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Glass in building — Explosion-resistant security glazing — Test and classification by shock-tube loading

Verre dans la construction — Vitrages de sécurité résistant à une explosion — Essai et classification par charge d'air envoyée d'un tube

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Foreword

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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 16934 was prepared by Technical Committee ISO/TC 160, *Glass in building*, Subcommittee SC 2, *Use considerations*.

Introduction

This International Standard provides a method for carrying out tests simulating high-explosive blasts in order to assess and classify the response of glazing to the overpressure and impulse characteristics of blast. This International Standard provides criteria for rating the level of damage to glazing from which can be assessed the hazard consequences to the area located behind the glazing. The increasing use of glazing designed to protect persons and property from accidental explosions, and from the effects of terrorist attacks with high explosives, has prompted the preparation of this International Standard.

A shock tube is a facility which simulates explosive blast waves to load test specimens with consistency, control and repeatability. Shock-tube tests provide an economic means to simulate relatively long-duration blast shock waves representing the effects of large explosive devices at some distance. The results can be assessed against broadly comparable arena tests.

Structural response to air-blast loading is dependent upon specimen size and edge constraint as well as material composition and thickness. The classifications and test results derived by using this International Standard can be used in conjunction with calculation procedures and further validation tests on framed glass during the process of designing complete glazing systems against explosive threats.

Glass in building — Explosion-resistant security glazing — Test and classification by shock-tube loading

1 Scope

This International Standard specifies a shock tube test method and classification requirements for explosion-pressure-resistant glazing, including glazing fabricated from glass, plastic, glass-clad plastics, laminated glass, glass/plastic glazing materials, and film-backed glass. This International Standard provides a structured procedure to determine the blast resistance and the hazard rating of glazing and glazing systems. This International Standard sets out procedures to classify such security glazing sheet materials by means of tests on specimens of a standard size in a standard frame for the purpose of comparing their relative explosion resistance and hazard rating.

The procedures and test method can also be used to test, but not classify, glazing systems where the sheet infill is incorporated into frames purposely designed as complete products of appropriate size for installation into buildings. This International Standard applies a method of test and classifications against blast waves generated in a shock tube facility to simulate high-explosive detonations of approximately 30 kg to 2 500 kg of trinitrotoluene (TNT) at distances from about 35 m to 50 m. The classifications approximately represent the reflected pressures and impulses that are experienced by these equivalent threat levels on the face of a large building facade positioned perpendicular to the path of the blast waves.

Classification is defined in terms of both blast shock-wave characteristics, expressed in terms of peak reflected pressure, impulse, positive phase duration and wave-form parameter (decay coefficient), and rating criteria, expressed in terms of degrees of glazing damage and fragment impact hazard. Classifications and ratings are assigned based upon the performance of the glazing and are specific to the blast characteristics under which the test has taken place. Glazing that has received an air-blast classification and rating is suitable for use in blast-resistant applications only for blasts of comparable characteristics and only if installed in a properly designed frame. Design based on knowledge of the air-blast resistance reduces the risk of personal injury.

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 48:1994, *Rubber, vulcanized or thermoplastic — Determination of hardness (hardness between 10 IRHD and 100 IRHD)*

3 Terms and definitions

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

3.1
air-blast pressure history
description of the pressure of a reflected or free-field air blast, as measured at a point on the surface and consisting of two separate phases:

— positive phase, which is characterized by a nearly instantaneous rise to a maximum pressure followed by an exponential decay to ambient pressure;

— negative phase, immediately following the positive phase, during which the pressure decreases below ambient for a period of time before returning to ambient

3.2
ambient temperature
air temperature around the test specimen measured within 30 min of the test

3.3
attack face
face of the test specimen intended to face the explosion source

3.4
blast shock wave
test pressure wave impinging on the attack face of the test specimen (defined in the terms below)

NOTE The pressure recorded and referred to shall be the peak positive pressure experienced by the test specimen positioned at the end of the shock tube. This is typically a reflected pressure.

3.5
breach
any perforation or opening through the test specimen or between the test specimen and the support frame, evident after the test, through which a 10 mm diameter rigid bar can be gently passed without force

NOTE An opening may be caused by the glazing sheet in-fill pulling away from the rebate sufficiently to result in a visible gap that exposes the edge of the sheet.

3.6
cartridge paper
thick white paper for pencil and ink drawings, typically about 130 g/m^2

3.7
fragment
any particle with a united dimension of 25 mm (1 in) or greater as defined in Clause 8

NOTE The united dimension of a glass particle is determined by adding its width, length and thickness. Glazing dust, slivers and all other smaller particles are not accounted as fragments.

3.8
fragment collecting mat or surface
clean, smooth surface at nominal floor level in the protected area suitable for observing and collecting ejected fragments

NOTE It shall extend over an area of width and of depth from the rear face to the witness panel as defined for a witness area in Clause 6 at a level at least 0,5 m but not exceeding 1,0 m below the bottom edge of the test specimen when that is representative of a typical window. The level of the mat may be adjusted to correspond with the intended level of floor in relation to the position of a non-standard test specimen in the building as defined in Clause 8.

3.9
glazing
glass or plastics glazing sheet material, including glass/plastic combinations

NOTE Glazing may also refer to a fenestration assembly in which glass or plastic sheet infill is set in and is complete with a framing system for installation into a building.

3.10
impulse
I_{pos}
area under the positive phase of the pressure-time trace

NOTE 1 This is usually obtained by automatic electronic numerical integration of the gauge readings. This is also sometimes called the specific positive phase impulse. If sharp irregularities in the recorded trace result in non-representative transient dips into negative pressure or the negative phase is absent, the positive phase impulse should be calculated over the period of the mean pressure-time trace duration.

NOTE 2 Different subscripts may be used for the blast parameters, as described in Annex A. For example, the positive phase impulse, I_{pos}, may be denoted I_c where it denotes the classification impulse or I_t where it denotes the impulse calculated from the measured test values.

