INTERNATIONAL STANDARD

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Fourth edition
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# Plastics — Determination of dynamic mechanical properties —

## Part 1: General principles

*Plastiques — Détermination des propriétés mécaniques dynamiques —*

*Partie 1: Principes généraux*



Reference number
ISO 6721-1:2019(E)

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# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.



This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 5, *Physical-chemical properties*.

This fourth edition cancels and replaces the third edition (ISO 6721-1:2011), which has been technically revised. The main changes compared to the previous edition are as follows:

— the document has been revised editorially;

— normative references have been changed to undated and added as references into Tables 4 and 5.

A list of all parts in the ISO 6721 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# Introduction

The methods specified in the first nine 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 ISO 6721-2 and ISO 6721-3). 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. This document specifies the definitions and describes the general principles including all aspects that are common to the individual test methods described in the subsequent parts.

Different deformation modes can 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 documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

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

ISO 6721-4, *Plastics — Determination of dynamic mechanical properties — Part 4: Tensile vibration — Non-resonance method*

ISO 6721-5, *Plastics — Determination of dynamic mechanical properties — Part 5: Flexural vibration — Non-resonance method*

ISO 6721-6, *Plastics — Determination of dynamic mechanical properties — Part 6: Shear vibration — Non-resonance method*

ISO 6721-7, *Plastics — Determination of dynamic mechanical properties — Part 7: Torsional vibration — Non-resonance method*

ISO 6721-8, *Plastics — Determination of dynamic mechanical properties — Part 8: Longitudinal and shear vibration — Wave-propagation method*

ISO 6721-9, *Plastics — Determination of dynamic mechanical properties — Part 9: Tensile vibration — Sonic-pulse propagation method*

ISO 6721-10, *Plastics — Determination of dynamic mechanical properties — Part 10: Complex shear viscosity using a parallel-plate oscillatory rheometer*

ISO 6721-12, *Plastics — Determination of dynamic mechanical properties — Part 12: Compressive vibration — Non-resonance method*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

NOTE Some of the terms defined here are also defined in ISO 472. The definitions given here are not strictly identical with, but more detailed than those in ISO 472.

### 3.1
**complex modulus**
$M^*$
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 $\sigma_A$ and $\varepsilon_A$ are the amplitudes of the stress and strain cycles, $f$ is the frequency, $\delta$ is the phase angle between stress and strain and $t$ is time



Note 1 to entry: It is expressed in Pascals (Pa).

Note 2 to entry: The *phase angle* (3.5), $\delta$, is shown in Figure 1.

Note 3 to entry: Depending on the mode of deformation, the complex modulus might be one of several types: $E^*$, $G^*$, $K^*$ or $L^*$ (see Table 3).



$$M^* = M' + i\, M''$$

where $i = (-1)^{1/2} = \sqrt{-1}$ and $M'$ and $M''$ are as defined in 3.2 and 3.3 respectively.

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

Note 4 to entry: For isotropic viscoelastic materials, only two of the elastic parameters $G^*$, $E^*$, $K^*$, $L^*$ and $\mu^*$ are independent ($\mu^*$ is the complex Poisson's ratio, given by $\mu^* = \mu' + i\mu''$).

Note 5 to entry: The most critical term containing Poisson's ratio $\mu$ is the "volume term" $1 - 2\mu$, which has values between 0 and 0,4 for $\mu$ 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 "volume 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.

Note 6 to entry: Up to now, no measurement 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.

Note 7 to entry: 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.

Note 8 to entry: The relationships given in Table 1 are valid for the complex moduli as well as their *magnitudes* (3.4).

