ENGINEERING STANDARDS

MANUAL

NGA
NATIONAL GLASS ASSOCIATION with GANA

Preface

This *Engineering Standards Manual* is an updated edition of the manual last updated by the Glass Association of North America (GANA) in 2008. NGA and GANA combined into one association in February 2018.
The purpose of the *Engineering Standards Manual* is to clarify the proper selection and use of heat-strengthened and fully tempered glass.

The test procedures and performance requirements herein will serve manufacturers and consumers who wish to adopt them on a systematic basis, to reflect the current technological advances within the tempering industry, and to incorporate Federal and State regulatory requirements affecting heat-strengthened and fully tempered glass and the products that benefit from its use. The Manual presents specifications to assist the engineer designing new and different products using heat-treated glass, as well as the manufacturer charged with making existing products better or more competitive. This Manual does not state that heat-strengthened or fully tempered glass shall be used or to what extent it should be used in the various applications. Such requirements rest with the designers and regulating authorities.

Requirements are included where appropriate if the quality of the raw glass affects the performance of fully tempered glass with respect to strength, heat resistance and safety. To maximize the performance of fully tempered glass, the Manual also defines the physical tolerances, such as dimensions and contours, practical to various products.

The National Glass Association, with the Glass Association of North America, expresses its appreciation to the engineers, scientists and operations people, both in the manufacturing and distribution of tempered glass products, for sharing their combined knowledge and experience.

The contributors to this Manual represent reliable and authoritative experience in the architectural, marine, automotive, furniture and appliance fields, and a number of other important industries. The Manual is under regular review, and updates will be supplied as new information becomes available and the organization is able to collate and produce such updates.

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About NGA
The National Glass Association (NGA) was founded in 1948. NGA combined with the Glass Association of North America (GANA) on February 1, 2018 to form the largest trade association serving the architectural glass and metals industry supply chain, including glazing contractors, full-service glass companies, glass fabricators, primary glass manufacturers and suppliers to the industry.

It is a technical powerhouse that brings some of the best minds to the table to create technical resources and promote and advocate for glass in buildings through its membership, its Forming, Fabricating and Installing committees and the Glazing Industry Code Committee (GICC).

NGA's education and training programs—both online at MyGlassClass.com and in-person at association-sponsored events—and its official publication Glass Magazine, keep the industry knowledgeable and well informed.

NGA produces the industry's largest annual trade show in the Americas, GlassBuild America. It hosts the Building Envelope Contractors (BEC) Conference, the Glazing Executives Forum, Glass Processing and Automation Days, as well as Annual and Fall Conferences. These educational and networking events bring together thousands of industry professionals to help them build more profitable businesses.

Engineering Standards Manual
2019 Edition

NGA
NATIONAL GLASS ASSOCIATION with GANA

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3. Clear, patterned, colored and decorated tempered glass for lighting fixtures used in household, commercial and specialized installations.

4. Clear, patterned, colored, coated and decorated tempered glass for specialized industrial and commercial installations such as countertops, impact-resistant windows, high-pressure dials and gauge glass, and electronic gear.

5. Clear, patterned, tinted, opaque and coated tempered safety glass for architectural glazing applications where safety is a primary consideration.

6. Colored and decorated heat-strengthened and fully tempered glass in general construction, such as spandrels and decorative non-vision panels.

Partial List Of Applications

Appliance backs, fronts and tops
Aquariums
Automotive glazing
Bar coding reader lenses
Baseboard and wall heaters
Basketball backboards
Boat windshields and windows
Carving boards
Copy machine lenses
Decorative panels
Display cases
Door sidelights
Entrance doors
Farm and construction equipment cab windows
Fire break-out panels
Fireplace screens
Food warmers
Gas grills
Grocery store cooler doors and lids
Handball courts
Hockey rinks
Instrument faceplates
Light fixture lenses
Microwave doors
Oven doors
Partitions
Patio doors
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SECTION 2 — SPECIFICATION NO. 66-9-20 REV. #8

Specification for Heat-Strengthened or Fully Tempered Ceramic Enameled Spandrel Glass for Use in Building Window/Curtain Walls and Other Architectural Applications

A. Scope

This specification shall cover heat-strengthened or fully tempered flat glass for use in spandrel applications that has a ceramic enamel fused onto a surface of the glass during the heat-treating process.

B. Applicable Specifications

Other specifications which may be referenced within this specification, either in whole or in part, are as follows:

ASTM C1036	Standard Specification for Flat Glass
ASTM C1048	Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass
ASTM C346	Standard Test Method for 45-degree Specular Gloss of Ceramic Materials
ASTM C724	Standard Test Method for Acid Resistance of Ceramic Decorations on Architectural-type Glass
ASTM C978	Standard Test Method for Photoelastic Determination of Residual Stress in a Transparent Glass Matrix using a Polarizing Microscope and Optical Retardation Compensation Procedures
ASTM C1279	Standard Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat-Strengthened and Fully Tempered Flat Glass
ANSI Z97.1	American National Standard for Safety Glazing Materials Used in Buildings – Safety Performance Specifications Method of Test
CAN/CGSB-12.10	Glass, Light and Heat-Reflecting
CAN/CGSB-12.9	Spandrel Glass
CPSC 16 CFR 1201	Safety Standard for Architectural Glazing Materials

Engineering Standards Manual **Appendix 6**

C. Objective

For certain applications, heat-treated glasses which are ceramic enameled may be the preferred choice for use in building facades. The objective of this specification is to provide a means by which ceramic enameled glass spandrels which are sold and/or identified as fully tempered or heat-strengthened, can be shown to be heat-treated to the level associated with the identified product. In addition, this specification outlines other test requirements that flat glass with ceramic enamel shall meet to ensure durability in final installed applications. Dimensional tolerances are also defined, as well as requirements for viewing and inspection.

This document does not instruct the user in the operation of specific instruments. The method of operation, measuring range and other limitations of the specific instruments may be obtained from the manufacturer.

