QUALITY STANDARDS MANUAL

ARCHITECTURAL GLASS

FQSM G-101: 2012

FEDERATION OF SAFETY GLASS

FOSG

Federation of Safety Glass

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Foreword

Although use of glass has increased tremendously during the last decade and a half, yet the building professionals and consumers alike are not aware of the types of value-added glass and their respective advantages. Lack of knowledge about application of various types of safety glasses and the price sensitivity of Indian consumers are yet another reason for non-acceptance of safety glasses, particularly in the residential sector.

Another dire problem facing the value-added glass industry is the lack of Indian codes, guidelines and awareness about the International codes for the selection and use of products with defined quality parameters.

Federation of Safety Glass has voluntarily brought out this *Quality Standards Manual (FQSM G-101: 2012)* for ready reference for the Manufacturers, Design Consultants and Construction Engineers to ensure sustainability of glass in the Built Environment. The consolidated references to both Indian and International Codes included in this Manual will be of immense value to the Building Professionals.

I appreciate the efforts of the FOSG for bringing out this Manual. I am sure this Manual will be quite useful to the Architects, Engineers and Builders from both the Government and the private sector in general, and the consumer in particular, and would facilitate them to select the right type of glass for different applications in the building infrastructure to meet with the architectural, structural and safety requirements.

D. S. Sachdev
Former Director General (Works), Central Public Works Department
New Delhi
July 2012

Preface

The *Quality Standards Manual* prepared by FOSG, fulfills an acute need in the market for clarity on acceptance criterion for various glass types and processed glass products.

The criterion specified are based on internationally accepted parameters and occasionally surpass them where technical improvements have made achieving higher quality control possible. The quality parameters specified in the manual will help standardize expectations, will help improve quality, and reduce unnecessary doubts and conflicts. The manual will help everyone, the client, the specifier, the installer and the manufacturer.

CCPS having worked with FOSG in developing these standards, will continue to participate in wider dissemination and will take feedback from the user community and work to keep the manual updated and relevant.

We also believe this initiative will give the confidence and motivate other similar industry bodies to come forward and also develop standards that will help reduce ambiguity and improve clarity.

FOSG's effort in bringing out the document and having its members agree to conform to these standards heralds a new chapter in industry led responsible initiatives.

Deepak Gahlowt
Architect & Hon. Convener, CCPS
New Delhi
July 2012

Acknowledgements

The *Quality Standards Manual* is a result of exceptional teamwork Mr. Sharanjit Singh, Mr. Tariq Kachwala, Mr. Vivek Dubey & Mr. Prem Dutt as FOSG members as well as Mr. Deepak Gahlowt and Mr. Shashi Kant of Confederation of Construction Products & Services (CCPS) who worked closely to develop this comprehensive manual.

The *Quality Standards Manual* developed jointly by FOSG and CCPS will serve the purpose of an acute need for clarity on acceptance criterion for various types of processed glass products. Once adopted, with the quality parameters specified, it will help standardize expectations, improve quality and resolve disputes and conflicts with buyers since it will have common acceptance norms and quality standards for the entire glass industry in India.

Last but not the least I would like to thank the members for their valuable contributions given which helped in the development of this magnificent manual and special thanks to Mr. Tariq Kachwala, for devoting his precious time and efforts for giving the manual a final shape.

We will look forward for comments and suggestions for improvements in days to come.

Gurmeet S Singh
Chairman, Federation of Safety Glass
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July 2012

1. Definitions

1.1 Glass Types

1.1.1 Annealed Glass

This is float glass (also termed soda lime silicate glass) and is a term for perfectly flat glass manufactured by the float process. This process was invented in the UK by Sir Alastair Pilkington in 1959. It is the most basic type of glass available today and forms the basis for several fabricated glasses that are used in construction. Float glasses have a surface compression less than 24 MPa (3500psi). For the purpose of conciseness, all standard terms that follow refer to float glass only and other forms of glass are not considered.

1.1.2 Tinted Glass

Tinted glasses are manufactured by adding colorants to normal clear float glass during manufacture to achieve tinting and solar-radiation absorption properties. The colour is achieved upon the addition of a mineral admixture. Tinting reduces heat and light penetration in buildings as compared with clear glasses.

1.1.3 Coated Float Glass

These are glasses (clear or tinted) that have been coated to reflect solar radiation striking the surface of the glass, thereby reducing solar heat gain. Coatings can be reflective or low-emissivity in nature and affect both the visual and the functional performance of the base glass.

1.1.4 Self Cleaning Glass

This is an ordinary float glass with a special photo-catalytic coating. It has a natural self-cleaning property. The active integrated coating on the outside of the glass absorbs the sun's ultraviolet rays. This causes a reaction on the surface which breaks down dirt and loosens it from the glass. It also has hydrophobic or hydrophilic properties. When it rains or water is poured over it, it washes the dust off the glass, instead of leaving it on the glass surface.

1.1.5 Anti Reflective Glass

It is a normal float glass, but with a special coating that allows very little reflection of light. It offers maximum clarity at all times. It has maximum transparency and lowest light reflection rates and allows optimum viewing through the glass.

1.1.6 Extra Clear Glass

It is glass that has an extremely low content of iron, giving it a remarkably clear look. Extra clear glass (also commonly called low-iron glass or ultra-clear glass) has the property of allowing high light transmission with minimum colour, resulting in brilliant optical clarity.

1.1.7 Tempered/Toughened Glass

Tempered Glass (also called Fully Tempered Glass or Toughened Glass or Fully Toughened Glass)[1] is produced when float glass panels are heated and then cooled rapidly in a controlled environment[2]. This process makes the glass several times stronger than regular glass. It also makes it safer because when broken it yields small pebble-like fragments. In the heat treating process, the annealed glass is subjected to a special heat-treatment in which it is heated to about 650ºC and afterwards cooled. During the quenching operation the surface of the glass cools quicker than the interior of the glass so that the residual compression stress is locked into the surface of the glass. These residual compression stresses must be overcome before the glass can fracture due to tensile stresses. The strength of the glass is determined by whether the glass is cooled rapidly or slowly.

The properties of toughened glasses are as follows:

1. Toughened glass can be as much as 5 times stronger than annealed glass. It resists breakage and can withstand temperatures up to maximum 300ºC.
2. Surface compression stress is greater than 10000 psi.
3. Unlike annealed glasses it breaks into small pieces without any sharp edges. For this reason toughened glass is classified as a safety glass[3].
4. Toughened glass however has a few limitations:
    a. Once toughened, the glass cannot be cut, drilled, beveled, deep-etched or acid-treated. Therefore, all design decisions have to be taken before the glass is processed.
    b. Tempered glass is prone to spontaneous breakage due to the presence of nickel sulphide, which cannot be completely eliminated during the float glass manufacturing process. To reduce the probability of breakage due to Nickel Sulphide inclusions, heat-soak test as described in Chapter 5 is strongly recommended.
    c. As it is heat-treated, it can have bows, warps and process roll distortion on the surface and this may interfere with the optics.

Toughened glass is used wherever strength is required and regular annealed glass will not be sufficient, like in high use areas like entrances, in conditions where high wind loads need to be taken by the glass surface, etc. Glass facades, sliding doors, building entrances and bath and shower enclosures are the most common uses. Fire knock-out panels, fireplace enclosures and kitchen objects like vegetable chopping board and cooking pot lids are other uses.

1.1.8 Heat Strengthened Glass

This is a particular heat treated glass that is popular for facade glazing applications like windows, vision panels and spandrel panels as well as the base material for lamination. Its mechanical strength is twice that of annealed glass and

[1] Toughened Glass and Tempered Glass terms are used interchangeably in this document.

[2] This definition applies only to thermally toughened glasses. Other forms of toughening such as chemical toughening are also available.

[3] Toughened glass is classified as a safety glazing material under specific application and installation criteria. Please consult manufacturer for details.

half of fully tempered glass. Surface compression is between 5000 to 8000 psi. Due to its breakage pattern, monolithic heat-strengthened glass is not classified as a safety glazing material.

1.1.9 Heat Soaked Glass

This is simply fully tempered glass that has been processed to reduce the probability of spontaneous breakage due to nickel sulphide inclusions. Heat soaked glass has shown 95% reliability in tests[4]. The glasses have the same advantages as fully toughened glass, but are relatively safer as the possibility of breakage is reduced.

1.1.10 Laminated Glass

This is composed of two or more lites of glass permanently bonded together with an interlayer material sandwiched in between. Interlayers like PVB (polyvinyl butyral) are bonded into the glass by the application of heat and pressure. Special security glass and other value-added glass can be made. The two or more sheets of glass may be regular float glasses, body-tinted, reflective, annealed, heat-strengthened or fully tempered glass, depending on the performance that is required. Laminated glass is a completely customizable product and can perform a wide range of functions.

Laminated glass is used as safety glazing in public buildings, commercial and retail structures, overhead glazing and large facades. It also serves as security glazing in residences, embassies, banks and combat vehicles and provides sound control in offices, institutions, malls, residences, airport, bus terminals and recording studios. Other applications include skylights, aquariums, entrance doors and glass floors[5].

Laminated glass offers several practical benefits and safety characteristics:

1. Safety: Laminated glass remains intact when broken, holding glass fragments in place.
2. Burglary Resistance: Laminated glass is extremely useful for security, and burglar intrusion is greatly minimized. The interlayer continues to be in place even if the glass is broken, increasing security. Ordinary glass cutters and break-in tools are not effective on laminated glass as it needs to be cut in from both the sides. In fact, laminated glass is the only glass to provide post-breakage strength.
3. Bullet-Resistance: Multiple layers of glass and interlayers provide resistance to bullet and blast resistance.
4. Sound Control: Use of regular and special interlayers can considerably reduce sound transmission. The visco-elastic properties of the interlayer have a dampening effect on noise.

1.1.11 Insulated glass

Insulated glass (IG) consists of two or more glass lites assembled with a space in between. This space is either left as an air gap or filled with an inert gas for better insulation. IG units offer excellent insulation from conductive heat and have lower U-Values than monolithic glasses[6]. Substantial energy savings have been demonstrated from use of IG glasses as a glazing material when compared to single glazing.

1.1.12 Sandblasted Glass

Sandblasted glass has a design or form done on it by spraying sand. This texture is rougher than the rest of the glass and it’s translucent. Sand is sprayed at high velocity over the surface of the glass. The area that does not need sandblasting is kept covered during the process. The depth and degree of translucence depends on the force and type of sand used.

1.1.13 Etched Glass

Acid-etched glass is formed when regular float-glass is acid-etched on one side. Acid etching gives a uniformly smooth and satin-like effect on the glass. Such glass admits light while providing softening and vision control. An industrially produced glass ensures uniformity of coating and will not show patching.

1.1.14 Lacquered Glass

This is another kind of decorative glass meant for interior use. It is made by depositing and then baking a coat of durable and resistant lacquer to one of the glass surfaces. It is opaque in appearance and combines the advantages of glass like moisture resistance and highly aesthetic surface shine, while adding opacity.

1.1.15 Ceramic Coated Glass

This is a tempered or heat-strengthened glass, one face of which is covered, either partially or totally, with ceramic inks. The colour pigment is added while heat strengthening the glass. In addition to its decorative function, ceramic glass is also a solar ray controller. It can be assembled into laminated glass or glazed insulation. It is stable, non-biodegradable and can be made into different patterns and shapes. It is used for glazing and cladding in facades, skylights, canopies and floors.

[4] Please note that even after heat-soaking the probability of NiS induced spontaneous breakage is not completely eliminated.

[5] In overhead glazing (skylights, canopies, etc.) and floors, use of laminated glass should be mandatory to prevent any risk of injury.

[6] U-Values can be further reduced by use of low emissivity coatings.

2. Float Glass

2.1 Manufacturing Process

Float glass (also called soda lime silicate glass) is manufactured by allowing the glass from a tank furnace to flow across a bath of molten tin in a controlled atmosphere of nitrogen and hydrogen which yields transparent glass sheets, the surface of which is flat and parallel so that they provide clear, undistorted vision and refraction. To know about the different quality assurance tests Annexure A may please be referred.

2.2 Quality Parameters

2.2.1 Thickness

The thickness tolerances of float glass shall be as specified in Table 2.1

Table 2.1: Thickness and Tolerance of Float Glass[7]

(All dimensions are in millimeters and as per IS14900 : 2000 (Reaffirmed 2005))

Nominal Thickness	Tolerance*
2	± 0.2
2.5	± 0.2
3	± 0.3
3.5	± 0.3
4	± 0.3
5	± 0.3
6	± 0.3
8	± 0.6
10	± 0.6
12	± 0.8
15	± 0.8
19	± 1.2

2.2.2 Dimensions

Tolerance on length and width of the float glass shall be in accordance with Table 2.2.

Table 2.2: Dimensional (Length or Width) Tolerance of Float Glass[8]

(All dimensions are in millimeters and as per IS14900 : 2000 (Reaffirmed 2005))

Nominal Thickness	Tolerance (Length or Width)	
	Up to and including 3 m	Above 3 m
2	+1 / -2	
2.5	+1 / -2	
3	+1 / -2	-
4.0	+1 / -2	+3 / -4
5.0	+2 / -2	+3 / -4
6.0	+2 / -2	+3 / -4
8.0	+2 / -3	+3 / -4
10.0	+2 / -3	+3 / -4
12.0	+3 / -3	+4 / -4
15.0	+3 / -3	+4 / -4
19.0	+5 / -5	+6 / -6

2.2.3 Diagonals

Tolerance on diagonal of float glass shall be in accordance with Table 2.3.

Table 2.3: Limit Deviation on Difference in Diagonals of Float Glass

Nominal Thickness	Tolerance (Diagonal)	
	Up to and including 3 m	Above 3 m
2	2	
2.5	2	
3	2	-
4.0	2	-
5.0	2	3
6.0	2	3
8.0	3	4

[7] Glass thickness shall be measured with a micrometer or caliper which is graduated to 0.01 mm or with a measuring instrument having an equivalent accuracy.

[8] Glass dimension shall be measured with a steel scale (tape) which is graduated to 1.00 mm. The measurement shall be made on adjacent two sides.

10.0	3	4
12.0	3	4
15.0	3	4
19.0	5	6

2.2.4 Glass Edge Finish

Edge damage usually occurs when cutting the glass (difficulty increases with thickness) and during grinding of glass. There is no standard acceptance criteria for the edge condition of the glass. Glass with edges that are severely cut, damaged or have deep, pointed shells/vents is generally not acceptable. The glass edge finish should be in accordance with Table 2.4.

Table 2.4: Glass Edge Finish

SNo.	Usage Type	Finish	Allowable Defects
1	Exposed edges	Neatly polished, straight line	Small glass fragment normally conchoidal ≤2mm
2	Siliconee or butt joint	Rough grinding without chips and defects	Small glass fragment normally conchoidal ≤3mm
3	Concealed edge	Rough grinding without chips and defects	Small glass fragment normally conchoidal ≤3mm

2.2.5 Warpage and Bow

The allowed warpage and bow tolerance should be in accordance with Table 2.5

Table 2.5: Warpage and Bow Tolerance Limit

Thickness	Sizes	Tolerance%	Maximum
Upto 6mm	<3 m	0.3	6 mm
Upto 6mm	>3 m	0.3	8 mm
Above 6mm	<3 m	0.3	6 mm
Above 6mm	>3 m	0.3	10 mm

Closer tolerances may be required for glasses having thickness greater than 6 mm in butt jointed applications like partitions. This should be specified by the customer in advance and agreed upon specifically between buyer and seller.

2.2.6 Conditions of Examination

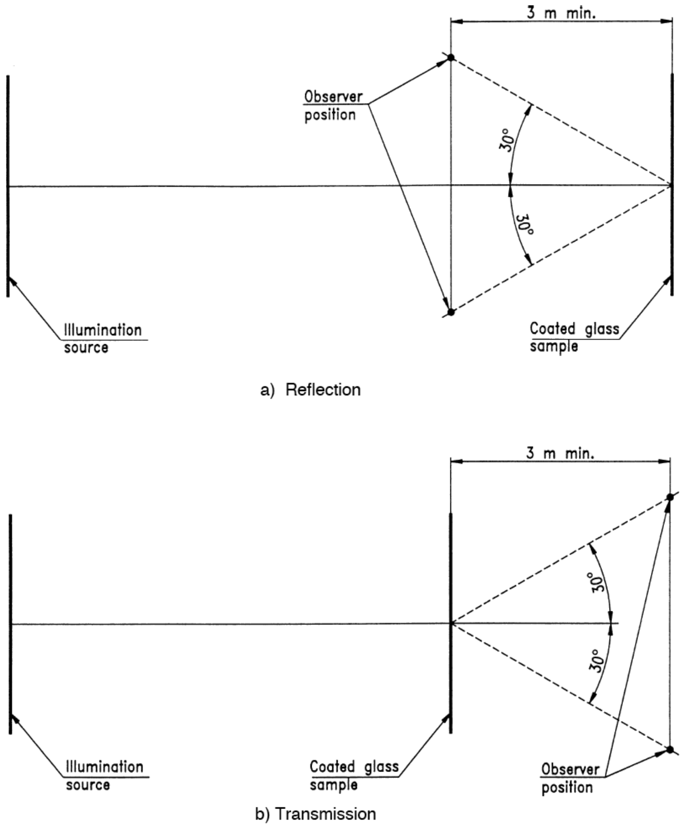
2.2.6.1 General

Float glass may be examined in stock size plates or in finished sizes ready for installation. The examination may be undertaken in the factory or on site when glazed.