3.11
peak pressure
P_{max}
initial peak positive reflected pressure above ambient atmospheric pressure experienced at the attack surface of the test specimen following an instantaneous rise at the time of arrival of the shock front

NOTE If the measured pressure-time trace has sharp spikes or irregularities, the trace should be smoothed to produce a pressure-time trace that closely matches the mean path of the recorded trace. The peak pressure, P_{max}, of relevance is the resulting smoothed value at the time of arrival.

3.12
positive phase duration
t_{pos}
duration of the positive phase of the mean pressure-time trace

NOTE The mean pressure-time trace should have positive phase duration, waveform and peak pressure such that the area under this curve equals the positive phase impulse obtained by direct integration of the original recorded trace. The duration can normally be derived by reference to the time of the peak of the impulse-time curve.

3.13
pressure-time wave trace
pressure values plotted against time

NOTE The instantaneous rise at the shock front to the peak positive pressure, P_{max}, is followed by a non-linear decay to ambient pressure over a time called the positive phase duration. The shape of the decay curve may be modelled by an exponential decay curve having a decay coefficient, A, also known as a waveform parameter. In a free-field blast, a period of negative pressure then follows for a period of time before returning to ambient. Within the confines of a shock tube, this period of negative pressure is sometimes absent or reduced in value.

3.14
protected area
area on the side of the test specimen away from the source of the shock wave

3.15
rear face
protected area side of the test specimen opposite to the attack face

3.16
reflected pressure
pressure experienced by a surface which obstructs the flow of a blast wave

NOTE The shock wave moving through the air impacts the test specimen and is "reflected", producing a pressure on the surface having a value higher than would have occurred within an unobstructed flow or on the side of a target parallel to the direction of travel of the pressure wave.

3.17
test specimen
sample of glazing submitted for test

3.18
witness panel
panel of deformable material positioned behind the test specimen in order to register the incidence of material forcibly detached from the test specimen during test

NOTE The composition and location of the witness panel is described in Clause 6.

3.19
witness panel perforations
any holes in the surface of the witness panel caused by impact of any material as a result of the blast

NOTE The number, size and depth of penetration of such perforations can be used as a guide to the injury potential of material detached from the test specimen.

3.20
witness panel indents
any detectable deformation of the surface of the witness panel caused by impact of any material as a result of the blast

4 Classification and hazard rating

A hazard rating is applied to glazing based on its performance under the classification blast conditions chosen for the test. The rating is specific only to those blast conditions. Hazard rating criteria are defined in Table 1.

Classifications are assigned according to the blast intensity measured in terms of pressure, impulse and duration. Each classification code is one of a series having defined blast values as listed in Table 2.

5 Test specimens

Test specimens may be submitted in two forms, as described in 5.1 and 5.2.

5.1 Glazing sheet

Glazing sheet submitted for test in a standard configuration and mounted in a standard frame in order to demonstrate or prove performance in relation to other sheet materials. For the purpose of obtaining a classification of the sheet material in accordance with this International Standard, a minimum of three test specimens, each (1 100 ± 5) mm × (900 ± 5) mm, shall be tested and shall be clearly identified by type and with an indication of the attack face. One additional specimen shall be provided for pre-test measurements. The test pieces shall conform to the specification of the manufacturer and shall be representative of normal production quality. They shall be arrissed for ease of handling.

For the purposes of obtaining a test assessment, a single glazing sheet test specimen may be supplied. The results cannot be used to classify the glazing.

5.2 Fenestration assemblies

This is glazing submitted complete with a framing system, fabricated and of a size typical for installation in a building and made up as a test specimen appropriate for mounting in the test apparatus.

The blast resistance of a fenestration assembly may be assessed by being tested and rated in accordance with the provisions of this International Standard. The test report and test report summary shall state that the results are applicable only to the product as tested. The number of assemblies tested shall be stated and shall be agreed prior to test. The results cannot be used to classify the fenestration assembly or the glazing infill independently as a sheet material.

5.3 Multiple specimens — Probability of achieving blast resistance

The air-blast resistance capacity of glazing does not imply that a particular specimen will resist the specific air blast for which it is rated with a probability of 1,0. However, the probability that a single glazing or glazing system will resist the specific air blast at the particular level for which it is rated increases proportionally with the number of test specimens that successfully resist that air blast at that level. The protection afforded against a blast by a single item of glazing depends not only upon the glazing but also upon the manner in which it is attached to the structure in which it is mounted.

5.4 Handling and storage

The test specimens shall be handled and stored in compliance with the manufacturer’s instructions.

5.5 Marking

Each specimen shall be marked with the manufacturer’s model and serial numbers and the date of manufacture. The attack side is intended to be oriented towards the explosive charge and shall be marked by the manufacturer to assure proper installation in the test frame. A number shall be assigned to each test specimen and marked accordingly.

5.6 Measurements

Thickness measurements of the glazing material shall be made at each corner, 25 mm from each edge and recorded. If the glazing sheet specimens are supplied already mounted in a frame and if four test specimens are supplied, one of the specimens shall be selected at random and inspected for details. Measurements shall include the edge dimensions of the frame and the glazing material; the cross-sectional dimensions of the frame and thickness measurements of the glazing material. The frame and glazing materials shall be verified to comply with the manufacturer’s specifications. If necessary for verification, the fourth specimen shall be disassembled. Measurements and records shall be made of the bolts, screws or other devices used for fixing the test specimen to the test specimen support and those used to mount the support onto the shock tube.

5.7 Photography

Prior to the test, a photographic record that adequately portrays the test specimens, the test frame and the test configuration shall be made. This photographic record shall consist of still photographs and may include motion pictures or video.

