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Zwick / Roell

Flexural Test report

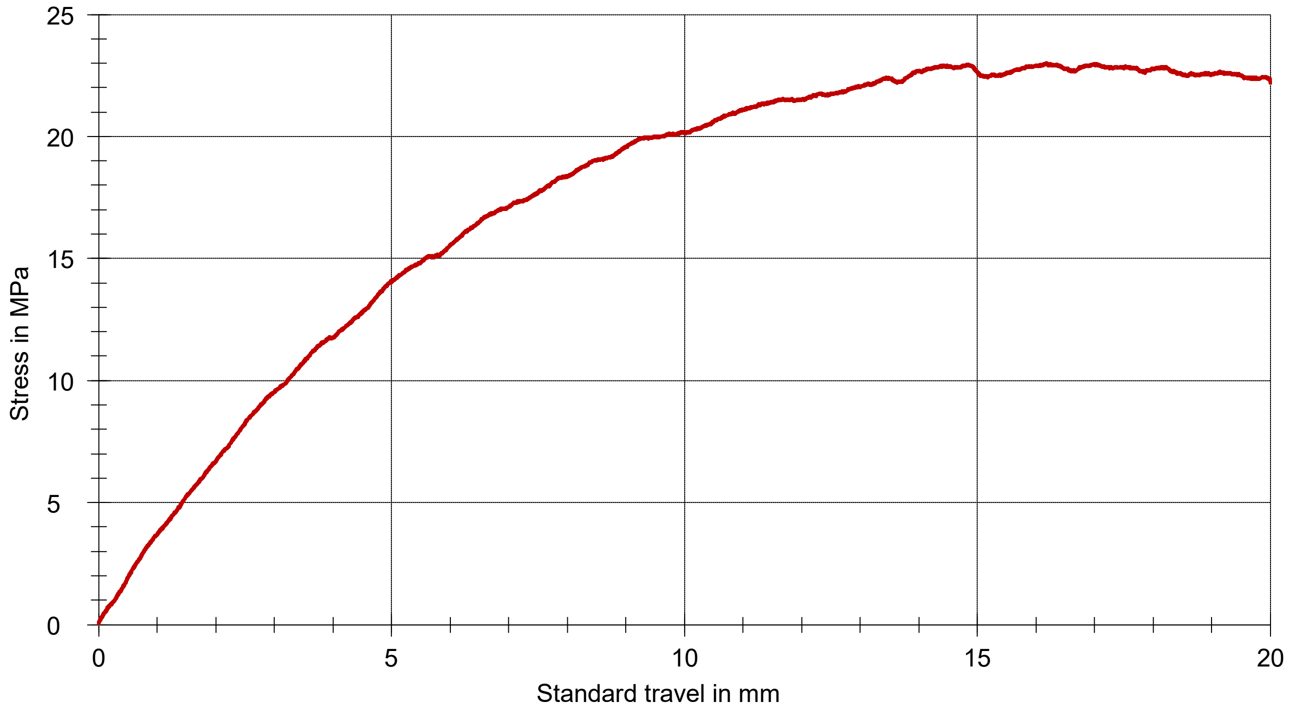
Customer : Rinto
Test standard : ASTM D 790
Material : HDPE
Notes : Raw Material
Machine data : Zwick Z020

Pre-load : 0,1 MPa
Test speed : 2 mm/min

Test results:

		Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
Legend	No.	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
🟥	1	33,45	704	6,75	11,8	23,0	-	-	9,9	80	5,28	6,26

Series graph:



Statistics:

Series	Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
n = 1	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
$\bar{x}$	33,45	704	6,75	11,8	23,0	-	-	9,9	80	5,28	6,26
s	-	-	-	-	-	-	-	-	-	-	-
ν [%]	-	-	-	-	-	-	-	-	-	-	-

Flexural Test report

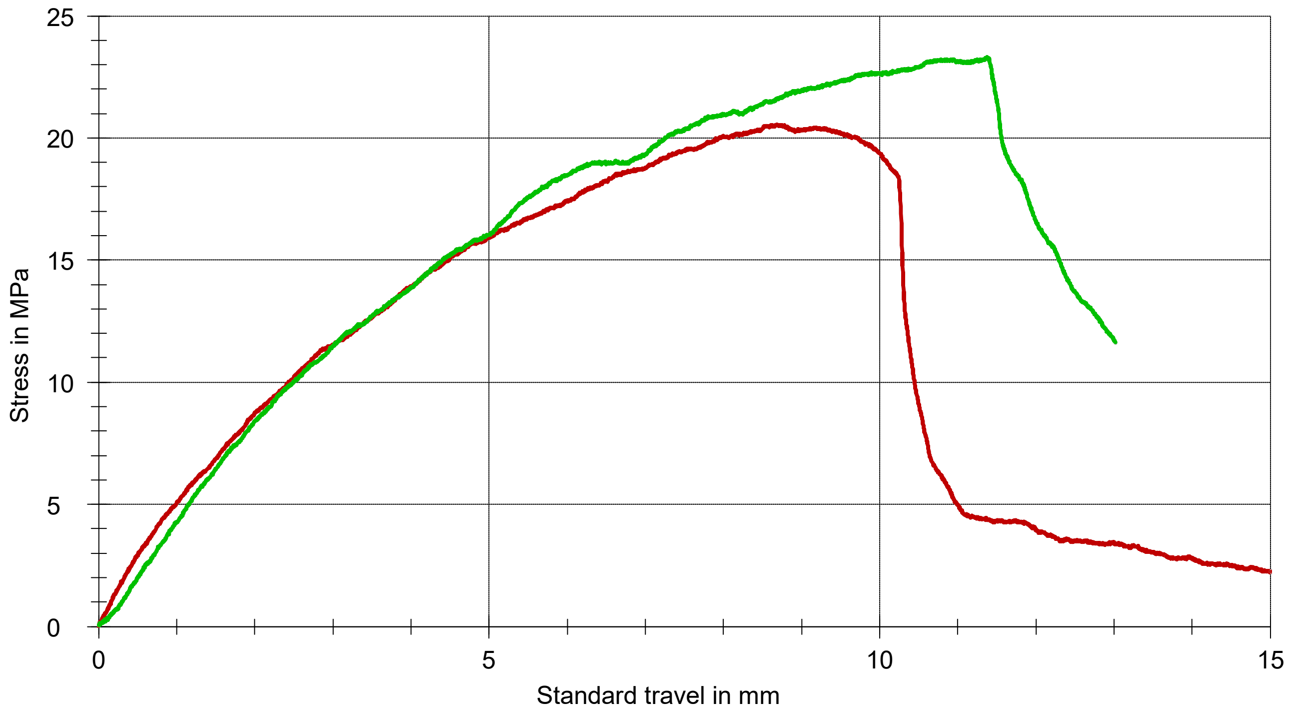
Customer : Aripin
Test standard : ASTM D 790
Material : HDPE
Notes : Rotation Speed 900 rpm Double
Machine data : Zwick Z020

Pre-load : 0,1 MPa
Test speed : 2 mm/min

Test results:

		Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
Legend	No.	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
🟥	1	19,66	1350	10,1	15,8	20,6	-	-	6,8	80	4,32	6,15
🟩	2	20,55	1200	10,2	16,5	23,3	5,1	11,7	5,1	80	4,14	6,17

Series graph:



Statistics:

Series	Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
n = 2	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
$\bar{x}$	20,11	1280	10,2	16,2	21,9	5,1	11,7	5,9	80	4,23	6,16
s	0,63	110	0,120	0,493	1,95	-	-	1,2	0,000	0,1273	0,01414
ν [%]	3,11	8,65	1,18	3,05	8,89	-	-	20,52	0,00	3,01	0,23

Flexural Test report

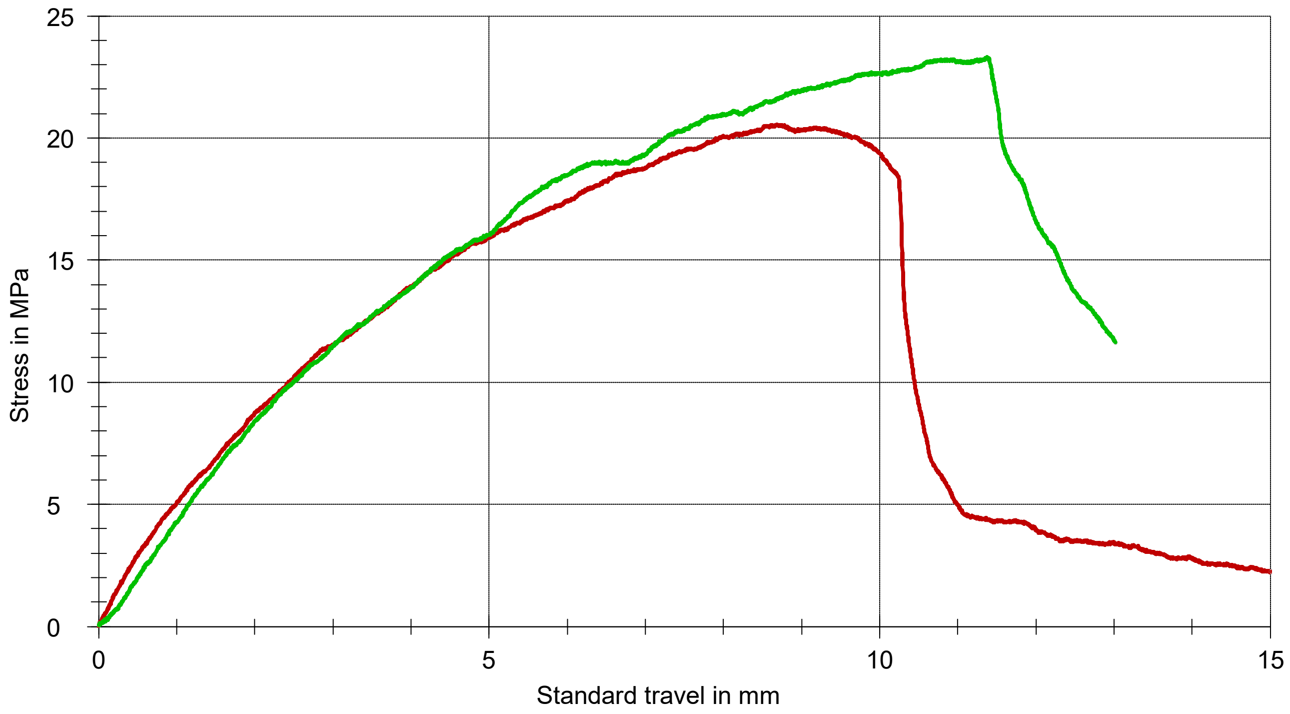
Customer : Aripin
Test standard : ASTM D 790
Material : HDPE
Notes : Rotation Speed 900 rpm Double
Machine data : Zwick Z020

Pre-load : 0,1 MPa
Test speed : 2 mm/min

Test results:

Legend	No.	Force N	E_H MPa	σ_1 MPa	σ_2 MPa	σ_{fM} MPa	ε_B %	σ_{fB} MPa	ε_f %	L mm	d mm	b mm
🟥	1	19,66	1350	10,1	15,8	20,6	-	-	6,8	80	4,32	6,15
🟩	2	20,55	1200	10,2	16,5	23,3	5,1	11,7	5,1	80	4,14	6,17

Series graph:



Statistics:

Series n = 2	Force N	E_H MPa	σ_1 MPa	σ_2 MPa	σ_{fM} MPa	ε_B %	σ_{fB} MPa	ε_f %	L mm	d mm	b mm
$\bar{x}$	20,11	1280	10,2	16,2	21,9	5,1	11,7	5,9	80	4,23	6,16
s	0,63	110	0,120	0,493	1,95	-	-	1,2	0,000	0,1273	0,01414
ν [%]	3,11	8,65	1,18	3,05	8,89	-	-	20,52	0,00	3,01	0,23

Flexural Test report

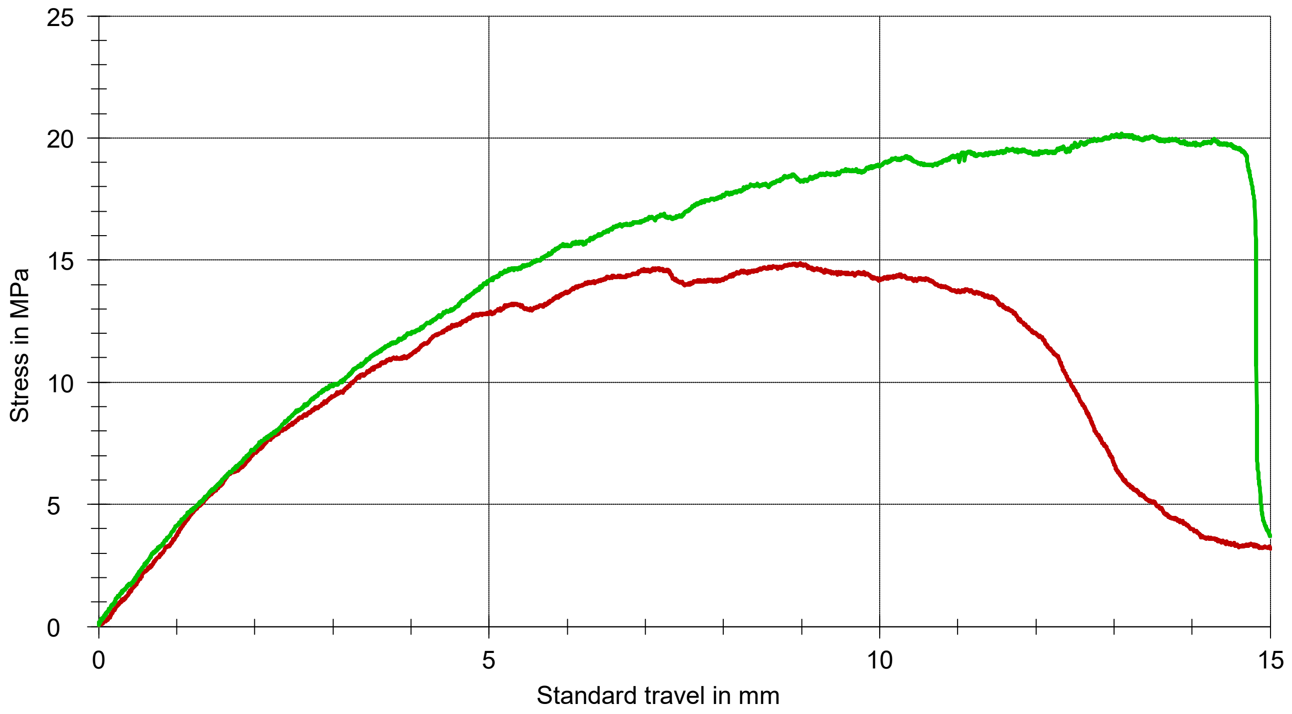
Customer : Aripin
Test standard : ASTM D 790
Material : HDPE
Notes : Rotation Speed 1500 rpm Double
Machine data : Zwick Z020