The pane of float glass being examined is viewed from a minimum distance of 3 meters. The actual distance will be dependent on the defect being considered and which illumination source is being used. The examination of the float glass in reflection is performed by the observer looking at the side which will be the outside of the glazing. The examination of the float glass in transmission is performed by the observer looking at the side which will be the inside of the glazing.

During the examination the angle between the normal to the surface of the float glass and the light beam proceeding to the eyes of the observer after reflection or transmission by the coated glass shall not exceed 30° (see Figure 2.1).

Figure 2.1: Schematics of Examination Procedures



2.2.7 Surface and Body Defects

2.2.7.1 Scratches

Scratches shall be classified into the following categories: light, medium and heavy. The allowed scratches should be in accordance with Table 2.6.

Table 2.6: Visual Limits for Scratches

S No.	Intensity and Length	Definition	Number/ sqm
1	Light Scratch	Shall not be detectable beyond 50 cm	Any number

2	Medium Scratch (should not be more than 15.0 mm)	Visible up to 50 - 100cm, not visible beyond 100 cm	2
3	Heavy Scratch Max 10 mm	Visible up to 150cm, not visible beyond 150 cm	1

2.2.7.2 Spot Defects

The allowed number of spot defects should be in accordance with Table 2.7.

Table 2.7: Allowable Number of Spot Defects[9]

Spot Defect Category	Dimension of Nuclei of Spot Fault (mm)	Max. Allowable Number per m^2
A	0.5 to 1	2
B	1 to 2	1
C	2 to 3	0.5
D	Greater than 3	None
If more than one type of defect is present, it will not be acceptable.		

[9] Spot fault is a nucleus, which is sometimes accompanied by a halo of distorted glass. The dimension of a spot fault comprising a nucleus with a halo is obtained by multiplying the dimension of the nucleus by a factor of approximately 3.

3. Coated Glass

3.1 Basic Definitions

3.1.1 Coated Glass

Glass substrate as defined in 2.1 to which a coating has been applied, as defined in 3.1.2 in order to modify one or more of its properties.

3.1.2 Coating

One or more thin solid layers of inorganic materials applied on to the surface of a glass substrate by various methods of deposition.

3.1.3 On-Line Coating

The treatment of the surface of a moving continuous ribbon of a basic glass, at a stage during its manufacture, before it is cut.

3.1.4 Off-line Coating

The application of a coating to individual pieces of glass within a manufacturer's or processor's premises.

3.1.5 Additive Methods of Deposition

Single or multilayer systems (consisting of metals, oxides, nitrides, fluorides or other compounds) added to the surface of the glass by different methods.

3.2 Definitions of Appearance Defects

3.2.1 Uniformity Defect

Slight visible variation in colour, either in reflection or transmission, within a coated glass pane or from pane to pane.

3.2.2 Stain

Defect in the coating larger than punctual defect, often irregularly shaped, partially of mottled structure.

3.2.3 Punctual Defect

Punctual disturbance of the visual transparence looking through the glass and of the visual reflectance looking at the glass[10].

3.2.3.1 Spot

Defect that commonly looks dark against the surrounding coating, when viewed in transmission.

3.2.3.2 Pinhole

Punctual void in the coating with partial or total absence of coating and it normally contrasts as clear relative to the coating, when viewed in transmission.

3.2.3.3 Scratch

Variety of linear score marks, whose visibility depends on their length, depth, width, position and arrangements.

3.2.4 Cluster

Accumulation of very small defects giving the impression of stain.

3.3 Appearance

3.3.1 General

The defects affecting appearance are:
- Specific to the glass substrate (see 2.2.6), and
- Specific to the coating.

If a defect specific to the glass substrate is more visible because of the coating, it will be treated as a coating defect.

3.3.2 Detection of Defects

The defects are detected visually by an observation of the coated glass in transmission and/or reflection. An artificial sky or daylight may be used, as the source of illumination. Daylight illumination is a uniform overcast sky, without direct sunlight.

3.3.3 Conditions of Examination

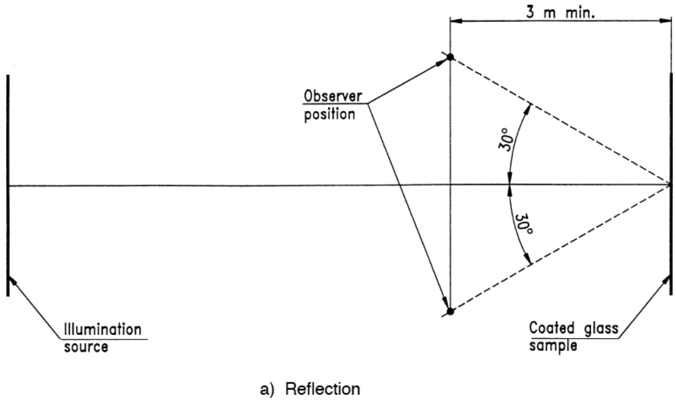
3.3.3.1 General

Coated glass may be examined in stock size plates or in finished sizes ready for installation. The examination may be undertaken in the factory or on site when glazed.

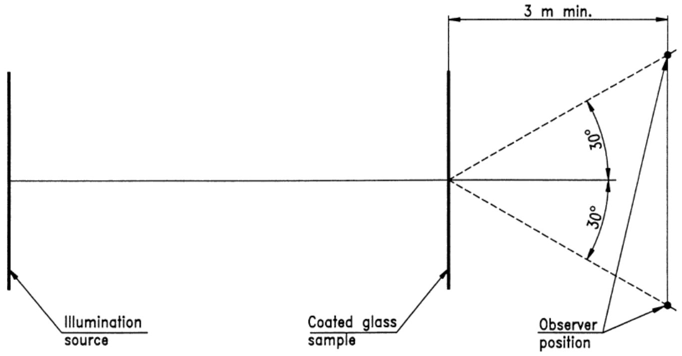
The pane of coated glass being examined is viewed from a minimum distance of 3 meters. The actual distance will be dependent on the defect being considered and which illumination source is being used. The examination of the coated glass in reflection is performed by the observer looking at the side which will be the outside of the glazing. The examination of the coated glass in transmission is performed by the observer looking at the side which will be the inside of the glazing.

During the examination the angle between the normal to the surface of the coated glass and the light beam proceeding to the eyes of the observer after reflection or transmission by the coated glass shall not exceed 30° (see Figure 1).

Figure 3.1: Schematics of Examination Procedures



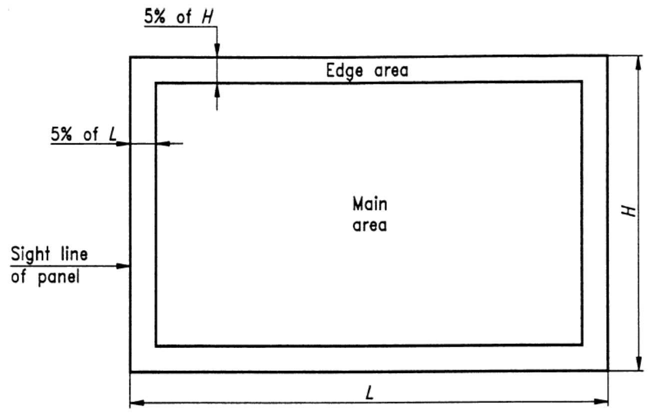
10 Spots, pinholes and scratches are types of punctual defects.



b) Transmission

For panes of coated glass in finished sizes ready to be installed both the main area and an edge area of the pane shall be examined (see Figure 2)[11].

Figure 3.2: Areas to be Examined on Finished Sizes Ready for Glazing



3.3.3.2 Uniformity Defects and Stains

Under the conditions of examination, given in 3.3.3.1, note any coating variations either within one pane or between neighbouring panes which are visually disturbing.

3.3.3.3 Punctual Defects

Under the conditions of examination, given in 3.3.3.1, note any spots, pinholes and/or scratches that are visually disturbing.

For spots and pinholes measure the size and note the number relative to the size of the pane. If any clusters are found, their position relative to the through vision area shall be determined.

For scratches determine whether they are in the main or edge area. Measure the length of any scratches noted. For scratches greater than 75 mm long determine the distance between adjacent scratches. For scratches less than 75 mm long note any area where their density produces visual disturbance.

3.3.4 Acceptance Criteria of Coated Glass Defects

The acceptance criteria for defects in coated glass, examined according to 3.3.3, are given in Table 3.1.

Table 3.1: Coated Glass Acceptance Criteria

DEFECT TYPES	ACCEPTANCE CRITERIA		
	Pane / Pane	Individual Pane	
		Main Area	Edge Area
Uniformity / Stain			
	Allowed as long as not visually disturbing	Allowed as long as not visually disturbing.	
Spots / Pinholes			
≤ 2mm	Allowed	Allowed	Allowed
> 2mm and ≤ 3mm	Not Applicable	Allowed if not more than 1/ m^2	Allowed if not more than 1/ m^2
> 3mm	Not Applicable	Not allowed	Not allowed
Clusters			
	Not Applicable	Not allowed	Allowed as long as not in area of through vision
Scratches			
> 75mm	Not Applicable	Not allowed	Allowed as long as they are separated by > 50 mm
≤ 75mm	Not Applicable	Allowed as long as local density is not visually disturbing	Allowed as long as local density is not visually disturbing

[11] Each examination will take no more than 20 seconds.

4. Toughened / Tempered Glass

4.1 Manufacturing Process

Toughened or tempered glass is produced when float glass panels are heated and then cooled rapidly in a controlled environment. This process makes the glass stronger than annealed glass. It also makes it safer because when broken it yields small pebble-like fragments (also called dice).

4.2 Quality Parameters

4.2.1 Thickness

The thickness tolerance of toughened glasses shall be in accordance with the tolerances mentioned for annealed float glasses. Please refer Table 2.1 for details.

4.2.2 Dimensions and Squareness

Tolerance limits for dimensions for rectangular glass panes are given in Figure 1 and tolerances on width and length should be in accordance with Table 4.1 and limit deviation on diagonals is illustrated in Table 4.2.

Figure 4.1: Tolerance Limits for Dimensions of Rectangular Panes

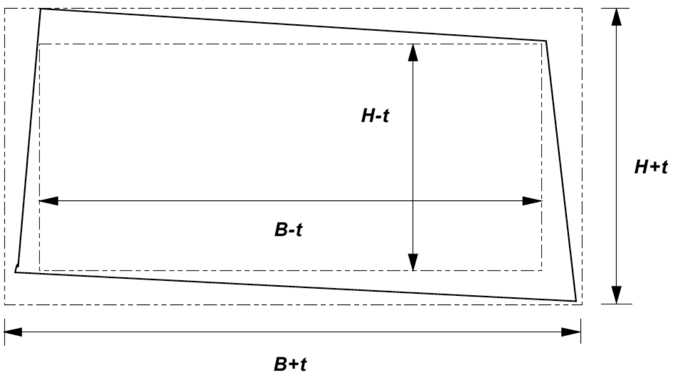


Table 4.1: Tolerances on Width B and Length H
(All dimensions are in millimeters and as per EN12150-1 2008)

Nominal Dimension of Side, B or H	Tolerance, t	
	Nominal Glass Thickness d ≤ 8	Nominal Glass Thickness d > 8
≤ 2000	+/-2	3
2000 < B or H ≤ 3000	3	4
> 3000	4	5

Table 4.2: Limit of Deviation of Difference in Diagonals
(All dimensions are in millimeters and as per EN12150-1 2008)

Limit Deviation v on the Difference between Diagonals		
Nominal Dimension of Side, B or H	Nominal Glass Thickness d ≤ 8	Nominal Glass Thickness d > 8
≤ 2000	≤ 4	≤ 6
2000 < B or H ≤ 3000	≤ 6	≤ 8
> 3000	≤ 8	≤ 10

4.2.3 Holes and Cutouts

4.2.3.1 Hole Dimensions

The allowable hole diameter tolerance should be in accordance with Table 4.3.

Table 4.3: Tolerances on Holes
(All dimensions are in millimeters)

	Hole Diameter Range	Dimensional Tolerance
All Thicknesses	4 to 20	± 1
	21 to 100	± 2
	Above 100	Consult the Manufacturer

4.2.3.2 Hole and Cutout Location

The allowed hole and cutout location tolerance should be in accordance with Table 4.4.

Table 4.4: Tolerances on Hole and Cutout Location
(All dimensions are in millimeters)

All Thicknesses	For holes tolerance should be from centre of hole	± 1.5mm
	For cutouts tolerance should be from edge	± 1.5mm

4.2.3.3 General Rules for Holes, Notches and Cutouts

4.2.3.3.1 Diameter of Holes

The diameter of holes, ∅, shall not, in general, be less than the nominal thickness of the glass. For smaller holes, the manufacturers should be consulted.

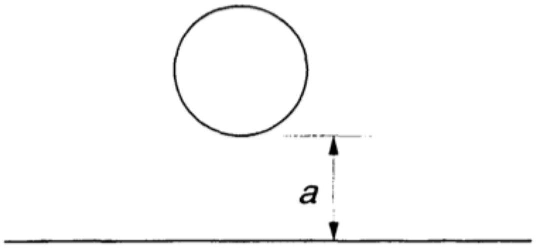
4.2.3.3.2 Limitation on Position of Holes

In general, the limitations on hole positions relative to the edges of the glass pane, the corners of the glass pane and to each other depends on:
- the nominal glass thickness (d)
- the dimensions of the pane (B, H)
- the hole diameter (∅)
- the shape of the pane
- the number of holes

The recommendations given below are those which are normally available and are limited to panes with a maximum of 4 holes.

1. The distance, a, of the edge of a hole to the glass edge should be not less than 2d.

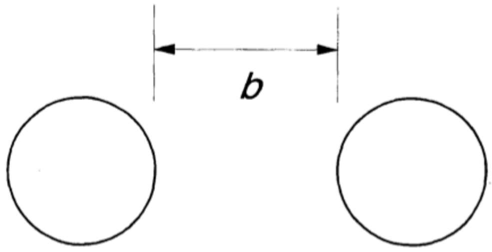
Figure 4.2: Relationship between Hole and Edge of Pane



$a \geq 2d$

2. The distance, b, between the edges of two holes should not be less than 2d.

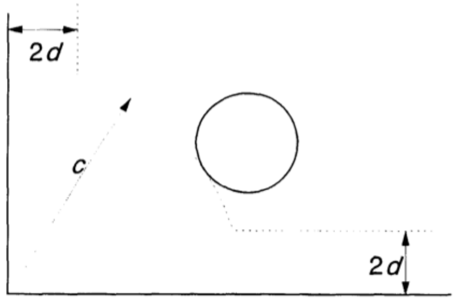
Figure 4.3: Relationship between Two Holes



$b \geq 2d$

3. The distance, c, of the edge of a hole to the corner of the glass should not be less than 6d.

Figure 4.4: Relationship between Hole and Corner of Pane



$c \geq 6d$

Note: If the distances from the edge of the hole to the edge of the glass is less than 35mm, it can be necessary to position the hole asymmetrically with respect to the corner. The manufacturers should be consulted.

4.2.4 Glass Edge Finish

Edge damage usually occurs when cutting the glass (difficulty increases with thickness) and during grinding of glass. There is no standard acceptance criteria for the edge condition of the glass. Glass with edges that are severely cut, damaged or have deep, pointed shells/vents is generally not acceptable. The glass edge finish should be in accordance with Table 4.5.