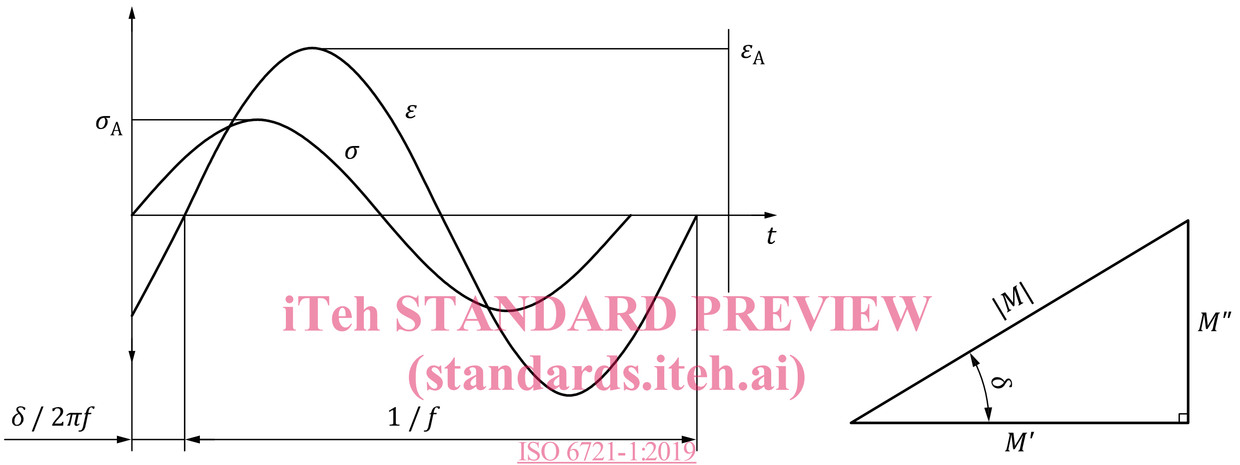
Note 9 to entry: Most of the relationships for calculating the moduli given in the other parts of this International Standard are, to some extent, approximate. They do not take into account, for example "end effects" caused by clamping the specimens, and they include other simplifications. Using the relationships given in Table 1 therefore often requires additional corrections to be made. These are given in the literature (see e.g. References [7] and [8] in the Bibliography).

Note 10 to entry: For linear-viscoelastic behaviour, the complex compliance $C^*$ is the reciprocal of the complex modulus $M^*$, i.e.

$$M^* = (C^*)^{-1}$$

Thus

$$M' + \mathrm{i}M'' = \frac{C' - \mathrm{i}C''}{(C')^2 + (C'')^2}$$






**a) Phase shift $\delta/2\pi f$ between the stress $\sigma$ and strain $\varepsilon$ in a viscoelastic material subjected to sinusoidal oscillation ($\sigma_A$ and $\varepsilon_A$ are the respective amplitudes, $f$ is the frequency)**

**b) Relationship between the storage modulus $M'$, the loss modulus $M''$, the phase angle $\delta$ and the magnitude [$M$] of the complex modulus $M^*$**

**Figure 1 — Phase angle and complex modulus**

**Table 1 — Relationships between moduli for uniformly isotropic materials**

| | $G$ and $\mu$ | $E$ and $\mu$ | $K$ and $\mu$ | $G$ and $E$ | $G$ and $K$ | $E$ and $K$ | $G$ and $L$[a] |
|---|---|---|---|---|---|---|---|
| Poisson's ratio, $\mu$ 1 − 2$\mu$ = [b] | | | | $3-\frac{E}{G}$ | $\frac{G/K}{1+G/3K}$ | $\frac{E}{3K}$ | $\frac{1}{L/G-1}$ |
| 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, $K$ = [c] | $\frac{2G(1+\mu)}{3(1-2\mu)}$ | $\frac{E}{3(1-2\mu)}$ | | $\frac{G}{3(3G/E-1)}$ | | | $L-\frac{4G}{3}$ |
| Unaxial-strain or longitudi-nal-wave modulus, $L$ = | $\frac{2G(1-\mu)}{1-2\mu}$ | $\frac{E(1-\mu)}{(1+\mu)(1-2\mu)}$ | $\frac{3K(1-\mu)}{1+\mu}$ | $\frac{G(4G/E-1)}{3G/E-1}$ | $K+\frac{4G}{3}$ | $\frac{K(1+E/3K)}{1-E/9K}$ | |

a See 3.1, Note 7 to entry

b See 3.1, Note 5 to entry.

c See 3.1, Note 6 to entry.



### 3.2
**storage modulus**

$M'$

real part of the complex modulus $M^*$

Note 1 to entry: The storage modulus is expressed in pascals (Pa).



Note 2 to entry: The storage modulus $M'$ is shown in Figure 1 b).

Note 3 to entry: It is proportional to the maximum energy stored during a loading cycle and represents the stiffness of a viscoelastic material.

Note 4 to entry: 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 storage modulus and $L'_w$ longitudinal-wave storage modulus.

### 3.3
**loss modulus**

$M''$

imaginary part of the complex modulus

Note 1 to entry: The loss modulus is expressed in pascals (Pa).

Note 2 to entry: The loss modulus $M''$ is shown in Figure 1 b).

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

### 3.4
**magnitude of the complex modulus**

$[M]$

root mean square value of the storage and the loss moduli as given by the formula

$$[M]^2 = (M')^2 + (M'')^2 = (\sigma_A / \varepsilon_A)^2$$

where $\sigma_A$ and $\varepsilon_A$ are the amplitudes of the stress and the strain cycles, respectively

Note 1 to entry: The complex modulus is expressed in pascals (Pa).

