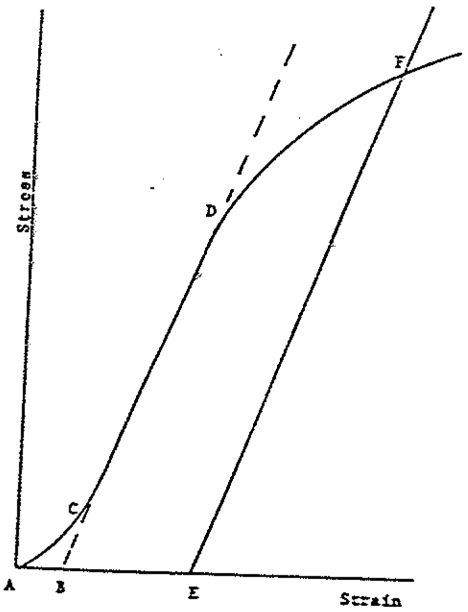


FIG. X1.1 Material with Hookean Region

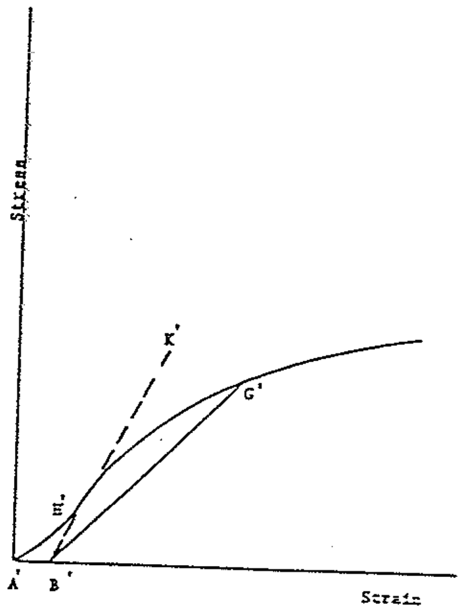


FIG. X1.2 Material with No Hookean Region
(Note that some chart recorders plot the mirror image of these graphs.)

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ındard Test Methods for EXURAL PROPERTIES OF UNREINFORCED AND INFORCED PLASTICS AND ELECTRICAL INSULATING ATERIALS (METRIC)[1]

ı standa… ssued under the fixed designation D 790M; the number immediately following the designation indicates the
of origi… doption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last
proval. …perscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

Scope

.1 Th… test methods cover the determina-
n of fl… al properties of unreinforced and
nforce… stics, including high-modulus com-
sites an… ectrical insulating materials in the
m of r… ngular bars molded directly or cut
m shee… ates, or molded shapes. These test
thods … generally applicable to rigid and
nirigid … terials. However, flexural strength
not be … mined for those materials that do
break … that do not fail in the outer fibers.
o test … ods are described as follows:
.1.1 M… od I—A three-point loading system
izing … r loading on a simply supported
m.
.1.2 M… od II—A four-point loading sys-
utilizi… wo load points equally spaced from
r adja… support points, with a distance
ween … points of either one third or one
of the … port span.
.2 Eit… test method can be used with the
procedures that follow:
.2.1 Procedure A, designed principally for
erials that break at comparatively small de-
tions.
.2.2 Procedure B, designed particularly for
se materials that undergo large deflections
ing testing.
.3 Comparative tests may be run according
ither test method or procedure, provided that
method or procedure is found satisfactory
the material being tested.

does not purport to address all of 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 Methods of Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 638 Test Method for Tensile Properties of Plastics[2]

D 790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[2]

D 4066 Specification for Nylon Injection and Extrusion Materials[3]

E 4 Practices for Load Verification of Testing Machines[3,4]

E 691 Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods[3]

3. Summary of Test Methods

3.1 A bar of rectangular cross section is tested in flexure as a beam as follows:

3.1.1 *Method I*—The bar rests on two supports and is loaded by means of a loading nose midway between the supports (see Fig. 1).

[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.

3.1.2 *Method II*—The bar rests on two supports and is loaded at two points (by means of two loading noses), each an equal distance from the adjacent support point. The distance between the loading noses (that is, the load span) is either one-third or one-half of the support span (see Fig. 2).

3.2 The specimen is deflected until rupture occurs in the outer fibers or until the maximum fiber strain (see 11.9) of 5 % is reached, whichever occurs first.

4. Significance and Use

4.1 Flexural properties, determined by Method I are especially useful for quality control and specification purposes.

4.2 Materials that do not fail at the point of maximum stress under Method I should be tested by Method II. Flexural properties determined by Method II are also useful for quality control and specification purposes. The basic difference between the two test methods is in the location of the maximum bending moment and maximum axial fiber stresses. The maximum axial fiber stresses occur on a line under the loading nose in Method I and over the area between the loading noses in Method II.

