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Plastics — Determination of damping properties and complex modulus by bending vibration

Plastiques — Détermination des propriétés d'amortissement et du module complexe au moyen de vibration en flexion

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Foreword

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It has been approved by the member bodies of the following countries:

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The member body of the following country expressed disapproval of the document on technical grounds:

United Kingdom

Plastics — Determination of damping properties and complex modulus by bending vibration

1 Scope and field of application

This International Standard specifies a bending vibration method for determining the damping properties and complex modulus of homogeneous and laminated plastics especially intended for acoustical insulation, for example systems of sheet metal coated with a damping plastic layer or sandwich systems consisting of two sheet metal layers with an intermediate plastic layer.†

For many purposes it is useful to determine these properties as functions of the temperature.

Other methods for the determination of damping properties are described in ISO 537 and ISO 2856.

2 References

ISO 537, *Plastics — Testing with the torsion pendulum.*

ISO 2856, *Elastomers — General requirements for dynamic testing.*

3 Definitions

3.1 complex modulus, $E^* = E' + \mathrm{i}\,E''$ **:** The stress-strain ratio of a viscoelastic material that is subjected to sinusoidal loading (circular frequency $\omega = 2\pi f$). The definition of E^* takes into account the phase shift between stress and strain.

3.2 storage modulus, E' **:** The real part of the complex modulus; it can be considered as a measure of the energy stored and regained during a loading cycle.

3.3 loss modulus, E'' **:** The imaginary part of the complex modulus; it can be considered as a measure of the energy lost (dissipated) during a loading cycle.

3.4 loss factor, d**; loss tangent,** $\tan \delta$**:** The tangent of the phase angle δ between stress and strain; it is given by the quotient $\tan \delta = E''/E'$. Commonly $d = \tan \delta$ is used as a measure of the damping of a system subject to forced vibrations.

3.5 resonance curve: Curve giving the frequency dependence of the amplitude of a damped system subjected to forced vibrations.

3.6 resonance frequency, $f_R = f_{max}$**:** The frequency of the maximum amplitude of the resonance curve; f_R is proportional to the square root of the storage modulus E' of a viscoelastic system.

3.7 half-width of the resonance curve, Δf**:** Quantity measured at the amplitudes $A = (1/\sqrt{2})A_R = 0{,}707\,A_R$ of the resonance curve, where A_R is the resonance amplitude. Δf is related to the loss factor d by the equation $d = \Delta f / f_R$.

4 Principle

The test is performed on bars or strips which are either vertically arranged, one end being clamped and the other end being free, or are supported horizontally by thin threads in two vibration nodes. The specimen is submitted to forced vibrations in a frequency range between about 100 and 1 000 Hz. From the resonance curve (see 3.5) determined by this test, the storage modulus E' (see 3.2) is calculated in the range of about 5×10^{-1} to 2×10^{5} MPa and the loss factor d (see 3.4) in the range of about 1×10^{-2} to 1×10^{-1}.

5 Apparatus

5.1 Calibrated instruments, for measuring dimensions and density.

5.2 Clamping or **supporting device,** for the specimen.

5.3 Two electromechanical transducers, one for excitation of the vibrations and one for reception of the vibrations.

† For supplementary information on this subject, see:

OBERST, H. and FRANKENFELD, K. *Acustica* **2** 1952: AB 181.

SCHWARZL, F. *Acustica* **8** 1958: 164.

OBERST, H. *Phil. Trans. R. Soc. London Ser. A* **263** 1968: 441.

5.4 Electronic equipment, consisting of a frequency generator, a device suitable to amplify and measure the vibration amplitude of the specimen, a frequency measuring device, a recorder of the resonance curve, and an oscillograph to control the shape of the vibration.

5.5 Thermostated enclosure, to contain the clamping or supporting device, the specimen and the electromechanical transducers.

The figure is a schematic diagram of the test apparatus with the specimen clamped at one end [see figure a)] and with the specimen supported at two vibration nodes by thin textile threads [see figure b)]. In the case of the clamped specimen, all parts of the instrument shall be sufficiently rigid and tight so that errors due to vibrations of the parts are excluded and no additional damping in the clamping device occurs. For testing laminated systems it is often necessary to remove the plastic layer from the steel sheet within the clamping region.

6 Test specimens

6.1 Preparation

The specimens (homogeneous or laminated bars or strips) shall have negligible plastic flow within the temperature range of the measurements. Specimens of homogeneous plastics may be prepared from moulded, extruded or cast sheets by machining or die-cutting or may be directly cast. Special care shall be taken to avoid anisotropy and frozen-in stresses. Small thin steel plates, sufficiently light, shall be glued on the specimens near their ends to permit the excitation and reception of the vibrations by means of electromechanical transducers. To avoid errors in E' greater than 4 %, it is necessary to maintain the ratio of the added mass to specimen mass below 1 %. To avoid added stiffness from the steel plates, these shall not extend along the specimen more than 2 % of its length. The distance between the steel plates shall be large enough to avoid cross-talk from the exciter to the receiver. Multilayer specimens shall be fabricated as a function of the thicknesses and by the production techniques to be used in the projected end-use. For example, for a plastic material on steel sheet, the plastic may be applied on the metal by spraying or as a mastic or an adhesive bonded sheet.

6.2 Shape and dimensions

The thickness of the specimens shall be at least sufficient so that their bending stiffness solely is decisive for the behaviour of the vibration. On the other hand the thickness has to be sufficiently small compared to the bending wavelength. The sample thickness may also be limited by considerations of shear deformation and rotational inertia if accurate values of E' are required. Length to thickness ratios less than 50 should be avoided if E' values are required to be reproduced within 5 %, from measurements on the sixth or higher modes for homogeneous, isotropic samples.