Table 4.5: Glass Edge Finish

SNo.	Usage Type	Finish	Allowable Defects
1	Exposed edges	Neatly polished, straight line	Small glass fragment normally conchoidal ≤2mm
2	Silicone or butt joint	Rough grinding without chips and defects	Small glass fragment normally conchoidal ≤3mm
3	Concealed edge	Rough grinding without chips and defects	Small glass fragment normally conchoidal ≤3mm

4.2.5 Flatness

4.2.5.1 General Information

By the very nature of the toughening process, it is not possible to obtain a product as flat as annealed glass. The difference depends on the nominal thickness, the glass size dimensions and the ratio between the dimensions. Therefore a distortion known as overall bow can occur. There are two kinds of bow (see Figure 4.3):
- overall or general bow
- local bow

NOTE 1: Overall bow can, in general, be accommodated by the framing system.

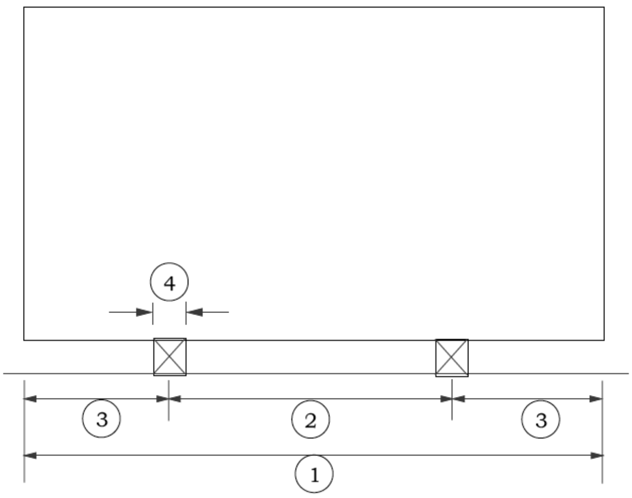
NOTE 2: Local bow needs to be allowed for in the glazing materials and the weather seals. For special requirements the manufacturers should be consulted.

4.2.5.2 Measurement of Overall Bow

The pane of glass shall be placed in a vertical position and supported on its longer side by two load bearing blocks at the quarter points (see Figure 4.5). The deformation shall be measured along the edges of the glass and along the diagonals, as the maximum distance between a straight metal ruler, or a stretched wire, and the concave surface of the glass (see Figure 4.6). The measurement should be done at room temperature.

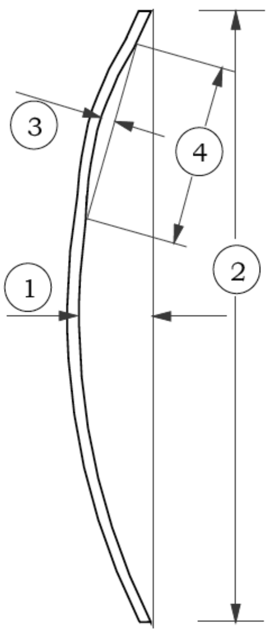
The value for the bow is then expressed as the deformation, in millimeters, divided by the measured length of the edge of the glass, or diagonal, in millimeters, as appropriate.

Figure 4.5: Support Conditions for Measurement of Overall Bow



(1) B or H
(2) (B or H)/2
(3) (B or H)/4
(4) maximum 100mm

Figure 4.6: Representation of Overall and Local Bow



(1) deformation for calculating overall bow
(2) B or H, or diagonal length
(3) local bow
(4) 300mm length

4.2.5.3 Warpage and Bow Tolerances

4.2.5.3.1 Overall Bow Tolerances

The allowed warpage or overall bow tolerance should be in accordance with Table 4.6.

Table 4.6: Overall Bow (Bend) Tolerance Limit

Thick-ness	Up to 1.2 m	1.2 to 2.5 m	2.5 to 3.05 m	3.05 to 3.66 m	Above 3.66 m
4mm	4mm	4mm	6mm	NA	-
5mm	3mm	4mm	5mm	7mm	-
6mm	3mm	4mm	5mm	7mm	-
8mm	3mm	4mm	5mm	6mm	10 mm
10mm	3mm	4mm	4mm	5mm	10mm
12mm	3mm	4mm	4mm	5mm	8mm
15mm	3mm	4mm	4mm	6mm	8mm
19mm	3mm	4mm	4mm	6mm	10mm

4.2.5.3.2 Local Bow Tolerances

Local bow can occur over relatively short distances on the edges of the glass. Local bow shall be measured over a limited length of 300mm by using a straight ruler, or a stretched wire, parallel to the edge at a distance of 25 mm from the edge of the glass (see Figure 4.3).

Local bow is expressed as millimeters / 300 mm length[12].

The maximum allowable values for the local bow, when measured according to 4.2.5.2, for glass without holes and/or notches and/or cutouts are given in Table 4.7[13].

Table 4.7: Maximum Values for Local Bow
(All dimensions are in millimeters and as per EN12150-1 2008)

Toughening Process	Local Bow mm/300 mm
Horizontal	0.5

For horizontal tempering, 200mm from either edges parallel to the roller waves shall be excluded from measurement. This method of measurement may not be applicable for non-rectangular glasses, e.g., triangles and trapezoids.

4.2.5.4 Important Considerations for Optical Distortion in Fully Toughened Glass[14]

1. Pressures, exerted around the periphery of glass by the glazing system, can also alter glass flatness thereby distorting reflected images. This is true regardless of whether or not the glass is heat treated.
2. Sealed insulating glass units also exhibit distortion regardless of glass type. Air or gas, trapped in the sealed airspace between the panes, expands or contracts with temperature and barometric changes,

[12] For patterned glass, local bow shall be determined by using a straight ruler resting on the high points of the pattern and measuring to a high point of the pattern.

[13] Source: para 4.2.8 to 4.2.8.4 from EN 12150-1 pages 9 to 12.

[14] Source: para 7.4.3 to 7.4.6 from ASTM C 1048 - 04.

creating a pressure differential between the airspace and the atmosphere. The glass reacts to the pressure differential by being deflected inward or outward.

3. Regardless of glass flatness, the degree of reflected distortion perceived is primarily and largely due to the characteristics or symmetry of the object being reflected. Linear objects (such as building curtain walls and telephone poles) and moving objects (such as cars) may appear distorted. Irregular and free-form objects such as trees and clouds will appear to have little perceived distortion.
4. Specified bow and warp limits may not adequately define, or control, the distortion that may become apparent after glazing. The factors, noted above, may have a larger influence on the perceived reflected distortion than that which is caused by bow and warp from the heat-treating process. Consultation with suppliers and the viewing of full-size mockups, under typical job conditions and surroundings, is highly recommended for user or architectural evaluation of the reflective distortion.
5. Aspect ratio, the ratio of the longer side of the panel to its shorter side, also plays a role in controlling distortion. Larger aspect ratios are preferred, limited to a maximum of 15:1. Aspect ratios close to 1:1 pose greater challenges in controlling overall and local bow.

4.2.6 Appearance

For surface and body defects in clear or tinted toughened glasses refer to 2.2.6.

For accepted criteria of coated toughened glasses, refer to 3.3.4 and all conditions mentioned in Section 3: Coated Glass.

4.2.7 Fragmentation Test

4.2.7.1 General

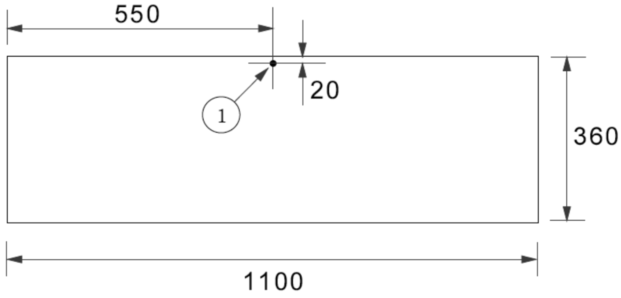
The fragmentation test determines whether the glass breaks in the manner prescribed for a thermally toughened safety float glass[15]. Five specimens from actual production batch shall be tested having dimensions 360 mm x 1100 mm each, without holes, notches or cutouts.

4.2.7.2 Test Procedure

Each test specimen shall be impacted, using a pointed steel tool, at a position 20 mm in from the longest edge of the test specimen at the mid-point of that edge, until breakage occurs (see Figure 4.7)[16]. Examples of steel tools are a hammer of about 75 gm mass, a spring loaded centre punch, or other similar appliances with a hardened point. The radius of curvature of the point should be approximately 0.2 mm.

The test specimen shall be laid flat on a table without any mechanical constraint. In order to prevent scattering of the fragments, the specimen shall be simply held at the edges, e.g. by a small frame, adhesive tape etc., so that the fragments remain interlocked after breakage yet extension of the specimen is not hindered[17].

Figure 4.7: Position of Impact Point

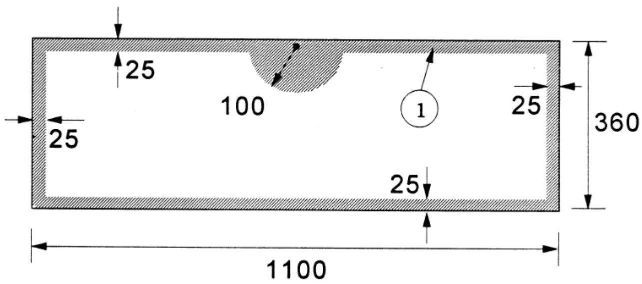


(1) Impact Point

4.2.7.3 Assessment of Fragmentation

The particle count and measuring of the dimensions of the largest particle shall be made between 4 minutes to 5 minutes after fracture. An area of radius 100 mm, centered on the impact point, and a border of 25 mm round the edge of the test specimen (see Figure 4.8), shall be excluded from the assessment.

Figure 4.8: Area to be Excluded from Particle Count



(1) Excluded Area

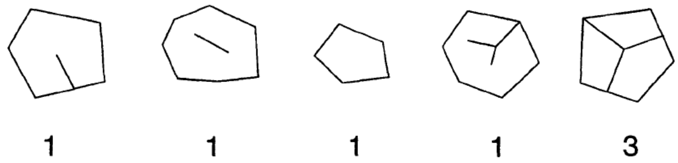
The particle count shall be made in the region of coarsest fracture (the aim being to obtain the minimum value). The particle count shall be made by placing a mask (50 ± 1) mm x (50 ± 1) mm on the test piece. The number of crack-free particles within the mask shall be counted. A particle is 'crack-free' if it does not contain any cracks which run from one edge to another (see Figure 4.9).

Figure 4.9: Examples of Crack-Free Particles and their Number Assessment

[15] In case of laminated glasses, the fragmentation pattern may not be indicative of correctly tempered glass due to the adhesion effect of interlayer.

[16] The fragmentation characteristics of glass are unaffected by temperatures between –50°C and ±100°C.

[17] For thermally toughened safety glass manufactured by vertical toughening, the impact point shall not be on the tong mark edge.



In the particle count, all particles wholly contained within the area of the mask shall be counted as one particle each and all the particles which are partially within the mask shall be counted as half particle each (see Figure 4.10 to 4.12).

Figure 4.10: Select Area of Coarsest Fracture

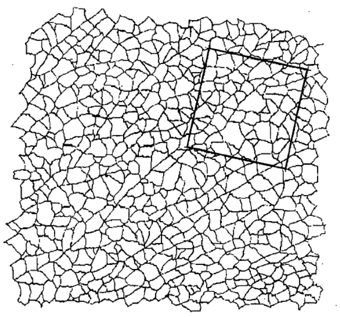
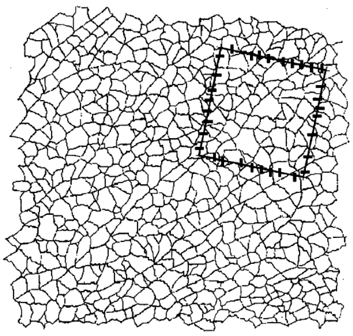
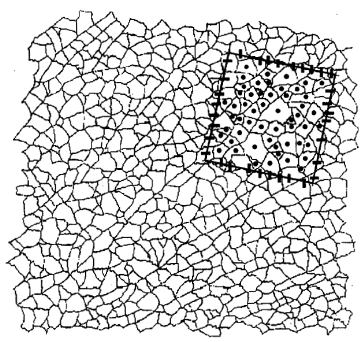


Figure 4.11: Count Perimeter Fragments as 1/2



e.g.: Number of Perimeter Particles = 32/2=16

Figure 4.12: Count Central Fragments and Add to Perimeter Count to Obtain Final Count



e.g.: Number of central fragments = 53, hence total fragments = 16 ± 53 = 69

4.2.7.4 Minimum Values from the Particle Count

In order to classify a glass as a fully toughened safety float glass, the particle count of each test specimen shall not be less than the values given in Table 4.9.

Table 4.9: Minimum Particle Count

Glass Type	Nominal Thickness (mm)	Minimum Particle Count
Float and Drawn Sheet	3	15
	4 to 12	40
	15 to 19	30
Patterned	3	15
	4 to 10	30

4.2.8 Stress Measurement Test

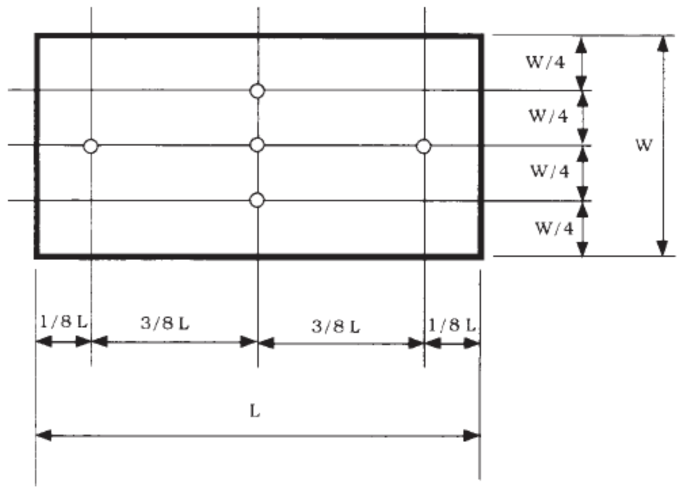
4.2.8.1 General

Stress measurement is a non-destructive test to check the toughening properties of fully toughened safety float glass. The specimens are examined by the polariscopic or light refraction methods[18] for surface or edge compression. When the range of the apparatus permits examination for edge compression only, obtain the averaged value for all midpoints of every edge.

4.2.8.2 Test Procedure

Two surface compression measurements shall be made in each of five locations, oriented in two directions at 90° to each other, for a total of ten readings on each specimen to be tested. Average the ten readings to determine the stress level of the test sample. The five locations to be examined are shown in Fig. 4.13.

Figure 4.13: Five Points to be Examined



4.2.8.3 Assessment of Measurements

Fully toughened glass shall have either a minimum surface compression of 69 MPa (10,000 psi) or an edge compression of not less than 67 MPa (9,700 psi). The difference between two measuring points should not exceed 10 MPa (1450 psi).

[18] The most common apparatus to conduct this test is the GASP instrument by Strainoptics Inc. Other methods like DSR may also be used.

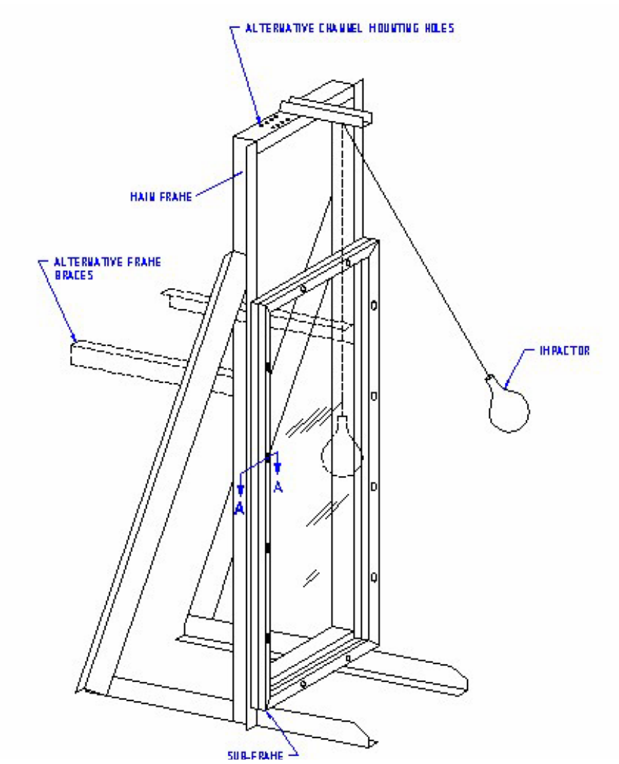
4.2.9 Shot Bag Test

4.2.9.1 Principle

The purpose of this test is to determine the impact resistance of toughened glass. A shot bag setup (as per ANZI Z97.1) is constructed. The following drop height classes are to be noted.