4.3 Flexural properties may vary with specimen depth, temperature, atmospheric conditions, and the difference in rate of straining specified in Procedures A and B (see also Note 7).

5. Apparatus

5.1 *Testing Machine*—A properly calibrated testing machine that can be operated at constant rates of crosshead motion over the range indicated, and in which the error in the load measuring system shall not exceed ±1 % of maximum load expected to be measured. It shall be equipped with a deflection-measuring device. The stiffness of the testing machine shall be such that the total elastic deformation of the system does not exceed 1 % of the total deflection of the test specimen during test, or appropriate corrections shall be made. The load-indicating mechanism shall be essentially free from inertial lag at the crosshead rate used. The accuracy of the testing machine shall be verified in accordance with Practices E 4.

directly under the loading nose or noses, t…
radius of the nose or noses and supports sh…
be at least 3 mm for all specimens. For spe…
mens 3 mm or greater in depth the radius …
the supports may be up to 1.5 times the spe…
men depth. They shall be this large if significa…
indentation or compressive failure occurs. T…
arc of the loading nose in contact with t…
specimen shall be sufficiently large to preve…
contact of the specimen with the sides of t…
nose or noses (see Fig. 1 for Method I, Fig…
for Method II).

6. Test Specimens

6.1 The specimens may be cut from shee…
plates, or molded shapes, or may be molded…
the desired finished dimensions.

NOTE 2—Any necessary polishing of specim…
shall be done only in the lengthwise direction of…
specimen.

6.2 *Sheet Materials* (except laminated th…
mosetting materials and certain materials u…
for electrical insulation, including vulcani…
fiber and glass-bonded mica):

6.2.1 *Materials 1.5 mm or Greater in Thi…
ness*—For flatwise tests, the depth of the sp…
imen shall be the thickness of the sheet. …
edgewise tests, the width of the specimen sh…
be the thickness of the sheet and the depth s…
not exceed the width (see Notes 3 and 4). …
all tests, the support span shall be 16 (tolera…
+4 or −2) times the depth of the beam. Sp…
men width shall not exceed one fourth of…
support span for specimens greater than 3 …
in depth. Specimens 3 mm or less in depth s…
be 10 mm in width. The specimen shall be l…
enough to allow for overhanging on each …
of at least 10 % of the support span, but in…
case less than 7 mm on each end. Overh…
shall be sufficient to prevent the specimen f…
slipping through the supports.

NOTE 3—Whenever possible, the original su…
of the sheet shall be unaltered. However, where…
ing machine limitations make it impossible to f…
the above criterion on the unaltered sheet, o…
both surfaces shall be machined to provide th…
sired dimensions, and the location of the speci…
with reference to the total depth shall be noted…
value obtained on specimens with machined sur…
may differ from those obtained on specimens …
original surfaces. Consequently, any specifica…

NOTE ... dgewise tests are not applicable for ...eets tha... so thin that specimens meeting these ...quireme... cannot be cut. If specimen depth ex...eds the ...h, buckling may occur.

6.2.2 ...erials Less than 1.5 mm in Thick...ss—Th... ...ecimen shall be 50 mm long by 10 ...m wid... ...sted flatwise on a 25-mm support ...an.

NOTE ... ...se of the formulas for simple beams cited ...these t... ...ethods for calculating results presumes ...t beam ...th is small in comparison with the sup...rt span. ...refore, the formulas do not apply rigor...sly to th... ...dimensions.

NOTE ... ...Where machine sensitivity is such that ...ecimens ...hese dimensions cannot be measured, ...ler spe... ...ns or shorter support spans, or both ...y be ... provided the support span-to-depth ...io is at ... 14 to 1. All dimensions must be stated ...the rep... ...see also Note 5).

6.3 *La... ...ated Thermosetting Materials and ...eet an... ...late Materials Used for Electrical ...sulatio... Including Vulcanized Fiber and ...ass-Bo... ...d Mica*—Test the specimens in ac...rdance ...h Table 1 for Method I, and Table ...r 3 for ...hod II. For paper-base and fabric...se gra... ...ver 25 mm in nominal thickness, ...speci... ...shall be machined on both sur...es to ...th of 25 mm. For glass-base and ...lon-ba... ...ades, specimens over 13 mm in ...minal ... shall be machined on both sur...es to ...th of 13 mm. The support span...depth ... shall be chosen such that failures ...ur in ... ...ter fibers of the specimens, due ...y to t... ...ending moment (Note 7). Three ...ommen... ...support span-to-depth ratios are ...32, a... ...to 1. When laminated materials ...ibit lo... ...mpressive strength perpendicular ...he lan... ...ions, they shall be loaded with a ...ge rad... ...loading nose (up to 4 times the ...cimen depth for Method I and 1.5 times the ...cimen depth for Method II) to prevent pre...ure damage to the outer fibers.