Pre-load : 0,1 MPa
Test speed : 2 mm/min

Test results:

		Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
Legend	No.	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
🟥	1	13,45	1010	8,44	12,9	14,9	-	-	5,9	80	4,2	6,15
🟩	2	18,08	984	8,81	14,3	20,2	-	-	5,9	80	4,2	6,1

Series graph:



Statistics:

Series	Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
n = 2	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
$\bar{x}$	15,76	996	8,62	13,6	17,5	-	-	5,9	80	4,2	6,125
s	3,28	16,9	0,264	0,992	3,74	-	-	0,00000080	0,000	0,000	0,03536
ν [%]	20,81	1,70	3,06	7,29	21,37	-	-	0,00	0,00	0,00	0,58

Flexural Test report

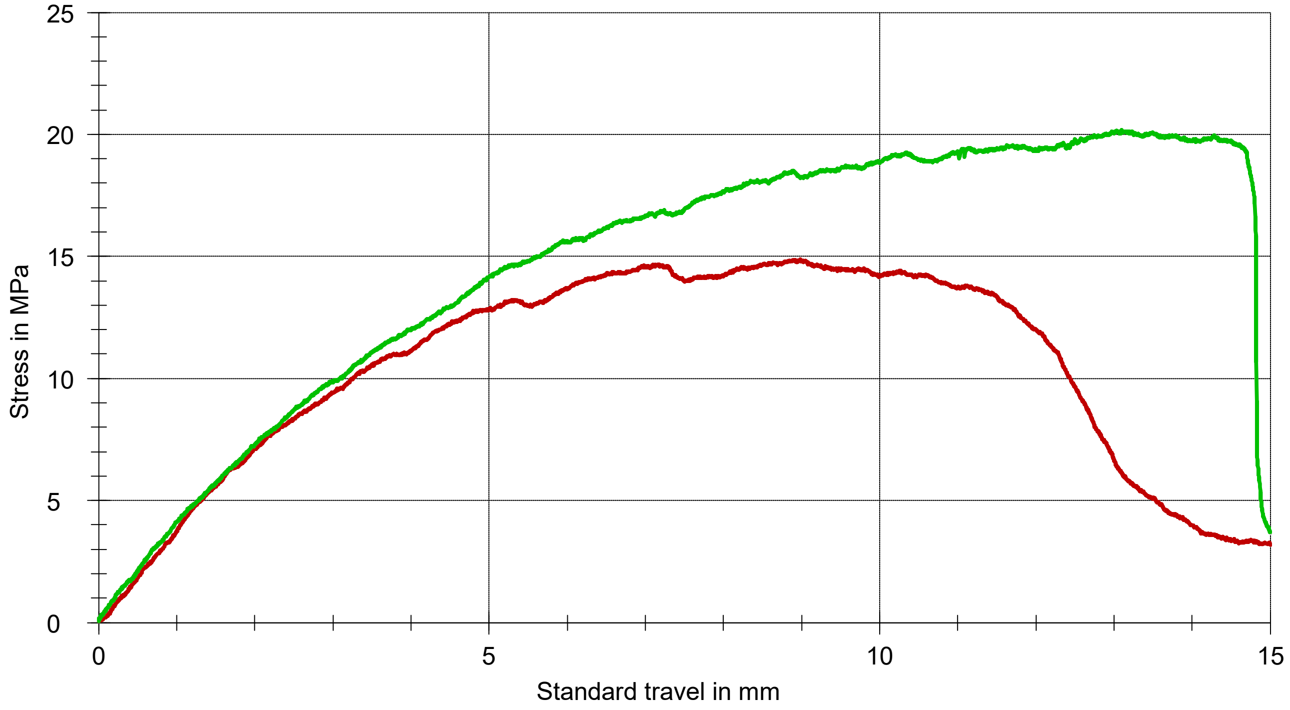
Customer : Aripin
Test standard : ASTM D 790
Material : HDPE
Notes : Rotation Speed 1500 rpm Double
Machine data : Zwick Z020

Pre-load : 0,1 MPa
Test speed : 2 mm/min

Test results:

		Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
Legend	No.	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
🟥	1	13,45	1010	8,44	12,9	14,9	-	-	5,9	80	4,2	6,15
🟩	2	18,08	984	8,81	14,3	20,2	-	-	5,9	80	4,2	6,1

Series graph:



Statistics:

Series	Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
n = 2	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
$\bar{x}$	15,76	996	8,62	13,6	17,5	-	-	5,9	80	4,2	6,125
s	3,28	16,9	0,264	0,992	3,74	-	-	0,00000080	0,000	0,000	0,03536
ν [%]	20,81	1,70	3,06	7,29	21,37	-	-	0,00	0,00	0,00	0,58

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Zwick / Roell

Flexural Test report

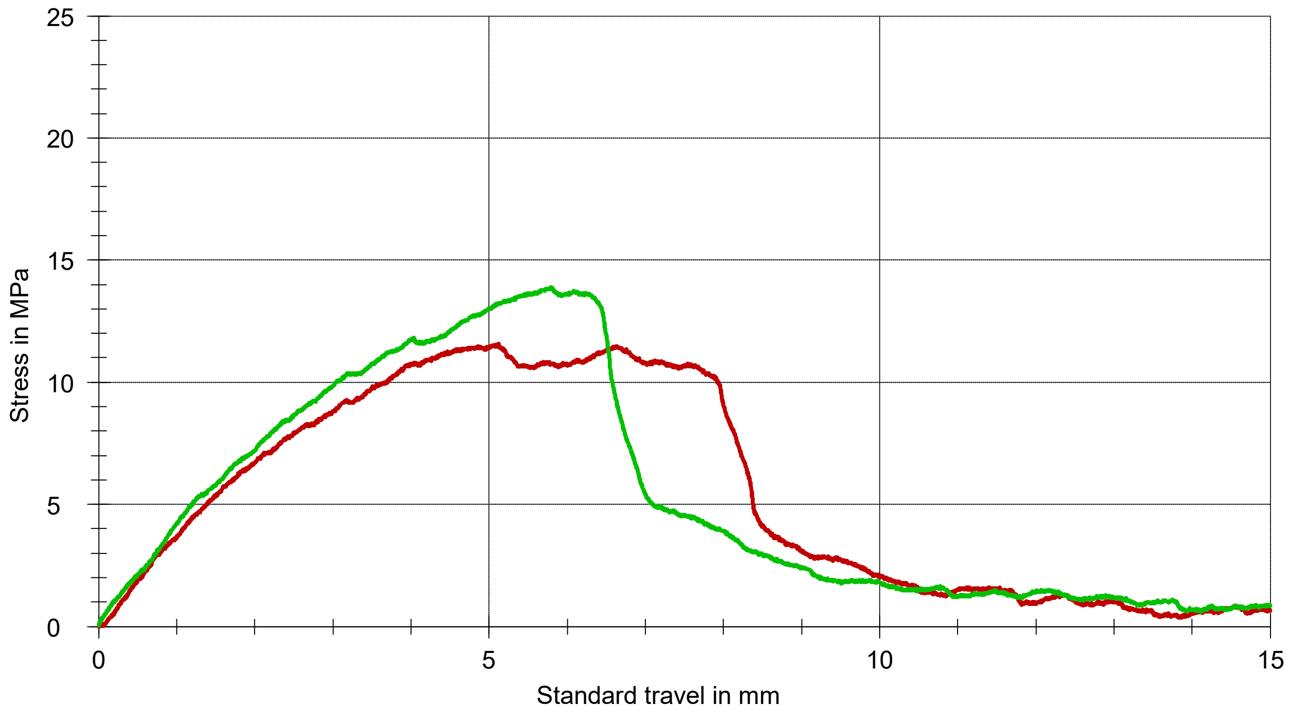
Customer : Aripin
Test standard : ASTM D 790
Material : HDPE
Notes : Rotation Speed 2000 rpm Double
Machine data : Zwick Z020

Pre-load : 0,1 MPa
Test speed : 2 mm/min

Test results:

		Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
Legend	No.	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
🟥	1	8,57	1180	8,37	10,7	11,6	-	-	5,3	80	3,8	6,16
🟩	2	12,63	912	8,74	13,1	13,9	-	-	5,9	80	4,2	6,18

Series graph:



Statistics:

Series	Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
n = 2	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
$\bar{x}$	10,60	1050	8,56	11,9	12,7	-	-	5,6	80	4	6,17
s	2,87	192	0,258	1,73	1,65	-	-	0,40	0,000	0,2828	0,01414
ν [%]	27,07	18,35	3,01	14,53	12,98	-	-	7,07	0,00	7,07	0,23

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Zwick / Roell

Flexural Test report

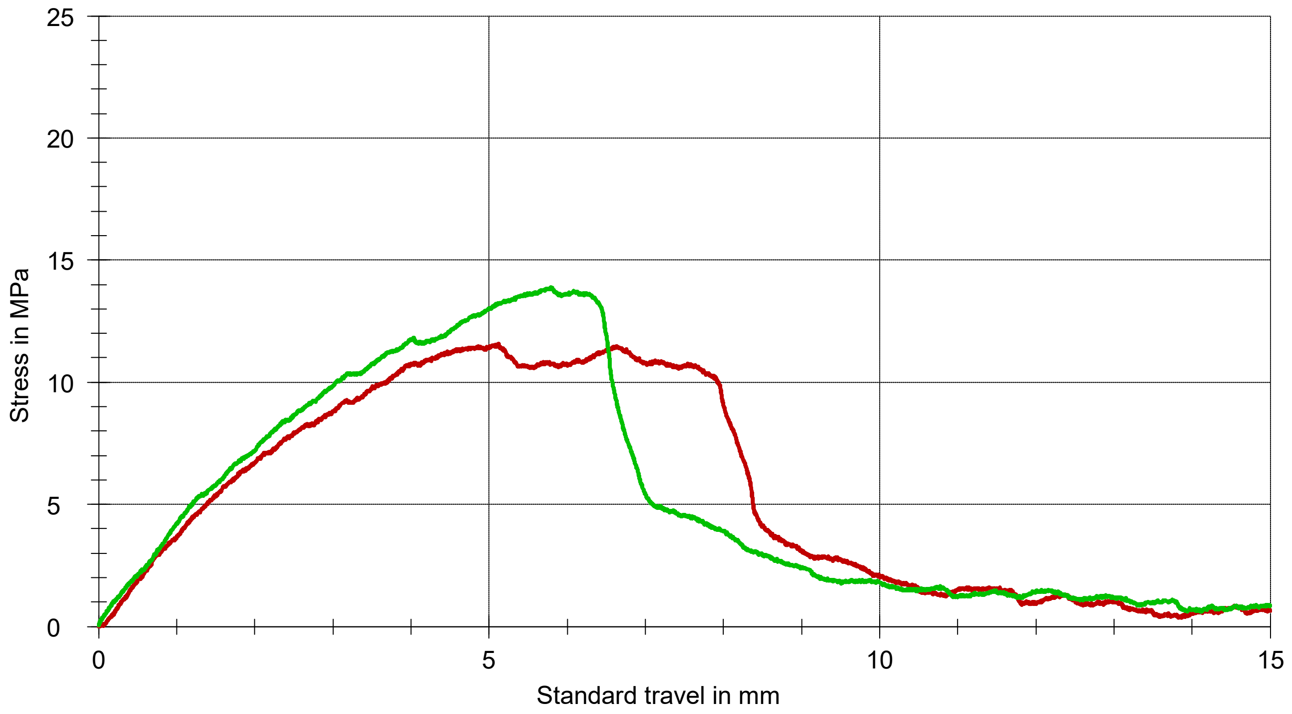
Customer : Aripin
Test standard : ASTM D 790
Material : HDPE
Notes : Rotation Speed 2000 rpm Double
Machine data : Zwick Z020

Pre-load : 0,1 MPa
Test speed : 2 mm/min

Test results:

		Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
Legend	No.	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
🟥	1	8,57	1180	8,37	10,7	11,6	-	-	5,3	80	3,8	6,16
🟩	2	12,63	912	8,74	13,1	13,9	-	-	5,9	80	4,2	6,18

Series graph:



Statistics:

Series	Force	E_H	σ_1	σ_2	σ_{fM}	ε_B	σ_{fB}	ε_f	L	d	b
n = 2	N	MPa	MPa	MPa	MPa	%	MPa	%	mm	mm	mm
$\bar{x}$	10,60	1050	8,56	11,9	12,7	-	-	5,6	80	4	6,17
s	2,87	192	0,258	1,73	1,65	-	-	0,40	0,000	0,2828	0,01414
ν [%]	27,07	18,35	3,01	14,53	12,98	-	-	7,07	0,00	7,07	0,23

