Standard Guide for Material Properties Needed in Engineering Design Using Plastics[1]

This standard is issued under the fixed designation D 5592; 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.

ϵ^1 NOTE—Editorially corrected items in the Referenced Documents section, as well as made minor editorial corrections in August 2002.

INTRODUCTION

Plastics are increasingly being used in durable applications as structural components on a basis comparable with traditional materials such as steels and aluminum, as well as high performance composite systems. Unlike many consumer-goods applications, where plastics typically serve as enclosures, these durables applications primarily involve load-bearing components exposed to rather broad varying operating environments over the life cycle of the product. This necessitates access to material property profiles over a wide range of conditions, rather than typical values reported at room temperature. In order to design effectively with plastics, the designer must take into account the effects of time, temperature, rate, and environment on the performance of plastics, and the consequences of failure.

1. Scope *

1.1 This guide covers the essential material properties needed for designing with plastics. Its purpose is to raise the awareness of the plastics community regarding the specific considerations involved in using the appropriate material properties in design calculations.

1.2 This guide is intended only as a convenient resource for engineering design. It should be noted that the specific operating conditions (temperature, applied stress or strain, environment, etc. and corresponding duration of such exposures) could vary significantly from one application to another. It is, therefore, the responsibility of the user to perform any pertinent tests under actual conditions of use to determine the suitability of the material in the intended application.

1.3 The applicable ISO and ASTM standard methods for the relevant material properties are listed in this guide for the benefit of design engineers.

1.4 It should be noted that for some of the desired properties, no ASTM or ISO standards exist. These include pvT data, no-flow temperature, ejection temperature, and fatigue in tension. In these instances, relying on available test methods is suggested.

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

NOTE 1—There is no similar or equivalent ISO standard.

2. Referenced Documents

2.1 *ASTM Standards:*

D 543 Standard Test Method for Resistance of Plastics to Chemical Reagents[2]
D 638 Test Method for Tensile Properties of Plastics[2]
D 671 Test Method for Flexural Fatigue of Plastics by Constant Amplitude-of-Force[2]
D 695 Test Method for Compressive Properties of Rigid Plastics[2]
D 883 Terminology Relating to Plastics[2]
D 1435 Practice for Outdoor Weathering of Plastics[2]
D 1894 Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting[2]
D 1999 Guide for the Selection of Specimens and Test Parameters for International Commerce[3]
D 2565 Practice for Operating Xenon-Arc Type Light Exposure Apparatus With and Without Water for Exposure of Plastics[4]
D 2990 Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics[4]

[1] This guide 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 September 15, 1994. Published November 1994.

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

[3] Discontinued; see *1999 Annual Book of ASTM Standards*, Vol 08.01.

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

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

D 2991 Practice for Testing Stress-Relaxation of Plastics[5]
D 3045 Practice for Heat Aging of Plastics Without Load[4]
D 3123 Test Method for Spiral Flow of Low-Pressure Thermosetting Molding Compounds[4]
D 3417 Test Method for Enthalapies of Fusion and Crystalization of Polymers by Differential Scanning Calorimetry[4]
D 3418 Test Method for Transition Temperatures of Polymers by Differential Scanning Calorimetry[4]
D 3641 Practice for Injection Molding Test Specimens of Thermoplastic Molding and Extrusion Materials[4]
D 3835 Test Method for Measuring Rheological Properties of Thermoplastics with a Capillary Rheometer[4]
D 4473 Test Method for Plastics: Dynamic Mechanical Properties: Cure Behavior[6]
D 5045 Test Method for Plane-Strain Fracture Toughness and Strain Energy Release Rate of Plastics Materials[6]
D 5279 Test Method for Plastics: Dynamic Mechanical Properties: In Torsion[6]
E 6 Terminology Relating to Methods of Mechanical Testing[6]
E 228 Test Method for Linear Thermal Expansion of Solid Materials with a Vitreous Silica Dilatometer[7]
E 1150 Definitions of Terms Relating to Fatigue[8]

