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Mechanical vibration and shock — Characterization of the dynamic mechanical properties of visco-elastic materials —

Part 6: Time-temperature superposition

Vibrations et chocs mécaniques — Caractérisation des propriétés mécaniques dynamiques des matériaux visco-élastiques —

Partie 6: Superposition du temps et de la température

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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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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*.

A list of all parts in the ISO 18437 series can be found on the ISO website.

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Introduction

Visco-elastic materials are used extensively to reduce vibration amplitudes in structural systems through dissipation of energy (damping) or isolation of components and in acoustical applications that require a modification of the reflection, transmission or absorption of energy. The design, modelling and characterization of such systems often require specific dynamic mechanical properties in order to function in an optimum manner. For most visco-elastic materials, these properties depend on frequency, temperature and amplitude of applied excitation. The aim of this document is to provide details on the best way of data acquisition for subsequent processing and to provide a standard method for analysis using the time-temperature superposition principle. This document applies to the linear behaviour observed at small strain (stress) amplitudes and to thermorheologically simple materials.

This document presents a method for checking the validity of a thermorheological simplicity of a material and for identifying and eliminating questionable data. It provides minimal criteria for data acquisition to be applied in mathematical methodologies, which allow multiple data sets of dynamic visco-elastic properties measured at different temperatures to be cast into a single master curve according to the time-temperature superposition (TTS) principle. When sufficient data are obtained or available, a standard method, which uses a closed form shifting algorithm[16][17], is defined.

TTS is the most widely-used method for accelerated prediction of long-term visco-elastic behaviour of materials[13]. In the frequency domain, TTS can be used for predicting the behaviour of materials at frequencies that are experimentally not assessable.

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Mechanical vibration and shock — Characterization of the dynamic mechanical properties of visco-elastic materials —

Part 6: Time-temperature superposition

1 Scope

This document specifies a standard method for the acquisition and analysis of data obtained using the test methods found in ISO 18437-1 to ISO 18437-5, ISO 6721-4 to ISO 6721-7 and ISO 6721-12.

It is applicable to visco-elastic materials that are thermorheologically simple and that have been tested at equilibrium state for every temperature.

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 18437-1, *Mechanical vibration and shock — Characterization of the dynamic mechanical properties of visco-elastic materials — Part 1: Principles and guidelines*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18437-1 and the following 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/

3.1
dynamic visco-elastic function
fundamental visco-elastic property, i.e. storage moduli and loss moduli, measured in tension, shear and compression and loss factor as functions of frequency and temperature

3.2
storage modulus
M'
real part of the complex modulus

Note 1 to entry: It is a measure of the energy stored and regained during a loading cycle.

Note 2 to entry: Storage moduli in tension, shear and compression are denoted as E', G' and K', respectively.

Note 3 to entry: It is expressed in pascals (Pa).

[SOURCE: ISO 472:2013, 2.998, modified — Notes to entry have been added.]

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3.3
loss modulus
M''
imaginary part of the complex modulus

Note 1 to entry: It is a measure of the energy lost (dissipated) during a loading cycle.

Note 2 to entry: Loss moduli in tension, shear and compression are denoted as E'', G'' and K'', respectively.

Note 3 to entry: It is expressed in pascals (Pa).

[SOURCE: ISO 472:2013, 2.559, modified — Notes to entry have been added.]

3.4
loss factor
$\tan \delta$
ratio of the *loss modulus* (3.3) to the *storage modulus* (3.2) measured in tension, shear, compression or longitudinal compression

Note 1 to entry: It is given by the quotient $\tan \delta = M''/M'$.

[SOURCE: ISO 472:2013, 2.557, modified — the definition has been revised.]

3.5
time-temperature superposition
TTS
principle by which, for visco-elastic materials, time and temperature are equivalent to the extent that data at one temperature can be superimposed upon data taken at different temperature merely by shifting the data curves along the logarithmic time axis

Note 1 to entry: In case of dynamic measurements, the term "frequency-temperature superposition" would be more accurate, but is less commonly used. The term "method of reduced variables" is also used to refer to this principle.

[SOURCE: ISO 18437-2:2005, 3.3, modified — "frequency axis" has been replaced by "logarithmic time axis" and Note 1 to entry has been added.]

3.6
thermorheologically simple material
material for which *time-temperature superposition* (3.5) is applicable

Note 1 to entry: A material which fails to superimpose, due to multiple transitions or crystallinity is, for example, thermorheologically complex.

Note 2 to entry: In thermorheologically complex systems, all relaxation times at a certain temperature may not be simply related to the relaxation times at a different temperature by a constant ratio. Thus, a multiphase system is thermorheologically complex if the individual *shift factors* (3.7) depend on time as well as temperature.

3.7
shift factor
$\lg a_T$
measure of the amount of shift along the logarithmic (base 10) axis of frequency for one set of constant-temperature data to superimpose upon another set of data

Note 1 to entry: The expression "shift factor" commonly refers to horizontal shift factor.

[SOURCE: ISO 18437-2:2005, 3.4, modified — Note 1 to entry has been added.]

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3.8
vertical shift factor
$\lg b_T$
measure of the amount of shift along the logarithmic (base 10) axis of modulus to account the effect of a change from reference temperature to the temperature of interest

3.9
master curve
curve constructed by *time-temperature superposition* (3.5), which is identical to the behaviour of material that would be found (measured) at broad frequency range at the reference temperature if the experiment can be performed

4 Prediction of complete range of visco-elastic properties and description of data

4.1 Time-temperature superposition (TTS) principle

TTS is the most widely-used method for the accelerated prediction of complete visco-elastic behaviour of materials[13]. TTS is applied as follows: a series of dynamic mechanical experiments is carried out at different constant temperatures over a given short frame of frequencies, commonly called the experimental window. Thus, a set of isothermal segments of dynamic visco-elastic function is obtained. The isotherms are first shifted vertically, to account for temperature and density change and then horizontally along the logarithmic frequency scale towards a reference segment measured at reference temperature, T_R. The curve constructed by TTS is called a master curve. TTS asserts that the resulting master curve is identical to the behaviour of a material if it was measured with a broad frequency range at the reference temperature. The result of applying TTS to isotherms measured within experimentally reasonable frequency frames is a measure of material behaviour over a broad frequency range.

NOTE 1 Loss factor, as the ratio between loss and storage data, does not require vertical shifting[17].

There are several criteria for the applicability of TTS[13].

a) The shapes of the isotherms at different temperatures shall match over a substantial range of frequencies.

b) The same values of shift factor, a_T, shall superimpose all dynamic visco-elastic functions.

c) The temperature dependence of a_T shall be a smooth function of temperature with no gross fluctuations or irregularities.

NOTE 2 The temperature dependence of the shift function, a_T, is commonly modelled with time-temperature superposition models, such as Arrhenius[14] or Williams-Landel-Ferry (WLF)[13] relationships. More information on the WLF model is given in ISO 18437-4 and ISO 4664-1.

4.2 Data acquisition

4.2.1 New data

The acquisition of new data shall be sufficiently detailed with enough temperatures and frequencies so as to provide sufficient overlap of the frequency data points when shifted from one temperature to another. An example of good quality data are dynamic mechanical analyser (DMA) data taken every 5 °C using frequencies of: 0,1; 0,2; 0,3; 0,5; 1; 2; 3; 5; 10; 20; and 30 Hz and/or the dynamic data which has one decade of overlapping between neighbouring isotherms along the logarithmic frequency axis.

Theoretically, TTS is not limited to any frequency range of experimental window. However, the frequency range shall be selected in line with other existing standards and capabilities of a measuring instrument.

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