Tensile Test report

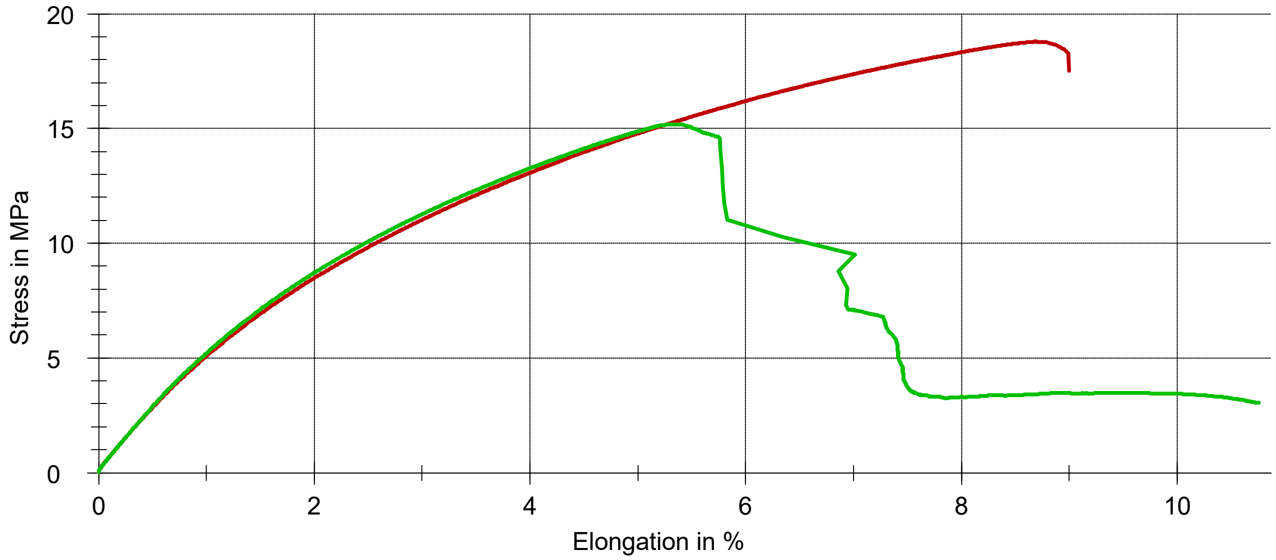
Customer : Aripin
Test standard : ASTM D 638 Tipe 4
Material : HDPE
Notes : Rotation Speed 900 rpm Double
Machine data : Zwick Z020

Pre-load : 0,1 MPa
Speed, tensile modulus : 5 mm/min
Test speed : 5 mm/min
Grip to grip separation at the start position : 65,00 mm
Gage length, standard travel : 25 mm
Elongation preset, secant modulus : 1 %

Test results:

		Force	E_t	σ_M	ε_M	σ_B	ε_B	h	b
Legend	No.	N	MPa	MPa	%	MPa	%	mm	mm
🟥	1	494,47	560	18,8	8,7	18,8	8,7	4,26	6,18
🟩	2	385,17	560	15,2	5,3	3,03	11	4,12	6,16

Series graph:



Statistics:

Series	Force	E_t	σ_M	ε_M	σ_B	ε_B	h	b
n = 2	N	MPa	MPa	%	MPa	%	mm	mm
$\bar{x}$	439,82	560	17,0	7,0	10,9	9,7	4,19	6,17
s	77,28	0,0370	2,55	2,4	11,1	1,5	0,09899	0,01414
ν [%]	17,57	0,01	15,01	34,18	102,08	15,08	2,36	0,23

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Zwick / Roell

Tensile Test report

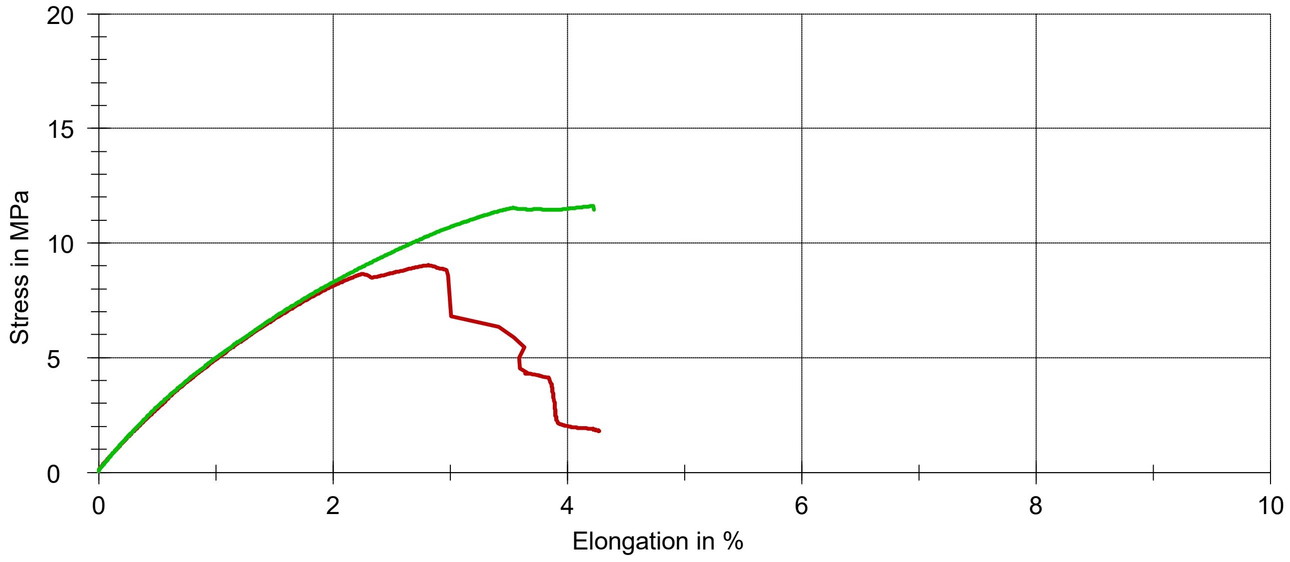
Customer	:	Aripin	Notes	:	Rotation Speed 1500 rpm Double
Test standard	:	ASTM D 638 Tipe 4	Machine data	:	Zwick Z020
Material	:	HDPE			

Pre-load	:	0,1	MPa
Speed, tensile modulus	:	5	mm/min
Test speed	:	5	mm/min
Grip to grip separation at the start position	:	65,00	mm
Gage length, standard travel	:	25	mm
Elongation preset, secant modulus	:	1	%

Test results:

Legend	No.	Force N	E_t MPa	σ_M MPa	ε_M %	σ_B MPa	ε_B %	h mm	b mm
🟥	1	213,34	553	9,03	2,8	1,80	4,3	3,88	6,09
🟩	2	304,91	590	11,6	4,2	11,6	4,2	4,24	6,19

Series graph:



Statistics:

Series n = 2	Force N	E_t MPa	σ_M MPa	ε_M %	σ_B MPa	ε_B %	h mm	b mm
$\bar{x}$	259,12	571	10,3	3,5	6,71	4,2	4,06	6,14
s	64,75	26,0	1,83	1,0	6,94	0,039	0,2546	0,07071
ν [%]	24,99	4,54	17,73	28,30	103,39	0,93	6,27	1,15

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Zwick / Roell

Tensile Test report

Customer : Aripin
Test standard : ASTM D 638 Tipe 4
Material : HDPE

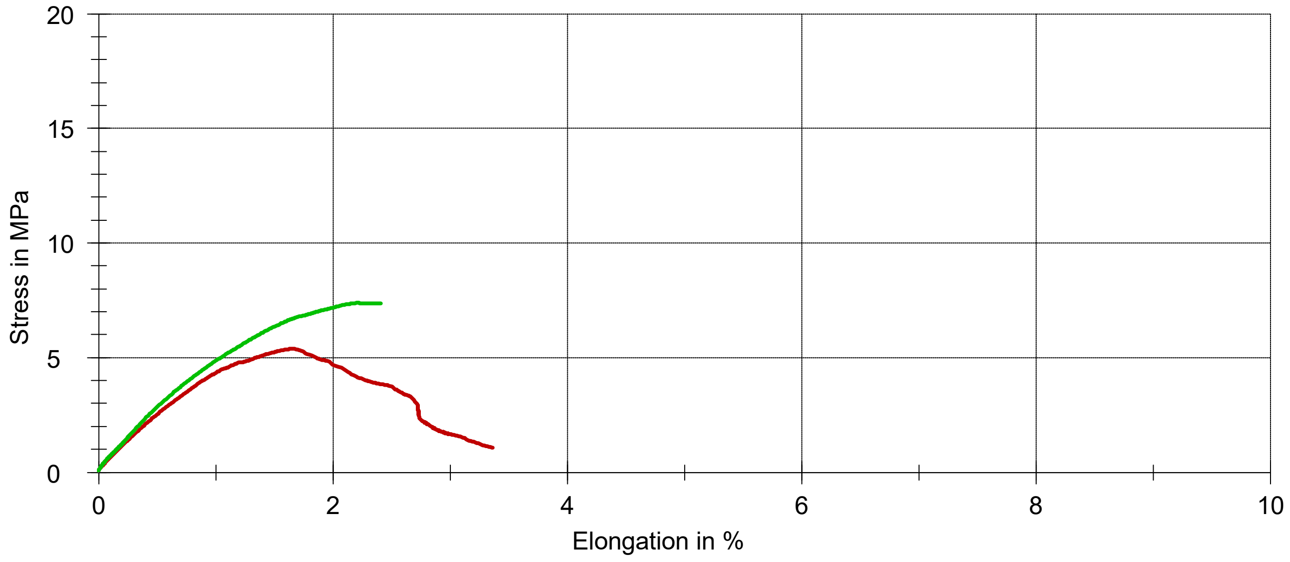
Notes : Rotation Speed 2000 rpm Double
Machine data : Zwick Z020

Pre-load : 0,1 MPa
Speed, tensile modulus : 5 mm/min
Test speed : 5 mm/min
Grip to grip separation at the start position : 65,00 mm
Gage length, standard travel : 25 mm
Elongation preset, secant modulus : 1 %

Test results:

		Force	E_t	σ_M	ε_M	σ_B	ε_B	h	b
Legend	No.	N	MPa	MPa	%	MPa	%	mm	mm
🟥	1	132,72	511	5,39	1,7	1,08	3,4	4,02	6,13
🟩	2	193,43	528	7,38	2,2	7,38	2,2	4,26	6,15

Series graph:



Statistics:

Series	Force	E_t	σ_M	ε_M	σ_B	ε_B	h	b
n = 2	N	MPa	MPa	%	MPa	%	mm	mm
$\bar{x}$	163,07	519	6,38	1,9	4,23	2,8	4,14	6,14
s	42,93	11,7	1,41	0,39	4,46	0,82	0,1697	0,01414
ν [%]	26,32	2,25	22,12	19,94	105,42	29,28	4,10	0,23

Designation: D 790 – 03

Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[1]

This standard is issued under the fixed designation D 790; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

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

1. Scope*

1.1 These test methods cover the determination of flexural properties of unreinforced and reinforced plastics, including high-modulus composites and electrical insulating materials in the form of rectangular bars molded directly or cut from sheets, plates, or molded shapes. These test methods are generally applicable to both rigid and semirigid materials. However, flexural strength cannot be determined for those materials that do not break or that do not fail in the outer surface of the test specimen within the 5.0 % strain limit of these test methods. These test methods utilize a three-point loading system applied to a simply supported beam. A four-point loading system method can be found in Test Method D 6272.

1.1.1 *Procedure A*, designed principally for materials that break at comparatively small deflections.

1.1.2 *Procedure B*, designed particularly for those materials that undergo large deflections during testing.

1.1.3 Procedure A shall be used for measurement of flexural properties, particularly flexural modulus, unless the material specification states otherwise. Procedure B may be used for measurement of flexural strength only. Tangent modulus data obtained by Procedure A tends to exhibit lower standard deviations than comparable data obtained by means of Procedure B.

1.2 Comparative tests may be run in accordance with either procedure, provided that the procedure is found satisfactory for the material being tested.

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

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

NOTE 1—These test methods are not technically equivalent to ISO 178.

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Practice for Conditioning Plastics for Testing[2]

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

D 883 Terminology Relating to Plastics[2]

D 4000 Classification System for Specifying Plastic Materials[3]

D 5947 Test Methods for Physical Dimensions of Solid Plastic Specimens[4]

D 6272 Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending[4]

E 4 Practices for Force Verification of Testing Machines[5]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

3. Terminology

3.1 *Definitions*—Definitions of terms applying to these test methods appear in Terminology D 883 and Annex A1 of Test Method D 638.

4. Summary of Test Method

4.1 A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose midway between the supports (see Fig. 1). A support span-to-depth ratio of 16:1 shall be used unless there is reason to suspect that a larger span-to-depth ratio may be required, as may be the case for certain laminated materials (see Section 7 and Note 8 for guidance).

4.2 The specimen is deflected until rupture occurs in the outer surface of the test specimen or until a maximum strain (see 12.7) of 5.0 % is reached, whichever occurs first.

4.3 Procedure A employs a strain rate of 0.01 mm/mm/min [0.01 in./in./min] and is the preferred procedure for this test method, while Procedure B employs a strain rate of 0.10 mm/mm/min [0.10 in./in./min].

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

Current edition approved March 10, 2003. Published April 2003. Originally approved in 1970. Last previous edition approved in 2002 as D 790 – 02.