D. General Requirements

For best assurance that products covered by this specification are properly fabricated, certain tests are prescribed. Further, use of ceramic enameled spandrel glass can require special consideration and/or handling in installation and application. For these reasons, it is recommended that the following variables be noted.

Glazing practices for spandrel glasses can significantly affect the durability of the glazed panels and it is essential that no glass-to-metal contact occurs, which can impart damage to the glass edges or surfaces. Precaution should be taken to protect ceramic frit coated spandrel glass surfaces against welding spatter, surface and/or edge handling damage, and other conditions that adversely affect the strength of the glass. All spandrel glass shall be glazed in accordance with the *GANA Glazing Manual*, or as recommended by the spandrel manufacturer. The fabricator of the spandrel glass should be consulted before any insulation is applied to the ceramic enamel.

D.1 Stress
Use either Test Method A or B to determine surface compression in heat-treated glass.

D.1.1 Test Method A
Non-destructive determination of surface compression using a surface stress measuring instrument or device.

D.1.1.1 Specimens to be Tested
Surface stress measurements are commonly made on production glass. The glass surface to be measured must be the tin side and free of ceramic enamel in the area of the measurements. If there is ceramic enamel on the tin side, an area that is free of enamel may be created by:

D.1.1.1.1 Leaving an area uncoated with ceramic enamel prior to firing OR

D.1.1.1.2 Removing the ceramic enamel with hydrofluoric acid (HF) OR

D.1.1.1.3 Removing the ceramic enamel with abrasive cloth. Index oil and a glass slide cover plate may be necessary to eliminate abraded surface to see edge compression color bands.

D.1.1.2 Test Apparatus
Surface stress measuring instrument or device.

D.1.1.3 Test Procedure
Surface compression to be measured by light refraction methods must be done per ASTM C1279 Standard Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat-Strengthened and Fully Tempered Flat Glass and Appendix 6 of this manual. 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 Figure 1.

D.1.2 Test Method B
Determination of edge compression by examination with a polariscope.

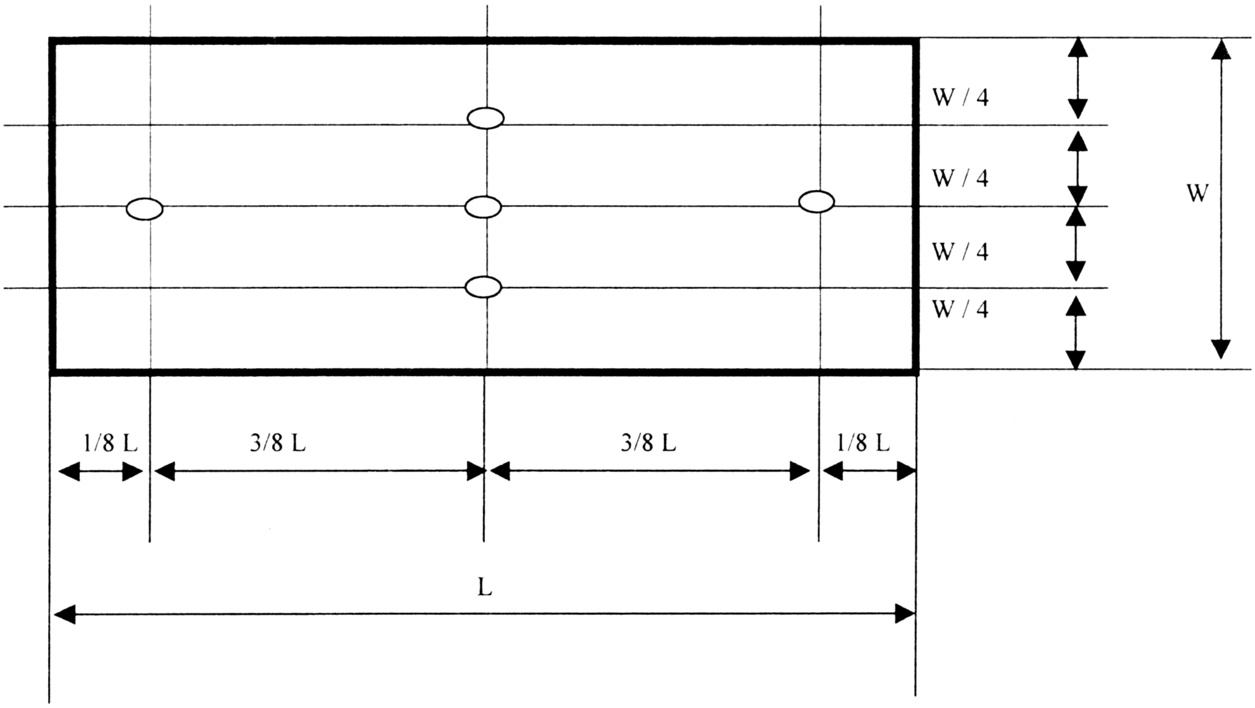
D.1.2.1 Specimens to be Tested
Specimens to be measured with this technique must be free of ceramic enamel at all points to be examined. This may be accomplished as follows:

D.1.2.1.1 Leaving an area uncoated with ceramic enamel prior to firing OR

D.1.2.1.2 Removing ceramic enamel with hydrofluoric acid (HF) OR

FIGURE 1

Five Locations Examined



D.1.2.1.3 Remove ceramic enamel with abrasive cloth. Index oil and a glass slide cover plate may be necessary to eliminate abraded surface to see edge compression color bands.

D.1.2.2 Test Apparatus
The test apparatus for polariscopic examination as per D.1.3.1 consists of a source of polarized light which may be passed through the sample and a sheet of polaroid material which may be positioned with its axis at a 90° angle to the original source to act as an analyzer of the light transmitted by the sample. A polarizing microscope with a quartz wedge may also be used for this examination.

D.1.2.3 Test Procedure
Refer to Appendix 1 of this manual, “Edge Stress Estimation by Polarized Light (Strain Viewer).”