6 Apparatus and equipment preparation

6.1 Shock tube — Pressure-generating device

The shock tube shall be a device capable of reproducing the required plane shock wave to simulate the effects from a high-explosive source and applying the blast load to a test specimen. The shock tube shall be capable of reproducing the shock wave consistently from test to test within a 0 % to + 15 % accuracy of a desired value for both the peak pressure and the impulse.

6.2 Test frame

The test specimen shall be supported by a rigid test frame through which the test specimen may be securely attached to the shock tube in a vertical position via a reaction structure of substantial construction. The whole assembly shall be sufficiently rigid to withstand repeated application of test loads without permanent distortion and without imparting deformations to the test specimen.

The reaction structure shall form or be integral with a rigid shield around the edges of the test specimen that meets the walls of the shock tube and prevents the escape of blast pressure other than through deformation or design intention of the test specimen.

6.3 Protected-area platform and fragment-collecting mat

A platform shall be provided in the protected area between the test specimen and the witness panel at a height representing floor level as defined in Clause 8. The platform shall have a surface, or be provided with a mat, suitable for collecting fragments in the witness area for the purpose of assessing hazard ratings. The witness area shall be of a width sufficient to capture all fragments or be provided with sides spaced apart not less than the width of the witness panel, as defined in 6.5, to channel and control the spread of fragments. The sides may be of transparent material to aid recording and photography.

6.4 Test frame and reaction structure

When glazing sheet material is to be classified, the following test frame and reaction structure requirements shall apply.

a) The test specimens shall each be mounted in the test frame, supported along the full length of all four edges so as to achieve a vision size of (1 000 ± 5) mm × (800 ± 5) mm.

b) The test frame shall be fixed securely on all four sides in a vertical position to the reaction structure. The test frame shall be provided with clamping plates to hold the glazing in position and means for producing uniform clamping of the glazing.

   NOTE Bolt or clamping device spacing of not more than 100 mm is recommended around the perimeter of each specimen.

c) The test specimens shall be mounted in a manner that meets the following requirements.

   — Mount standard sized test specimens so that the bottom edge is between 0,5 m and 1,0 m above the floor of the witness area

   — Each standard sheet glazing test specimen shall have an edge capture of not less than 45 mm on all edges.

   — Each standard sheet glazing test specimen shall be separated from the frame and the clamping plate by continuous rubber strips, (4 ± 0,5) mm thick, (50 ± 5) mm wide and of hardness (50 ± 10) IRHD in accordance with ISO 48:1994.

   — At the bottom of the rebate, the glazing shall be seated on rubber strips, 4 mm thick, of hardness (50 ± 10) IRHD in accordance with ISO 48:1994 and of a width equal to the full thickness of the test specimen.

   — All four edges of each standard sheet glazing test specimen shall be uniformly clamped with a clamping pressure of 140 ± 30 kN/m^2.

     NOTE The clamping pressure can have a significant effect on the test results.

d) If the glazing is supplied in its own unique frame or in the form of a fenestration assembly, it shall be attached to the reaction structure as directed by the manufacturer and in a manner that closely models the manner in which it will be mounted in the field. Non-standard test specimens may be mounted at heights above the fragment-collecting mat appropriate to the manner in which they will be mounted in the field.

— The attack surface of each test specimen shall be aligned in a plane positioned in relation to the attack surface of the test frame and reaction structure such that the blast values experienced by the test specimen are accurately measured or computed.

— It is recommended that the attack surface of the test specimen be not more than 25 mm behind the surface of the test frame and that the reaction structure be inside the shock tube to minimize entrapment and enhancement of the blast effects.

— Each test specimen shall be placed normal to the direction of the explosive shock wave (or normal to the axis of the shock tube) with an accuracy of + 2° in any orientation.

6.5 Witness panel

A witness panel shall be mounted (3 000 + 150) mm behind each test piece, parallel to the plane of the test specimen. The witness panel shall consist of sheets of non-ductile, foam insulation board, of material equivalent to extruded polystyrene, polyisocyanurate or urethane, of density (30 ± 5) kg/m^3. The board shall be in one or two layers of combined thickness at least 35 mm, mounted in a frame capable of remaining in place even if forcibly impacted by failed pieces of the test specimen. The witness panel shall have a width of not less than 2,0 m if contained within sides as defined in 6.3, or, if not so contained, a width of at least 2,4 m, (i.e. 1,2 m either side of the centre axis of the shock tube, or the width of the test specimen, if greater) and at a height extending from the level of the collecting mat to at least 200 mm above the top of the test specimen. In order to aid the recording of the damage and reduce waste, the board may contain a removable face layer at least 12 mm thick and the witness panel may be faced with contiguous sheets of aluminium foil of thickness not more than 0,025 mm or cartridge paper of weight between 100 g/m^2 and 150 g/m^2.

6.6 Pressure-measuring equipment

The pressure-measuring equipment shall permit the determination of the magnitude, above ambient pressures, and time development of the reflected shock wave impinging on the test specimen. Calibration records shall be maintained that demonstrate the equipment can measure pressure with an accuracy of ± 5 % with a rise-time sensitivity response to peak pressure of 10 µs. In order to perform this task, the equipment shall record the pressure at intervals not greater than 0,01 ms, i.e. a sampling rate of 100 000 samples per second, starting before the shock wave reaches the test specimen and for a length of time at least 10 times the duration of the positive phase from the time of arrival at the test specimen. The pressure-time history shall be recorded by means of at least two blast gauges (pressure transducers). The blast pressure gauges shall be positioned to enable accurate determination of the reflected pressure-time values (above ambient) at the centre of the test specimen. Gauges at the test-mounting location shall be calibrated during special pre-tests against gauges set in the centre of rigid blanking plates fixed in the test specimen support. The calibration records shall either demonstrate that the readings are identical in the two locations or provide means of adjusting the test-location gauge readings to values that accurately represent the reflected pressure-time values at the centre of the test specimen.

