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Standard Terminology for Plastics: Dynamic Mechanical Properties[1]

This standard is issued under the fixed designation D4092; 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 This terminology is a compilation of definitions and descriptions of technical terms used in dynamic mechanical property measurements on polymeric materials, including solutions, melts, and solids. Terms that are generally understood or defined adequately in other readily available sources are either not included or sources identified.

1.2 A definition is a single sentence with additional information included in notes. It is reviewed every five years and the year of the last review or revision is appended.

1.3 Definitions identical to those published by another standards organization or ASTM committee are identified with the abbreviation of the name of the organization or the ASTM committee.

1.4 Descriptions of terms specific to dynamic mechanical measurements are identified with an italicized introductory phrase.

NOTE 1—This terminology standard is similar to ISO 6721–1 however, the ISO document cites fewer terms.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D883 Terminology Relating to Plastics

D2231 Practice for Rubber Properties in Forced Vibration (Withdrawn 1998)[3]

E6 Terminology Relating to Methods of Mechanical Testing

2.2 *ISO Standards:*[4]

ISO 472: 1988 (E/F) Definitions

ISO 6721–1 1994 (E) Plastics-Determination of Dynamic Mechanical Properties, Part 1, General Principles

3. Terminology Definitions and Descriptions

alpha (α) loss peak (*in dynamic mechanical measurement*)**—**the first peak in the damping curve below the melt, in order of decreasing temperature or increasing frequency. (1981)

beta (β) loss peak (*in dynamic mechanical measurement*)**—**the second peak in the damping curve below the melt, in order of decreasing temperature or increasing frequency. (1981)

complex modulus, *E*, K*,* or *G**—the ratio of the stress to strain where each is a vector that may be represented by a complex number.

$$E^* = E' + iE''$$
$$G^* = G' + iG''$$
$$K^* = K' + iK''$$

where:

E^* = complex modulus, measured in tension or flexure,
E' = storage modulus, measured in tension or flexure,
E'' = loss modulus, measured in tension or flexure,

G^* = complex modulus, measured in shear,
G' = storage modulus, measured in shear,
G'' = loss modulus, measured in shear,

K^* = complex modulus, measured in compression,
K' = storage modulus, measured in compression
K'' = loss modulus, measured in compression, and
i = $\sqrt{-1}$, measured in compression.

DISCUSSION—The complex modulus may be measured in tension (E^*), compression (K^*), flexure (E^*), or in shear (G^*). (1981)

complex shear compliance, *J **—the reciprocal of complex shear modulus. (1981)

$$J^* = \frac{1}{G^*}$$

[1] This terminology 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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[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.

[4] 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**

complex tensile compliance, D^*—the reciprocal of complex tensile modulus. (1981)

$$D^* = \frac{1}{E^*}$$

critical damping (*in dynamic mechanical measurement*)**—**that damping required for the borderline condition between oscillatory and nonoscillatory behavior. (1983).

damping—the loss in energy, dissipated as heat, that results when a material or material system is subjected to an oscillatory load or displacement. (1981)

damping ratio, μ —the ratio of actual damping to critical damping. (1983).

DISCUSSION—Damping ratio is a function of the logarithmic decrement (Δ):

$$\mu = \frac{\Delta/2\pi}{\sqrt{1+(\Delta/2\pi)^2}} = \sin\arctan(\Delta/2\pi)$$

For small values of Δ, it is: $\mu = \Delta/2\pi$

dissipation factor— see **tan delta.**

dynamic mechanical measurement—a technique in which either the modulus or damping, or both, of a substance under oscillatory load or displacement is measured as a function of temperature, frequency, or time, or combination thereof. (1981)

dynamic modulus—see **complex modulus.**

elasticity—that property of materials that causes them to return to their original form or condition after the applied force is removed. (1981)

elastic modulus—see **complex modulus and storage modulus.**

energy loss—the energy per unit volume that is lost in each deformation cycle. (ISO) (1983)

DISCUSSION—Energy loss is the hysteresis loop area, calculated with reference to coordinate scales.

free vibration (*in dynamic mechanical measurement*)**—**a technique for performing dynamic mechanical measurements in which the sample is deformed, released, and allowed to oscillate freely at the system's natural resonant frequency.

