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# Plastics — Determination of water absorption

*Plastiques — Détermination de l'absorption d'eau*

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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 62 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 6, *Ageing, chemical and environmental resistance*.

This third edition cancels and replaces the second edition (ISO 62:1999), to which a precision statement has been added.

# Introduction

Plastics exposed to water are subject to several different effects:

a) dimensional changes (e.g. swelling) caused by absorption of water;

b) extraction of water-soluble components;

c) changes in other properties.

However, exposure to humidity, immersion and exposure to boiling water can result in distinctly different material responses. The equilibrium moisture content can be used to compare the amount of water absorbed by different types of plastics when they are exposed to moisture. Moisture content determined under non-equilibrium conditions can be used to compare different batches of the same material and to determine the diffusion constant of the material when determined under carefully controlled non-equilibrium conditions of exposure to moisture and when using plastic specimens of defined dimensions.

# Plastics — Determination of water absorption

## 1 Scope

**1.1** This International Standard describes a procedure for determining the moisture absorption properties in the “through-the-thickness” direction of flat or curved-form solid plastics. This International Standard also describes procedures for determining the amount of water absorbed by plastic specimens of defined dimensions, when immersed in water or when subjected to humid air under controlled conditions. The “through-the-thickness” moisture diffusion coefficient can be determined for single-phase material by assuming Fickian diffusion behaviour with constant moisture absorption properties through the thickness of the test specimen. This model is valid for homogeneous materials and for reinforced polymer-matrix composites tested below their glass transition temperature. However, some two-phase matrices such as hardened epoxies may require a multi-phase absorption model which is not covered by this International Standard.

**1.2** Ideally, the best comparison of the water absorption properties and/or diffusion coefficients of materials should be carried out only using the equilibrium moisture content of plastics exposed to identical conditions. The comparison of materials using properties at moisture equilibrium does not assume, and is therefore not limited to, single-phase Fickian diffusion behaviour.

**1.3** Alternatively, water absorption of plastic specimens of defined dimensions exposed to immersion or humidity under controlled conditions but for an arbitrary time period can be used to compare different batches of the same material or for quality control tests of a given material. For this type of comparison, it is essential that all test specimens be of identical dimensions and, as nearly as possible, have the same physical attributes, e.g. surface smoothness, internal stresses, etc. However, moisture equilibrium is not reached under these conditions. Therefore, results from this type of test cannot be used to compare the water absorption properties of different types of plastics. For more reliable results, simultaneous tests are recommended.

**1.4** The results obtained using the methods described in this International Standard are applicable to most plastics but are not applicable to cellular plastics, granulates or powders, which can show additional absorption and capillary effects. Plastics exposed to moisture under controlled conditions for defined periods of time provide relative comparisons between them. The tests described for the determination of the diffusion coefficient may not be applicable to all plastics. Plastics that do not retain their shape when immersed in boiling water should not be compared using method 2 (see 6.4).

## 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 175:1999, *Plastics — Methods of test for the determination of the effects of immersion in liquid chemicals*

ISO 294-3, *Plastics — Injection moulding of test specimens of thermoplastic materials — Part 3: Small plates*

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

## 3 Principle

Test specimens are immersed in distilled water at 23 °C or in boiling distilled water, or exposed to 50 % relative humidity at given temperatures, for prescribed periods. The amount of water absorbed by each test specimen is determined by measuring its change in mass, i.e. the difference between its initial mass and that after exposure to water, the change being expressed as a percentage of the initial mass. If required, the amount of water lost after drying the test specimens can also be determined.

In some applications, 70 % to 90 % relative humidity and temperatures of 70 °C to 90 °C may be necessary. Relative humidities and temperatures higher than those recommended in this International Standard may be used by agreement between the interested parties. When relative humidity and temperature conditions other than those recommended are used, a complete description of these conditions (with appropriate tolerances) shall be included in the test report.

## 4 Apparatus

**4.1 Balance**, with an accuracy of ± 0,1 mg (see also 6.1.3).

**4.2 Oven**, with forced-air convection or vacuum, maintained at (50,0 ± 2,0) °C or at any other agreed temperature (see also 6.1.2).

**4.3 Containers**, containing distilled water or water of equivalent purity, equipped with a means of heating capable of maintaining the temperature specified.

**4.4 Desiccator**, with a desiccant (e.g. $P_2O_5$).

**4.5 Means of measuring the dimensions of the test specimens** to an accuracy of ± 0,1 mm, if required.

## 5 Test specimens

### 5.1 General

For each material evaluated, test at least three test specimens. Test specimens of the required dimensions may be prepared by moulding or extrusion. The methods used for preparation of all test specimens shall be included in the test report.