D.1.3 Interpretation of Test Results of Measured Surface and/or Edge Compression

D.1.3.1 Heat-Strengthened Glass
Heat-strengthened glass 6 mm (0.25 in.) or thinner shall have an average surface compression between 24 MPa to 52 MPa (3,500 to 7,500 psi):*

***Note:** Heat-strengthening glass thicker than 6 mm (0.25 in.) within narrow limits of surface compression is difficult. Consult manufacturer.

D.1.3.2 Fully Tempered Glass
Must meet at least ONE of the TWO following criteria:

D.1.3.2.1 When examined using a test procedure described in D.1.1, fully tempered glass shall have an average surface compression of not less than 69 MPa (10,000 psi) OR

D.1.3.2.2 When examined using a test procedure described in D.1.2, fully tempered glass shall have an average edge compression of not less than 67 MPa (9,700 psi).

D.1.4 Safety Glass
Glass that is fully tempered may or may not be designed to meet the requirements for “safety glass.” In order to be considered safety glass, it must meet the following standards:

D.1.4.1 ANSI Z97.1 OR

D.1.4.2 CPSC 16 CFR 1201

D.2 Expansion Fit

D.2.1 Specimens To Be Tested
The specimen is to be a section cut from a sample not less than 12 in. x 12 in., processed normally with a regular production lot and dead annealed. Specimen preparation is discussed in ASTM C978.

For purposes of this test, dead annealed means the substrate will have stresses at a low enough level so that any stress existing at the glass-ceramic enamel interface will be prominent and sharply defined.

D.2.2 Test Apparatus
The test apparatus is a polarizing microscope and quartz wedge or equivalent optical compensation device, as defined in ASTM C978.

D.2.3 Test Procedure
The stress at the glass-ceramic enamel interface will be measured using the procedure outlined in ASTM C978.
To properly evaluate the residual stress arising from the thermal expansion mismatch between the enamel and substrate, a blank substrate also needs to be heat-treated and then subsequently annealed in the same manner as the decorated piece of glass. The blank must be of the same substrate lot as the fired sample.

The residual stress on both the enameled piece and the blank may then be measured. The residual stress of the blank is then subtracted from the enameled measurement to determine the residual stress resulting from the expansion mismatch.

D.2.4 Interpretation of Test Results
Because the expansion match between the glass and ceramic enamel influences the strength characteristics of spandrel glass significantly, proper match is essential.

After appropriately adjusting for the residual stress of the blank, the stress measured in the glass at the glass-ceramic enamel interface shall be a maximum of 220 psi, either compression or tension.

D.3 Durability

D.3.1 Porosity of the Ceramic Enamel
Use Test A or Test B.

D.3.1.1 Test Method A – Gloss Test

D.3.1.1.1 Specimens to be Tested
Specimens for durability tests shall have a representative thickness of ceramic coating of the same type and color as provided on specimens in D.1.1 for Stress Measurement and D.2.1 for Expansion Fit Test. Specimens are to be fired in a normal manner with a production lot. The samples may be of any convenient size.

D.3.1.1.2 Test Apparatus
Gloss meter conforming to ASTM C346 as manufactured by Photovolt Corp., Hunter Assoc. Laboratory, Gardner Laboratory, Inc., or others using a 45° geometry.

D.3.1.1.3 Test Procedure
Measure the gloss value. The gloss meter must be calibrated such that the gloss value reading with black glass (Black Carrara or any similar product with polished surfaces) has a value of 54.5 (see ASTM C346 for detailed discussion).

D.3.1.1.4 Interpretation of Test Results
The gloss value should be a minimum of 35 at the time of manufacturing.

D.3.1.2 Test Method B – India Ink Test

D.3.1.2.1 Specimens to be Tested
Specimens for durability tests shall have a representative thickness of ceramic coating of the same type and color as provided on specimens in D.1.1 for Stress Measurement and D.2.1 for Expansion Fit Test. Specimens are to be fired in a normal manner with a production lot. The samples may be of any convenient size.

D.3.1.2.2 Test Apparatus
Apparatus is noted in the below procedure.

D.3.1.2.3 Test Procedure
Lightly scrape an area of 25 mm x 75 mm (1 in. x 3 in.) ten times with a single razor blade at an angle of 45° to the painted surface. Apply a line of India ink along the 75 mm (3 in.) dimension and allow to sit for 15 minutes. Remove the ink from the surface with a fine abrasive paste and brush.

D.3.1.2.4 Interpretation of Test Results
When the area in contact with the India ink is viewed with the unaided eye and diffuse light, no residual ink should be visible.

D.3.2 Acid Resistance

D.3.2.1 Specimens to be Tested
Specimens for durability tests shall have a representative thickness of ceramic coating of the same type and color as provided on specimens in D.1.1 for Stress Measurement and D.2.1 for Expansion Fit Test. Specimens are to be fired in a normal manner with a production lot. The samples may be of any convenient size.

D.3.2.2 Test Apparatus
Apparatus is noted in the below procedure.

D.3.2.3 Test Procedure
Perform the acid resistance test according to the procedure outlined in ASTM C724 with a 10 percent citric acid solution and a 3.7 percent hydrochloric acid solution. Place four drops of the citric acid solution at one location and four drops of the hydrochloric acid solution at a different location on the enamel surface at room temperature. Cover

the areas with a one inch diameter watch glass. After 15 minutes, rinse with tap water and air dry. View the area and determine a rating based on the choices below.

D.3.2.4 Interpretation of Test Results

Ratings
1 = No attack apparent.

2 = Appearance of iridescence or visible stain on the exposed surface when viewed at a 45° angle but not apparent at angles less than 30°.

3 = A definite stain which does not blur reflected images and is visible at angles less than 30°.

4 = Definite stain with a gross color change or strongly iridescent surface visible at angles less than 30° and which may blur reflected images.

5 = Surface dull or matte, with chalking possible.

6 = Significant removal of enamel with pinholing evident.

7 = Complete removal of enamel in exposed area.