7 Test procedure and requirements

7.1 Pre-test procedure

Determine the required reflected pressure and impulse from Table 2 according to the level of explosion resistance required.

Mount the test specimen in the frame and position in the shock tube. Inspect for correct installation and tightness of fixings, and record the inspection results.

Record the ambient pressure, relative humidity, shade temperature and the protected/rear face surface temperature of the test specimen within 30 min of the test. Verify that these are within the criteria for a test leading to classification. Provide the shock tube and test specimen with appropriate shading if necessary to avoid heat build-up or loss from sun or wind chill until the test takes place.

Sweep the protected fragment collecting mat area clear of any debris and fragments and set the witness panel in place.

Carry out appropriate safety procedures and prepare for test.

7.2 Test procedure

Subject the test specimen to one shock wave with the required peak pressure and impulse load for the class for which it is being tested.

7.3 Post-test procedure

Examine the protected/rear face of the test specimen for breakage or cracking of any surface or laminate layer and for any openings between back and front. Record descriptions of the condition of the test specimen, measurements and locations of deformations with dimensions of all cracks, tears, openings and pull-outs. Photograph the test specimen, fragment-collecting area and witness panel at this point before any aspects are disturbed.

Record the presence, location and description of fragments in the protected area.

Inspect the witness panel. Describe and record the dimensions and locations of all perforations or indentations within the required area.

Carefully remove the test specimen from the reaction structure and examine the attack face. Record descriptions and measurements with details as required to determine the rating.

Record the measurements of the pressure and impulse according to Annex A and calculate the mean values of the peak pressure and impulse.

Determine the validity of the test in accordance with 7.4 and 7.5. Describe and evaluate the results and record the hazard rating and preliminary classification level achieved in accordance with Tables 1 and 2.

When a classification is required, repeat the above procedure on another two specimens in order to determine an overall rating and classification.

7.4 Validity of the test

The test is valid for a particular class if, allowing for a tolerance of ± 5 % in any one test permitted for the pressure-measuring equipment (see 6.6), all of the following characteristics are achieved, based on the mean values of the data.

a) The derived peak pressure is above the minimum specified.

b) The calculated impulse load is above the minimum specified.

c) The positive phase duration is more than the minimum specified.

d) The positive phase wave-decay shape lies, by inspection, within the wave-form-parameter limits specified in Table 2, footnote b.

e) The shield and reaction structure remain in position with no openings between the walls of the shock tube and the test frame.

7.5 Validity of the blast measurements

All pressure-time readings shall be examined to derive the peak pressure values from the smoothed path of the measured trace. The individual peak pressure values subsequently recorded shall in each case be that adjusted by smoothing as necessary to eliminate sharp spikes arising from recording and instrumentation irregularities. The value derived by taking the average of several of these individual, adjusted peak-pressures is referred to as the “mean peak air blast-pressure” for comparison with the classification peak-pressure criteria, as in Table 2, footnote b. Further information is given in Annex A. The recorded blast values should be within a range of ± 12,5 % about mean values from test to test. This deviation is derived from the combination of the 0 % to + 15 % accuracy of the pressure-generating device required in 6.1 and the + 5 % accuracy of the pressure-measuring equipment required in 6.6. This leads to a potential variation from − 5 % to + 20 %; a range of 25 % with a latitude from a mean point of ± 12,5 %.

If the mean derived blast values are less than the classification value in two out of three tests, the pressure-generating device shall be reset to achieve the required values.

If any one pressure gauge records less than − 5 % of the required value, the test shall be invalid unless the other gauge(s) is(are) within tolerance and it can be incontrovertibly demonstrated that the erroneous gauge is giving a defective reading. This process has more credibility if there are three or more gauges and two or more are in agreement and within tolerance.

8 Performance requirements

8.1 Inspection

The location and description of all parts of the specimen shall be recorded, whether retained in the frame or fallen inside or outside the shock tube, with identification of rear- and attack-face leaves of glass where appropriate.

The side of the glazing located away from the blast shall be examined. It shall be determined and noted whether or not any breakage or rupture of this protected side surface has occurred. The witness panel shall be carefully inspected for the presence of perforations and indents that have resulted from the blast. If present, the locations and dimensions of perforations and indents shall be documented, recording their height above the fragment-collecting surface that represents floor level.

8.2 Hazard rating

The results of the inspection of the test specimen and the witness panel are used to rate the performance of the glazing for each test specimen according to Table 1. For rating purposes, only the portion of the witness panel defined in 6.5 shall be considered.

The opening referred to in Table 1 under Minimal Hazard is the total length of pullouts from the frame along which the edge of the glass is visible plus the total length of tears in the glazing.

The rating of the glazing or glazing system shall be in accordance with the hazard rating criteria definitions in this subclause and in Figure 1. The hazard rating that glazing or glazing systems receive is based upon the severity of fragments and hazard effects, evidenced by distribution of fragments and damage to the witness panel generated during a blast test. The fragment severity is determined based upon the number, size, effects and location of fragments that lie at or behind the original location away from the blast source observed during post-test data gathering. Fragments to be considered in rating the glazing or glazing system include those generated by the glazing and any other parts of the glazing-fenestration assembly not considered to be part of the test apparatus; see Clause 6 for a definition of the test apparatus. For hazard ratings B and C, parts of the outer leaves may be projected any distance from the attack face towards the blast source. For hazard ratings D, E and F, any part(s) of the glazing or frame may be projected any distance from the attack face towards the blast source.

