International
Standard

ISO 899-2

Plastics — Determination of creep behaviour —

Part 2:
Flexural creep by three-point loading

Plastiques — Détermination du comportement au fluage —

Partie 2: Fluage en flexion par mise en charge en trois points

Third edition
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Foreword

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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 document 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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This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical behavior,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 249, *Plastics,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 899-2:2003), which has been technically revised. It also incorporates the Amendment ISO ISO 899-2:2003/Amd. 1:2015.

The main changes are as follows:

- the accuracy requirements for the deflection measurement device have been updated;
- the normative references have been updated;
- the definition of "creep" has been adapted for clarity;
- the definitions for shape and dimensions of test specimens were adapted from ISO 178:2019;
- identified inconsistencies and mistakes have been corrected.

A list of all parts in the ISO 899 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.

Plastics — Determination of creep behaviour —

Part 2:
Flexural creep by three-point loading

1 Scope

1.1 This document specifies a method for determining the flexural creep of plastics in the form of standard test specimens under specified conditions such as those of pre-treatment, temperature and humidity. It is only applicable to a simple freely supported beam loaded at mid-span (three-point-loading test).

1.2 The method is suitable for use with rigid and semi-rigid non-reinforced, filled and fibre-reinforced plastics materials (see ISO 472 for definitions) test specimens moulded directly or machined from sheets or moulded articles.

NOTE The method can be unsuitable for certain fibre-reinforced materials due to differences in fibre orientation.

1.3 The method is intended to provide data for engineering-design, quality control, research and development purposes.

1.4 The method might not be applicable for determining the flexural creep of rigid cellular plastics (attention is drawn in this respect to ISO 1209-1 and ISO 1209-2).

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 178, *Plastics — Determination of flexural properties*

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

ISO 472, *Plastics — Vocabulary*

ISO 9513, *Metallic materials — Calibration of extensometer systems used in uniaxial testing*

ISO 16012, *Plastics — Determination of linear dimensions of test specimens*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 472 and the following apply.

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

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

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

3.1

creep

increase in strain with time under constant force, measured from the first moment when the loading of the specimen started

3.2

load

force applied to the test specimen at mid-span

Note 1 to entry: It is expressed in Newtons

3.3

flexural stress

σ

surface stress in the mid-span section of the test specimen

Note 1 to entry: It is expressed in megapascals.

Note 2 to entry: It is calculated from the relationship given in 7.1.3

3.4

deflection

s_t

distance over which the top or bottom surface of the test specimen at mid-span deviates from its unloaded original position during flexure

Note 1 to entry: It is expressed in millimetres.

3.5

flexural-creep strain

ε_t

strain at the surface of the test specimen produced by a stress at any given time *t* during a creep test

Note 1 to entry: It is calculated according to 7.1.4.

Note 2 to entry: It is expressed as a dimensionless ratio or as a percentage.

3.6

flexural-creep modulus

E_t

ratio of flexural stress to flexural-creep strain

Note 1 to entry: It is calculated as in 7.1.1.

Note 2 to entry: It is expressed in megapascals.

3.7

flexural-creep compliance

D_t

ratio of flexural-creep strain to flexural stress

Note 1 to entry: It is calculated as in 7.1.2.

Note 2 to entry: It is expressed in gigapascals^{-1}

3.8

isochronous stress-strain curve

Cartesian plot of stress versus creep strain, at a specific time after application of the load to the specimen

3.9

time to rupture

period of time the specimen is under full load until rupture

3.10
creep-strength limit

initial stress which will just cause rupture ($\sigma_{B,t}$) or will produce a specified strain ($\sigma_{\varepsilon,t}$) at a specified time t, at a given temperature and relative humidity

Note 1 to entry: It is expressed in megapascals.

3.11
initial distance between specimen supports

span

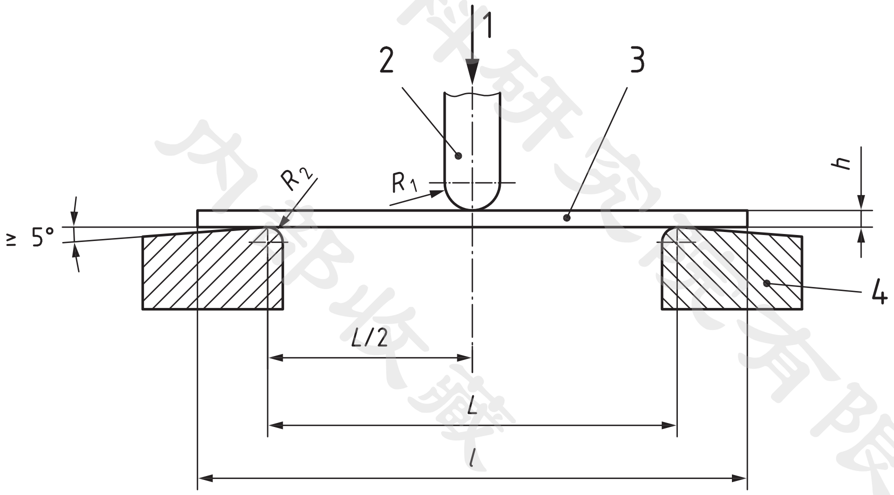
L

initial distance between lines of contact between test specimen and supports (see Figure 1)

Note 1 to entry: It is expressed in millimetres.

