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

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

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

Partie 2: Essais avec doubles anneaux concentriques sur éprouvettes planes, avec de grandes surfaces de sollicitation

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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 2:
Coaxial double-ring test on flat specimens with large test surface areas

1 Scope

This part of ISO 1288 specifies a method for determining the bending strength of glass for use in buildings, excluding the effects of the edges.

The limitations of this part of ISO 1288 are described in ISO 1288-1.

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 48, *Rubber, vulcanized or thermoplastic — Determination of hardness (hardness between 10 IRHD and 100 IRHD)*

ISO 1288-1, *Glass in building - Determination of the bending strength of glass - Part 1: Fundamentals of testing glass*

3 Terms and definitions

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

3.1
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.

3.2
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

3.3
bending strength
tensile bending stress or effective bending stress which leads to breakage of the specimen

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

4 Symbols

A	effective surface area of quasi-uniform stress	m^2
E	modulus of elasticity (Young's modulus) of the specimen NOTE For soda lime silicate glass (see ISO 16293-1), a value of 70 GPa is used.	Pa
F	piston force	N
F_{max}	piston force upon breakage, "breaking force"	N
F_{ring}	force transmitted by the loading ring to the specimen, "ring load"	N
h	thickness or average thickness of specimen	m
L	side length of the square specimens	m
μ	Poisson number of specimen NOTE For soda lime silicate glass (see ISO 16293-1), a value of 0,23 is used.	
p	gas pressure on the surface area defined by the loading ring	Pa
$p(F)$	nominal gas pressure as a function of the piston force	Pa
$p_{max}(F_{max})$	nominal gas pressure upon breakage	Pa
r	location coordinate	m
r_1	radius of loading ring	m
r_2	radius of supporting ring	m
r_{3m}	average specimen radius (for evaluation)	m
σ	stress	Pa
σ_{bB}	bending strength	Pa
σ_{beqB}	equivalent bending strength	Pa
t	time	s
$\Delta F/\Delta t$	rate at which piston force rises	N/s
F^*, p^*, σ^*	non-dimensional quantities corresponding to F, p and σ [see Formulae (1) to (5)]	

5 Principle of test method

The square specimen, of side length, L, and having virtually plain parallel surfaces, is placed loosely on a supporting ring (a circular ring with a radius r_2). The specimen is subjected to a load, F_{ring}, by means of a loading ring (radius r_1), which is arranged concentrically to the supporting ring. In addition, the area, A, defined by the loading ring $0 < r < r_1$ is placed under gas pressure, p, which has a specific relationship with the ring load, F_{ring} (see Figure 1).

When the specimen is subjected to the ring load and the associated gas pressure, depending upon the dimensions r_1, r_2, L, and h, a radial tensile stress field, which is sufficiently homogeneous for the test purpose, is developed on the convexly bent surface over the area defined by the loading ring (see References [2], [3], [4]). The tangential tensile stress is equal to the radial tensile stress at the central point ($r = 0$) of the specimen, but decreases as the radius, r, increases.

Outside the loading ring, the radial and tangential stresses fall sharply towards the edge of the specimen, so that the risk of breakage outside the loading ring is low. On the edge of the specimen itself, the radial stress is zero and the tangential stress is a compressive stress, this being the case on both the concavely and the convexly bent sides of the specimen. The edge of the specimen is thus always under tangential compressive stress (see ISO 1288-1).

By increasing the force, F, and the gas pressure, p, the tensile stress in the central part of the specimen is increased at a constant rate [see (6.1 b)] until breakage, so the origin of the break can be expected to occur in the surface area subjected to maximum tensile stress within the loading ring.

With the test apparatus as shown in Figure 1, a force, pA, acts against the piston force, F, due to the gas pressure, p. The force transferred by the loading ring is $F_{ring} = F - pA$. Thus a distinction should be made between the piston force and the ring load.