2.2 *ISO Standards:*[9]
ISO 175 Plastics—Determination of the Effects of Immersion in Liquid Chemicals
ISO 294-1 Plastics—Injection Moulding of Test Specimens of Thermoplastic Materials—General Principles, and Moulding of Multipurpose and Bar Test Specimens
ISO 294-4 Plastics—Injection molding of Test Specimens of Thermoplastic Materials - Determination of Moulding Shrinkage
ISO 527-1 Plastics—Determination of Tensile Properties—Part 1: General Principles
ISO 527-2 Plastics—Determination of Tensile Properties—Part 2: Test Conditions for Moulding and Extrusion Plastics
ISO 527-4 Plastics—Determination of Tensile Properties—Part 4: Test Conditions for Isotropic and Orthotropic Fibre Reinforced Plastic Composites
ISO 604 Plastics—Determination of Compressive Properties
ISO 899-1 Plastics—Determination of Creep Behaviour - Tensile Creep
ISO 899-2 Plastics—Determination of Creep Behaviour - Flexural Creep by Three-Point Loading
ISO 2578 Plastics—Determination of Time-Temperature Limits After Prolonged Exposure to Heat
ISO 3167 Plastics—Multipurpose Test Specimens
ISO 4607 Plastics—Methods of Exposure to Natural Weathering
ISO 4892-1 Plastics—Methods of Exposure to Laboratory Light Sources—Part 1: General Guidance
ISO 4892-2 Plastics—Methods of Exposure to Laboratory Light Sources—Part 2: Xenon Arc Sources
ISO 6721-2 Plastics—Determination of Dynamic Mechanical Properties—Part 2: Torsion Pendulum
ISO 8295 Plastics—Film and Sheeting—Determination of the Coefficients of Friction
ISO 10350.1 Plastics—Acquisition and Presentation of Comparable Single-Point Data— Part 1: Moulding Materials
ISO 11403-1 Plastics—Acquisition and Presentation of Comparable Multipoint Data—Part 1: Mechanical Properties
ISO 11403-2 Plastics—Acquisition and Presentation of Comparable Multipoint Data—Part 2: Thermal and Processing Properties
ISO 11443 Plastics—Determination of the Fluidity of Plastics Using Capillary and Slit-Die Rheometers

3. Terminology

3.1 *Definitions:*

3.1.1 *aging*—the effect on materials of exposure to an environment for an interval of time (see Terminology D 883).

3.1.2 *coefficient of friction*—a measure of the resistance to sliding of one surface in contact with another surface.

3.1.3 *coefficient of linear thermal expansion*—the change in linear dimension per unit of original length of a material for a unit change in temperature.

3.1.4 *compressive strength*—the compressive stress that a material is capable of sustaining. In the case of a material that does not fail in compression by a shattering fracture, the value for compressive strength is an arbitrary value depending upon the degree of distortion that is regarded as indicating complete failure of the material (modified from Terminology E 6).

3.1.5 *creep*—the time-dependent increase in strain in response to applied stress (modified from Terminology E 6).

3.1.6 *creep modulus*—the ratio of initial applied stress to creep strain (see Test Method D 2990).

3.1.7 *creep rupture stress*—stress to produce material failure corresponding to a fixed time to rupture (modified from Test Method D 2990).

3.1.8 *critical stress intensity factor*—toughness parameter indicative of the resistance of a material to fracture at fracture initiation (see Test Method D 5045).

3.1.9 *engineering stress*—stress based on initial cross sectional area of the specimen.

3.1.10 *fatigue*—the process of progressive localized permanent deleterious change or loss of properties occurring in a material subjected to cyclic loading conditions (modified from Definitions E 1150).

3.1.11 *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 (see Terminology D 883).

3.1.12 *proportional limit*—the greatest stress that a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law) (see Test Method D 638).

---

[5] Discontinued; see *1992 Annual Book of ASTM Standards*, Vol 08.02.
[6] *Annual Book of ASTM Standards*, Vol 08.03.
[7] *Annual Book of ASTM Standards*, Vol 03.01.
[8] Discontinued; see *1996 Annual Book of ASTM Standards*, Vol 03.01. Replaced by Terminology E 1823.
[9] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

3.1.13 *PV limit*—the limiting combination of pressure and velocity that will cause failure of any polymer rubbing against another surface without lubrication at a specific ambient temperature and tested in a specific geometry.