NOTE The results of this method may be influenced by surface effects. For some materials, different results can be obtained between moulded specimens and specimens cut from a larger sheet.

Any contaminant on the test specimen surface which could influence water absorption shall be removed by a cleaning agent which does not attack the plastic, the degree of attack being determined in accordance with ISO 175 — for example, the notation “none” (no change in appearance) in ISO 175:1999, Table 1. Allow specimens to dry at 23 °C and 50 % relative humidity for at least 2 h after cleaning and before beginning the test. Wear clean gloves when handling test specimens to prevent contamination.

The cleaning agent shall have no effect on the the water absorption. When determining the moisture equilibrium content in accordance with 6.3 (method 1) and 6.6 (method 4), the effects of the cleaning agent can be ignored.

### 5.2 Square-shaped test specimens for homogeneous plastics

Unless otherwise specified or agreed by all interested parties, the dimensions and dimensional tolerances of the square-shaped specimens shall be the same as those given in ISO 294-3, with a thickness of (1,0 ± 0,1) mm. They can be prepared by moulding in accordance with ISO 294-3, using conditions given in standards applicable to the material being tested (or using conditions recommended by the material supplier). For some materials, such as polyamides, polycarbonates and some reinforced plastics, use of a 1 mm thick specimen may not give meaningful results. Furthermore, some product specifications require the use of thicker test specimens for the determination of water absorption. In these cases, test specimens of (2,05 ± 0,05) mm thickness may be used. If specimens of thickness other than 1 mm are used, the specimen thickness shall be indicated in the test report. There are no requirements for the radii of the edges and corners. However, they shall be smooth and clean to prevent material from the edges and corners from being lost during the test.

Some materials may exhibit mould shrinkage. If specimens of these materials are prepared using a mould with dimensions at the lower limits specified in ISO 294-3, the final dimensions of the specimens may be beyond the tolerances given in this International Standard, in which case they shall be noted in the test report.

### 5.3 Test specimens of reinforced plastics affected by anisotropic diffusion effects

For some reinforced plastic materials, such as carbon-fibre-reinforced epoxies, anisotropic diffusion effects caused by the reinforcing material may produce erroneous results when small specimens are used. Where this is of concern, test specimens that meet one of the following types of specimen shall be used and the specific dimensions and methods of test specimen preparation shall be included in the test report:

a) A nominally square-shaped plate or curved panel with dimensions that satisfy the relation:

$$w \leqslant 100d$$

where

$w$ is the nominal length of one side, in millimetres;

$d$ is the nominal thickness, in millimetres.

b) A 100 mm × 100 mm square-shaped plate with stainless steel or aluminium foil bonded to the edges so that moisture absorption through the edges is minimized. When this specimen is prepared, care shall be taken to weigh the specimen before and after bonding of the foil in order to obtain the mass increase due to the foil and the adhesive. Use only poorly absorbing adhesive which will not affect the results.

### 5.4 Tubular test specimens

Unless specifically required by other International Standards, tubular test specimens shall have the following dimensions:

a) For tubes having an internal diameter of 76 mm or less, cut sections of tube that are (25 ± 1) mm in length from a longer tube of the material being evaluated. The cut shall be made perpendicular to the longitudinal axis of the tube. The cut can be made by machining, sawing or shearing and shall produce smooth edges free from cracks.

b) For tubes having an internal diameter larger than 76 mm, cut out rectangular specimens (76 ± 1) mm in length (measured along the outside surface of the tube) by (25 ± 1) mm in width. The cut edges shall be smooth and free from cracks.

### 5.5 Rod-shaped test specimens

Rod-shaped test specimens shall have the following dimensions:

a) For rods 26 mm in diameter or less, cut off a section of (25 ± 1) mm in length. The cut shall be made perpendicular to the longitudinal axis of the rod. The diameter of the test specimen shall be the diameter of the rod.

b) For rods larger than 26 mm in diameter, cut off a section of (13 ± 1) mm in length. The cut shall be made perpendicular to the longitudinal axis of the rod. The diameter of the test specimen shall be the diameter of the rod.

### 5.6 Specimens cut from finished products, extrusion compounds, sheets or laminates

Unless required by another International Standard, cut a piece from the product that

— meets the requirements for the square-shaped test specimen

or

— has a length and width of (61 ± 1) mm and has the same shape (thickness and curvature) as the material being tested.