1. Class A - Drop height is between 1219 mm and 1232 mm.
2. Class B - Drop height is between 457 mm and 470 mm.

Figure 4.14: Arrangement of Impact Resistance Equipment



4.2.9.2 Procedure

1. Place and centre each specimen in the sub-frame so each edge is encased in the elastomeric rubber strip to a depth of at least 10 mm.
2. The impactor shall be suspended from an overhead support in such a way when it is free hanging there may be 13 mm space between the bag and the surface of the specimen. The space shall not exceed 51 mm.
3. The impactor shall be raised to the least drop height (Class B) and stabilized.
4. The impactor is then released and falls without any initial velocity or axial rotation.
5. The impactor shall impact the specimen only once and further impact on the specimen shall be restricted.
6. Inspect each test specimen after each impact, record and report the observation.
7. For asymmetric materials, the test shall be carried out on both sides using equal numbers of separate specimens.

4.2.10 Marking

Logo position from corner edge (preferably bottom-right) should be preferably 25mm ± 5mm. All float toughened glass should have mark 'TF' along with brand name.

4.3 Other Physical Characteristics

4.3.1 Anisotropy (Iridescence)

Heat-treated glass (heat-strengthened or tempered) can have an optical phenomenon that is called strain pattern or quench pattern. This phenomenon can appear as faint spots, blotches, or lines. This is the result of the air quenching (cooling) of the glass when it is heat-treated and should not be considered a glass defect.

The heat treatment process results in a higher surface compression directly opposite the air quench, air nozzles or slots. The higher compression areas are denser and can exhibit a darker appearance under some viewing conditions especially when light is polarized, such as a skylight or other forms of reflected light. The colours of the strain pattern are sometimes referred to as iridescent, or the general condition as iridescence. The pattern that is seen under certain lighting conditions may vary from manufacturer, depending on the design of the cooling apparatus. The intensity of the quench or strain pattern is influenced by the viewing angle, lighting conditions and by the perceptiveness of the viewer. It is nearly impossible to eliminate the strain pattern or quench pattern in heat treated glass products.

The presence of a strain pattern or the perceivable differences in the strain pattern is not a glass defect or blemish and is not cause for rejection. In addition, the presence of a strain pattern does not alter the structural integrity or safety of the glass lite.

When viewing from the interior of the building, the quench pattern may be visible from a 10° viewing angle and not apparent at a 90° viewing angle from the surface of the glass. When viewing the glass in reflectance from the exterior of the building, the quench pattern may be visible when looking at the glass surface at a 30-60° angle. Visibility of the quench pattern may be accentuated with thicker glass, tinted glass substrates, coated glass and multiple lites of heat-treated glass in laminated or insulating glass products.

Construction sites may yield viewing angles and conditions that cause the quench pattern to become visible. However, upon completion of construction; the presence of interior walls; finishes; furniture; and plants frequently results in the strain pattern being less visible or not visible at all.

The stresses introduced in the heat-treating of glass are an inherent part of the fabrication process, and while they may be affected or altered depending on the heating process, controls and/or quench design, they cannot be eliminated. Design professionals should be aware that quench patterns are not a defect in heat-treated glass and, therefore, are not a basis for product rejection.

4.3.2 Spontaneous Breakage due to Nickel Sulphide Inclusions

In various situations fully tempered glass may break for no reason. Many factors might cause such spontaneous breakages, but the most common are nickel sulphide inclusions. Nickel sulphide inclusion, also known as NiS, occurs during the manufacturing process for float glass. In the glass batch, nickel-rich contaminants such as stainless steel might be present, and then combine with sulphur to form nickel sulphide inclusions.

Nickel sulphide is an interesting compound that exists in different phases at different temperatures. Two specific phases of NiS exist, known as the alpha-phase and the beta-phase. At temperatures below 380°C (715 F), nickel sulphide is stable in the beta-phase. Above this temperature, it is stable in the alpha-phase. Therefore, when glass is produced in the furnace, it is overwhelmingly likely that any NiS inclusions will be in the alpha-phase. In typical annealed glass, the slow cooling process provided by the annealing lehr allows the NiS ample time to transform to its beta-phase as the glass cools. However, in the fast cooling process used in both heat-strengthened and tempered glass, there is insufficient time to complete the phase transition (which is a relatively slow process). The inclusions therefore are “trapped” in the glass in their high-temperature alpha-phase.

However, once the glass cools past the phase change temperature, the NiS inclusion seeks to reenter its lower energy beta-phase. For “trapped” inclusions, this process takes anywhere from months to years. When NiS changes from alpha-phase to beta-phase, it increases in volume by 2 to 4%. This expansion creates localized tensile stresses that are estimated to be as much as 860 MPa (125,000 psi) at the glass-NiS Interaction surface. The magnitude of this stress drops off sharply away from the face of the inclusion, but is sufficient at the face to cause microcracking.

In the core tension zone of the glass, these microcracks are propagated by stress concentrations at the tip of the crack until the structure of the glass is undermined completely and the tempered glass undergoes its characteristic shattering, which causes the seemingly spontaneous failure. It is important to understand that since there is no data available worldwide on the amount of NiS inclusions that could occur, breakage due to NiS induced spontaneous breakage is a property, and not a defect in tempered glasses. The breakage patten, if suggestive of tempered glass breakage as described in the fragmentation test, proves that the glass has been correctly heat-treated and does not form a basis for replacement.

To reduce the probability of breakage due to Nickel Sulphide inclusions, heat-soak test as described in Chapter 5 is strongly recommended.

5. Heat-Soaked Glass

5.1 Definition

Heat-soaked glass is one within which a permanent surface compressive stress has been induced in order to give it greatly increased resistance to mechanical and thermal stress and prescribed fragmentation characteristics and which has a known level of residual risk of spontaneous breakage due to the presence of critical nickel sulphide (NiS) inclusions. The risk of spontaneous breakage of heat soaked thermally toughened soda lime silicate safety glass, on a statistical basis, due to the presence of critical nickel sulphide inclusions, is no more than one breakage per 400 tonnes of heat soaked thermally toughened soda lime silicate safety glass.

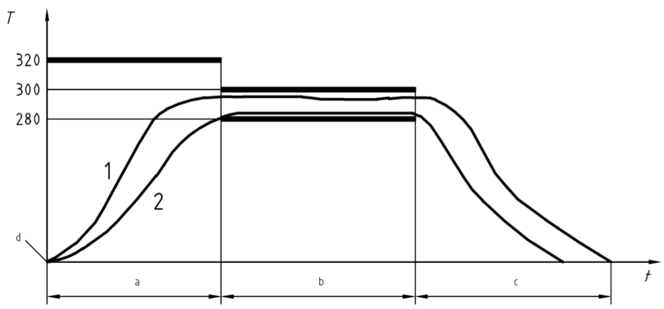
5.2 Manufacturing Process

Heat soaked thermally toughened soda time silicate safety glass is manufactured as follows:
Basic soda lime silicate glass products are cut to size, shaped and edge-worked. The prepared glass panes are then thermally toughened (see Section 4). The thermally toughened panes are then subjected to the heat soak process cycle. After manufacture the heat soaked thermally toughened soda lime silicate glass shall comply with the Fragmentation Test (see Clause 4.2.7) and Stress Measurement Test (see Clause 4.2.8) requirements.

5.3 Heat-Soak Cycle

The heat-soak cycle consists of a heating phase, a holding phase and a cooling phase (see Figure 5.1).

Figure 5.1: Heat-Soak Process Cycle



Key

T : glass temperature at any point, °C
t : time, h
1 : first glass to reach 280°C
2 : last glass to reach 280°C
d : ambient temperature a heating phase
a : heating phase
b : holding phase
c : cooling phase

5.3.1 Heating Phase

The heating phase commences with all the glasses at ambient temperature and concludes when the surface temperature of the last glass reaches 280°C. The time to reach this temperature is defined in the calibration process. This time will be dependent on the size of the oven, the amount of glass to be treated, the separation between glasses and the heating system capacity.

The glass separation and rate of heating should be controlled to minimise the risk of glass breakage as a result of thermal stress. To facilitate economic heating, the air temperature within the oven may exceed 320°C. However, the glass surface temperature shall not be allowed to exceed 320°C. The period of glass surface temperature in excess of 300°C shall be minimised.

When the temperature of the glass exceeds 300°C, care should be taken to ensure that the properties of the heat soaked thermally toughened soda lime silicate safety glass are not significantly altered.

5.3.2 Holding Phase

The holding phase commences when the surface temperature of all the glasses has reached a temperature of 280°C. The duration of the holding phase is 2 hours.

Precise oven control is necessary in order to ensure that the glass surface temperature shall be maintained in the range of 290°C ± 10°C during the holding phase.

5.3.3 Cooling Phase

The cooling phase commences when the last glass to reach 280°C has completed its holding phase, i.e. been held for two hours at 290°C ± 10 °C. During this phase the glass temperature shall be brought down to ambient temperature.

The cooling phase can be concluded when the air temperature in the oven reaches 70 °C. The rate of cooling should be controlled to minimise the risk of glass breakage as a result of thermal stress.

5.4 Heat-Soak Process System

5.4.1 General

The heat soak process system consists of:
- oven;
- glass support;
- separation system.

The oven shall be calibrated, see 5.5 and Annex A, and this determines the method of operation of the heat soak process system during manufacture of heat soaked thermally toughened soda lime silicate safety glass.

5.4.1.1. Oven

The oven shall be heated by convection and shall allow an unhindered air circulation around each glass pane. In the event of glass breakage the airflow shall not be hindered.[19]

5.4.1.2 Glass Support

Glasses may be supported vertically or horizontally. The glasses shall not be fixed or clamped, they have to be supported to allow free movement[20].

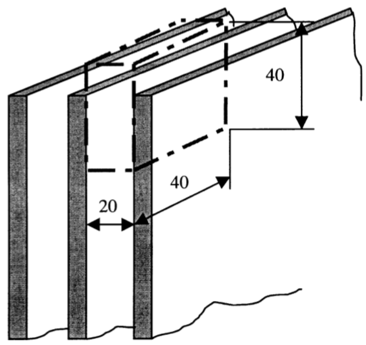
The distance between glasses affects the airflow, heat exchange and the heating time. Glass to glass contact shall not be allowed.

5.4.1.3 Glass Separation

The glasses shall be separated in a manner that does not hinder the airflow. The separators shall also not hinder the airflow.

The minimum separation of the glasses shall be determined during the calibration of the oven, see 5.5 and Annex A. Generally, a minimum separation of 20 mm is recommended (see Figure 5.2).

Figure 5.2: Example of Vertical Glass Support



If glasses of very different size are put on the same stillage, they will require greater separation in order to prevent glass breakage when the furnace is opened alter the heat soak process. The same applies to glasses with notches and cut-outs.

The positioning of the separators, material of the manufacture and their shape shall be specified during the calibration test of the oven and shall be reproduced during the manufacturing process.

5.4.2 Calibration

The heat soak system, e.g. oven, glass separation, separators, etc., shall be calibrated. The calibration shall determine the heating phase of the process, glass separation distance, the positioning, material and shape of separators, the type and positioning of stillage(s) and define the operating conditions for use during manufacture.

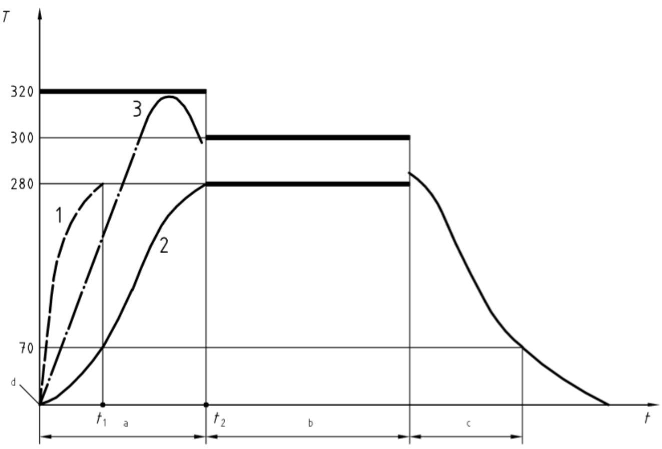
5.5 Quality Parameters

Heat-soaked glass shall conform to the quality characteristics and parameters as defined in Clauses 4.2 and 4.3.

5.5 Calibration Criteria

The heat soak process system shall comply with the time/ temperature regime as shown in Figure 5.3. The system shall be capable of meeting in the regime at both 100% and 10% load.

Figure 5.3: Time/Temperature Regime as Calibration Criteria



Key

T : glass temperature at any point, °C
t : time, h
t_1 : time for the first glass to reach 280°C
t_2 : time for the last glass to reach 280°C
1 : first glass to reach 280°C
2 : last glass to reach 280°C
3 : glass temperature
d : ambient temperature a heating phase
b : holding phase
c : cooling phase

5.5.1 Loading of Oven and Position for Glass Surface Temperature Measurement

Figures 5.4 to 5.10 show the appropriate pattern of stillage(s) loading and thermocouple placements for ovens, which take 1, 2, 6, 8 or 9 stillage(s). The duration of the heating phase is dependent on the capacity of the oven and the level of load being used.

Full load will be dependent on glass size, thickness and oven volume. Generally full load will be defined based on 6 mm or 8 mm thickness. The separation of the glasses shall be specified as shall also the type, position, material and shape of the separators. The separation of the glasses shall be constant on the stillage(s).

[19] The openings for the air ingress/egress should be designed to ensure that fragments of broken glass do not cause blockages

[20] Vertically means true vertical or up to 15° either side of true vertical

The minimum separation used during calibration is the minimum separation that can be employed during the manufacturing process. Generally, a minimum separation of 20 mm is recommended.

5.5.2 Procedure
The measurements of the air temperature in the oven and the glass surface temperatures shall be carried out when the furnace is fully loaded. They shall be repeated for a 10% loading.

The oven air temperature is monitored by a control element, which is located near the air egress. The measurement of the glass surface temperatures is carried out by thermocouples that are stuck, with good thermal contact, to the glass surfaces.

At the beginning of the calibration, the air temperature in the oven shall not exceed 35°C.

During the heating phase the oven shall be heated up until the last glass surface temperature reaches 280°C.

During the heating phase the glass temperature shall not exceed 320°C at any place.

During the heating phase the following parameters shall be recorded:

1. T_c: temperature of the control element (at any time);
2. t_1: time for the first thermocouple and a glass to reach a temperature of 280°C;
3. T_{c1}: temperature of control element at time t_1;
4. t_2: time for the last thermocouple and a glass to reach a temperature of 280°C;
5. T_{cmax}: maximum temperature of the control element during the heating phase;
6. t_{cmax} : time at which T_{cmax} occurs;
7. T_{glass}: temperature of the glass surfaces, measured by the thermocouples (at any time)

The holding phase starts at time t_2 and shall last for a period of 2 hours. The glass surface temperatures T_{glass} shall remain within the range 290°C ± 10 °C. The control element temperature T_c shall be recorded.

The cooling phase starts at time t_2 + 2 h. The control element temperature T_c shall be recorded. The oven can be opened when T_c reaches 70°C.

5.5.3 Records
The following test parameters shall be recorded:

– t_1, T_{c1}
– t_{cmax}, T_{cmax}
– t_2
– T_c, T_{glass}
– glass separation distance
– separator position, material, shape
– stillage(s) configuration

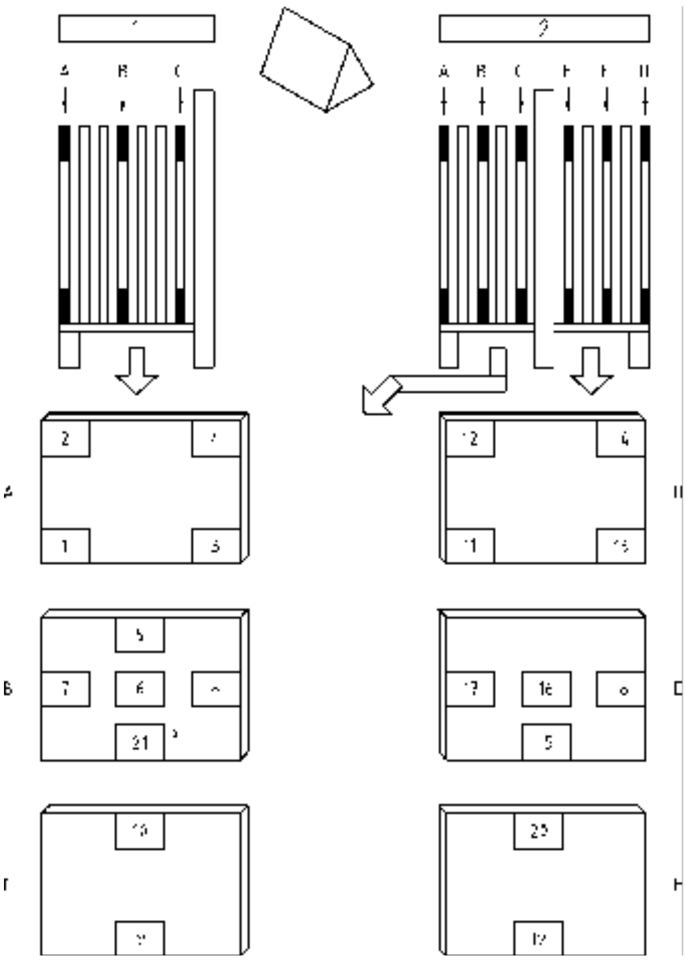
5.5.4 Interpretation of the Calibration Test

If the conditions for temperatures laid down in A.1 are not met then the oven shall not be regarded as calibrated.