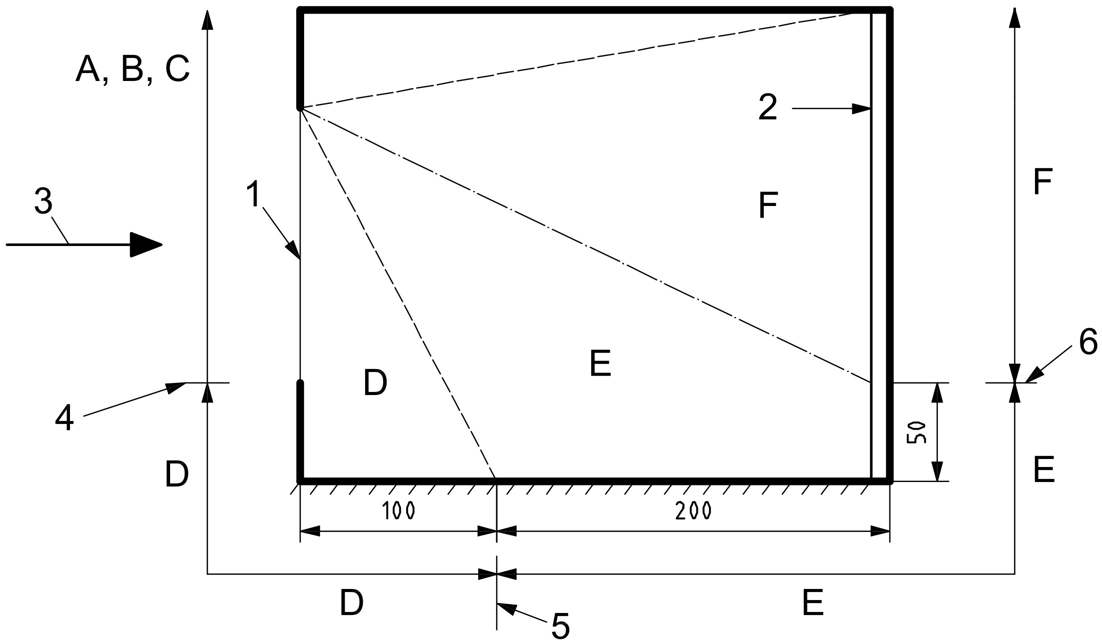
A fragment (3.7) is defined as any particle with a united dimension of 25 mm (1 in) or greater. The united dimension of a glass particle is determined by adding its width, length and thickness. Glazing dust and slivers are all other smaller particles and their effects are not accounted for in the rating. Indents and perforations of less than 3 mm in each direction (depth, length and width) or caused by particles classed as smaller than fragments are not accounted for in the rating.

The witness panel shall be marked with lines at, and 0,5 m above, the notional floor level. The notional floor level shall be taken to be 0,5 m below the level of the bottom of the test specimen (the sill), unless a different level is recorded as applicable to the intended use of a non-standard specimen. Except for special purposes, this shall not normally exceed 1,0 m. If the bottom edge of the test specimen is intended, in application, to be closer than 0,5 m to the floor, as for example a glazed door threshold, then that floor level and a point 0,5 m above shall be marked on the witness panel.

Table 1 — Hazard rating criteria for shock tube tests

Hazard rating	Hazard rating description	Definition
A	No break	The glazing is observed not to fracture and there is no visible damage to the glazing system.
B	No hazard	The glazing is observed to fracture but the rear face leaf is fully retained in the test frame or glazing system frame with no breach and no material is lost from the rear face (the protected side opposite the blast loaded side of the specimen). Leaves from the attack face may be sacrificed and may fall or be projected towards the blast source.
C	Minimal hazard	The glazing is observed to fracture. Leaves from the attack face may be sacrificed and may fall or be projected towards the blast source. The rear face leaf shall be substantially retained having the total length of tears plus the total length of pullout from the edge of the frame less than 50 % of the glazing sight perimeter. Also, there are no more than three rateable perforations or indents anywhere in the witness panel and any fragments on the collecting surface between 1 m and 3 m from the rear face of the specimen have a sum total united dimension of 250 mm or less. Glazing dust and slivers are not accounted for in the hazard rating. If by design intent there is more than 50 % pullout but the glazing remains firmly anchored by purpose designed fittings, a rating of C (minimal hazard) may be awarded provided that the other fragment limitations are met. The survival condition and anchoring provisions shall be described in the test report.
D	Very low hazard	The glazing is observed to fracture and significant parts are located no further than 1 m behind the original location of the rear face. Parts may be projected any distance from the attack face towards the blast source. Also, there are no more than three rateable perforations and indents anywhere in the witness panel, and any fragments on the collecting surface between 1 m and 3 m from the rear face of the specimen have a sum total united dimension of 250 mm or less. Glazing dust and slivers are not accounted for in the hazard rating.
E	Low hazard	The glazing is observed to fracture, and significant parts or the whole of the glazing may fall between 1 m and 3 m behind the rear face of the specimen and up to 0,5 m above the notional floor level against the witness panel. Also, there are no more than 10 rateable perforations in the area of the witness panel higher than 0,5 m above the notional floor, and none of the perforations penetrates more than 12 mm.
F	High hazard	The glazing is observed to fracture, and there are more than 10 rateable perforations or any one perforation that exceeds 12 mm depth in the witness panel more than 0,5 m above floor level.

Dimensions in centimetres



Key

1	window	A to F	hazard ratings:
2	witness panel	A	no break
3	blast	B	no hazard
4	low-hazard threshold	C	minimum hazard
5	high-hazard threshold	D	very low hazard
6	very low hazard threshold	E	low hazard
		F	high hazard

Figure 1 — Cross-section through witness area for shock tube test

9 Classification of explosion-resistant glazing

The glazing shall be classified only if

— the test is valid;

— all three test pieces achieve a hazard rating of A to E according to Table 1 at the required classification. The highest damage level attained shall be recorded in the test certificate;

— the ambient-air temperature and glazing-surface temperature of the test specimen measured within 30 min of the test are within the range (22 ± 17) °C.

Glazing shall be classed as “blast-resistant” to a given classification code (as in Table 2) only if it achieves a “minimal hazard” rating C or safer.

Glazing may be classed as offering “hazard reduction” to a given classification code (as in Table 2) if it achieves a rating between D (very low hazard) and E (low hazard).