The machining conditions used to prepare the test specimens shall be agreed by all interested parties. They shall also be in accordance with ISO 2818 and shall be included in the test report.

If the nominal thickness is greater than 1,1 mm and in the absence of special provisions concerning the relevant application, the thickness of the test specimens shall be reduced to 1,0 mm to 1,1 mm by machining on one surface only.

When the surface of a laminate is machined, the water absorption properties will be influenced to such an extent that the test results will not be valid. Therefore, the specimens shall be tested at their original thickness and the dimensions shall be indicated in the test report.

## 6 Test conditions and procedures

### 6.1 General

**6.1.1** Certain materials may require that the test specimens be weighed in a weighing vessel.

**6.1.2** Drying procedures other than those described in 6.3 to 6.6 may be used by agreement between the interested parties.

**6.1.3** When the water absorption of the material is greater than or equal to 1 %, specimens which have been weighed accurately to ± 1 mg and whose mass is constant to ± 1 mg are acceptable.

### 6.2 General conditions

**6.2.1** Specimens shall be carefully dried prior to testing. At 50 °C, for instance, a drying period of between one and ten days will be necessary, the exact duration depending on the thickness of the specimens.

**6.2.2** Use at least 8 ml of distilled water per square centimetre of the total surface of the test specimen but not less than 300 ml per test specimen. This will prevent any extraction product from becoming excessively concentrated in the water during the test.

**6.2.3** Place each set of three test specimens in a separate container (4.3) and completely immerse them in water or expose them to 50 % RH (method 4).

When several samples of the same composition are to be tested, the test specimens may be placed together in the same container with at least 300 ml of water per test specimen. However, in this case, significant surface contact between test specimens or with the walls of the container is unacceptable and shall be prevented.

NOTE Grids made of stainless steel may help to ensure an acceptable distance between the test specimens.

For specimens having a density lower than that of water, immerse the specimens by placing them in a stainless-steel wire basket connected to an anchor-weight by a stainless-steel wire. Avoid surface contact of the anchor-weight with the specimens.

**6.2.4** Time intervals for water immersion are given in 6.3 and 6.4. However, longer immersion periods may be used by agreement between the interested parties. In such cases, the following precautions shall be taken:

- for tests performed in water at 23 °C, agitate the water at least once daily, for example by swirling the contents of the container;
- for tests performed in boiling water, add boiling water as required in order to maintain the volume.

**6.2.5** During weighing operations, the specimens shall not absorb or release any water. They shall therefore be weighed immediately after being taken from the exposure environment (and, if necessary, removing any surface water). Special care shall be taken in the case of thin specimens and materials with a high coefficient of diffusion for water.

**6.2.6** In the case of 1 mm thick specimens and materials with a high coefficient of diffusion for water, the first weighings shall be carried out after 2 h and 6 h.

## 6.3 Method 1: Determination of amount of water absorbed after immersion in water at 23 °C

Dry all replicate test specimens in an oven (4.2) maintained at (50 ± 2) °C for at least 24 h (see 6.2.1) and allow them to cool to room temperature in the desiccator (4.4) before weighing them to the nearest 0,1 mg. Repeat this process until the mass of the specimens is constant (mass $m_1$) to within ± 0,1 mg.

Then place the test specimens in a container (4.3) filled with distilled water maintained at 23,0 °C ± 1,0 °C or ± 2,0 °C, depending on the relevant specification. In the absence of a specification, the tolerance shall be ± 1,0 °C.

After immersion for (24 ± 1) h, take the test specimens from the water and remove all surface water with a clean, dry cloth or with filter paper. Reweigh the test specimens to the nearest 0,1 mg within 1 min of removing them from the water (mass $m_2$).

The water content at saturation is measured by re-immersing the test specimens and reweighing them at given time intervals. A typical immersion time scale is 24 h, 48 h, 96 h, 192 h, etc. At each of these intervals (± 1 h), remove the test specimens from the water, remove all surface water and reweigh each test specimen to the nearest 0,1 mg within 1 min of removing them from the water (e.g. $m_{2/24\ \mathrm{h}}$).

## 6.4 Method 2: Determination of amount of water absorbed after immersion in boiling water

Dry all replicate test specimens in an oven (4.2) maintained at (50,0 ± 2,0) °C for at least 24 h (see 6.2.1) and allow them to cool to room temperature in the desiccator (4.4) before weighing them to the nearest 0,1 mg. Repeat this process until the mass of the specimens is constant (mass $m_1$) to within ± 0,1 mg.