The bending strength, σ_{bB}, or equivalent bending strength, σ_{beqB}, is calculated from the maximum value, F_{max}, of the piston force, measured at the time of breakage, and the thickness, h, of the specimen, taking into account the prescribed dimensions of the specimen and various characteristic material values. This assumes that the gas pressure, p, follows the piston force, F, according to the nominal function $p(F)$, (see Figure 3).

6 Apparatus

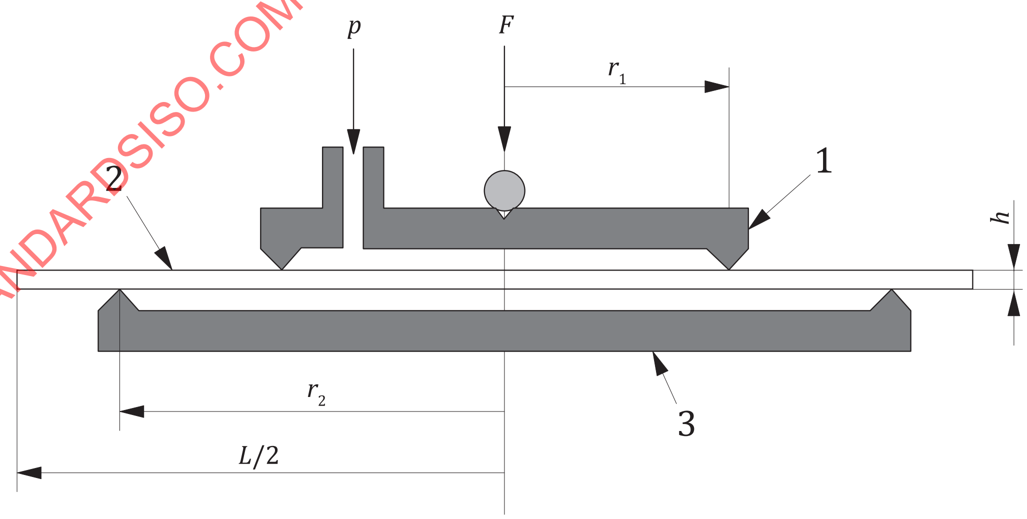
6.1 Testing machine

The bending test shall be carried out using a suitable bending testing machine, which shall incorporate the following features.

a) The stressing of the specimen shall be capable of being applied from zero up to a maximum value in a manner which minimizes shock and is stepless.

b) The stressing device shall be capable of the specified rate of stressing.

c) The testing machine shall incorporate a load measuring device with a limit of error of ±2,0 % within the measuring range.