A test certificate with the classification and rating in accordance with this International Standard shall be awarded only on the basis of comparable tests on three test specimens of sheet glazing of size and framed as defined in Clauses 5 and 6.

If any single test specimen of the three tested attains a rating of D (very low hazard) or more hazardous, the product may not be classified as “blast-resistant” according to this International Standard but may be characterized as having been submitted for test in accordance with this International Standard with the result being a hazard reduction obtained at the classification tested, with a description of the ratings achieved.

A test-assessment report, stating the blast level and hazard rating attained, may be issued on the basis of a valid test on a single test specimen, but it cannot be awarded a classification in accordance with this International Standard.

For classification purposes, explosion-resistant glazing intended to withstand a certain severity of attack shall be classified in accordance with Table 2.

Table 2 — Classification of explosion-resistant glazing

Classification Code[a]	**Minimum values**[b]	
	Peak pressure P_c kPa	**Impulse** I_c kPa-ms
ER30 (X)	30	170
ER50 (X)	50	370
ER70 (X)	70	550
ER100 (X)	100	900
ER150 (X)	150	1 500
ER200 (X)	200	2 200

[a] In the classification code the letters, i.e. “ER”, refer to the classification code, the number designates the peak pressure, expressed in kilopascals and the (X) denotes the hazard rating received during the test; for example classification ER100 (C) would apply to a test in which a standard blast having peak blast pressure of 100 kPa and positive phase impulse of 900 kPa-ms resulted in damage to the glazing resulting in hazard rating C.

[b] For the following conditions:

— The positive phase duration should be not less than 20 ms except for ER30 (X) (30 kPa), for which a duration of about 15 ms can be expected.

— The recorded pressure-time trace shall conform to an idealised curve having a modified Friedlander decay coefficient (wave form parameter) assessed as lying between 0 and 4. Refer to Annex A for definitions.

Specimens may be tested at different or intermediate blast intensities, in which case a test classification may be awarded at the next lower value provided the relevant conditions are met. The test report shall record the actual values achieved.

Specimens may be tested at a client's request at different blast values or combinations in accordance with the test method in this International Standard. In this case, the test report shall clearly state the blast values and test conditions without claiming classification in accordance with this International Standard, except as allowed above.

10 Test report and test-report summary

10.1 Mandatory information

Upon completion of a test, a written test report shall be provided. The original copy of the test report shall be furnished to the sponsor of the test. The testing laboratory or agency shall keep a copy of the test report on file. Aspects of the report or information therein that are sensitive for reasons of security or of commercial interest shall be clearly identified and shall not be issued to third parties without mutual or client consent as appropriate.

The following mandatory information shall be reported:

a) testing-agency information:

— name and address of the laboratory or agency conducting the test,

— statement about when calibration of the apparatus and measuring equipment was last undertaken, the accuracy or tolerance achieved and where the records are lodged and can be inspected;

b) test specimen information:

— manufacturer's name and address,

— product name, trademark and type and/or serial number of the glazing and date of manufacture,

— description of the glazing, including pertinent dimensions, construction and materials,

— description and drawings of the framing if it has been supplied with the glazing,

— complete description of the condition of the specimens as received;

c) test set-up information:

— number of specimens tested,

— class of explosion used for the test,

— date and time of the test,

— description with drawings of the test apparatus, the test frame and clamping method, dimensions and composition of the witness panel,

— orientation of the specimens with respect to the apparatus and attack face and the relative disposition and levels of all relevant apparatus, including the fragment collecting surface and the witness panel,

— number and locations of all air-blast pressure transducers,

— air temperature measured just prior to the test,

— temperature of the exterior surface of the glazing measured just prior to the test,

— relative humidity at the time of the test,

— elevation of the test site;

d) test results:

- peak positive air-blast pressure, impulse and duration measured at each air-blast pressure transducer and the derived mean of the peak, smoothed reflected air-blast values experienced by each test specimen,
- air-blast pressure history recorded from each air-blast pressure transducer over the positive and negative phase periods in accordance with Clause 6,
- condition and location of all parts of the test specimens immediately following the test, including the length and location of any openings made in the specimens during the test, whether the test specimens are retained in the frame and the disposition and description of all components or fragments, as defined in the ratings criteria in Table 1, with the calculation used to determine the united fragment dimensions,
- damage to the witness panels resulting from the blast, including the location and dimensions of any perforations or indents,
- hazard rating of the glazing in accordance with Table 1 with supporting data,
- classification code of the glazing if tested with a standard blast as defined in Table 2.

e) The test report shall contain the photographic record of the test apparatus set-up as described in 5.7. In addition, the test report shall contain detailed photographs of each test specimen following the test in accordance with 7.3. Each specimen shall be labelled in the post-test photographs to allow for their clear identification.

10.2 Supplemental information (optional)

If any motion picture or video records are made of the performance of the test specimens, such records shall become part of the test report.

10.3 Test-report summary

The testing laboratory shall issue a test-report summary to enable the applicant to make trade use of the results obtained with the test specimen.

The test-report summary shall state that it is valid only for the individual specimen of design as tested, with particulars recorded on the test specimen size, composition, attack face and orientation. Photographs may be included.

The test-report summary shall include the following:

- reference to the test standard (i.e. ISO 16934);
- relevant classification or blast value and hazard rating obtained;
- test report reference and date of issue;
- identity of the test laboratory;
- identity of the applicant;
- reference and the manufacturer's stated trademark, type of the product together with the dimensions of the test specimen;
- orientation of the test specimen in relation to the apparatus and attack face;

- description of the test frame, method of glazing retention, size and quantity of fixings;
- any observations concerning particular phenomena directly related to the behaviour of the test specimen, including a summary description of the level of damage suffered by the test specimen during the test such as perforation, splintering, fragment disposition and damage to the witness panel.