4 Apparatus

4.1 Test rack, comprising a rigid frame with two supports, one for each end of the test specimen, the distance between the supports being adjustable to (16 ± 1) times the thickness (height) of the specimen (see Figure 1) for normal specimens, or to greater than 17 times the thickness (height) of the specimen or a fixed distance (100 mm) for rigid unidirectional-fibre-reinforced test specimens (see 6.3). The test rack shall be levelled, and sufficient space shall be allowed below the specimen for the specimen to flex under constant loading at mid-span.



Key

1	applied force, F	L	initial distance between specimen supports
2	loading edge	l	specimen length
3	test specimen	h	specimen thickness
4	support	R_1	radius of the loading edge
		R_2	radius of the supports

Figure 1 — Characteristics of flexural-creep apparatus

The radius R_1 of the loading edge and the radius R_2 of the supports shall conform to the values given in Table 1.

Table 1 — Radii of the loading edge and the supports

Values in millimetres

Thickness of test specimen	Radius of loading edge R_1	Radius of supports R_2
≤ 3	5 ± 0,1	2 ± 0,2
> 3	5 ± 0,1	5 ± 0,2

4.2 Loading system, capable of ensuring that the load is applied smoothly, without causing transient overloading, and that the load is maintained to within ±1 % of the desired load. In creep-to-rupture tests, provision shall be made to prevent any shocks which occur at the moment of rupture being transmitted to adjacent loading systems. The loading mechanism shall allow rapid, smooth and reproducible loading.

4.3 Deflection-measuring device, comprising any contactless or contact device capable of measuring the deflection of the specimen under load without influencing the specimen behaviour by mechanical effects (e.g. undesirable deformations, notches), other physical effects (e.g. heating of the specimen) or chemical effects.

The deflection measurement device shall conform to class 1 of ISO 9513. At its calibration, the initial position of the deflection measurement device shall conform to its position at the unloaded specimen before test.

Data for engineering-design purposes requires the use of a deflectometer to measure the deflection of the specimen. Data for research or quality-control purposes may use the displacement between the loading edge and the supports.

4.4 Time-measurement device, accurate to 0,1 %.

4.5 Micrometer, reading to 0,01 mm or closer, for measuring the initial thickness and width of the test specimen.

4.6 Vernier callipers, accurate to 0,1 % of the span between the test supports or better, for determining the span.

5 Test specimens

5.1 Shape and dimensions

The dimensions of the test specimens shall comply with the relevant material standard and, as applicable, with 5.2 or 5.3. Otherwise, the type of specimen shall be agreed between the interested parties.

5.2 Preferred specimen type

The dimensions, in millimetres, of the preferred test specimen are:

length, l:	80 ± 2
width, b:	10,0 ± 0,2
thickness, h:	4,0 ± 0,2

In any one test specimen, the thickness within the central one third of the length shall not deviate by more than 2 % from its mean value. The width shall not deviate from its mean value within this part of the specimen by more than 3 %. The specimen cross section should preferably be rectangular, with no rounded edges.

The preferred specimen may be machined from the central part of a multipurpose test specimen complying with ISO 20753.

5.3 Other test specimens

If it is not possible or desirable to use the preferred test specimen, use a specimen with the dimensions given in Table 2.

NOTE Certain specifications require that test specimens from sheets of thickness greater than a specified upper limit be reduced to a standard thickness by machining one face only. In such cases, it is conventional practice to place the test specimen such that the original surface of the specimen is in contact with the two supports and the force is applied by the central loading edge to the machined surface of the specimen.

Table 2 — Values of specimen width, b, in relation to thickness, h

Dimensions in millimetres

Nominal thickness h	**Width** b^{a} (± 0,5)
$1 \leq h \leq 3$	25,0
$3 < h \leq 5$	10,0
$5 < h \leq 10$	15,0
$10 < h \leq 20$	20,0
$20 < h \leq 35$	35,0
$35 < h \leq 50$	50,0

[a] For materials with very coarse fillers, the minimum specimen width shall be 30 mm.

6 Procedure

6.1 General

Flexural creep may vary significantly with differences in specimen preparation and dimensions and in the test environment. The thermal history of the test specimen can also have profound effects on its creep behaviour (see Annex A). Consequently, when precise comparative results are required, these factors shall carefully be controlled.

If flexural-creep properties are to be used for engineering-design purposes, the plastics materials should be tested over a broad range of stresses, times and environmental conditions.

