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Plastics — Determination of dynamic mechanical properties

Part 1. General principles

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ICS 83.080

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Committees responsible for this British Standard

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- The British Apparel and Textile Confederation
- British Plastics Federation
- Department of the Environment (Building Research Establishment)
- Department of Trade and Industry (National Physical Laboratory)
- Electrical and Electronic Insulation Association (BEAMA Ltd.)
- GAMBICA (BEAMA Ltd.)
- Institute of Materials
- Ministry of Defence
- Packaging and Industrial Films Association
- PIRA International
- RAPRA Technology Ltd.
- Royal Society of Chemistry

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National foreword

This British Standard has been prepared by Technical Committee PRI/21 and is the English language version of EN ISO 6721-1 : 1996 *Plastics — Determination of dynamic mechanical properties — Part 1 : General principles*. It is identical with ISO 6721-1 : 1994 including its Technical Corrigendum 1 : March 1995, published by the International Organization for Standardization (ISO).

This three part series of standards has been dual-numbered with BS 2782 *Methods of testing plastics Part 3 Mechanical properties* as follows:

BS EN ISO 6721-1 is designated Method 342A

BS EN ISO 6721-2 is designated Method 342B

BS EN ISO 6721-3 is designated Method 338A

Cross-references

Publication referred to	Corresponding British Standard
ISO 293 : 1986	BS 2782 <i>Methods of testing plastics</i> Part 9 <i>Sampling and test specimen preparation</i> Method 901A : 1988 <i>Compression moulding test specimens of thermoplastic materials</i>
ISO 294 : 1996 ¹⁾	Method 910A : 1977 <i>Injection moulding test specimens of thermoplastic materials</i>
ISO 295 : 1991	Method 902A : 1992 <i>Plastics. Compression moulding of test specimens of thermosetting materials</i>
ISO 1268 : 1974	Method 920A to 920C : 1977 <i>Preparation of glass fibre reinforced, resin bonded, low-pressure laminated plates or panels for test purposes</i>
ISO 4593 : 1993	Part 6 <i>Dimensional properties</i> Method 630A : 1994 <i>Determination of thickness by mechanical scanning of flexible sheet</i>
ISO 6721-2 : 1994	BS EN ISO 6721 <i>Plastics — Determination of dynamic mechanical properties</i>
ISO 6721-3 : 1994	BS EN ISO 6721-2 : 1996 <i>Torsion pendulum method</i> BS EN ISO 6721-3 : 1996 <i>Flexural vibration — Resonance curve method</i>

NOTE. International and European Standards as well as overseas standards, are available from Customer Services, BSI, 389 Chiswick High Road, London, W4 4AL.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

¹⁾In preparation. The cited British Standard is identical with ISO 294 : 1975.

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English version

Plastics — Determination of dynamic mechanical properties — Part 1: General principles

(ISO 6721-1 : 1994, including Technical Corrigendum 1 : 1995)

Plastiques — Détermination des propriétés
mécaniques dynamiques —
Partie 1: Principes généraux
(ISO 6721-1 : 1994, Rectificatif Technique 1 : 1995
inclus)

Kunststoffe — Bestimmung
dynamisch-mechanischer Eigenschaften —
Teil 1: Allgemeine Grundlagen
(ISO 6721-1 : 1994, einschließlich Technische
Korrektur 1 : 1995)

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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Foreword

The text of the International Standard from Technical Committee ISO/TC 61, Plastics, of the International Organization for Standardization (ISO) has been taken over as a European Standard by Technical Committee CEN/TC 249, Plastics, the secretariat of which is held by IBN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 1996, and conflicting national standards shall be withdrawn at the latest by August 1996.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

The methods specified in the various parts of ISO 6721 can be used for determining storage and loss moduli of plastics over a range of temperatures or frequencies by varying the temperature of the specimen or the frequency of oscillation. Plots of the storage or loss moduli, or both, are indicative of viscoelastic characteristics of the specimen. Regions of rapid changes in viscoelastic properties at particular temperatures or frequencies are normally referred to as transition regions. Furthermore, from the temperature and frequency dependencies of the loss moduli, the damping of sound and vibration of polymer or metal-polymer systems can be estimated.