Acceptable Limit — Rating 4 or better.

No visible stain can be observed on the undercoated side of the test specimen when the sample is viewed over an opaque background.

D.3.3 Alkali Resistance
The test should be performed in accordance with the procedures outlined in ASTM C1203. The sample is weighed before and after exposure to chemical attack. The weight loss in grams per square centimeter is then calculated.

D.3.3.1 Specimens to be Tested
The test specimen should be fired, ceramic enameled glass consisting of a specially prepared trial sample or an item of production ware which has been cut to a size which will be easily accommodated by a 1200-ml. beaker. It should be small enough for accurate weighing to the nearest 0.0001 gram. Microscope slides which are 50 mm x 75 mm (2 in. x 3 in.) can be used to prepare a fired trial or similarly sized glass or sections of fired ware can be used depending on the nature of the test. The fired specimen should be annealed, seamed if necessary to remove feathered edges, then weighed.

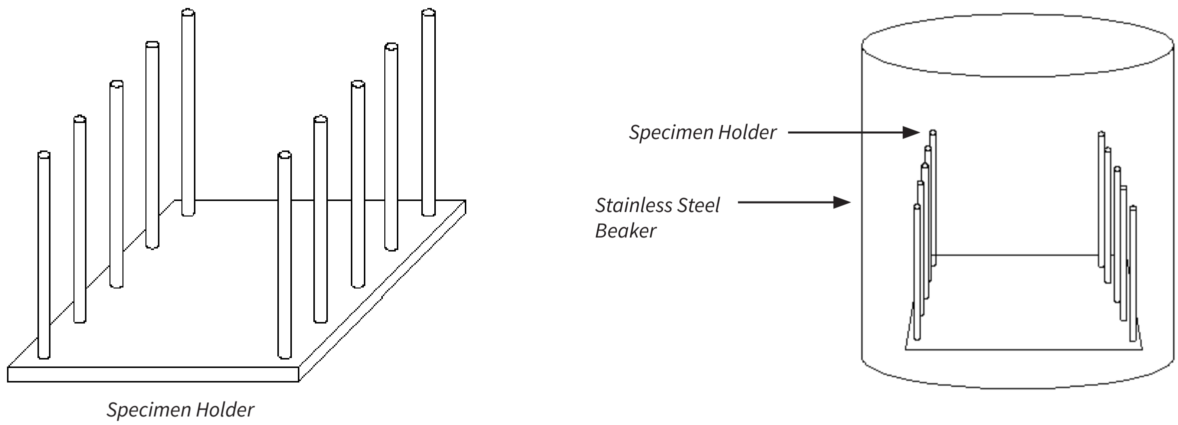
D.3.3.2 Test Solution
A test solution consisting of 70 grams of sodium hydroxide and 630 ml. of distilled water is prepared in a 1200-ml. stainless steel beaker.

D.3.3.3 Test Procedure
The use of proper safety procedures and protective equipment is essential. The test piece(s) are placed vertically into the beaker with the test solution. A support such as shown in Figure 2 can be used, if necessary, to maintain the sample in a vertical orientation. The beaker containing the samples in the alkali solution is covered and rapidly heated in a temperature-controlled water bath at 95°C + 2°C (203°F + 4°F).

To achieve 95°C (203°F) in the temperature-controlled water bath, a commercial antifreeze solution of two parts water to one part antifreeze should be used. Temperature should be monitored throughout the test.

FIGURE 2

Test Procedure Specimen Support



The specimens are exposed to the heated solution for two hours from the time the solution is placed in the controlled temperature bath.

After two hours, remove the beaker from the bath and the samples from the test solution, and allow them to cool for 1-2 minutes. Clean the specimens using tap water and vigorous scrubbing with a wet, soft cotton cloth. Rinse the samples thoroughly with tap water, followed by distilled water, then place in a drying oven at 65°C (149°F) for at least 15 minutes, or until dry.

D.3.3.4 Interpretation of Test Results
Divide the net weight loss by the calculated surface area of the test specimen to determine the weight loss per square centimeter. The weight loss in grams per square centimeter should be reported.

When tested as described in ceramic enamel test for alkali resistance, the maximum weight loss shall not exceed 0.0028 grams/cm2.T

D.3.4 Glazing Material Compatibility

D.3.4.1 Specimens to be Tested
Specimens for durability tests shall have a representative thickness of ceramic coating of the same type and color as provided on specimens in D.1.1 for Stress Measurement and D.2.1 for Expansion Fit Test. Specimens are to be fired in a normal manner with a production lot. The samples may be of any convenient size.

D.3.4.2 Test Apparatus
Commercial-quality glazing compound.

D.3.4.3 Test Procedure
Apply strips of the glazing compound to the ceramic surface. When viewed from the non-enameled side, a shadow line may be visible and, particularly when light colored ceramic is used, some change in color may occur due to light transmission through the ceramic coating.

The glazing compound is allowed to cure for 120 hours. At the end of this period, all traces of the glazing compound are removed from the ceramic surface in order to permit observation of the ceramic surface.

TABLE 1

Nominal thickness, length, width and squareness tolerances for float glass commonly used for flat fully tempered and heat-strengthened spandrels:

Nominal Designation		Thickness Range				Length and Width Tolerance				Squareness (D1-D2)			
SI Designation[B] mm	Traditional Designation	mm		in.		Cut Size		Stock Sheet		Cut Size		Stock Sheet	
		min.	max.	min.	max.	+/- mm	(+/- in.)	+/- mm	(+/- in.)	mm	(in.)	mm	(in.)
1	microslide	0.79	1.24	0.031	0.049	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
1.5	photo	1.27	1.78	0.050	0.070	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
2	picture	1.80	2.13	0.071	0.084	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
2.5	single	2.16	2.57	0.085	0.101	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
2.7	lami	2.59	2.90	0.102	0.114	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
3[C]	double, 1/8 in.	2.92	3.40	0.115	0.134	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
4	5/32 in.	3.78	4.19	0.149	0.165	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
5	3/16 in.	4.57	5.05	0.180	0.199	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
6	1/4 in.	5.56	6.20	0.219	0.244	1.6	(1/16)	6.4	(1/4)	2.0	(5/64)	3.0	(1/8)
8	5/16 in.	7.42	8.43	0.292	0.332	2.0	(5/64)	6.4	(1/4)	2.8	(7/64)	6.0	(1/4)
10	3/8 in.	9.02	10.31	0.355	0.406	2.4	(3/32)	6.4	(1/4)	3.4	(1/8)	6.0	(1/4)
12	1/2 in.	11.91	13.49	0.469	0.531	3.2	(1/8)	6.4	(1/4)	4.5	(11/64)	10.0	(3/8)
16	5/8 in.	15.09	16.66	0.595	0.656	4.0	(5/32)	6.4	(1/4)	5.7	(7/32)	12.0	(1/2)
19	3/4 in.	18.26	19.84	0.719	0.781	4.8	(3/16)	6.4	(1/4)	6.8	(1/4)	14.0	(9/16)
22	7/8 in.	21.44	23.01	0.844	0.906	5.6	(7/32)	6.4	(1/4)	7.9	(19/64)	16.0	(5/8)
25	1 in.	24.61	26.19	0.969	1.031	6.4	(1/4)	6.4	(1/4)	9.0	(11/32)	18.0	(3/4)

[A] Length and width of cut size and stock sheets of flat glass include flares and bevels.

[B] These designations apply only to ASTM International and may not reflect other international standards.

[C] Within the 3.0 designation there are some applications that may require different thickness ranges such as DST (Typical minimum thickness for DST is 0.120 in.)

D.3.4.4 Interpretation of Test Results
No visible effect on the ceramic coating is allowed.

D.4 Dimensional Tolerances

D.4.1 Thickness, length, width and squareness

D.4.2 Flatness

D.4.2.1 Localized Bow
1.6 mm. (0.063 in.) over any 300 mm (12 in.) span is permissible except that for strips (as determined above), 2.4 mm. (0.094 in.) over any 300 mm (12 in.) span is permissible.

D.4.2.2 Localized Kink
Any localized kink centered at any tong location shall not exceed 1.6 mm. (0.063 in.) over a 50 mm (2 in.) span.

D.4.2.3 Overall Bow
Place sample glass in a free-standing vertical position, resting on blocks at the quarter points. With the glass in this position, place a straight edge across the concave surface parallel to and within one inch from the edge and measure the maximum deviation with a taper, feeler gauge or a dial indicator in accordance with the recommendations of ASTM C1048. The maximum permissible bow can be found in Table 2.

E. Edge Finish

Spandrel glass edges may be clean-cut, swiped, seamed, beveled or ground prior to tempering or heat-strengthening.

TABLE 2

Overall Bow, Maximum

	Edge Dimension, cm (in.)											
	0–50 (0–20)	>50–90 (>20–35)	>90–120 (>35–47)	>120–150 (>47–59)	>150–180 (>59–71)	>180–210 (>71–83)	>210–240 (>83–94)	>240–270 (>94–106)	>270–300 (>106–118)	>300–330 (>118–130)	>330–370 (>130–146)	>370–400 (>146–158)
Nominal Thickness Designation mm (in.)	Maximum Bow, mm (in.)											
3 ($^1/_8$)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	...	...	...
3 ($^1/_8$) Alternate Method[A]	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	3.0 (0.12)	5.0 (0.20)	6.0 (0.24)	7.0 (0.28)	8.0 (0.31)	10.0 (0.39)	...	...	...
4 ($^5/_{32}$)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	...	...	...
5 ($^3/_{16}$)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	...	...	...
6 ($^1/_4$)	2.0 (0.08)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	21.0 (0.83)	24.0 (0.94)
8 ($^5/_{16}$)	2.0 (0.08)	2.0(0.08)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	6.0 (0.24)	8.0 (0.31)	10.0 (0.39)	13.0 (0.51)	15.0 (0.59)	18.0 (0.71)	20.0 (0.79)
10 ($^3/_8$)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	5.0 (0.20)	6.0 (0.24)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)
12–22 ($^1/_{12}$ –$^7/_8$)	1.0 (0.04)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	5.0 (0.20)	5.0 (0.20)	7.0 (0.28)	10.0 (0.39)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)

Values apply to 3 mm ($^1/_8$ in.) thickness only when the alternative checking procedure in 10.7.2 is used.

F. Viewing and Inspection

Spandrel glass is designed to be viewed from the exterior against an unlit, uniform background. Spandrel glass is not to be viewed in transmission. Whether it is fully or partially covered, if it is used where light may be seen through the glass, consultation with the glass fabricator is mandatory. Pinholes and uneven appearance of the ceramic coating may be visible prior to the completion of the opaque backup construction. These conditions are not a reason for rejection.

SECTION 2.1— SPECIFICATION NO. 89-1-69 REV. #2

Specification for Environmental Durability of Heat-Treated Spandrel Glass with Applied Opacifiers

A. Scope

This specification shall cover opacifiers such as applied films, organic coatings and adhesive laminates, which are applied to the interior (non-weathered) surface of heat-treated glass. Refer to ASTM C1048 for heat-treated glass standard.

Spandrels with ceramic enamel are not addressed by this specification.

Refer to Engineering Standards Manual Specification No. 66-9-20 (Section 2).

Laminated glass is not addressed by this specification. Refer to ANSI Z97.1.