6.2 Conditioning and test atmosphere

Condition the test specimens as specified in the International Standard for the material under test. In the absence of any information on conditioning, use the most appropriate set of conditions specified in ISO 291, unless otherwise agreed by the interested parties.

The creep behaviour will be affected not only by the thermal history of the specimen under test, but also by the temperature and (where applicable) humidity used in conditioning. It is recommended that a conditioning-time ≥ t_{90} be used.

Conduct the test in the same atmosphere as used for conditioning, unless otherwise agreed upon by the interested parties, e.g. for testing at elevated or low temperatures. Ensure that the variation in temperature during the duration of the test remains within ±2 °C.

6.3 Measurement of test-specimen dimensions and distance between supports

Measure the dimensions of the conditioned test specimens in accordance with ISO 16012 and ISO 178.

When using the preferred specimen type, adjust the initial distance between the test specimen supports, L, to

$$(16 \pm 1)\,h$$

where h is the thickness of the specimen.

In the case of rigid unidirectional-fibre-reinforced test specimens, the distance between the supports may be adjusted to a value $> 17h$ or to a fixed distance of 100 mm, if necessary, to avoid delamination by shearing or delamination in the compression zone.

Measure the distance between the supports to within ±0,5 %.

6.4 Mounting the test specimens

Mount a conditioned and measured specimen symmetrically with its long axis at right angles to the supports and set up the deflection-measuring device as required.

6.5 Selection of stress value

Select a stress value appropriate to the application envisaged for the material under test, and calculate, using the formula given in 7.1.3, the load to be applied to the test specimen.

Choose the stress such that the deflection is not greater than 0,1 times the distance between the supports at any time during the test.

6.6 Loading procedure

6.6.1 Preloading

When it is necessary to preload the test specimen prior to increasing the load to the test load, take care to ensure that the preload does not influence the test results. Do not apply the preload until the temperature and humidity of the test specimen (positioned in the test apparatus) correspond to the test conditions.

Set the load measurement system to zero before any contact with the specimen. The force applied by preload weights adds to the applied force, in case such preload weights are used.

Directly after application of the preload, set the deflection-measuring device to zero.

6.6.2 Loading

Load the test specimen progressively so that full loading of the specimen is reached between 1 s and 5 s after the beginning of the application of the load. Use the same rate of loading for each of a series of tests on one material.

Take the total load (including the preload) to be the test load.

6.7 Deflection-measurement schedule

Record the point in time at which the specimen is fully loaded as $t = 0$. Unless the deflection is automatically and/or continuously recorded, choose the times for making individual measurements as a function of the creep curve obtained from the particular material under test. It is preferable to use the following measurement schedule:

- 1 min, 3 min, 6 min, 12 min and 30 min;
- 1 h, 2 h, 5 h, 10 h, 20 h, 50 h, 100 h, 200 h, 500 h, 1 000 h, etc.

If discontinuities are suspected or observed in the creep-strain versus time plot, take readings more frequently.

6.8 Time measurement

Measure, to within ±0,1 % or ±2 s (whichever is the less severe tolerance), the total time which has elapsed up to each creep measurement.

6.9 Temperature and humidity control

Unless temperature and relative humidity (where applicable) are recorded automatically, record them at the beginning of the test and then at least three times a day initially. When it has become evident that the conditions are stable within the specified limits, they may be checked less frequently (but at least once a day).

6.10 Measurement of recovery rate (optional)

Upon completion of non-rupture tests, remove the load rapidly and smoothly and measure the recovery rate using, for instance, the same schedule as was used for creep measurement.

7 Expression of results

7.1 Method of calculation

7.1.1 Flexural-creep modulus

Calculate the flexural-creep modulus, E_t, expressed in megapascals, at each of the selected measurement times using Formula (1):

$$E_t = \frac{L^3 \cdot F}{4b \cdot h^3 \cdot s_t} \tag{1}$$

where

L is the initial distance, in millimetres, between the test specimen supports;

F is the applied force, in newtons;

b is the width, in millimetres, of the test specimen;

h is the thickness (height), in millimetres, of the test specimen;

s_t is the deflection, in millimetres, at mid-span at time, t.

7.1.2 Flexural-creep compliance

Calculate the flexural-creep compliance, D_t, expressed in 1/gigapascals, at each of the selected measurement times using Formulae (2) and (3):

$$D_t = \frac{1\,000}{E_t} \tag{2}$$

or

$$D_t = \frac{4\,000 \cdot b \cdot h^3 \cdot s_t}{F \cdot L^3} \tag{3}$$

where

E_t is the flexural creep modulus, in megapascals, at the selected measurement time, t;

L is the initial distance, in millimetres, between the test specimen supports;

F is the applied force, in newtons;

b is the width, in millimetres, of the test specimen;

h is the thickness (height), in millimetres, of the test specimen;

s_t is the deflection, in millimetres, at mid-span at time, t;

7.1.3 Flexural stress

Calculate the flexural stress, σ, expressed in megapascals, using Formula (4):

$$\sigma = \frac{3F \cdot L}{2b \cdot h^2} \qquad (4)$$

where

F is the applied force, in newtons;

L is the distance, in millimetres, between the test specimen supports;

b is the width, in millimetres, of the test specimen;

h is the thickness (height), in millimetres, of the test specimen.