...4 *Molding Materials (Thermoplastics and ...rmosets)*—The recommended specimen for ...ding materials is 80 by 10 by 4 mm tested ...wise on a support span, resulting in a sup... span-to-depth ratio of 16 (tolerance +4 or

...5 *High-Strength Reinforced Composites, ...uding Highly Orthotropic Laminates*—Spec...

(Note 7). Three recommended support span-to-depth ratios are 16, 32, and 40 to 1. However, for some highly anisotropic composites, shear deformation can significantly influence modulus measurements, even at span-to-depth ratios as high as 40:1. Hence, for these materials, an increase in span-to-depth ratio to 60:1 is recommended to eliminate shear effects when modulus data are required. It should also be noted that the flexural modulus of highly anisotropic laminates is a strong function of ply-stacking sequence and will not necessarily correlate with tensile modulus, which is not stacking-sequence dependent.

NOTE 7—As a general rule, a support span-to-depth ratio of 16 is satisfactory when the ratio of the tensile strength to shear strength is less than 8 to 1, but the support span-to-depth ratio must be increased for composite laminates having relatively low-shear strength in the plane of the laminate and relatively high tensile strength parallel to the support span.

7. Number of Test Specimens

7.1 At least five specimens shall be tested for each sample in the case of isotropic materials or molded specimens.

7.2 For each sample of anisotropic material in sheet form, at least five specimens shall be tested for each of the following conditions. Recommended conditions are flatwise and edgewise tests on specimens cut in lengthwise and crosswise directions of the sheet. For purposes of this test, "lengthwise" shall designate the principal axis of anisotropy and shall be interpreted to mean the direction of the sheet known to be stronger in flexure. "Crosswise" shall be the sheet direction known to be the weaker in flexure, and shall be at 90° to the lengthwise direction.

8. Conditioning

8.1 *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 Practices D 618 for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ± 1°C and ± 2 % relative humidity.

8.1.1 Note that for some hygroscopic materials, such as nylons, the material specifications

tainers 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 and 50 ± 5 % relative humidity, unless otherwise specified in the test methods. In cases of disagreement, the tolerance shall be ± 1°C and ± 2 % relative humidity.

9. Procedure

9.1 *Method I—Procedure A:*

9.1.1 Use an untested specimen for each measurement. Measure the width and depth of the specimen to the nearest 0.01 mm at the center of the support span. For specimens less than 2.5 mm in depth, measure the depth to the nearest 0.001 mm.

9.1.2 Determine the support span to be used as described in Section 6 and set the support span to within 1 % of the determined value.

9.1.3 If Table 1 is used, set the machine to the specified rate of crosshead motion, or as near as possible to it. If Table 1 is not used, calculate the rate of crosshead motion as follows and set the machine for the calculated rate, or as near as possible to it:

$$R = ZL^2/6d \quad (1)$$

where:

R = rate of crosshead motion, mm/min,
L = support span, mm,
d = depth of beam, mm, and
Z = rate of straining of the outer fiber, mm/mm·min. Z shall equal 0.01.

In no case shall the actual crosshead rate differ from that specified by Table 1, or that calculated from Eq 1, by more than ± 50 %.

9.1.4 Align the loading nose and supports so that the axes of the cylindrical surfaces are parallel and the loading nose is midway between the supports. This parallelism may be checked by means of a plate with parallel grooves into which the loading nose and supports will fit when properly aligned. Center the specimen on the supports, with the long axis of the specimen perpendicular to the loading nose and supports.

9.1.5 Apply the load to the specimen at the specified crosshead rate, and take simultaneous

of the loading nose relative to the support... either case, make appropriate corrections... indentation in the specimens and deflection... the weighing system of the machine. Lo... deflection curves may be plotted to deter... the flexural yield strength, secant or tan... modulus of elasticity, and the total work r... sured by the area under the load - deflec... curve.

9.1.6 Terminate the test if the maxi... strain in the outer fibers has reached 0.05 ... mm (Notes 8 and 9). The deflection at w... this strain occurs may be calculated by le... r equal 0.05 mm/mm as follows:

$$D = rL^2/6d$$

where:

D = midspan deflection, mm,
r = strain, mm/mm,
L = support span, mm, and
d = depth of beam, mm.

