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AASHTO Submission
Product Evaluation Application

ASTM Standards for Material Performance

-ASTM Standard 71216-09 for Rehab of Existing Pipelines and Conduits

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

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Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube[1,2]

This standard is issued under the fixed designation F1216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice describes the procedures for the reconstruction of pipelines and conduits (4 to 108-in. diameter) by the installation of a resin-impregnated, flexible tube which is inverted into the existing conduit by use of a hydrostatic head or air pressure. The resin is cured by circulating hot water or introducing controlled steam within the tube. When cured, the finished pipe will be continuous and tight-fitting. This reconstruction process can be used in a variety of gravity and pressure applications such as sanitary sewers, storm sewers, process piping, electrical conduits, and ventilation systems.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see 7.4.2.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D543 Practices for Evaluating the Resistance of Plastics to Chemical Reagents

D638 Test Method for Tensile Properties of Plastics

D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

D903 Test Method for Peel or Stripping Strength of Adhesive Bonds

D1600 Terminology for Abbreviated Terms Relating to Plastics

D3567 Practice for Determining Dimensions of "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Pipe and Fittings

D3839 Guide for Underground Installation of "Fiberglass" (Glass-Fiber Reinforced Thermosetting-Resin) Pipe

D5813 Specification for Cured-In-Place Thermosetting Resin Sewer Piping Systems

E797 Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method

F412 Terminology Relating to Plastic Piping Systems

2.2 *AWWA Standard:*

Manual on Cleaning and Lining Water Mains, M 28[4]

2.3 *NASSCO Standard:*

Recommended Specifications for Sewer Collection System Rehabilitation[5]

3. Terminology

3.1 Definitions are in accordance with Terminology F412 and abbreviations are in accordance with Terminology D1600, unless otherwise specified.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cured-in-place pipe (CIPP)*—a hollow cylinder containing a nonwoven or a woven material, or a combination of nonwoven and woven material surrounded by a cured thermosetting resin. Plastic coatings may be included. This pipe is formed within an existing pipe. Therefore, it takes the shape of and fits tightly to the existing pipe.

3.2.2 *inversion*—the process of turning the resin-impregnated tube inside out by the use of water pressure or air pressure.

[1] This practice is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.67 on Trenchless Plastic Pipeline Technology.

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[2] The following report has been published on one of the processes: Driver, F. T., and Olson, M. R., "*Demonstration of Sewer Relining by the Insituform Process, Northbrook, Illinois*," EPA-600/2-83-064, Environmental Protection Agency, 1983. Interested parties can obtain copies from the Environmental Protection Agency or from a local technical library.

[3] 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.

[4] Available from American Water Works Association (AWWA), 6666 W. Quincy Ave., Denver, CO 80235, http://www.awwa.org.

[5] Available from the National Association of Sewer Service Companies, 101 Wymore Rd., Suite 501, Altamonte, FL 32714.

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

3.2.3 *lift*—a portion of the CIPP that has cured in a position such that it has pulled away from the existing pipe wall.

4. Significance and Use

4.1 This practice is for use by designers and specifiers, regulatory agencies, owners, and inspection organizations who are involved in the rehabilitation of conduits through the use of a resin-impregnated tube inverted through the existing conduit. As for any practice, modifications may be required for specific job conditions.

5. Materials

5.1 *Tube*—The tube should consist of one or more layers of flexible needled felt or an equivalent nonwoven or woven material, or a combination of nonwoven and woven materials, capable of carrying resin, withstanding installation pressures and curing temperatures. The tube should be compatible with the resin system used. The material should be able to stretch to fit irregular pipe sections and negotiate bends. The outside layer of the tube should be plastic coated with a material that is compatible with the resin system used. The tube should be fabricated to a size that, when installed, will tightly fit the internal circumference and the length of the original conduit. Allowance should be made for circumferential stretching during inversion.

5.2 *Resin*—A general purpose, unsaturated, styrene-based, thermoset resin and catalyst system or an epoxy resin and hardener that is compatible with the inversion process should be used. The resin must be able to cure in the presence of water and the initiation temperature for cure should be less than 180°F (82.2°C). The CIPP system can be expected to have as a minimum the initial structural properties given in Table 1. These physical strength properties should be determined in accordance with Section 8.

6. Design Considerations

6.1 *General Guidelines*—The design thickness of the CIPP is largely a function of the condition of the existing pipe. Design equations and details are given in Appendix X1.

7. Installation

7.1 *Cleaning and Inspection:*

7.1.1 Prior to entering access areas such as manholes, and performing inspection or cleaning operations, an evaluation of the atmosphere to determine the presence of toxic or flammable vapors or lack of oxygen must be undertaken in accordance with local, state, or federal safety regulations.

TABLE 1 CIPP Initial Structural Properties[A]

Property	Test Method	Minimum Value	
		psi	(MPa)
Flexural strength	D790	4 500	(31)
Flexural modulus	D790	250 000	(1 724)
Tensile strength (for pressure pipes only)	D638	3 000	(21)

[A]The values in Table 1 are for field inspection. The purchaser should consult the manufacturer for the long-term structural properties.

7.1.2 *Cleaning of Pipeline*—All internal debris should be removed from the original pipeline. Gravity pipes should be cleaned with hydraulically powered equipment, high-velocity jet cleaners, or mechanically powered equipment (see NASSCO Recommended Specifications for Sewer Collection System Rehabilitation). Pressure pipelines should be cleaned with cable-attached devices or fluid-propelled devices as shown in AWWA Manual on Cleaning and Lining Water Mains, M 28.

7.1.3 *Inspection of Pipelines*—Inspection of pipelines should be performed by experienced personnel trained in locating breaks, obstacles, and service connections by closed-circuit television or man entry. The interior of the pipeline should be carefully inspected to determine the location of any conditions that may prevent proper installation of the impregnated tube, such as protruding service taps, collapsed or crushed pipe, and reductions in the cross-sectional area of more than 40 %. These conditions should be noted so that they can be corrected.

7.1.4 *Line Obstructions*—The original pipeline should be clear of obstructions such as solids, dropped joints, protruding service connections, crushed or collapsed pipe, and reductions in the cross-sectional area of more than 40 % that will prevent the insertion of the resin-impregnated tube. If inspection reveals an obstruction that cannot be removed by conventional sewer cleaning equipment, then a point repair excavation should be made to uncover and remove or repair the obstruction.

7.2 *Resin Impregnation*—The tube should be vacuum-impregnated with resin (wet-out) under controlled conditions. The volume of resin used should be sufficient to fill all voids in the tube material at nominal thickness and diameter. The volume should be adjusted by adding 5 to 10 % excess resin for the change in resin volume due to polymerization and to allow for any migration of resin into the cracks and joints in the original pipe.

7.3 *Bypassing*—If bypassing of the flow is required around the sections of pipe designated for reconstruction, the bypass should be made by plugging the line at a point upstream of the pipe to be reconstructed and pumping the flow to a downstream point or adjacent system. The pump and bypass lines should be of adequate capacity and size to handle the flow. Services within this reach will be temporarily out of service.

7.3.1 Public advisory services will be required to notify all parties whose service laterals will be out of commission and to advise against water usage until the mainline is back in service.

7.4 *Inversion:*

7.4.1 *Using Hydrostatic Head*—The wet-out tube should be inserted through an existing manhole or other approved access by means of an inversion process and the application of a hydrostatic head sufficient to fully extend it to the next designated manhole or termination point. The tube should be inserted into the vertical inversion standpipe with the impermeable plastic membrane side out. At the lower end of the inversion standpipe, the tube should be turned inside out and attached to the standpipe so that a leakproof seal is created. The inversion head should be adjusted to be of sufficient height to

cause the impregnated tube to invert from point of inversion to point of termination and hold the tube tight to the pipe wall, producing dimples at side connections. Care should be taken during the inversion so as not to over-stress the felt fiber.

7.4.1.1 An alternative method of installation is a top inversion. In this case, the tube is attached to a top ring and is inverted to form a standpipe from the tube itself or another method accepted by the engineer.

NOTE 1—The tube manufacturer should provide information on the maximum allowable tensile stress for the tube.

7.4.2 *Using Air Pressure*—The wet-out tube should be inserted through an existing manhole or other approved access by means of an inversion process and the application of air pressure sufficient to fully extend it to the next designated manhole or termination point. The tube should be connected by an attachment at the upper end of the guide chute so that a leakproof seal is created and with the impermeable plastic membranes side out. As the tube enters the guide chute, the tube should be turned inside out. The inversion air pressure should be adjusted to be of sufficient pressure to cause the impregnated tube to invert from point of inversion to point of termination and hold the tube tight to the pipe wall, producing dimples at side connections. Care should be taken during the inversion so as not to overstress the woven and nonwoven materials.

NOTE 2—**Warning:** Suitable precautions should be taken to eliminate hazards to personnel in the proximity of the construction when pressurized air is being use.

7.4.3 *Required Pressures*—Before the inversion begins, the tube manufacturer shall provide the minimum pressure required to hold the tube tight against the existing conduit, and the maximum allowable pressure so as not to damage the tube. Once the inversion has started, the pressure shall be maintained between the minimum and maximum pressures until the inversion has been completed.

7.5 *Lubricant*—The use of a lubricant during inversion is recommended to reduce friction during inversion. This lubricant should be poured into the inversion water in the downtube or applied directly to the tube. The lubricant used should be a nontoxic, oil-based product that has no detrimental effects on the tube or boiler and pump system, will not support the growth of bacteria, and will not adversely affect the fluid to be transported.

7.6 *Curing:*

7.6.1 *Using Circulating Heated Water*—After inversion is completed, a suitable heat source and water recirculation equipment are required to circulate heated water throughout the pipe. The equipment should be capable of delivering hot water throughout the section to uniformly raise the water temperature above the temperature required to effect a cure of the resin. Water temperature in the line during the cure period should be as recommended by the resin manufacturer.

7.6.1.1 The heat source should be fitted with suitable monitors to gage the temperature of the incoming and outgoing water supply. Another such gage should be placed between the impregnated tube and the pipe invert at the termination to determine the temperatures during cure.

7.6.1.2 Initial cure will occur during temperature heat-up and is completed when exposed portions of the new pipe appear to be hard and sound and the remote temperature sensor indicates that the temperature is of a magnitude to realize an exotherm or cure in the resin. After initial cure is reached, the temperature should be raised to the post-cure temperature recommended by the resin manufacturer. The post-cure temperature should be held for a period as recommended by the resin manufacturer, during which time the recirculation of the water and cycling of the boiler to maintain the temperature continues. The curing of the CIPP must take into account the existing pipe material, the resin system, and ground conditions (temperature, moisture level, and thermal conductivity of soil).

7.6.2 *Using Steam*—After inversion is completed, suitable steam-generating equipment is required to distribute steam throughout the pipe. The equipment should be capable of delivering steam throughout the section to uniformly raise the temperature within the pipe above the temperature required to effect a cure of the resin. The temperature in the line during the cure period should be as recommended by the resin manufacturer.

7.6.2.1 The steam-generating equipment should be fitted with a suitable monitor to gage the temperature of the outgoing steam. The temperature of the resin being cured should be monitored by placing gages between the impregnated tube and the existing pipe at both ends to determine the temperature during cure.

7.6.2.2 Initial cure will occur during temperature heat-up and is completed when exposed portions of the new pipe appear to be hard and sound and the remote temperature sensor indicates that the temperature is of a magnitude to realize an exotherm or cure in the resin. After initial cure is reached, the temperature should be raised to post-cure temperatures recommended by the resin manufacturer. The post-cure temperature should be held for a period as recommended by the resin manufacturer, during which time the distribution and control of steam to maintain the temperature continues. The curing of the CIPP must take into account the existing pipe material, the resin system, and ground conditions (temperature, moisture level, and thermal conductivity of soil).

7.6.3 *Required Pressures*—As required by the purchase agreement, the estimated maximum and minimum pressure required to hold the flexible tube tight against the existing conduit during the curing process should be provided by the seller and shall be increased to include consideration of the external ground water, if present. Once the cure has started and dimpling for laterals is completed, the required pressures should be maintained until the cure has been completed. For water or steam, the pressure should be maintained within the estimated maximum and minimum pressure during the curing process. If the steam pressure or hydrostatic head drops below the recommended minimum during the cure, the CIPP should be inspected for lifts or delaminations and evaluated for its ability to fully meet the applicable requirements of 7.8 and Section 8.

7.7 *Cool-Down:*

7.7.1 *Using Cool Water After Heated Water Cure*—The new pipe should be cooled to a temperature below 100°F (38°C)

before relieving the static head in the inversion standpipe. Cool-down may be accomplished by the introduction of cool water into the inversion standpipe to replace water being drained from a small hole made in the downstream end. Care should be taken in the release of the static head so that a vacuum will not be developed that could damage the newly installed pipe.

7.7.2 *Using Cool Water After Steam Cure*—The new pipe should be cooled to a temperature below 113°F (45°C) before relieving the internal pressure within the section. Cool-down may be accomplished by the introduction of cool water into the section to replace the mixture of air and steam being drained from a small hole made in the downstream end. Care should be taken in the release of the air pressure so that a vacuum will not be developed that could damage the newly installed pipe.

7.8 *Workmanship*—The finished pipe should be continuous over the entire length of an inversion run and be free of dry spots, lifts, and delaminations. If these conditions are present, remove and replace the CIPP in these areas.

7.8.1 If the CIPP does not fit tightly against the original pipe at its termination point(s), the space between the pipes should be sealed by filling with a resin mixture compatible with the CIPP.

7.9 *Service Connections*—After the new pipe has been cured in place, the existing active service connections should be reconnected. This should generally be done without excavation, and in the case of non-man entry pipes, from the interior of the pipeline by means of a television camera and a remote-control cutting device.

8. Inspection Practices

8.1 For each inversion length designated by the owner in the Contract documents or purchase order, the preparation of a CIPP sample is required, using one of the following two methods, depending on the size of the host pipe.

8.1.1 For pipe sizes of 18 in. or less, the sample should be cut from a section of cured CIPP at an intermediate manhole or at the termination point that has been inverted through a like diameter pipe which has been held in place by a suitable heat sink, such as sandbags.

8.1.2 In medium and large-diameter applications and areas with limited access, the sample should be fabricated from material taken from the tube and the resin/catalyst system used and cured in a clamped mold placed in the downtube when circulating heated water is used and in the silencer when steam is used. This method can also be used for sizes 18 in. or less, in situations where preparing samples in accordance with 8.1.1 can not be obtained due to physical constrains, if approved by the owner.

8.1.3 The samples for each of these cases should be large enough to provide a minimum of three specimens and a recommended five specimens for flexural testing and also for tensile testing, if applicable. The following test procedures should be followed after the sample is cured and removed.

8.1.3.1 *Short-Term Flexural (Bending) Properties*—The initial tangent flexural modulus of elasticity and flexural stress should be measured for gravity and pressure pipe applications in accordance with Test Methods D790 and should meet the requirements of Table 1.

8.1.3.2 *Tensile Properties*—The tensile strength should be measured for pressure pipe applications in accordance with Test Method D638 and must meet the requirements of Table 1.

8.2 *Gravity Pipe Leakage Testing*—If required by the owner in the contract documents or purchase order, gravity pipes should be tested using an exfiltration test method where the CIPP is plugged at both ends and filled with water. This test should take place after the CIPP has cooled down to ambient temperature. This test is limited to pipe lengths with no service laterals and diameters of 36 in. or less. The allowable water exfiltration for any length of pipe between termination points should not exceed 50 U.S. gallons per inch of internal pipe diameter per mile per day, providing that all air has been bled from the line. During exfiltration testing, the maximum internal pipe pressure at the lowest end should not exceed 10 ft (3.0 m) of water or 4.3 psi (29.7 kPA) and the water level inside of the inversion standpipe should be 2 ft (0.6 m) higher than the top of the pipe or 2 ft higher than the groundwater level, whichever is greater. The leakage quantity should be gaged by the water level in a temporary standpipe placed in the upstream plug. The test should be conducted for a minimum of one hour.

NOTE 3—It is impractical to test pipes above 36-in. diameter for leakage due to the technology available in the pipe rehabilitation industry. Post inspection of larger pipes will detect major leaks or blockages.

8.3 *Pressure Pipe Testing*—If required by the owner in the contract documents or purchase order, pressure pipes should be subjected to a hydrostatic pressure test. A recommended pressure and leakage test would be at twice the known working pressure or at the working pressure plus 50 psi, whichever is less. Hold this pressure for a period of two to three hours to allow for stabilization of the CIPP. After this period, the pressure test will begin for a minimum of one hour. The allowable leakage during the pressure test should be 20 U.S. gallons per inch of internal pipe diameter per mile per day, providing that all air has been evacuated from the line prior to testing and the CIPP has cooled down to ambient temperature.

NOTE 4—The allowable leakage for gravity and pressure pipe testing is a function of water loss at the end seals and trapped air in the pipe.

8.4 *Delamination Test*—If required by the owner in the contract documents or purchase order, a delamination test should be performed on each inversion length specified. The CIPP samples should be prepared in accordance with 8.1.2, except that a portion of the tube material in the sample should be dry and isolated from the resin in order to separate tube layers for testing. (Consult the tube manufacturer for further information.) Delamination testing shall be in accordance with Test Method D903, with the following exceptions:

8.4.1 The rate of travel of the power-actuated grip shall be 1 in. (25 mm)/min.

8.4.2 Five test specimens shall be tested for each inversion specified.

8.4.3 The thickness of the test specimen shall be minimized, but should be sufficient to adequately test delamination of nonhomogeneous CIPP layers.

8.5 The peel or stripping strength between any nonhomogeneous layers of the CIPP laminate should be a minimum of 10 lb/in. (178.60 g/mm) of width for typical CIPP applications.

NOTE 5—The purchaser may designate the dissimilar layers between which the delamination test will be conducted.

NOTE 6—For additional details on conducting the delamination test, contact the CIPP contractor.

8.6 *CIPP Wall Thickness*—The method of obtaining CIPP wall thickness measurements should be determined in a manner consistent with 8.1.2 of Specification D5813. Thickness measurements should be made in accordance with Practice D3567 for samples prepared in accordance with 8.1. Make a minimum of eight measurements at evenly spaced intervals around the circumference of the pipe to ensure that minimum and maximum thicknesses have been determined. Deduct from the measured values the thickness of any plastic coatings or CIPP layers not included in the structural design of the CIPP. The average thickness should be calculated using all measured values and shall meet or exceed minimum design thickness as agreed upon between purchaser and seller. The minimum wall thickness at any point shall not be less than 87.5% of the specified design thickness as agreed upon between purchase and seller.