DISCUSSION—Elastic modulus is calculated from the measured resonant frequency, and damping is calculated from the rate at which the amplitude of the oscillation decays. (1981)

frequency profile , *n*—a plot of the dynamic properties of a material, at a constant temperature, as a function of test frequency. (1981)

gamma (γ) loss peak , *n*—the third peak in the damping curve below the melt, in the order of decreasing temperature or increasing frequency. (1981)

glass transition—the reversible change in amorphous polymer, or in amorphous regions of a partially crystalline polymer, from (or to) a viscous or rubbery condition to (or from) a hard and relatively brittle one.

DISCUSSION—The glass transition generally occurs over a relatively narrow temperature region and is similar to the solidification of a liquid to a glassy state; it is not a phase transition. Not only do hardness and brittleness undergo rapid changes in this temperature region, but other properties, such as coefficient of thermal expansion and specific heat, also change rapidly. This phenomenon has been called second-order transition, rubber transition, and rubbery transition. The word transformation has also been used instead of transition. When more than one amorphous transition occurs in a polymer, the one associated with segmental motions of the polymer backbone chain, or accompanied by the largest change in properties, is usually considered to be the glass transition. (D20) (1981)

glass transition temperature, T_g —the approximate midpoint of the temperature range over which the glass transition takes place.

DISCUSSION—The glass transition temperature can be determined readily only by observing the temperature at which a significant change takes place in a specific electrical, mechanical, or other physical property. Moreover, the observed temperature can vary significantly, depending on the specific property chosen for observation and on details of the experimental technique (for example, rate of heating, frequency). Therefore, the observed T_g should be considered only an estimate. The most reliable estimates are normally obtained from the loss peak observed in dynamic mechanical tests or from dilatometric data. (D20) (1981)

hysteresis loop (*in dynamic mechanical measurement*)**—**the closed curve representing successive stress-strain status of the material during a cyclic deformation. (ISO) (1983)

DISCUSSION—Hysteresis loops may be centered around the origin of coordinates or, more frequently, displaced to various levels of strain or stress; in this case, the shape of the loop becomes variously asymmetrical, but this fact is frequently disregarded.

logarithmic decrement, Δ (*in dynamic mechanical measurement*)**—**the natural logarithm of the ratio of any two (or more) successive amplitudes of like sign, in the decay of single frequency oscillation:

$$\Delta = \frac{1}{k} \ln\frac{A_n}{A_{n+k}}$$

where: A_n and A_{n+k} are amplitudes (in radians of rotation) of two oscillations, and k is the number of oscillations separating the two amplitude measurements. (1981)

loss angle, δ— see **phase angle.**

loss factor—see **tan δ.**

loss modulus—M''(Pa)—[loss compliance O" (Pa^{-1})]: the imaginary part of the complex modulus (compliance).

DISCUSSION—It is a measure of the energy lost (dissipated during a loading cycle). (See also **complex modulus** and **complex compliance**.) (See ISO 6721–1.)

loss tangent—see **tan delta.**

mean modulus—the ratio of mean stress to mean strain. (ISO) (1983)

mean strain—the average value of strain during a single complete hysteresis loop of cyclic deformation. (ISO) (1983)

mean stress—the average value of the stress during a single complete hysteresis loop of cyclic deformation. (ISO) (1983)

modulus, complex—see **complex modulus.**

modulus, elastic—see **complex modulus and storage modulus.**

modulus, loss—see **complex modulus and loss modulus.**

modulus, storage—see **complex modulus and storage modulus.**

modulus of elasticity— see **complex modulus and storage modulus.**

nonresonant forced and vibration technique , *n*—a technique for performing dynamic mechanical measurements, in which the sample is oscillated mechanically at a fixed frequency.

DISCUSSION—Storage modulus and damping are calculated from the applied strain and the resultant stress and shift in phase angle. (1981)

normal stress, s—the stress component perpendicular to a plane on which the forces act. (E28) (1981)

phase angle, δ—the angle between a sinusoidally applied strain and the resultant sinusoidal stress. (1981)

Poisson's ratio, ν—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.

DISCUSSION—Poisson's ratio will have more than one value if the material is anisotropic. (E-28) (1981)

power loss—the power, per unit volume, that is transformed into heat through hysteresis. (ISO) (1983)

DISCUSSION—Power loss is the product of energy loss and frequency.

quality factor, Q—the ratio of elastic modulus to loss modulus, measured in tension, compression, flexure, or shear.

DISCUSSION—The quality factor is a nondimensional term. The quality factor is the reciprocal of tan delta. (1981)

relative rigidity (*in dynamic mechanical measurement*)**—**the ratio of modulus at any temperature, frequency, or time to the modulus at a reference temperature, frequency, or time. (1981)

resonant forced vibration technique (*in dynamic mechanical measurement*)**—**a technique for performing dynamic mechanical measurements, in which the sample is oscillated mechanically at the system's natural resonant frequency.