Only ovens, which meet the calibration criteria at full and 10% load may be used for the heat soak process cycle during manufacture. The longer of the two times $t_{2,1}$ (full load) or $t_{2,2}$ (10% load) shall be used for regular production.

The heat soak process system used for manufacture shall comply with the details of the system as calibrated.

Figure 5.4: 1st Category – 1 Stillage – Full Load

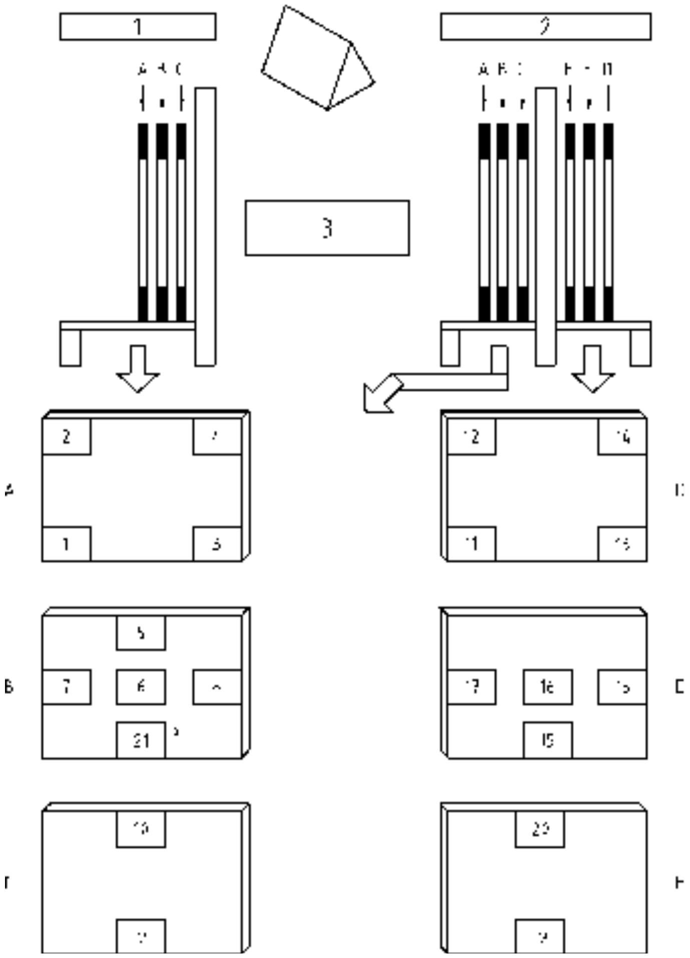


NOTE: Thermocouples should not be fixed nearer to the edge than 25 mm.

Key

a : is only used for mono side stillages
1 : mono side stillage
2 : double sided stillage

Figure 5.5: 1st Category – 1 Stillage – 10% Load

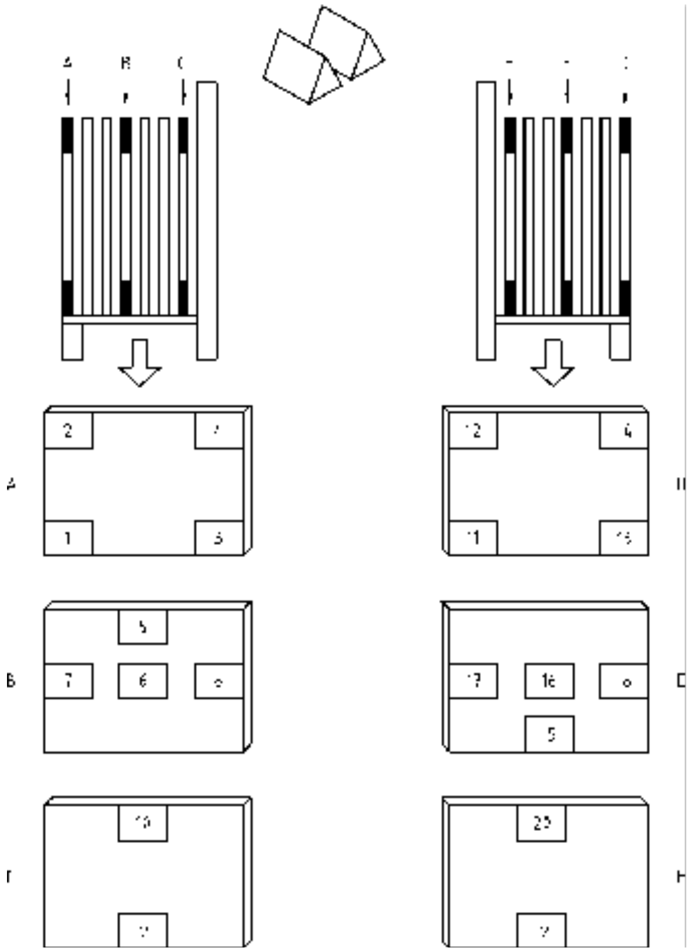


NOTE: Thermocouples should not be fixed nearer to the edge than 25 mm.

Key

a : is only used for mono side stillages
1 : mono side stillage
2 : double sided stillage
3 : on the stillage: minimum 3 glasses in parallel side by side

Figure 5.6: 2nd category – 2 Mono Side Stillages – Full Load

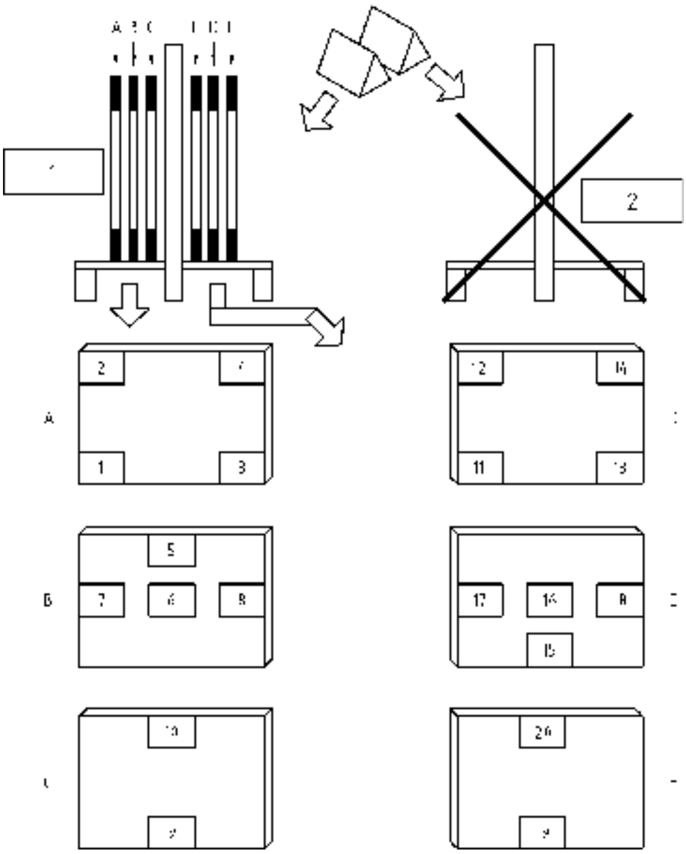


NOTE: Thermocouples should not be fixed nearer to the edge than 25 mm.

Key

a : is only used for mono side stillages
1 : mono side stillage
2 : double sided stillage
3 : on the stillage: minimum 3 glasses in parallel side by side

Figure 5.7: 2nd category – 2 Mono Side Stillages – 10% Load

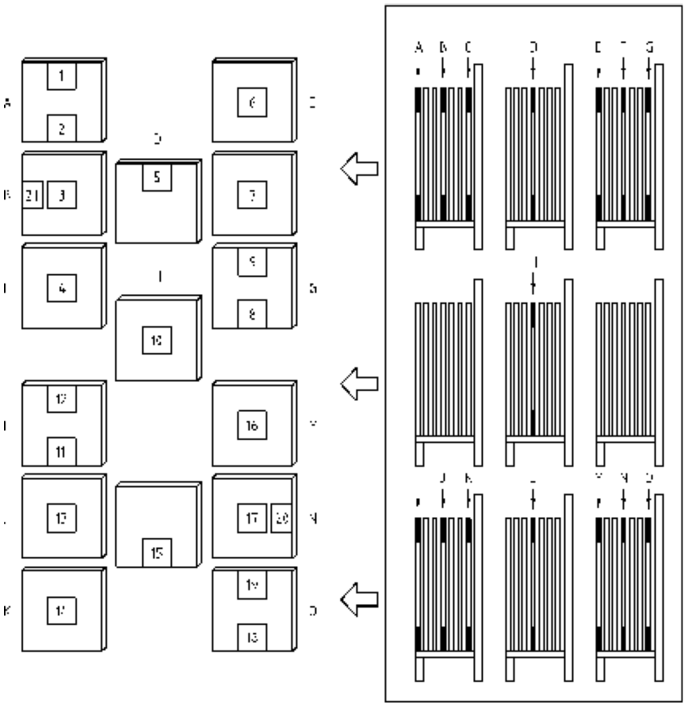


NOTE: Thermocouples should not be fixed nearer to the edge than 25 mm.

Key

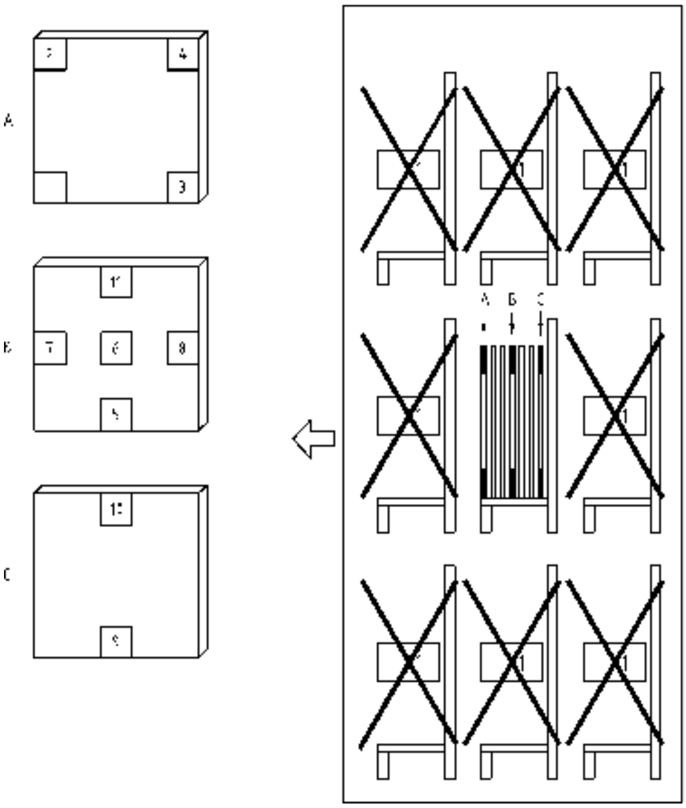
1 : 1st stillage: minimum 3 glasses in parallel side by side
2 : don't use the 2nd stillage

Figure 5.8: 3rd category – 6 or 8 or 9...Stillages – Full Load



NOTE: Thermocouples should not be fixed nearer to the edge than 25 mm.

Figure 5.9: 3rd category – 6 or 8 or 9...Stillages – 10% Load



NOTE: Thermocouples should not be fixed nearer to the edge than 25 mm.

Key

1 : don’t use

6. Heat-Strengthened Glass

6.1 Manufacturing Process

Heat-strengthened glass is produced when float glass panels are heated and then cooled gradually in a controlled environment. This process makes the glass stronger than annealed glass. Since the cooling is more gradual, the stresses formed in heat-strengthened glass is less than that of fully tempered glass. Heat-strengthened glasses are approximately twice as strong as annealed glasses. They break into relatively large fragments that stick to its glazing framework when broken. Heat-strengthened glasses are not classified as a safety glazing material.

6.2 Quality Parameters

6.2.1 Thickness

The thickness tolerance of toughened glasses shall be in accordance with the tolerances mentioned for annealed float glasses. Please refer Table 2.1 for details.

6.2.2 Dimensions and Squareness

Tolerance limits for dimensions for rectangular glass panes are given in Figure 1 and tolerances on width and length should be in accordance with Table 6.1.

Figure 6.1: Tolerance Limits for Dimensions of Rectangular Panes

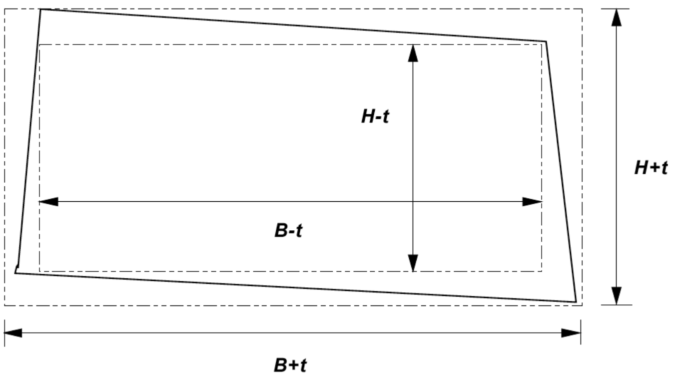


Table 6.1: Tolerances on Width B and Length H
(All dimensions are in millimeters and as per EN12150-1 June 2000)

Nominal Dimension of Side, B or H	Tolerance, t	
	Nominal Glass Thickness d ≤ 8	Nominal Glass Thickness d > 8 and d ≤ 10
≤ 2000	2.5	3
2000 < B or H ≤ 3000	3	4
> 3000	4	5

6.2.3 Holes and Cutouts[21]

6.2.3.1 Hole Dimensions

The allowable hole diameter tolerance should be in accordance with Table 5.2.

Table 6.2: Tolerances on Holes
(All dimensions are in millimeters)

	Hole Diameter Range	Dimensional Tolerance
All Thicknesses	4 to 20	± 1
	21 to 100	± 2
	Above 100	Consult the Manufacturer

6.2.3.2 Hole and Cutout Location

The allowed hole and cutout location tolerance should be in accordance with Table 6.3.

Table 6.3: Tolerances on Hole and Cutout Location
(All dimensions are in millimeters)

All Thicknesses	For holes tolerance should be from centre of hole	± 1.5mm
	For cutouts tolerance should be from edge	± 1.5mm

6.2.4 Glass Edge Finish

Edge damage usually occurs when cutting the glass (difficulty increases with thickness) and during grinding of glass. There is no standard acceptance criteria for the edge condition of the glass. Glass with edges that are severely cut, damaged or have deep, pointed shells/vents is generally not acceptable. The glass edge finish should be in accordance with Table 6.4.

Table 6.4: Glass Edge Finish

SNo.	Usage Type	Finish	Allowable Defects
1	Exposed edges	Neatly polished, straight line	Small glass fragment normally conchoidal ≤2mm
2	Silicone or butt joint	Visible line should be straight	Small glass fragment normally conchoidal ≤2mm
3	Concealed edge	Rough grinding without chips and defects	Small glass fragment normally conchoidal ≤3mm

6.2.5 Flatness

6.2.5.1 General Information

By the very nature of the toughening process, it is not

[21] Please note that since it does not have a high compressive strength, it is not recommended to drill holes and cutouts in heat-strengthened glasses.

possible to obtain a product as flat as annealed glass. The difference depends on the nominal thickness, the glass size dimensions and the ratio between the dimensions. Therefore a distortion known as overall bow can occur. There are two kinds of bow (see Figure 4.3):
- overall or general bow
- local bow

NOTE 1: Overall bow can, in general, be accommodated by the framing system.