8.6.1 *Ultrasonic Testing of Wall Thickness*—An alternative method to 8.6 for measuring the wall thickness may be performed within the installed CIPP at either end of the pipe by the ultrasonic pulse echo method as described in Practice E797. A minimum of eight (8) evenly spaced measurements should be made around the internal circumference of the installed CIPP within the host pipe at a distance of 12 to 18 in. from the end of the pipe. For pipe diameters of fifteen (15) in. or greater, a minimum of sixteen (16) evenly spaced measurements shall be recorded. The ultrasonic method to be used is the flaw detector with A-scan display and direct thickness readout as defined in 6.1.2 of E797. A calibration block shall be manufactured from the identical materials used in the installed CIPP to calibrate sound velocity through the liner. Calibration of the transducer shall be performed daily in accordance with the equipment manufacturer's recommendations. The average thickness should be calculated using all measured values and shall meet or exceed minimum design thickness as agreed upon between purchaser and seller. The minimum wall thickness at any point shall not be less than 87.5 % of the specified design thickness as agreed upon between purchaser and seller.

8.7 *Inspection and Acceptance*—The installation may be inspected visually if appropriate, or by closed-circuit television if visual inspection cannot be accomplished. Variations from true line and grade may be inherent because of the conditions of the original piping. No infiltration of groundwater should be observed. All service entrances should be accounted for and be unobstructed.

APPENDIXES

(Nonmandatory Information)

X1. DESIGN CONSIDERATIONS

X1.1 *Terminology*:

X1.1.1 *partially deteriorated pipe*—the original pipe can support the soil and surcharge loads throughout the design life of the rehabilitated pipe. The soil adjacent to the existing pipe must provide adequate side support. The pipe may have longitudinal cracks and up to 10.0% distortion of the diameter. If the distortion of the diameter is greater than 10.0%, alternative design methods are required (see Note 1).

X1.1.2 *fully deteriorated pipe*—the original pipe is not structurally sound and cannot support soil and live loads or is expected to reach this condition over the design life of the rehabilitated pipe. This condition is evident when sections of the original pipe are missing, the pipe has lost its original shape, or the pipe has corroded due to the effects of the fluid, atmosphere, soil, or applied loads.

X1.2 *Gravity Pipe*:

X1.2.1 *Partially Deteriorated Gravity Pipe Condition*—The CIPP is designed to support the hydraulic loads due to groundwater, since the soil and surcharge loads can be supported by the original pipe. The groundwater level should be determined by the purchaser and the thickness of the CIPP should be sufficient to withstand this hydrostatic pressure without collapsing. The following equation may be used to determine the thickness required:

$$P = \frac{2KE_L}{(1-\nu^2)} \cdot \frac{1}{(DR-1)^3} \cdot \frac{C}{N} \qquad \text{(X1.1)}$$

where:

P = groundwater load, psi (MPa), measured from the invert of the pipe
K = enhancement factor of the soil and existing pipe adjacent to the new pipe (a minimum value of 7.0 is recommended where there is full support of the existing pipe),
E_L = long-term (time corrected) modulus of elasticity for CIPP, psi (MPa) (see Note X1.1),
ν = Poisson's ratio (0.3 average),
DR = dimension ratio of CIPP,
C = ovality reduction factor =

$$\left[\left(1-\frac{\Delta}{100}\right)/\left(1+\frac{\Delta}{100}\right)^2\right]^3$$

Δ = percentage ovality of original pipe equals

$$100 \times \frac{(Mean\ Inside\ Diameter - Minimum\ Inside\ Diameter)}{Mean\ Inside\ Diameter}$$

or

$$100 \times \frac{(Maximum\ Inside\ Diameter - Mean\ Inside\ Diameter)}{Mean\ Inside\ Diameter}$$

and

N = factor of safety.

NOTE X1.1—The choice of value (from manufacturer's literature) of E_L will depend on the estimated duration of the application of the load, P, in relation to the design life of the structure. For example, if the total duration of the load, P, is estimated to be 50 years, either continuously applied, or the sum of intermittent periods of loading, the appropriately conservative choice of value for E_L will be that given for 50 years of continuous loading at the maximum ground or fluid temperature expected to be reached over the life of the structure.

NOTE X1.2—If there is no groundwater above the pipe invert, the CIPP should typically have a maximum *SDR* of 100, dependent upon design conditions.

X1.2.1.1 If the original pipe is oval, the CIPP design from Eq X1.1 shall have a minimum thickness as calculated by the following formula:

$$1.5\left(\frac{\Delta}{100}\right)\left(1+\frac{\Delta}{100}\right)DR^2 - 0.5\left(1+\frac{\Delta}{100}\right)DR = \frac{\sigma_L}{PN} \quad (X1.2)$$

where:

σ_L = long-term (time corrected) flexural strength for CIPP, psi (MPa) (see Note X1.5).

X1.2.1.2 See Table X1.1 for typical design calculations.

X1.2.2 *Fully Deteriorated Gravity Pipe Condition*—The CIPP is designed to support hydraulic, soil, and live loads. The groundwater level, soil type and depth, and live load should be determined by the purchaser, and the following equation should be used to calculate the CIPP thickness required to withstand these loads without collapsing:

$$q_t = \frac{1}{N}\left[32\,R_w\,B'\,E'_s \cdot C\,(E_L I/D^3)\right]^{1/2} \quad (X1.3)$$

TABLE X1.1 Maximum Groundwater Loads for Partially Deteriorated Gravity Pipe Condition

Diameter, in. (Inside Diameter of Original Pipe)	Nominal CIPP Thickness, mm	CIPP Thickness, *t*, in.	Maximum Allowable Groundwater Load[A] (above invert)	
			ft	m
8	6	0.236	40.0	12.2
10	6	0.236	20.1	6.1
12	6	0.236	11.5	3.5
15	9	0.354	20.1	6.1
18	9	0.354	11.5	3.5
18	12	0.472	27.8	8.5
24	12	0.472	11.5	3.5
24	15	0.591	22.8	6.9
30	15	0.591	11.5	3.5
30	18	0.709	20.1	6.1

[A]Assumes K = 7.0, E = 125 000 psi (862 MPa) (50-year strength), ν = 0.30, C = 0.64 (5 % ovality), and N = 2.0

where:

q_t = total external pressure on pipe, psi (MPa),
= $0.433H_w + wHR_w/144 + W_s$, (English Units),
$0.00981H_w + wHR_w/1000 + W_s$, (Metric Units)
R_w = water buoyancy factor (0.67 min) = 1 − 0.33 (H_w/H),
w = soil density, lb.ft^3 (KN/m^3),
W_s = live load, psi (Mpa),
H_w = height of water above top of pipe, ft (m)
H = height of soil above top of pipe, ft (m),
B' = coefficient of elastic support = $1/(1 + 4e^{-0.065H})$ inch-pound units, $(1/(1 + 4e^{-0.213H})$ SI units
I = moment of inertia of CIPP, in.^{4}/in. (mm^4/mm) = $t^3/12$,
t = thickness of CIPP, in. (mm),
C = ovality reduction factor (see X1.2.1),
N = factor of safety,
E'_s = modulus of soil reaction, psi (MPa) (see Note X1.4),
E_L = long-term modulus of elasticity for CIPP, psi (MPa), and
D = mean inside diameter of original pipe, in. (mm)

X1.2.2.1 The CIPP design from Eq X1.3 should have a minimum thickness as calculated by the following formula:

$$\frac{EI}{D^3} = \frac{E}{12(DR)^3} \geq 0.093\ (inch - pound\ units), \quad (X1.4)$$

or

$$\frac{E}{12(DR)^3} \geq 0.00064\ (SI\ units)$$

where:

E = initial modulus of elasticity, psi (MPa)

NOTE X1.3—For pipelines at depth not subject to construction disturbance, or if the pipeline was originally installed using tunneling method, the soil load may be calculated using a tunnel load analysis. Finite element analysis is an alternative design method for noncircular pipes.

NOTE X1.4—For definition of modulus of soil reaction, see Practice D3839.

X1.2.2.2 The minimum CIPP design thickness for a fully deteriorated condition should also meet the requirements of Eq X1.1 and X1.2.

X1.3 *Pressure Pipe*:

X1.3.1 *Partially Deteriorated Pressure Condition*—A CIPP installed in an existing underground pipe is designed to support external hydrostatic loads due to groundwater as well as withstand the internal pressure in spanning across any holes in the original pipe wall. The results of Eq X1.1 are compared to those from Eq X1.6 or Eq X1.7, as directed by Eq X1.5, and the largest of the thicknesses is selected. In an above-ground design condition, the CIPP is designed to withstand the internal pressure only by using Eq X1.5-X1.7 as applicable.

X1.3.1.1 If the ratio of the hole in the original pipe wall to the pipe diameter does not exceed the quantity shown in Eq X1.5, then the CIPP is assumed to be a circular flat plate fixed at the edge and subjected to transverse pressure only. In this case, Eq X1.6 is used for design. For holes larger than the d/D

value in Eq X1.5, the liner cannot be considered in flat plate loading, but rather in ring tension or hoop stress, and Eq X1.7 is used.

$$\frac{d}{D} \# 1.83\left(\frac{t}{D}\right)^{1/2} \quad \text{(X1.5)}$$

where:

d = diameter of hole or opening in original pipe wall, in. (mm),
D = mean inside diameter of original pipe, in. (mm), and
t = thickness of CIPP, in. (mm).

$$P = \frac{5.33}{(DR-1)^2}\left(\frac{D}{d}\right)^2 \frac{\sigma_L}{N} \quad \text{(X1.6)}$$

where:

DR = dimension ratio of CIPP,
D = mean inside diameter of original pipe, in. (mm),
d = diameter of hole or opening in original pipe wall, in. (mm),
σ_L = long-term (time corrected) flexural strength for CIPP, psi (MPa) (see Note X1.5), and
N = factor of safety.

NOTE X1.5—The choice of value (from manufacturer's literature) of σ_L will depend on the estimated duration of the application of the load, P, in relation to the design life of the structure. For example, if the total duration of the load, P, is estimated to be 50 years, either continuously applied, or the sum of intermittent periods of loading, the appropriately conservative choice of value of σ_L will be that given for 50 years of continuous loading at the maximum ground or fluid temperature expected to be reached over the life of the structure.

X1.3.2 *Fully Deteriorated Pressure Pipe Condition*—A CIPP to be installed in an underground condition is designed to withstand all external loads and the full internal pressure. The design thicknesses are calculated from Eq X1.1, Eq X1.3, Eq X1.4, and Eq X1.7, and the largest thickness is selected. If the pipe is above ground, the CIPP is designed to withstand internal pressure only by using Eq X1.7.

$$P = \frac{2\sigma_{TL}}{(DR-2)\,N} \quad \text{(X1.7)}$$

where:

P = internal pressure, psi (MPa),
σ_{TL} = long-term (time corrected) tensile strength for CIPP, psi (MPa) (see Note 12),
DR = dimension ratio of CIPP, and
N = factor of safety.

NOTE X1.6—The choice of value (from manufacturer's literature) of σ_{TL} will depend on the estimated duration of the application of the load, P, in relation to the design life of the structure. For example, if the total duration of the load, P, is estimated to be 50 years, either continuously applied, or the sum of intermittent periods of loading, the appropriately conservative choice of value of σ_{TL} will be that given for 50 years of continuous loading at the maximum ground or fluid temperature expected to be reached over the life of the structure.

X1.4 *Negative Pressure*—Where the pipe is subject to a vacuum, the CIPP should be designed as a gravity pipe with the external hydrostatic pressure increased by an amount equal to the negative pressure.

NOTE X1.7—Table X1.1 presents maximum groundwater loads for partially deteriorated pipes for selected typical nominal pipe sizes. CIPP is custom made to fit the original pipe and can be fabricated to a variety of sizes from 4 to 96-in. diameter which would be impractical to list here.

X2. CHEMICAL-RESISTANCE TESTS

X2.1 *Scope*:

X2.1.1 This appendix covers the test procedures for chemical-resistance properties of CIPP. Minimum standards are presented for standard domestic sewer applications.

X2.2 *Procedure for Chemical-Resistance Testing*:

X2.2.1 Chemical resistance tests should be completed in accordance with Practices D543. Exposure should be for a minimum of one month at 73.4°F (23°C). During this period, the CIPP test specimens should lose no more than 20 % of their initial flexural strength and flexural modulus when tested in accordance with Section 8 of this practice.

X2.2.2 Table X2.1 presents a list of chemical solutions that serve as a recommended minimum requirement for the chemical-resistant properties of CIPP in standard domestic sanitary sewer applications.

X2.2.3 For applications other than standard domestic sewage, it is recommended that chemical-resistance tests be conducted with actual samples of the fluid flowing in the pipe. These tests can also be accomplished by depositing CIPP test specimens in the active pipe.

TABLE X2.1 Minimum Chemical Resistance Requirements for Domestic Sanitary Sewer Applications

Chemical Solution	Concentration, %
Tap water (pH 6–9)	100
Nitric acid	5
Phosphoric acid	10
Sulfuric acid	10
Gasoline	100
Vegetable oil	100
Detergent	0.1
Soap	0.1

SUMMARY OF CHANGES

Committee F17 has identified the location of selected changes to this standard since the last issue (F1216–08) that may impact the use of this standard. (Approved March 1, 2009.)

(1) 8.1, 8.1.1 and 8.1.2 were revised.

Committee F17 has identified the location of selected changes to this standard since the last issue (F1217–07b) that may impact the use of this standard.

(1) Added Practices D3567, E797, and Specification D5813 to Section 2, Reference Documents.
(2) Added 8.6 and 8.6.1 to include an alternative method of wall thickness measurement by Ultrasonic Methods.
(3) Renumbered Inspection and Acceptance from 8.6 to 8.7.

AASHTO Submission
Product Evaluation Application

ASTM Standards for Material Performance

- ASTM Standard D638-14 for Tensile Properties

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

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

[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

[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.

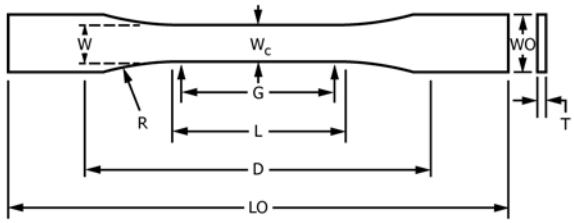
6.1.4 *Preparation*—Methods of preparing test specimens include injection molding, machining operations, or die cutting, from materials in sheet, plate, slab, or similar form. Materials thicker than 14 mm (0.55 in.) shall be machined to 14 mm (0.55 in.) for use as Type III specimens.

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.

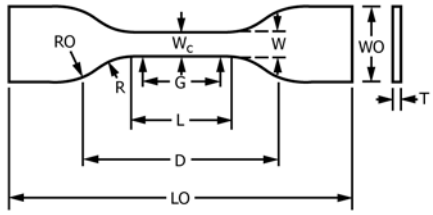
NOTE 8—When preparing specimens from certain composite laminates such as woven roving, or glass cloth, exercise care in cutting the specimens parallel to the reinforcement. The reinforcement will be significantly weakened by cutting on a bias, resulting in lower laminate properties, unless testing of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



TYPES I, II, III & V



TYPE IV

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.

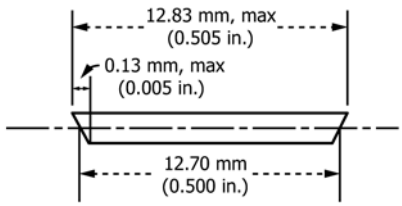
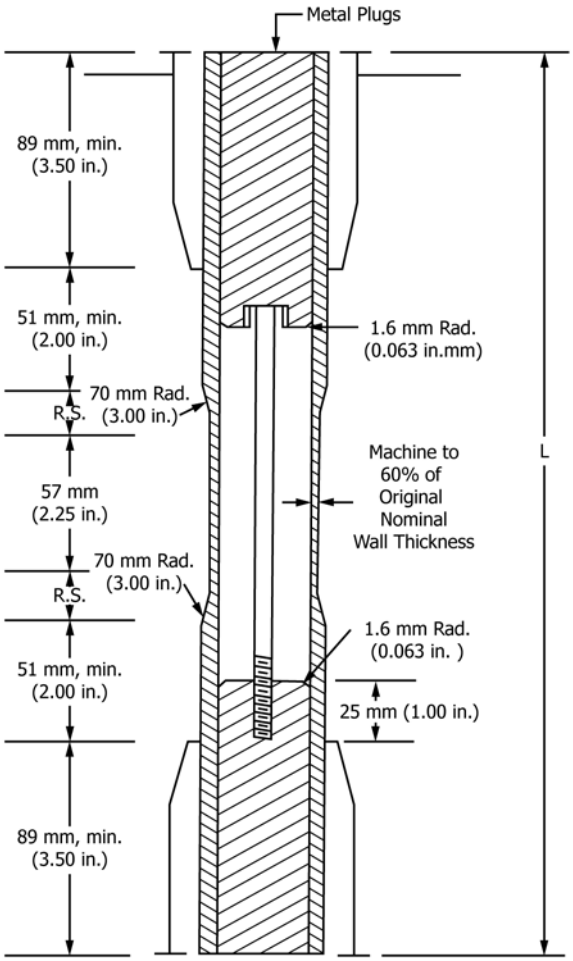


FIG. 1 Tension Test Specimens for Sheet, Plate, and Molded Plastics



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.

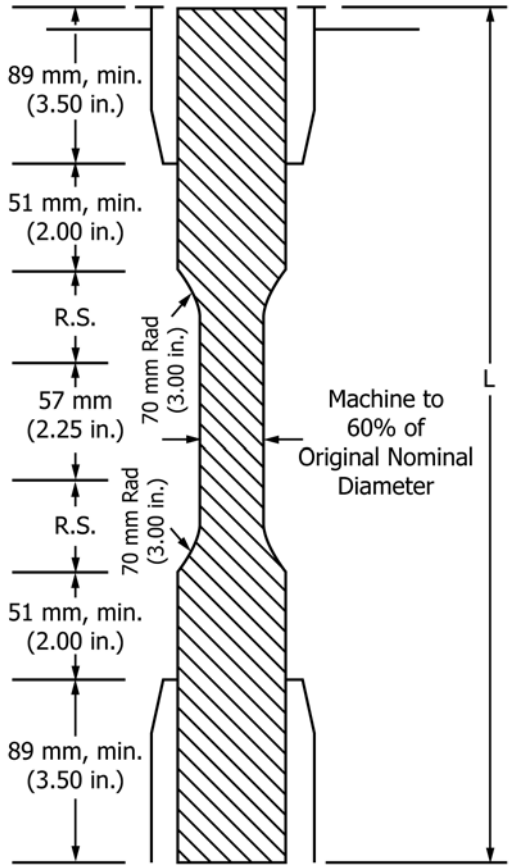
7.2 For anisotropic materials, when applicable, test five specimens, normal to, and five parallel with, the principle axis of anisotropy.