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

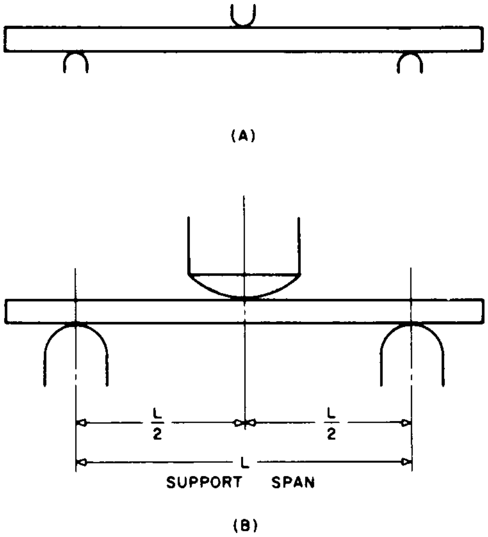
[3] *Annual Book of ASTM Standards*, Vol 08.02.

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

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

[6] *Annual Book of ASTM Standards*, Vol 14.02.

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



NOTE—(*a*) Minimum radius = 3.2 mm [⅛ in.]. (*b*) Maximum radius supports 1.6 times specimen depth; maximum radius loading nose = 4 times specimen depth.

FIG. 1 Allowable Range of Loading Nose and Support Radii

5. Significance and Use

5.1 Flexural properties as determined by these test methods are especially useful for quality control and specification purposes.

5.2 Materials that do not fail by the maximum strain allowed under these test methods (3-point bend) may be more suited to a 4-point bend test. 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 3-point bending and over the area between the loading noses in 4-point bending.

5.3 Flexural properties may vary with specimen depth, temperature, atmospheric conditions, and the difference in rate of straining as specified in Procedures A and B (see also Note 8).

5.4 Before proceeding with these test methods, reference should be made to the specification of the material being tested. Any test specimen preparation, conditioning, dimensions, or testing parameters, or combination thereof, covered in the materials specification shall take precedence over those mentioned in these test methods. If there are no material specifications, then the default conditions apply. Table 1 in Classification System D 4000 lists the ASTM materials standards that currently exist for plastics.

6. Apparatus

6.1 *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 the 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 testing, 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.

TABLE 1 Flexural Strength

Material	Mean, 10^3 psi	Values Expressed in Units of % of 10^3 psi			
		V_r[A]	V_R[B]	r[C]	R[D]
ABS	9.99	1.59	6.05	4.44	17.2
DAP thermoset	14.3	6.58	6.58	18.6	18.6
Cast acrylic	16.3	1.67	11.3	4.73	32.0
GR polyester	19.5	1.43	2.14	4.05	6.08
GR polycarbonate	21.0	5.16	6.05	14.6	17.1
SMC	26.0	4.76	7.19	13.5	20.4

[A] V_r = within-laboratory coefficient of variation for the indicated material. It is obtained by first pooling the within-laboratory standard deviations of the test results from all of the participating laboratories: $Sr = [[(s_1)^2 + (s_2)^2 \ldots + (s_n)^2]/n]^{1/2}$ then V_r = (S_r divided by the overall average for the material) × 100.

[B] V_r = between-laboratory reproducibility, expressed as the coefficient of variation: $S_R = \{S_r^2 + S_L^2\}^{1/2}$ where S_L is the standard deviation of laboratory means. Then: V_R = (S_R divided by the overall average for the material) × 100.

[C] r = within-laboratory critical interval between two test results = 2.8 × V_r.

[D] R = between-laboratory critical interval between two test results = 2.8 × V_R.

6.2 *Loading Noses and Supports*—The loading nose and supports shall have cylindrical surfaces. In order to avoid excessive indentation, or failure due to stress concentration directly under the loading nose, the radii of the loading nose and supports shall be 5.0 ± 0.1 mm [0.197 ± 0.004 in.] unless otherwise specified or agreed upon between the interested clients. When other loading noses and supports are used they must comply with the following requirements: they shall have a minimum radius of 3.2 mm [⅛ in.] for all specimens, and for specimens 3.2 mm or greater in depth, the radius of the supports may be up to 1.6 times the specimen depth. They shall be this large if significant indentation or compressive failure occurs. The arc of the loading nose in contact with the specimen shall be sufficiently large to prevent contact of the specimen with the sides of the nose (see Fig. 1). The maximum radius of the loading nose shall be no more than 4 times the specimen depth.

NOTE 2—Test data have shown that the loading nose and support dimensions can influence the flexural modulus and flexural strength values. The loading nose dimension has the greater influence. Dimensions of the loading nose and supports must be specified in the material specification.

6.3 *Micrometers*— Suitable micrometers for measuring the width and thickness of the test specimen to an incremental discrimination of at least 0.025 mm [0.001 in.] should be used. All width and thickness measurements of rigid and semirigid plastics may be measured with a hand micrometer with ratchet. A suitable instrument for measuring the thickness of nonrigid test specimens shall have: a contact measuring pressure of 25 ± 2.5 kPa [3.6 ± 0.36 psi], a movable circular contact foot 6.35 ± 0.025 mm [0.250 ± 0.001 in.] in diameter and a lower fixed anvil large enough to extend beyond the contact foot in all directions and being parallel to the contact foot within 0.005 mm [0.002 in.] over the entire foot area. Flatness of foot and anvil shall conform to the portion of the Calibration section of Test Methods D 5947.

7. Test Specimens

7.1 The specimens may be cut from sheets, plates, or molded shapes, or may be molded to the desired finished dimensions. The actual dimensions used in Section 4.2, Calculation, shall be measured in accordance with Test Methods D 5947.

NOTE 3—Any necessary polishing of specimens shall be done only in the lengthwise direction of the specimen.

7.2 *Sheet Materials (Except Laminated Thermosetting Materials and Certain Materials Used for Electrical Insulation, Including Vulcanized Fiber and Glass Bonded Mica)*:

7.2.1 *Materials 1.6 mm [1⁄16 in.] or Greater in Thickness*—For flatwise tests, the depth of the specimen shall be the thickness of the material. For edgewise tests, the width of the specimen shall be the thickness of the sheet, and the depth shall not exceed the width (see Notes 4 and 5). For all tests, the support span shall be 16 (tolerance ±1) times the depth of the beam. Specimen width shall not exceed one fourth of the support span for specimens greater than 3.2 mm [1⁄8 in.] in depth. Specimens 3.2 mm or less in depth shall be 12.7 mm [1⁄2 in.] in width. The specimen shall be long enough to allow for overhanging on each end of at least 10 % of the support span, but in no case less than 6.4 mm [1⁄4 in.] on each end. Overhang shall be sufficient to prevent the specimen from slipping through the supports.

NOTE 4—Whenever possible, the original surface of the sheet shall be unaltered. However, where testing machine limitations make it impossible to follow the above criterion on the unaltered sheet, one or both surfaces shall be machined to provide the desired dimensions, and the location of the specimens with reference to the total depth shall be noted. The value obtained on specimens with machined surfaces may differ from those obtained on specimens with original surfaces. Consequently, any specifications for flexural properties on thicker sheets must state whether the original surfaces are to be retained or not. When only one surface was machined, it must be stated whether the machined surface was on the tension or compression side of the beam.

NOTE 5—Edgewise tests are not applicable for sheets that are so thin that specimens meeting these requirements cannot be cut. If specimen depth exceeds the width, buckling may occur.

7.2.2 *Materials Less than 1.6 mm [1⁄16 in.] in Thickness*—The specimen shall be 50.8 mm [2 in.] long by 12.7 mm [1⁄2 in.] wide, tested flatwise on a 25.4-mm [1-in.] support span.

NOTE 6—Use of the formulas for simple beams cited in these test methods for calculating results presumes that beam width is small in comparison with the support span. Therefore, the formulas do not apply rigorously to these dimensions.

NOTE 7—Where machine sensitivity is such that specimens of these dimensions cannot be measured, wider specimens or shorter support spans, or both, may be used, provided the support span-to-depth ratio is at least 14 to 1. All dimensions must be stated in the report (see also Note 6).

7.3 *Laminated Thermosetting Materials and Sheet and Plate Materials Used for Electrical Insulation, Including Vulcanized Fiber and Glass-Bonded Mica*—For paper-base and fabric-base grades over 25.4 mm [1 in.] in nominal thickness, the specimens shall be machined on both surfaces to a depth of 25.4 mm. For glass-base and nylon-base grades, specimens over 12.7 mm [1⁄2 in.] in nominal depth shall be machined on both surfaces to a depth of 12.7 mm. The support span-to-depth ratio shall be chosen such that failures occur in the outer fibers of the specimens, due only to the bending moment (see Note 8). Therefore, a ratio larger than 16:1 may be necessary (32:1 or 40:1 are recommended). When laminated materials exhibit low compressive strength perpendicular to the laminations, they shall be loaded with a large radius loading nose (up to four times the specimen depth to prevent premature damage to the outer fibers.

7.4 *Molding Materials (Thermoplastics and Thermosets)*—The recommended specimen for molding materials is 127 by 12.7 by 3.2 mm [5 by 1⁄2 by 1⁄8 in.] tested flatwise on a support span, resulting in a support span-to-depth ratio of 16 (tolerance ±1). Thicker specimens should be avoided if they exhibit significant shrink marks or bubbles when molded.

7.5 *High-Strength Reinforced Composites, Including Highly Orthotropic Laminates*—The span-to-depth ratio shall be chosen such that failure occurs in the outer fibers of the specimens and is due only to the bending moment (see Note 8). A span-to-depth ratio larger than 16:1 may be necessary (32:1 or 40:1 are recommended). 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 the 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 8—As a general rule, support span-to-depth ratios of 16:1 are 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.

8. Number of Test Specimens

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

8.2 For each sample of anisotropic material in sheet form, test at least five specimens 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 the purposes of this test, “lengthwise” designates the principal axis of anisotropy and shall be interpreted to mean the direction of the sheet known to be stronger in flexure. “Crosswise” indicates the sheet direction known to be the weaker in flexure and shall be at 90° to the lengthwise direction.

9. Conditioning

9.1 *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 prior to test in accordance with Procedure A of Practice D 618 unless otherwise specified by contract or the relevant ASTM material specification. Reference pre-test conditioning, to settle disagreements, shall apply tolerances of ±1°C [1.8°F] and ±2 % relative humidity.

9.2 *Test Conditions*—Conduct the tests at 23 ± 2°C [73.4 ± 3.6°F] and 50 ± 5 % relative humidity unless otherwise specified by contract or the relevant ASTM material specification. Reference testing conditions, to settle disagreements, shall apply tolerances of ±1°C [1.8°F] and ±2 % relative humidity.

10. Procedure

10.1 *Procedure A*:

10.1.1 Use an untested specimen for each measurement. Measure the width and depth of the specimen to the nearest 0.03 mm [0.001 in.] at the center of the support span. For specimens less than 2.54 mm [0.100 in.] in depth, measure the depth to the nearest 0.003 mm [0.0005 in.]. These measurements shall be made in accordance with Test Methods D 5947.

10.1.2 Determine the support span to be used as described in Section 7 and set the support span to within 1 % of the determined value.

10.1.3 For flexural fixtures that have continuously adjustable spans, measure the span accurately to the nearest 0.1 mm [0.004 in.] for spans less than 63 mm [2.5 in.] and to the nearest 0.3 mm [0.012 in.] for spans greater than or equal to 63 mm [2.5 in.]. Use the actual measured span for all calculations. For flexural fixtures that have fixed machined span positions, verify the span distance the same as for adjustable spans at each machined position. This distance becomes the span for that position and is used for calculations applicable to all subsequent tests conducted at that position. See Annex A2 for information on the determination of and setting of the span.

10.1.4 Calculate the rate of crosshead motion as follows and set the machine for the rate of crosshead motion as calculated by Eq 1:

$$R = ZL^2/6d \tag{1}$$

where:
R = rate of crosshead motion, mm [in.]/min,
L = support span, mm [in.],
d = depth of beam, mm [in.], and
Z = rate of straining of the outer fiber, mm/mm/min [in./in./min]. Z shall be equal to 0.01.

In no case shall the actual crosshead rate differ from that calculated using Eq 1, by more than ±10 %.

10.1.5 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. The parallelism of the apparatus may be checked by means of a plate with parallel grooves into which the loading nose and supports will fit when properly aligned (see A2.3). Center the specimen on the supports, with the long axis of the specimen perpendicular to the loading nose and supports.

10.1.6 Apply the load to the specimen at the specified crosshead rate, and take simultaneous load-deflection data. Measure deflection either by a gage under the specimen in contact with it at the center of the support span, the gage being mounted stationary relative to the specimen supports, or by measurement of the motion of the loading nose relative to the supports. Load-deflection curves may be plotted to determine the flexural strength, chord or secant modulus or the tangent modulus of elasticity, and the total work as measured by the area under the load-deflection curve. Perform the necessary toe compensation (see Annex A1) to correct for seating and indentation of the specimen and deflections in the machine.

10.1.7 Terminate the test when the maximum strain in the outer surface of the test specimen has reached 0.05 mm/mm [in./in.] or at break if break occurs prior to reaching the maximum strain (Notes 9 and 10). The deflection at which this strain will occur may be calculated by letting r equal 0.05 mm/mm [in./in.] in Eq 2:

$$D = rL^2/6d \tag{2}$$

where:
D = midspan deflection, mm [in.],
r = strain, mm/mm [in./in.],
L = support span, mm [in.], and
d = depth of beam, mm [in.].

NOTE 9—For some materials that do not yield or break within the 5 % strain limit when tested by Procedure A, the increased strain rate allowed by Procedure B (see 10.2) may induce the specimen to yield or break, or both, within the required 5 % strain limit.

NOTE 10—Beyond 5 % strain, this test method is not applicable. Some other mechanical property might be more relevant to characterize materials that neither yield nor break by either Procedure A or Procedure B within the 5 % strain limit (for example, Test Method D 638 may be considered).

10.2 *Procedure B*:

10.2.1 Use an untested specimen for each measurement.

10.2.2 Test conditions shall be identical to those described in 10.1, except that the rate of straining of the outer surface of the test specimen shall be 0.10 mm/mm [in./in.]/min.

