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Plastics — Guide to the acquisition and presentation of design data

Plastiques — Lignes directrices pour l'acquisition et la présentation de caractéristiques de conception

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Contents

Page

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.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 17282 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

This corrected version of ISO 17282:2004 incorporates the following corrections:

— in paragraph 4 of the Introduction, the references to Tables 6 and 7 have been corrected;

— Clause 2 (normative references) has been updated, the only important change being the replacement of ISO 6252 (which has been withdrawn) by ISO 22088-2;

— in the heading to 3.4, the references to the tables have been corrected;

— in Table 12, ISO 6252 has been replaced by ISO 22088-2 (twice);

— Equations (A.6) and (A.7), which were missing, have been inserted;

— throughout the document, a number of symbols and their subscripts have been corrected;

— a number of minor editorial improvements have been made.

Introduction

Plastics and composites are increasingly being used in load-bearing applications where they compete with traditional materials such as steels and aluminium. In these applications, it is important to achieve a confident knowledge of the safe operating limits of the component through competent design. Computer methods for design are available, and are continually being improved, that enable predictions to be made of the performance of plastics under a variety of situations. These situations include mechanical performance under service loads and environments as well as a flow of the polymer melt during the manufacture of a component.

In order to design effectively with plastics in load-bearing applications, comprehensive data are generally needed which take into account the effects of time, temperature, rate and environment on properties. A number of International Standards have been developed that specify how certain data for plastics should be measured and presented. These are ISO 10350-1 and ISO 10350-2, and ISO 11403-1, ISO 11403-2 and ISO 11403-3.

The purpose of these standards is to enable comparable data to be measured on different materials from different sources to aid the process of materials selection. A substantial quantity of data is specified by these standards and, although not the primary purpose of the standards, some of these data are suitable for design. However, additional or alternative data will also be needed for many applications.

The purpose of this guide is to augment existing data presentation standards by identifying data that are needed specifically for design with plastics. The selection of these data is guided by the requirements of available computer methods for design. Preferred test methods, test specimens and test conditions are recommended in section 5 for determining these data. For some properties, ISO test methods or specimens are not yet available. Reference is then made in the Notes to Tables 12 and 13 to suitable procedures for data acquisition that may become standardised at a later stage.

It is intended that this guide assist the development of databases that will interface with computer methods for design so that the property data required by these methods can be readily accessed. For certain properties, some analysis and interpretation of data is needed in order to present information in the form required by the design analysis. Some procedures for data analysis are described in the annexes.

Plastics — Guide to the acquisition and presentation of design data

1 Scope

This International Standard gives guidelines for the acquisition and presentation of data that can be used for design with plastics. Emphasis is given to the acquisition of data needed by computerised methods for design. It includes data needed for the analysis of the flow of polymer melts during the manufacture of a component as well as data needed for the prediction of mechanical performance of the component in service. The data requirements cover design with unfilled plastics as well as filled, short-fibre reinforced and continuous-fibre reinforced materials.

2 Normative references

The following referenced documents are indispensable for the application 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 294-3, *Plastics — Injection moulding of test specimens of thermoplastics materials — Part 3: Small plates*

ISO 294-5, *Plastics — Injection moulding of test specimens of thermoplastics materials — Part 5: Preparation of standard specimens for investigating anisotropy*

ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

ISO 527-4, *Plastics — Determination of tensile properties — Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites*

ISO 527-5, *Plastics — Determination of tensile properties — Part 5: Test conditions for unidirectional fibre-reinforced plastic composites*

ISO 899-1, *Plastics — Determination of creep behaviour — Part 1: Tensile creep*

ISO 1183, *Plastics — Methods for determining the density and relative density of non-cellular plastics*

ISO 2577, *Plastics — Thermosetting moulding materials — Determination of shrinkage*

ISO 3167, *Plastics — Multipurpose test specimens*

ISO 6603-2, *Plastics — Determination of puncture impact behaviour of rigid plastics — Part 2: Instrumented impact test*

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 6721-7, *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 6721-10, *Plastics — Determination of dynamic mechanical properties — Part 10: Complex shear viscosity using a parallel-plate oscillatory rheometer*

ISO 10350-1, *Plastics — Acquisition and presentation of comparable single-point data — Part 1: Moulding materials*

ISO 11357-2, *Plastics — Differential scanning calorimetry (DSC) — Part 2: Determination of glass transition temperature*