NOTE 8—For some materials the increase in ... rate provided under Procedure B may induc... specimen to yield or rupture, or both, withi... required 5 % strain limit.

NOTE 9—Beyond 5 % strain, these test metho... not applicable, and some other property may be ... sured (for example, Test Method D 638 may be c... ered).

9.2 *Method II—Procedure A:*

9.2.1 See 9.1.1.

9.2.2 See 9.1.2.

9.2.3 If Table 2 or 3 is used, set the mac... for the specified rate of crosshead motion, ... near as possible to it. If Table 2 or 3 is not ... calculate the rate of crosshead motion as... lows and set the machine as near as possib... that calculated rate for a load span of one ... of the support span:

$$R = 0.185ZL^2/d$$

For a load span of one half of the support...

$$R = 0.167ZL^2/d$$

where:

R = rate of crosshead motion, mm/min...
L = support span, mm,
d = depth of beam, mm, and
Z = rate of straining of the outer fibers, mm·min. Z shall equal 0.01.

In no case shall the actual crosshead rate ...

...es of the cylindrical surfaces are ...e load span is either one third or ...e support span. This parallelism ...d by means of a plate containing ...es into which the loading noses ... will fit when properly aligned. ...ecimen on the supports, with the ...e specimen perpendicular to the ... and supports. The loading nose ...ll be of the type that will not

... the load to the specimen at the ...head rate, and take simultaneous ...on data. Measure deflection by a ...e specimen in contact with it at ...enter of the spans, the gage being ...ionary relative to the specimen ...e appropriate corrections for in... the specimens and deflections in ...system of the machine. Load - ...ves may be plotted to determine ...ield strength, secant or tangent ...sticity, and the total work mea... area under the load - deflection

...break has occurred in a specimen ...e maximum strain in the outer ...ched 0.05 mm/mm, discontinue ...8 and 9). The deflection at which ...ir may be calculated by letting ...m/mm as follows for a load span ...the support span:

$$D = 0.21rL^2/d \quad (2a)$$

...n of one half of the support span:

$$D = 0.23rL^2/d \quad (2b)$$

10. Retests

10.1 Values for properties at rupture shall not be calculated for any specimen that breaks at some obvious, fortuitous flaw, unless such flaws constitute a variable being studied. Retests shall be made for any specimen on which values are not calculated.

11. Calculation

11.1 *Maximum Fiber Stress, Method I*—When a beam of homogeneous, elastic material is tested in flexure as a simple beam supported at two points and loaded at the midpoint, the maximum stress in the outer fibers occurs at midspan. This stress may be calculated for any point on the load - deflection curve by the following equation (Notes 10 and 11):

$$S = 3PL/2bd^2 \quad (3)$$

where:

S = stress in the outer fibers at midspan, MPa,
P = load at a given point on the load-deflection curve, N,
L = support span, mm,
b = width of beam tested, mm, and
d = depth of beam tested, mm.

NOTE 10—Equation 3 applies strictly to materials for which the stress is linearly proportional to strain up to the point of rupture and for which the strains are small. Since this is not always the case, a slight error will be introduced in the use of this equation. The equation will, however, be valid for comparison data and specification values up to the maximum fiber strain of 5 % for specimens tested by the procedure herein described. It should be noted that the maximum stress may not occur in the outer fibers for a highly orthotropic laminate[6]. Laminated beam theory must be applied to determine the maximum tensile stress at failure. Thus, Eq 3 yields an apparent strength based on homogeneous beam theory. This apparent strength is highly dependent on the ply-stacking sequence for highly orthotropic laminates.

NOTE 11—The above calculation is not valid if the specimen is slipping excessively between the supports.

11.2 *Maximum Fiber Stress for Beams Tested at Large Support Spans, Method I*—If support span-to-depth ratios greater than 16 to 1 are used such that deflections in excess of 10 % of the support span occur, the maximum stress for a simple beam can be reasonably approximated with the following equation (Note 12):

$$S = (3PL/2bd^2) \times [1 + 6(D/L)^2 - 4(d/L)(D/L)] \quad (3a)$$

where S, P, L, b, and d are the same as for Eq 3 and D is the deflection in millimetres of the centerline of the specimen at the middle of the support span.

NOTE 12—When large support span-to-depth ratios are used, significant end forces are developed at the supports which affect the moment in a simply supported beam. An approximate correction factor is given in Eq 3a to correct for these end forces in large support span-to-depth ratio beams where relatively large deflections exist.