B. Applicable Specifications

Other specifications which may be referenced within this specification, either in whole or in part, are as follows:

ASTM C1036	Standard Specification for Flat Glass
ASTM C1048	Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass
ASTM G153	Standard Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials
ASTM G154	Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Non-Metallic Materials
ASTM G155	Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials
CAN/CGSB-12.9	Spandrel Glass
CAN/CGSB-12.20	Structural Design of Glass for Buildings
ANSI Z97.1	American National Standards for Safety Glazing Materials Used in Building – Safety Performance Specifications Method of Test
CPSC 16 CFR 1201	Safety Standard for Architectural Glazing Materials

GANA Glazing Manual, 50th Anniversary Edition
Engineering Standards Manual Appendix 6

C. Objective

For certain applications, heat-treated glass with an applied opacifier on the interior surface may be the preferred choice for use in building facades. The objective of this specification is to ensure the durability of heat-treated glass spandrels with an opacifier. A test method to validate fallout resistance has been included for those projects that have this requirement based upon applicable codes or project specifications.

D. General Requirements

For best assurance that products covered by this specification are properly fabricated, certain tests are prescribed. Further, glass spandrels with an applied opacifier can require special consideration and/or handling in their application and installation. For these reasons, the following considerations are recommended:

Glazing practices for glass spandrels with an applied opacifier can significantly affect the durability of the glazed panel. It is essential that no glass-to-metal contact, improper glazing methods or inadvertent contact occur which will impart damages to the glass edges and surfaces or to the opacifier. Precaution should be taken to protect glass spandrel surfaces against welding spatter, surface and/or edge handling damage, and any other conditions which may adversely affect the strength of the glass. Chemical compatibility of the opacifier with other materials used in the spandrel cavity is critical. A chemical instability may result from aggressive adhesives applied to the opacifier, the use of insulation with unstable resins or binders, overspray of fire-safing with high amounts of petroleum distillates, adhesives or paints which outgas, household detergents used as lubricants, solvents used in cleaning, primers used in structural glazing or low-grade glazing gaskets. These chemicals, in combination with other factors such as moisture, heat and/or ultraviolet exposure, may aggressively attack the opacifier, certain glass coatings, and the glass itself. Consultation with the component supplier regarding chemical compatibility and project specific testing is essential.

The compatibility of materials is essential to the long-term performance of any glazing installation. Chemical reaction from physical contact or close proximity exposure to incompatible materials can occur. Compatibility should always be a concern and should never be assumed.

Good starting points for guidance include: ASTM C510 *Standard Test Method for Staining and Color Change of Single or Multicomponent Joint Sealants*, C 794 *Standard Test Method for Adhesion-Peel of Elastomeric Joint Sealants*, C864 *Standard Specification for Dense Elastomeric Compression Seal Gaskets, Setting Blocks, and Spacers*, and C1087 *Standard Test Method for Determining Compatibility of Liquid-Applied Sealants with Accessories Used in Structural Glazing Systems*.

All heat-treated glass with an applied opacifier shall be glazed in accordance with the GANA Glazing Manual, 50th Anniversary Edition or as recommended by the spandrel manufacturer.

Insulation must be applied strictly in accordance with the spandrel glass manufacturer’s specifications. Some manufacturers do not recommend the application of insulation directly in contact with their opacified glass spandrel products.

Some manufacturers of spandrel glass products can furnish panels with an applied opacifier which is intended to retain glass in place should breakage occur. Broken panels should be removed as soon as possible. For spandrel applications requiring glass fallout protection to meet applicable codes or project specifications, spandrel panels with an applied opacifier are recommended.

D.1 Environmental Durability Testing of Opacifier Bond

D.1.1 Specimens to be Tested
Fifteen (various sizes – check test labs) specimens, each affixed with an opacifier and representative of the end product, shall be prepared for the four tests indicated: high temperature – low humidity, high temperature – high humidity, cyclical temperature and humidity, and ultraviolet radiation. Three samples shall be retained as control specimens. For test purposes only, because of heat-treating equipment limitations on small sizes and because of lab apparatus limitations on large sizes, annealed glass may be used.

D.1.2 Test Aparatus
A humidity chamber shall be capable of providing and controlling temperatures -28.9°C to 93.3°C ± 2.8°C (-20°F to 200°F ± 5°F) and humidity (up to 95 percent) for the cyclical periods as required in D.1.3.3.

D.1.3 Test Procedure

D.1.3.1 High Temperature – Low Humidity Test
Place three specimens positioned vertically and separated by at least 25 mm. (1 in.) air space in a humidity chamber for 3 days (72 continuous hours) at 93.3°C (200°F) and ambient humidity. Interpretation of results is expressed in paragraph D.1.4.

D.1.3.2 High Temperature – High Humidity Test
Place three specimens positioned vertically and separated by at least 25 mm. (1 in.) air space in a humidity chamber for 7 days (168 continuous hours) at 93.3°C (200 °F) and 95 percent relative humidity. Interpretation of results is expressed in paragraph D.1.4.

D.1.3.3 Cyclical Temperature and Humidity Test
Three specimens are placed vertically in a humidity chamber and subjected to 100 cycles, each cycle to proceed in sequence, a, b, c and d as follows and repeat with no time delay between cycles:

a. 1 hour at -28.9°C (-20°F) at ambient humidity.

b. During the next 3 hours, elevate temperature from -28.9°C (-20°F) to 93.3°C (200°F) with relative humidity at 95 percent beginning above the 4.4°C (40°F) temperature level.

c. Hold for 1 hour at 93.3°C (200°F) at 95 percent relative humidity.

d. During the next 3 hours, decrease the temperature from 93.3°C (200°F) to -28.9°C (-20°F) at ambient humidity. Interpretation of results is expressed in paragraph D.1.4.

D.1.3.4 Ultraviolet Radiation Test

D.1.3.4.1 Specimens to be Tested
Three specimens, each affixed with an opacifier and representative of the end product, shall be prepared for the test indicated.

D.1.3.4.2 Test Apparatus
An accelerated weathering apparatus will be provided, such as:

Carbon arc lamp – as referenced in ASTM G153

QUV chamber – as referenced in ASTM G154

Xenon lamp – as referenced in ASTM G155

D.1.3.4.3 Test Procedure
Three specimens with the opacified surface facing away from either radiation source shall be exposed for 1,000 hours in the manner described in ASTM D1499. Radiation striking the specimens should be the same intensity as solar radiation of 1400 W/M2 for the 1,000 hours. The temperature of the specimens shall be maintained within 37.8°C to 48.9°C (100°F to 120°F) throughout the test. The three remaining specimens shall be maintained as controls.