DISCUSSION—The amplitude of oscillation is maintained constant through the addition of makeup energy. Elastic modulus is calculated from the measured frequency. Damping is calculated from the additional energy required to maintain constant amplitude. (1981)

root–mean–square strain—the square root of the mean value of the square of the strain, averaged over one cycle of deformation. (ISO) (1983).

DISCUSSION—For a symmetrical sinusoidal strain, the root-mean-square strain equals the strain amplitude divided by $\sqrt{2}$.

root–mean–square stress—the square root of the mean value of the square of the stress, averaged over one cycle of deformation. (ISO) (1983)

DISCUSSION—For a symmetrical sinusoidal stress, the root-mean-square stress equals the stress amplitude divided by $\sqrt{2}$.

shear—an action or stress, resulting from applied forces, which causes (or tends to cause) two contiguous parts of a body to slide, relative to each other, in a direction parallel to their plane of contact. (1981)

shear modulus, *G* (Pa) —the quotient of shear stress and shear strain. (See ISO 537.)

$$G = \frac{\sigma}{\gamma}$$

shear rate, γ—the time rate of change of shear strain. For a one-dimensional shear flow, it is the velocity gradient. (1981)

shear strain, γ—the tangent of the angular change, due to force, between two lines originally perpendicular to each other through a point in a body. (E-28) (1981)

shear stress, τ—the stress component tangential to the plane on which forces act. (E-28) (1981)

storage compliance, *C* (Pa^{-1})—the quotient of strain and stress.

$$C = \frac{\varepsilon}{\sigma} = \frac{1}{M}$$

where: *D* is the tensile compliance; *J* is the shear compliance; *C* is the storage compliance; and *M* is the storage modulus.

storage modulus—*M'* (Pa), [storage compliance *C* (Pa $^{-1}$)]— the real part of the complex modulus (complex compliance).

DISCUSSION—It is a measure of the energy stored and retained during a loading cycle. (See also **complex modulus** and **complex compliance.**) (See ISO 6721–1.)

strain, ε—the unit change, due to force, in the size or shape of a body referred to its original size or shape.

DISCUSSION—Strain at a point is defined by six components of strain: three normal components and three shear components, referred to a set of coordinate axes. With appropriate rotation of coordinate axis, the strain may be fully described by three normal components alone. (E-28) (1981)

strain amplitude—the ratio of the maximum deformation, measured from the mean deformation, to the free length of the unstrained test specimen. (ISO) (1983)

DISCUSSION—Strain amplitude is measured zero to peak on one side only.

stress, σ—the intensity at a point in a body of the internal forces or components of force that act on a given plane through the point. (E-28) (1981)

stress amplitude—the ratio of the maximum applied force, measured from the mean force, to the cross-sectional area of the unstressed test specimen. (ISO) (1983)

tan delta, tan δ—the ratio of the loss modulus to the storage modulus, measured in compression, tension, flexure, or shear. (1981)

$$Tan\,\delta = \frac{K''}{K'} = \frac{E''}{E'} = \frac{G''}{G'}$$

time profile—a plot of the modulus or damping, or both of a material versus time. (1981)

torsional pendulum—a device for performing dynamic mechanical analysis, in which the sample is deformed torsionally and allowed to oscillate in free vibration.

DISCUSSION—Modulus is determined by the frequency of the resultant oscillation, and damping is determined by the decreasing amplitude of the oscillation. (1981)

torsional stress—the shear stress on a transverse cross section, resulting from a twisting action. (E-28) (1981)

viscosity, η—the property of resistance to steady flow exhibited within the body of the material.

DISCUSSION—In determining the ratio of the shearing stress to the rate of shear of a fluid, viscosity is usually taken to mean "Newtonian Viscosity", in which case the ratio of shearing stress to the rate of shearing strain is constant. In non-Newtonian behavior, which is the usual case with plastic materials, the ratio varies with the shearing rate. Such ratios are often called the "Apparent Viscosity" at the corresponding shear rate. (D20) (1981)

viscosity coefficient—the shearing stress necessary to induce a unit velocity gradient in a material.

DISCUSSION—In actual measurement, the viscosity coefficient of a material is obtained from the ratio of shearing stress to shearing rate. This assumes the ratio to be constant and independent of the shearing stress, a condition which is satisfied only by Newtonian fluids. Consequently, in all other cases, values obtained are apparent and represent one point in the flow curve. (D20) (1981)