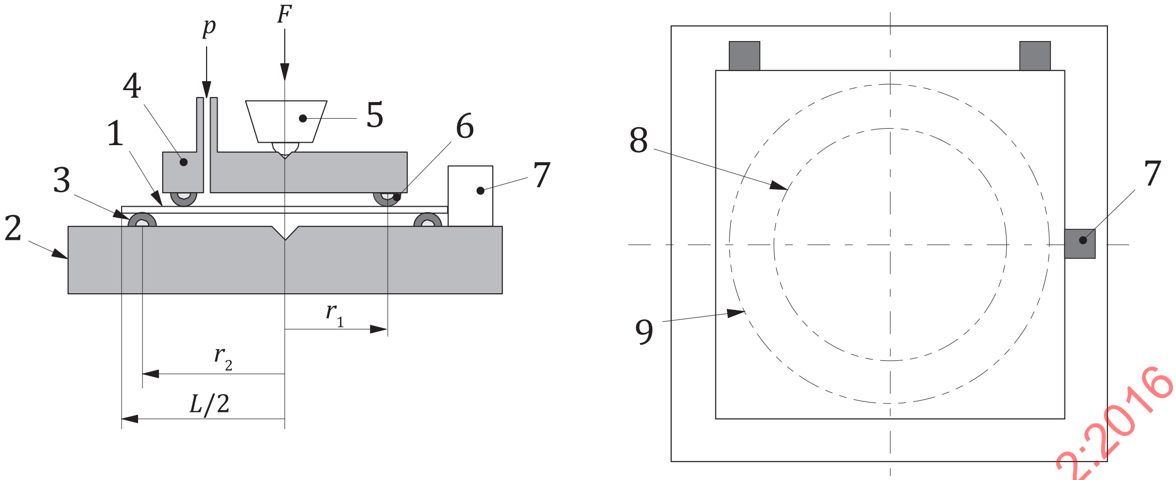
Key

1 loading ring

2 specimen

3 supporting ring

Figure 1 — Basic diagram of test apparatus



Key

1 specimen

2 rigid base plate, preferably made of steel, with supporting ring (radius r_2)[a]

3 rubber profile, adapted to the supporting ring, 3 mm thick, with a hardness (40 ± 10) IRHD (in accordance with ISO 48)

4 rigid loading ring (radius r_1), preferably made of steel[a]

5 force transmitting component, with a ball mechanism to ensure the force is centred in the loading ring

6 rubber profile, adapted to the loading ring, 3 mm thick with a hardness (40 ± 10) IRHD (in accordance with ISO 48)[b]

7 adjustment jaws for centring the specimen[c]

8 contact circle of the loading ring

9 contact circle of the supporting ring

a The radius of curvature of the bearing surface of the ring is 5 mm.

b In the case of specimens which are patterned on the loading ring side, a sponge rubber profile approximately 5 mm thick should also be used to ensure an adequate seal for the gas pressure.

c The jaws are removed before the bending test is started, in order that the edge of the specimen is not clamped.

Figure 2 — Loading device

6.2 Loading device

6.2.1 Ring load

The ring load shall be applied using a loading device as shown in Figure 2. The dimensions of the loading device are given in Table 1.

Table 1 — Dimensions for the loading ring and supporting ring

Dimensions in millimetres

Loading ring r_1	Supporting ring r_2	Effective surface area mm^2
300 ± 1	400 ± 1	240 000

6.2.2 Surface pressure regulator

The loading device for the surface pressure is shown in Figure 2.

The regulator shall be chosen with regard to accuracy and flow rate in such a way that the nominal function, $p(F)$, as shown in Figure 3 or Table 3, can be met (see Annex A).

6.3 Measuring instruments

The following measuring instruments are required:

— a measuring instrument enabling the width of the specimen to be measured to the nearest 1 mm;

— a measuring instrument allowing the thickness of the specimen to be measured to the nearest 0,01 mm.

7 Sample

7.1 Shape and dimensions of the specimens

Square specimens of the dimensions shown in Table 2 shall be used.

The minimum thickness given for the specimens has been calculated in such a way that the effect of the self-weight of the specimen upon the stress distribution can be ignored.

Table 2 — Dimensions of specimens

Dimensions in millimetres

Specimen side length L	Minimum nominal specimen thickness	Average specimen radius (for evaluation) r_{3m}
1 000 ± 4	3	600

The following tolerances for the specimens shall be observed.

In the case of specimens with flat surfaces:

— the evenness tolerance shall be 0,3 mm;

— the parallelism tolerance shall be 2 % of the specimen thickness.

In the case of specimens with one or two patterned surfaces:

— the fluctuations of the plate thickness (see 8.3) shall be not more than 4 % and the local deviations from the average thickness (due to the depth of the pattern) shall be a maximum 30 % or 2 mm, whichever is the lower.

7.2 Sampling and preparation of specimens

7.2.1 Cutting and handling

The greatest care shall be taken that the test surface, which will be subsequently subjected to tensile stress, does not come into contact with tools, grinding agents, glass splinters, etc., and also is not damaged during storage.

NOTE 1 In order to preserve specific surface conditions, the test surface can be provided with a protective coating (glued down) during specimen preparation.

NOTE 2 The method of cutting specimens is not significant and no edge processing is necessary.