D.1.4 Interpretation of Results
The exposed samples when compared to the control specimens shall not exhibit any bubbles, peeling, crazing, cracking, tunneling, shrinkage, staining, discoloration or delamination of the opacifier, in tests D.1.3.1, D.1.3.2, D.1.3.3 and D.1.3.4. Staining of the glass is permitted for test purposes only.

D.2 Compatibility of Components in the Spandrel Cavity
The compatibility of the opacifier material with sealants, gaskets, thin film coatings or other materials with which it may come into contact needs to be evaluated.

D.2.1 Test Procedure
The testing method must be representative of the conditions found in the installed application. Certain existing methods, such as ASTM C1087, although not specifically designed to assess opacifier compatibility, may provide some guidance as to sample preparation and testing conditions. The manufacturers of sealants, gaskets, coatings on glass and opacifying materials should be consulted on other potential testing methods or assessment techniques.

D.2.2 Interpretation of Results
Incompatibility may be indicated by the occurrence of bubbles, peeling, crazing, cracking, tunneling, shrinkage, staining, discoloration or loss of adhesion. These occurrences may be seen in the opacifier or other components of the system (i.e. sealant, glass surface, setting block, gasket, etc.).

D.3 Fallout Resistance Test
When specified, spandrel glass with an opacifier shall meet the fallout resistance requirements when tested in accordance with D.3.3.

D.3.1 Specimen to be Tested
The size of the four heat-treated opacified specimens shall be 86.40 cm (34 in.) x 1.93 cm (76 in.) with a tolerance of ± 0.32 cm (0.125 in.) on each dimension.

D.3.2 Test Apparatus
Each opacified specimen shall be mounted for testing in a test frame as specified in ANSI Standard Z97.1 as modified to conduct pressure test of D.3.3.3.

D.3.3 Test Procedure

D.3.3.1 Test for 100 cycles, each cycle to proceed in sequence a, b, c and d as follows, and repeat with no time delay between cycles:

a. One hour at -18°C (0°F) at ambient humidity.

b. During the next 3 hours increase temperature from -18°C (0°F) to 82.2°C (180°F), with relative humidity at 95 to 100 percent above 4.4°C (40°F).

c. Hold for 1 hour at 82.2°C (180°F) at 95 to 100 percent relative humidity.

d. During the next 3 hours, decrease temperature from 82.2°C (180°F) to -18°C (0°F) at ambient humidity.

D.3.3.2 Fracturing Glass
While the specimen is in the test frame, break specimen using a spring-loaded prick punch at the midpoint of either vertical edge and 25 mm (1 in.) inboard of the edge. Cracks and fissures of the opacifier which may develop are permissible, providing they conform to the requirements of D.3.4.

D.3.3.3 Static Pressure
Subject each specimen after breakage to 10 cycles of positive and negative pressure at 4 pounds per square foot (psf) for 5 minutes to simulate the action of wind load against a building.

D.3.4 Interpretation of Tests
Although cracks and fissures are permissible, no opening shall occur through which a 7.62 cm (3 in.) sphere may be freely passed, nor shall there be areas in which the opacifier is detached from the glass more than 58.1 sq. cm (9 sq. in.).

D.4 Viewing and Inspection of Surface Quality in Opacified Spandrels
Spandrel glass is designed to be viewed from the exterior against an unlit, uniform background. The glass with the applied opacifier, when placed in a vertical position and viewed at a distance of three meters through the glass (glass surface facing observer) in daylight, shall have a uniform appearance; free from blisters, bubbles, cracks, folds, uneven butt joints or tears.

SECTION 3— SPECIFICATION NO. 76-12-10A REV. #3

Specification for Fully Tempered Glass for Uses Requiring Strength and Resistance to Temperature

A. Scope

This specification covers flat and bent fully tempered soda lime glass for use in indoor and outdoor lighting fixtures, enclosures, partitions and other applications where strength and temperature resistance are required.

B. Applicable Specifications

ASTM C1036	Standard Specification for Flat Glass
ASTM C1048	Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass
ASTM C1464	Standard Specification for Bent Glass
CAN/CGSB-12.1	Tempered or Laminated Safety Glass
CAN/CGSB-12.3	Flat, Clear Float Glass
UL 1598	Underwriters Laboratories, Inc. Standard for Luminaires
ANSI Z97.1	American National Standards Institute, Inc.

C. General Requirements

C.1 Glass shall be fully tempered per ASTM C1048.

C.2 Fully tempered glass shall not be cut, drilled, edged, abraded or etched (except for small areas such as identifying monograms) after tempering.

C.3 It is not recommended that the temperature of fully tempered glass exceed 260°C (500°F).
Surface and edge compression loss begins to occur at glass temperatures nearing 260°C (500°F). For example, after 1,000 hours at 204°C (400°F), approximately 2 percent reduction of original compression occurs. At 260°C (500°F), approximately 7 percent reduction occurs. At 315°C (600°F), approximately 21 percent reduction occurs. However, at 371°C (700°F), approximately 54 percent reduction occurs. Please refer to the Time-Temperature Curves in Appendix 2.

C.4 Dimensional Tolerance

C.4.1 For thicknesses of 6 mm (¼ in.) or less, the dimensions of fully tempered glass shall be within a tolerance of +1.6 mm (+ 1⁄16 in.). Thicker glass shall conform to the thicknesses specified in ASTM C1036.

C.4.2 The fully tempered glass thickness shall be at least 3 mm (⅛ in.). Thickness tolerances shall be as specified in ASTM C1036.

C.4.3 Shape accuracy, twist and cross bend of bent glass shall be determined as specified in ASTM C1464.