10.2.3 If no break has occurred in the specimen by the time the maximum strain in the outer surface of the test specimen has reached 0.05 mm/mm [in./in.], discontinue the test (see Note 10).

11. Retests

11.1 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.

12. Calculation

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

12.2 *Flexural Stress* (σ_f)—When a 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 surface of the test specimen occurs at the midpoint. This stress may be calculated for any point on the load-deflection curve by means of the following equation (see Notes 11-13):

$$\sigma_f = 3PL/2bd^2 \tag{3}$$

where:
σ = stress in the outer fibers at midpoint, MPa [psi],

P = load at a given point on the load-deflection curve, N [lbf],
L = support span, mm [in.],
b = width of beam tested, mm [in.], and
d = depth of beam tested, mm [in.].

NOTE 11—Eq 3 applies strictly to materials for which 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 if Eq 3 is used to calculate stress for materials that are not true Hookean materials. The equation is valid for obtaining comparison data and for specification purposes, but only up to a maximum fiber strain of 5 % in the outer surface of the test specimen for specimens tested by the procedures described herein.

NOTE 12—When testing highly orthotropic laminates, the maximum stress may not always occur in the outer surface of the test specimen.[7] Laminated beam theory must be applied to determine the maximum tensile stress at failure. If Eq 3 is used to calculate stress, it will yield an apparent strength based on homogeneous beam theory. This apparent strength is highly dependent on the ply-stacking sequence of highly orthotropic laminates.

NOTE 13—The preceding calculation is not valid if the specimen slips excessively between the supports.

12.3 *Flexural Stress for Beams Tested at Large Support Spans* (σ_f)—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 stress in the outer surface of the specimen for a simple beam can be reasonably approximated with the following equation (see Note 14):

$$\sigma_f = (3PL/2bd^2)[1 + 6(D/L)^2 - 4(d/L)(D/L)] \qquad (4)$$

where:

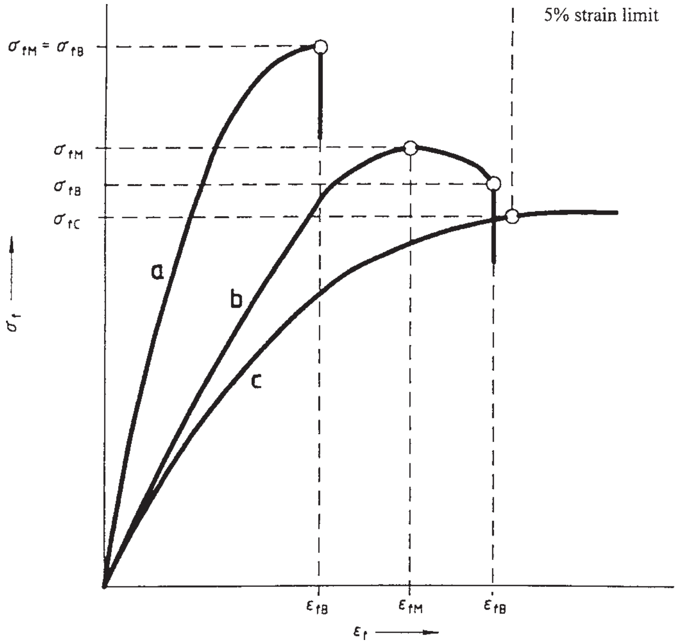
σ_f, P, L, b, and d are the same as for Eq 3, and
D = deflection of the centerline of the specimen at the middle of the support span, mm [in.].

NOTE 14—When large support span-to-depth ratios are used, significant end forces are developed at the support noses which will affect the moment in a simple supported beam. Eq 4 includes additional terms that are an approximate correction factor for the influence of these end forces in large support span-to-depth ratio beams where relatively large deflections exist.

12.4 *Flexural Strength* (σ_{fM})—Maximum flexural stress sustained by the test specimen (see Note 12) during a bending test. It is calculated according to Eq 3 or Eq 4. Some materials that do not break at strains of up to 5 % may give a load deflection curve that shows a point at which the load does not increase with an increase in strain, that is, a yield point (Fig. 2, Curve B), *Y*. The flexural strength may be calculated for these materials by letting *P* (in Eq 3 or Eq 4) equal this point, *Y*.

12.5 *Flexural Offset Yield Strength*—Offset yield strength is the stress at which the stress-strain curve deviates by a given strain (offset) from the tangent to the initial straight line portion of the stress-strain curve. The value of the offset must be given whenever this property is calculated.

NOTE 15—This value may differ from flexural strength defined in 12.4.



NOTE—Curve a: Specimen that breaks before yielding.
Curve b: Specimen that yields and then breaks before the 5 % strain limit.
Curve c: Specimen that neither yields nor breaks before the 5 % strain limit.

FIG. 2 Typical Curves of Flexural Stress (ς_f) Versus Flexural Strain (ϵ_f)

Both methods of calculation are described in the annex to Test Method D 638.

12.6 *Flexural Stress at Break* (σ_{fB})—Flexural stress at break of the test specimen during a bending test. It is calculated according to Eq 3 or Eq 4. Some materials may give a load deflection curve that shows a break point, *B*, without a yield point (Fig. 2, Curve a) in which case $\sigma_{fB} = \sigma_{fM}$. Other materials may give a yield deflection curve with both a yield and a break point, *B* (Fig. 2, Curve b). The flexural stress at break may be calculated for these materials by letting *P* (in Eq 3 or Eq 4) equal this point, *B*.

12.7 *Stress at a Given Strain*—The stress in the outer surface of a test specimen at a given strain may be calculated in accordance with Eq 3 or Eq 4 by letting *P* equal the load read from the load-deflection curve at the deflection corresponding to the desired strain (for highly orthotropic laminates, see Note 12).

12.8 *Flexural Strain*, ϵ_f—Nominal fractional change in the length of an element of the outer surface of the test specimen at midspan, where the maximum strain occurs. It may be calculated for any deflection using Eq 5:

$$\epsilon_f = 6Dd/L^2 \qquad (5)$$

where:

ϵ_f = strain in the outer surface, mm/mm [in./in.],
D = maximum deflection of the center of the beam, mm [in.],
L = support span, mm [in.], and

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[7] For a discussion of these effects, see Zweben, C., Smith, W. S., and Wardle, M. W., "Test Methods for Fiber Tensile Strength, Composite Flexural Modulus and Properties of Fabric-Reinforced Laminates, " *Composite Materials: Testing and Design (Fifth Conference), ASTM STP 674*, 1979, pp. 228–262.

d = depth, mm [in.].
D = maximum deflection of the center of the beam, mm [in.],
L = support span, mm [in.], and
d = depth, mm [in.].

12.9 *Modulus of Elasticity*:

12.9.1 *Tangent Modulus of Elasticity*—The tangent modulus of elasticity, often called the "modulus of elasticity," is the ratio, within the elastic limit, of stress to corresponding strain. It is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve and using Eq 6 (for highly anisotropic composites, see Note 16).

$$E_B = L^3 m / 4bd^3 \tag{6}$$

where:
E_B = modulus of elasticity in bending, MPa [psi],
L = support span, mm [in.],
b = width of beam tested, mm [in.],
d = depth of beam tested, mm [in.], and
m = slope of the tangent to the initial straight-line portion of the load-deflection curve, N/mm [lbf/in.] of deflection.

NOTE 16—Shear deflections can seriously reduce the apparent modulus of highly anisotropic composites when they are tested at low span-to-depth ratios.[7] For this reason, a span-to-depth ratio of 60 to 1 is recommended for flexural modulus determinations on these composites. Flexural strength should be determined on a separate set of replicate specimens at a lower span-to-depth ratio that induces tensile failure in the outer fibers of the beam along its lower face. Since the flexural modulus of highly anisotropic laminates is a critical function of ply-stacking sequence, it will not necessarily correlate with tensile modulus, which is not stacking-sequence dependent.

12.9.2 *Secant Modulus*— The secant modulus is the ratio of stress to corresponding strain at any selected point on the stress-strain curve, that is, 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 [pounds per square inch]. The selected point is chosen at a prespecified stress or strain in accordance with the appropriate material specification or by customer contract. It is calculated in accordance with Eq 6 by letting m equal the slope of the secant to the load-deflection curve. The chosen stress or strain point used for the determination of the secant shall be reported.

TABLE 2 Flexural Modulus

Material	Mean, 10^3 psi	Values Expressed in units of % of 10^3 psi			
		V_r[A]	V_R[B]	r[C]	R[D]
ABS	338	4.79	7.69	13.6	21.8
DAP thermoset	485	2.89	7.18	8.15	20.4
Cast acrylic	810	13.7	16.1	38.8	45.4
GR polyester	816	3.49	4.20	9.91	11.9
GR polycarbonate	1790	5.52	5.52	15.6	15.6
SMC	1950	10.9	13.8	30.8	39.1

[A] V_r = within-laboratory coefficient of variation for the indicated material. It is obtained by first pooling the within-laboratory standard deviations of the test results from all of the participating laboratories: $Sr = [[(s_1)^2 + (s_2)^2 \ldots + (s_n)^2]/n]^{1/2}$ then V_r = (S_r divided by the overall average for the material) × 100.

[B] V_r = between-laboratory reproducibility, expressed as the coefficient of variation: $S_R = \{S_r^2 + S_L^2\}^{1/2}$ where S_L is the standard deviation of laboratory means. Then: V_R = (S_R divided by the overall average for the material) × 100.

[C] r = within-laboratory critical interval between two test results = 2.8 × V_r.

[D] R = between-laboratory critical interval between two test results = 2.8 × V_R.

12.9.3 *Chord Modulus* (*E_f*)—The chord modulus may be calculated from two discrete points on the load deflection curve. The selected points are to be chosen at two prespecified stress or strain points in accordance with the appropriate material specification or by customer contract. The chosen stress or strain points used for the determination of the chord modulus shall be reported. Calculate the chord modulus, E_f using the following equation:

$$E_f = (\sigma_{f2} - \sigma_{f1})/(\epsilon_{f2} - \epsilon_{f1}) \tag{7}$$

where:

σ_{f2} and σ_{f1} are the flexural stresses, calculated from Eq 3 or Eq 4 and measured at the predefined points on the load deflection curve, and ϵ_{f2} and

ϵ_{f1} are the flexural strain values, calculated from Eq 5 and measured at the predetermined points on the load deflection curve.

12.10 *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.

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

$$s = \sqrt{(\Sigma X^2 - n\bar{X}^2)/(n-1)} \tag{8}$$

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

13. Report

13.1 Report the following information:

13.1.1 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),

13.1.2 Direction of cutting and loading specimens, when appropriate,

13.1.3 Conditioning procedure,

13.1.4 Depth and width of specimen,

13.1.5 Procedure used (A or B),

13.1.6 Support span length,

13.1.7 Support span-to-depth ratio if different than 16:1,

13.1.8 Radius of supports and loading noses if different than 5 mm,

13.1.9 Rate of crosshead motion,

13.1.10 Flexural strain at any given stress, average value and standard deviation,

13.1.11 If a specimen is rejected, reason(s) for rejection,

13.1.12 Tangent, secant, or chord modulus in bending, average value, standard deviation, and the strain level(s) used if secant or chord modulus,

13.1.13 Flexural strength (if desired), average value, and standard deviation, 13.1.14 Stress at any given strain up to and including 5 % (if desired), with strain used, average value, and standard deviation,

13.1.15 Flexural stress at break (if desired), average value, and standard deviation,

13.1.16 Type of behavior, whether yielding or rupture, or both, or other observations, occurring within the 5 % strain limit, and

13.1.17 Date of specific version of test used.

14. Precision and Bias [8]

14.1 Tables 1 and 2 are based on a round-robin test conducted in 1984, in accordance with Practice E 691, involving six materials tested by six laboratories using Procedure A. For each material, all the specimens were prepared at one source. Each "test result" was the average of five individual determinations. Each laboratory obtained two test results for each material.

NOTE 17—**Caution:** The following explanations of *r* and *R* (14.2-14.2.3) are intended only to present a meaningful way of considering the approximate precision of these test methods. The data given in Tables 2 and 3 should not be applied rigorously to the acceptance or rejection of materials, as those data are specific to the round robin and may not be representative of other lots, conditions, materials, or laboratories. Users of these test methods 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 14.2-14.2.3 would then be valid for such data.

14.2 *Concept of "r" and "R" in* Tables 1 and 2—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 five specimens for each test result, then:

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

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

14.2.3 The judgments in 14.2.1 and 14.2.2 will have an approximately 95 % (0.95) probability of being correct.

14.3 *Bias*—No statement may be made about the bias of these test methods, as there is no standard reference material or reference test method that is applicable.

15. Keywords

15.1 flexural properties; plastics; stiffness; strength

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[8] Supporting data are available from ASTM Headquarters. Request RR: D20 – 1128.