7.2.2 Conditioning

Protective coatings shall be removed 24 h before the test (see ISO 1288-1). The specimen shall be stored in the test environment (see 8.1 and 8.2) for at least 4 h before testing.

7.2.3 Examination

Before the bending strength test, all specimens shall be examined over the test surface area for any faults which are not representative of the quality characteristics of the material tested.

7.2.4 Adhesive film

To hold together the fragments, an adhesive film shall be fixed to the side of the specimen facing the loading ring. This facilitates location of the fracture origin and measurement of the specimen thickness.

7.3 Number of specimens

The number of specimens to be tested shall be determined depending on the confidence limits required, especially with regard to estimating the extremes of the strength distribution (see ISO 1288-1 for a discussion of numbers of specimens).

8 Procedure

8.1 Temperature

The coaxial ring bending test shall be carried out at a temperature of (23 ± 5) °C. During the test, the temperature of the specimen shall be kept constant to 1 °C, in order to avoid the development of thermal stresses.

8.2 Humidity

The coaxial ring bending test shall be carried out at a relative humidity between 40 % and 70 %.

8.3 Thickness measurement

Since the nominal pressure function, $p(F)$, in accordance with Figure 3 or Table 3, is dependent upon the specimen thickness, h, this shall be determined before starting the test.

For this purpose, the thickness shall be measured at a minimum of eight points on the edge of the specimen. For specimens with one or two ornamental surfaces, both the plate thickness and the core thickness shall be measured. The average is taken from all these measured values.

The value obtained in this way for the specimen thickness or the equivalent specimen thickness, h, is used to determine the nominal pressure function, $p(F)$. By measuring the thickness on the edge of the specimen, undesirable damage to the surface caused by measuring tools does not affect the fracture behaviour.

8.4 Base plate

The base plate is centred by moving down the force transmitting component (without the loading ring and specimen) into the adjusting cone (see Figure 2). The base plate shall be fixed in this position. Glass splinters and other hard and sharp-edged particles shall be cleaned from the supporting ring. Damage to the supporting ring shall be eliminated.

8.5 Positioning of specimen and loading ring

The specimen is positioned with the surface to be tested downwards. The loading ring, from which glass splinters and other hard and sharp-edged particles have been removed, is placed on the upper side of the specimen and centred. The rubber connection attached to the loading ring shall be checked for its sealing effect and if necessary replaced. Damage to the loading ring shall be eliminated.

8.6 Load application

The piston force, F, and the gas pressure, p, shall be increased continuously until the specimen breaks. The inter-relationship, $p(F)$, to be maintained during the loading, shall be determined from the non-dimensional representation in Figure 3 (curve p^*) or Table 3. The following relationships exists between the non-dimensional parameters, p^* and F^*, and the values p and F.

$$p = p^* \frac{Eh^4}{r_{3m}^4 \left(1 - \mu^2\right)} \qquad (1)$$

$$F = F^* \frac{Eh^4}{r_{3m}^2 \left(1 - \mu^2\right)} \qquad (2)$$

The piston force, F, and the gas pressure, p, shall be monitored up to breakage of the specimen, to check whether the nominal function, $p(F)$, meets that shown in Figure 3 or Table 3.

NOTE Only if the nominal pressure function, $p(F)$, is followed, is a uniform radial tensile stress distribution developed on the convexly bent surface, in that area of the specimen defined by the loading ring. Keeping the gas pressure, p, in line with the piston force, F, may be carried out manually by means of a control valve, but it is recommended that the gas pressure, p, be controlled automatically as a function of the piston force, F. It is permissible to linearize the function $p^*(F^*)$ given in Figure 3 for loads close to fracture. A suitable arrangement is described in Annex A.

The maximum force, F_{max}, and the associated gas pressure, p_{max}, shall be measured.

From these two values, the stress at break, σ_{bB} or σ_{beqB}, in MPa, shall be determined in accordance with Figure 3 or Table 3 (see 9.2).