11.3 *Maximum Fiber Stress, Method II*—When a beam is loaded in flexure at two central points and supported at two outer points, the maximum stress in the outer fibers occurs between the two central loading points that define the load span (Fig. 2). This stress may be calculated for any point on the load - deflection curve for relatively small deflections by the following equation for a load span of one-third of the support span (Note 13):

$$S = PL/bd^2 \quad (3b)$$

For a load span of one-half of the support span:

$$S = 3PL/4bd^2 \quad (3c)$$

where:

S = stress in the outer fiber throughout the load span, MPa,
P = load at a given point on the load deflection curve, N,
L = support span, mm,
b = width of beam, mm, and
d = depth of beam, mm.

NOTE 13—The limitations defined for Eq 3 in Notes 10 and 11 apply also to Eq 3a, 3b, 3c, 3d, and 3e.

11.4 *Maximum Fiber Stress–Method II–for Beams Tested at Large Support Spans*—If support span-to-depth ratios greater than 16 to 1 are used with resultant deflections in excess of 10 % of the support span occuring, the maximum stress may be reasonably approximated with the following formula for a load span of maxim... strain in the outer fibers occur at midspa...nd may be calculated as follows for a load s... of one-third of the support span:

$$r = 4.70Dd/L^2 \quad (4a)$$

For a lo...span of one-half of the support span:

$$r = 4.36Dd/L^2 \quad (4b)$$

where ... L, and r are the same as for Eq 2a.

11.11 ...odulus of Elasticity:

11.11... Tangent Modulus of Elasticity, Method ...The tangent modulus of elasticity, often ca... the "modulus of elasticity," is the ratio, w... the elastic limit of stress to corresponding ...train and shall be expressed in megapa...s. It is calculated by drawing a tan...ent to ... steepest initial straight-line portion of the l... - deflection curve and using Eq 5 or hig... anisotropic composites, see Note 5).

$$E_B = L^3m/4bd^3 \quad (5)$$

where:

E_B = m...lus of elasticity in bending, MPa,
L = su... span, mm,
b = wi... of beam tested, mm,
d = de... of beam tested, mm, and
m = sl... the tangent to the initial straight-lin... portion of the load - deflection curve, N... of deflection.

NOTE ... Shear deflections can seriously reduce the appar... modulus of highly anisotropic compos...s when ... tested at low span-to-depth ratios[8]. ...r this ... a span-to-depth ratio of 60 to 1 is recommen... for flexural modulus determinations. ...exural s... th should be determined on a separate ... of rep... specimens at a lower span-to-depth ...io that ... tensile failures in the outer fibers ...the bea... along its lower face. Since the flexural ...odulus ... highly anisotropic laminates is a critical ...ction c... stacking sequence, it will not neces-...ily correlate with tensile modulus, which is not ...cking-sequence dependent.

11.11.2 *Tangent Modulus of Elasticity, Method II*—The tangent modulus of elasticity ...he ratio, within the elastic limit, of stress to ...responding strain and shall be expressed in ...gapascals. It is calculated by drawing a tan-...t to the steepest initial straight-line portion ...the load - deflection curve and using Eq 5a ... a load span of one third the support span ...l Eq 5a for a load span of one half of the

5 (for highly anisotropic composites, see Note 15).

11.11.3 *Secant Modulus of Elasticity*—The secant modulus of elasticity is the ratio of stress to corresponding strain at any given point on the stress - strain curve, or the slope of the straight line that joins the origin and a selected point on the actual stress - strain curve. It shall be expressed in megapascals. The selected point is generally chosen at a specified stress or strain. It is calculated in accordance with Eq 5 or 5a by letting *m* equal the slope of the secant to the load - deflection curve.

11.12 *Arithmetic Mean*—For each series of tests, the arithmetic mean of all values obtained shall be calculated to three significant figures and reported as the "average value" for the particular property in question.

11.13 *Standard Deviation*—The standard deviation (estimated) shall be calculated as follows and reported to two significant figures:

$$s = \sqrt{\frac{\Sigma X^2 - n\bar{X}^2}{n - 1}}$$

where:

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

12. Report

12.1 The report shall include the following:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form, principal dimensions, and previous history. For laminated materials, ply-stacking sequence shall be reported.

12.1.2 Direction of cutting and loading specimens.

12.1.3 Conditioning procedure and strain level used in secant modulus.

12.1.4 Depth and width of specimen.

12.1.5 Method used.

12.1.6 Procedure used.

12.1.7 Support-span length.

12.1.8 Support span-to-depth ratio.

12.1.9 Radius of supports and loading noses.

12.1.10 Rate of crosshead motion.

12.1.11 Maximum strain in the outer fibers of the specimen.

12.1.12 Flexural strength (if applicable), average value, and standard deviation.

12.1.13 Tangent or secant modulus of elasticity in bending, average value, and standard deviation.

12.1.14 Flexural yield strength (if desired), average value and standard deviation.

12.1.15 Flexural offset yield strength (if desired), with offset or strain used, average value, and standard deviation.

12.1.16 Stress at any given strain up to and including 5 % (if desired), with strain used, average value, and standard deviation.