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 (1⁄16)	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

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

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.

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:

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

where:

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

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.

[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 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

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

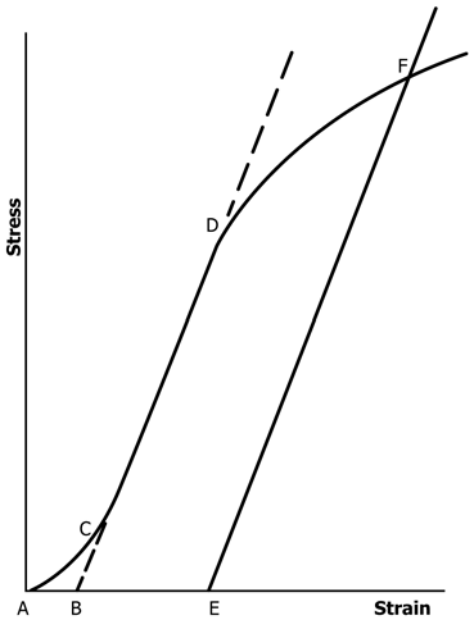
(Mandatory Information)

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.

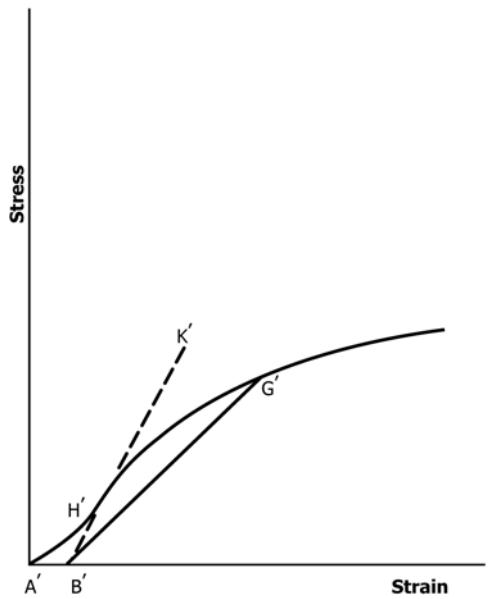
A1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. A1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured, 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).

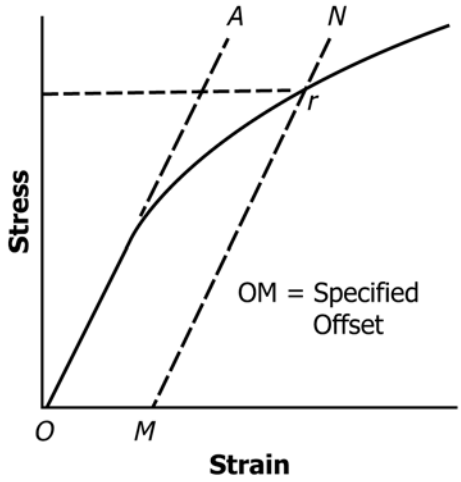


FIG. A2.1 Offset Yield Strength

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.*)

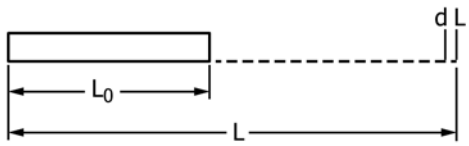


FIG. A2.2 Illustration of True Strain Equation

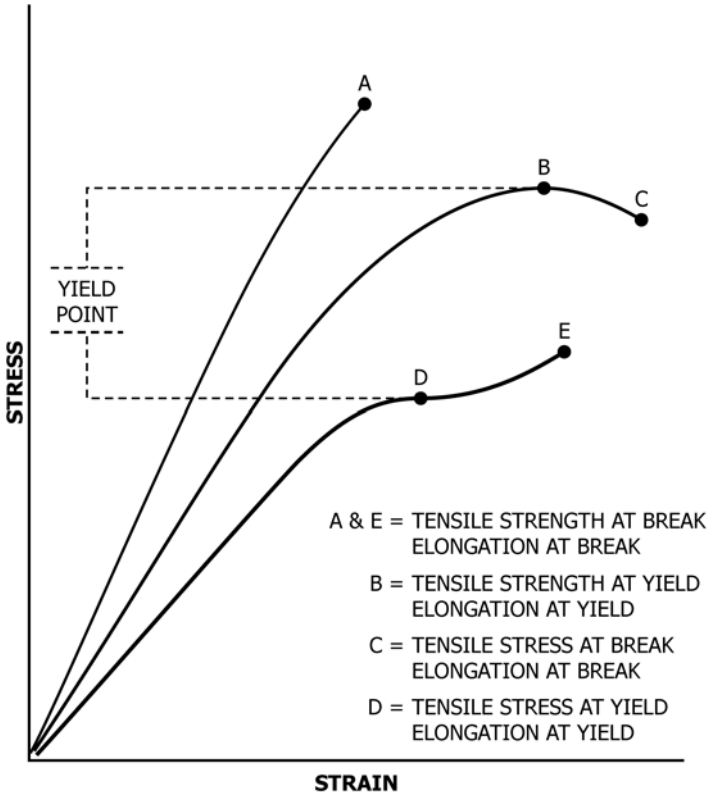


FIG. A2.3 Tensile Designations

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)
$\varepsilon = \Delta L/L_o = (L - L_o)/L_o$
$\varepsilon_U = (L_u - L_o)/L_o$
$\varepsilon_T = \int_{L_o}^{L} dL/L = lnL/L_o$
%*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:

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

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

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

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_a, indicated by the axial extensometer, and the transverse strain, ε_t, indicated by the transverse extensometers, are plotted against the applied load, *P*, as shown in Fig. 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, $|\mu|$, is then calculated as follows:

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

where:

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

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

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

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

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

A3.11. Report

A3.11.1 Report the following information:

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

A3.11.1.2 Method of preparing test specimens,

A3.11.1.3 Type of test specimen and dimensions,

A3.11.1.4 Conditioning procedure used,

A3.11.1.5 Atmospheric conditions in test room,

A3.11.1.6 Number of specimens tested,

A3.11.1.7 Speed of testing,

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

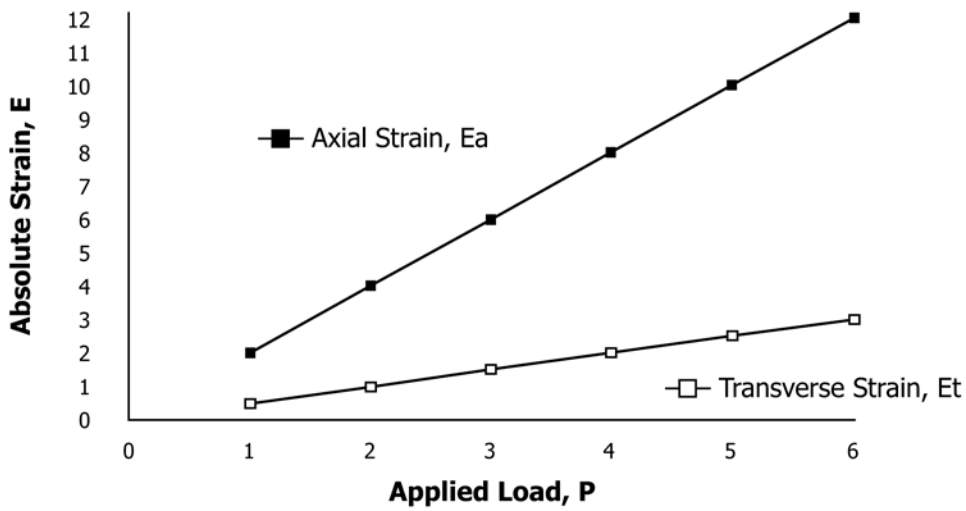


FIG. A3.1 Plot of Strains Versus Load for Determination of Poisson's Ratio

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

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.

AASHTO Submission
Product Evaluation Application

ASTM Standards for Material Performance

- ASTM Standard D695 -15 for Compressive Strength

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

Designation: D695 – 15

Standard Test Method for Compressive Properties of Rigid Plastics[1]

This standard is issued under the fixed designation D695; 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 mechanical properties of unreinforced and reinforced rigid plastics, including high-modulus composites, when loaded in compression at relatively low uniform rates of straining or loading. Test specimens of standard shape are employed. This procedure is applicable for a composite modulus up to and including 41,370 MPa (6,000,000 psi).

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

NOTE 1—For compressive properties of resin-matrix composites reinforced with oriented continuous, discontinuous, or cross-ply reinforcements, tests may be made in accordance with Test Method D3410/D3410M or D6641/D6641M.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* A specific precautionary statement is given in 13.1.

NOTE 2—This standard is equivalent to ISO 604.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing

D638 Test Method for Tensile Properties of Plastics

D883 Terminology Relating to Plastics

D3410/D3410M Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading

D4000 Classification System for Specifying Plastic Materials

D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

D6641/D6641M Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture

E4 Practices for Force Verification of Testing Machines

E83 Practice for Verification and Classification of Extensometer Systems

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

2.2 *ISO Standard:*[3]

ISO 604 Plastics—Determination of Compressive Properties

3. Terminology

3.1 *General*—The definitions of plastics used in this test method are in accordance with Terminology D883 unless otherwise indicated.

3.2 *Definitions:*

3.2.1 *compressive deformation*—the decrease in length produced in the gage length of the test specimen by a compressive load. It is expressed in units of length.

3.2.2 *compressive strain*—the ratio of compressive deformation to the gage length of the test specimen, that is, the change in length per unit of original length along the longitudinal axis. It is expressed as a dimensionless ratio.

3.2.3 *compressive strength*—the maximum compressive stress (nominal) carried by a test specimen during a compression test. It may or may not be the compressive stress (nominal) carried by the specimen at the moment of rupture.

3.2.4 *compressive strength at failure (nominal)*—the compressive stress (nominal) sustained at the moment of failure of the test specimen if shattering occurs.

3.2.5 *compressive stress (nominal)*—the compressive 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.

3.2.5.1 *Discussion*—The expression of compressive properties in terms of the minimum original cross section is almost

[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 Sept. 1, 2015. Published September 2015. Originally approved in 1942. Last previous edition approved in 2010 as D695 - 10. DOI: 10.1520/D0695-15.

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

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

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

universally used. Under some circumstances the compressive properties have been expressed per unit of prevailing cross section. These properties are called "true" compressive properties.

3.2.6 *compressive stress-strain diagram*—a diagram in which values of compressive stress are plotted as ordinates against corresponding values of compressive strain as abscissas.

3.2.7 *compressive yield point*—the first point on the stress-strain diagram at which an increase in strain occurs without an increase in stress.

3.2.8 *compressive yield strength*—normally the stress at the yield point (see also section 3.2.11).

3.2.9 *crushing load*—the maximum compressive force applied to the specimen, under the conditions of testing, that produces a designated degree of failure.

3.2.10 *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 based on the average initial cross-sectional area.

3.2.11 *offset compressive yield strength*—the stress at which the stress-strain curve departs from linearity by a specified percent of deformation (offset).

3.2.12 *percent compressive strain*—the compressive deformation of a test specimen expressed as a percent of the original gage length.

3.2.13 *proportional limit*—the greatest stress that 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.

3.2.14 *slenderness ratio*—the ratio of the length of a column of uniform cross section to its least radius of gyration. For specimens of uniform rectangular cross section, the radius of gyration is 0.289 times the smaller cross-sectional dimension. For specimens of uniform circular cross section, the radius of gyration is 0.250 times the diameter. For specimens of tubular cross section, the radius of gyration is calculated as follows:

$$R_g = \frac{\sqrt{D^2 + d^2}}{4} \quad (1)$$

where:

R_g = radius of gyration,
D = outside diameter, and
d = inside diameter.

4. Significance and Use

4.1 Compression tests provide information about the compressive properties of plastics when employed under conditions approximating those under which the tests are made.

4.2 Compressive properties include modulus of elasticity, yield stress, deformation beyond yield point, and compressive strength (unless the material merely flattens but does not fracture). Materials possessing a low order of ductility may not exhibit a yield point. In the case of a material that fails in compression by a shattering fracture, the compressive strength has a very definite value. In the case of a material that does not fail in compression by a shattering fracture, the compressive strength is an arbitrary one depending upon the degree of distortion that is regarded as indicating complete failure of the material. Many plastic materials will continue to deform in compression until a flat disk is produced, the compressive stress (nominal) rising steadily in the process, without any well-defined fracture occurring. Compressive strength can have no real meaning in such cases.

4.3 Compression tests provide a standard method of obtaining data for research and development, quality control, acceptance or rejection under specifications, and special purposes. The tests cannot be considered significant for engineering design in applications differing widely from the load-time scale of the standard test. Such applications require additional tests such as impact, creep, and fatigue.

4.4 Before proceeding with this test method, reference should be made to the ASTM specification for the material being tested. Any test specimen preparation, conditioning, dimensions, and testing parameters covered in the materials specification shall take precedence over those mentioned in this test method. If there is no material specification, then the default conditions apply. Table 1 in Classification D4000 lists the ASTM materials standards that currently exist.

5. Apparatus

5.1 *Testing Machine*—Any suitable testing machine capable of control of constant-rate-of-crosshead movement and comprising essentially the following:

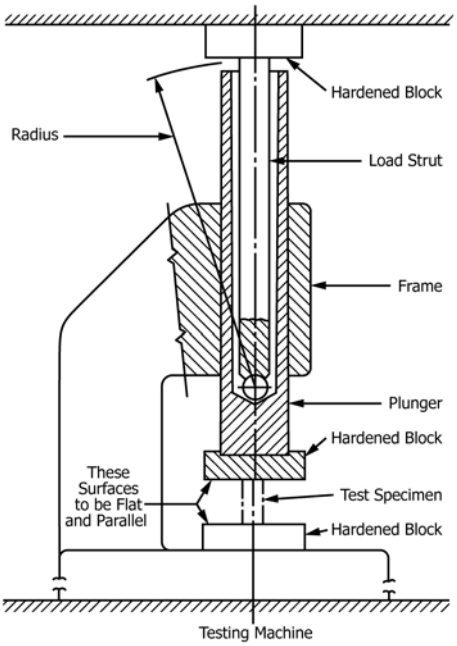
5.1.1 *Drive Mechanism*—A drive mechanism for imparting to the movable cross-head member, a uniform, controlled velocity with respect to the base (fixed member), with this velocity to be regulated as specified in Section 9.

5.1.2 *Load Indicator*—A load-indicating mechanism capable of showing the total compressive load carried by the test specimen. The mechanism shall be essentially free from inertia-lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the maximum indicated value of the test (load). The accuracy of the testing machine shall be verified at least once a year in accordance with Practices E4.

5.2 *Compressometer*—A suitable instrument for determining the distance between two fixed points on the test specimen at any time during the test. It is desirable that this instrument automatically record this distance (or any change in it) as a function of the load on the test specimen. The instrument shall be essentially free of inertia-lag at the specified rate of loading and shall conform to the requirements for a Class B-2 extensometer as defined in Practice E83.

NOTE 3—The requirements for extensometers cited herein apply to compressometers as well.

5.3 *Compression Tool*—A compression tool for applying the load to the test specimen. This tool shall be so constructed that loading is axial within 1:1000 and applied through surfaces that are flat within 0.025 mm (0.001 in.) and parallel to each other in a plane normal to the vertical loading axis. Examples of suitable compression tools are shown in Fig. 1 and Fig. 2.



NOTE 1—Devices similar to the one illustrated have been successfully used in a number of different laboratories. Details of the device developed at the National Institute for Standards and Technology are given in the paper by Aitchinson, C. S., and Miller, J. A., "A Subpress for Compressive Tests," National Advisory Committee for Aeronautics, Technical Note No. 912, 1943.

FIG. 1 Subpress for Compression Tests

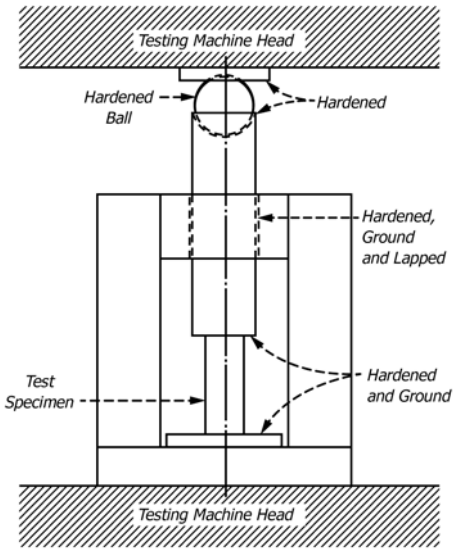


FIG. 2 Compression Tool

5.4 *Supporting Jig*—A supporting jig for thin specimens is shown in Fig. 3 and Fig. 4.

5.5 *Micrometers*—Suitable micrometers, reading to 0.01 mm or 0.001 in. for measuring the width, thickness, diameter, and length of the specimens.

6. Test Specimens

6.1 Unless otherwise specified in the materials specifications, the specimens described in 6.2 through 6.8 shall be used. These specimens may be prepared by machining operations from materials in sheet, plate, rod, tube, or similar form, or they may be prepared by compression or injection molding of the material to be tested. All machining operations shall be done carefully so that smooth surfaces result. Great care shall be taken in machining the ends so that smooth, flat parallel surfaces and sharp, clean edges, to within 0.025 mm (0.001 in.) perpendicular to the long axis of the specimen, result.