The thickness of the layers of a multilayer system depends on the technical purpose of the system. When comparing various systems by the bending vibration test, the preferable mass ratio of the plastic layer and the sheet metal is 0,2. The width of the specimen has to be below one half of the wavelength in order to avoid lateral resonance vibrations. A width of 10 ± 0,1 mm may be suitable in most cases. The length of the specimens depends on the desired frequency. For specimens clamped at one end, the length shall be sufficiently large to avoid a noticeable influence of the clamping device on the vibration; usually a length of 180 ± 0,5 mm will be suitable. If the specimen is not clamped at one end, the free length of the specimen shall be 150 ± 0,5 mm.

6.3 Number

At least two specimens with identical dimensions shall be tested.

7 Procedure

7.1 Specimen clamped at one end

This arrangement is suitable for testing specimens from most plastics, including relatively soft materials.

Determine the density ϱ and the thickness h of the specimen with a precision of ± 0,5 %, using the calibrated instruments (5.1). Measure h at five points located at nearly equal distances along the main axis of the specimen. If the thickness at one of these points differs more than 0,05 mm from the mean value, the specimen shall normally not be used. If testing a piece of uniform thickness from a finished article is impossible, the test can still be carried out but only the loss factor can be determined.

Clamp the specimen in such a way that the clamping force is high enough to avoid additional damping by friction between the specimen and the clamping device (5.2) so far as possible. Measure the free length l of the specimen with a precision of ± 0,2 % (± 0,3 mm for l = 150 mm).

Adjust the receiver and the exciter systems as near as possible to the specimen but far enough from it to avoid a noticeable influence of the permanent magnet on the vibration. With the usual test apparatus (5.4) the favourable distance is about 3 mm.

After the desired temperature has been attained in the thermostated enclosure (5.5), excite the specimen using the frequency generator (see 5.4) and determine the maximum (or the effective) vibration amplitude by use of the amplifier and the recorder (see 5.4). By shifting the frequency, record the resonance curve.

Measure the amplitude A and the frequency f with a precision of ± 1 % and ± 0,5 Hz, respectively. Usually, it is possible to measure the resonance curve in the range from the first up to the sixth or seventh order number of the vibration. But because the first order is the one mostly affected by external damping in the clamping device, and because the amplitudes of the vibrations of higher order numbers decrease rapidly, intermediate order numbers shall be chosen for the measurements.

If the loss factor and the modulus are to be measured as functions of temperature, after reaching the chosen temperature within the thermostated enclosure (see the figure) this temperature shall be maintained for about 10 min in order that the whole specimen attains the desired temperature. On the other hand, the temperature shall not be maintained much longer than 10 min to avoid degradation of the tested material.

7.2 Specimen with both ends free

This arrangement is especially suitable for testing rigid form-stable specimens, for example sheet metal damped by a plastic layer.

Mount the specimen at vibration nodes, usually at the nodes adjacent to the ends of the specimen. Calculate the distance l_n of the first nodes from the ends of the specimen.

The quotient of l_n and the length l of the specimen is given (as a good approximation) by the equations

$$\frac{l_n}{l} = 0{,}224 \qquad \text{for } n = 1$$

and

$$\frac{l_n}{l} = \frac{0{,}660}{2n + 1} \qquad \text{for } n > 1$$

where n is the order number of the vibration.

Suspend the specimen from a suitable supporting device (5.2) by thin threads (preferably textile threads) at the calculated first vibration nodes. Carry out the test procedure as described in 7.1. Repeat the whole procedure including the mounting of the specimen if the resonance frequency at another order number is to be measured.

8 Expression of results

8.1 Calculation of the storage modulus from the resonance frequency

The storage modulus, E', is given by the equation

$$E' = \left(\frac{4\pi\sqrt{3\varrho}\, l^2}{h}\right)^2 \left(\frac{f_n}{k_n}\right)^2$$

where

ϱ is the density of the specimen;

l is the (free) length of the specimen;

h is the thickness of the specimen;

f_n is the resonance frequency;

k_n is a numerical factor.

For the specimen clamped at one end, $k_1 = 3{,}52$, $k_2 = 22{,}0$

For the specimen with both ends free, $k_1 = 22{,}4$, $k_2 = 61{,}7$

For order numbers $n > 2$, k_n can be calculated (as a good approximation) by the following equations.

For the specimen clamped at one end

$$k_n = (n - 1/2)^2 \pi^2$$

For the specimen with both ends free

$$k_n = (n + 1/2)^2 \pi^2$$

If all the instructions regarding the determination of each single quantity in the equation are followed, the precision of the measurement of E' is between ± 3 % and ± 4 %. In the case of laminated systems, E' represents an effective modulus of the system.

8.2 Calculation of the loss factor from the half-width of the resonance curve

After the half-width Δf of the resonance curve has been determined according to 3.7, calculate the loss factor d at the resonance frequency f_R, using the equation

$$d = \frac{\Delta f}{f_R}$$

The precision of the measurement of the loss factor is about ±2 % to ± 3 % if the instructions given in 7.1 are followed.

8.3 Plotting the loss factor as a function of temperature

If the loss factor d is measured as a function of temperature, not only d but also the frequency at which d is measured must be plotted as a function of the temperature because the resonance frequency of a given plastic specimen is shifted to lower frequency values as the temperature increases. The temperature-dependent loss factor at constant frequency can be obtained by interpolation only if the curve of d as a function of temperature has been measured at several frequencies (for example at several order numbers of the vibration).

8.4 Calculation of the loss modulus from the storage modulus and the loss factor

Calculate the loss modulus E'', which is proportional to the energy lost during one vibration cycle, from the storage modulus E' (see 8.1) and the loss factor d (see 8.2 and 8.3) using the equation

$$E'' = E' d$$