7.1.4 Flexural-creep strain

Calculate the flexural-creep strain, ε_t, using Formula (5):

$$\varepsilon_t = \frac{6\, s_t \cdot h}{L^2} \qquad (5)$$

where

s_t is the deflection, in millimetres, at mid-span at time, t.

h is the thickness (height), in millimetres, of the test specimen;

L is the distance, in millimetres, between the test specimen supports.

7.1.5 Time to rupture

If break of the specimen was observed during the selected deflection measurement schedule, determine the period of time from the moment the specimen is under full load until rupture occurs.

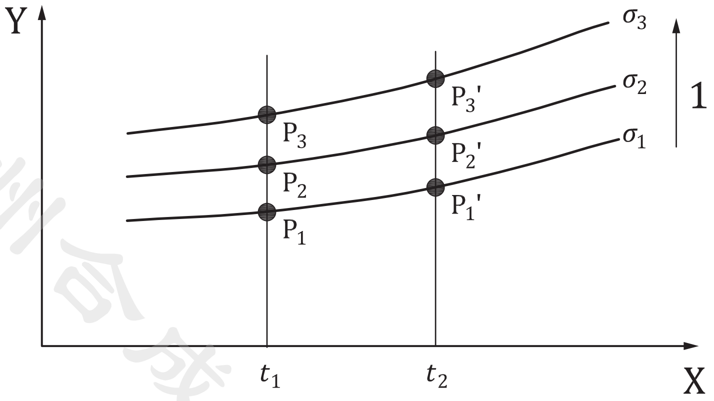
7.1.6 Creep-strength limit

If required, determine initial stress which will just cause rupture ($\sigma_{B,t}$) or will produce a specified strain ($\sigma_{\varepsilon,t}$) at specified time t, at a given temperature and relative humidity

7.2 Presentation of results

7.2.1 Creep curves

If testing is carried out at different temperatures, the raw data should preferably be presented, for each temperature, as a series of creep curves showing the flexural strain plotted against the logarithm of time, one curve being plotted for each initial stress used (see Figure 2).



Key

X log$_{10}$ time, t

Y creep strain, ε_t

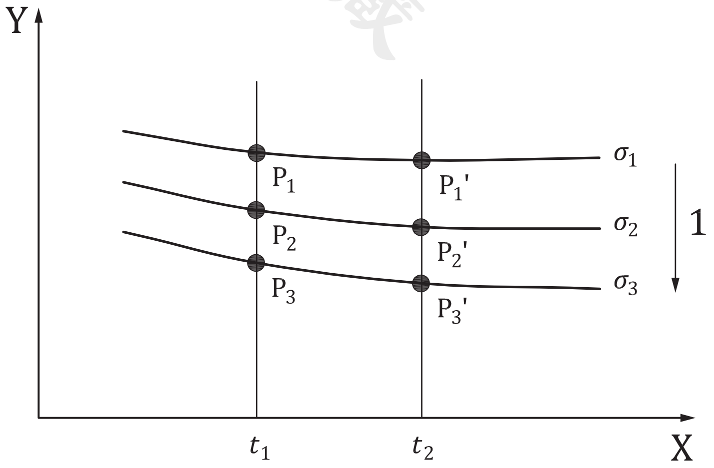
1 increasing stress, σ

Figure 2 — Creep curves

The data may also be presented in other ways, for example as described in 7.2.3 and 7.2.4, to provide information required for particular applications.

7.2.2 Creep-modulus/time curves

For each initial stress used, the flexural-creep modulus, calculated in accordance with 7.1.1, should be plotted against the logarithm of the time under load (see Figure 3).



Key

X log$_{10}$ time, t

Y creep modulus, E_t

1 increasing stress, σ

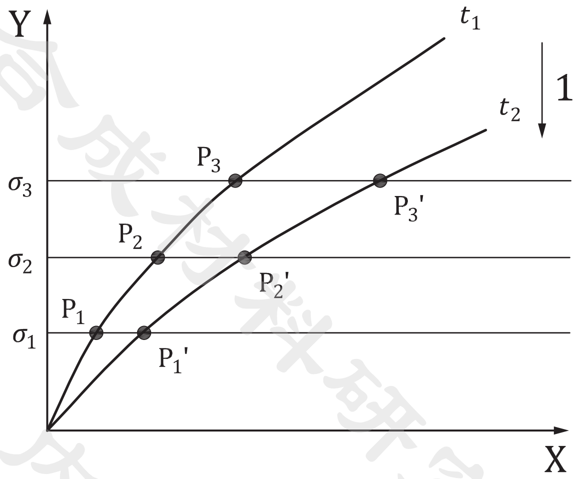
Figure 3 — Creep-modulus/time curves

If testing is carried out at different temperatures, plot a series of curves for each temperature.