Note 2 to entry: The relationship between the storage modulus $M'$, the loss modulus $M''$, the phase angle $\delta$, and the magnitude $[M]$ of the complex modulus is shown in Figure 1 b). As with the storage modulus, the mode of deformation is designated as in Table 3, e.g. $[E_t]$ is the magnitude of the tensile complex modulus.

**3.5**
**phase angle**
$\delta$
phase difference between the dynamic stress and the dynamic strain in a viscoelastic material subjected to a sinusoidal oscillation

Note 1 to entry: The phase angle is expressed in radians (rad).

Note 2 to entry: The phase angle $\delta$ is shown in Figure 1.

Note 3 to entry: As with the *storage modulus* (3.2), the mode of deformation is designated as in Table 3, e.g. $\delta_t$ is the tensile phase angle.

**3.6**
**loss factor**
$\tan \delta$
ratio between the loss modulus and the storage modulus given by the formula

$$\tan \delta = M'' / M'$$



where $\delta$ is the phase angle between the stress and the strain

Note 1 to entry: The loss factor is expressed as a dimensionless number.



Note 2 to entry: The ratio between loss modulus $M''$ and storage modulus $M'$ is shown in Figure 1 b).

Note 3 to entry: The loss factor $\tan \delta$ is commonly used as a measure of the damping in a viscoelastic system. As with the *storage modulus* (3.2), the mode of deformation is designated as in Table 3, e.g. $\tan \delta_t$ is the tensile loss factor.

**3.7**
**stress-strain hysteresis loop**
stress expressed as a function of the strain in a viscoelastic material subject to sinusoidal vibrations

Note 1 to entry: Provided the viscoelasticity is linear in nature, this curve is an ellipse (see Figure 2).

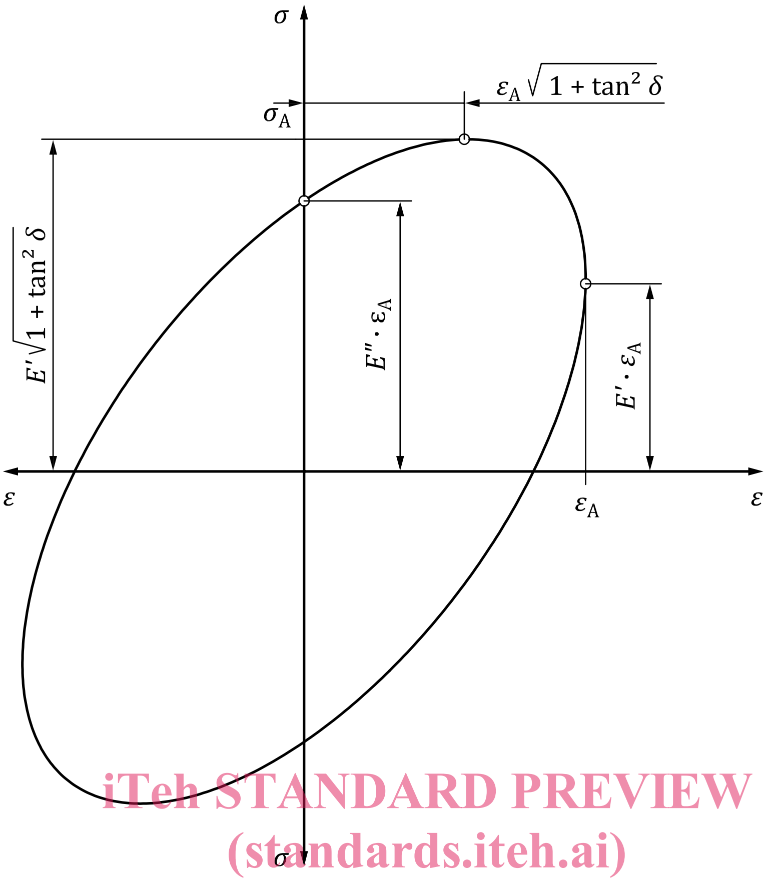





**Figure 2 — Dynamic stress-strain hysteresis loop for a linear-viscoelastic material subject to sinusoidal tensile vibrations**



**3.8**
**damped vibration**
time-dependent deformation or deformation rate $X(t)$ of a viscoelastic system undergoing freely decaying vibrations, given by the formula

$$X(t) = X_0 \exp(-\beta t) \times \sin 2\pi f_d t$$

where

$X_0$ is the magnitude, at zero time, of the envelope of the cycle amplitudes;

$f_d$ is the frequency of the damped system;

$\beta$ is the *decay constant* (3.9)

Note 1 to entry: A typical curve of freely decaying damped vibrations is shown in Figure 3.