3.1.14 *secant modulus*—the ratio of engineering stress to corresponding strain at a designated strain point on the stress-strain curve (see Test Method D 638).

3.1.15 *shear modulus*—the quotient of the shearing stress and the resulting angular deformation of the test specimen measured in the range of small recoverable deformations (see ISO 6721-2).

3.1.16 *shear strength*—the maximum shear stress that a material is capable of sustaining. Shear strength is calculated from the maximum load during a shear or torsion test and is based on the original dimensions of the cross section of the specimen (see Terminology E 6).

3.1.17 *tensile modulus*—the ratio of engineering stress to corresponding strain below the proportional limit of a material in tension (modified from Test Method D 638).

3.1.18 *tensile stress at break*—the tensile stress sustained by the material at break (modified from Test Method D 638).

3.1.19 *tensile stress at yield*—the tensile stress sustained by the material at the yield point (modified from Test Method D 638).

3.1.20 *warpage*—distortion caused by non-uniform change of internal stresses (D 883).

3.1.21 *yield point*—the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress (see Test Method D 638).

4. Significance and Use

4.1 This guide is intended to serve as a reference to the plastics community for material properties needed in engineering design.

4.2 Product datasheets or product literature typically report single-point values at ambient conditions and hence, by their very nature, are inadequate for engineering design and structural analysis of a component or system. A detailed property profile for the particular grade chosen for a given part not only enhances the confidence of the design engineer by allowing a more realistic assessment of the material under close-to-actual service environments but also may avoid premature failure of the designed component and potential liability litigation later. Additionally, it would also eliminate use of larger "design safety factors" that result in "overengineering" or "overdesign." Not only is such overdesign unwarranted, but it adds to the total part cost, resulting in a good example of ineffective design with plastics and a prime target for substitution by other materials.

4.3 One of the problems faced by design engineers is access to comparable data among similar products from different material suppliers because of the lack of standardized reporting format in the plastics industry. ISO 10350.1, 11403-1, and 11403-2 are intended to address the comparability of data issue only as far as single-point and multipoint data for material selection. This guide attempts to serve as a means to standardize the format to report comparable data for engineering design. It is essential that incorporating standardized test specimen geometry and specific test conditions as recommended in Guide D 1999, Practice D 3641, or ISO 3167 and 294-1 are an integral part of the data generation.

5. Material Properties in Engineering Design

5.1 Finite element analysis is an integral part of computer aided design/engineering (CAD/CAE). It serves as a powerful tool for design engineers in performing engineering analysis of plastics components to predict the performance. The material data inputs required for carrying out these analyses essentially constitute the minimum data needed in engineering design.

5.2 The material properties essential in engineering design can be grouped into three main categories; (1) properties essential for structural analysis, (2) properties essential for assessing manufacturability, and (3) properties essential for evaluating assembly. The properties essential for structural analysis are employed in assessing the structural integrity of the designed part over its useful life or in determining the required geometry of the part to ensure structural integrity. The properties essential for assessing manufacturability are employed in simulating the part filling/post filling steps to optimize processing conditions and for predictions of dimensional stability of the manufactured part. The properties essential for assembly considerations are employed in evaluating the ability to join/assemble the component parts.

5.3 As functional requirements are often specific to each application, the material properties essential for structural analysis can be classified into two categories—those that are somewhat application specific and those that are not.

5.4 Whether the individual property is application-specific or not, certain properties are directly employed in design calculations while others are employed more or less for verification of the design limits. For example, although parts may fail in service under multi-axial impact loading conditions, the impact energy data can be used only in design verification, at best. Additional examples of properties that are useful only for design verification include fatigue (S-N) curves, wear factor, PV limit, retention of properties following exposure to chemicals and solvents, and accelerated aging or UV exposure/outdoor weathering.

5.5 Almost all structural design calculations fall under one of the following types of analysis or some combination thereof: beam or plate; pipe; snap fits, pressfits, threads, bearing, bolts; or buckling. The properties needed for each of these design calculations are summarized in Table 1.