7.2.3 Isochronous stress-strain curves

An isochronous stress-strain curve is a Cartesian plot showing how the strain depends on the applied load, at a specific point in time after application of the load. Several curves are normally plotted, corresponding to times under load of 1 h, 10 h, 100 h, 1 000 h and 10 000 h. Since each creep test gives only one point on each curve, it is necessary to carry out the test at, at least, three different stresses, and preferably more, to obtain an isochronous curve.

To obtain an isochronous stress-strain curve for a particular time under load (say 10 h) from a series of creep curves as shown in Figure 2, read off, from each creep curve, the strain at 10 h, and plot these strain values (*x*-axis) against the corresponding stress values (*y*-axis). Repeat the process for other times to obtain a series of isochronous curves (see Figure 4).



Key

X	creep strain, ε_t
Y	stress, σ
1	increasing time, t

Figure 4 — Isochronous stress-strain curves

If testing is carried out at different temperatures, plot a series of curves for each temperature.

7.2.4 Three-dimensional representation

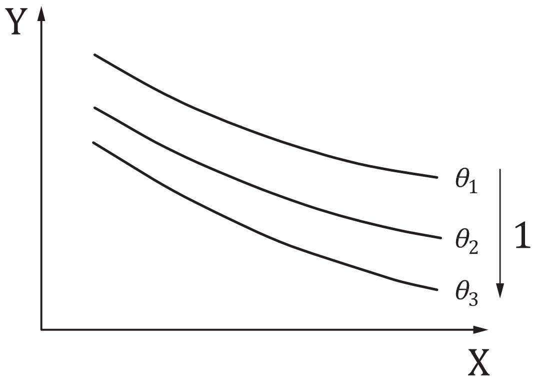
A relationship of the form $\varepsilon = f\,(t,\sigma)$ exists between the different types of curve (see Figures 2 to 4) that can be derived from the raw creep-test data. This relationship can be represented as a surface in a three-dimensional space (see Reference [9]).

All the curves that can be derived from the raw creep-test data form part of this surface. Because of the experimental error inherent in each measurement, the points corresponding to the actual measurements normally do not lie on the curves but just off them.

The surface $\varepsilon = f\,(t,\sigma)$ can therefore be generated by deriving a number of the curves which form it, but a number of sophisticated smoothing operations are usually necessary. Computer techniques permit this to be done rapidly and reliably.

7.2.5 Creep-to-rupture curves

Creep-to-rupture curves allow the prediction of the time to failure at any stress. They should be plotted as stress against log time to rupture (see Figure 5) or log stress against log time to break.



Key

X	$\log_{10}$ time to rupture, t
Y	stress, σ
1	increasing temperature, Θ

NOTE The stress, σ, can also be plotted on a logarithmic scale.

Figure 5 — Creep-to-rupture curves

7.3 Precision

Interlaboratory data are not available at the time of publication. Once interlaboratory data are obtained, a precision statement will be added at the following revision.

8 Test report

The test report shall at least include the following:

a) a reference to this document, i.e. ISO 899-2:2024;

b) a complete description of the material tested, if available including all pertinent information on composition, preparation, manufacturer, tradename, code number, date of manufacture, type of moulding and any annealing;

c) the dimensions of each test specimen and the span-to-thickness ratio, L/h, or distance between supports, if other than 16 (see 6.3);

d) the method of preparation of the test specimens;

e) the directions of the principal axes of the test specimens with respect to the dimensions of the product or some known or inferred orientation in the material;

f) details of the atmosphere used for conditioning and testing;

g) the creep-test data for each temperature at which testing was carried out, presented in one or more of the graphical forms described in 7.2, or in tabular form;

h) the time-dependent strain after unloading the test specimen, in case recovery-rates are measured (see 6.10);

i) any deviations from the procedure;

j) any unusual features observed;

k) the date when the test was completed.

Annex A
(informative)

Physical-ageing effects on the creep of polymers

A.1 General

Physical ageing takes place when a polymer is cooled from an elevated temperature at which the molecular mobility is high to a lower temperature at which relaxation times for molecular motions are long in comparison with the storage time at that temperature. Under these circumstances, changes in the structure will take place over a long period of time, involving rearrangement in the shape and packing of molecules as the polymer approaches the equilibrium structural state for the lower temperature. Associated with this ageing process, there is a progressive decrease in the molecular mobility of the polymer, even when the temperature remains constant. As a direct consequence of this, the creep deformation produced by an applied stress will depend upon the age of the polymer, creep rates being lower in more highly aged material.