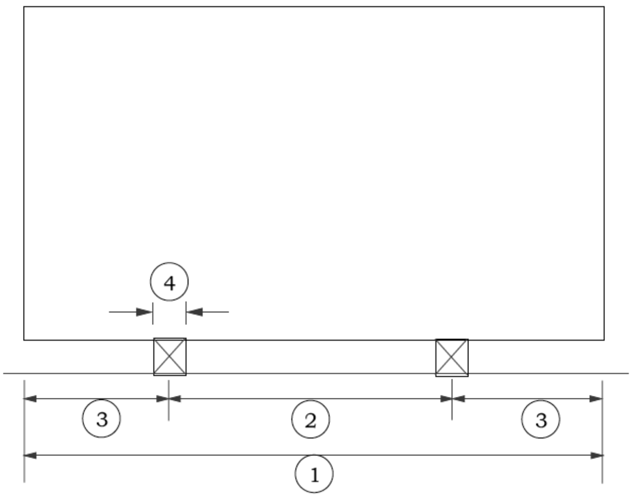
NOTE 2: Local bow needs to be allowed for in the glazing materials and the weather seals. For special requirements the manufacturers should be consulted.

6.2.5.2 Measurement of Overall Bow

The pane of glass shall be placed in a vertical position and supported on its longer side by two load bearing blocks at the quarter points (see Figure 6.2). The deformation shall be measured along the edges of the glass and along the diagonals, as the maximum distance between a straight metal ruler, or a stretched wire, and the concave surface of the glass (see Figure 6.3). The measurement should be done at room temperature.

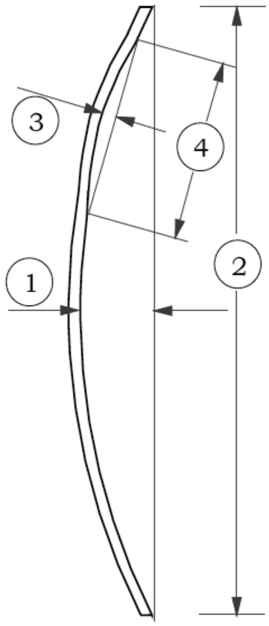
The value for the bow is then expressed as the deformation, in millimeters, divided by the measured length of the edge of the glass, or diagonal, in millimeters, as appropriate.

Figure 6.2: Support Conditions for Measurement of Overall Bow



(1) B or H
(2) (B or H)/2
(3) (B or H)/4
(4) maximum 100mm

Figure 6.3: Representation of Overall and Local Bow



(1) deformation for calculating overall bow
(2) B or H, or diagonal length
(3) local bow
(4) 300mm length

6.2.5.3 Warpage and Bow Tolerances

6.2.5.3.1 Overall bow Tolerances

The allowed warpage or overall bow tolerance should be in accordance with Table 6.5.

Table 6.5: Overall Bow (Bend) Tolerance Limit

Thick-ness	Up to 1.2 m	1.2 to 2.5 m	2.5 to 3.05 m	3.05 to 3.66 m	Above 3.66 m
4mm	4mm	4mm	6mm	NA	-
5mm	3mm	4mm	5mm	7mm	-
6mm	3mm	4mm	5mm	7mm	-
8mm	3mm	4mm	5mm	6mm	10 mm
10mm	3mm	4mm	4mm	5mm	10mm
12mm	3mm	4mm	4mm	5mm	8mm

6.2.5.3.2 Local Bow Tolerances

Local bow can occur over relatively short distances on the edges of the glass. Local bow shall be measured over a limited length of 300mm by using a straight ruler, or a stretched wire, parallel to the edge at a distance of 25 mm from the edge of the glass (see Figure 6.3).

Local bow is expressed as millimeters / 300 mm length[22].

The maximum allowable values for the local bow, when

[22] For patterned glass, local bow shall be determined by using a straight ruler resting on the high points of the pattern and measuring to a high point of the pattern.

measured according to 6.2.5.2, for glass without holes and/or notches and/or cutouts are given in Table 6.6[23].

Table 6.6: Maximum Values for Local Bow

Toughening Process	Local Bow mm/300 mm
Horizontal	0.5

For horizontal tempering, 200mm from either edges parallel to the roller waves shall be excluded from measurement. This method of measurement may not be applicable for non-rectangular glasses, e.g., triangles and trapezoids.

6.2.5.4 Important Considerations for Optical Distortion in Heat-Strengthened Glass[24]

1. Pressures, exerted around the periphery of glass by the glazing system, can also alter glass flatness thereby distorting reflected images. This is true regardless of whether or not the glass is heat treated.
2. Sealed insulating glass units also exhibit distortion regardless of glass type. Air or gas, trapped in the sealed airspace between the panes, expands or contracts with temperature and barometric changes, creating a pressure differential between the airspace and the atmosphere. The glass reacts to the pressure differential by being deflected inward or outward.
3. Regardless of glass flatness, the degree of reflected distortion perceived is primarily and largely due to the characteristics or symmetry of the object being reflected. Linear objects (such as building curtain walls and telephone poles) and moving objects (such as cars) may appear distorted. Irregular and free-form objects such as trees and clouds will appear to have little perceived distortion.
4. Specified bow and warp limits may not adequately define, or control, the distortion that may become apparent after glazing. The factors, noted above, may have a larger influence on the perceived reflected distortion than that which is caused by bow and warp from the heat-treating process. Consultation with suppliers and the viewing of full-size mockups, under typical job conditions and surroundings, is highly recommended for user or architectural evaluation of the reflective distortion.
5. Aspect ratio, the ratio of the longer side of the panel to its shorter side, also plays a role in controlling distortion. Larger aspect ratios are preferred, limited to a maximum of 15:1. Aspect ratios close to 1:1 pose greater challenges in controlling overall and local bow.

6.2.6 Appearance

For surface and body defects in clear or tinted toughened glasses refer to 2.2.6.

For accepted criteria of coated toughened glasses, refer to 3.3.4 and all conditions mentioned in Section 3: Coated Glass.

6.2.7 Stress Measurement Test

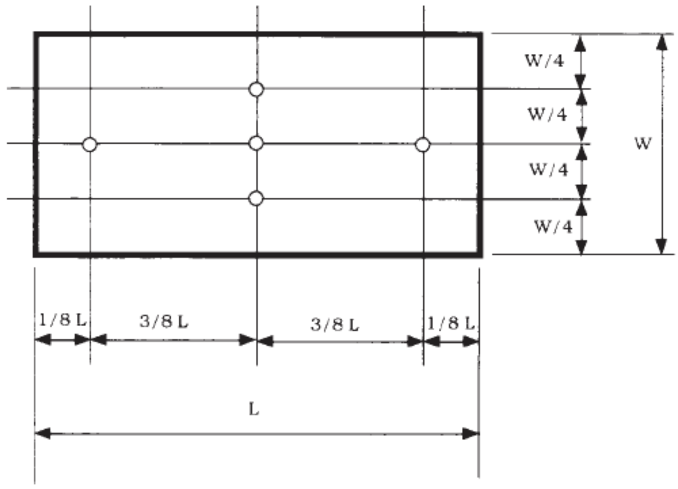
6.2.7.1 General

Stress measurement is a non-destructive test to check the toughening properties of fully toughened safety float glass. The specimens are examined by the polariscopic or light refraction methods[25] for surface or edge compression. When the range of the apparatus permits examination for edge compression only, obtain the averaged value for all midpoints of every edge.

6.2.7.2 Test Procedure

Two surface compression measurements shall be made in each of five locations, oriented in two directions at 90° to each other, for a total of ten readings on each specimen to be tested. Average the ten readings to determine the stress level of the test sample. The five locations to be examined are shown in Fig. 4.10.

Figure 6.4: Five Points to be Examined



6.2.7.3 Assessment of Measurements

Heat-strengthened glass with thicknesses of 6 mm and less[26] shall have a surface compression between 24 to 55 MPa (3,500 to 8,000 psi) or an edge compression of not less than 67 MPa (9,700 psi).

6.2.8 Marking

Logo position from a corner edge (preferably bottom right) should be preferably 25mm ± 5mm. All float heat-strengthened glass should have mark 'HS' along with brand name.

[23] Source: para 4.2.8 to 4.2.8.4 from EN 12150-1 pages 9 to 12.

[24] Source: para 7.4.3 to 7.4.6 from ASTM C 1048 - 04.

[25] The most common apparatus to conduct this test is the GASP instrument by Strainoptics Inc. Other methods like DSR may also be used.

[26] Heat strengthening of glass thicker than 6 mm (1⁄4 in.) within narrow limits of surface compression is difficult. Consult manufacturer.

6.3 Other Physical Characteristics

6.3.1 Anisotropy (Iridescence)

Heat-treated glass (heat-strengthened or tempered) can have an optical phenomenon that is called strain pattern or quench pattern. This phenomenon can appear as faint spots, blotches, or lines. This is the result of the air quenching (cooling) of the glass when it is heat-treated and should not be considered a glass defect.

The heat treatment process results in a higher surface compression directly opposite the air quench, air nozzles or slots. The higher compression areas are denser and can exhibit a darker appearance under some viewing conditions especially when light is polarized, such as a skylight or other forms of reflected light. The colors of the strain pattern are sometimes referred to as iridescent, or the general condition as iridescence. The pattern that is seen under certain lighting conditions may vary from manufacturer, depending on the design of the cooling apparatus. The intensity of the quench or strain pattern is influenced by the viewing angle, lighting conditions and by the perceptiveness of the viewer. It is nearly impossible to eliminate the strain pattern or quench pattern in heat treated glass products.

The presence of a strain pattern or the perceivable differences in the strain pattern is not a glass defect or blemish and is not cause for rejection. In addition, the presence of a strain pattern does not alter the structural integrity or safety of the glass lite.

When viewing from the interior of the building, the quench pattern may be visible from a 10° viewing angle and not apparent at a 90° viewing angle from the surface of the glass. When viewing the glass in reflectance from the exterior of the building, the quench pattern may be visible when looking at the glass surface at a 30-60° angle. Visibility of the quench pattern may be accentuated with thicker glass, tinted glass substrates, coated glass and multiple lites of heat-treated glass in laminated or insulating glass products.

Construction sites may yield viewing angles and conditions that cause the quench pattern to become visible. However, upon completion of construction; the presence of interior walls; finishes; furniture; and plants frequently results in the strain pattern being less visible or not visible at all.

The stresses introduced in the heat-treating of glass are an inherent part of the fabrication process, and while they may be affected or altered depending on the heating process, controls and/or quench design, they cannot be eliminated. Design professionals should be aware that quench patterns are not a defect in heat-treated glass and, therefore, are not a basis for product rejection.

7. Insulated Glass

7.1 Manufacturing Process

Insulated glasses are two or more panels of glass spaced apart and hermetically sealed to form a single unit with an air or gas space between each panel. Typically the spacer is made of aluminum that is either mill-finished or painted/anodized in different colours/finishes. Desiccants are filled inside the spacer framework to prevent condensation inside the air gap. Butyl is the most popular primary sealant that joins the spacer to both glass lites. The secondary sealant can be either silicone (used primarily for structural glazing), or polysulphide or polyurethane (used in window glasses).

7.2 Quality Parameters

7.2.1 Thickness

Dual-pane Insulated glass units shall conform to the nominal thickness values specified in Table 7.1. The nominal thickness of the insulated glass unit shall be the sum of the nominal thickness of constituent panes of glass and the cavity.

Table 7.1: Thickness Tolerance of IGU
All dimensions in millimeters

Nominal Thickness	IGU Thickness Tolerance
12 to 24mm	± 1.0
25 to 36mm	± 1.7
Greater then 36mm	± 2.0

The thickness tolerances of multi-cavity insulating glass units are obtained by using the following rules:

a) determine the tolerance of each composition glass/cavity/glass in accordance with Table 7.1;
b) calculate the squares of those values;
c) sum all those square values;
d) calculate the square root of that sum.

7.2.2 Dimensions

Tolerance limits for dimensions for rectangular glass panes are given in Figure 6.1 and tolerances on width and length should be in accordance with Table 6.2.

Figure 6.1: Tolerance Limits for Dimensions of Rectangular Insulated Glass Panes

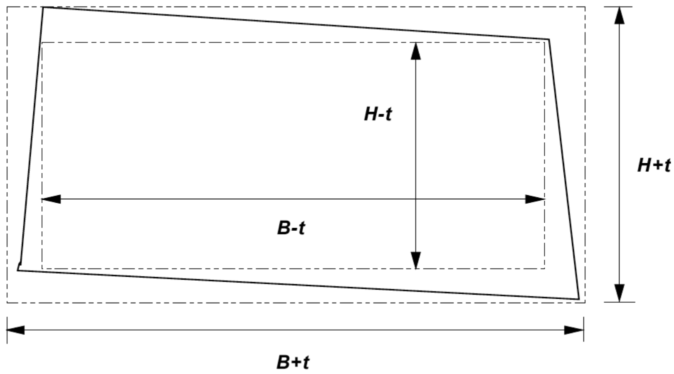


Table 7.2: Tolerances on Width B and Length H
(All dimensions are in millimeters and as per EN12150-1 2008)

Nominal Dimension of Side, B or H	Tolerance, t	
	Nominal Glass Thickness d ≤ 8	Nominal Glass Thickness d > 8
≤ 2000	±2.5	±3
2000 < B or H ≤ 3000	±3	±4
> 3000	±4	±5

7.2.3 Displacement / Mismatch

Displacement/mismatch tolerance between the two glass panes shall be in accordance with Table 7.3.

Table 7.3: Displacement and Mismatch Tolerance Limit

All Thickness	All Available Range of Dimensions	± 2.0

7.2.4 Glass Edge Finish

Since most insulated glass units are used in applications where edges are either concealed or sealed with secondary sealant, it is generally not required to have glasses with polished or perfectly ground edges. In most cases arising of the edges is generally enough. However, it is recommended to have the edge finish specified as part of the quality contract with the customer.

7.2.5 Sealant Protrusion

The allowed primary sealant protrusion should be in accordance with Table 7.4[27].

Table 7.4: Allowed Sealant Protrusion

All Thickness	Uniform Application of Sealant	± 2.0

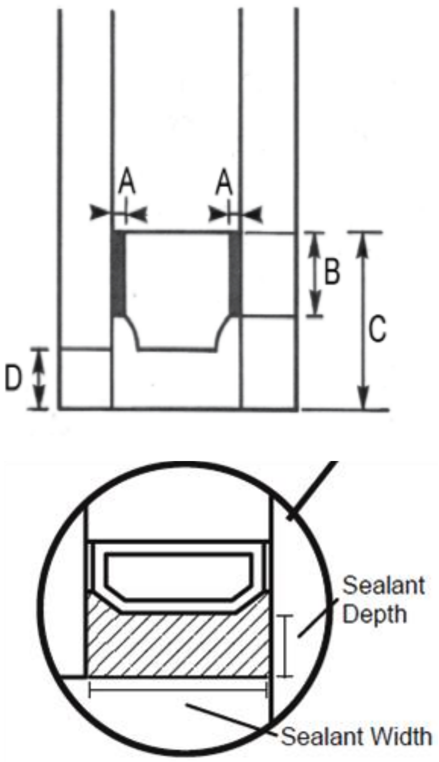
7.2.6 Bite Size

Bite size is the distance of the butyl bottom sight line to the edge of the insulated glass pane. The minimum bite size in all units should be 6mm.

[27] Although slight variations is butyl application straightness is allowed, it is absolutely critical that there are no breaks in sealant application and the line is continuous, to protect against failures of the insulated unit over its life cycle.

The minimum bite size considering the application, installation technique, glass thickness, panel size and wind and other subjected loads, etc. is the responsibility of the specifier. The manufacturer of the insulated glass unit is not responsible for unit failure due to incorrectly specified bite size. The minimum recommended seal dimensions are highlighted below.

Figure 7.2: Recommended Seal Dimensions for Insulated Glass Units



A : 0.25mm to 0.40mm
B : 4.78mm to 6.00mm
C : 11.13mm to 13.59mm
D : 6.00mm

7.2.7 Appearance

For surface and body defects in insulated glass units consisting of clear or tinted glasses refer to 2.2.6.

For accepted criteria of insulated glass units consisting of coated glasses, refer to 3.3.4 and all conditions mentioned in Section 3: Coated Glass.

The allowable joints in case of bendable spacers used in construction of insulated glass should be between 1 and 4.

7.3 Factory Tests for Insulated Glass Raw Materials

7.3.1 Delta-T Test for Desiccant

This test is used to check the adsorption capacity of desiccants used in insulated glass units.

1. Take room temperature water in a beaker and measure its initial temperature (Ti) and quantity.
2. Add equal quantity of desiccant in milligrams (mg). Now the temperature of water will start rising automatically.
3. Wait till the temperature of water reaches the maximum value.
4. Measure the final temperature (Tf).
5. Calculate $\Delta T = Tf - Ti$. ΔT should be more than 32°C.