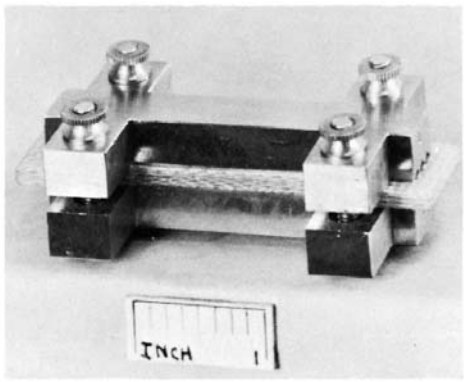


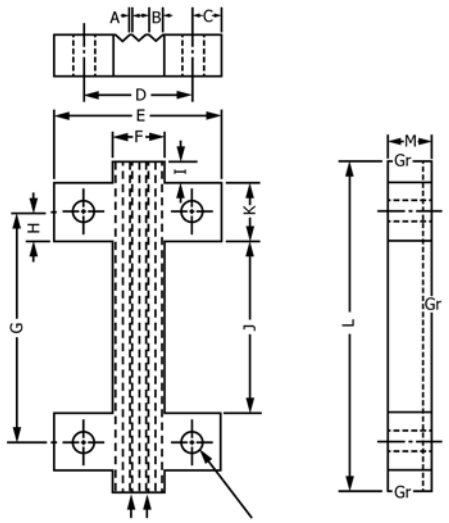
FIG. 3 Support Jig for Thin Specimen

6.2 The standard test specimen for strength measurements, except as indicated in 6.3 – 6.8, shall be in the form of a right cylinder or prism whose length is twice its principal width or diameter. Preferred specimen sizes are 12.7 by 12.7 by 25.4 mm (0.50 by 0.50 by 1 in.) (prism), or 12.7 mm in diameter by 25.4 mm (cylinder). The standard test specimen for modulus or offset yield measurements shall be of such dimensions that the slenderness ratio is in the range from 11 to 16:1. In this case, preferred specimen sizes are 12.7 by 12.7 by 50.8 mm (0.50 by 0.50 by 2 in.) (prism), or 12.7 mm in diameter by 50.8 mm (cylinder).

6.2.1 When the standard specimens (right cylinders or prisms) cannot be obtained due to the thinness of the material (typically less than 6.4 mm (0.25 in.)), alternative specimens outlined in 6.7.1 and 6.7.2 shall be used.

6.3 For rod, the test specimen for strength measurements shall have a diameter equal to the diameter of the rod and a length twice the diameter of the rod. The test specimen for modulus or offset yield measurements shall have a diameter equal to the diameter of the rod and a length such that slenderness ratio is in the range from 11 to 16:1. If the diameter of the rod is too large to obtain failure due to limitations of the test equipment, specimens outlined in 6.2 shall be machined from the center of the rod.

6.4 For tubes, the test specimen for strength measurements shall have a diameter equal to the diameter of the tube and a length of 25.4 mm (1 in.). This specimen shall be used for tubes with a wall thickness of 1 mm (0.039 in.) or over, to inside diameters of 6.4 mm (0.25 in.) or over, and to outside diameters of 50.8 mm (2.0 in.) or less. If the diameter of the tube is too large to obtain failure due to limitations of the test equipment, specimens outlined in 6.2 shall be machined from the wall of the tube. For crushing-load determinations (at right



LETTER	METRIC SYSTEM	BRITISH SYSTEM
A	.40 mm.	.0156 in.
B	3.18	.125
C	6.35	.250
D	23.8	.9375
E	36.5	1.4375
F	11.1	.4375
G	50.8	2.00
H	6.35	.250
I	4.76	.1875
J	38.1	1.500
K	12.7	.500
L	73.0	2.875
M	9.53	.375
N	3.58	.141
O	4.76 d.	.1875 d.

NOTE 1—Cold rolled steel.
NOTE 2—Furnished four steel machine screws and nuts, round head, slotted, length 31.75 mm (1¼ in.).
NOTE 3—Grind surfaces denoted "Gr."

FIG. 4 Support Jig, Details

angles to the longitudinal axis), the specimen size shall be the same, with the diameter becoming the height. The test specimen for modulus or offset yield measurements shall have a diameter equal to the diameter of the tube and a length such that the slenderness ratio is in the range from 11 to 16:1.

6.5 Where it is desired to test conventional high-pressure laminates in the form of sheets, the thickness of which is less than 25.4 mm (1 in.), a pile-up of sheets 12.7 mm square, with a sufficient number of layers to produce a height of approximately 25.4 mm (actual height achievable will be dependent upon individual layer thickness), shall be used for strength measurements. The test specimen for modulus or offset yield measurements shall consist of a pile-up of 12.7 mm square sheets to produce a height such that slenderness ratio is in the range from 11 to 16:1.

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

6.7 *Reinforced Plastics, including High-Strength Composites and Highly Orthotropic Laminates*—The following specimens shall be used for reinforced materials.

6.7.1 For materials 3.2 mm to 6.4 mm (0.125 in. to 0.25 in.), the specimen used for strength measurements shall consist of a prism having a cross section of 12.7 mm (0.5 in.) by the thickness of the material and a length of 12.7 mm (0.5 in). (Specimen length may be shortened if buckling is observed). For material greater than 6.4 mm (0.25 in.) in thickness, specimens outlined in 6.2 shall be used. The test specimen for modulus or offset yield measurements shall be of such dimensions that slenderness ratio is in the range from 11 to 16:1 (Note 4).

6.7.2 For materials under 3.2 mm (0.125 in.) thick, or where elastic modulus testing is required and the slenderness ratio does not provide for enough length for attachment of a compressometer or similar device, a specimen conforming to that shown in Fig. 5 shall be used. The supporting jig shown in Fig. 3 and Fig. 4 shall be used to support the specimen during testing (Note 5).

NOTE 4—If failure for specimens utilized in 6.7.1 is by delamination rather than by the desirable shear plane fracture, the material may be tested in accordance with 6.7.2.

NOTE 5—Round-robin tests have established that relatively satisfactory measurements of modulus of elasticity may be obtained by applying a compressometer to the edges of the jig-supported specimen.

6.8 When testing syntactic foam, the standard test specimen shall be in the form of a right cylinder 25.4 mm (1 in.) in diameter by 50.8 mm (2 in.) in length. This specimen is appropriate for both strength and modulus determinations.

7. Conditioning

7.1 *Conditioning*—Condition the test specimens in accordance with Procedure A of Practice D618 unless otherwise specified by contract or 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.

7.2 *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.

8. Number of Test Specimens

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

8.2 Ten specimens, five normal to and five parallel with the principal axis of anisotropy, shall be tested for each sample in the case of anisotropic materials.

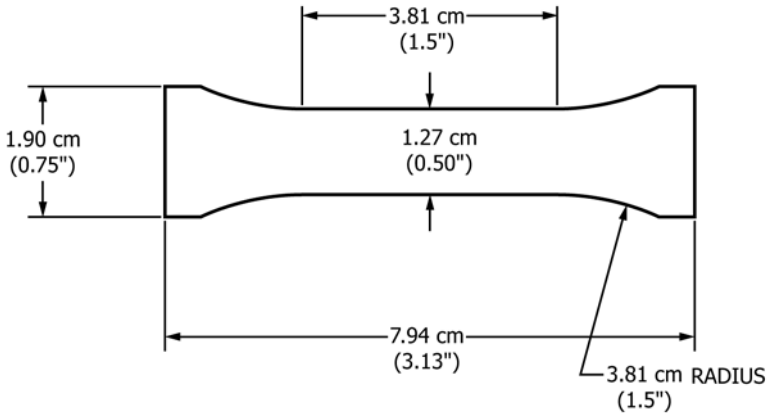


FIG. 5 Compression Test Specimen for Materials Less than 3.2 mm Thick

8.3 Specimens that break at some obvious flaw shall be discarded and retests made, unless such flaws constitute a variable, the effect of which it is desired to study.

9. Speed of Testing

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

9.2 The standard speed of testing shall be 1.3 ± 0.3 mm (0.050 ± 0.010 in.)/min, except as noted in 10.5.4.

10. Procedure

10.1 Measure the width and thickness (or diameter) of the specimen to the nearest 0.025 mm (0.001 in.) at several points along its length. Calculate and record the minimum value of the cross-sectional area. Measure the length of the specimen and record the value.

10.2 Place the test specimen between the surfaces of the compression tool, taking care to align the center line of its long axis with the center line of the plunger and to ensure that the ends of the specimen are parallel with the surface of the compression tool. Adjust the crosshead of the testing machine until it just contacts the top of the compression tool plunger.

NOTE 6—The compression tool may not be necessary for testing of lower modulus (for example, 700 MPa to 3500 MPa (100,000 psi to 500,000 psi)) material if the loading surfaces are maintained smooth, flat, and parallel to the extent that buckling is not incurred.

10.3 Place thin specimens in the jig (Fig. 3 and Fig. 4) so that they are flush with the base and centered (Note 7). The nuts or screws on the jig shall be finger tight (Note 8). Place the assembly in the compression tool as described in 5.3.

NOTE 7—A round-robin test, designed to assess the influence of specimen positioning in the supporting jig (that is, flush versus centered mounting), showed no significant effect on compressive strength due to this variable. However, flush mounting of the specimen with the base of the jig is specified for convenience and ease of mounting.[4]

NOTE 8—A round-robin test on the effect of lateral pressure at the supporting jig has established that reproducible data can be obtained with the tightness of the jig controlled as indicated.

10.4 If only compressive strength or compressive yield strength, or both, are desired, proceed as follows:

10.4.1 Set the speed control at 1.3 mm/min (0.050 in./min) and start the machine.

10.4.2 Record the maximum load carried by the specimen during the test (usually this will be the load at the moment of rupture).

10.5 If stress-strain data are desired, proceed as follows:

10.5.1 Prepare the compressive strain indicator to directly read strain on the specimen.

10.5.2 Set the speed control at 1.3 mm/min (0.050 in./min) and start the machine.

10.5.3 Record loads and corresponding compressive strain at appropriate intervals of strain or, if the test machine is equipped with an automatic recording device, record the complete load-deformation curve.

10.5.4 After the yield point has been reached, it is allowable to increase the speed from 5 to 6 mm/min (0.20 to 0.25 in./min) and allow the machine to run at this speed until the specimen breaks. This may be done only with relatively ductile materials and on a machine with a weighing system with response rapid enough to produce accurate results.

11. Calculation

11.1 *Compressive Strength*—Calculate the compressive strength by dividing the maximum compressive load carried by the specimen during the test by the original minimum cross-sectional area of the specimen. Express the result in megapascals or pounds-force per square inch and report to three significant figures.

11.2 *Compressive Yield Strength*—Calculate the compressive yield strength by dividing the load carried by the specimen at the yield point by the original minimum cross-sectional area of the specimen. Express the result in megapascals or pounds-force per square inch and report to three significant figures.

11.3 *Offset Yield Strength*—Calculate the offset yield strength by the method referred to in 3.2.11.

11.4 *Modulus of Elasticity*—Calculate the modulus of elasticity by drawing a tangent to the initial linear portion of the

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1061.

TABLE 1 Precision, Compressive Strength
(*Values in Units of Megapascals*)

Material	Average	S_r[A]	S_R[B]	r[C]	R[D]
Acetal	100	1.1	2.1	3.1	5.9
Polystyrene	106	1.4	3.5	3.9	9.8
Linen-filled phenolic	158	3.7	7.5	10.4	21.0

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

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

[B] S_R is the between-laboratories reproducibility, expressed as a standard deviation, for the indicated material.
[C] r is the within-laboratory repeatability limit, $r = 2.8 \times S_r$.
[D] R is the between-laboratory reproducibility limit, $R = 2.8 \times S_R$.

TABLE 2 Precision, Compressive Modulus
(*Values in Units of Gigapascals*)

Material	Average	S_r[A]	S_R[B]	r[C]	R[D]
Acetal	3.28	0.14	0.25	0.39	0.70
Polystyrene	3.88	0.07	0.74	0.20	2.07
Linen-filled phenolic	6.82	0.23	0.90	0.64	2.52

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

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

[B] S_R is the between-laboratories reproducibility, expressed as a standard deviation, for the indicated material.
[C] r is the within-laboratory repeatability limit, $r = 2.8 \times S_r$.
[D] R is the between-laboratory reproducibility limit, $R = 2.8 \times S_R$.

load deformation curve, selecting any point on this straight line portion, and dividing the compressive stress represented by this point by the corresponding strain, measure from the point where the extended tangent line intersects the strain-axis. Express the result in gigapascals or pounds-force per square inch and report to three significant figures (see Annex A1).

11.5 For each series of tests, calculate to three significant figures the arithmetic mean of all values obtained and report as the "average value" for the particular property in question.

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

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

where:

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

NOTE 9—The method for determining the offset compressive yield strength is similar to that described in the Annex of Test Method D638.

12. Report

12.1 Report the following information:

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

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimensions,

12.1.4 Conditioning procedure used,

12.1.5 Atmospheric conditions in test room,

12.1.6 Number of specimens tested,

12.1.7 Speed of testing,

12.1.8 Compressive strength, average value, and standard deviation,

12.1.9 Compressive yield strength and offset yield strength average value, and standard deviation, when of interest,

12.1.10 Modulus of elasticity in compression (if required), average value, standard deviation,

12.1.11 Date of test, and

12.1.12 Date of test method.

13. Precision and Bias

13.1 Table 1 and Table 2 are based on a round-robin test conducted in 1987 in accordance with Practice E691, involving three materials tested by six laboratories for Test Method D695M. Since the test parameters overlap within tolerances and the test values are normalized, the same data are used for both test methods. For each material, all of the samples were prepared at one source. Each test result was the average of five individual determinations. Each laboratory obtained two test results for each material. (**Warning—**The following explanations of r and R (13.2 – 13.2.3) are only intended to present a meaningful way of considering the *approximate* precision of this test method. The data in Table 1 and Table 2 should not be rigorously applied to acceptance or rejection of material, as these data apply only to the materials tested in the round robin and are unlikely to be rigorously representative of other lots, formulations, conditions, materials, or laboratories. Users of this test method should apply the principles outlined in Practice E691 to generate data specific to their laboratory and materials or between specific laboratories. The principles of 13.2 – 13.2.3 would then be valid for such data.)

13.2 *Concept of r and R in* Table 1 *and* Table 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 of five specimens for each test result, then:

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

13.2.2 *Reproducibility, R*—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 the two test results for the same material, obtained by different operators using different equipment in different laboratories.

13.2.3 Any judgement in accordance with 13.2.1 and 13.2.2 would have an approximate 95 % (0.95) probability of being correct.

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

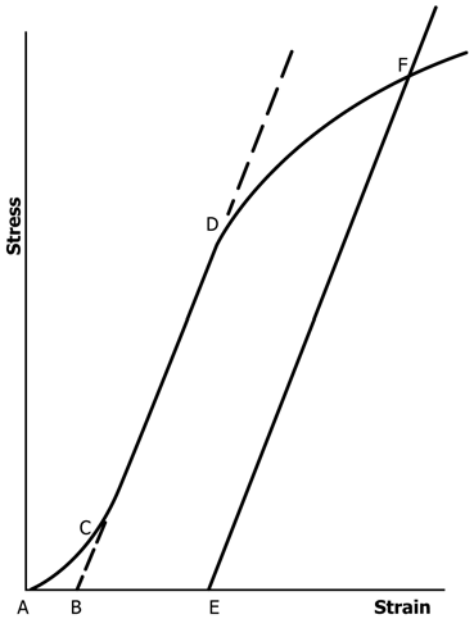
14. Keywords

14.1 compressive properties; compressive strength; modulus of elasticity; plastics

ANNEX

(Mandatory Information)

A1. TOE COMPENSATION

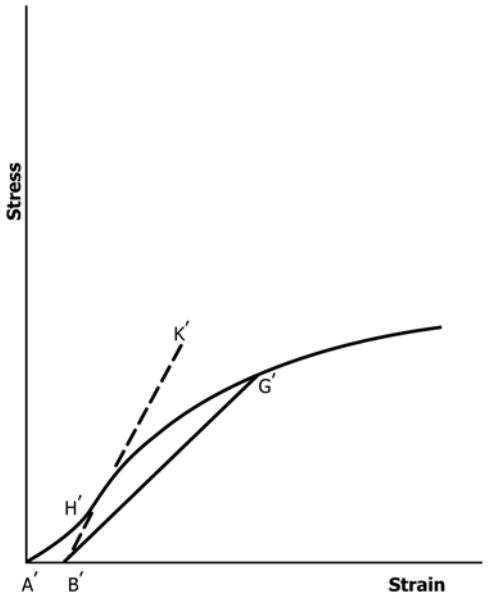


NOTE 1—Some chart recorders plot the mirror image of this graph.

FIG. A1.1 Material with Hookean Region

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).



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

FIG. A1.2 Material with No Hookean Region

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.

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D695 - 10) that may impact the use of this standard. (September 1, 2015)

(1) Added Test Method D6641/D6641M to Note 1 and 2.1.
(2) Subsection 3.2.14—Added calculation for radius of gyration for tubes to determine slenderness ratio.
(3) Subsection 5.5—Added "diameter" to one of the dimensions that can be measured.
(4) Subsection 6.1—Only referred to 6.2 – 6.7. This was updated to include 6.2 – 6.8.
(5) Subsection 6.2—Clarified specimens to be used for strength and modulus, and changed 6.3 - 6.7 to 6.3 - 6.8.
(6) Added subsection 6.2.1.
(7) Added wording to clarify specimen dimension selection for strength and modulus to 6.3, 6.4, 6.5, 6.7, 6.7.1, and 6.8.
(8) Removed Note 4 and placed it in the body of 6.4 as it was not appropriate as a note.
(9) Renumbered subsequent notes since Note 4 was removed.
(10) Subsection 10.1—Added diameter as a dimension that can be measured and corrected the unit conversion from mm to inch.
(11) Subsection 10.5.1—Revised the wording so the interpretation of "attach compressometer" was not misconstrued as only being able to use a contact extensometer. The wording now implies any type of compressometer (contact or noncontact) can be used.
(12) Subsection 10.5.4—Revised the wording "may be desirable" to "is allowable."
(13) Subsection 11.6—The standard deviation calculation referenced number "(1)"; this was changed to "(2)" since the Radius of Gyration calculation for tubes is now "(1)."

AASHTO Submission
Product Evaluation Application

ASTM Standards for Material Performance

- ASTM Standard D790 - 10 for Flexural Modulus

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

Designation: D790 – 10

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

This standard is issued under the fixed designation D790; 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 D6272.

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:*[2]

D618 Practice for Conditioning Plastics for Testing

D638 Test Method for Tensile Properties of Plastics

D883 Terminology Relating to Plastics

D4000 Classification System for Specifying Plastic Materials

D4101 Specification for Polypropylene Injection and Extrusion Materials

D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

D6272 Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending

E4 Practices for Force Verification of Testing Machines

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

2.2 *ISO Standard:*[3]

ISO 178 Plastics—Determination of Flexural Properties

3. Terminology

3.1 *Definitions*—Definitions of terms applying to these test methods appear in Terminology D883 and Annex A1 of Test Method D638.

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. A support span-to-depth ratio of 16:1 shall be used unless there is reason to suspect that a larger span-to-depth

[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.

