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# Standard Guide for Material Properties Needed in Engineering Design Using Plastics<sup>1</sup>

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## 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 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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.*

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

### 2. Referenced Documents

2.1 *ASTM Standards*:<sup>2</sup>

D543 Practices for Evaluating the Resistance of Plastics to Chemical Reagents

D638 Test Method for Tensile Properties of Plastics

D695 Test Method for Compressive Properties of Rigid Plastics

D883 Terminology Relating to Plastics

D1435 Practice for Outdoor Weathering of Plastics

D1894 Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting

D1999 Guide for Selection of Specimens and Test Parameters from ISO/IEC Standards (Withdrawn 2000)<sup>3</sup>

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

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<sup>2</sup> 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.

<sup>3</sup> 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

D2565 Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications

D2990 Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics

D2991 Test Method for Stress-Relaxation of Plastics (Withdrawn 1990)<sup>3</sup>

D3045 Practice for Heat Aging of Plastics Without Load

D3123 Test Method for Spiral Flow of Low-Pressure Thermosetting Molding Compounds

D3418 Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry

D3641 Practice for Injection Molding Test Specimens of Thermoplastic Molding and Extrusion Materials

D3835 Test Method for Determination of Properties of Polymeric Materials by Means of a Capillary Rheometer

D4473 Test Method for Plastics: Dynamic Mechanical Properties: Cure Behavior

D5045 Test Methods for Plane-Strain Fracture Toughness and Strain Energy Release Rate of Plastic Materials

D5279 Test Method for Plastics: Dynamic Mechanical Properties: In Torsion

E6 Terminology Relating to Methods of Mechanical Testing

E228 Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer

E1823 Terminology Relating to Fatigue and Fracture Testing

2.2 ISO Standards:<sup>4</sup>

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 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 4892-2 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 D883).

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 E6).

3.1.5 *creep*—the time-dependent increase in strain in response to applied stress (modified from Terminology E6).

3.1.6 *creep modulus*—the ratio of initial applied stress to creep strain (see Test Method D2990).

3.1.7 *creep rupture stress*—stress to produce material failure corresponding to a fixed time to rupture (modified from Test Method D2990).

3.1.8 *critical stress intensity factor*—toughness parameter indicative of the resistance of a material to fracture at fracture initiation (see Test Method D5045).

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 E1823).

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 D883).

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 D638).

3.1.13 *PV limit*—the limiting combination of pressure and velocity that will cause failure of any polymer rubbing against

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

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 **D638**).

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 **E6**).

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 **D638**).

3.1.18 *tensile stress at break*—the tensile stress sustained by the material at break (modified from Test Method **D638**).

3.1.19 *tensile stress at yield*—the tensile stress sustained by the material at the yield point (modified from Test Method **D638**).

3.1.20 *warpage*—distortion caused by non-uniform change of internal stresses (**D883**).

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 **D638**).

#### 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, ISO 11403-1, and ISO 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 **D1999**, Practice **D3641**, or ISO 3167 and ISO 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