11 Precision and bias

No statement is made concerning either the precision or bias of this test method since the result merely states what hazard level rating and classification (if the glazing is classified) a glazing can receive for a specific air-blast loading.

Annex A
(normative)

Blast parameters and derivation

A.1 Scope

This annex sets out the procedures to be followed by the testing authority to achieve consistent measurement and derivation of the test blast parameters for comparison with the classification parameters given in Table 2. Different subscripts may be used for the blast parameters. For example, the positive phase impulse, I_{pos}, may be denoted I_c where it denotes the classification impulse or I_t where it denotes the impulse calculated from the measured test values.

A.2 Symbols for positive phase of blast

$P(t)$ pressure above ambient pressure at time, t

P_c classification peak reflected overpressure

P_{max} peak overpressure of mean reflected P-t wave trace derived from measured test values (this parameter is sometimes designated P_r or Pr)

I_c classification impulse

I_t impulse calculated from measured test values

t_{pos} positive phase duration of classification P-t wave trace

t_{tr} positive phase duration of derived mean test P-t wave trace

t_t equivalent triangular duration calculated from P_{max} and I

A decay coefficient

A.3 Mathematical relationships

The pressure, $P(t)$, above ambient pressure at time, t, can be determined from the shape of an idealized exponential pressure-time curve, such as the modified Friedlander equation, as given in Equation (A.1):

$$P(t) = P_{max}(1 - t/t_p) \exp(- At/t_p) \qquad \text{(A.1)}$$

where t_p is the positive phase duration of the classification P-t wave trace.

Integration of the modified Friedlander equation yields the area under the curve that represents the impulse, I, as given in Equation (A.2).

$$I = P_{max}\, t_p \{(1/A) - [1 - \exp(- A)]/A_2\} \qquad \text{(A.2)}$$

where A_2 is the term A^2 from the Friedlander equation.

The limiting case occurs when the value of $A = 0$ and the decay curve is a straight line; then the duration is the equivalent triangular duration, t_t, as given in Equation (A.3):

$$t_t = 2I / P_{max} \qquad \text{(A.3)}$$

A.4 Procedure

Calculate the value of I_t by numerical integration of the recorded positive phase of the pressure-time wave trace before it is smoothed.

Match the measured and recorded pressure-time trace, $P(t)$, for the positive phase to the best fit, smoothed mean curve through the measured points to derive the values of P_{max}, t_{tr} and A. This may be done by numerical methods or a combination of numerical methods and curve smoothing by eye.

Establish the value of the resulting measured peak pressure, P_{max}, by recording the pressure value from the point at which the mean pressure-time trace crosses the time of arrival axis. Note that this can differ from the instantaneous peak value recorded by the gauges, sometimes in the form of a sharp spike of very short duration which should be discarded.

If there is no clear time at which the recorded p-t trace crosses zero overpressure, or if the trace continues positive for a long period, then the time at which the smoothed curve, extrapolated if necessary, reaches zero overpressure shall be used to determine the positive phase duration for the calculation of the impulse from the non-smoothed trace.

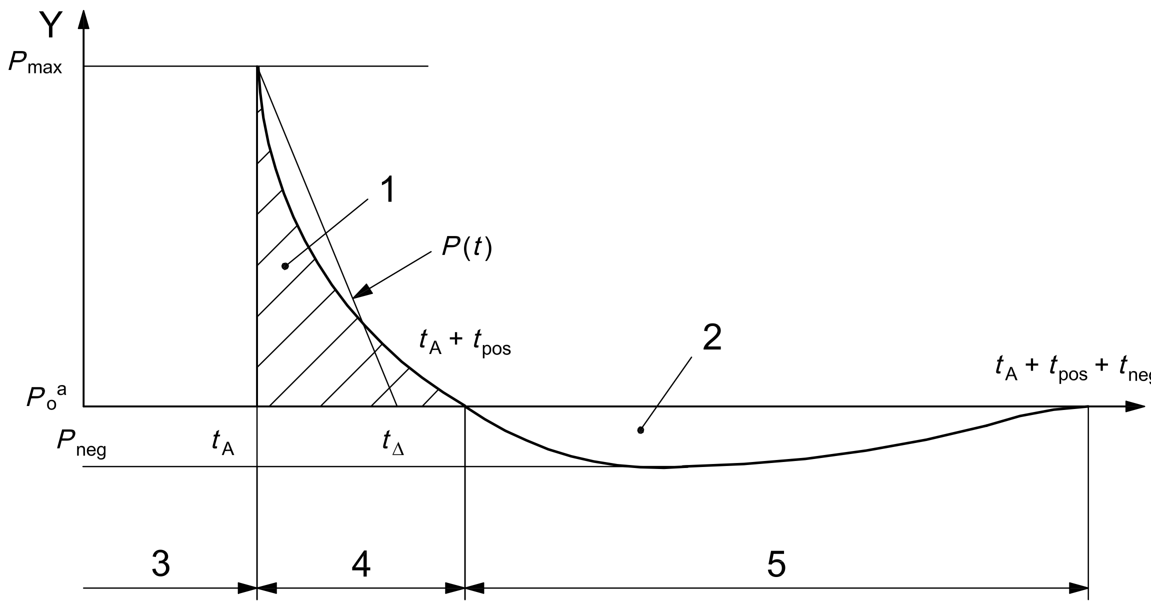
Compare the shape of the mean trace with an idealized (Friedlander) curve having the same values of peak positive pressure, duration and impulse. Iterate the process, if necessary, to obtain the optimum idealized pressure trace. Determine the value of the decay coefficient, A, sufficiently precisely to verify that it lies between 0 and 4. The purpose of this exercise is to ensure that the blast, or shock, pulse truly represents a high-explosive blast and not a gas or deflagration-type of explosion.