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

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

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

ratio may be required, as may be the case for certain laminated materials (see Section 7 and Note 7 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).

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 7).

5.4 Before proceeding with these test methods, reference should be made to the ASTM specification of the material being tested. Any test specimen preparation, conditioning, dimensions, or testing parameters, or combination thereof, covered in the ASTM material specification shall take precedence over those mentioned in these test methods. Table 1 in Classification System D4000 lists the ASTM material specifications 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 E4.

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. The default radii of the loading nose and supports shall be 5.0 ± 0.1 mm (0.197 ± 0.004 in.) unless otherwise specified in an ASTM material specification or as agreed upon between the interested parties. When the use of an ASTM material specification, or an agreed upon modification, results in a change to the radii of the loading nose and supports, the results shall be clearly identified as being obtained from a modified version of this test method and shall include the specification (when available) from which the modification was specified, for example, Test Method D790 in accordance with Specification D4101.

6.2.1 *Other Radii for Loading Noses and Supports*—When other than default loading noses and supports are used, in order to avoid excessive indentation, or failure due to stress concentration directly under the loading nose, they must comply with the following requirements: they shall have a minimum radius of 3.2 mm (⅛ in.) for all specimens. 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. The maximum radius of the loading nose shall be no more than four times the specimen depth.

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 D5947.

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 D5947.

NOTE 2—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 3 and 4). 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 (⅛ in.) in depth. Specimens 3.2 mm or less in depth shall be 12.7 mm (½ 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 (¼ in.) on each end. Overhang shall be sufficient to prevent the specimen from slipping through the supports.

NOTE 3—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 4—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 (½ in.) wide, tested flatwise on a 25.4-mm (1-in.) support span.

NOTE 5—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 6—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 5).

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 (½ 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 7). 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 ½ by ⅛ 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 7). 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 7—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 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 *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 D5947.

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:

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

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 8 and 9). The deflection at which this strain will occur may be calculated by letting r equal 0.05 mm/mm (in./in.) in Eq 2:

$$D = rL^2/6d \quad (2)$$

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 8—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 9—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 D638 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 9).

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 10-12):

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

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 10—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 11—When testing highly orthotropic laminates, the maximum stress may not always occur in the outer surface of the test specimen.[4] 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 12—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 13):

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

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 13—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.

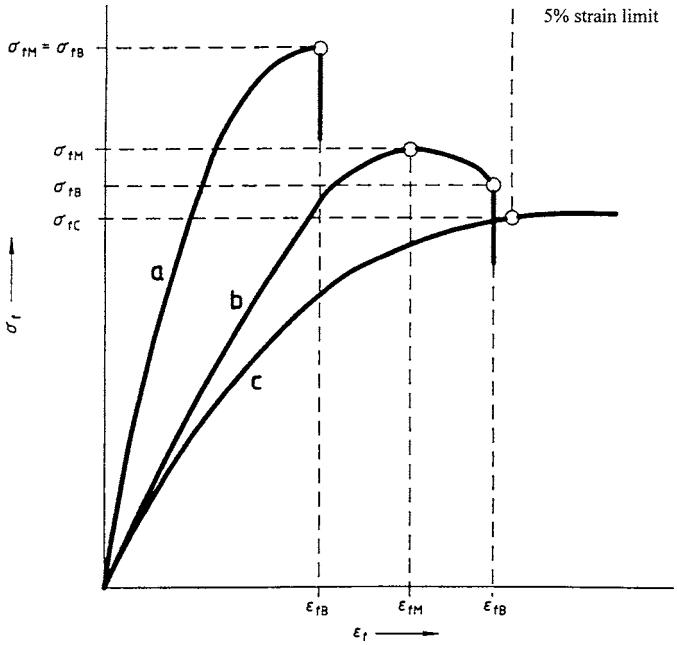
12.4 *Flexural Strength (σ_{fM})*—Maximum flexural stress sustained by the test specimen (see Note 11) during a bending test. It is calculated according to Eq 3 or Eq 4. Some materials that do not break at strains of up to 5 % may give a load deflection curve that shows a point at which the load does not increase with an increase in strain, that is, a yield point (Fig. 1, 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 14—This value may differ from flexural strength defined in 12.4. Both methods of calculation are described in the annex to Test Method D638.

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. 1, 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. 1, 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 11).



NOTE 1—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. 1 Typical Curves of Flexural Stress (s_f) Versus Flexural Strain (ε_f)

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:

$$\varepsilon_f = 6Dd/L^2 \quad (5)$$

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
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 15).

$$E_B = L^3m/4bd^3 \quad (6)$$

where:

E_B = modulus of elasticity in bending, MPa (psi),

[4] 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.

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 15—Shear deflections can seriously reduce the apparent modulus of highly anisotropic composites when they are tested at low span-to-depth ratios.[4] 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.

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:

$$E_f = (\sigma_{f2} - \sigma_{f1})/(\varepsilon_{f2} - \varepsilon_{f1}) \quad (7)$$

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

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.

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:

$$s = \sqrt{\left(\sum X^2 - n\bar{X}^2\right)/(n-1)} \quad (8)$$

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. When support and/or loading nose radii other than 5 mm are used, the results shall be identified as being generated by a modified version of this test method and the referring specification referenced as to the geometry used.

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

14.1 Tables 1 and 2 are based on a round-robin test conducted in 1984, in accordance with Practice E691, 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 16—**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 E691 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

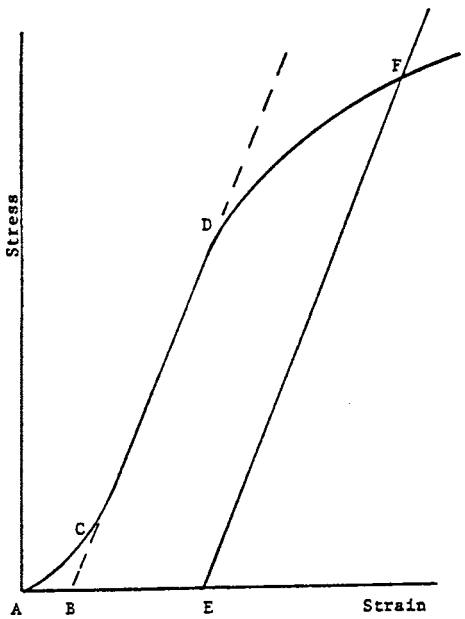
15.1 flexural properties; plastics; stiffness; strength

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.

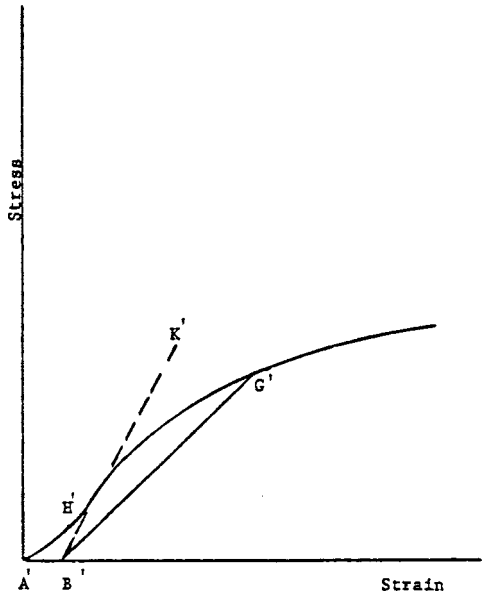


NOTE 1—Some chart recorders plot the mirror image of this graph.

FIG. A1.1 Material with Hookean Region

A1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (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 point. Using Point *B′* as zero strain, the stress at any point *(G′)* on the curve can be divided by the strain at that point to obtain a secant modulus (slope of Line *B′ G′).* For those materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.



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

FIG. A1.2 Material with No Hookean Region

A2. 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.

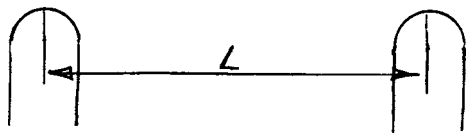


FIG. A2.1 Markings on Fixed Specimen Supports

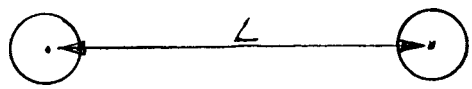


FIG. A2.2 Markings on Rotatable Specimen Supports

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.

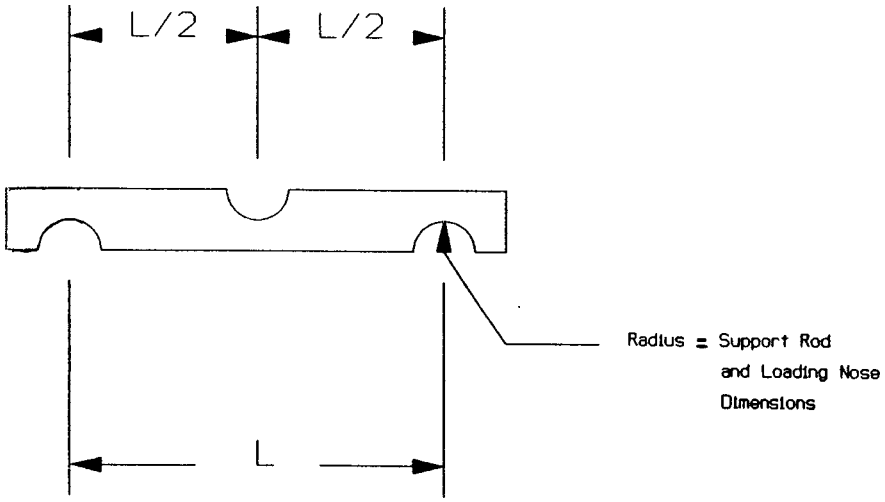


FIG. A2.3 Fixture Used to Set Loading Nose and Support Spacing and Alignment

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.

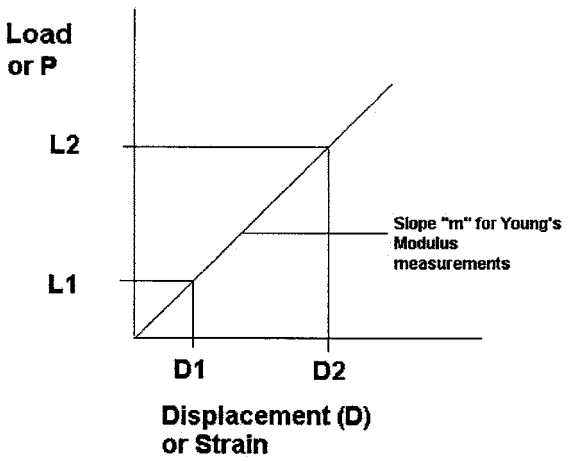


FIG. X1.1 Example of Modulus Curve for a Material

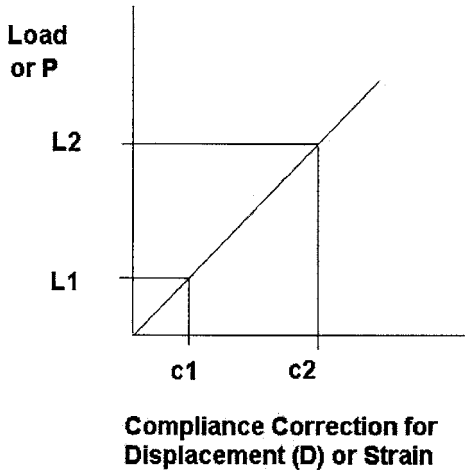


FIG. X1.2 Compliance Curve for Steel Bar

X1.6 Calculations

X1.6.1 Calculation of Chord Modulus

X1.6.1.1 Calculate the stresses (σf1, σf2) for load points L1 and L2 from Fig. X1.1 using the equation in 12.2, Eq 3.

X1.6.1.2 Calculate the strains (εf1, εf2) 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 σf1 = 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.

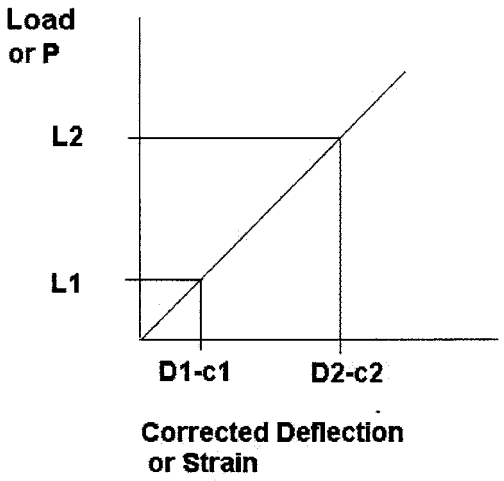


FIG. X1.3 Example of the Material Curve Corrected for the Compliance Corrected Displacement or Strain

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

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue (D790 - 07$^{\varepsilon 1}$) that may impact the use of this standard. (April 1, 2010)

(1) Revised Section 9.

AASHTO Submission
Product Evaluation Application

ASTM Standards for Post-Application Testing

- ASTM Standard D7234-12 for Pull Off Adhesion Strength of Coatings

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

Designation: D7234 – 12

Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers[1]

This standard is issued under the fixed designation D7234; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers procedures for evaluating the pull-off adhesion strength of a coating on concrete. The test determines the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached. Failure will occur along the weakest plane within the system comprised of the test fixture, adhesive, coating system, and substrate, and will be exposed by the fracture surface.

1.2 This test method uses a class of apparatus known as portable pull-off adhesion testers.[2] They are capable of applying a concentric load and counter load to a single surface so that coatings can be tested even though only one side is accessible. Measurements are limited by the strength of adhesion bonds between the loading fixture, coating system and the substrate or the cohesive strengths of the adhesive, coating layers, and substrate.

1.3 Pull-off adhesion strength measurements depend upon both material and instrumental parameters. There are different instruments used that comply with this test method. The specific instrument used should be identified when reporting results. This test is destructive and spot repairs may be necessary.

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

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

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C1583 Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)

D16 Terminology for Paint, Related Coatings, Materials, and Applications

D2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding

D3933 Guide for Preparation of Aluminum Surfaces for Structural Adhesives Bonding (Phosphoric Acid Anodizing)

D4541 Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E178 Practice for Dealing With Outlying Observations

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

3. Terminology

3.1 The terms and definitions in Terminology D16 apply to this test method.

3.2 *Definitions:*

3.2.1 *adhesive, n*—(with respect to this test method) adhesive refers to the material that bonds the bottom of the loading fixture to the top surface of the coating to be tested.

3.2.2 *loading fixture, n*—(also referred to as dollies or studs) a metal structure that is flat on one end for bonding to the coating surface and shaped on the other end for attachment to the adhesion tester and is used to determine the pull-off adhesion strength of coatings.

3.2.3 *portable pull-off adhesion testers, n*—instruments that are capable of applying a concentric load and counter load to

[1] This test method is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.46 on Industrial Protective Coatings.

Current edition approved July 1, 2012. Published October 2012. Originally approved in 2005. Last previous edition approved in 2005 as D7234 – 05. DOI: 10.1520/D7234-12.

[2] The term adhesion tester may be somewhat of a misnomer, but its adoption by two manufacturers and at least two patents indicates continued usage.

[3] 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.

a single surface so that coatings can be tested even though only one side is accessible.

4. Summary of Test Method

4.1 The general pull-off adhesion test is performed by scoring through the coating down to the surface of the concrete substrate at a diameter equal to the diameter of the loading fixture (dolly, stud), and securing the loading fixture normal (perpendicular) to the surface of the coating with an adhesive. After the adhesive is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is then uniformly increased and monitored until a plug of material is detached. When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system. The nature of the failure is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved. The pull-off adhesion strength is computed based on the maximum indicated load, the instrument calibration data, and the surface area stressed. Pull-off adhesion strength results obtained using different devices may be different because the results depend on instrumental parameters.

5. Significance and Use

5.1 The pull-off adhesion strength and mode of failure of a coating from a concrete substrate are important performance properties that are used in specifications. This test method serves as a means for uniformly preparing and testing coated surfaces, and evaluating and reporting the results.

5.2 Variations in strength results obtained using different instruments, different substrates, or different loading fixtures with the same coating are possible. Therefore, it is recommended that the specific test instrument and loading fixture be mutually agreed upon between the interested parties.

5.3 This test method should not be used to determine surface strength of uncoated concrete. Test Method C1583 is suitable for that determination.

6. Apparatus

6.1 *Adhesion Tester,* including the components and accessories described in 6.1.1 – 6.1.5

6.1.1 *Loading Fixtures,* having a flat surface on one end that can be adhered to the coating and a means of attachment to the tester on the other end. The bonding surface may be round, square or rectangular. The round loading fixtures are usually 50 mm (2.0 in) in diameter but may range from 20 mm (0.75 in) to 75 mm (3.0 in) in diameter.

6.1.2 *Detaching Assembly,* having a central grip for engaging the loading fixture.

6.1.3 *Base,* on the detaching assembly, for uniformly pressing against the coating surface around the fixture either directly, or by way of an intermediate bearing ring. A means of aligning the base is needed so that the resultant force is normal to the surface.

6.1.4 *Force Applicator,* means of moving the grip away from the base in as smooth and continuous a manner as possible so that a torsion free, co-axial (opposing pull of the grip and push of the base along the same axis) force results between them.

6.1.5 *Force Indicator and Calibration Information,* for determining the actual force delivered to the loading fixture. The force indicator shall be verified to be within +/-5 % of the force measured by a calibrated testing machine at a frequency determined by the user, typically once a year.

6.2 *Timer,* or means of limiting the rate of stress to less than or equal to 0.2 MPa/s (30 psi/s) so that the maximum stress (failure) is obtained in about 5 to 30 s.

6.3 *Solvent,* or other means for cleaning the loading fixture surface.

6.4 *Fine Sandpaper,* or other means of cleaning or preparing the coating that will not alter its integrity.

6.5 *Adhesive,* for securing the fixture to the coating that does not affect the coating properties. Two-component epoxies and acrylics[4] have been found to be the most versatile.

6.6 *Mechanical Clamps,* if needed, for holding the fixture in place while the adhesive cures.

6.7 *Cotton Swabs,* or other means for removing excess adhesive.

6.8 *Core Bit with Drill Press or Hand Drill,* and means to ensure that the scoring is normal to the coating for the procedures that use a round loading fixture. The core bit inside diameter should equal the diameter of the loading fixture. If a core bit with an inside diameter equal to the diameter of the loading fixture is not available, the closest size available should be used. The core bit or saw blades should be diamond tipped and, when required to minimize heat and suppress dust, supplemented with water lubrication. For the test procedures that use a square or rectangular loading fixture, a circular saw is required instead of a core bit and drill. Alternately, for thin or elastomeric coatings, a sharp knife or hole saw may be sufficient to score around the loading fixture.