5.6 In plate and beam analyses, flexural modulus is often used in determining the beam deflection or stiffness. However, development of apparent stress gradient across the beam or plate thickness in flexure fails to satisfy the basic assumptions of uniformity of stress in most material models used in engineering analysis. For this reason, tensile modulus is more appropriate and is therefore recommended.

5.7 Creep and fatigue data are commonly reported in flexure. However, the most useful data to the designer is uniaxial loading in tension mode.

5.8 Material properties in molded parts are a function of processing conditions because of their influence on orientation and morphology developed in the molded part. Thus the properties measured from large molded parts may differ from

TABLE 1 Material Properties Needed for Engineering Design Using Plastics

I. Structural Considerations	
Plate or Beam Analysis (stiffness versus deflection)	Pipe Analysis (stiffness versus hoop stresses)
Tensile modulus Poisson's ratio Creep modulus Tensile creep rupture stress Shear strength	Tensile modulus Poisson's ratio Critical stress intensity factor, K_{1c} Tensile creep rupture stress
Snap Fits Analysis (cantilever beam deflection)	Press Fits Analysis (hoop stress)
Tensile modulus Poisson's ratio Creep modulus Secant modulus Shear modulus Tensile strength at yield Coefficient of friction	Tensile modulus Poisson's ratio Compression modulus Compression strength Coefficient of friction Tensile strength at yield Creep modulus Stress relaxation[A]
Threads Analysis (screw pullout forces, thread stripping torque)	Bearing Analysis
Shear strength Coefficient of friction Tensile strength at break Tensile modulus Compressive modulus	Coefficient of friction Coefficient of thermal expansion Wear factor[B] PV limit[B] Compressive yield strength
Bolts Analysis	Buckling Analysis
Compressive strength Tensile creep strain Tensile creep rupture stress Stress relaxation[A] Compressive creep modulus	Compressive modulus Secant modulus Creep modulus Poisson's ratio
II. Manufacturability Considerations	
Mold Filling/Cooling Analysis	Shrinkage and Warpage Analysis
Viscosity—shear rate data Flowability (thermosets) Melt density[B] Thermal conductivity[B] Specific heat[B] Ejection temperature[B] No-flow temperature Cure kinetics (thermosets) pvT data[B]	Mold shrinkage as function of thickness, gate geometry, and processing parameters Coefficient of linear thermal expansion No-flow temperature[B] Glass transition temperature Crystallinity Crystallization temperature Heat of crystallization Crystallization kinetics[B] Elastic modulus Poisson's ratio Shear modulus
III. Assembly Considerations	
Weldability	
Shear strength Density Coefficient of friction Thermal conductivity[B] Specific heat[B] Crystalline melting temperature	

[A] See Practice D 2991.
[B] No ASTM or ISO standards exist today.

those obtained with standard test specimens. Use of filled or reinforced materials may magnify these differences.

5.9 Molded parts frequently display anisotropy. As a result, significant property differences between flow and the transverse directions can result. The use of filled or reinforced materials may magnify this effect. It is, therefore, essential to consider the material properties such as properties in tension, creep, and coefficient of linear thermal expansion, in both directions.

5.10 The required materials characterizations are summarized in Table 2. Suggested conditions are intended to serve as a guide in establishing standardized specific test conditions for the purpose of providing comparable data.