Apparent discrepancies may arise in results obtained under different experimental conditions. Without changing the observed data, reporting in full (as described in the various parts of ISO 6721) the conditions under which the data were obtained will enable apparent differences observed in different studies to be reconciled.

The definitions of complex moduli apply exactly only to sinusoidal oscillations with constant amplitude and constant frequency during each measurement. On the other hand, measurements of small phase angles between stress and strain involve some difficulties under these conditions. Because these difficulties are not involved in some methods based on freely decaying vibrations and/or varying frequency near resonance, these methods are used frequently (see part 2 and part 3). In these cases, some of the equations that define the viscoelastic properties are only approximately valid.

Plastics — Determination of dynamic mechanical properties —

Part 1: General principles

1 Scope

The various parts of ISO 6721 specify methods for the determination of the dynamic mechanical properties of rigid plastics within the region of linear viscoelastic behaviour. Part 1 is an introductory section which includes the definitions and all aspects that are common to the individual test methods described in the subsequent parts.

Different deformation modes may produce results that are not directly comparable. For example, tensile vibration results in a stress which is uniform across the whole thickness of the specimen, whereas flexural measurements are influenced preferentially by the properties of the surface regions of the specimen.

Values derived from flexural-test data will be comparable to those derived from tensile-test data only at strain levels where the stress-strain relationship is linear and for specimens which have a homogeneous structure.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 6721. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 6721 are encouraged to investigate the possibility of applying the most recent editions of the

standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 291:1977, *Plastics — Standard atmospheres for conditioning and testing*.

ISO 293:1986, *Plastics — Compression moulding test specimens of thermoplastic materials*.

ISO 294:—¹⁾, *Plastics — Injection moulding of test specimens of thermoplastic materials*.

ISO 295:1991, *Plastics — Compression moulding of test specimens of thermosetting materials*.

ISO 1268:1974, *Plastics — Preparation of glass fibre reinforced, resin bonded, low-pressure laminated plates or panels for test purposes*.

ISO 2818:1994, *Plastics — Preparation of test specimens by machining*.

ISO 4593:1993, *Plastics — Film and sheeting — Determination of thickness by mechanical scanning*.

ISO 6721-2:1994, *Plastics — Determination of dynamic mechanical properties — Part 2: Torsion-pendulum method*.

ISO 6721-3:1994, *Plastics — Determination of dynamic mechanical properties — Part 3: Flexural vibration — Resonance-curve method*.

1) To be published. (Revision of ISO 294:1975)

3 Definitions

For the purposes of the various parts of this International Standard, the following definitions apply.

NOTE 1 Most of the terms defined here are also defined in ISO 472:1988, *Plastics — Vocabulary*. The definitions given here are not strictly identical with, but are equivalent to, those in ISO 472:1988.

3.1 complex modulus, M^* : The ratio of dynamic stress, given by $\sigma(t) = \sigma_A \exp(i2\pi ft)$, and dynamic strain, given by $\varepsilon(t) = \varepsilon_A \exp[i(2\pi ft - \delta)]$, of a viscoelastic material that is subjected to a sinusoidal vibration, where σ_A and ε_A are the amplitudes of the stress and strain cycles, f is the frequency, δ is the phase angle between stress and strain (see 3.5 and figure 1) and t is time.

It is expressed in pascals (Pa).

Depending on the mode of deformation, the complex modulus may be one of several types: E^* , G^* , K^* or L^* (see table 3).

$$M^* = M' + iM'' \quad (\text{see 3.2 and 3.3}) \quad \dots (1)$$

where

$$i = (-1)^{1/2} = \sqrt{-1}$$

For the relationships between the different types of complex modulus, see table 1.