ANNEXES

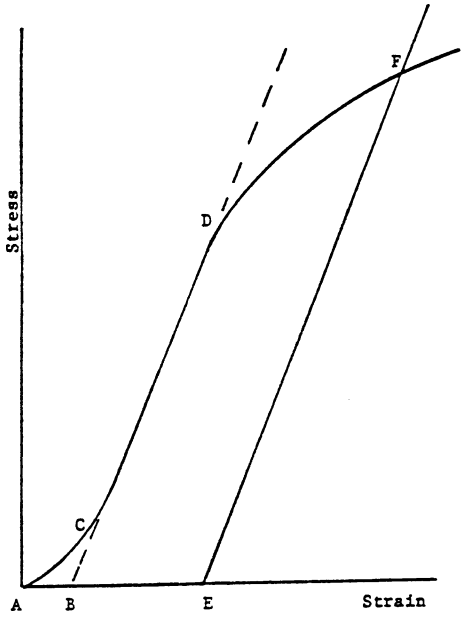
(Mandatory Information)

A1. TOE COMPENSATION

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

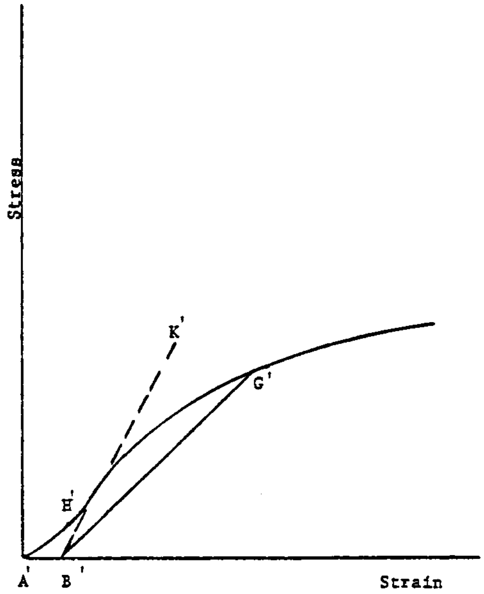
A1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (see Fig. A1.1), a continuation of the linear *(CD)* region of the curve is constructed through the zero-stress axis. This intersection *(B)* is the corrected zero-strain point from which all extensions or strains must be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

A1.3 In the case of a material that does not exhibit any linear region (see Fig. A1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection Point H'. This is extended to intersect the strain axis at Point B', the corrected zero-strain



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

FIG. A1.1 Material with Hookean Region



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

FIG. A1.2 Material with No Hookean Region

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.

A2. MEASURING AND SETTING SPAN

A2.1 For flexural fixtures that have adjustable spans, it is important that the span between the supports is maintained constant or the actual measured span is used in the calculation of stress, modulus, and strain, and the loading nose or noses are positioned and aligned properly with respect to the supports. Some simple steps as follows can improve the repeatability of your results when using these adjustable span fixtures.

A2.2 Measurement of Span:

A2.2.1 This technique is needed to ensure that the correct span, not an estimated span, is used in the calculation of results.

A2.2.2 Scribe a permanent line or mark at the exact center of the support where the specimen makes complete contact. The type of mark depends on whether the supports are fixed or rotatable (see Figs. A2.1 and A2.2).

A2.2.3 Using a vernier caliper with pointed tips that is readable to at least 0.1 mm [0.004 in.], measure the distance between the supports, and use this measurement of span in the calculations.

FIG. A2.1 Markings on Fixed Specimen Supports

FIG. A2.2 Markings on Rotatable Specimen Supports

A2.3 *Setting the Span and Alignment of Loading Nose(s)*—To ensure a consistent day-to-day setup of the span and ensure the alignment and proper positioning of the loading nose, simple jigs should be manufactured for each of the standard setups used. An example of a jig found to be useful is shown in Fig. A2.3.

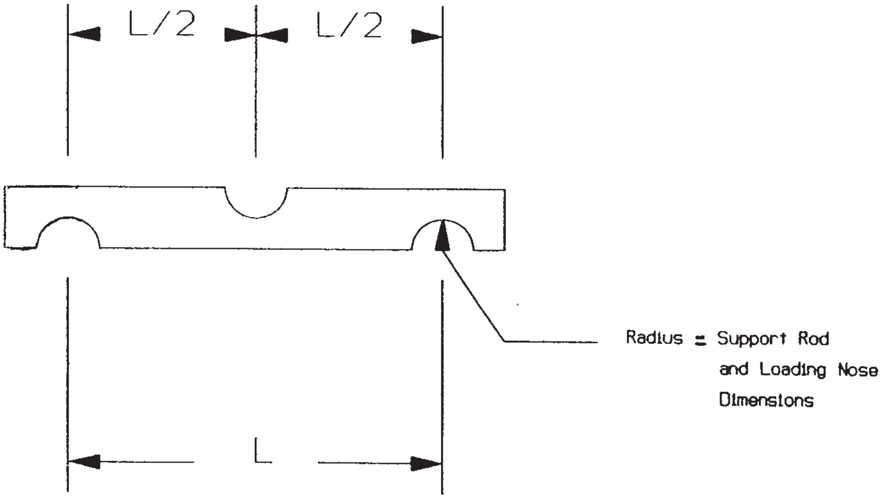


FIG. A2.3 Fixture Used to Set Loading Nose and Support Spacing and Alignment

APPENDIX

(Nonmandatory Information)

X1. DEVELOPMENT OF A FLEXURAL MACHINE COMPLIANCE CORRECTION

X1.1 Introduction

X1.1.1 Universal Testing instrument drive systems always exhibit a certain level of compliance that is characterized by a variance between the reported crosshead displacement and the displacement actually imparted to the specimen. This variance is a function of load frame stiffness, drive system wind-up, load cell compliance and fixture compliance. To accurately measure the flexural modulus of a material, this compliance should be measured and empirically subtracted from test data. Flexural modulus results without the corrections are lower than if the correction is applied. The greater the stiffness of the material the more influence the system compliance has on results.

X1.1.2 It is not necessary to make the machine compliance correction when a deflectometer/extensometer is used to measure the actual deflection occurring in the specimen as it is deflected.

X1.2 Terminology

X1.2.1 *Compliance*—The displacement difference between test machine drive system displacement values and actual specimen displacement

X1.2.2 *Compliance Correction*—An analytical method of modifying test instrument displacement values to eliminate the amount of that measurement attributed to test instrument compliance.

X1.3 Apparatus

X1.3.1 Universal Testing machine

X1.3.2 Load cell

X1.3.3 Flexure fixture including loading nose and specimen supports

X1.3.4 Computer Software to make corrections to the displacements

X1.3.5 Steel bar, with smoothed surfaces and a calculated flexural stiffness of more than 100 times greater than the test material. The length should be at least 13 mm greater than the support span. The width shall match the width of the test specimen and the thickness shall be that required to achieve or exceed the target stiffness.

X1.4 Safety Precautions

X1.4.1 The universal testing machine should stop the machine crosshead movement when the load reaches 90 % of load cell capacity, to prevent damage to the load cell.

X1.4.2 The compliance curve determination should be made at a speed no higher than 2 mm/min. Because the load builds up rapidly since the steel bar does not deflect, it is quite easy to exceed the load cell capacity.

X1.5 Procedure

NOTE X1.1—A new compliance correction curve should be established each time there is a change made to the setup of the test machine, such as, load cell changed or reinstallation of the flexure fixture on the machine. If the test machine is dedicated to flexural testing, and there are no changes to the setup, it is not necessary to re-calculate the compliance curve.

NOTE X1.2—On those machines with computer software that automatically make this compliance correction; refer to the software manual to determine how this correction should be made.

X1.5.1 The procedure to determine compliance follows:

X1.5.1.1 Configure the test system to match the actual test configuration.

X1.5.1.2 Place the steel bar in the test fixture, duplicating the position of a specimen during actual testing.

X1.5.1.3 Set the crosshead speed to 2 mm/min. or less and start the crosshead moving in the test direction recording crosshead displacement and the corresponding load values.

X1.5.1.4 Increase load to a point exceeding the highest load expected during specimen testing. Stop the crosshead and return to the pre-test location.

X1.5.1.5 The recorded load-deflection curve, starting when the loading nose contacts the steel bar to the time that the highest load expected is defined as test system compliance.

X1.5.2 Procedure to apply compliance correction is as follows:

X1.5.2.1 Run the flexural test method on the material at the crosshead required for the measurement.

X1.5.2.2 It is preferable that computer software be used to make the displacement corrections, but if it is not available compliance corrections can be made manually in the following manner. Determine the range of displacement (D) on the load versus displacement curve for the material, over which the modulus is to be calculated. For Young's Modulus that would steepest region of the curve below the proportional limit. For Secant and Chord Modulii that would be at specified level of strain or specified levels of strain, respectively. Draw two vertical lines up from the displacement axis for the two chosen displacements (D1, D2) to the load versus displacement curve for the material. In some cases one of these points maybe at zero displacement after the toe compensation correction is made. Draw two horizontal lines from these points on the load displacement curve to the Load (P) axis. Determine the loads (L1, L2).

X1.5.2.3 Using the Compliance Correction load displacement curve for the steel bar, mark off L1 and L2 on the Load (P) axis. From these two points draw horizontal lines across till they contact the load versus displacement curve for the steel bar. From these two points on the load deflection curve draw two vertical lines downwards to the displacement axis. These two points on the displacement axis determine the corrections (c1, c2) that need to be made to the displacements measurements for the test material.

X1.5.2.4 Subtract the corrections (c1, c2) from the measured displacements (D1, D2), so that a true measures of test specimen deflection (D1-c1, D2-c2) are obtained.

X1.6 Calculations

X1.6.1 Calculation of Chord Modulus

X1.6.1.1 Calculate the stresses ($\sigma f1$, $\sigma f2$) for load points L1 and L2 from Fig. X1.1 using the equation in 12.2 3.

X1.6.1.2 Calculate the strains ($\epsilon f1$, $\epsilon f2$) for displacements D1-c1 and D2-c2 from Fig. X1.3 using the equation in 12.8 Eq. 5.

X1.6.1.3 Calculate the flexural chord modulus in accordance with 12.9.3 Eq. 7.

X1.6.2 Calculation of Secant Modulus

X1.6.2.1 Calculation of the Secant Modulus at any strain along the curve would be the same as conducting a chord modulus measurement, except that $\sigma f1 = 0$, L1= 0, and D1-c1 = 0.

X1.6.3 Calculation of Young's Modulus

X1.6.3.1 Determine the steepest slope "m" along the curve, below the proportional limit, using the selected loads L1 and L2 from Fig. X1.1 and the displacements D1-c1 and D2-c2 from Fig. X1.3.

X1.6.3.2 Calculate the Young's modulus in accordance with 12.9.1 Eq. 6.

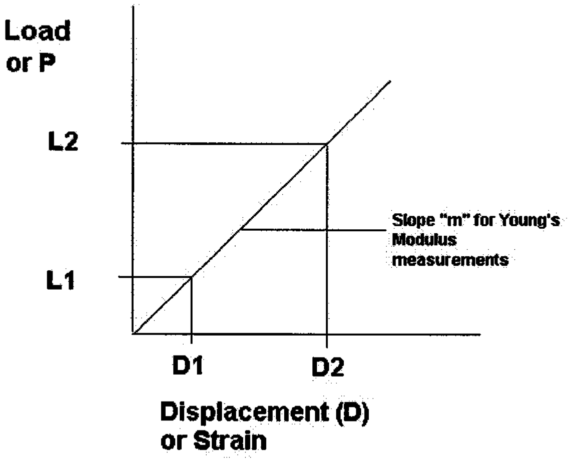


FIG. X1.1 Example of Modulus Curve for a Material

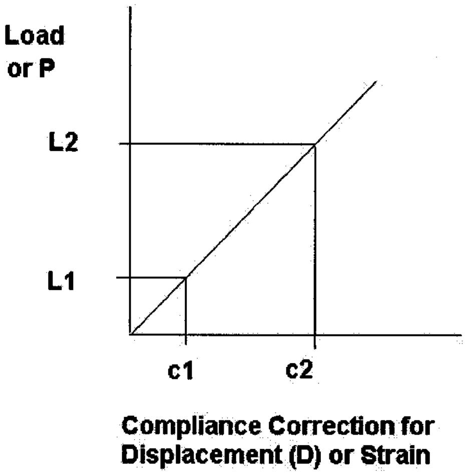


FIG. X1.2 Compliance Curve for Steel Bar

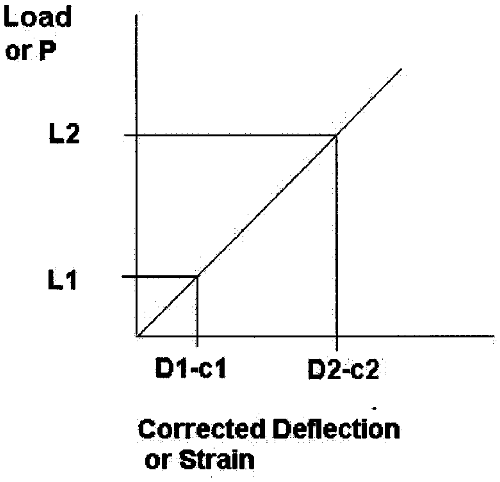


FIG. X1.3 Example of the Material Curve Corrected for the Compliance Corrected Displacement or Strain

SUMMARY OF CHANGES

This section identifies the location of selected changes to these test methods. For the convenience of the user, Committee D20 has highlighted those changes that may impact the use of these test methods. This section may also include descriptions of the changes or reasons for the changes, or both.

D 790 – 03:

(*1*) Added Appendix X1.

D 790 – 02:

(*1*) Revised 9.1 and 9.2.

D 790 – 00:

(*1*) Revised 12.1.

D 790 – 99:

(*1*) Revised 10.1.3.

D 790 – 98:

(*1*) Section 4.2 was rewritten extensively to bring this standard closer to ISO 178.

(*2*) Fig. 2 was added to clarify flexural behaviors that may be observed and to define what yielding and breaking behaviors look like, as well as the appropriate place to select these points on the stress strain curve.

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Designation: D638 − 14

Standard Test Method for Tensile Properties of Plastics[1]

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

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

1. Scope*

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

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

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

NOTE 1—This standard and ISO 527-1 address the same subject matter, but differ in technical content.

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

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

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

1.4 Test data obtained by this test method have been found to be useful in engineering design. However, it is important to consider the precautions and limitations of this method found in Note 2 and Section 4 before considering these data for engineering design.