Then place the test specimens in a container (4.3) of boiling distilled water so that they are supported on one edge and entirely immersed. After (30 ± 2) min, remove the test specimens from the boiling water and cool them in distilled water maintained at room temperature. After cooling the test specimens for (15 ± 1) min, remove them from the water one at a time. Remove all surface water with a dry cloth, then immediately weigh them to the nearest 0,1 mg (mass $m_2$). If the thickness of the test specimens is less than approximately 1,5 mm, a small but measurable amount of water desorption may occur during the weighing procedure. In this case, it is preferable to weigh the specimens in a weighing bottle.

The water content at saturation is measured by re-immersing the test specimens and reweighing them at (30 ± 2) min intervals. After each of these intervals, the test specimens shall be removed from the water, cooled in distilled water, dried and weighed as described above.

Cracks may form after repeated immersion and drying. If so, the number of cycles at which the cracks are first observed shall be noted in the test report.

### 6.5 Method 3: Determination of water-soluble matter lost during immersion

When materials are known or suspected to contain appreciable amounts of water-soluble ingredients, it is necessary to correct for the water-soluble matter lost during the immersion test. For this purpose, after immersion in accordance with 6.3 or 6.4, recondition the test specimens to constant mass (mass $m_3$) in the same way as in the original drying period in 6.3 and 6.4. If this reconditioned mass $m_3$ is less than the conditioned mass $m_1$, the difference shall be considered as the water-soluble matter lost during the immersion test. For such materials, the water absorption value shall be taken as the sum of the increase in mass following immersion and the mass of the water-soluble matter.

### 6.6 Method 4: Determination of amount of water absorbed after exposure to 50 % relative humidity

Dry all replicate test specimens in an oven (4.2) maintained at (50,0 ± 2,0) °C for at least 24 h (see 6.2.1) and allow them to cool to room temperature in a desiccator (4.4) before weighing them to the nearest 0,1 mg. Repeat this process until the mass of the specimens is constant (mass $m_1$) to within ± 0,1 mg.

Then place the test specimens in enclosure or room containing air with a relative humidity of (50 ± 5) % maintained at 23,0 °C ± 1,0 °C or ± 2,0 °C, depending on the relevant specification. In the absence of a specification, the tolerance shall be ± 1,0 °C. After exposing the test specimens for (24 ± 1) h, reweigh them to the nearest 0,1 mg (mass $m_2$) within 1 min after the removal from the enclosure or room containing the air with a relative humidity of (50 ± 5) %.

The equilibrium moisture content is measured by repeating the exposure of the test specimens to 50 % relative humidity, following the same weighing procedure and using the same time intervals as given in method 1 (see 6.3).

## 7 Expression of results

### 7.1 Percentage by mass of water absorbed

For each test specimen, calculate the percentage change in mass $c$ relative to the initial mass by using the appropriate formula:

$$c = \frac{m_2 - m_1}{m_1} \times 100\ \%$$

or

$$c = \frac{m_2 - m_3}{m_1} \times 100\ \%$$

where

$m_1$ is the mass of the test specimen, in milligrams (mg), after initial drying and before immersion;

$m_2$ is the mass of the test specimen, in milligrams (mg), after immersion;

$m_3$ is the mass of the test specimen, in milligrams (mg), after immersion and final drying.

Express the result as the arithmetic mean of the three values obtained at the same exposure duration.

NOTE In certain instances, it may be required to express the amount of water absorbed as a percentage by mass with respect to the test specimen mass after final drying, using the following formula:

$$c = \frac{m_2 - m_3}{m_3} \times 100\ \%$$

## 7.2 Determination of the water content at saturation and the water diffusion coefficient using Fick's laws

At temperatures well below the glass transition temperature of the wet polymer, the water absorption of most polymers (determined by methods 1, 3 and 4) correlates well with Fick's laws (see Annex A), and a water diffusion coefficient independent of time and concentration [1] can be calculated as described in the example below.

However, in this case, the water content at saturation $c_s$ as well as the diffusion coefficient $D$, expressed in millimetres squared per second ($mm^2/s$), can be determined by fitting the experimental data to Fick's law for sheets [2, 3] without waiting for constant mass to be reached (see Clause A.2).

The water content at saturation is expressed as $c_s$ when the test specimens are immersed in water in accordance with method 1, 2 or 3 and as $c_s(50\ \%)$ when the test specimens are exposed to air at 50 % relative humidity (method 4). Graphical methods may be used to verify the Fickian diffusion behaviour of the test specimens, substituting the calculated $D$-value, e.g. by a log plot which is then fitted to the theoretical data or by using a commercially available software package. In order to verify that the water absorption of a polymer follows Fickian diffusion behaviour, the experimental data have to be taken for a longer period up to the equilibrium concentration $c_s$.