Annex B
(informative)

Blast shock-wave characteristics

The blast wave in a shock tube can be generated by means of explosive gases or by the rupture of a membrane to suddenly release highly compressed air. This sudden release causes the air to be driven at supersonic speeds, when air molecules cannot respond as they would to a normal input of energy. As a result, the air “shocks up” to form a blast wave. The blast wave is characterized at any given point by an instantaneous rise in pressure followed by a decay over a time called the positive phase duration. See Figure B.1.

This shock front, which travels along the tube through the air, closely simulates the positive phase pressure-time pulse of a blast wave produced by detonation of a high explosive. When a blast wave encounters the surface of a target structure, it is reinforced and reflected. The target initially experiences what is termed a peak reflected pressure, denoted P_{max} or P_r, which is, strictly speaking, the over-pressure above ambient.



Key

X time after explosion

Y pressure

1 positive specific impulse, i_{pos}

2 negative specific impulse, i_{neg}

3 time of arrival, t_A

4 positive phase duration, t_{pos}

5 negative phase duration, t_{neg}

[a] Ambient.

Figure B.1 — Idealized pressure-time variation for a blast wave

In a true, free-field explosion, as the energy of the expanding gases becomes dissipated, so their momentum falls and they begin to contract. The effect on the blast wave is to produce rarefaction, which manifests itself as a period of “under-pressure”, known as the negative phase. It is this phase which, combined with the tendency of panels to undergo elastic rebound, often causes window glass to bulge or fall towards the blast source. In the confines of a shock tube. there is usually very little negative phase pressure; indeed reverberations back and forth along the tube can cause small, positive after-shocks that can rupture a pane that survived the first pulse. Measures can be taken to bleed off pressures and reduce after-shock effects.

Annex C
(informative)

Equivalent threat levels

The blast values in Table C.1 are calculated following the principles stated in US Army Technical Manual 5-855[9]. They assume a hemispherical surface burst of TNT at a standoff from a vertical building of infinite size. It should be noted that in most live events against single building facades or test structures of finite size, the values of reflected impulse are less than shown. However, in congested or narrow city streets, the impulse values can be higher on account of multiple reflections off other buildings.

Results from the tests are specific to the test blast conditions. However, the results may be used for estimation of the glazing performance under other conditions based on theoretical considerations and/or experimental work. Further information is provided in Reference [8].

Table C.1 — Surface airburst threats equivalent to the classifications

Classification Code	Classification minimum values[a]		Corresponding TNT equivalent for specified parameter values				
	Peak over-pressure kPa	Impulse kPa-ms	Charge mass kg	Standoff m	Pressure kPa	Impulse kPa-ms	Duration ms
ER30	30	170	30	33	29	173	15
ER50	50	370	100	34	51	384	20
ER70	70	550	160	33	70	550	22
ER100	100	900	500	39	104	1 016	30
ER150	150	1 500	1 000	41	153	1 568	34
ER200	200	2200	2 000	46	201	2 250	41
			2 500	49	206	2 460	44

[a] The positive phase duration should be not less than 20 ms except for ER30.

Annex D
(informative)

Fragment definitions and criteria comparisons with other standards

D.1 Fragment dimensions

A fragment (3.7) in this International Standard is defined as any particle with a united dimension of 25 mm or greater.

The united dimension of a glass particle is determined by adding its width and length and thickness. Glazing dust and slivers are all other smaller particles. These definitions accord with ASTM F1642.

In order to aid data collection, this definition is quantified in Table D.1, which shows examples of minimum sizes classed as fragments for typical glass thicknesses.

Table D.1 — Relationship of dimensions, volume and mass for framents

Particle dimensions [a] mm			Volume mm^3	Mass [b] g
10	12	3	360	0,90
10	11	4	440	1,10
10	9	6	540	1,35
8	8	8	576	1,44
9	10	10	540	1,35
6	16	3	288	0,72
6	15	4	360	0,90
6	13	6	468	1,17
6	11	8	528	1,32

[a] The sum of the three dimensions equals 25 mm, in accordance with the definition of a fragment (3.7).

[b] Assuming a density of 0,002 5 g/mm^3. 1 m^2 of 10 mm thick glass weighs 25 kg assuming a glass density 2 500 kg/m^3.

D.2 Criteria assessments and comparisons

Further information on assessing blast, tests, criteria and effects on glazing may be found in Reference [8], which contains charts that plot pressure against impulse and indicate estimated relationships between glazing thickness, type and size. This reference and charts show the test-classification blast values applicable to small-reaction structures related to a grid of calculated values for large facades. Arena test classifications and effects are compared with those of the shock tube test classifications as in Reference [2].

Bibliography

[1] ASTM F1642, *Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings*

[2] ISO 16933, *Glass in buildings — Explosion-resistant security glazing — Test and classification for arena air-blast loading*

[3] EN 13123-1, *Windows, doors and shutters — Explosion resistance — Requirements and classification — Part 1: Shock tube*

[4] EN 13123-2, *Windows, doors and shutters — Explosion resistance — Requirements and classification — Part 2: Range test*

[5] EN 13124-1, *Windows, doors and shutters — Explosion resistance — Test method — Part 1: Shock tube*

[6] EN 13124-2, *Windows, doors and shutters — Explosion resistance — Test method — Part 2: Range test*

[7] EN 13541[1)], *Glass in building — Security glazing — Testing and classification of resistance against explosion pressure*

[8] Johnson, N. F. International Standards for Blast Resistant Glazing, Paper ID JAI 12892, *Journal of ASTM International*, April 2006, 3, (4); ISSN: 1546-962X[2)]

[9] US Army Technical Manual 5-855, *Fundamentals of protective design for conventional weapons*

1) EN 13541 is based on simulating blast using a shock tube, as are References [2], [3] and [5].

2) Available online at http://www.astm.org. To download ($25 fee): proceed through / Books & Journals / Journal of ASTM International (JAI) / Search; enter “blast” in the space for the title of paper or “International Standards for Blast Resistant Glazing”.

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