TABLE 2 Material Property Characterization Requirements

	Test Method		Suggested Conditions
	ASTM	ISO	
I. Structural Criteria			
Properties in tension	D 638	527-1, 2, and 4	at 23°C, at least three elevated temperatures and one temperature below standard laboratory conditions at standard strain rate; at three additional strain rates at 23°C
Poisson's ratio	D 638	...	at 23°C, at least one elevated temperature and one temperature below standard laboratory conditions
Properties in compression	D 695	604	at 23°C, two additional elevated temperatures and one temperature below standard laboratory conditions
Shear modulus (DMA/DMTA)	D 5279	6721-2	−150°C to T_g + 20°C or T_m + 10°C at approximately 1 Hz
Creep in tension	D 2990	899-1	at 23°C and at least two elevated temperatures for 1000 h at three stress levels
Fatigue in tension	...	...	(*a*) S − N curves at three Hz at 23°C; 80, 70, 60, 55, 50, and 40 % of tensile stress at yield; R = 0.5; 1 million cycles run out.
	...	...	(*b*) a − N curves at 3 Hz at 23°C; single edge notched specimens; three stress levels; R = 0.5.
Coefficient of friction	D 1894	8295	against itself and steel
Application specific			
Creep in bending	D 2990	899-2	at 23°C and at least two elevated temperatures for 1000 h and at least three stress levels
Creep in compression	D 2990	899	at 23°C and at least two elevated temperatures for 1000 h and at least three stress levels
Fatigue In Bending[A]	...	...	at 23°C; fully reversed; 80, 70, 60, 55, 50, and 40 % of tensile stress at yield at approximately 3 Hz
Fracture toughness	D 5045	...	K_{1c} or G_{1c}
Solvent resistance	D 543	175	Retention of tensile properties exposed to specific chemicals under no strain as well as 0.1, 0.25, and 0.5 % strain
UV Exposure/Weathering	D 2565	4892-2	1. Xenon Arc (0.35 to 0.70 W/m^2 at 340 nm; 65°C black panel; and 50 % RH at approximately 315, 630, 1260, 1890, and 2520 kJ/m^2; borosilicate/borosilicate or equivalent filters); Retention of tensile properties, color (CIELAB, D 65, 10° standard observer, specular included), and 60° Gardner gloss.
	D 1435	4607	2. 45° unbacked outdoor weathering (Florida and Arizona) for 3, 6, 9, 12, 18, and 24 months; Retention of tensile properties, color (CIELAB, D 65, 10° standard observer, specular included), and 60° Gardner gloss.
Accelerated Aging	D 3045	2578	Retention of instrumented impact strength and tensile properties, color and Gloss at three temperatures for 1000 h
II. Manufacturing Criteria			
Viscosity-shear rate data	D 3835	11403-2 and 11443	At approximately three temperatures, over shear rate range 10 to 10 000 s^{-1}
Flowability	D 3123	...	
Melt density	...	...	at 0 MPa and processing temperature
Thermal conductivity	...	...	23°C to processing temperature
Specific heat	...	...	23°C to processing temperature
No-flow temperature	...	...	
Ejection temperature	...	...	
Crystallization temperature	D 3418	...	
Heat of crystallization	D 3417	...	
Glass transition temperature	D 3418	...	
Flowlength versus nominal wall thickness	...	...	simulations at three combinations of melt temperature and mold temperature
pvT data	...	...	23°C to processing temperature; over 0 to 200 bars
Coefficient of linear thermal expansion	E 228	...	over the range − 40° to 85°C
Mold shrinkage	...	294–1	at least two thicknesses as function of cavity pressure, melt temperature, mold temperature, injection time, and fixed gate geometry
Crystallization kinetics	...	...	
Cure kinetics	D 4473	...	

[A] Although the test frequency is restricted to 30 Hz only, Test Method D 671 may, in principle, be used.

6. Data Reporting Format

6.1 Standardization of format for reporting the data for engineering design acquired using harmonized test methods is deemed essential for providing comparable data among similar products from different suppliers.

6.2 In the case of single-point data, the reporting format for each property shall include average, standard deviation, and number of specimens tested. These are required to enhance the confidence level of the designer.

6.3 In the case of multipoint data, the reporting format for each property shall be in both graphical format and tabulated data. The graphical format is desired to illustrate the behavior of the material in response to changes in temperature, time, and strain rate, in a format that is concise, indicative of the trends, and compatible with the needs of design methods employed. The tabulated data lend itself to extraction of the information for design calculations.

7. Keywords

7.1 computer aided design (CAD); computer aided engineering (CAE); engineering design; finite element analysis; manufacturability; plastics; structural analysis

SUMMARY OF CHANGES

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

D 5592 – 94(02)$^{\epsilon 1}$:
(*1*) Updated referenced documents.
(*2*) Made minor editorial changes.