7. Test Preparation

7.1 The method for selecting the coating sites to be prepared for testing depends upon the objectives of the test and agreements between the contracting parties. There are, however, a few physical restrictions imposed by the general method and apparatus. The following requirements apply to all sites:

7.1.1 The selected test area must be a flat surface large enough to accommodate the specified number of replicate tests. The surface may have any orientation with reference to gravitational pull. Each test site must be separated by at least the distance needed to accommodate the detaching apparatus. The size of a test site is essentially that of the secured loading

[4] The sole source of supply of the acrylics known to the committee at this time is Versiloc 201 and 204 with accelerator, available from Lord Corp., Industrial Adhesive Div., 2000 W. Grandview Blvd., P.O. Box 10038, Erie, PA 16514. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

fixture. At least three replications are required in order to statistically characterize the test area.

7.1.2 The selected test areas must also have enough perpendicular and radial clearance to accommodate the apparatus, and be flat enough to permit alignment. It should be noted that measurements close to an edge may not be representative of the coating as a whole.

7.2 Scoring the coating down to the surface of the substrate is required for all coatings thicker than 0.5 mm (20 mils) and for all reinforced or elastomeric coatings. While scoring is recommended for coatings thinner than 0.5 mm (20 mils), the test may be performed without scoring, but the results should note this exception. Scoring shall be performed in a manner that ensures the cut is made normal to the coating surface and in a manner that does not twist or torque the test area and minimizes heat generated and edge damage or microcracks to the coating and the concrete substrate. For thick coatings it is recommended to cool the coating and substrate during the cutting process with water lubrication. When using a round loading fixture, scoring is performed before the loading fixture is attached (see Fig. 1). When using square or rectangular loading fixtures, scoring is typically performed after the loading fixture is attached (see Fig. 2).

7.3 Clean the surfaces in a manner that will not affect integrity of the coating or leave a residue. Clean the loading fixture surface as indicated by the apparatus manufacturer. Failures at the fixture-adhesive interface can often be avoided by treating the fixture surfaces in accordance with an appropriate ASTM standard practice for preparing metal surfaces for adhesive bonding. Fingerprints, moisture, and oxides tend to be the primary contaminants.

NOTE 1—Guides D2651 and D3933 are typical of well-proven methods for improving adhesive bond strengths to metal surfaces.

7.4 Prepare the adhesive in accordance with the adhesive manufacturer's recommendations. Apply the adhesive to the fixture or the surface to be tested, or both, using a method recommended by the adhesive manufacturer. Be certain to apply the adhesive across the entire surface. Position fixture on the surface to be tested centered directly over the scored section with the fixture outer sides lined up with the inside circumference of the scored section. Carefully remove the excess adhesive from around the fixture. (**Warning**—Movement, especially twisting, can cause tiny bubbles to coalesce into large holidays that constitute stress discontinuities during testing.)

NOTE 2—Adding about 1 percent of #5 glass beads to the adhesive assists in even alignment of the test fixture to the surface.

7.5 Based on the adhesive manufacturer's recommendations and the anticipated environmental conditions, allow enough time for the adhesive to set up and reach the recommended cure. During the adhesive set and early cure stage, a constant contact pressure should be maintained on the fixture. Mechanical clamping systems work well, but systems relying on tack, such as masking tape, should be used with care to ensure that they do not relax with time and allow air to intrude between the fixture and the test area.

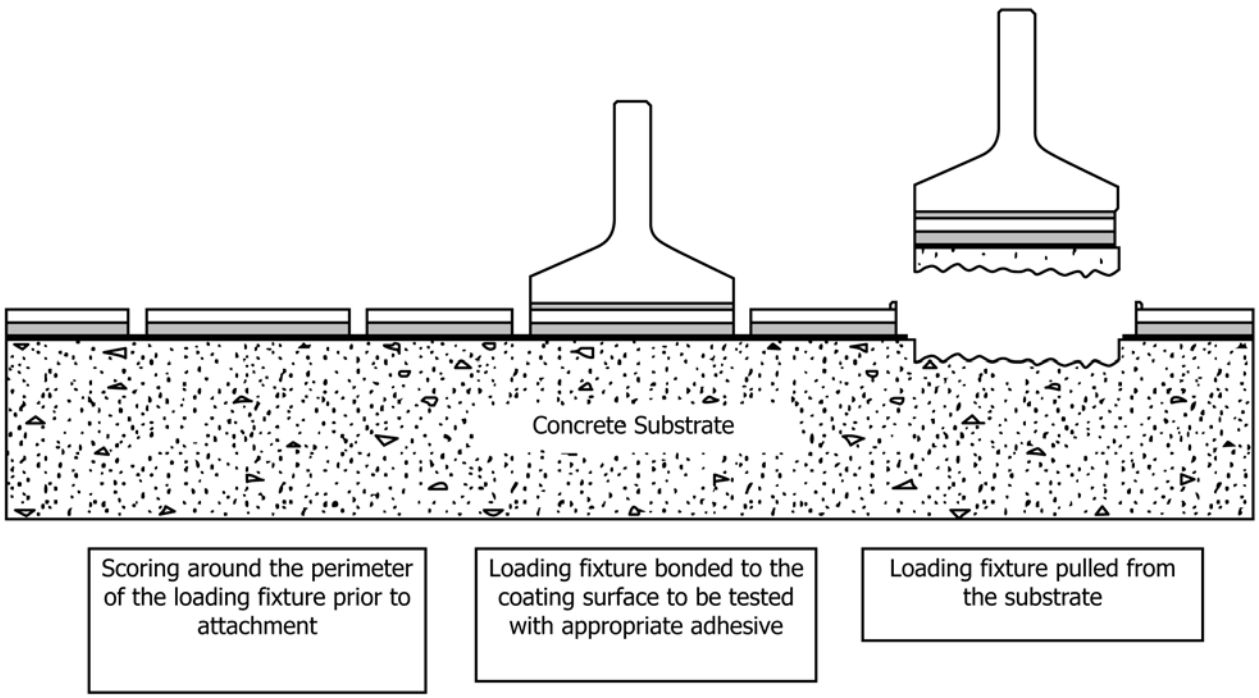


FIG. 1 Scoring Around the Loading Fixture Prior to Attachment of the Fixture (Round Loading Fixtures)

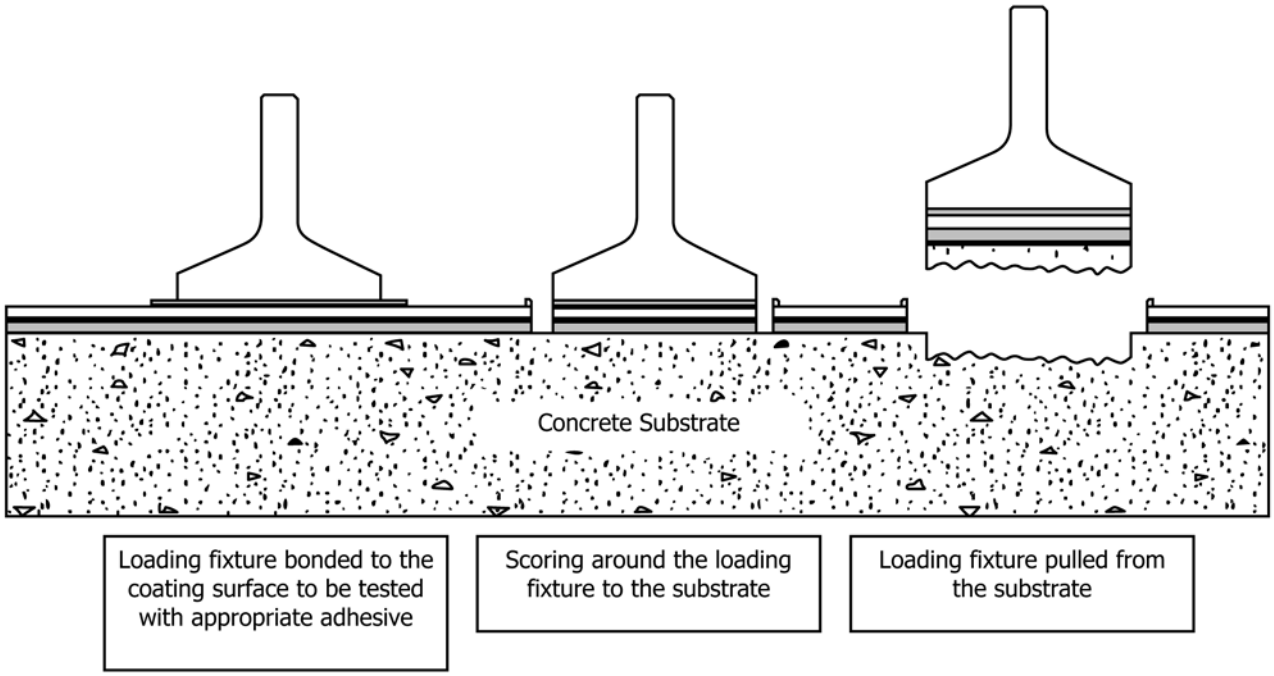


FIG. 2 Scoring Around the Loading Fixture After Attachment of the Fixture (Square or Rectangular Fixtures)

7.6 Note the temperature and relative humidity during the time of test.

8. Test Procedure

8.1 Select an adhesion-tester having a force calibration spanning the range of expected values along with its compatible loading fixture. Mid-range measurements are usually the best, but read the manufacturer's operating instructions before proceeding.

8.2 If a bearing ring or comparable device is to be used, place it concentrically around the loading fixture on the coating surface. If shims are required when a bearing ring is employed, place them between the tester base and bearing ring rather than on the coating surface.

8.3 Carefully connect the central grip of the detaching assembly to the loading fixture without bumping, bending, or otherwise prestressing the sample and connect the detaching assembly to its control mechanism, if necessary. For nonhorizontal surfaces, support the detaching assembly so that its weight does not contribute to the force exerted in the test.

8.4 Align the device according to the manufacturer's instructions and set the force indicator to zero.

NOTE 3—Proper alignment is critical. If alignment is required, use the procedure recommended by the manufacturer of the adhesion tester.

8.5 Increase the load to the fixture in as smooth and continuous a manner as possible, at a uniform rate of less than or equal to 0.2 MPa/s (30 psi/s) so that failure occurs or the maximum stress is reached before 30 s.

8.6 Record the force attained at failure.

8.7 When the plug of material is detached, label and store the fixture for qualification of the failed surface in accordance with 9.3.

8.8 Report any departures from the procedure such as possible misalignment, hesitations in the force application, etc.

9. Calculation and Interpretation of Results

9.1 If provided by the manufacturer, use the instrument calibration factors to convert the indicated force for each test into the actual force applied.

9.2 Either use the calibration chart supplied by the manufacturer or compute the relative stress applied to each coating sample as follows:

$$X = \frac{4F}{\pi d^2} \quad (1)$$

where:

X = pull-off adhesion strength achieved at failure in MPa (psi).
F = Maximum force applied to the test surface at failure and as determined in 9.1 in N(lb_f), and
d = diameter of the loading fixture in mm (in.).

NOTE 4—d should be the inside diameter of the scored sample if this does not equal the diameter of the loading fixture.

9.3 Estimate the percent of adhesive and cohesive failures in accordance to their respective areas and location within the test system comprised of substrate, coating and adhesive layers. A convenient scheme that describes the total test system is outlined in 9.3.1 – 9.3.4.

9.3.1 Describe the specimen as substrate *A, B, C,* upon which successive coating layers *D, E, F*, etc., have been applied, including the adhesive, *Y*, that secures the fixture, *Z*, to the top coat.

9.3.2 Designate cohesive substrate failures by the quantity and type of substrate removed (see Fig. 3).

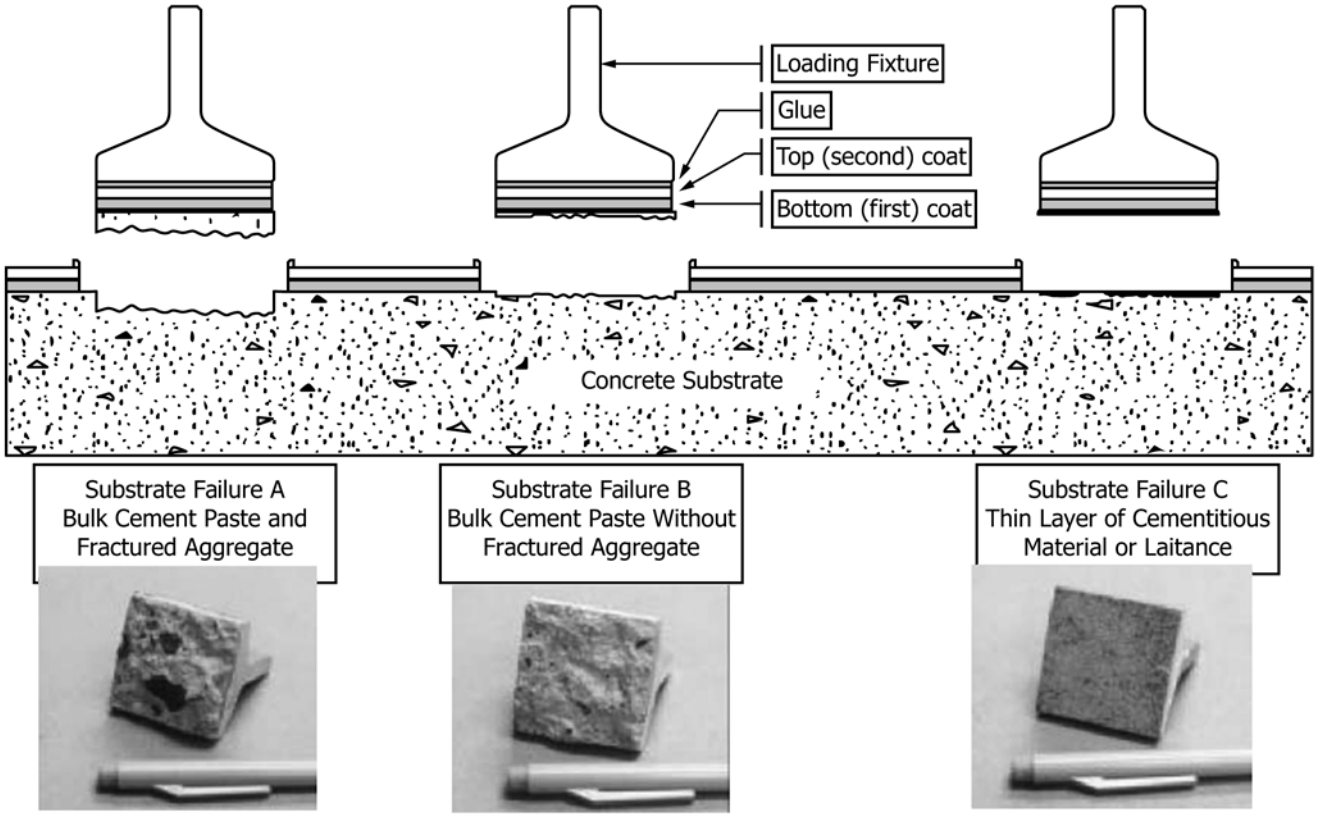


FIG. 3 Substrate Failure Classification

9.3.3 Designate cohesive coating failures by the layers within which they occur as *D, E, F,* etc., and the percentage of each.

9.3.4 Designate adhesive failures by the interfaces at which they occur as *A/B, B/C, C/D*, etc., and the percent of each.

9.4 A result that is very different from most of the results may be caused by a mistake in recording or calculating, among other things. If either of these is not the cause, then examine the experimental circumstances surrounding this run. If an irregular result can be attributed to an experimental cause, drop this result from the analysis. However, do not discard a result unless there are valid nonstatistical reasons for doing so or unless the result is a statistical outlier. Valid nonstatistical reasons for dropping results include alignment of the apparatus that is not normal to the surface, poor definition of the area stressed due to improper application of the adhesive, poorly defined glue lines and boundaries, holidays in the adhesive caused by voids or inclusions, improperly prepared surfaces, and sliding or twisting the fixture during the initial cure. Dixon's test, as described in Practice E178, may be used to detect outliers.

9.5 Disregard any test where adhesive failure (between the adhesive, *Y*, and the loading fixture, *Z* or the coating surface) represents more than 20 % of the area.

10. Report

10.1 Report the following information:

10.1.1 Brief description of the general nature of the test, such as, field or laboratory testing, generic type of coating, etc.

10.1.2 Temperature and relative humidity and any other pertinent environmental conditions during the test period.

10.1.3 Description of the apparatus used, including: apparatus manufacturer and model number, loading fixture type and dimensions, and bearing ring type and dimensions.

10.1.4 Description of the test system, if possible, by the indexing scheme outlined in 9.3 including: product identity and generic type for each coat and any other information supplied, the substrate identity (thickness, type, orientation, etc.), and the adhesive used.

10.1.5 Test results, including:

10.1.5.1 Date, test location, testing agent.

10.1.5.2 Report all values computed in 9.2 along with the nature and location of the failures as specified in 9.3. Report the average % failure for each mode of failure, and the average pull-off adhesion strength for each predominant mode of failure, rounded to the nearest 0.1 MPa (10 psi).

10.1.5.3 If corrections of the results have been made, or if certain values have been omitted such as the lowest or highest values or others, reasons for the adjustments and criteria used.

10.1.5.4 For any test where scoring was not employed, indicate it by placing a footnote superscript beside each data point affected and a footnote to that effect at the bottom of each page on which such data appears. Note any other deviations from the procedure.

11. Precision and Bias

11.1 The precision of this test method is based on an interlaboratory study of Test Method D7234, Standard Test

TABLE 1 Pull-Off Adhesion Measurements for Instruments 1 to 7 Separately

Coating – Instrument	Average[A] $\bar{X}$	Repeatability Standard Deviation s_r	Reproducibility Standard Deviation S_R	Repeatability Limit (2σ) r	Reproducibility Limit (2σ) R
1–1	270.1	44.0	62.5	87.9	125.1
1–2	219.7	44.7	46.9	89.3	93.7
1–3	243.7	32.4	67.0	64.7	133.9
1–4	271.4	60.9	60.9	121.7	121.7
1–5	264.4	52.9	63.0	105.9	126.1
1–6	293.3	44.7	50.4	89.4	100.7
1–7	182.5	35.8	46.0	71.6	91.9
2–1	365.3	47.4	61.4	94.9	122.7
2–2	303.9	30.5	37.4	61.0	74.8
2–3	399.8	38.8	61.9	77.5	123.8
2–4	404.4	58.3	58.3	116.6	116.6
2–5	361.4	53.2	57.0	106.4	114.0
2–6	457.8	75.0	75.0	150.0	150.0
2–7	228.3	64.0	87.4	128.1	174.9

[A] The average of the laboratories' calculate averages.