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

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D229 Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation
D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
D618 Practice for Conditioning Plastics for Testing
D651 Test Method for Test for Tensile Strength of Molded Electrical Insulating Materials (Withdrawn 1989)[3]
D882 Test Method for Tensile Properties of Thin Plastic Sheeting
D883 Terminology Relating to Plastics
D1822 Test Method for Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials
D3039/D3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials
D4000 Classification System for Specifying Plastic Materials
D4066 Classification System for Nylon Injection and Extrusion Materials (PA)
D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens
E4 Practices for Force Verification of Testing Machines

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

Current edition approved Dec. 15, 2014. Published March 2015. Originally approved in 1941. Last previous edition approved in 2010 as D638 - 10. DOI: 10.1520/D0638-14.

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

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

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

E83 Practice for Verification and Classification of Extensometer Systems

E132 Test Method for Poisson's Ratio at Room Temperature

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

2.2 *ISO Standard:*[4]

ISO 527-1 Determination of Tensile Properties

3. Terminology

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

4. Significance and Use

4.1 This test method is designed to produce tensile property data for the control and specification of plastic materials. These data are also useful for qualitative characterization and for research and development.

4.2 Some material specifications that require the use of this test method, but with some procedural modifications that take precedence when adhering to the specification. Therefore, it is advisable to refer to that material specification before using this test method. Table 1 in Classification D4000 lists the ASTM materials standards that currently exist.

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

4.4 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, exercise great care to ensure that all samples are prepared in exactly the same way, unless the test is to include the effects of sample preparation. Similarly, for referee purposes or comparisons within any given series of specimens, care shall be taken to secure the maximum degree of uniformity in details of preparation, treatment, and handling.

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

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

5. Apparatus

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

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

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

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

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

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

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

5.1.4 *Drive Mechanism*—A drive mechanism for imparting a uniform, controlled velocity to the movable member with

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

respect to the stationary member. This velocity is to be regulated as specified in Section 8.

5.1.5 *Load Indicator*—A suitable load-indicating mechanism capable of showing the total tensile load carried by the test specimen when held by the grips. This mechanism shall be essentially free of inertia lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the indicated value, or better. The accuracy of the testing machine shall be verified in accordance with Practices E4.

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

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

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

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

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

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

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

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

6. Test Specimens

6.1 *Sheet, Plate, and Molded Plastics:*

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

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

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

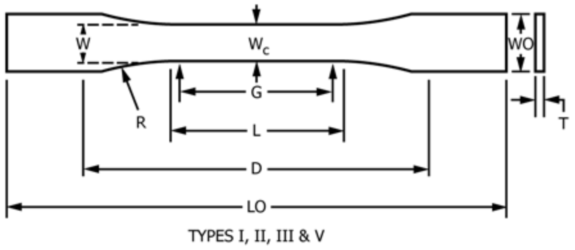
6.1.4 *Preparation*—Methods of preparing test specimens include injection molding, machining operations, or die cutting, from materials in sheet, plate, slab, or similar form. Materials thicker than 14 mm (0.55 in.) shall be machined to 14 mm (0.55 in.) for use as Type III specimens.

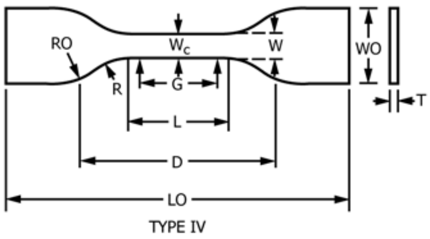
NOTE 7—Test results have shown that for some materials such as glass cloth, SMC, and BMC laminates, other specimen types should be considered to ensure breakage within the gage length of the specimen, as mandated by 7.3.

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

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

6.2 *Rigid Tubes*—The test specimen for rigid tubes shall be as shown in Fig. 2. The length, *L*, shall be as shown in the table in Fig. 2. A groove shall be machined around the outside of the specimen at the center of its length so that the wall section after





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

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)

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

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

[C] The Type V specimen shall be machined or die cut to the dimensions shown, or molded in a mold whose cavity has these dimensions. The dimensions shall be:

W = 3.18 ± 0.03 mm (0.125 ± 0.001 in.),
L = 9.53 ± 0.08 mm (0.375 ± 0.003 in.),
G = 7.62 ± 0.02 mm (0.300 ± 0.001 in.), and
R = 12.7 ± 0.08 mm (0.500 ± 0.003 in.).
The other tolerances are those in the table.

[D] Supporting data on the introduction of the L specimen of Test Method D1822 as the Type V specimen are available from ASTM Headquarters. Request RR:D20-1038.

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

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

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

[H] Overall lengths greater than the minimum indicated are used for some materials to avoid breaking in the grips or to satisfy special test requirements.

[I] Test marks or initial extensometer span.

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

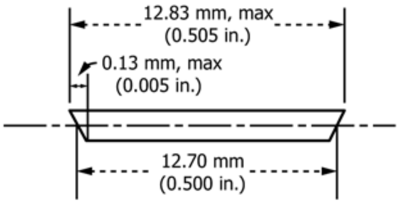
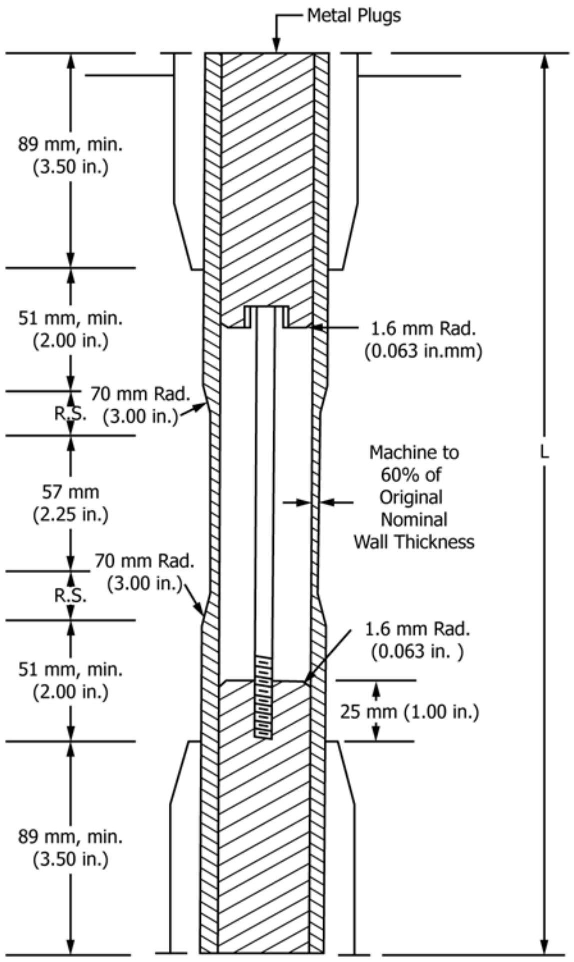


FIG. 1 Tension Test Specimens for Sheet, Plate, and Molded Plastics



DIMENSIONS OF TUBE SPECIMENS

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

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

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

machining shall be 60 % of the original nominal wall thickness. This groove shall consist of a straight section 57.2 mm (2.25 in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter. Steel or brass plugs having diameters such that they will fit snugly inside the tube and having a length equal to the full jaw length plus 25 mm (1 in.) shall be placed in the ends of the specimens to prevent crushing. They can be located conveniently in the tube by separating and supporting them on a threaded metal rod. Details of plugs and test assembly are shown in Fig. 2.

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

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

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

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

7. Number of Test Specimens

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

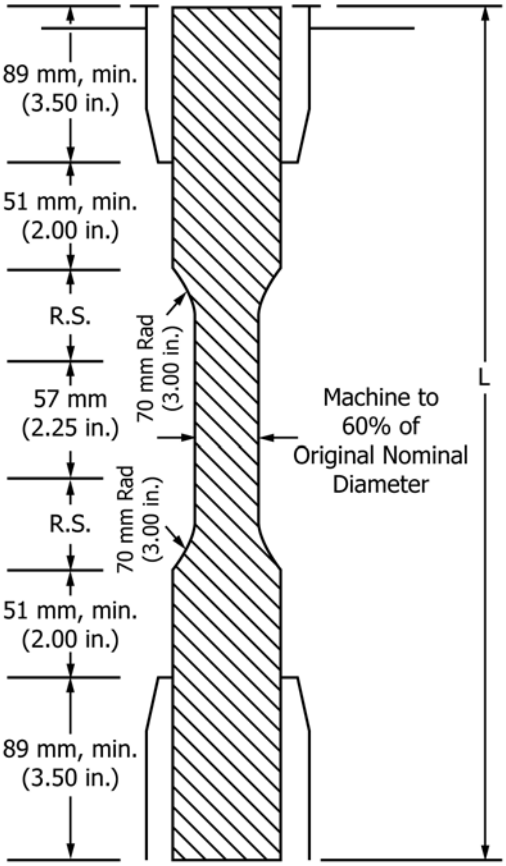
7.2 For anisotropic materials, when applicable, test five specimens, normal to, and five parallel with, the principle axis of anisotropy.

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

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

8. Speed of Testing

8.1 Speed of testing shall be the relative rate of motion of the grips or test fixtures during the test. The rate of motion of the driven grip or fixture when the testing machine is running



DIMENSIONS OF ROD SPECIMENS

Nominal Diameter	Length of Radial Sections, 2R.S.	Total Calculated Minimum Length of Specimen	Standard Length, *L*, of Specimen to Be Used for 89-mm (3.5-in.) Jaws[A]
		mm (in.)	
3.2 (⅛)	19.6 (0.773)	356 (14.02)	381 (15)
4.7 (3⁄16)	24.0 (0.946)	361 (14.20)	381 (15)
6.4 (¼)	27.7 (1.091)	364 (14.34)	381 (15)
9.5 (⅜)	33.9 (1.333)	370 (14.58)	381 (15)
12.7 (½)	39.0 (1.536)	376 (14.79)	400 (15.75)
15.9 (⅝)	43.5 (1.714)	380 (14.96)	400 (15.75)
19.0 (¾)	47.6 (1.873)	384 (15.12)	400 (15.75)
22.2 (⅞)	51.5 (2.019)	388 (15.27)	400 (15.75)
25.4 (1)	54.7 (2.154)	391 (15.40)	419 (16.5)
31.8 (1¼)	60.9 (2.398)	398 (15.65)	419 (16.5)
38.1 (1½)	66.4 (2.615)	403 (15.87)	419 (16.5)
42.5 (1¾)	71.4 (2.812)	408 (16.06)	419 (16.5)
50.8 (2)	76.0 (2.993)	412 (16.24)	432 (17)

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

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

TABLE 1 Designations for Speed of Testing[A]

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

[A] Select the lowest speed that produces rupture in 0.5 to 5 min for the specimen geometry being used (see 8.2).
[B] See Terminology D883 for definitions.
[C] The initial rate of straining cannot be calculated exactly for dumbbell-shaped specimens because of extension, both in the reduced section outside the gage length and in the fillets. This initial strain rate can be measured from the initial slope of the tensile strain-versus-time diagram.

idle may be used, if it can be shown that the resulting speed of testing is within the limits of variation allowed.

8.2 Choose the speed of testing from Table 1. Determine this chosen speed of testing by the specification for the material being tested, or by agreement between those concerned. When the speed is not specified, use the lowest speed shown in Table 1 for the specimen geometry being used, which gives rupture within 0.5 to 5-min testing time.

8.3 Make modulus determinations at the speed selected for the other tensile properties when the recorder response and resolution are adequate.

9. Conditioning

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

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

10. Procedure

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

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

10.1.2 For injection molded specimens, the actual measurement of only one specimen from each sample will suffice when it has previously been demonstrated that the specimen-to-specimen variation in width and thickness is less than 1 %.

10.1.3 For thin sheeting, including film less than 1.0 mm (0.04 in.), take the width of specimens produced by a Type IV die as the distance between the cutting edges of the die in the narrow section. For all other specimens, measure the actual width of the center portion of the specimen to be tested, unless it can be shown that the actual width of the specimen is the same as that of the die within the specimen dimension tolerances given in Fig. 1.

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

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

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

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

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

10.5 Record the load-extension curve of the specimen.

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

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

11. Calculation

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

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

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

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

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

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

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

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

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

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

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

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

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

where:

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

11.8 See Annex A1 for information on toe compensation.

11.9 See Annex A3 for the determination of Poisson's Ratio.

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; for anisotropic materials, the number of specimens tested and the direction in which they were tested,

12.1.7 Speed of testing,

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

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

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

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

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

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

12.1.14 Date of test, and

12.1.15 Revision date of Test Method D638.

13. Precision and Bias[5]

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

TABLE 2 Modulus, 10^6 psi, for Eight Laboratories, Five Materials

	Mean	S_r	S_R	I_r	I_R
Polypropylene	0.210	0.0089	0.071	0.025	0.201
Cellulose acetate butyrate	0.246	0.0179	0.035	0.051	0.144
Acrylic	0.481	0.0179	0.063	0.051	0.144
Glass-reinforced nylon	1.17	0.0537	0.217	0.152	0.614
Glass-reinforced polyester	1.39	0.0894	0.266	0.253	0.753

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

	Mean	S_r	S_R	I_r	I_R
Polypropylene	2.97	1.54	1.65	4.37	4.66
Cellulose acetate butyrate	4.82	0.058	0.180	0.164	0.509
Acrylic	9.09	0.452	0.751	1.27	2.13
Glass-reinforced polyester	20.8	0.233	0.437	0.659	1.24
Glass-reinforced nylon	23.6	0.277	0.698	0.784	1.98

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

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

	Mean	S_r	S_R	I_r	I_R
Glass-reinforced polyester	3.68	0.20	2.33	0.570	6.59
Glass-reinforced nylon	3.87	0.10	2.13	0.283	6.03
Acrylic	13.2	2.05	3.65	5.80	10.3
Cellulose acetate butyrate	14.1	1.87	6.62	5.29	18.7
Polypropylene	293.0	50.9	119.0	144.0	337.0

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

13.1.1 Tables 5-8 are based on a round-robin test conducted by the polyolefin subcommittee in 1988, involving eight polyethylene materials tested in ten laboratories. For each material, all samples were molded at one source, but the individual specimens were prepared at the laboratories that tested them. Each test result was the average of five individual determinations. Each laboratory obtained three test results for each material. Data from some laboratories could not be used for various reasons, and this is noted in each table.