13. Precision and Bias[7]

13.1 Tables 4 and 5 are based on round-robin tests conducted in 1984, involving six materials tested by six laboratories. Each test result was the average of five individual determinations. Each laboratory obtained two test results for each material.

13.2 For materials indicated and for test results that are averages from testing five specimens, see Tables 4 and 5.

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

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

13.2.5 The judgments in 13.3 and 13.4 will have an approximately 95 % (0.95) probability of being correct.

13.2.6 Other formulations may give somewhat different results.

13.3 For further information on the methodology used in this section, see Practice E 691.

13.4 *Bias*—No statement may be made about bias of the method, as there is no standard ref-

TABLE 1 Recommended Dimensions for Test Spe... of Section 6.3 and 6.5 for Various Support Span-to-... Ratios (See Note 7)

Method I (3-Point Loading)

Nominal Specimen Depth, mm	Specimen Width, mm	Specimen Length, mm	Support Span, mm	Ra... Cross... Mo... (Proc... A)[A], m...
		L/d = 16 to 1		
1	25	50	16	0
2	25	50	32	0
3	25	60	48	1
4	10	80	64	1
5	10	100	80	2
6	10	125	96	2
10	10	200	160	4
15	20	270	240	6
20	20	350	320	8
25	25	450	400	10
		L/d = 32 to 1		
1	25	50	32	1.
2	25	80	64	3.
3	25	125	96	5.
4	10	150	128	6.
5	10	200	160	8.
6	10	250	192	10.
10	10	350	320	17.
15	20	550	480	25.
20	20	700	640	34.
25	25	900	800	42.
		L/d = 40 to 1		
1	25	60	40	2
2	25	100	80	5
3	25	150	120	8
4	10	200	160	10
5	10	240	200	13
6	10	270	240	16
10	10	450	400	26
15	20	680	600	40
20	20	900	800	53
25	25	1100	1000	66
		L/d = 60 to 1		
1	25	75	60	6
2	25	150	120	12
3	25	200	180	18
4	10	300	240	24
5	10	350	300	30
6	10	400	360	36
10	10	700	600	60
15	20	1000	900	90
20	20	1400	1200	120
25	25	1800	1500	150

[A] Rates indicated are for Procedure A where strai... 0.01 mm/mm·min. To obtain rates for Procedure B... strain rate is 0.10 mm/mm·min., multiply these val... 10. Procedure A is to be used for all specification p... unless otherwise stated in the specifications. See 9.1.3 ... method of calculation.

ABLE 2 ecommended Dimensions for Test Specimens of Section 6.3 and 6.5 for Various Support Span-to-Depth Ratios (See Note 7)

Method II [4-Point Loading at ⅓ Points, Fig. 2 (A)]

ominal S men Dep mm	Specimen Width, mm	Specimen Length, mm	Support Span, mm	Load Span, mm	Rate of Cross-head Motion (Procedure A), mm/min[A]
		L/d = 16 to 1			
1	25	50	16	5.3	0.47
2	25	50	32	10.7	0.94
3	25	60	48	16.0	1.4
4	10	80	64	21.3	1.9
5	10	100	80	26.7	2.4
6	10	125	96	32.0	2.8
10	10	200	160	53.3	4.7
15	20	270	240	80.0	7.1
20	20	350	320	106.7	9.5
25	25	450	400	133.3	11.8
		L/d = 32 to 1			
1	25	50	32	10.7	1.9
2	25	80	64	21.3	3.8
3	25	125	96	32.0	5.7
4	10	150	128	42.7	7.6
5	10	200	160	53.3	9.5
6	10	250	192	64.0	11.4
10	10	350	320	106.7	18.9
15	20	550	480	160.0	28.4
20	20	700	640	213.3	37.9
25	25	900	800	266.7	47.4
		L/d = 40 to 1			
1	25	60	40	13.3	3.0
2	25	100	80	26.7	5.9
3	25	150	120	40.0	8.9
4	10	200	160	53.3	11.8
5	10	240	200	66.7	14.8
6	10	270	240	80.0	17.8
10	10	450	400	133.3	29.6
15	20	680	600	200.0	44.4
20	20	900	800	266.7	59.2
25	25	1100	1000	333.3	74.0
		L/d = 60 to 1			
1	25	75	60	20	6.7
2	25	150	120	40	13.3
3	25	200	180	60	20.0
4	10	300	240	80	26.6
5	10	350	300	100	33.3
6	10	400	360	120	40.0
10	10	700	600	200	66.6
15	20	1000	900	300	99.9
20	20	1400	1200	400	133.0
25	25	1800	1500	500	166.0

ates indicated are for Procedure A where strain rate is 0.01 mm/mm·min. To obtain speeds for Procedure B where rate is 0.10 mm/mm·min, multiply these values by 10. Procedure A is to be used for all specification purposes, unless wise stated in the specifications. See 9.2.3 for the method of calculation.