TABLE 2 Pull-Off Adhesion Measurements for Instruments 1 to 5 Combined

Material	Average[A] $\bar{X}$	Repeatability Standard Deviation s_r	Reproducibility Standard Deviation S_R	Repeatability Limit (2σ) r	Reproducibility Limit (2σ) R
Coating 1	253.9	53.5	60.9	107.0	121.8
Coating 2	367.0	61.3	64.9	122.7	129.8

[A] The average of the laboratories' calculated averages.

Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers, conducted in 2011. Six analysts, using seven different instruments, tested samples of two coatings prepared on the same substrate. Every analyst reported three test results for each instrument/coating combination in this study. While the test results are representative of individual determinations, the data was combined for analysis in two ways (instruments 1 to 7 considered separately, and instruments 1 to 5 combined, as 1 to 5 all used 50 mm dollies and were drilled and prepared the same way). Practice E691 was followed for the study design; the details are given in ASTM Research Report No. RR:D01-1163.[5]

11.1.1 *Repeatability Limit (r)*—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 substrate and the same coating at the same intended applied coating weight, obtained by the same operator using the same equipment on the same day in the same laboratory.

11.1.1.1 Repeatability limits are listed in Table 1 and Table 2.

11.1.2 *Reproducibility Limit (R)*—Two test results 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 substrate and the same coating at the same intended applied coating weight, obtained by different operators using different equipment in different laboratories.

11.1.2.1 Reproducibility limits are listed in Table 1 and Table 2.

11.1.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice E177.

11.1.4 Any judgment in accordance with statements 11.1.1 and 11.1.2 would have an approximate 95 % probability of being correct.

11.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

11.3 The precision statement was determined through statistical examination of 252 results, from a total of six analysts, using seven instruments, on two coatings.

11.3.1 Coatings used in the study:

11.3.1.1 *Coating 1* — Zero VOC Acrylic Latex Paint (two coats, each applied at 0.25 mm wet film thickness to give a total of 0.2 mm dry film thickness).

11.3.1.2 *Coating 2* — Troweled Flooring System (6 mm thick 100 % solids, amine cured epoxy, silica filled mortar/screed over 0.1 mm WFT/DFT 100 % solids, amine cured epoxy primer.

11.3.2 Mode of Failure — In this ILS, all individual results were above 80 % substrate failure (in fact 90 % of the results were 100 % substrate failure) so any variability in the failure mode was ignored in the analysis.

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D01-1163.

11.3.3 While there are numerous variables for each test result, in this study a number of the items were kept constant for all the tests performed here; all labs used the same location and concrete (note, all testers came to the same location as testing was performed on a single poured concrete slab, not blocks of concrete); same coatings (since this was one continuous slab, the coatings were also continuous); same dolly adhesive (2K fast set, amine cured epoxy); same drill press and core bits (for the five instruments only); and, the same instrument for each of the different instruments noted.

11.3.4 Variability in these results is due to natural variability in the following items and procedures; the concrete (despite being from the same pour, concrete varies in strength every inch), the drilling procedure (despite using the same press and bits), the adhesive application and dolly attachment procedure, and the loading rate of the instrument (which, except for one of the instruments, is regulated by the operator).

12. Keywords

12.1 adhesion; coatings; concrete; field; paint; portable; pull-off adhesion strength; tensile test

APPENDIX

(Nonmandatory Information)

X1. INTERPRETATION OF RESULTS

X1.1 Mode of Failure

X1.1.1 *General Failure Modes*—The mode of failure is usually categorized as either substrate failure (cohesive failure in the substrate, see Fig. 3), adhesive failure between the coating system and the substrate (see Fig. X1.1), adhesive failure between the layers in the coating system (see Fig. X1.1), cohesive failure in the coating system (see Fig. X1.1), or adhesive failure of the loading fixture adhesive (see Fig. X1.1). This explanation is necessary as the mode of failure is as important as the resulting value for determining the integrity of coatings on concrete.

X1.1.1.1 *Substrate Failure*—This is the preferred mode of failure for coatings on concrete. The value obtained in this failure mode is primarily dependent on the tensile strength of the concrete at or close to the surface. Low values in this failure mode point to a deficiency in the concrete.

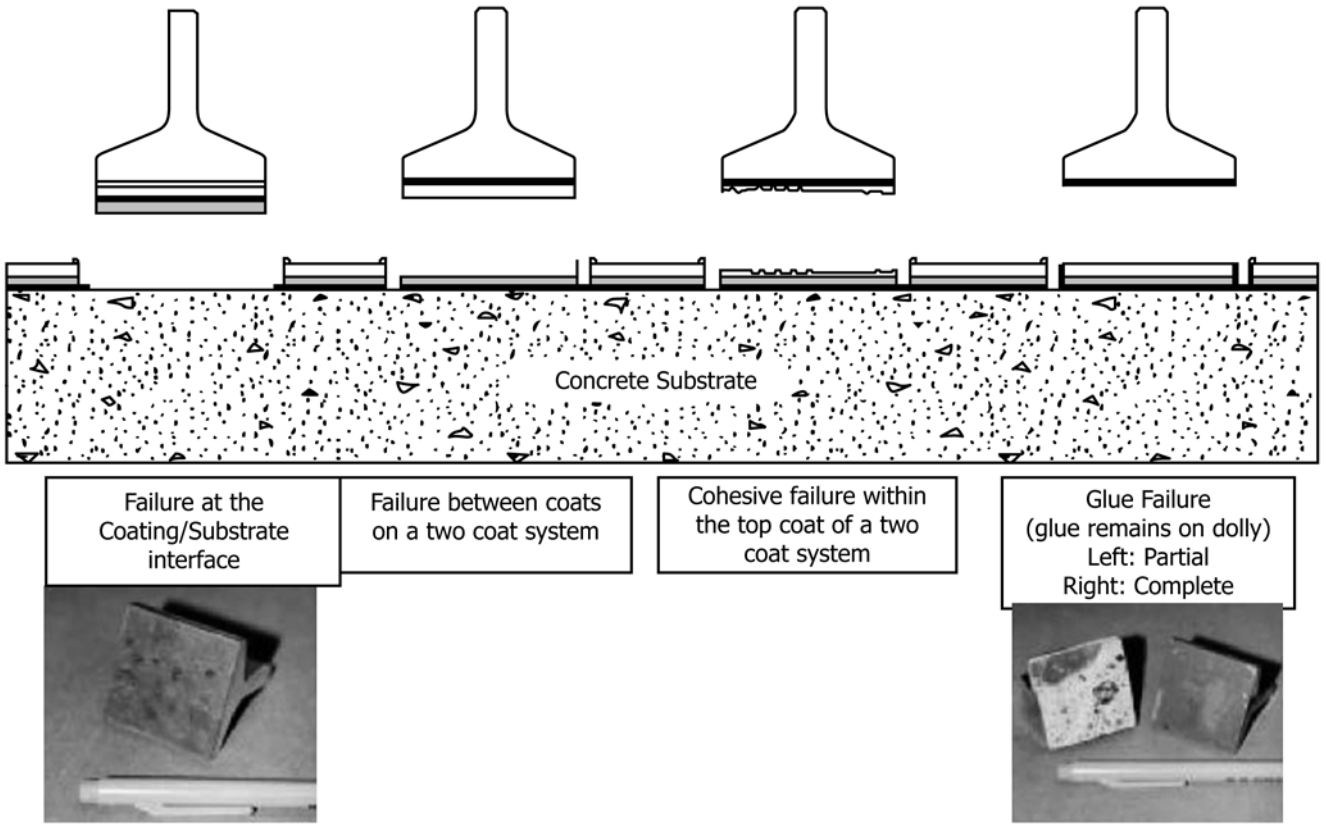


FIG. X1.1 Other Failure Modes

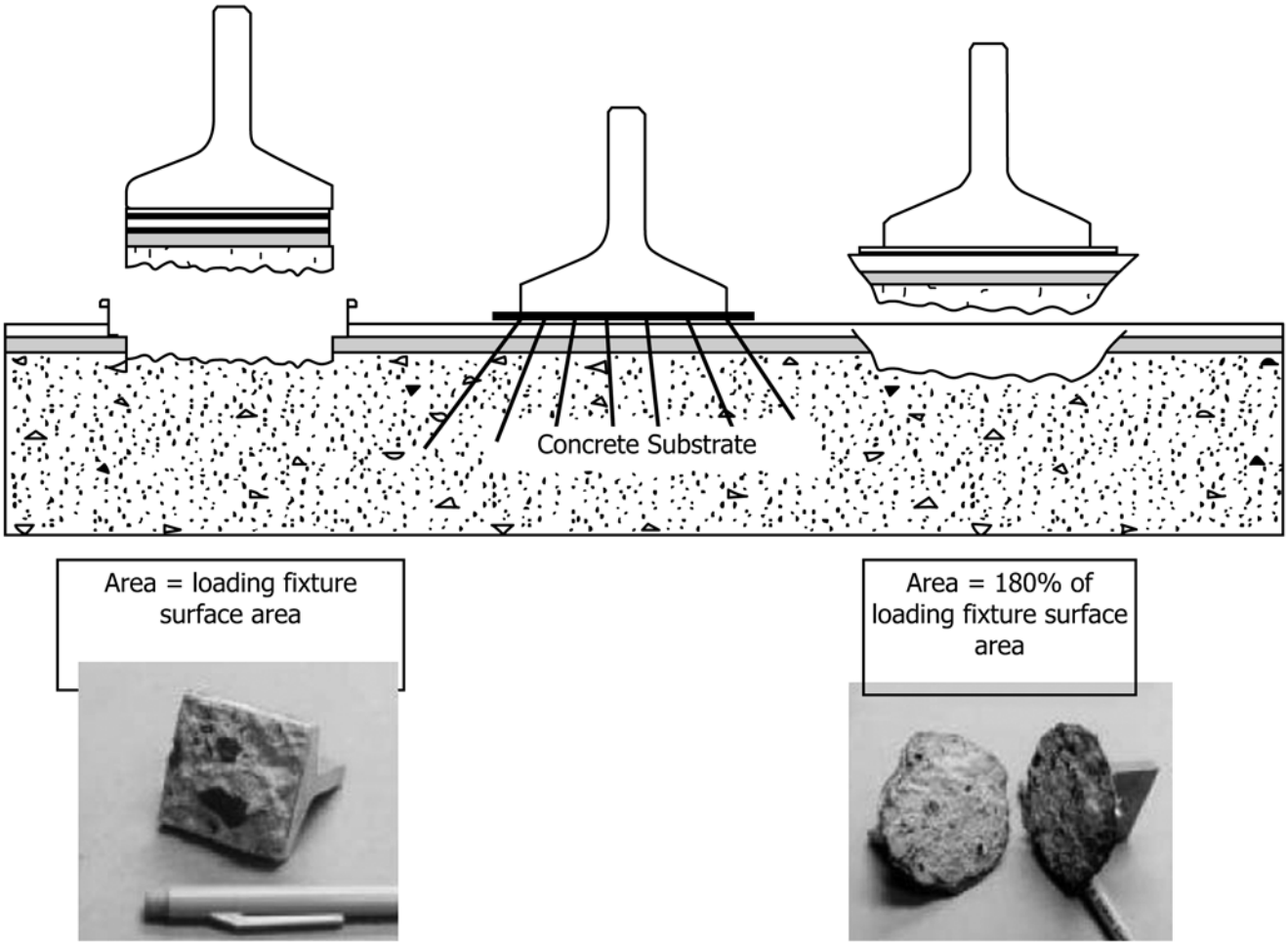


FIG. X1.2 Effect of Not Scoring Around the Loading Fixture Prior to Pulling

X1.1.1.2 *Adhesive Failure Between the Coating System and the Substrate*—This is not the preferred mode of failure for coatings on concrete, especially when low pull-off adhesion values are obtained. This mode of failure is usually due to insufficient surface preparation of the concrete, contamination on the concrete surface, or incompatibility between the coating and the concrete. One exception is elastomeric coatings, which occasionally fail in this mode (see X1.3).

X1.1.1.3 *Adhesive Failure Between the Layers in the Coating System*—This is not the preferred mode of failure for coatings on concrete, especially when low pull-off adhesion values are obtained.

X1.1.1.4 *Cohesive Failure in the Coating System*—This is not the expected mode of failure for most coatings on concrete. If the tensile strength of the coating exceeds the tensile strength of the concrete (approximately 1.4 to 2.8MPa (200 to 400 psi)) this failure mode should not be encountered unless there is a deficiency in the coating.

X1.1.1.5 *Adhesive Failure of the Loading Fixture Adhesive*—As stated in 9.5, when this mode of failure accounts for 20 % or more of the failure surface, the results are disregarded as failure in this mode indicates that the result is not a measure of the adhesion of the system to the substrate. Additional specimens may be needed if the number of tests does not meet the requirements stated in 7.1.1.

X1.2 Effect of Not Scoring

X1.2.1 In cases where the specimen is not scored prior to testing, depending on the properties of the coating and the concrete, the effective test area may not be able to be specifically defined. This may result in test values that are higher than results from scored specimens on the same sample (see Fig. X1.2).

X1.3 Elastomeric Coatings

X1.3.1 *Interpretation of Results*—In cases where elastomeric coatings are applied directly onto concrete or onto a non-elastic primer, the elastomeric coating may show an adhesive failure between the elastomer and the primer or the substrate. If the test value is low in this failure mode then the interpretation in X1.1.1.2 may be valid, however, if the test value is high in this failure mode, this may not indicate a deficiency in the adhesion of this coating. The reason is that when subjected to pull-off load, the elastomer will elongate, and if the elongation or strain is sufficient, then the failure can be induced by a simulated peel-type load starting at the edges

of the cut sample. This phenomena is exacerbated by low modulus elastomers, scoring techniques, low loading rates, and loading at angles not exactly perpendicular to the coating.

AASHTO Submission
Product Evaluation Application

ASTM Standards for Post-Application Testing

- ASTM Standard G62-14 for Holiday Detection in Pipeline Coatings

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

Designation: G62 – 14

Standard Test Methods for Holiday Detection in Pipeline Coatings[1]

This standard is issued under the fixed designation G62; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods cover the apparatus and procedure for detecting holidays in pipeline type coatings.

1.2 Method A is designed to detect holidays such as pinholes and voids in thin-film coatings from 0.025 to 0.254 mm (1 to 10 mils) in thickness using ordinary tap water and an applied voltage of less than 100 V d-c. It is effective on films up to 0.508 mm (20 mils) thickness if a wetting agent is used with the water. It should be noted, however, that this method will not detect thin spots in the coating. This may be considered to be a nondestructive test because of the relatively low voltage.

1.3 Method B is designed to detect holidays such as pinholes and voids in pipeline coatings; but because of the higher applied voltages, it can also be used to detect thin spots in the coating. This method can be used on any thickness of pipeline coating and utilizes applied voltages between 900 and 20 000 V d-c.[2] This method is considered destructive because the high voltages involved generally destroy the coating at thin spots.

1.4 The values stated in SI units to three significant decimals are to be regarded as the standard. The values given in parentheses are for information only.

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

2. Referenced Documents

2.1 *ASTM Standards:*[3]

A742/A742M Specification for Steel Sheet, Metallic Coated and Polymer Precoated for Corrugated Steel Pipe

3. Terminology

3.1 *Definitions:*

3.1.1 *holiday, n*—small faults or pinholes that permit current drainage through protective coatings on steel pipe or polymeric precoated corrugated steel pipe.

3.1.2 *mil, n*—0.001 in.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *holiday detector, n*—a highly sensitive electrical device designed to locate holidays such as pinholes, voids, and thin spots in the coating, not easily seen by the naked eye. These are used on the coatings of relatively high-electrical resistance when such coatings are applied to the surface of materials of low-electrical resistance, such as steel pipe.

3.2.2 *pipeline type coating, n*—coatings of relatively high-electrical resistance applied to surfaces of relatively low-electrical resistance, such as steel pipe.

4. Summary of Test Methods

4.1 Both methods rely on electrical contact being made through the pipeline coating because of a holiday or a low-resistance path created by metal particles, or thin spots in the coating. This electrical contact will activate an alarm alerting the operator of the incidence of a holiday.

4.2 In Method A, the applied voltage is 100 V d-c or less.

4.3 In Method B, the applied voltage is 900 to 20 000 V d-c.

5. Significance and Use

5.1 *Method A*—Method A describes a quick, safe method for determining if pinholes, voids, or metal particles are protruding

[1] These test methods are under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and are the direct responsibility of Subcommittee D01.48 on Durability of Pipeline Coating and Linings.

Current edition approved July 1, 2014. Published July 2014. Originally approved in 1979. Last previous edition approved in 2013 as G62 – 07 (2013). DOI: 10.1520/G0062-14.

[2] This was taken from the pamphlet "Operating Instructions for Tinker and Rasor Model EP Holiday Detector." Other manufacturers' holiday detectors can be expected to have similar voltage specifications.

[3] 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.

through the coating. This method will not, however, find any thin spots in the coating. This method will determine the existence of any gross faults in thin-film pipeline coatings.

5.2 *Method B*—Method B describes a method for determining if pinholes, voids, or metal particles are protruding through the coating, and thin spots in pipeline coatings. This method can be used to verify minimum coating thicknesses as well as voids in quality-control applications.

6. Apparatus

6.1 *Low-Voltage Holiday Detector*—A holiday detector tester having an electrical energy source of less than 100 V d-c, such as a battery; an exploring electrode having a cellulose sponge dampened with an electrically conductive liquid such as tap water; and an audio indicator to signal a defect in a high-electrical resistance coating on a metal substrate. A ground wire connects the detector with the low-resistance metal surface.

6.2 *High-Voltage Holiday Detector*—A holiday detector tester having an electrical energy source of 900 to 20 000 V d-c; an exploring electrode consisting of wire brush, coil-spring, or conductive silicon electrode capable of moving along the pipeline coating; and an audio indicator to signal a defect in a high-electrical resistance coating on a metal substrate. A ground wire connects the detector with the low-resistance metal surface.

6.3 *Peak or Crest Reading Voltmeter*—A kilovoltmeter capable of detecting a single pulse and holding it long enough for the meter circuits to indicate.

7. Reagents and Materials

7.1 *Tap Water,* plain or with a wetting agent.