ISO 11357-3, *Plastics — Differential scanning calorimetry (DSC) — Part 3: Determination of temperature and enthalpy of melting and crystallization*

ISO 11357-4, *Plastics — Differential scanning calorimetry (DSC) — Part 4: Determination of specific heat capacity*

ISO 11357-5, *Plastics — Differential scanning calorimetry (DSC) — Part 5: Determination of characteristic reaction-curve temperatures and times, enthalpy of reaction and degrees of conversion*

ISO 11357-7, *Plastics — Differential scanning calorimetry (DSC) — Part 7: Determination of crystallization kinetics*

ISO 11359-2, *Plastics — Thermomechanical analysis (TMA) — Part 2: Determination of coefficient of linear thermal expansion and glass transition temperature*

ISO 11403-1, *Plastics — Acquisition and presentation of comparable multipoint data — Part 1: Mechanical properties*

ISO 11403-2, *Plastics — Acquisition and presentation of comparable multipoint data — Part 2: Thermal and processing properties*

ISO 11443, *Plastics — Determination of the fluidity of plastics using capillary and slit-die rheometers*

ISO 15310, *Fibre-reinforced plastic composites — Determination of the in-plane shear modulus by the plate twist method*

ISO 17744, *Plastics — Determination of specific volume as a function of temperature and pressure (pvT diagram) — Piston apparatus method*

ISO 22088-2, *Plastics — Determination of resistance to environmental stress cracking (ESC) — Part 2: Constant tensile load method*

3 Symbols

3.1 Test variables

ε tensile strain

NOTE Use of the true strain $\log_e (1 + \varepsilon)$ in place of the engineering strain is necessary when engineering strain values exceed about 0,1. Below a strain of 0,1, there is no significant difference between these quantities.

$\dot{\varepsilon}$ tensile strain rate

ε^p plastic component of the tensile strain

NOTE This is used in elastic–plastic models for describing non-linear behaviour.

γ shear strain

$\dot{\gamma}$ shear strain rate

γ^p plastic component of the shear strain

t time

σ stress

T temperature

f frequency

ch chemical environment

N number of cycles to failure in a fatigue test

R ratio of minimum to maximum stresses in a fatigue test

$\dot{T}$ rate of change of temperature

p pressure

p_{CH} cavity pressure at hold

t_H hold time

h specimen thickness

v_s slip velocity

3.2 Material properties for stress analysis (see Tables 2 and 3)

E tensile modulus obtained from a test at constant strain rate

E_p, E_n tensile moduli along and transverse to, respectively, the direction of preferred fibre or molecular orientation in a transversely isotropic material

G_p shear modulus of a transversely isotropic material for stress application in the direction of preferred orientation

D tensile creep compliance

E_R tensile stress relaxation modulus

D_p, D_n tensile creep compliances along and transverse to, respectively, the direction of preferred orientation in a transversely isotropic material

E', E'' tensile storage and loss moduli, respectively

G', G'' shear storage and loss moduli, respectively

σ_T true tensile yield stress (see Note 4 to Table 12)

λ hydrostatic stress sensitivity parameter (see Note 6 to Table 12)

σ_{Tp}, σ_{Tn} tensile yield stresses for loading along and transverse to, respectively, the direction of preferred orientation in a transversely isotropic material (see Notes 4 and 9 to Table 12)

σ_{Sp}, σ_{Sn} shear yield stresses for loading along and transverse to, respectively, the direction of preferred orientation in a transversely isotropic material (see Note 9 to Table 12)

ν Poisson's ratio

ν^e elastic component of the Poisson's ratio

ν^p plastic component of the Poisson's ratio equal to minus the ratio of the plastic component of the lateral strain to the plastic component of the axial strain in a specimen under a tensile stress (see Note 5 to Table 12)

ν_{pn} Poisson's ratio for an anisotropic material determined with the uniaxial stress applied along the direction of preferred orientation

ψ flow parameter

α coefficient of linear thermal expansion

α_p, α_n coefficients of linear thermal expansion parallel and normal to the direction of preferred orientation in a transversely isotropic material

c_p specific heat

3.3 Failure properties (see Table 4)

σ_u tensile strength obtained from a test at constant specimen deformation rate

σ_{up}, σ_{un} tensile strengths for loading along and transverse to, respectively, the direction of preferred orientation in a transversely isotropic material