Figure A.1 shows a fairly exact solution of Fick's laws for sheets. A slope of 0,5 has been found for

$$c \leqslant 0{,}51 c_s$$

or

$$c/c_s \leqslant 0{,}51$$

or

$$\frac{D\pi^2 t}{d^2} \leqslant 0{,}50$$

where

$t$ is the duration of immersion of the test specimen in the water or humid air, in seconds;

$d$ is the thickness of the test specimen, in millimetres.

In the case where

$$D\pi^2 t/d^2 \geqslant 5$$

use the value

$$c = c_s$$

Additional values are given in Table 1.

**Table 1 — Theoretical dimensionless values from Fick's law for sheets**

| $D\pi^2t/d^2$ | $c/c_s$ |
|---|---|
| 0 | 0 |
| 0,01 | 0,07 |
| 0,10 | 0,22 |
| 0,5 | 0,51 |
| 0,7 | 0,60 |
| 1,0 | 0,70 |
| 1,5 | 0,82 |
| 2,0 | 0,89 |
| 3,0 | 0,96 |
| 4,0 | 0,99 |
| 5,0 | 1,00 |

EXAMPLE For a test running till constant mass is reached, after fitting the experimental data to the theoretical graph, take the experimental concentration $c_{70\,\%}$ from the calculation $c/c_s = 0{,}7$, and calculate:

$$c_s = \frac{c_{70\,\%}}{0{,}7}$$

where $c_s$ and $c_{70\,\%}$ are expressed in milligrams per gram or as a percentage by mass.

The experimental period $t_{70}$ at $c_{70\,\%}$ enables the diffusion coefficient $D$, expressed in millimetres squared per second (mm$^2$/s), to be calculated from

$$\frac{D\pi^2 t_{70}}{d^2} = 1$$

or

$$D = \frac{d^2}{\pi^2 t_{70}}$$

If $t_{70}$ is given in seconds, $\pi^2$ is approximated as 10 and the thickness for a flat test specimen is 1 mm, then:

$$D \approx \frac{1}{10 t_{70}}$$

NOTE Typical values of $D$ for plastics at 23 °C are $10^{-6}$ mm$^2$/s, which gives a $t_{70}$ of $10^5$ s (approximately 1 day) with the 1 mm test specimen. With this thickness, the immersion period necessary to calculate $c_s$ and $D$ will not normally exceed one week.

## 8 Precision

For precision data, see Annex B.

## 9 Test report

The test report shall include the following:

a) a reference to this International Standard;

b) all details necessary for complete identification of the material or product tested;

c) the type of test specimen used and the method of preparation, stating whether the specimens have been cut or not, their dimensions, their initial mass and, if applicable, their initial surface area and their surface condition (for example whether they are machined or not);

d) the method (1, 2, 3 or 4) used and the immersion period(s);

e) the water absorption, calculated by one or more of the ways of expressing the results given in Clause 7, reporting the mean and the standard deviation of the results (if the calculations described in 7.1 and 7.2 give a negative value for the water absorption, this fact shall be stated clearly in the test report);

f) the water absorption at saturation $c_\mathrm{s}$ or $c_\mathrm{s}(50\ \%)$ at 23 °C, calculated in accordance with 7.2;

g) the diffusion coefficient at 23 °C, calculated in accordance with 7.2;

h) any incidents likely to have affected the results;

i) the date(s) of testing.

# Annex A
(informative)

# Correlation between water absorption by test specimens and Fick's diffusion laws

## A.1 General

In cases when the water absorption correlates with Fick's laws, the time-dependent water content can be expressed as a function of the diffusion coefficient $D$ and the water absorption at saturation $c_\mathrm{s}$ as follows:

$$c(t) = c_\mathrm{s} - c_\mathrm{s} \frac{8}{\pi^2} \sum_{k=1}^{20} \frac{1}{(2k-1)^2} \exp\left[ -\frac{(2k-1)^2 D \pi^2}{d^2} t \right] \tag{A.1}$$

where

$k$ = 1, 2, 3, …, 20;

$d$ is the thickness of the specimen.

NOTE The use of 20 summands is generally considered sufficient.