7.3.2 Tests for Silicone (Two-Part)

It is very important that two part sealant be checked properly to ensure well curing. Improper mixing of silicone will result in adhesion failure and eventually lead to unit failure.

7.3.2.1 Butterfly Test

The purpose of butterfly test is to check for an adequate mixing of the base and catalyst components. The test is performed by dispensing a bead of sealant on to a piece of white paper and folding the paper in half, smearing down the sealing bead. Then the paper is reopened and inspected visually. This should appear uniform in colour with no white streaks.

7.3.2.2 Butterfly Adhesion Test

The purpose of this test is to evaluate the adhesion of sealant to glass and spacers. Improper mixing ratio and bad raw material quality of silicone can result in improper adhesion of silicone to glass and spacers and ultimately cause unit failure.

1. Prepare complete insulated glass samples of approx. 200 X 200 mm or equivalent.
2. Allow the silicone to cure completely.
3. Score then break the glass at the midpoint of the pane.
4. Bend the two halves outward at a 180º angle. Inspect the adhesion of the secondary seal.

There should be no greater than 5% adhesive failure on the glass surfaces. Note whether the sealant fill is complete and free of voids or bubbles. Observe the quality and continuity of the PIB application.

7.3.2.3 Peel Adhesion Test

The purpose of this test is to verify adhesion of sealant to the glass substrate. An adhesive or cohesive failure of silicone with glass substrate can result due to improper curing of silicone or bad raw material quality.

1. Clean and prime the substrate.
2. Place a piece of bond breaker tape across the flat surface.
3. Apply a bead of sealant and tool it to form a strip approximately 20 cm long, 1.5 cm wide and 6 mm thick. At least 4 cm of the sealant should be applied over the bond breaker tape.
4. After sealant cure, grasp the 4 cm tab of sealant which overlays the bond breaker tape. Pull the sealant at a 180° angle. Peel back only 1 to 2 cm of sealant leaving the remainder in place for additional testing.
5. If the sealant tears within itself and remains fully bonded to the substrate, this is called “cohesive failure”. 100% cohesive failure is desirable since this indicates that the

strength of adhesion is greater than the strength of cohesion.

7.3.2.4 Snap Time Test

The purpose of this test is to determine if the mix ratio is correct and whether the sealant is curing properly. Mixed sealant will handle like a one-component sealant until the chemical reaction between the base material and curing agent begins to occur. The sealant will in a matter of minutes begin to "snap" and begin to show elastomeric or rubber properties.

1. Fill a small container with mixed sealant.
2. Place a small stick or spatula into the sealant. Record the time.
3. Every few minutes, pull the stick out of the sealant. Do not stir or agitate the sealant. As the sealant becomes more cured, the sealant will become stringy. Once the sealant tears cohesively and snaps back once it is pulled, this is the "snap time". Record this time.

The measured snap time should be between 30 and 60 minutes.

7.3.3 Butyl Quantity Test

This test is used to calculate the minimum quantity of butyl applied on a spacer. Butyl needs to be applied on spacers in a certain minimum quantity to effectively provide a primary glass to spacer seal.

1. Take a spacer system from running production and extrude butyl under standard production conditions.
2. Remove the butyl from the spacer.
3. Measure the weight of butyl.
4. Measure the length of the spacer system.
5. Calculate the ratio (length:weight) and calculate the weight of butyl per running meter.
6. The butyl quantity should be more than or equal to 2.7 grams per side per running meter

7.3.4 Test for Aluminium Spacers

This test applies to hollow spacers with profile showing a closing slit on the back. In order to have a stiff and tight spacer, the closing slit is welded. This test checks the tightness of the welded slit.

1. Take approximately one meter of spacer bar.
2. Place the test piece in a horizontal, slightly sloping position, with the welded slit downwards.
3. Spray a penetrating liquid (according to MIL-I-25135) inside the spacer until the liquid comes out at the opposite end.
4. Wait for 5 minutes.
5. Check with a black light for liquid leakage along the welded slit.

7.3.5 Tests for Finished Insulated Glass Units

7.3.5.1 Leakage Test

The insulated glass specimen of size 305mm X 305mm is placed in a water tank for five minutes. There should be no bubbles appearing in the water tank and no seepage of water inside the insulated glass unit.

7.3.4.2 Dew Point Test

The dew point temperature test is used to check the humidity content in the insulated glass unit air space. A sample is cooled down until condensation (dew) forms on the interior surface. This dew point should be minimum -40°C.

7.3.4.3 Shore A Hardness Test

The insulated glass sample is cured for a total of 24 hours at 23°C and 25% humidity and a Shore A hardness meter is used to check the hardness of the cured silicone sealant. For structural silicone the Shore A hardness reading should be between 40 and 50.

7.4 Important Considerations for Optical Distortion in Insulated Glass

7.4.1 Interference Colouration

7.4.1.1 Brewster's Fringes

When the glass pane surfaces exhibit near perfect parallelism and the surface quality is high, the insulated glass pane shows interference coloration. These are lines varying in colour as a result of decomposition of the light spectrum. When the sun is the light source, the colours vary from red to blue. This phenomenon is not considered a defect but it is inherent to the insulated glass unit construction.

7.4.1.2 Newton Rings

This optical effect only occurs in faulty insulated glass units and occurs when the two panes of glass are touching or nearly touching in the centre. The optical effect is a series of concentric coloured rings with the centre being in the point of contact/near contact of the two panes. The rings are roughly circular or elliptical.

7.4.2 Iridescence due to Heat-Treated Glasses

Some processed glasses also show coloration inherent to the product, e.g. toughened glass and heat strengthened glass. Refer to sections 4.2.9.1 and 5.2.9.1 for details. Effect more….

7.4.3 Glass Deflection due to Variations in Temperature and Barometric Pressure

Temperature variations of the space filled with air and/or gas and barometric pressure variations of the atmosphere and altitude will contract or expand the air and/or gas in the cavity and consequently deflections of the glass pane will occur, resulting in distortion of reflected images. These deflections, which cannot be prevented, show variations over time. The magnitude depends partially on the stiffness and size of the glass panes, as well as on the width of the cavity. Small sizes, thick glasses, and/or small cavities reduce these deflections significantly.

If the difference in altitude between the manufacturing facility and the installation site is more than 1000 meters, pressure equalisation through use of capillary tubes or breather tubes is highly recommended to avoid undesirable glass deflection.

7.4.4 External Condensation

External condensation on insulated glass units may occur either inside or outside the building. Whenever there is a substantial difference of temperature and humidity between inside and outside environments, condensation will occur on the surface with lower temperature. These phenomena do not constitute failures of the insulating glass, but are due to atmospheric conditions or by induced forced cooling from the interiors.

7.4.5 Moiré Effect

When using silkscreen patterns in architectural building applications, there may be, in rare cases, a potential to see a moiré pattern develop in the glass when viewed in certain light conditions and at specific solar angles.

Moiré is an optical phenomenon that may present itself as a "wavy, rippled or circular" pattern under certain conditions. Moiré patterns can be created whenever one semi-transparent object with a repetitive pattern is placed over another. The moiré pattern is not a defect in the glass or silkscreen pattern, but rather a pattern in the image formed by the eye.

The moiré image is a pattern formed when two regularly spaced patterns "overlap" and are not aligned. In architectural glass applications, this may occur when silkscreen patterns of lines or dots are closely spaced and a secondary pattern image is formed (as in the case of an insulating glass unit or shadowbox assembly.) The "secondary" pattern can be created by the shadow of the ceramic frit on a second surface, as in the case of a spandrel panel installed behind the silkscreened glass. Another possibility is the second pattern may be the result of light transmitted through the glass portion not covered with ceramic frit.

7.5 Other Considerations

7.5.1 Compatibility of Installation Sealants with Insulated Glass Sealant

It is important to identify and use installation sealants which are compatible with the two-part secondary sealant used in sealing insulated glass units. Use of general purpose sealants with high acetic curing properties can seriously dent the performance of the secondary sealant and cause flaking.

The secondary sealant and structural sealant suppliers must approve the proposed structural sealant choice for the structural sealant glazing applications. Under certain conditions, the corrosive vapours liberating from acetoxy cure silicone sealants can cause degradation of two-part silicone secondary sealants, potentially leading to premature failure of the insulating glass unit. Also acetoxy silicone sealants should not be used as secondary IG sealants.

7.5.1.1 Sealant Compatibility

Check with the secondary sealant and structural sealant suppliers to confirm and approve the compatibility of the sealants and any accessory materials they may contact, such as setting-blocks, gaskets, spacers, and weather-seals. Most silicone sealant suppliers will perform the 22-day ASTM C 1087 compatibility test upon request. The sealant is applied in direct contact with the accessory material in question. The test specimen is placed in a chamber with high-intensity ultraviolet radiation. After the test period, samples are inspected for compatibility in the form of sealant discolouration and adhesion. Please note that non-silicone setting and edge blocks have the ability to cause discolouration of IG secondary seals and field-applied silicone weather-seals.

7.5.1.2 Exposure to Solvents

Silicone insulating glass sealants are susceptible to swelling when in contact with solvents such as isopropanol, volatile siloxane fluids, methylethylketone, and terpenes. These solvents will not decompose the silicone, but will permeate the silicone and attack the PIB primary seal. Solvent-based water repellents that are post-applied to a masonry building and allowed to enter the glazing weep system have been documented to cause PIB flow within a sealed IG unit. Setting blocks and edge blocks that are saturated with solvent have been documented to cause PIB flow within a unit. Solvent-extended sealants and solvent-based sealants contacting the secondary seals of an IG unit can have similar effects. PIB flow within a unit is very unsightly and may result in premature fogging.

8. Laminated Glass

8.1 Manufacturing Process

Laminated glasses are constructed using two or more glass lites and joining them by using an interlayer in between under temperature and high pressure. Polyvinyl butyral (PVB) is the most common form of interlayer used[28]. Interlayers can be either clear or coloured and is available in transparent, translucent or opaque form depending on requirement.

8.2 Quality Parameters

8.2.1 Nominal Thickness

The nominal thickness of laminated glass shall be the sum of the nominal thickness of constituent panes of glass and interlayer material.

The thickness of the pane shall be calculated as the mean of measurements taken at the centers of the four sides. The measurements shall be taken to an accuracy of 0.01mm and the mean is then rounded to the nearest 0.1mm. The individual measurements when rounded to the nearest 0.1mm shall also be within the limit deviation.

8.2.2 Dimensions

Tolerance limits for dimensions for rectangular glass panes are given in Figure 8.1 and tolerances on width and length should be in accordance with Table 8.1.

Figure 8.1: Tolerance Limits for Dimensions of Rectangular Panes

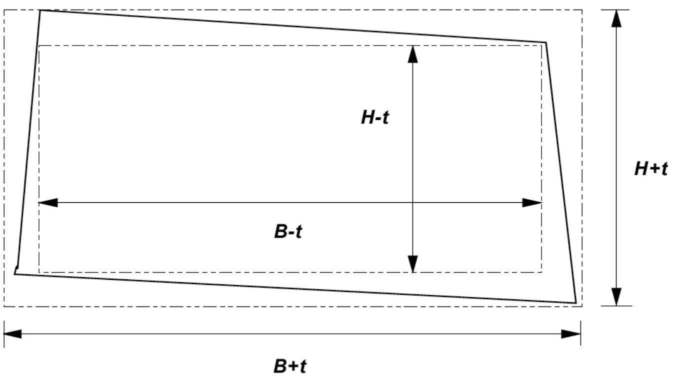


Table 8.1: Tolerances on Width B and Length H

Limit Deviations t on Width B or Length H			
Nominal Dimension of Side, B or H	Nominal Glass Thickness d ≤ 8 mm	Nominal Glass Thickness d > 8 mm	
		Each Glass Pane < 10 mm Thickness	At Least One Glass Pane ≥ 10 mm Thicknes
< 1100	±2 / -2	±2 / -2	±3 / -2.5
< 2440	±3 / -2	±3 / -2	±4 / -3
> 2440	±4 / -3	±4 / -3	±4.5 / -4

8.2.3 Displacement

Displacement is the misalignment at any one edge of the constituent glass panes making up the laminated glass. The maximum allowable displacement is as given in Table 8.2.

Table 8.2: Maximum Displacement in Laminated Glass

Nominal Dimension of Side, B or H	Maximum Permissible Displacement
B, H ≤ 1000	2
1000 < B, H ≤ 2000	3
2000 < B, H ≤ 4000	4
B, H > 4000	5

8.2.4 Glass Edge Finish

Once the glass is toughened or heat-strengthened, it shall not be edge-worked after making into a laminate. These panels need to be individually worked upon before toughening and then assembled into a laminate.

For details of acceptable edge finishes refer to the relevant toughened and heat-strengthened standards (4.2.4 and 5.2.4 respectively).

8.2.5 Appearance

8.2.5.1 Common Definitions

8.2.5.1.1 Spot Defects

This type of defect includes opaque spots, bubbles and foreign bodies.

8.2.5.1.2 Linear Defects

This type of defect includes foreign bodies and scratches or grazes.

8.2.5.1.3 Other Defects

Glass defects such as vents and interlayer defects such as creases, shrinkage and streaks.

[28] Newer forms of interlayers such as ionomers are also getting increasingly popular.

8.2.5.1.4 Opaque Spots
Visible defects in the laminated glass (for e.g., tin marks, inclusions in the glass or interlayer).

8.2.4.1.5 Bubbles
Usually air bubbles, these can be in the glass or in the interlayer.

8.2.5.1.6 Foreign Bodies
Any unwanted item introduced into the laminated glass during manufacture.

8.2.5.1.7 Scratches or Grazes
Linear damage to the outside surface of the laminated glass.

8.2.5.1.8 Vents
Sharp tipped fissures or cracks running into the glass from an edge.

8.2.5.1.9 Creases
Distortions introduced into the interlayer by folds visible after manufacture.

8.2.5.1.10 Streaks due to Interlayer Inhomogeneity
Optical defects in the interlayer that are caused by manufacturing defects in the interlayer, and are visible after manufacture.

8.2.5.1.11 Edge Area
For panes sizes ≤ 5m^2 the width of the edge area is 15 mm. The edge area width is increased to 20 mm for pane sizes > 5m^2.

For glass with holes, 3mm from edge of hole is considered as edge area.

8.2.5.1.12 Vision Area
The area outside of the edge area is called as vision area.

8.2.5.2 Test Method for Inspection
The laminated glass to be observed is put in a vertical position, in front of and parallel to a matt grey screen, lit by diffused daylight or equivalent. The observer will be at a distance of 2 meters from the glass and shall observe it perpendicularly (the matt screen being on the other side of the glass). Defects that are disturbing when viewed shall be marked.

8.2.5.3 Defects in the Vision Area
8.2.5.3.1 Spot Defects in the Vision Area
When inspected according to the test method stated in 8.2.4.2, the admissibility of spot defects depends on the following:
- Size of the defect
- Frequency of the defect
- Size of the pane
- Number of panes as components of a laminated glass.

This is expressed in Table 8.3.

Table 8.3: Permissible Spot Defects in the Vision Area

Size of Defect *d* in mm		**$0.5 < d \le 1.0$**	**$1.0 < d \le 3.0$**			
Size of Pane *A* in m^2		For all Sizes	$A \le 1$	$1 < A \le 2$	$2 < A \le 8$	$A > 8$
Number of Allowed Defects	2 Panes	No limitation, however no accumulation of defects	1	2	1 / m^2	1.2 / m^2
	3 Panes		2	3	1.5 / m^2	1.8 / m^2
	4 Panes		3	4	2 / m^2	2.4 / m^2
	≥ 5 Panes		4	5	2.5 / m^2	3 / m^2

Defects less than 0.5 mm are not considered and defects greater than 3 mm are not permitted[29].

An accumulation of defects occurs if four or more defects are at a distance of < 200 mm from each other. This distance is reduced to:
- 180 mm for laminated glass consisting of three panes,
- 150 mm laminated glass consisting of 4 panes, and
- 100 mm laminated glass consisting of five or more panes.

The number of permissible defects in Table 8.1 shall be increased by 1 for each individual interlayer which is thicker than 2 mm.

8.2.5.3.2 Linear Defects in the Vision Area
When inspected according to the test method given in 8.2.4.2, the linear defects are allowed as given in Table 8.2.

Table 8.2: Number of Permissible Defects in the Vision Area

Area of Pane	**Number of Permissible Defects ≥ 30 mm in Length**
≤ 5 m^2	Not Allowed
5 to 8 m^2	1
> 8 m^2	2

Linear defects less than 30 mm in length are allowed.

8.2.5.4 Defects in the Edge Area for Framed Glasses
When inspected according to the test method stated in 8.2.4.2, defects which do not exceed 5 mm in diameter are permitted in the edge area. If bubbles are present, the bubbled area shall not exceed 5% of the edge area.