NOTES

2 For isotropic viscoelastic materials, only two of the elastic parameters G^* , E^* , K^* , L^* and μ^* are independent (μ^* is the complex Poisson's ratio, given by $\mu^* = \mu' + i\mu''$).

3 The most critical term containing Poisson's ratio μ is the "volume term" $1 - 2\mu$, which has values between 0 and 0,4 for μ between 0,5 and 0,3. The relationships in table 1 containing the "volume term" $1 - 2\mu$ can only be used if this term is known with sufficient accuracy.

It can be seen from table 1 that the volumetric term $1 - 2\mu$ can only be estimated with any confidence from a knowledge of the bulk modulus K or the uniaxial-strain modulus L and either E or G . This is because K and L measurements involve deformations when the volumetric strain component is relatively large.

4 Up to now, no measurements of the dynamic mechanical bulk modulus K , and only a small number of results relating to relaxation experiments measuring $K(t)$, have been described in the literature.

5 The uniaxial-strain modulus L is based upon a load with a high hydrostatic-stress component. Therefore values of L compensate for the lack of K values, and the "volume term" $1 - 2\mu$ can be estimated with sufficient accuracy based upon the modulus pairs (G, L) and (E, L) . The pair (G, L) is preferred, because G is based upon loads without a hydrostatic component.

6 The relationships given in table 1 are valid for the complex moduli as well as their magnitudes (see 3.4).

7 Most of the relationships for calculating the moduli given in the other parts of this International Standard are, to some extent, approximate. They do not take into account e.g. "end effects" caused by clamping the specimens, and they include other simplifications. Using the relationships given in table 1 therefore often requires additional corrections to be made. These are given in the literature (see e.g. references [1] and [2] in the bibliography).

8 For linear-viscoelastic behaviour, the complex compliance C^* is the reciprocal of the complex modulus M^* , i.e.

$$M^* = (C^*)^{-1} \quad \dots (2)$$

Thus

$$M' + iM'' = \frac{C' - iC''}{(C')^2 + (C'')^2} \quad \dots (3)$$

3.2 storage modulus, M' : The real part of the complex modulus M^* [see figure 1 b)].

The storage modulus is expressed in pascals (Pa).

It is proportional to the maximum energy stored during a loading cycle and represents the stiffness of a viscoelastic material.

The different types of storage modulus, corresponding to different modes of deformation, are: E'_t tensile storage modulus, E'_f flexural storage modulus, G'_s shear storage modulus, G'_{to} torsional storage modulus, K' bulk storage modulus, L'_c uniaxial-strain and L'_w longitudinal-wave storage modulus.

3.3 loss modulus, M'' : The imaginary part of the complex modulus [see figure 1 b)].

The loss modulus is expressed in pascals (Pa).

It is proportional to the energy dissipated (lost) during one loading cycle. As with the storage modulus (see 3.2), the mode of deformation is designated as in table 3, e.g. E''_t is the tensile loss modulus.