This is illustrated in Figure A.1, which shows creep compliance curves for PVC specimens of different ages. Each of these specimens has been rapidly cooled from a temperature of 85 °C (close to T_g) and stored at the test temperature of 23 °C for different times t_e prior to load application. The physical age of a specimen is then defined by the time t_e and it can be seen that the older the specimen the further its creep curve is shifted on the time axis.

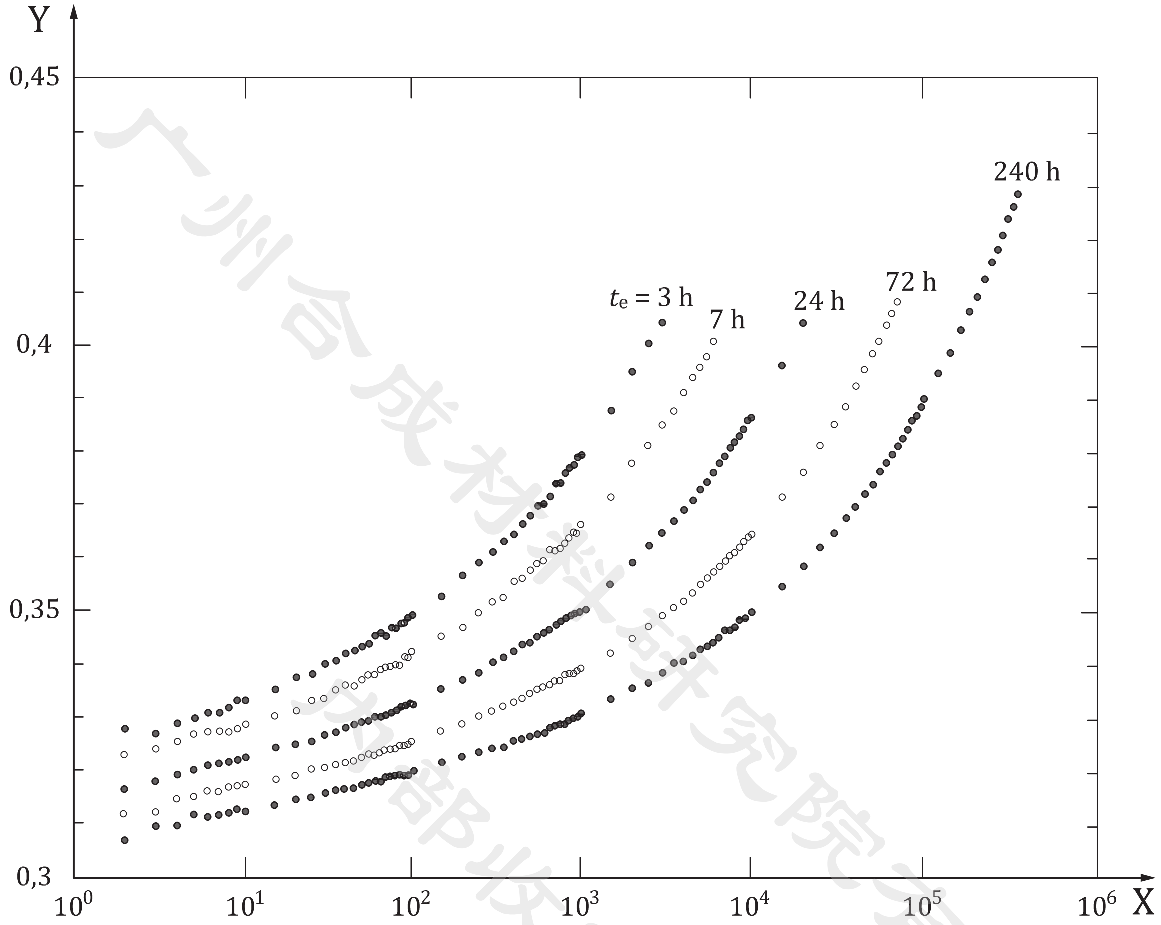
A.2 Creep at elevated temperatures

The influence of physical ageing on creep behaviour is more complicated when measurements are made at elevated temperatures following a storage period at a lower temperature. It is well known that an increase in temperature leads to an increase in molecular mobility and thus a higher rate of creep deformation. In addition to this, changes in molecular structure take place on heating that are associated with a reduction in the physical age of the polymer and lead to a further increase in mobility. Creep deformation at the higher temperature is therefore more rapid than expected from the temperature increase alone. With increasing time, physical ageing is reactivated, and the associated progressive decrease in mobility thus leads to a shift in creep behaviour to longer time, as described in A.1, and thus to a dependence of creep behaviour on dwell time at the high temperature prior to load application. The timescales associated with the changes in physical age depend on the age of the polymer prior to the temperature increase, the magnitudes of the temperature increase and the glass-transition temperature.