ε_u strain at break obtained from a tensile test at constant specimen deformation rate

ε_{up}, ε_{un} strains at break for loading along and transverse to, respectively, the direction of preferred orientation in a transversely isotropic material

σ_c tensile creep rupture strength

σ_{cp}, σ_{cn} creep rupture strengths for loading along and transverse to, respectively, the direction of preferred orientation in a transversely isotropic material

σ_f tensile fatigue strength

σ_{fp}, σ_{fn} tensile fatigue strengths for loading along and transverse to, respectively, the direction of preferred orientation in a transversely isotropic material

3.4 Material properties for processing simulation (see Tables 5 to 11)

η melt viscosity

η_{eu} uniaxial extensional viscosity

η_{eb} biaxial extensional viscosity

$\eta_{reactive}$ viscosity of the reactive system

N_1 first normal stress difference

ρ_B bulk density

ρ_m melt density

ρ_s density of the solid

$\rho_{reacted}$ density of reacted system

k thermal conductivity

k_m thermal conductivity of the polymer melt

c_p specific heat

c_{pm} specific heat of the polymer melt

T_s solidification temperature, a reference temperature defined by the mould filling simulation software

T_{ej} ejection temperature, a reference temperature defined by the mould filling simulation software

v specific volume

ΔH_r heat of reaction

t_{ind} isothermal induction time

α_{gel} gelation conversion

$\dot{R}$ reaction rate

μ_b, μ_s dynamic coefficients of friction between plastic and metal used for the barrel or screw respectively

T_m melting temperature

T_g glass transition temperature

T_c crystallisation temperature

ΔH_f enthalpy of melting

ΔH_c enthalpy of crystallization

X degree of crystallinity

$\dot{X}$ rate of crystallization

S_{Mp} moulding shrinkage parallel to the direction of preferred orientation

S_{Mn} moulding shrinkage normal to the direction of preferred orientation

ν_{pn} Poisson's ratio for a transversely isotropic material determined with the uniaxial stress applied along the direction of preferred orientation

ν_{np} Poisson's ratio for a transversely isotropic material determined with the applied stress along a direction normal to the direction of preferred orientation and the lateral strain measured in the preferred orientation direction

G_p shear modulus of a transversely isotropic material for stress application in the direction of preferred orientation

α_p coefficient of linear thermal expansion parallel to the direction of preferred orientation in an anisotropic material

α_n coefficient of linear thermal expansion normal to the direction of preferred orientation in an anisotropic material

4 Data needed for design

4.1 General

The design data identified here are grouped under two headings:

— Data for analysis of thermomechanical performance (section 4.2)

— Data for processing analysis (section 4.3)

4.2 Design for thermomechanical performance

4.2.1 The design process

The process of design for the mechanical performance of a component involves two operations. The first is an analysis of the stress and strain distributions in the component under service load. The second is a comparison of the maximum levels of stress, strain or displacement predicted by the analysis with maximum allowable values based on failure criteria for the material or operating conditions of the component. These operations are then repeated in order to select component dimensions and geometry whilst ensuring that safe limits are not exceeded. The data requirements for these two operations are different.

The data requirements for stress analysis are determined by the constitutive law that relates stress and strain under the appropriate service loading conditions. Choice of a valid constitutive relationship will depend upon the following factors.

— Mechanical behaviour, whether the material is isotropic or anisotropic or shows glassy or rubber-like behaviour.

— The level of induced strain. If this is small, then linear viscoelastic or linear elastic behaviour may be considered but, at higher strains, relationships between stress and strain will be non-linear.

— The history of the applied load or displacement and the temperature. Since plastics are viscoelastic, properties depend on time, frequency and strain rate and so their response to short-term loads such as impact will be very different from that under sustained load.

A finite element analysis (FEA) is a versatile method for calculating stress, strain and temperature distributions in a component of complex geometry. For this reason, the data requirements identified here for performing a stress analysis have been guided by available materials models that are suitable for plastics. An accurate calculation relies on the use of a materials model for the analysis which employs a realistic constitutive relationship.

The satisfactory operating limits of a component may be specific to the component or the plastics material from which it is made. Safe operating limits for the material are generally expressed in terms of ultimate values of stress or strain and will depend on many factors such as the temperature, the humidity, processing conditions, the presence of an aggressive environment and the history of the applied load. Where failure is caused by crack growth, additional property data may be needed.

