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Glass in building — Determination of the bending strength of glass —

Part 1: Fundamentals of testing glass

Verre dans la construction — Détermination de la résistance du verre à la flexion —

Partie 1: Principes fondamentaux des essais sur le verre

Reference number
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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 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 meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 160, *Glass in building*, Subcommittee SC 2, *Use considerations.*

ISO 1288 consists of the following parts, under the general title *Glass in building — Determination of the bending strength of glass*:

— *Part 1: Fundamentals of testing glass*

— *Part 2: Coaxial double ring test on flat specimens with large test surface areas*

— *Part 3: Test with specimen supported at two points (four point bending)*

— *Part 4: Testing of channel shaped glass*

— *Part 5: Coaxial double ring test on flat specimens with small test surface areas*

Glass in building — Determination of the bending strength of glass —

Part 1: Fundamentals of testing glass

1 Scope

This part of ISO 1288 specifies the determination of the bending strength of monolithic glass for use in buildings. The testing of insulating units or laminated glass is excluded from this part of ISO 1288.

This part of ISO 1288 describes

— considerations to be taken into account when testing glass,

— explanations of the reasons for designing different test methods,

— limitations of the test methods, and

— gives pointers to safety requirements for the personnel operating the test equipment.

ISO 1288-2, ISO 1288-3, ISO 1288-4 and ISO 1288-5 specify test methods in detail.

The test methods specified in this part of ISO 1288 are intended to provide large numbers of bending strength values that can be used as the basis for statistical evaluation of glass strength.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1288-2, *Glass in building — Determination of the bending strength of glass — Part 2: Coaxial double ring test on flat specimens with large test surface areas*

ISO 1288-3, *Glass in building — Determination of the bending strength of glass — Part 3: Test with specimen supported at two points (four point bending)*

ISO 1288-4, *Glass in building — Determination of the bending strength of glass — Part 4: Testing of channel shaped glass*

ISO 1288-5, *Glass in building — Determination of the bending strength of glass — Part 5: Coaxial double ring test on flat specimens with small test surface areas*

ISO 16293-1, *Glass in building — Basic soda lime silicate glass products — Part 1: Definitions and general physical and mechanical properties*

NOTE ISO TC 160/SC 1 is commencing work on standards for “thermally tempered soda lime silicate safety glass”, “heat strengthened soda lime silicate glass” and “chemically strengthened glass.”

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
flat glass
any glass product conforming to ISO 16293-2, ISO 16293-3, ISO 16293-4 and ISO 16293-5, or any transformed glass made from these products without deliberately inducing profile or curvature

3.2
bending stress
tensile bending stress induced in the surface of a specimen

Note 1 to entry: For testing purposes, the bending stress should be uniform over a specified part of the surface.

3.3
effective bending stress
weighted average of the tensile bending stresses, calculated by applying a factor to take into account non-uniformity of the stress field

3.4
bending strength
bending stress (3.2) or *effective bending stress* (3.3) which leads to breakage of the specimen

3.5
equivalent bending strength
apparent *bending strength* (3.4) of patterned glass, for which the irregularities in the thickness do not allow precise calculation of the *bending stress* (3.2)

3.6
profile bending strength
quotient of the maximum bending moment and the section modulus of a channel shaped glass

3.7
stress intensity factor
measure of the stress at a crack tip

3.8
prestressed glass
any glass product that has a surface prestress, i.e. thermally tempered soda lime silicate safety glass, heat strengthened soda lime silicate glass and chemically strengthened glass