Illustrations of the transient changes in creep behaviour that can occur with dwell time at the elevated temperature are shown in Figures A.2 and A.3. In Figure A.2, PVC specimens were stored at 23 °C for 200 h prior to heating to the test temperature of 44 °C. Creep curves were then measured after different dwell times t_{e2} at 44 °C prior to load application. The shift in creep behaviour to longer times is interpreted as the reactivation of physical ageing at 44 °C before loading following the reduction in age state from that at 23 °C resulting from the increase in temperature. In Figure A.3, creep tests were carried out under the same conditions but following a storage period of greater than 1 year at 23 °C prior to heating to the test temperature. The progressive reduction in the structural age of the specimens is observed here as a shift in the curves to shorter creep times and arises because of the more extensive structural changes that have taken place through physical ageing at 23 °C before heating that are not fully overcome by the relatively short times t_e at temperature prior to loading.

A further issue needs to be considered in the analysis of creep data at elevated temperatures. The shape of a creep curve at the elevated temperature will change if, during the reactivation of physical ageing, significant changes in age take place in the duration of the creep test. Any attempt to construct creep master curves using procedures based on time-temperature equivalence shall take account of these transient changes in molecular mobility linked to physical ageing for predictions of long-term behaviour to have any validity.

The changes in creep behaviour with time shown in these figures following cooling or heating are associated with changes in the non-equilibrium structure of the amorphous phase established when the polymer is cooled below its glass-transition temperature. Similar effects are observed in the creep behaviour of semi-crystalline polymers even if the glass transition temperature is below ambient. These effects are believed to be caused by physical ageing in the amorphous phase associated with a relaxation process (the α-process) involving coupled motions of molecules spanning both the crystal and amorphous phases.

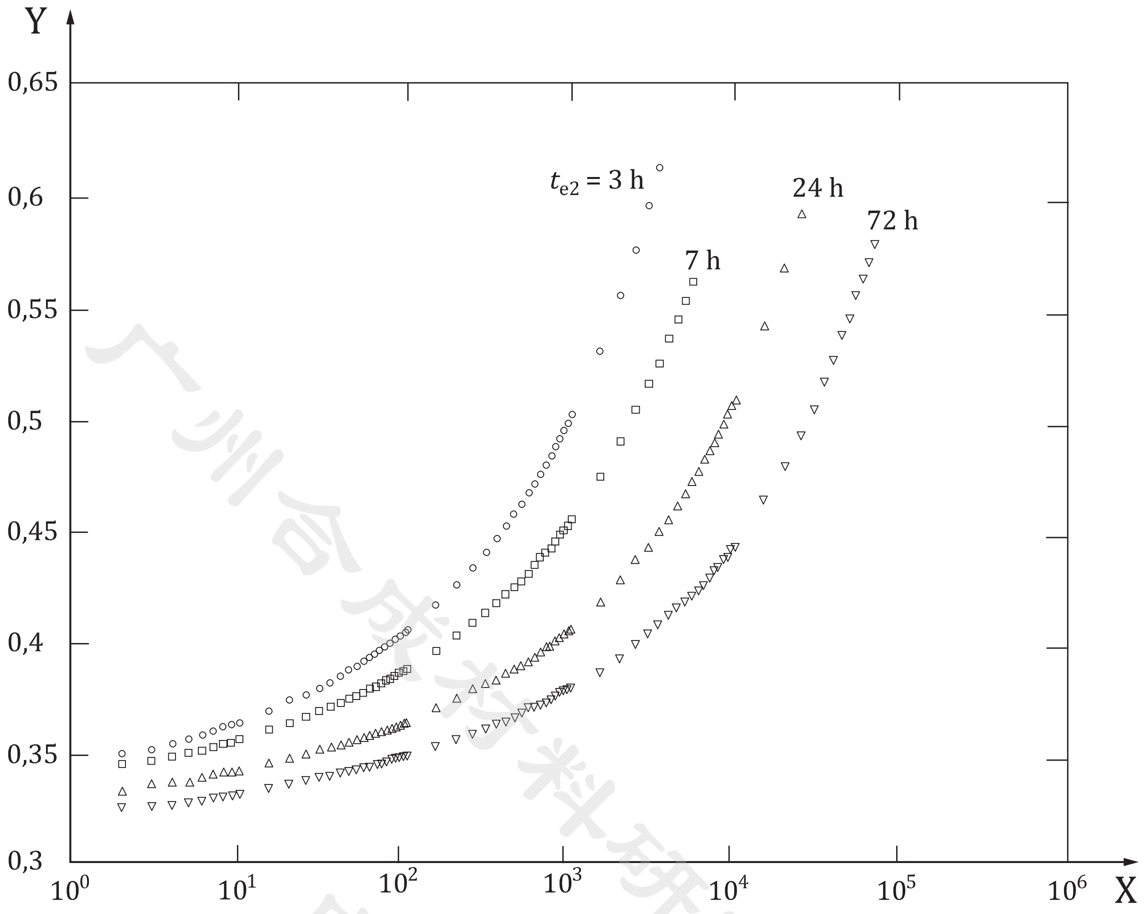


Key

X time, t, in seconds

Y $D_{(t)}$, (GPa^{-1})