4.2.2 Design data for thermomechanical performance

Data required for design for thermomechanical performance consist of data for carrying out a stress analysis and data for estimating material failure. In principle, these data requirements depend on the detailed materials characteristics exhibited by the material, and on the service conditions relevant to the application. However, in practice, the designer may adopt various simplifications by approximating materials behaviour or service conditions in order to make the design analysis technically tractable and financially viable. This influences data requirements and the practical use of data.

From the designer’s point of view, the simplest form of materials behaviour is that of an isotropic, linear, temperature-insensitive, elastic material. However, as stated in section 4.2.1, plastics may exhibit aspects of anisotropy, nonlinearly, temperature-dependence, viscoelasticity or plasticity. Where a particular aspect is relevant to a design problem, the designer may decide to avoid a more complex analysis by assuming a simpler form of behaviour and compensate for this by use of “effective” material properties. Examples include use of a secant or tangent modulus to represent nonlinearity in a linear analysis, use of a long-time creep modulus to represent viscoelasticity in an elastic analysis, and use of “average” or “representative” property values to replace anisotropy and temperature-sensitivity. However, although a simpler (approximate) form of representation may be used, data for the more complex form of behaviour will generally be required in order to select appropriate “effective” properties.

Definition of the design problem involves specification of component geometry (shape, size, etc.) and service conditions (e.g. loads and other constraints). Although FEA packages can handle complex circumstances, the designer may idealise component geometry and may approximate service conditions in order to simplify the design calculations (e.g. by creating a “statically determinate” situation for which stresses and strains can be calculated separately, only the latter calculation requiring material properties). Similarly, the designer may use an approximate design calculation (e.g. assuming “pseudo-elasticity”). These idealisations and assumptions introduce inaccuracies into the design predictions which are not attributable to the quality of the design data, although appropriate data selection is required.

A crucial aspect of design analysis is the selection of suitable materials models. This selection determines consequent requirements for materials design data, and depends, in particular, on the nature of the service loads, for example:

— sustained loading, involving effects such as creep or stress relaxation, for which time under load is the important parameter;

— cyclic loading, for example in damped vibrations, for which frequency is the important parameter;

— high-rate loading, for example due to impact, for which strain rate is the important parameter.

Table 1 — Typical service conditions, materials behaviour and model types

Service conditions	Crucial parameter	Relevant types of materials behaviour	Model type(s) (see below)
Simpler conditions	—	Elastic	A, B
		Elastic–plastic	C
Sustained loading	Time	Viscoelastic or viscoplastic	C1, D1, E1
Cyclic loading	Frequency		C2, D2, E2
High-rate loading	Strain rate		C3, D3, E3

Model type:

a) Linear elasticity is the simplest and most commonly used materials model, at least for a first analysis.

b) A hypoelastic model enables approximate solutions to be obtained under strain levels where behaviour is non-linear. Hyperelastic models are available for elastomeric materials and are not considered in this International Standard.

c) Elastic–plastic models for metals are available in most FEA packages and are able to handle non-linear and three-dimensional stress conditions. Those based on von Mises yielding may have restricted suitability for plastics, and a more general form of the yield criterion with sensitivity to hydrostatic stress (the linear Drucker–Prager model) is considered here. Some versions of elastic–plastic models combine the effects of elasticity, plasticity and also time, frequency or rate. These latter types of model (C1, C2 and C3) are indicated in this table, but only C3 is considered in this International Standard.

d) Linear viscoelasticity is limited to small-strain behaviour, but data can be used in the three different forms (D1, D2, D3) depending on whether time, frequency or rate is the crucial service parameter.

e) Non-linear viscoelasticity models for general service conditions are not available in a useable form, but models exist for use under special conditions. These include a creep form (E1) based on isochronous curves, a finite-linear form (E2) for large amplitude vibrations and a rate-dependent form (E3): the last two are not discussed further in this International Standard.

As already noted, the stress analysis will also need to consider isotropic or anisotropic properties, linear or non-linear behaviour and the effects of temperature. It is therefore evident that there are many sets of conditions under which materials properties may be needed in principle, and it is necessary to focus on the most important cases. This is discussed now with reference to the model types indicated in Table 1.