13.1.2 Tables 9 and 10 are based on a round-robin test conducted by the polyolefin subcommittee in 1988, involving three materials tested in eight laboratories. For each material, all samples were molded at one source, but the individual specimens were prepared at the laboratories that tested them. Each test result was the average of five individual determinations. Each laboratory obtained three test results for each material.

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

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1544	52.4	64.0	146.6	179.3
LDPE	20	1894	53.1	61.2	148.7	171.3
LLDPE	20	1879	74.2	99.9	207.8	279.7
LLDPE	20	1791	49.2	75.8	137.9	212.3
LLDPE	20	2900	55.5	87.9	155.4	246.1
LLDPE	20	1730	63.9	96.0	178.9	268.7
HDPE	2	4101	196.1	371.9	549.1	1041.3
HDPE	2	3523	175.9	478.0	492.4	1338.5

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

TABLE 6 Tensile Yield Elongation, for Eight Laboratories, Eight Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	17.0	1.26	3.16	3.52	8.84
LDPE	20	14.6	1.02	2.38	2.86	6.67
LLDPE	20	15.7	1.37	2.85	3.85	7.97
LLDPE	20	16.6	1.59	3.30	4.46	9.24
LLDPE	20	11.7	1.27	2.88	3.56	8.08
LLDPE	20	15.2	1.27	2.59	3.55	7.25
HDPE	2	9.27	1.40	2.84	3.91	7.94
HDPE	2	9.63	1.23	2.75	3.45	7.71

TABLE 7 Tensile Break Stress, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1592	52.3	74.9	146.4	209.7
LDPE	20	1750	66.6	102.9	186.4	288.1
LLDPE	20	4379	127.1	219.0	355.8	613.3
LLDPE	20	2840	78.6	143.5	220.2	401.8
LLDPE	20	1679	34.3	47.0	95.96	131.6
LLDPE	20	2660	119.1	166.3	333.6	465.6

TABLE 8 Tensile Break Elongation, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	567	31.5	59.5	88.2	166.6
LDPE	20	569	61.5	89.2	172.3	249.7
LLDPE	20	890	25.7	113.8	71.9	318.7
LLDPE	20	64.4	6.68	11.7	18.7	32.6
LLDPE	20	803	25.7	104.4	71.9	292.5
LLDPE	20	782	41.6	96.7	116.6	270.8

TABLE 9 Tensile Stress at Yield, 10^3 psi, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
Polypropylene	3.63	0.022	0.161	0.062	0.456
Cellulose acetate butyrate	5.01	0.058	0.227	0.164	0.642
Acrylic	10.4	0.067	0.317	0.190	0.897

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

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

TABLE 10 Elongation at Yield, %, for Eight Laboratories, Three Materials

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

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

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

13.1.4.1 S_r is the within-laboratory standard deviation of the average; $I_r = 2.83\ S_r$. (See 13.1.4.3 for application of I_r.)

13.1.4.2 S_R is the between-laboratory standard deviation of the average; $I_R = 2.83\ S_R$. (See 13.1.4.4 for application of I_R.)

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

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

13.1.4.5 Any judgment in accordance with 13.1.4.3 and 13.1.4.4 will have an approximate 95 % (0.95) probability of being correct.

13.1.4.6 Other formulations may give somewhat different results.

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

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

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

14. Keywords

14.1 modulus of elasticity; percent elongation; plastics; Poisson's Ratio; tensile properties; tensile strength

ANNEXES

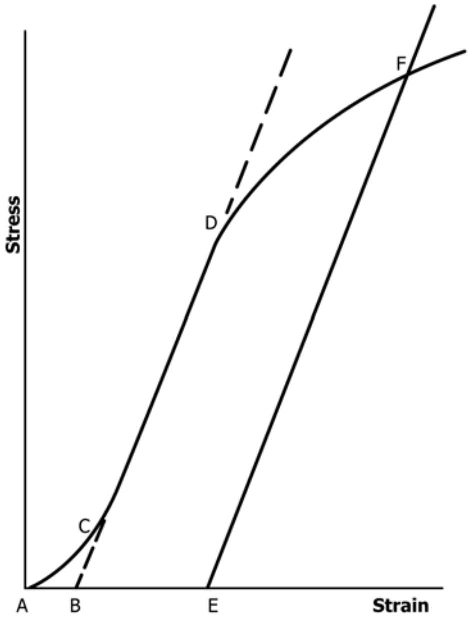
(Mandatory Information)

A1. TOE COMPENSATION

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

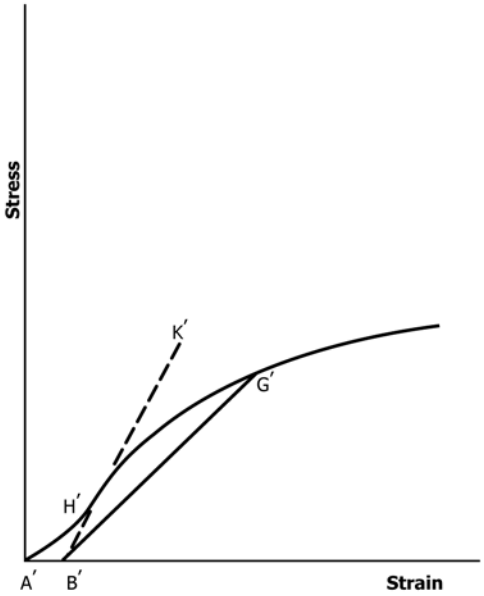
A1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. A1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured,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

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



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

FIG. A1.1 Material with Hookean Region



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

FIG. A1.2 Material with No Hookean Region

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The stress at the point of intersection *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 (psi), or yield strength at 0.1 % offset ... MPa (psi).

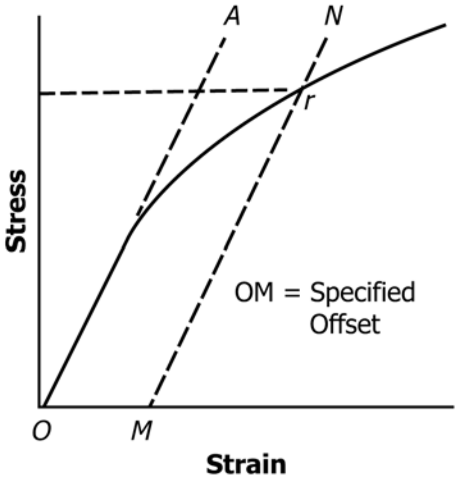


FIG. A2.1 Offset Yield Strength

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

where:

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

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

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

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

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

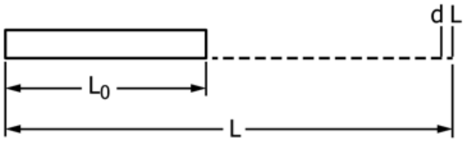


FIG. A2.2 Illustration of True Strain Equation

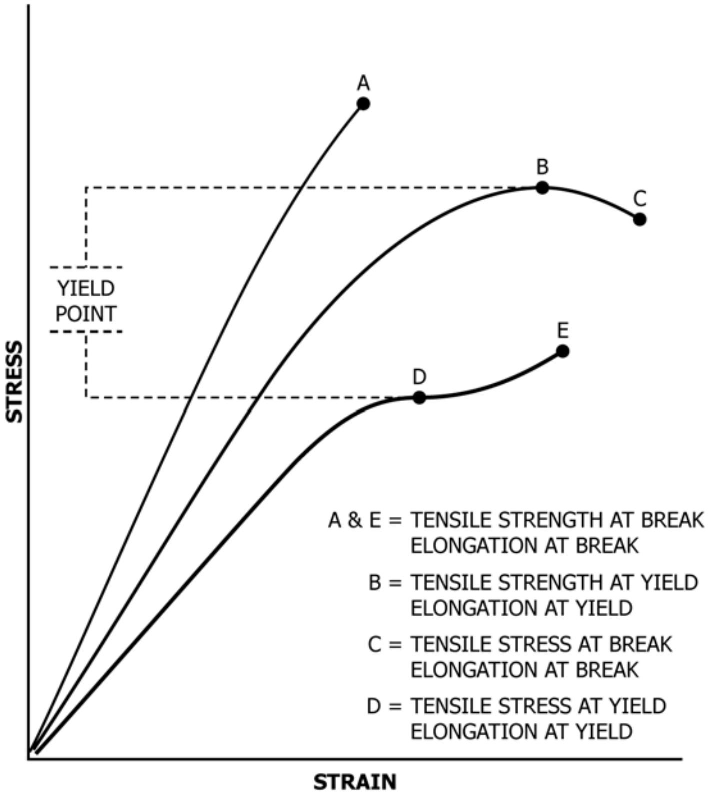


FIG. A2.3 Tensile Designations

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

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

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

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

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

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

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

$$\sigma_{UT} = \sigma_U(1+\varepsilon_U) = \sigma_U L_u/L_o$$

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

A3. MEASUREMENT OF POISSON'S RATIO

A3.1. Scope

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

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

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

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

A3.2. Referenced Documents

A3.2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing
D883 Terminology Relating to Plastics
D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens
E83 Practice for Verification and Classification of Extensometer Systems
E132 Test Method for Poisson's Ratio at Room Temperature
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

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

A3.2.2 *ISO Standard:*[4]

ISO 527–1 Determination of Tensile Properties

A3.3. Terminology

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

A3.4. Significance and Use

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

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

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

A3.5. Apparatus

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

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

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

A3.6. Test Specimen

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

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

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

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

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

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

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

A3.7 Number of Test Specimens

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

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

A3.8. Conditioning

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

A3.9. Procedure

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

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

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

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

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

A3.9.6 Rebalance the extensometers to zero.

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

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

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

A3.10. Calculation

A3.10.1 *Poisson's Ratio*—The axial strain, ε_α, indicated by the axial extensometer, and the transverse strain, ε_t, indicated by the transverse extensometers, are plotted against the applied load, *P*, as shown in Fig. A3.1.

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

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

where:

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

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

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

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

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

A3.11. Report

A3.11.1 Report the following information:

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

A3.11.1.2 Method of preparing test specimens,

A3.11.1.3 Type of test specimen and dimensions,

A3.11.1.4 Conditioning procedure used,

A3.11.1.5 Atmospheric conditions in test room,

A3.11.1.6 Number of specimens tested,

A3.11.1.7 Speed of testing,

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

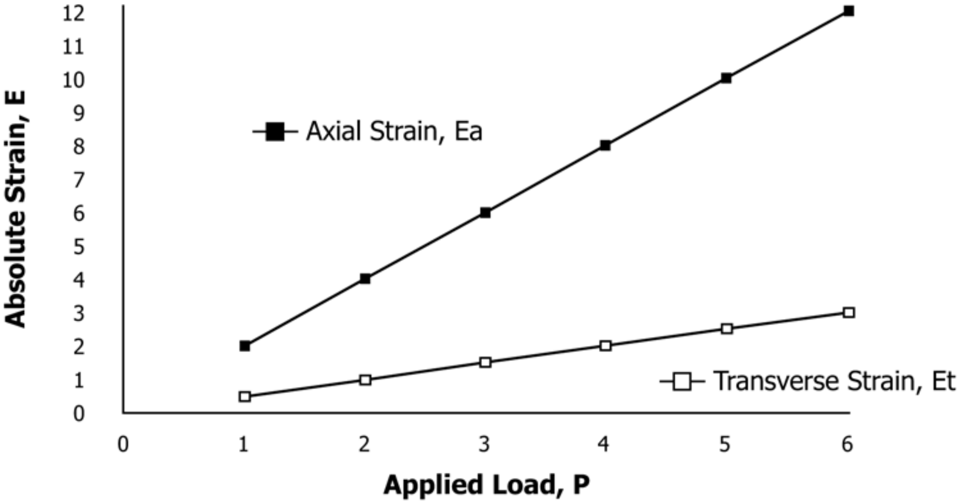


FIG. A3.1 Plot of Strains Versus Load for Determination of Poisson's Ratio

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

A3.11.1.10 Date of test, and

A3.11.1.11 Revision date of Test Method D618.

A3.12. Precision and Bias

A3.12.1 *Precision*—The repeatability standard deviation has been determined to be the following (see Table A3.1.) An attempt to develop a full precision and bias statement for this test method will be made at a later date. For this reason, data on precision and bias cannot be given. Because this test method does not contain a round-robin based numerical precision and bias statement, it shall not be used as a referee test method in case of dispute. Anyone wishing to participate in the development of precision and bias data should contact the Chairman, Subcommittee D20.10 Mechanical Properties, ASTM International, 100 Barr Harbor, West Conshohocken, PA 19428.

A3.13 Keywords

axial strain; Poisson's ratio; transverse strain

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

Material	Extensometer Type	Average	V_r[A]	V_R[B]	r[C]	R[D]
PP Copolymer	2–point	0.408	0.011		0.031	
PP Copolymer	4–point	0.392	0.010		0.028	
PP Homopolymer with 20 % Glass	2–point	0.428	0.013		0.036	
PP Homopolymer with 20 % Glass	4–point	0.410	0.015		0.042	

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

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

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

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

[D] R = between-laboratories critical interval between two test results = 2.8 × S_R

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D638 - 10) that may impact the use of this standard. (December 15, 2014)

(1) Revised Note 1 since changes were made to ISO 527-1, and it is no longer equivalent to this standard.
(2) Removed permissive language.
(3) Made some editorial changes.
(4) Moved Tables 2-5 to Section 13 on Precision and Bias.
(5) Revised Summary of Changes section.

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