4 Symbols

F	applied load	N
h	specimen thickness	M
L	length of side of square test sample	M
k	constant for calculation of bending stress in ISO 1288-3	M
K_1, K_2	constants for calculation of bending stress in ISO 1288-5	
M_{bB}	maximum bending moment	Nm
p	gas pressure applied within loading ring in ISO 1288-2	Pa
P_{bB}	profile bending strength (of channel shaped glass) = M_{bB}/Z	Pa
r_1	radius of loading ring	M
r_2	radius of supporting ring	M

r_3	radius of circular specimen	M
r_{3m}	average specimen radius (for evaluation)	M
y_0	central deflection of specimen	M
Z	section modulus (of channel shaped glass)	m^3
μ	poisson number of specimen	
NOTE	For soda lime silicate glass (see ISO 16293-1), a value of 0,23 is used.	
σ_b	bending stress	Pa
σ_{beff}	effective bending stress	Pa
σ_{bB}	bending strength	Pa
σ_{beqB}	equivalent bending strength	Pa
σ_{rad}	radial stress	Pa
σ_T	tangential stress	Pa
σ_L	stress in a direction along the length of the specimen	Pa

5 Factors to be taken into account when testing glass

5.1 Glass as a material

5.1.1 General

Glass is a homogeneous isotropic material having almost perfect linear-elastic behaviour over its tensile strength range.

Glass has a very high compressive strength and theoretically, a very high tensile strength, but the surface of the glass has many irregularities which act as weaknesses when glass is subjected to tensile stress. These irregularities are caused by attack from moisture and by contact with hard materials (e.g. grit) and are continually modified by moisture which is always present in the air.

Tensile strengths of around 10 000 MPa can be predicted from the molecular structure, but bulk glass normally fails at stresses considerably below 100 MPa.

The presence of the irregularities and their modification by moisture contributes to the properties of glass which need consideration when performing tests of strength.

Because of the very high compressive strength, glass always fails under tensile stress. Since glass in buildings is very rarely used in direct tension, the most important property for load resistance is the tensile bending strength. All the tests described in this part of ISO 1288 are intended to evaluate the tensile bending strength of glass.

The bending strength is influenced by the following factors:

a) surface condition (see 5.1.2);

b) rate and duration of loading (see 5.1.3);

c) area of surface stressed in tension (see 5.1.4);

d) ambient medium, through stress corrosion cracking, as well as healing of surface damage in the glass (see 5.1.5 and Reference [1]);

e) age, i.e. time elapsing since the last mechanical surface treatment or modification to simulate damage (see 5.1.6);

f) temperature (see 5.1.7).

The influence exerted by factors b) to f) on bending strength has been taken into account in this part of ISO 1288.

5.1.2 Effect of surface condition

For the purpose of bending strength tests according to this part of ISO 1288, glass behaves as an almost ideally linear-elastic material that fails in a brittle manner. This brittleness means that contact with any hard object can lead to surface damage in the form of ultra-fine, partly submicroscopic cracks and chips. Surface damage of this kind, which is practically unavoidable during normal handling of glass, exerts a notch action which is a major factor in reducing mechanical strength, whereas the chemical composition of the glass has only a minor, and in some cases, entirely negligible, significance.

Hence, it follows that the bending strength determined by the methods referred to in this part of ISO 1288 is related largely to the surface condition of the specimen to be tested.

This surface condition is characterized by the following main features:

a) the surface condition imparted by a particular method of treatment, which produces a specific damage spectrum and thus, results in a strength which is specific to the finished surface condition;

b) residual stress, e.g. in the form of thermal or chemical prestress intentionally imparted, as well as unintended residual stresses.

5.1.3 Effect of rate of loading

For the interpretation of the bending strength values determined as described in this part of ISO 1288, the rate of loading is of special importance.

Cracks propagate in glass over a wide range of values of tensile stress (see Reference [2]). There is a lower limit to the stress intensity factor below which cracks do not propagate (see Reference [1]). There is then some subcritical crack propagation at higher levels of stress intensity factor, which is influenced by humidity, temperature and chemical agents. Above a critical stress intensity factor, crack propagation is very rapid and leads to (almost) instantaneous failure. The consequence of the subcritical crack propagation is, for example, that the rate of load increase and/or the duration of static loading influences the bending strength.

For prestressed glass, this time dependence does not manifest itself until the tensile stress induced in the surface exceeds the compressive stress permanently present there (see Reference [3]).