Further consideration of these types leads to identification of the data required for design for thermomechanical performance. These data are summarised in Table 2 for isotropic materials. Anisotropic materials require additional data that describe the variation of properties with direction in the material. The simplest situation arises with the loading of parts in the form of a plate or panel where stresses are confined to a plane and stresses through the thickness direction are neglected. This is assumed in Table 3. Criteria for determining when material rupture will take place under multiaxial stress states and arbitrary loading histories have not been established for plastics. Ultimate values obtained from tensile tests under specific loading histories are indicated in Table 4. The symbols used in these tables are explained in Section 3.

When material behaviour is actually isotropic linear elastic, the data shown in Table 2 for model A are all that is required. When the behaviour is more complex, but an isotropic linear elastic analysis is performed, *data relevant to the other models may be needed in order to select appropriate "effective" properties.* For example, data for models D and E give effective properties to represent viscoelastic effects, data for models C and E can be used to select effective properties to handle nonlinearly, and data from Table 3 can be used to select effective properties to take account of the effects of anisotropy. When the design analysis takes these factors into account in full, then data for models C, D and E, and from Table 3, are required in their own right (but see Note to Table 3).

Table 2 — Data required for stress analysis (isotropic material)

Behaviour	Model type	Properties	Variable(s)
Linear elastic	A	$E,\ \nu$	T
Non-linear elastic	B	$E,\ \nu,$ σ	T $\varepsilon,\ T$
Non-linear (elastic–plastic)	C	$E,\ \nu^{e}$ σ_T $\lambda,\ \nu^{p},\ \psi$	T $\varepsilon^{p},\ T$ $\varepsilon^{p},\ T$
Linear viscoelastic	D1 D2 D3	$D,\ E_R,\ \nu$ $E',\ E''$ (or $G',\ G''$), ν ρ $E,\ \nu$	$t,\ T$ $f,\ T$ T $\dot{\varepsilon},\ T$
Non-linear viscoelastic	E1	$D,\ \nu$ $E_R,\ \nu$	$t,\ \sigma,\ T$ $t,\ \varepsilon,\ T$
Rate-dependent, elastic–plastic	C3	$E,\ \nu^{e}$ σ_T $\lambda,\ \nu^{p},\ \psi$	$\dot{\varepsilon},\ T$ $\varepsilon^{p},\ \dot{\varepsilon}^{p},\ T$ $\varepsilon^{p},\ \dot{\varepsilon}^{p},\ T$

Table 3 — Data required for stress analysis (anisotropic material)

Behaviour	Model Type	Properties	Variables
Linear elastic	A	$E_p,\ E_n,\ \nu_{pn},\ G_p$	T
Non-linear (Elastic–plastic)	C	$E_p,\ E_n,\ \nu_{pn},\ G_p$ $\varepsilon_{Tp},\ \sigma_{Tn}$ $\sigma_{Sp},\ \sigma_{Sn}$	T $\varepsilon^{p},\ T$ $\varepsilon^{p},\ T$
Linear Viscoelastic	D1	$D_p,\ D_n$	$t,\ T$
Non-linear Viscoelastic	E1	$D_p,\ D_n$	$t,\ \sigma,\ T$
Rate-dependent, Elastic–plastic	C3	$E_p,\ E_n,\ \nu_{pn},\ G_p$ $\sigma_{Tp},\ \sigma_{Tn}$ $\sigma_{Sp},\ \sigma_{Sn}$	$\dot{\varepsilon},\ T$ $\varepsilon^{p},\ \dot{\varepsilon}^{p},\ T$ $\varepsilon^{p},\ \dot{\gamma}^{p},\ T$
NOTE The above models and data requirements for anisotropic materials are clearly more complicated than those for isotropic materials and, except for the linear elastic case, are likely to be used very rarely except for the purpose of selecting effective properties.			

Under certain circumstances, additional property data will be required over and above those identified in Tables 2 and 3. If the analysis involves changes in temperature during loading, then the thermal expansion coefficient α (α_p and α_n for anisotropic materials) will be needed. If the loading generates high accelerations such that inertial forces are significant, then the density ρ of the material must be known. In situations where it is necessary to predict the effects of internal heating of the plastic material arising from large strain and high strain-rate loading, then data on the specific heat c_p will also be needed.

Furthermore, materials whose properties are sensitive to the concentration of absorbed water will need to have data supplied for material that has been conditioned at the relevant humidity for the application.