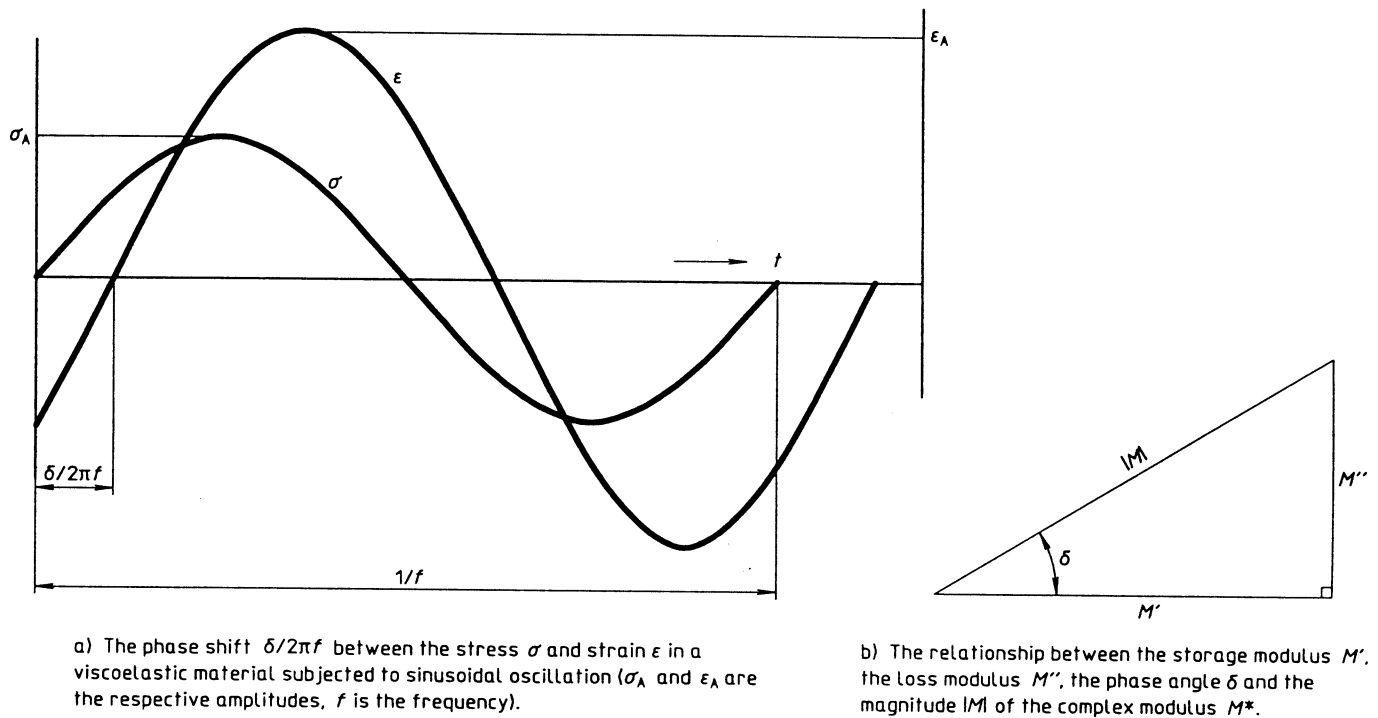


Figure 1 — Phase angle and complex modulus

Table 1 — Relationships between moduli for uniformly isotropic materials

	G and μ	E and μ	K and μ	G and E	G and K	E and K	G and L ¹⁾
Poisson's ratio, μ $1 - 2\mu = 2)$				$3 - \frac{E}{G}$	$\frac{G/K}{1 + G/3K}$	$\frac{E}{3K}$	$\frac{1}{L/G - 1}$
Shear modulus, $G =$		$\frac{E}{2(1 + \mu)}$	$\frac{3K(1 - 2\mu)}{2(1 + \mu)}$			$\frac{E}{3 - E/3K}$	
Tensile modulus, $E =$	$2G(1 + \mu)$		$3K(1 - 2\mu)$		$\frac{3G}{1 + G/3K}$		$\frac{3G(1 - 4G/3L)}{1 - G/L}$
Bulk modulus, $K =$ ³⁾	$\frac{2G(1 + \mu)}{3(1 - 2\mu)}$	$\frac{E}{3(1 - 2\mu)}$		$\frac{G}{3(3G/E - 1)}$			$L - \frac{4G}{3}$
Unaxial-strain or longitudinal-wave modulus, $L =$	$\frac{2G(1 - \mu)}{1 - 2\mu}$	$\frac{E(1 - \mu)}{(1 + \mu)(1 - 2\mu)}$	$\frac{3K(1 - \mu)}{1 + \mu}$	$\frac{G(4G/E - 1)}{3G/E - 1}$	$K + \frac{4G}{3}$	$\frac{K(1 + E/3K)}{1 - E/9K}$	
1) See note 5. 2) See note 3. 3) See note 4.							