5.1.4 Effect of test surface area

The decrease in bending strength of glass with increasing size of the test area exposed to high stress is also of importance (see Reference [4]). This area effect is accounted for by the statistical distribution of surface defects varying in effectiveness; the larger the test area, the greater is the probability of its containing a large surface defect. Consequently, the influence of the area effect increases with decreasing incidence of defects in the surface, so that this influence is more pronounced in the case of undamaged, e.g. fire-finished glass surfaces (see Reference [5]).

Differences are likely between the mean values of the bending strength as measured in accordance with ISO 1288-2 (maximally stressed area: 240 000 mm^2), or by using devices R105, R60, R45 and R30 in accordance with ISO 1288-5 (maximally stressed areas: 3 850 mm^2, 1 260 mm^2, 254 mm^2 and 113 mm^2), due to the size of the stressed area. Depending on surface damage, the results obtained from testing smaller surface areas may be significantly higher than those obtained from testing larger surface areas, as shown in Table 1.

Table 1 — Approximate effects of test surface area on the mean measured bending strength

Test method	Device	Relative bending strength
ISO 1288-2	—	100 %
ISO 1288-5	R105	120 % to 180 %
ISO 1288-5	R65	125 % to 210 %
ISO 1288-5	R45	140 % to 270 %
ISO 1288-5	R30	145 % to 300 %

Since glass for use in buildings is often in large sizes, the test methods specified in ISO 1288-2 and ISO 1288-3 give values which are more appropriate as the basis for designing flat glass for use in buildings. The test method specified in ISO 1288-5 can be useful as a method of evaluating the comparative bending strength of flat glass.

5.1.5 Effect of ambient medium

The surrounding medium in which the glass is tested has an influence on the strength of the glass, particularly if the moisture level is very low. When glass is used in buildings, the relative humidity typically ranges from 30 % to 100 %. Within this range, the effect on the bending strength, as tested according to this part of ISO 1288, is not great. However, tests on glass for use in buildings shall be undertaken in test conditions with relative humidity levels in the range of 40 % to 70 %, in order to eliminate this effect when comparing bending strength results.

5.1.6 Effect of aging

If the glass surface is modified (by abrasion, etching, edge working, etc.) before the testing, it is necessary to allow the fresh damage to heal before the test is undertaken. The continual surface modification by moisture affects the damage in a way that can reduce any weakening effect (see Reference [1]). In practice, glass is highly unlikely to be stressed directly after it has been treated, so it shall be conditioned for at least 24 h before testing.

5.1.7 Effect of temperature

The bending strength of glass is affected by changes in temperature. Within the normal range of temperatures experienced by glass in buildings, this effect is not very significant, but to avoid possible complications in the comparison of bending strength values, testing shall be undertaken in a restricted range of temperatures.

5.2 Bending stress and bending strength

5.2.1 General

The test methods described in ISO 1288-2, ISO 1288-3, ISO 1288-4 and ISO 1288-5 are designed to induce a uniform bending stress over an area (the test area) of the specimen. However, the stresses induced by the applied loads depend on the nature of the material tested as well as the load distribution.

5.2.2 Effective stress

Where the stress varies significantly over the test area, as is the case in ISO 1288-3 (see 6.1.6), it can be represented by a weighted average stress called the effective bending stress, σ_{beff}. The weighting is obtained by statistically evaluating the probability of fracture at any point in the stressed area.

5.2.3 Equivalent bending strength

Variations in homogeneity or thickness of the specimen affect the stress distribution. Hence, the bending strength, σ_{bB}, is never entirely an accurate value and, in some instances, it is better termed the equivalent bending strength, σ_{beqB}.

For some of the glass types tested (for example, float glass), such variations are very small and the bending strength determined by the tests is sufficiently close to the actual bending strength for the difference to be unimportant.

In the case of patterned glass, however, only the equivalent bending strength can be determined.