Figure A.1 — Creep compliance curves for PVC at 23 °C obtained at different times t_e after rapid cooling of the specimen from 85 °C to 23 °C

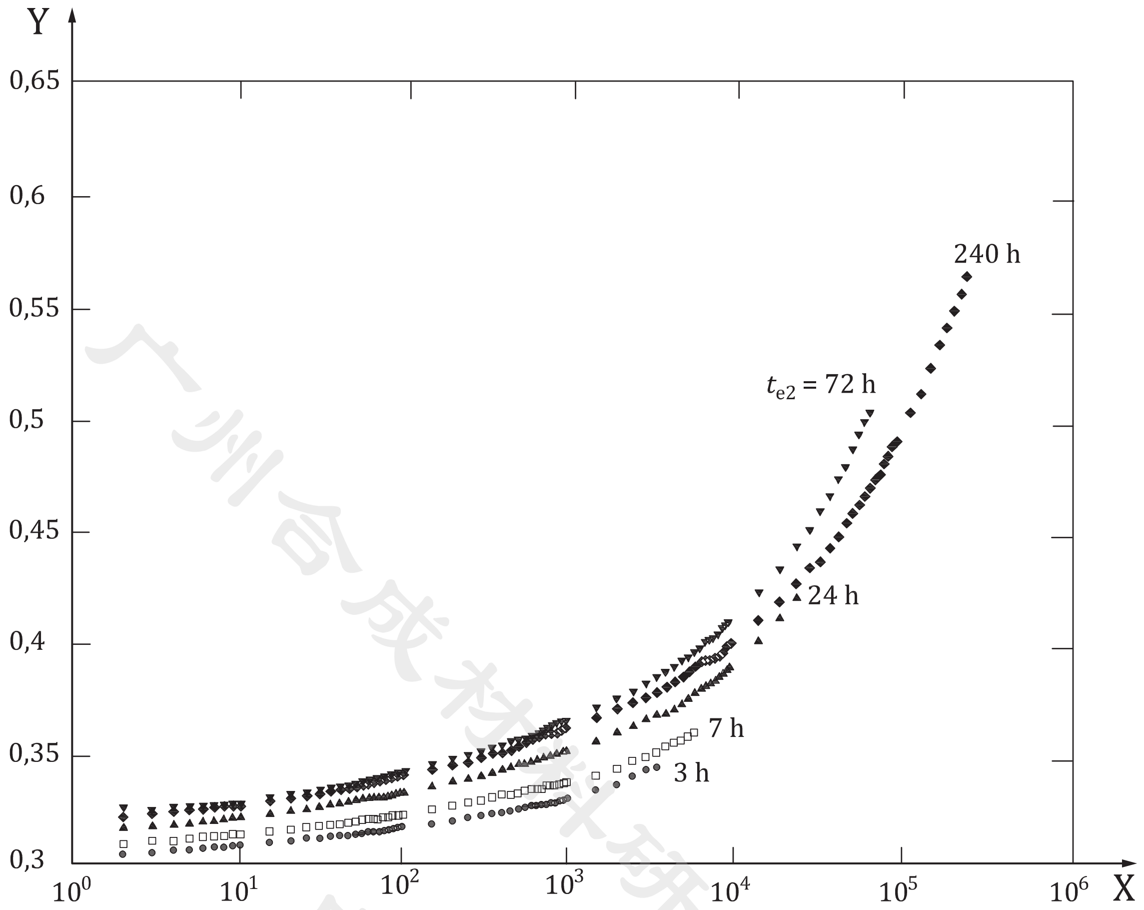


Key

X time, t, in seconds

Y $D_{(t)}$, (GPa^{-1})

Figure A.2 — Creep compliance curves for PVC at 44 °C obtained by application of the load at different times t_{e2} after heating from 23 °C (the specimen had been stored for 200 h at 23 °C prior to heating)



Key

X time, t, in seconds

Y $D_{(t)}$, (GPa^{-1})

Figure A.3 — Creep compliance curves as for Figure A.2, but following storage for more than 1 year at 23 °C prior to heating

Bibliography

[1] ISO 1209-1, *Rigid cellular plastics — Determination of flexural properties — Part 1: Basic bending test*

[2] ISO 1209-2, *Rigid cellular plastics — Determination of flexural properties — Part 2: Determination of flexural strength and apparent flexural modulus of elasticity*

[3] ISO 293, *Plastics — Compression moulding of test specimens of thermoplastic materials*

[4] ISO 294-1, *Plastics — Injection moulding of test specimens of thermoplastic materials — Part 1: General principles, and moulding of multipurpose and bar test specimens*

[5] ISO 295, *Plastics — Compression moulding of test specimens of thermosetting materials*

[6] ISO 2602, *Statistical interpretation of test results — Estimation of the mean — Confidence interval*

[7] ISO 2818, *Plastics — Preparation of test specimens by machining*

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