TABLE 3 Recommended Dimensions for Test Specimens of Sections 6.3 and 6.5 for Various Support Span-to-Dep Ratios (See Note 7)

Method II [4-Point Loading at ¼ Points, Fig. 2 (B)]

Nominal Specimen Depth, mm	Specimen Width, mm	Specimen Length, mm	Support Span, mm	Load Span, mm	Rate of Cros head Motio (Procedure A mm/min[A]
		L/d = 16 to 1			
1	25	50	16	8	0.42
2	25	50	32	16	0.85
3	25	60	48	24	1.3
4	10	80	64	32	1.7
5	10	100	80	40	2.1
6	10	125	96	48	2.6
10	10	200	160	80	4.3
15	20	270	240	120	6.4
20	20	350	320	160	8.6
25	25	450	400	200	10.7
		L/d = 32 to 1			
1	25	50	32	16	1.7
2	25	80	64	32	3.4
3	25	125	96	48	5.1
4	10	150	128	64	6.8
5	10	200	160	80	8.6
6	10	250	192	96	10.3
10	10	350	320	160	17.1
15	20	550	480	240	25.7
20	20	700	640	320	34.2
25	25	900	800	400	42.8
		L/d = 40 to 1			
1	25	60	40	20	2.7
2	25	100	80	40	5.3
3	25	150	120	60	8.0
4	10	200	160	80	10.7
5	10	240	200	100	13.4
6	10	270	240	120	16.0
10	10	450	400	200	26.7
15	20	680	600	300	40.0
20	20	900	800	400	53.4
25	25	1100	1000	500	66.8
		L/d = 60 to 1			
1	25	75	60	30	6.0
2	25	150	120	60	12.0
3	25	200	180	90	18.0
4	10	300	240	120	24.0
5	10	350	300	150	30.0
6	10	400	360	180	36.1
10	10	700	600	300	60.1
15	20	1000	900	450	90.2
20	20	1400	1200	600	120.0
25	25	1800	1500	750	150.0

[A] Rates indicated are for Procedure A where strain rate is 0.01 mm/mm·min. To obtain rates for Procedure B where rate is 0.10 mm/mm·min, multiply these values by 10. Procedure A is to be used for all specification purposes, otherwise stated in the specifications. See 9.2.3 for the method of calculation.

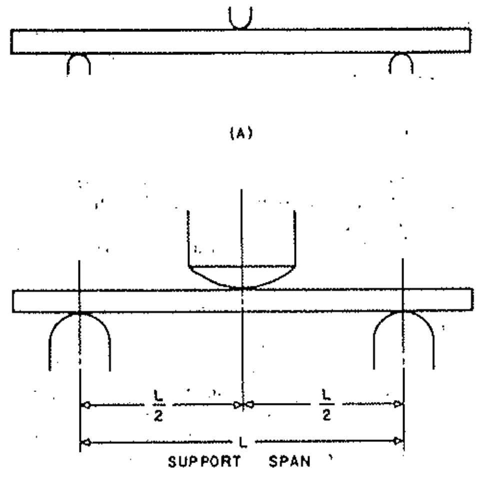
BLE 4 Flexural Strength

OTE 1—\ he within-laboratory coefficient of variation average I_r = 2.83 V_r. (See 13.3 for application of I_r.)
OTE 2—\ the total between-laboratory coefficient of ion of th erage and I_R = 2.83 V_R. (See 13.4 for appli- of I_R.)