8.7 Loading rate

The increase with time of the piston force and the associated gas pressure shall be chosen in such a way that the radial tensile stress in the centre of the specimen increases at a rate of (2 ± 0,4) MPa/s until the specimen breaks. Since there is no linear relationship between the stress and the piston force, the permissible loading rate shall be determined in accordance with Figure 3 or Table 3.

A preliminary test is recommended in order to determine the rate of loading.

NOTE Since the breakage stress is most dependent on the loading rate in the few seconds before fracture, it is permissible to set that loading rate required at loads close to fracture constant over the entire test.

8.8 Location of the origin

The location of the origin of the fracture (see Reference [5]) shall be determined from the fragments. The position of the origin of the fracture “inside or outside the contact circle of the loading ring” shall be determined for every specimen.

NOTE After fracture, further thickness measurements, for control purposes, can be made on fragments from the centre of the specimen bounded by the loading ring contact circle, preferably as close to the fracture origin as possible.

8.9 Assessment of residual stresses

If the specimens are considered to be free from inherent stresses, (that is, they are of annealed glass), this condition shall be examined photo-elastically, in the case of transparent glasses, on specimens or suitable fragments. Stress-free specimens placed between cross-polarized polarizing filters shall not show any significant brightness variations when viewed through the cross-section over an optical path length of 5 mm.

9 Evaluation

9.1 Limitation of the evaluation

For evaluation purposes, only those specimens shall be considered in which the origin of the fracture lies within the area defined by the loading ring.

9.2 Calculation of bending strength

The bending strength, σ_{bB}, or equivalent bending strength, σ_{beqB}, associated with the fracture force, F_{max}, and the associated gas pressure, $p_{max}(F_{max})$, is determined from the non-dimensional representation in Figure 3 (curve σ*) or Table 3, taking into account the specimen thickness, h. For this purpose, the measured variables, F_{max} and $p_{max}(F_{max})$, are converted with the aid of the Formulae (3) and (4) into the corresponding non-dimensional factors F^*_{max} and p^*_{max}.

$$F^*_{max} = F_{max} \frac{r_{3m}^2 \left(1 - \mu^2\right)}{Eh^4} \tag{3}$$

$$p^*_{max} = p_{max} \left(F_{max}\right) \frac{r_{3m}^4 \left(1 - \mu^2\right)}{Eh^4} \tag{4}$$

The non-dimensional fracture stress, σ^*_{bB}, shall be determined from these values using Figure 3 (curve σ^*) or Table 3 and then converted into the bending strength σ_{bB} in accordance with Formula (5):