NOTE 1—Ordinary tap water will suffice to wet the sponge electrode when inspecting coatings up to 0.254 mm (10 mils) in thickness. On films between 0.254 and 0.508 mm (10 and 20 mils), a nonsudsing type wetting agent added to the water is recommended to allow for faster penetration of the liquid into pinhole defects.

8. Test Specimen

8.1 The test specimen shall be a representative length of production-coated pipe or polymeric precoated corrugated steel pipe.

9. Standardization of Instruments

9.1 The instruments shall be standardized with respect to voltage output in accordance with the manufacturer's instructions, using a peak or crest reading voltmeter. This is used more commonly with Method B where voltage may vary from test to test but can also be used for verification of the voltage on a Method A test.

9.2 The low-voltage holiday detector shall be standardized with respect to sensitivity by having the alarm activated when a selected resistance, having a ½ W rating, is placed across its terminals. A common factory setting for sensitivity is 100 000 Ω. Most units can be reset to any predetermined sensitivity value in this manner.

10. Procedure for Method A

10.1 Use the low-voltage holiday detector described in 6.1.

10.2 Assemble the wand and electrode according to the manufacturer's instructions and attach the ground wire to the metal surface.

10.3 Attach the electrode clamps to the end of the wand, dampen the sponge electrode with tap water, and place it between the clamps. Then tighten the clamps with the screw until they are well down into the sponge electrode. Attach the ground wire (lead with battery clamp) and the wand to the terminals. Clip the ground wire to some point where the metal surface is bare. Now touch the electrode to a second point where the surface is bare and note that the audible signal will be activated. The detector is now ready to operate by passing the damp sponge over the coated surface. When a holiday is picked up by the audible alarm, the electrode can be turned on end and the exact spot of failure can be noted by searching with the tip of the electrode.

10.4 The voltage between the electrode (sponge) and the metal surface upon which the coating lies shall not exceed 100 V d-c, measured between the electrode sponge and the coated metal when the detector is in its normal operating position.

10.5 Prior to making the inspection, ensure that the coated surface is dry. This is particularly important if formed surfaces are to be inspected. If the surface is in an environment where electrolytes might form on the surface, such as salt spray, wash the coated surface with fresh water and allow to dry before testing. Take care to keep the electrolyte at least 12.7 mm (½ in.) from any bare sheared or slit edge.

10.6 A low-voltage holiday detector is not satisfactory for the inspection of pipeline coatings over 0.508 mm (20 mils) in thickness. This type of holiday detector will not detect thin spots in pipeline coatings.

11. Procedure for Method B

11.1 Use the high-voltage holiday detector.

11.2 Determine the test voltage desired by multiplying the dielectric breakdown voltage per millimetre (mil) of the coating (Note 2) times the minimum allowable thickness of the coating in millimetres (mils).

NOTE 2—The dielectric breakdown voltage per millimetre (mil) can be determined for each coating experimentally as follows: Increase the holiday detector voltage over a known coating thickness and measure the voltage at the point where the detector will just begin to ring. Divide this voltage by the known coating thickness to obtain the amount of volts per millimetre (mil). This can also be obtained from most coating manufacturers' literature.

DATA SHEET AND REPORT

Holiday Detection in Pipeline Coatings
Detector Type and Manufacturer _____ Report No. _____
Coating Manufacturer _____ Page _____ of _____
Coating _____
Production Date _____
Production Run No. _____
Applied by _____

Specimen	Coating Thickness		Detector Voltage	Test Method	Detector Resistance	Number of Holidays	Pipe Diameter	
	mm	mils			ohms		mm	in.

FIG. 1 Suggested Form for Use in Presenting Data for Method A and Method B

11.2.1 An alternative method of determining test voltage is by use of one of the following equations depending on coating thickness.

11.2.2 If the coating thickness is less than 1.016 mm (40 mils):

$$V = M\sqrt{Tc} \quad (1)$$

where:

V = test voltage
Tc = coating thickness
M = 3294 if Tc is in millimetres
M = 525 if Tc is in mils.

11.2.3 If the coating thickness is greater than 1.041 mm (41 mils):

$$V = K\sqrt{Tc} \quad (2)$$

where:

V = test voltage
Tc = coating thickness
K = 7843 if Tc is in millimetres
K = 1250 if Tc is in mils

11.2.4 These equations are predicated on the amount of voltage needed to jump an air gap of the same length as the coating thickness. Therefore, they are useful for testing voids, pinholes and thin spots in the coating, but would not be useful as a coating thickness quality control tool.

11.3 Ground the test specimen by attaching the ground wire to a bare metal spot on the pipe surface. Plug the ground wire into the holiday detector. Then make up the searching electrode in accordance with the manufacturer's recommendations, using a brush wire or conductive silicon electrode. Plug the searching electrode into the holiday detector. Turn on the holiday detector.

11.3.1 **CAUTION:** Because of the high voltages involved, do not touch the ground wire and the metal part of the electrode at the same time if the instrument is on.

11.4 The detector is now ready to operate by passing the electrode over the test specimen. The detector will ring if it passes any void, pinhole, or area of the coating thinner than the minimum allowable thickness. When a holiday is detected by the audible alarm, the electrode can be repositioned to determine the exact holiday area by observing the origin of the spark jump.

11.5 Prior to making the inspection, ensure that the coated surface is dry. Dryness is critical in a high voltage test. Take care to keep the electrode at least 12.7 mm (½ in.) from any bare sheared or slit edge.

12. Report

12.1 The report shall include the following (see Fig. 1):

12.2 Complete identification of the specimen including names and code number of the coating, pipe diameter, source, production data, and production run number. For polymeric precoated corrugated steel pipe, the reporting requirements of Specification A742/A742M shall be used for identification,

12.3 Name and type of instrument used, method of standardization, and whether Method A or Method B was used, and

12.4 If Method B was used, state the test voltage, the method used to calculate the voltage, and the minimum allowable thickness in millimetres (mils) of the test sample.

13. Precision and Bias

13.1 Precision data are limited to adjacent specimens taken from the production-coated pipe as for the polymeric corrugated steel pipe assuming that the production process was uniform with respect to pipe surface condition and coating material. Specimens that were not adjacent in the as-produced condition, or were taken from different lengths of pipe, may represent differing process conditions.

13.2 *Repeatability*—When the same instrument is used by the same operator, duplicate measurements on the same specimen shall agree within ±5 %.

13.3 *Reproducibility*—Different operators using different instruments, set at the same voltage, inspecting the same specimen shall obtain average results agreeing with each other within ±10 %.

13.4 *Bias*—This test detects the presence of a conductive path through the coating and is therefore not a measurement. No value for bias can be determined.

14. Keywords

14.1 holiday detector; holidays; piping; pinhole; wet sponge detector

AASHTO Submission
Product Evaluation Application

Third Part Test Results against ASTM and Other Standards

- ASTM D638 - Tensile Properties

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

October 2, 2012

Mail To:

Mr. Jerry Gordon
Sprayroq, Inc.
248 Cahaba Valley Pkwy
Pelham, Al 35124

e-mail: jgordon@sprayroq.com
cce-mail: bsalvano@sprayroq.com
cce-mail: cjohnson@sprayroq.com

Bill To:

<= Same

Dear Mr. Gordon

Thank you for consulting TRI/Environmental, Inc. (TRI) for your geosynthetics testing needs. TRI is pleased to submit this final report for laboratory testing.

TRI Job Reference Number:	E2372-22-08
Material(s) Tested:	1, SprayWall
Test(s) Requested:	Tensile Strength (ASTM D 638)

If you have any questions or require any additional information, please call us at 1-800-880-8378.

Sincerely,

Mansukh Patel
Sr. Laboratory Coordinator
Geosynthetic Services Division
www.GeosyntheticTesting.com

GeosyntheticTesting.com
9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

LABORATORY TEST RESULTS

TRI Client: Sprayroq, Inc.

Material: SprayWall
Sample Identification: SprayWall
TRI Log #: E2372-22-08

PARAMETER	TEST REPLICATE NUMBER										MEAN	STD. DEV.
	1	2	3	4	5	6	7	8	9	10		
Tensile Properties (ASTM D 638, mod. Bar Tensile)				(WITH 2.0 INCH GAUGE LENGTH)								
Tensile Break Strength (ppi)	835	794	784	614	894	706					**771**	98.6
Tensile Break Strength (psi)	9541	8349	8178	6671	9469	7719					**8321**	1087
Break Elongation (%)	4.53	4.25	4.52	3.19	4.27	3.46					**4.04**	0.57
Modulus (psi)	418171	371876	344614	345917	405005	366124					**375285**	30401

The testing is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested. TRI neither accepts responsibility for nor makes claim as to the final use and purpose of the material. TRI observes and maintains client confidentiality. TRI limits reproduction of this report, except in full, without prior approval of TRI.

GeosyntheticTesting.com
9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

AASHTO Submission
Product Evaluation Application

Third Part Test Results against ASTM and Other Standards

- ASTM D695 - Compressive Strength

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

March 9, 2009

Mail To:

Mr. Thomas Palmer
Sprayroq, Inc.
4707 Alton Court
Birmingham, AL 35210-3744

phone: 205 957 0020
e-mail: tpalmer@sprayroq.com

Bill To:

<= Same

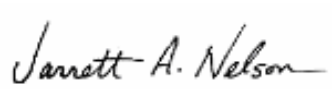
Dear Mr. Palmer:

Thank you for consulting TRI/Environmental, Inc. (TRI) for your geosynthetics testing needs. TRI is pleased to submit this final report for laboratory testing.

TRI Job Reference Number:	E2324-25-07
Material(s) Tested:	1 Spraywall Plaque(s)
Test(s) Requested:	Compressive Strength (ASTM D 695)

If you have any questions or require any additional information, please call us at 1-800-880-8378.

Sincerely,



Jarrett A. Nelson
Special Projects Manager
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9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

LABORATORY TEST RESULTS

TRI Client: Sprayroq, Inc.

Material: Spraywall Plaque
Sample Identification: Spraywall
TRI Log #: E2324-25-07

PARAMETER	TEST REPLICATE NUMBER										MEAN	STD. DEV.
	1	2	3	4	5	6	7	8	9	10		
Compressive Properties (ASTM D 695, 0.05 in/min)												
Compressive Strength (psi)	19971	20782	19388	19723	18754						**19724**	747
Modulus of Elasticity (psi)	268054	320655	253326	263869	254523						**272085**	27853

Note: Three layers of 1" x 1" pieces were stacked to create 1" thick cube specimens for testing.

GeosyntheticTesting.com
9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

AASHTO Submission
Product Evaluation Application

Third Part Test Results against ASTM and Other Standards

- ASTM D790 - Flexural Modulus

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

October 2, 2012

Mail To:

Mr. Jerry Gordon
Sprayroq, Inc.
248 Cahaba Valley Pkwy
Pelham, Al 35124

e-mail: jgordon@sprayroq.com
cce-mail: bsalvano@sprayroq.com
cce-mail: cjohnson@sprayroq.com

Bill To:

<= Same

Dear Mr. Gordon

Thank you for consulting TRI/Environmental, Inc. (TRI) for your geosynthetics testing needs. TRI is pleased to submit this final report for laboratory testing.

TRI Job Reference Number:	E2372-22-08
Material(s) Tested:	1, SprayWall
Test(s) Requested:	Flexural Modulus (ASTM D 790)

If you have any questions or require any additional information, please call us at 1-800-880-8378.

Sincerely,

Mansukh Patel
Laboratory Coordinator
Geosynthetic Services Division
www.GeosyntheticTesting.com

GeosyntheticTesting.com
9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

LABORATORY TEST RESULTS

TRI Client: Sprayroq, Inc.

Material: SprayWall
Sample Identification: SprayWall
TRI Log #: E2372-22-08

PARAMETER	TEST REPLICATE NUMBER										MEAN	STD. DEV.
	1	2	3	4	5	6	7	8	9	10		
Flexural Modulus (ASTM D 790)												
Flexural modulus (psi)	898316	768729	722640	824990	856002	756434					**804519**	66580
Maximum Flexural Strength (psi)	15900	14716	12997	13870	15111	14000					**14432**	1026

GeosyntheticTesting.com
9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

AASHTO Submission
Product Evaluation Application

Third Part Test Results against ASTM and Other Standards

- ASTM D2240 - Hardness

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

October 2, 2012

Mail To:

Mr. Jerry Gordon
Sprayroq, Inc.
248 Cahaba Valley Pkwy
Pelham, Al 35124

e-mail: jgordon@sprayroq.com
cce-mail: bsalvano@sprayroq.com
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Bill To:

<= Same

Dear Mr. Gordon

Thank you for consulting TRI/Environmental, Inc. (TRI) for your geosynthetics testing needs. TRI is pleased to submit this final report for laboratory testing.

TRI Job Reference Number:	E2372-22-08
Material(s) Tested:	1, SprayWall
Test(s) Requested:	Hardness (ASTM D 2240)

If you have any questions or require any additional information, please call us at 1-800-880-8378.

Sincerely,

MPatel

Mansukh Patel
Sr. Laboratory Coordinator
Geosynthetic Services Division
www.GeosyntheticTesting.com

GeosyntheticTesting.com
9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

LABORATORY TEST RESULTS

TRI Client: Sprayroq, Inc.

Material: SprayWall
Hardness (ASTM D 2240)
TRI Log #: E2372-22-08

PARAMETER	TEST REPLICATE NUMBER										MEAN	STD. DEV.
	1	2	3	4	5	6	7	8	9	10		
Sample Identification: SprayWall												
Shore D Hardness (index)	88	86	87	87	86						**87**	1

The testing is based upon accepted industry practice as well as the test method listed. Test results reported herein do not apply to samples other than those tested. TRI neither accepts responsibility for nor makes claim as to the final use and purpose of the material. TRI observes and maintains client confidentiality. TRI limits reproduction of this report, except in full, without prior approval of TRI.

GeosyntheticTesting.com
9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

AASHTO Submission
Product Evaluation Application

Third Part Test Results against ASTM and Other Standards

- ASTM D4060 - Taber Abrasion

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

October 2, 2012

Mail To:

Mr. Jerry Gordon
Sprayroq, Inc.
248 Cahaba Valley Pkwy
Pelham, Al 35124

e-mail: jgordon@sprayroq.com
cce-mail: bsalvano@sprayroq.com
cce-mail: cjohnson@sprayroq.com

Bill To:

<= Same

Dear Mr. Gordon

Thank you for consulting TRI/Environmental, Inc. (TRI) for your geosynthetics testing needs. TRI is pleased to submit this final report for laboratory testing.

TRI Job Reference Number:	E2372-22-08
Material(s) Tested:	SprayWall
Test(s) Requested:	Tabor Abrasion 4060-95 (as a guide)

If you have any questions or require any additional information, please call us at 1-800-880-8378.

Sincerely,

MPatel

Mansukh Patel
Sr. Laboratory Coordinator
Geosynthetic Services Division
www.GeosyntheticTesting.com

cc: Sam R. Allen, Vice President and Division Manager

GeosyntheticTesting.com
9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

TRI / Environmental, Inc.
A Texas Research International Company

LABORATORY TEST RESULTS

TRI Client: Sprayroq, Inc.

Material:SprayWall
Sample Identification: Spraywll
TRI Log #: E2372-22-08
Test: Taber Abrasion (ASTM D 4060-95 - as aguide)

Results : Specimen 1

Number of Cycles	Test Material Identification	Initial Weight (mg)	Final Weight (mg)	Weight Loss (mg)	Wear Index (mg/1000 cycles)
0	Spraywall	62438	*	*	*
1000	Spraywall	62438	62198	240	240.00
2000	Spraywall	62198	62025	413	206.50
3000	Spraywall	62025	61888	550	183.33
4000	Spraywall	61888	61773	425.3	106.33
5000	Spraywall	61773	61687	338.0	67.60

Results: Specimen 2

Number of Cycles	Test Material Identification	Initial Weight (mg)	Final Weight (mg)	Weight Loss (mg)	Wear Index (mg/1000 cycles)
0	Spraywall	55089	*	*	*
1000	Spraywall	55089	55058	31	31.00
2000	Spraywall	55058	55024	65.4	32.70
3000	Spraywall	55024	55005	84.5	28.17
4000	Spraywall	55005	54989	69.2	17.30
5000	Spraywall	54989	54975	48.2	9.64

Parameters

Abrasion Wheel:	**CS-17**
Weight Load (g):	**1000 (g) / side**
Test Cycles: (max)	**5000**

GeosyntheticTesting.com
9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

AASHTO Submission
Product Evaluation Application

Third Part Test Results against ASTM and Other Standards

- Manning's N Factor

Product: SprayWall
Category: Spray-Applied Structural Polyurethane

TRI / Environmental, Inc.
A Texas Research International Company

April 30, 2008

Mail To:

Mr. Thomas Palmer
Sprayroq, Inc.
4707 Alton Court
Birmingham, AL 35210-3744

phone: 205 957 0020
e-mail: tpalmer@sprayroq.com

Dear Mr. Palmer:

Thank you for consulting TRI/Environmental, Inc. (TRI) for your geosynthetics testing needs. TRI is pleased to submit this final report for laboratory testing.

TRI Job Reference Number:	E2280-13-01
Material(s) Tested:	1 Spray Wall Plaque
Test(s) Requested:	Mannings "n" Determination

If you have any questions or require any additional information, please call us at 1-800-880-8378.

Sincerely,

Jarrett A. Nelson

Jarrett A. Nelson
Special Projects Manager
Geosynthetic Services Division

GeosyntheticTesting.com
9063 Bee Caves Road / Austin, TX 78733 / 512 263 2101 / fax: 512 263 2558

Measure tractive shear and depth during test
Calculate Velocity = RPM x circumference / 60
(at 2.0 ft to centerpoint of pot)
Calculate Slope, S = Shear / (Unit Wt of Water x Water Depth)
Calculate R = Area / Wetted Perimeter
(Note: Area and wetted perimeter are based on X-Section above pot)

	Tank Radius (ft)	Radius to Pot (ft)	Initial Depth over Pot (in)	Diameter of Pot (in)	Unit Wt of Water (pcf)
Large Tank	3.00	2.00	22.75	8.00	62.4

Product: **Spray Wall**

RPM	Vel (ft/s)	Shear (psf)	depth (in)	Area over Pot (sf)	S (ft/ft)	S1/2	R2/3	"n"
16.4	3.43	0.26	22.95	1.28	0.0022	0.0467	0.4301	0.009
23.8	4.98	0.65	23.30	1.29	0.0054	0.0732	0.4308	0.009
26.0	5.45	0.76	23.50	1.31	0.0062	0.0789	0.4311	0.009
								0.009