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

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## Foreword

This translation has been made based on the original Japanese Industrial Standard established by the Minister of International Trade and Industry through deliberations at Japanese Industrial Standards Committee in accordance with the Industrial Standardization Law:

**JIS K 7244** consists of the following parts, under the general title *Plastics—Determination of dynamic mechanical properties*:

*Part 1 : General principles*

*Part 2 : Torsion-pendulum method*

*Part 3 : Flexural vibration—Resonance-curve method*

*Part 4 : Tensile vibration—Non-resonance method*

*Part 5 : Flexural vibration—Non-resonance method*

*Part 6 : Shear vibration—Non-resonance method*

*Part 7 : Torsional vibration—Non-resonance method*

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

**Introduction** This Japanese Industrial Standard has been prepared based on ISO 6721-1 : 1994, *Plastics—Determination of dynamic mechanical properties—Part 1 : General principles* without modifying its technical content and structure.

The parts underlined with dots are items not included in the original International Standard.

**1 Scope** The various parts of this Standard specify methods for the determination of the dynamic mechanical properties of rigid plastics within the region of linear viscoelastic behavior. 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 the Standard. 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 the Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

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

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

Informative reference : JIS K 7151 *Plastics—Compression moulding test specimens of thermoplastic materials* is identical with ISO 293.

ISO 294 : — *Plastics—Injection moulding of test specimens of thermoplastic materials*

Informative reference : JIS K 7152 *Plastics—Injection moulding of test specimens of thermoplastic materials* is identical with ISO 294.

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*

Informative reference : JIS K 7144 *Plastics—Preparation of test specimens by machining* is identical with ISO 2818.

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*

Informative reference : JIS K 7244-2 *Plastics—Determination of dynamic mechanical properties—Part 2 : Torsion-pendulum method* is identical with ISO 6721-2.

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

**3 Definitions** For the purposes of the various parts of this Standard, the following definitions apply.

**Remarks 1** Most of the terms defined here are also defined in **JIS K 6900-1994 (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  $\sigma_A$  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 (see 3.5 and Fig. 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).

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

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

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

**Remarks 2** 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  $\mu^* = \mu' + i\mu''$ ).

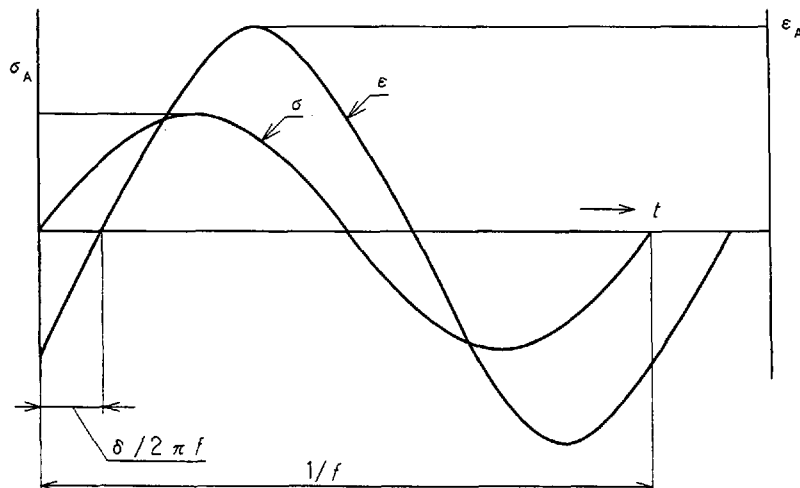
**3** The most critical term containing Poisson's ratio  $\mu$  is the "volume term"  $1 - 2\mu$ , which has values between 0 and 0.4 for  $\mu$  between 0.5 and 0.3. The relationships in Table 1 containing the "volume term"  $1 - 2\mu$  can only be used if this term is known with sufficient accuracy. It can be seen from Table 1 that the 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 Standard are, to some extent, approximate. They do not take into account e.g. "end effects" caused by clamping the specifications, 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 behaviors, the complex compliance  $C^*$  is the reciprocal of the complex modulus  $M^*$ , i.e.

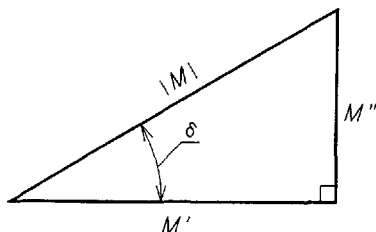
$$M^* = (C^*)^{-1} \dots\dots\dots (2)$$

Thus

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



- a) The phase shift  $\delta/2\pi f$  between the stress  $\delta$  and strain  $\epsilon$  in a viscoelastic material subjected to sinusoidal oscillation ( $\delta_A$  and  $\epsilon_A$  are the respective amplitudes,  $f$  is the frequency).



- b) The relationship between the storage modulus  $M'$ , the loss modulus  $M''$ , the phase angle  $\delta$  and the magnitude  $|M^*|$  of the complex modulus  $M^*$ .

**Fig. 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 $L^{(1)}$           |
|-------------------------------------------------------------------------------------------------------|-------------------------------|------------------------------------|-------------------------------|----------------------------|----------------------|----------------------------|-----------------------------|
| Poisson's ratio, $\mu$<br>$1-2\mu^{(2)}$                                                              |                               |                                    |                               | $3-\frac{E}{G}$            | $\frac{G/K}{1+G/3K}$ | $\frac{E}{3K}$             | $\frac{1}{L/G-1}$           |
| 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, $K^{(3)}$                                                                               | $\frac{2G(1+\mu)}{3(1-2\mu)}$ | $\frac{E}{3(1-2\mu)}$              |                               | $\frac{G}{3(3G/E-1)}$      |                      |                            | $L-\frac{4G}{3}$            |
| Uniaxial-strain or longitudinal-wave modulus, $L$                                                     | $\frac{2G(1-\mu)}{1-2\mu}$    | $\frac{E(1-\mu)}{(1+\mu)(1-2\mu)}$ | $\frac{3K(1-\mu)}{1+\mu}$     | $\frac{G(4G/E-1)}{3G/E-1}$ | $K+\frac{4G}{3}$     | $\frac{K(1-E/3K)}{1-E/9K}$ |                             |
| Notes <sup>(1)</sup> See Remarks 5.<br><sup>(2)</sup> See Remarks 3.<br><sup>(3)</sup> See Remarks 4. |                               |                                    |                               |                            |                      |                            |                             |

**3.2 storage modulus,  $M'$ :** The real part of the complex modulus  $M^*$  [see Fig. 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 Fig. 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.

**3.4 magnitude of the complex modulus,  $|M^*|$ :** The root mean square value of the storage and the loss moduli as given by the equation

$$|M^*|^2 = (M')^2 + (M'')^2 = (\sigma_A / \varepsilon_A)^2 \dots\dots\dots (4)$$

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

The complex modulus is expressed in pascals (Pa).

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 Fig. 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,  $\delta$ :** The phase difference between the dynamic stress and the dynamic strain in a viscoelastic material subjected to a sinusoidal oscillation (see Fig. 1).

The phase angle is expressed in radians (rad).

As with the storage modulus (see 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 ( $\tan \delta$ ):** The ratio between the loss modulus and the storage modulus, given by the equation

$$\tan \delta = M'' / M' \dots\dots\dots (5)$$

where,  $\delta$  is the phase angle (see 3.5) between the stress and the strain.

The loss factor is expressed as a dimensionless number.

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

**3.7 stress-strain hysteresis loop:** The stress expressed as a function of the strain in a viscoelastic material subject to sinusoidal vibrations. Provided the viscoelasticity is linear in nature, this curve is an ellipse (see Fig. 2).