8.2.5.5 Vents
Vents are not permitted.

8.2.5.6 Creases and Streaks
These are not allowed in the visual area.

[29] Admissibility of spot defects in laminated glass is independent of the individual glass thickness.

8.2.5.7 Defects on Edge which will not be Framed

Laminated glass is usually installed in frames; when it is unframed, its edges may be
- ground edges,
- polished edges, or
- bevelled edges.

In such conditions shells, bubbles, interlayer defects and retractions are permissible if they do not become obvious when subjected to the test method in 8.2.4.2.

8.2.6 Tests for Finished Laminated Glass Units

8.2.6.1 Sampling Plan for Laminated Safety Glass

Test specimens should be representative of standard production. Test specimens should either be specially manufactured to the test size or be cut from larger panes. Test specimen with cut edges should contain at least one edge from the original pane from which it was cut. If the final product has all its edges sealed/protected then the test specimen should also have all its edges sealed/protected.

The method of supporting the test specimen shall not cover two edges of the test specimen. If the test specimen is cut from a larger pane at least one original edge shall not be covered.

Inspect the samples prior to the test at a distance between 30 cm and 50 cm in front of a white diffuse background. Only samples free of faults (bubbles, delamination, cloudiness) shall be used for the test.

8.2.6.2 Boil Test

8.2.6.2.1 Principle

This test is used to determine whether the laminated safety glass will withstand exposure to high temperatures over an extended period of time without its properties being substantially altered.

8.2.6.2.2 Procedure

Three test specimens of minimum size 100 X 300 mm shall be used.

Immerse all the three test specimens vertically, supported on its edge[30], first in water at 65 ± 2°C for three minutes and then immediately in boiling water for two hours.

8.2.6.2.3 Interpretation of Results

The samples are removed from the boiling water bath and inspected between 30 and 50 cm in front of a white diffuse background.

Record the number and extent of the faults occurring in the interlayer (bubbles, delamination and cloudiness, but not discolouration) for each test specimen. Disregard all faults within 15 mm from an original edge and 25 mm from a cut edge[31].

Delamination taken as a criterion for evaluation after the boil test, may be described as essentially a two dimensional phenomena, in the interface between the glass and the interlayer, in which area no adhesion exists.

8.2.6.2.4 Acceptance Criteria

No faults (bubbles, delamination, cloudiness) shall be found in the three test specimens, as per the interpretation criteria mentioned in 8.2.5.3.1. If faults are found in only one test specimen, a further test may be carried out on three new test specimens, in which case no faults shall be found in any of these test specimens.

8.2.6.3 Humidity Test

8.2.6.3.1 Principle

This test is used to determine whether the laminated safety glass will withstand exposure to atmospheric humidity over an extended period of time without its properties being substantially altered.

8.2.6.3.2 Procedure

Three test specimens of size minimum 100 X 300 mm shall be used.

Keep all the three test specimens vertically, supported on its edge[32], over water in a closed container for two weeks. The air temperature within the container should be maintained within the limits of 50°C[33].

8.2.6.3.3 Interpretation of Results

The samples are removed from the boiling water bath and inspected between 30 and 50 cm in front of a white diffuse background.

Record the number and extent of the faults occurring in the interlayer (bubbles, delamination and cloudiness, but not discolouration) for each test specimen. Disregard all faults within 15 mm from an original edge, 25 mm from a cut edge or 10 mm from any crack[34].

Delamination taken as a criterion for evaluation after the humidity test, may be described as essentially a two dimensional phenomena, in the interface between the glass and the interlayer, in which area no adhesion exists.

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30 The specimen shall be kept in the vessel of boiling water in such a way as not to touch the bottom of the testing vessel directly. A suitable arrangement may be used.

31 If wire or mesh inlays are used, individual bubbles in the immediate vicinity of inlaid wires are permissible.

32 The specimen shall be kept in the vessel of boiling water in such a way as not to touch the bottom of the testing vessel directly. A suitable arrangement may be used.

33 These conditions give a relative humidity of about 100% and will lead to water condensation on the surface of the test specimen.

34 If wire or mesh inlays are used, individual bubbles in the immediate vicinity of inlaid wires are permissible.

8.2.6.3.4 Acceptance Criteria
No faults (bubbles, delamination, cloudiness) shall be found in the three test specimens, as per the interpretation criteria mentioned in 8.2.5.2.3. If faults are found in only one test specimen, a further test may be carried out on three new test specimens, in which case no faults shall be found in any of these test specimens.

8.2.6.4 Fracture and Adhesion Test
8.2.6.4.1 Principle
The purpose of this test is to test the integrity of the laminated glass sample when subjected to external forced impact. The laminated safety glass is given a sudden punch and fragments from the under-surface are collected and weighed.

8.2.6.4.2 Procedure
A hardened steel ball with a diameter of 38 mm and weighing about 227 ± 2g shall be used for the test. A square hard wood frame shall be constructed so that when the test specimen rests symmetrically on the frame, 290 X 290 mm of the specimen shall remain unsupported. The frame shall be rigidly mounted on a 12 mm steel plate and the screws or bolts used for attaching it to the steel plate shall not project below the under-surface of the plate. The complete frame shall stand upon a substantial concrete bed.
A means for dropping the ball freely from a height of 4.88 meters shall be provided such that it strikes the specimen within 25 mm from its centre[35].

Ten specimens of 300 X 300 mm shall be tested. Prior to the test each specimen shall be weighed. The specimens shall be kept at 20 ± 2°C for four hours immediately preceding the test. Each specimen in turn shall be supported on the wooden frame in such a way that the plane of the test specimen when in the frame shall be substantially horizontal. The ball shall be dropped as described above. The fragments from the under-surface of each specimen shall be separately collected and weighed.

8.2.6.4.3 Acceptance Criteria
The test specimens shall be deemed acceptable if out of the ten specimens tested:
1. the number of specimens shown to be pierced[36] in the test does not exceed four, of which not more than two are brittle[37], and
2. if the total weight of the fragments from the underside of the unpierced specimens does not exceed 0.5 percent of the total weight of these unpierced specimens, and
3. if no unpierced specimen yields any fragment which individually weighs more than 0.5 grams.

8.2.6.5 Radiation Test
8.2.6.5.1 Principle
The purpose of this test is to determine whether exposure of laminated glass or laminated safety glass to radiation over an extended period of time produces any appreciable change in its properties. The change in its properties is judged by a change in luminous transmittance and the occurrence of bubbles, delamination and cloudiness (not discolouration).

8.2.6.5.2 Procedure
A radiation source which emits a spectrum similar to solar radiation shall be used. Such a spectral distribution can be obtained by lamps which consist of a combination of a high pressure mercury vapour lamp with an incandescant tungsten filament.

To obtain reproducible and comparable test results suitable lamps shall show the following spectral characteristics:

UVB	(280nm to 315nm)	3%±1%
UVA	(315nm to 380nm)	8%±1%
visible range	(380nm to 780nm)	18%±1%
IRA	(780 nm to 1400 nm)	24%±2%
IRB	(1400nm to 2600nm)	27%±4%
IRC	(>2600nm)	20%±3%

8.2.6.5.3 Test Conditions
The exposure time for the radiation test shall be 2000 h. The temperature of the test specimen shall be maintained at 45°C ± 5°C. The lamps have to be replaced when their irradiance level in the UVA decreases by more than 50%. The total irradiance level in the plane of the test samples shall be 900 W/m^2 ± 100 W/m^2.

8.2.6.5.4 Arrangement of Test Apparatus
The test samples are mounted vertically in front of the radiation array. The radiation array consists of lamps uniformly separated to give the optimum radiation density in the plane of the test specimens. The minimum distance between the array of the test specimens and the bottom of the test room shall be 400 mm and the air space behind the array shall be at least 500 mm (to obtain undisturbed free natural convection upwards).

In order to obtain a sufficiently uniform irradiance level the area covered by the test specimens shall not exceed the area of the lamp array A given by the relation

$$A = n \times l_1^2$$

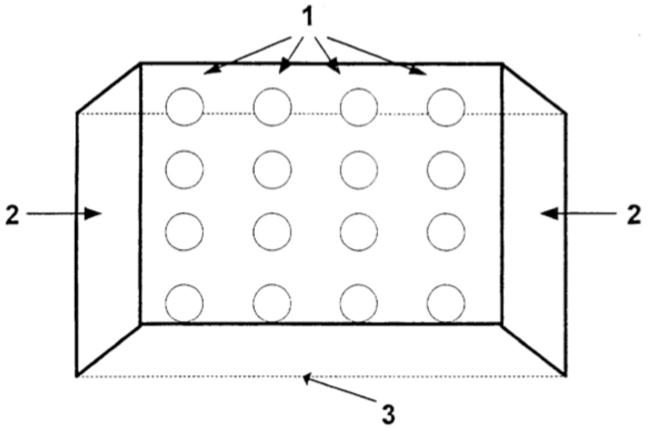
where
n = number of lamps
l_1 = distance between the axes of neighbouring lamps
Figure 8.2 shows a possible arrangement of lamps for the test

[35] An electro-magnet may conveniently be used for this purpose.

[36] The specimen will be deemed to have been pierced if a split or tear exceeding 38 mm in length develops in the interlayer.

[37] A pierced specimen shall be deemed to be brittle if the breaks into two or more large pieces, or if the fracture is sufficient to allow the ball to pass through.

Figure 8.2: Arrangement of Lamps for Radiation Test



1 lamps
2 aluminium foil
3 plane of test specimens

8.2.6.5.5 Size and Number of Test Specimens

The size of the test specimens shall be 300 mm x 300 mm. There shall be three test specimens.

8.2.6.5.6 Procedure

Determine the luminous transmittance of the three test specimens before exposure.

Orientate the test specimens so that, if there is a designated outer surface, it faces the lamp array. Asymmetric laminated glass, which does not have a designated outer surface, shall be tested both ways round.

After exposure, determine the luminous transmittance of each test specimen once again.

8.2.6.5.7 Expression of Results

If the initial light transmittance was > 20% compare the results of the luminous transmittance measurement of each exposed test specimen with the values obtained for the same test specimen before exposure. Express the deviation as a percentage. If the initial luminous transmittance was ≤ 20%, give the difference between initial and final light transmittance.

Inspect the samples at a distance between 30 cm and 50 cm in front of a white diffuse background. Record the number and extent of delamination occurring in the interlayer for each test specimen. Disregard all delamination within 15 mm from an original edge or 25 mm from a cut edge.

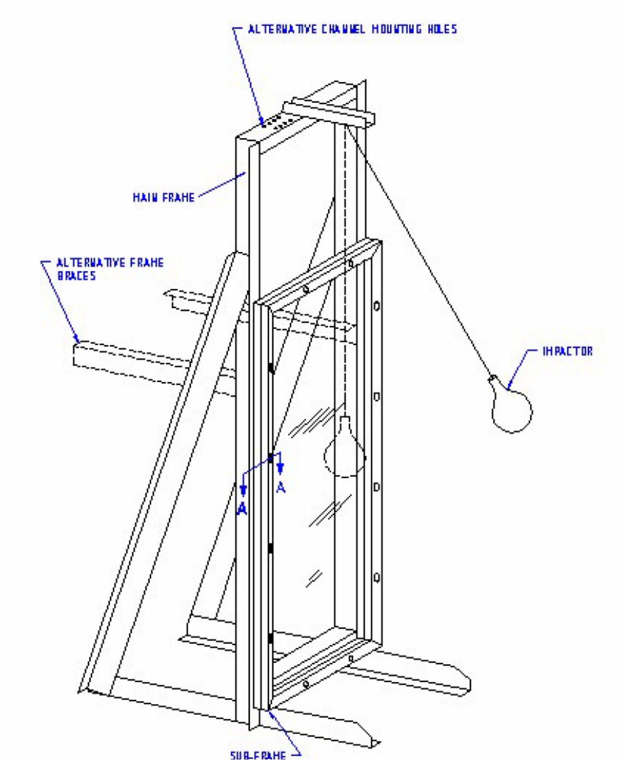
8.2.6.6 Shot Bag Test

8.2.6.6.1 Principle

The purpose of this test is to determine the impact resistance of laminated glass. A shot bag setup (as per ANZI Z97.1) is constructed. The following drop height classes are to be noted.

1. Class A - Drop height is between 1219 mm and 1232 mm.
2. Class B - Drop height is between 457 mm and 470 mm.

Figure 8.3: Arrangement of Impact Resistance Equipment



8.2.6.6.2 Procedure

1. Place and centre each specimen in the sub-frame so each edge is encased in the elastomeric rubber strip to a depth of at least 10 mm.
2. The impactor shall be suspended from an overhead support in such a way when it is free hanging there may be 13 mm space between the bag and the surface of the specimen. The space shall not exceed 51 mm.
3. The impactor shall be raised to the least drop height (Class B) and stabilized.
4. The impactor is then released and falls without any initial velocity or axial rotation.
5. The impactor shall impact the specimen only once and further impact on the specimen shall be restricted.
6. Inspect each test specimen after each impact, record and report the observation.
7. For asymmetric materials, the test shall be carried out on both sides using equal numbers of separate specimens.

8.2.6.6.3 Expression of Results

The laminated specimen shall be deemed to pass the impact test, if the breakage occurs with appearance of numerous cracks and fissures, but remains substantially in one piece and no tear or shear or opening develops within the vertical specimens through which a 76 mm diameter sphere can pass freely using a horizontally applied force of 18 N or less.

8.2.6.7 Bake Test

8.2.6.7.1 Principle

The purpose of this test is to determine whether the laminated glass product is able to withstand exposure to high temperature, without their properties becoming substantially altered. A hot air oven and an observation board are required to conduct this test.

8.2.6.7.2 Procedure

1. Heat the three laminated specimens of size 300mm X 300 mm to 100°C in a hot air oven.
2. Maintain the test temperature for a period of 2 hours.
3. Take the specimens out; allow them to cool to room temperature by storing them vertically.
4. The assessment of the test sample maybe carried out when the glass surface temperature is lower than 30°C.
5. Inspect the samples at a distance between 300mm and 500mm in front of a white diffused background.
6. Disregard any delamination, PVB shrinkage, bubble formation within 15mm from an original edge and 20mm from a cut edge and record any of the alteration in the remaining areas.
7. Disregard the specimen showing cracks and perform the test on a new sample in it's place.
8. In case of wired laminated glass, individual bubbles in the immediate vicinity of inlaid wires are permissible.

8.2.6.7.3 Expression of Results

The quality and adhesion property of the of the PVB in laminated glass is checked under the test in terms of bubble formation, delamination, cloudiness or haze. 8.2.6.8 Pummel Test

8.2.6.8.1 Principle

The purpose of this test is to determine adhesion of PVB film to glass surfaces.

8.2.6.8.2 Procedure

1. Take a PVB laminated glass specimen and store it at -18°C for 3 hours. If the laminated glass is constructed with ionomer interlayers refrigeration is not required.
2. Using a one pound hammer, pummel the specimen at points as shown in the diagram.
3. Pummel should be done on an anvil at a 15 deg. angle with a flat headed hammer of 0.5 kg.
4. Hit a row at 1.25 cm intervals, use an interval of 2 cm between the rows.
5. Pummel should cover almost one half of the sample.
6. Check the amount of glass still adhered to the PVB interlayer.
7. Rate the pummelled sample on a range from 1 to 10 with 0 corresponding to complete exposure of the PVB and 10 to complete coverage of PVB by glass fragments.
8. Record this range.

8.2.6.8.3 Expression of Results

Higher pummel numbers are desired. Lower pummel (less than 4) indicate extremely poor adhesion of glass with PVB. A pummel range of 6 and more is generally acceptable.

Notes

Notes

Closing Note

This *Quality Standards Manual* is intended to serve as a single-point quality reference guide for glass processors, aluminum fabricators, facade consultants, architects and developers. While formulating these guidelines we have looked upon various relevant world standards in existence and have based our tolerances considering a pragmatic approach on both the manufacturing and installation fronts. Wherever possible, we have used the most stringent limits from available standards, which will facilitate dispute resolution when required.

Since its inception in May 2012, the guide has undergone three significant revisions in consultation with industry experts and now enjoys complete endorsement from all stakeholders of the material supply chain, both on supply and demand side.

Although detailed attention has been given to ensure that this manual is complete and comprehensive in all respects, we invite suggestions for improving this guide and make it more workable for manufacturing and installation purposes. Please do write to us and we shall incorporate your valuable suggestions in the forthcoming editions.

Tariq Kachwala
Hon. General Secretary, Federation of Safety Glass
Mumbai
July 2014

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