## A.2 Determination of $D$ and $c_\mathrm{s}$ without waiting for constant mass to be reached

Assuming correlation with Fick's laws, a linear dependency between $\lg\left(c(t)/c_\mathrm{s}\right)$ and $\lg\left(D \cdot t\right)$ can be assumed to be approximately true for small values (see Figure A.1). Including the theoretical values from Table 1, the diffusion coefficient in the linear range can be expressed as follows:

$$\sqrt{D} \approx \frac{1}{c_\mathrm{s}} \cdot \frac{d}{0{,}52\pi} \cdot \frac{c(t)}{\sqrt{t}} \tag{A.2}$$

where

$c_\mathrm{s}$ is the water absorption at saturation;

$d$ is the thickness of the specimen;

$t$ is the exposure duration;

$c(t)$ is the measured water absorption at time $t$.

The value of $c_\mathrm{s}$ can then be estimated using Equation (A.1) in combination with graphical or mathematical tools [1].

---

[1] Possible methods are curve fitting, numerical tools and commercial computer programmes.

## A.3 Verification of correlation with Fick's diffusion laws

“Good agreement” of the water absorption of a polymer specimen with Fickian diffusion behaviour is observed if, after the bend in the graph $c = f(t)$ at approximately $t_{70}$ (see Figure A.1), the values of $c_s$ and $D$ determined by fitting Equation (A.1) to the experimental data are not changed significantly by increasing the duration of immersion to $t_{max}$. $t_{max}$ is the maximum experimental time $> t_{70}$. Typically, the difference between $c_s$ determined at about $t_{70}$ and $c_s$ determined for $t \to \infty$ is less than 10 %. Similarly, the difference between $D$ determined at about $t_{70}$ and $D$ determined for $t \to \infty$ is typically less than 20 %.

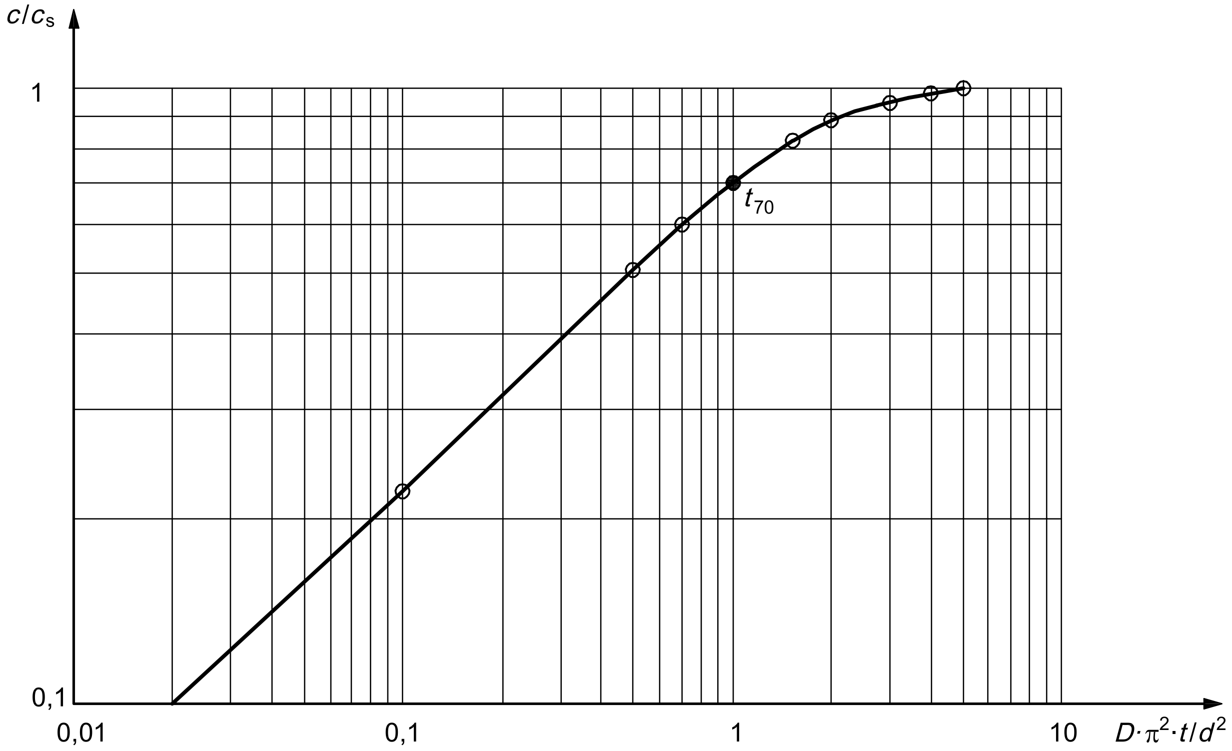


**Figure A.1 — Water absorption $c/c_s$ of sheets as a function of the dimensionless function $D \cdot \pi^2 \cdot t/d^2$**
($D$ = diffusion coefficient, $t$ = immersion duration, $d$ = thickness of specimen)