$$\sigma_{bB} = \sigma^*_{bB} \frac{Eh^2}{r_{3m}^2 (1 - \mu^2)} \tag{5}$$

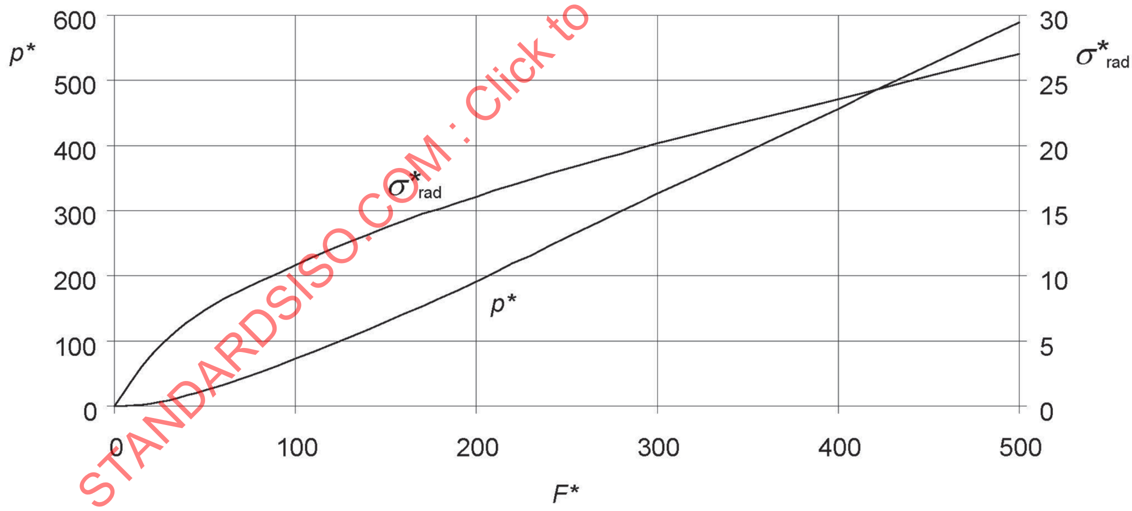


Figure 3 — Relationship between the virtually uniform radial tensile stress, σ^*_{rad}, the nominal gas pressure, $p^*(F^*)$, and the piston force, F^*, in a non-dimensional representation (where r_1:r_2 = 1: 1,33 and r_2:r_{3m} = 1: 1,5)

Table 3 — Relationship between the virtually uniform radial tensile stress, σ^*_{rad}, the nominal gas pressure, $p^*(F^*)$, and the piston force, F^*, in a non-dimensional representation (where r_1:r_2 = 1: 1,33 and r_2:r_{3m} = 1: 1,5)

F^*	$p^*(F^*)$	σ^*_{rad}		F^*	$p^*(F^*)$	σ^*_{rad}
5	0	1,00		210	205,0	16,55
10	0,5	2,05		220	219,0	16,95
15	1,8	3,05		230	231,0	17,40
20	3,5	3,85		240	245,0	17,80
25	6,0	4,60		250	259,0	18,20
30	9,0	5,25		260	272,0	18,30
35	12,5	5,85		270	285,0	19,00
40	16,5	6,40		280	299,0	19,35
45	20,0	6,90		290	312,0	19,75
50	24,0	7,35		300	326,0	20,15
60	32,5	8,20		320	351,0	20,85
70	41,2	8,90		340	377,0	21,55
80	51,0	9,55		360	404,0	22,20
90	61,5	10,15		380	430,0	22,85
100	72,5	10,80		400	456,0	23,55
110	83,5	11,45		420	484,0	24,25
120	94,7	12,05		440	510,0	24,95
130	106,0	12,60		460	536,0	25,65
140	117,0	13,15		480	563,0	26,35
150	129,0	13,70		500	589,0	27,00
160	141,0	14,20				
170	153,0	14,65				
180	166,0	15,15				
190	178,0	15,60				
200	191,0	16,05				

10 Test report

The test report shall contain the following information:

a) a reference to this part of ISO 1288, i.e. ISO 1288-2;

b) type and name of glass;

c) pre-treatment and surface condition of the tested specimen surface including the sequence of treatment stages. In the case of specimens with one patterned surface, the surface which is placed under tensile stress (flat or patterned side) shall be indicated;

d) inherent stress of the specimen, annealed or prestressed glass, including nature and if possible degree of prestressing;

e) number of specimens;

f) for each specimen, the following information:

   1) thickness, h, in mm, to the nearest 0,05 mm, in the case of specimens with flat surfaces; maximum thickness (plate thickness), minimum thickness (core thickness) and average thickness, h, in mm, to the nearest 0,05 mm, in the case of specimens with one or two patterned surfaces;

   2) bending strength, σ_{bB} or σ_{beqB}, in MPa, rounded off to 0,1 MPa, of each specimen broken in accordance with 9.1;

   3) time to breakage in seconds to the nearest 1 s;

   No average for the measured results shall be given.

g) number of specimens not broken in accordance with 9.1;