5.2.4 Profile bending strength

When channel shaped glass is tested according to ISO 1288-4, most of the specimens fail from fractures originating at the corner of the profile, where the web and flange meet, and not at the extreme of the flange or surface of the web. This is due to secondary stresses generated by the spreading of the flanges when the channel section is bent. In this test, the bending strength is better expressed as the profile bending strength, P_{bB}.

5.3 Types of glass

5.3.1 General

The tests specified in ISO 1288-2, ISO 1288-3 and ISO 1288-5 are for testing flat glass. This includes float glass, drawn sheet glass, patterned glass, patterned wired glass, polished wired glass and prestressed glass, provided there has been no deliberately induced curvature or profile (other than the patterned surface of patterned glass).

5.3.2 Patterned glass

The coaxial double ring test for large test surface areas (see ISO 1288-2) can be used to determine the equivalent bending strength of patterned glass, provided the maximum and minimum thicknesses do not deviate by more than 30 % or 2 mm, whichever is the lower, from the average thickness. This is because of difficulties in sealing the pressure ring to a patterned surface.

There is no limitation on the depth of pattern if the four point bending test (ISO 1288-3) is used.

5.3.3 Laminated glass

The testing of the bending strength of laminated glass (see ISO 12543-1) is excluded from this part of ISO 1288.

In a bending test, additional shear deformation arises in the elastic or plastic interlayers (sliding of the hard glass plies on the interlayer). This effect means that measuring the bending strength of laminated glass is likely to give a strength value less than the actual bending strength of a monolithic glass of the same thickness. This shear deformation is particularly sensitive to the effects of temperature and loading rate.

Laminated glass is manufactured from monolithic glass products that can be tested individually by the test methods described in ISO 1288-2, ISO 1288-3 and ISO 1288-5.

The process of manufacture is unlikely to cause significant changes in the bending strength of the component glasses, so it is unnecessary to test laminated glass which can be assumed to have bending strengths appropriate to their individual components.

The load resistance of laminated glass depends on the interactions between the component parts of the composite structure, which is beyond the scope of this part of ISO 1288.

5.4 Orientation of the specimens

Many glass products lack symmetry in their production. This may be immediately obvious, such as a patterned glass, which is likely to have one surface much more deeply patterned than the other and possibly in which the pattern is directional, or it may be less obvious, such as the side on which the wheel cut was made (see ISO 1288-3:—, Figure 1).

Where such asymmetry is present, it may be necessary to test the glass in several different orientations in order to determine the bending strength. Samples of glass to be tested shall have all the specimens nominally identical.

5.5 Number of specimens in a sample

The bending strength of glass displays a large variation between nominally identical specimens. Very little information can be obtained by testing only a few specimens, since there is considerable uncertainty about whether the results are representative.

In statistical terms, this uncertainty can be expressed as confidence limits, values between which there is a given probability that the target being sought will lie.

Where the target being sought is in the central part of the bending strength distribution (for instance, the mean value), then the confidence limits can be fairly narrow even with just a few specimens.

An accurate determination of the tensile stress which leads to a low crack probability can require large numbers of specimens when, for example, a characteristic stress, a permissible stress or a design value of bending strength is to be determined.

6 Explanations of the test methods

6.1 Coaxial double ring test for large test surface areas

NOTE This test is specified in ISO 1288-2.

6.1.1 Elimination of edge effects

The special feature of the coaxial double ring bending test in accordance with ISO 1288-2 lies in the fact that only a circular shaped limited area of the surface of the specimen (not, however, its edges) is subjected to maximum stressing. In contrast to other bending tests (for example, see ISO 1288-3), in which the edge of the specimen is subjected to the maximum stress, the procedure in accordance with ISO 1288-2 is suitable for exclusively subjecting surfaces (or different surface conditions) to bending stress. The effect of the specimen edge condition is, for the most part, suppressed.

6.1.2 Analysis of the stress development

When the deflections are relatively small, the central surface area is subjected to uniform tensile stressing [see Figure 1 a)], where the radial and tangential stresses are of equal size.