# Annex B
(informative)

# Precision statement

## B.1 Round-robin test

Precision data are based on a round-robin test involving 16 laboratories in five countries [4]. Two types of PMMA [standard PMMA and impact-resistant PMMA (PMMA-IR)] and one type of PC were used. The dimensions of the test specimens were 60 mm × 60 mm × 1 mm and 60 mm × 60 mm × 2 mm. All materials were prepared and distributed by one laboratory.

## B.2 Drying of the specimens

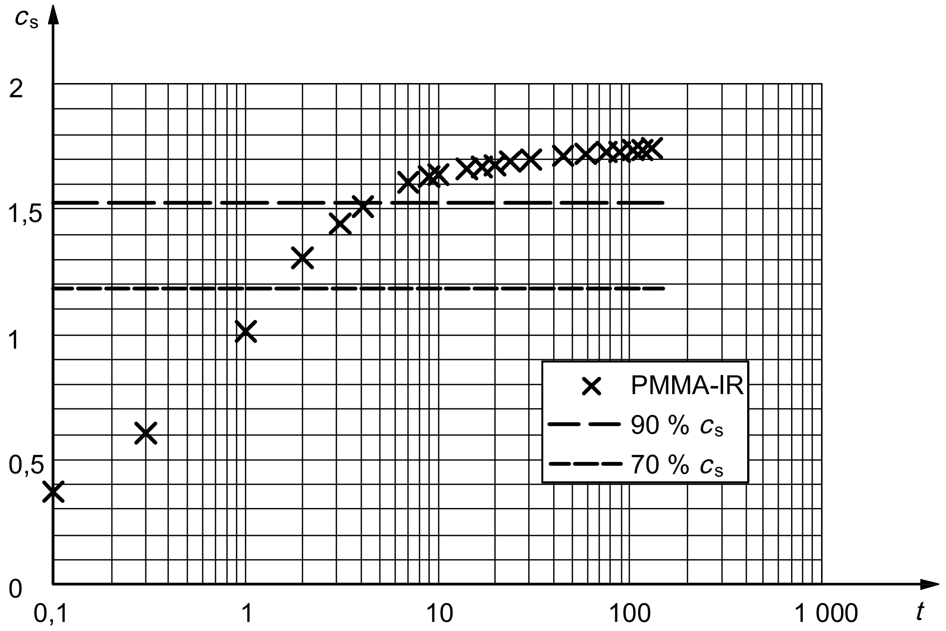
For most materials, a conditioning period of $t_{90}$ corresponding to absorption or release of roughly 90 % of the attainable water content is a sufficient approximation to the equilibrium moisture content. Typically, $t_{90}$ is about twice $t_{70}$. At 50 °C, the drying period is usually one to ten days, with the exact duration depending on the diffusion coefficient and the thickness of the test specimens.

For the 1 mm thick PC specimens, a drying time of one day at 50 °C or two or three days at 23 °C was used in the round-robin test. For the 2 mm thick PMMA specimens, drying times of 8 days at 50 °C or 30 days at 23 °C were used. In all cases, specimens were dried to constant mass (to within ± 0,1 mg).

## B.3 Determination of water content absorbed after immersion in water at 23 °C (method 1)

After different exposure periods the water content was determined. The experimental data from one laboratory are shown in Figure B.1.

The water absorption data from 11 laboratories were fitted in accordance with Annex A to determine $c_\mathrm{s}$ and $D$ for the three different materials. The mean values and standard deviations obtained are shown in Table B.1 and Table B.2, respectively. $s_R$ indicates the between-laboratory standard deviation, $R$ indicates the 95 % reproducibility limit. Data to determine the within-laboratory standard deviation (repeatability) were not available.



NOTE Water content $c_s$ expressed in mass %.