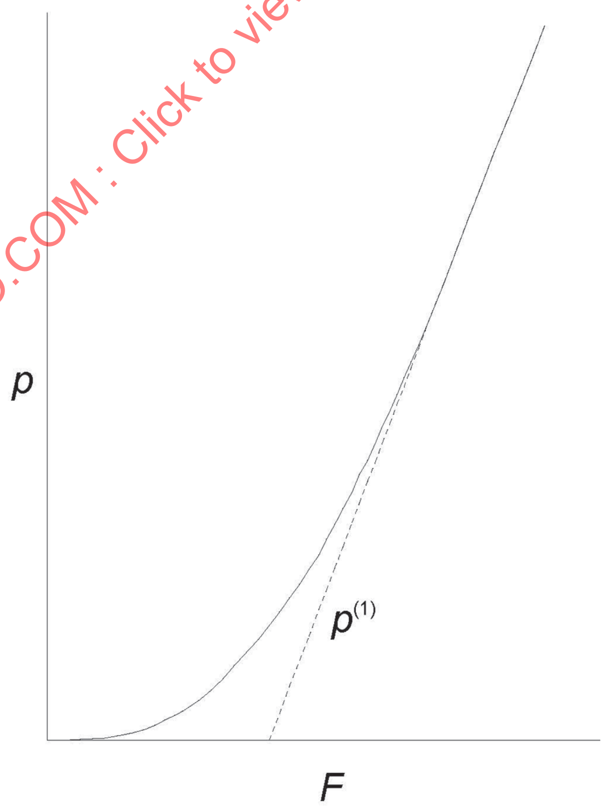
h) any deviation from this part of ISO 1288 which may have affected the results.

Annex A
(informative)

Example of a device for keeping the gas pressure, *p*, in line with the piston force, *F*

If the gas pressure within the loading ring is applied in accordance with the relevant loading specification (taking the plate and ring geometries into account), the testing procedure corresponds to that of conventional bending tests, where knowledge of the force triggering off the fracture is sufficient for determining fracture stress. When designing the gas pressure control system (the gas pressure depends on the piston force applied), it was the major concern to develop a device which ensured that it was easy to apply in spite of varying loading specifications.

If a typical plot of the nominal gas pressure against piston force is considered (see Figure A.1), it is apparent that the curve runs almost linearly in the middle and upper regions, and it can be approximated by a straight line without any great error. The slope of a straight line and its zero point displacement can be set with simple electrical devices, while copying a nonlinear function is more complicated and costly. As far as ease of operation is concerned, a linear approximation function brings considerable advantages for control of the system. A linearized loading specification obtained in this way, however, no longer leads to optimized stress distributions in the lower region of the curve, where the deviation from the nominal loading specification becomes greater. As long as the stresses generated in this region of the curve do not reach values which are critical for the initiation of fracture, this disadvantage is insignificant.



NOTE The dashed line is the linearized value of *p*.

Figure A.1 — Typical plot of force against pressure

In cases where the values, $p(F)$, necessary for a series of measurements, lie in the bent part of the curve (see Figure A.1), linearization on the basis of the least square method, using the values in Table 3 can be carried out. This assumes that estimated values for the maximum and minimum fracture stresses, which occur in the series of measurements, are known. Linearization is only permissible in a region in which the deviation between the linearized function and the nominal function remains less than 5 % of the respective nominal value.

Given these considerations, the electrical part of the control unit (see Figure A.2) was developed and tested. An input voltage proportional to the piston force is sent from the load cell to an amplifier. The output of this amplifier is connected to the input of a function generator which supplies a current proportional to the respective piston force to control a current-pressure transmitter. The electrical signal is changed by the transmitter into a pneumatic signal, which is subsequently converted into the pressure range necessary for the test according to the linearized function, $p(F)$.

In principle, it is also possible to copy the exact nominal function, $p(F)$, by means of a microprocessor-controlled gas pressure regulator. By this means a higher degree of accuracy can be achieved, particularly in the case of specimens with very low fracture stresses, but at a considerably higher expenditure.

In theory, any gas available may be chosen as the medium. For cost and safety reasons, however, the use of compressed air is recommended.