Material	Mean (MPa)	Values as a Percentage of the Mean			
		V_r	V_R	I_r	I_R
	70.9	3.98	5.11	11.3	14.6
hermos	92.6	14.2	14.2	40.2	40.2
crylic	112.	4.09	11.0	11.6	31.1
lyester	138.	9.09	9.09	25.7	25.7
lycarbo	142.	2.43	2.43	6.88	6.88
	181.	12.4	12.4	35.1	35.1
	Average (RMS)	8.93	9.93	25 2	28.1

TABLE 5 Flexural Modulus

Material	Mean (MPa)	Values as a Percentage of the Mean			
		V_r	V_R	I_r	I_R
ABS	2.42	4.83	5.17	13.7	14.6
Cast acrylic	3.22	5.81	13.8	16.4	39.1
GR polycarbonate	4.96	3.10	3.59	8.77	10.2
GR polyester	5.75	8.92	8.92	25.2	25.2
DAP thermoset	12.1	5.98	8.22	16.9	23.3
SMC	13.3	8.09	8.09	22.9	22.9
	Average (RMS)	6.42	8.59	18.2	24.3



NOTE—(A) Minimum radius = 3 mm. (B) Maximum radius supports = 1.5 times specimen depth, maximum radius loading nose = 4 times specimen depth.

FIG. 1 Loading Nose and Support Diagram 3-Point Loading

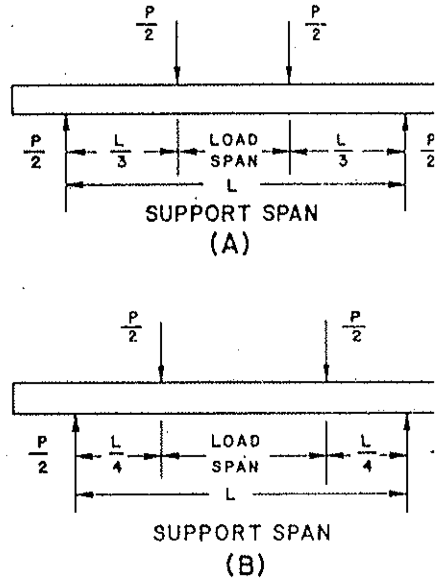
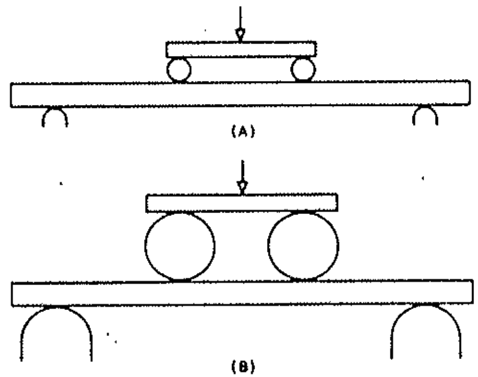


FIG. 2 Loading Diagram



NOTE (A) Minimum radius = 3 mm. (B) Maximum radius = 1.5 times specimen depth.

FIG. 3 Loading and Support Noses Diagram 4-Point Loading

APPENDIX

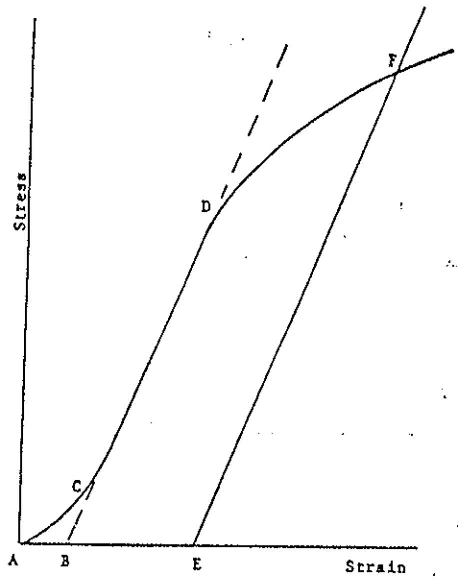
(Nonmandatory Information)

X1. TOE COMPENSATION

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

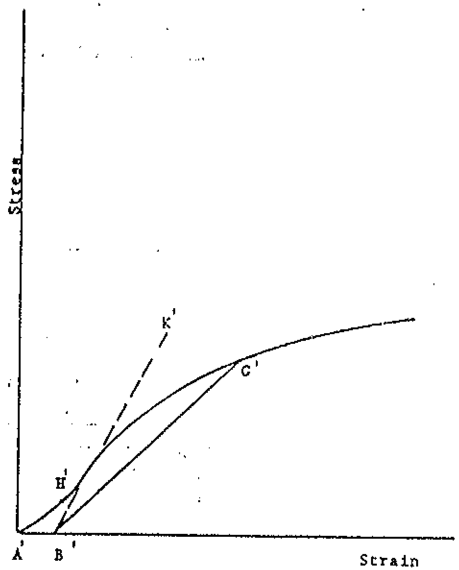
X1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. X1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured, 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 that 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 those materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.



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

FIG. X1.1 Material with Hookean Region



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

FIG. X1.2 Material with No Hookean Region