Figure B.1 — Experimental values of water content of PMMA-IR (also showing the 70 % and 90 % $c_s$-value)

**Table B.1 — $c_s$-value fitted to the experimental water-absorption data**

| **Material** | $c_s$ mass % | $s_R$ | $R$ |
|---|---|---|---|
| PMMA | 1,87 | 0,06 | 0,17 |
| PMMA-IR | 1,67 | 0,05 | 0,13 |
| PC | 0,340 | 0,009 | 0,025 |

**Table B.2 —$D$-value fitted to the experimental water-absorption data**

| **Material** | $D$ $\text{mm}^2/\text{s}$ (× $10^7$ ) | $s_R$ | $R$ |
|---|---|---|---|
| PMMA | 5,2 | 1,0 | 2,7 |
| PMMA-IR | 7,7 | 0,6 | 1,6 |
| PC | 42 | 11 | 31 |

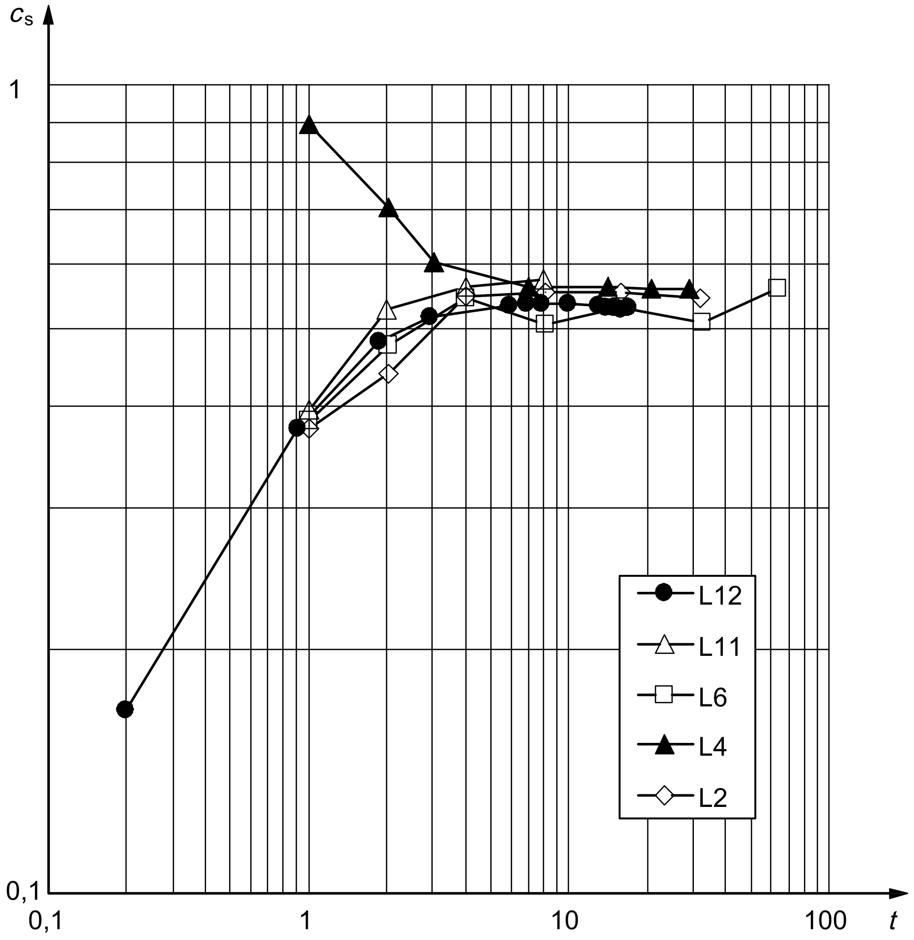
Permitting an uncertainty of 10 % for $c_s$ and 30 % for $D$, acceptable results were available after 7 days. In general, the test may be terminated after $t_{90}$, although at this stage the equilibrium will not have been attained.

For thin (1 mm) specimens of materials with high $D$-values, several weighings needed to be made within the first 24 h (e.g. after 2 h and after 6 h).

## B.4 Determination of amount of water absorbed after exposure to 50 % relative humidity (method 4)

The correct value of $c_s$ for standard PMMA at 50 % RH seems to range from 0,5 mass % to 0,6 mass %. This value, as well as the exposure periods required to attain equilibrium, is independent of the way in which saturation is achieved, either from dry to wet or from wet to dry.

The data for the impact-resistant PMMA-IR are shown in Figure B.2. All participants quoted a value of $c_s$ from 0,5 mass % to 0,6 mass %, again irrespective of the way in which saturation was achieved.



NOTE Water content $c_s$ expressed in mass %.

**Figure B.2 — Water absorption by 1 mm thick PMMA-IR at 50 % RH measured by five different laboratories (L2, L4, etc.)**

In the case of 1 mm thick PC, the specimens very quickly became saturated at around 0,15 mass %, again irrespective of the way in which saturation was achieved. $t_{70}$ was only five to eight hours.

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