C.4.4 Flat glass shall not show warpage greater than 1.6 mm per 300 mm of length (1⁄16 in. per linear foot) as measured on the concave surface within 25.4 mm (1 in.) of the glass edge as described in D.1.

C.4.5 Any localized kink centered at any tong location shall not exceed 1.6 mm (1⁄16 in.) in a 50 mm (2 in.) span.

C.4.6 There shall be no irregularities more than 3 mm (⅛ in.) from edge of the glass, except tong marks and warpage to the extent specified in paragraph C.3.4.

C.4.7 Tong marks, when present, shall be within 6 mm (¼ in.) of the edge of the glass. This distance should be measured from the center of the tong mark to the edge of the glass. Other glass support marks are also acceptable within 6 mm (¼ in.) of the edge of the glass.

C.5 Strength

C.5.1 When tested as described in paragraph D.2, the glass shall withstand an impact of 6.78 Joules (5 ft. lb.).

C.5.2 When tested under paragraph D.3 and disintegration occurs, the ten largest crack-free particles selected 5 minutes subsequent to the test shall weigh no more than the equivalent weight of 6450 mm2 (10 square in.) of the original test specimen. As prescribed in ANSI Z97.1, no one particle shall be longer than 102 mm (4.0 in.) excluding those within a 102 mm (4.0 in.) radius area of the center punch and a 25.4 mm (1.0 in.) perimeter of the test specimen.

C.5.3 When tested as described in paragraph D.4, the glass shall withstand a thermal down shock differential of 177°C (350°F).

C.6 Surface and Interior Quality
Fully tempered Type 1 Transparent Flat glass and Type II Patterned Class 1 and Class 2 glass shall be at least Q3 quality, complying with the requirements of ASTM C1036.

D. Test Procedures

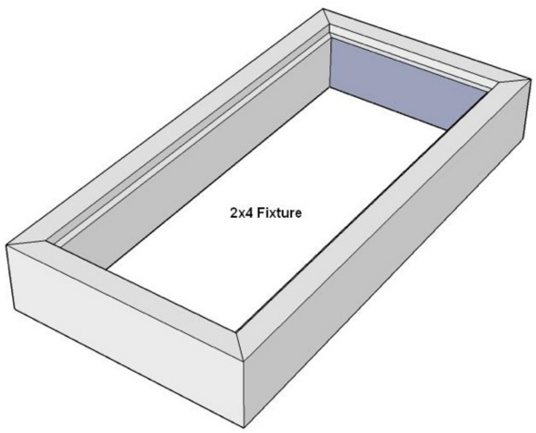
D.1 Flat Glass Warpage
Fully tempered flat glass warpage shall be measured by placing the sample in a vertical, freestanding position, resting on blocks at its quarter points. Using a straight edge along the concave surface, 25.4 mm (1.0 in) from the edge, measure the maximum deviation with a taper gage, feeler gage, dial indicator or fine scale ruler. The sample shall conform to C.4.4.

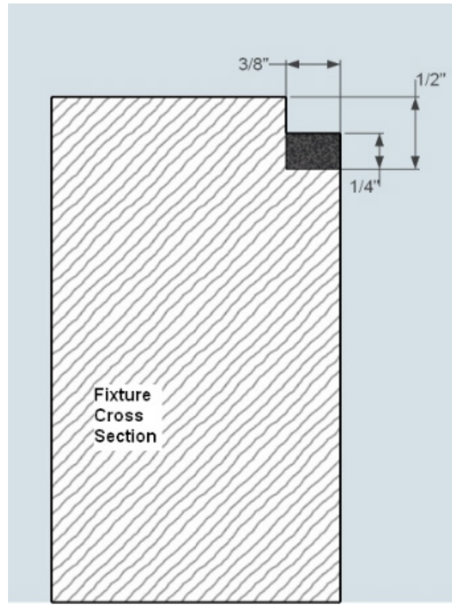
D.2 Impact Test
The testing frame shall consist of a horizontal, rigidly supported rectangular wooden frame of such size to support the glass being tested. The interior perimeter of the frame shall be equipped with a rabbet approximately 10 mm (⅜ in.) wide and 12.7 mm (½ in.) deep. The 10 mm (⅜ in.) supporting ledge shall be lined with a rubber gasket with a hardness of approximately Shore A 30-to-50 durometer. The thickness of the gasket shall be 6 mm (¼ in.). It shall be installed so the periphery of the glass is supported by approximately 10 mm (⅜ in.) (see Figure 1). With the glass supported as outlined in this section, a 50.8 mm (2 in.) diameter steel ball weighing approximately 535 grams (1.18 lbs.) shall be dropped onto the approximate center of the glass surface from a distance of 1.31 m (4.3 ft.) above the glass surface to impact the glass with approximately 6.78 Joules (5 ft. lb.) of energy. The glass shall not break when impacted.

D.2.1 Convex glass shall be mounted on four points on four Shore A 30-to-50 durometer rubber pads 50.8 mm (2 in.) wide x 50.8 mm (2 in.) wide x 6 mm (¼ in.) thick in a horizontal position with the convex side up.

FIGURE 3

Fixture Opening Dimensions Based on Glass Size





D.2.2 Flat glass shall be mounted in a horizontal position supported on the two short sides only by a rigid support. Shore A 30-to-50 durometer rubber pads 25.4 mm (1 in.) wide and 6 mm (¼ in.) thick, contacting a maximum marginal area of 12.7 mm (½ in.) from the glass edge.

D.2.3 Bent glass (cylindrical curved) shall be mounted in a horizontal position supported on two edges by Shore A 30-to-50 durometer pads 25.4 mm (1 in.) side by 6 mm (¼ in.) thick with the convex side up.

D.3 Break Pattern Test

Glass selected for impact test shall be broken by means of a spring loaded center punch 25.4 mm (1 in.) inboard of the mid-point of the longest edge, as prescribed by ANSI Z97.1 and GANA TD 101-04 Test Method.

D.4 Thermal Shock Resistance

A full-size panel shall be heated in a temperature-controlled oven at a temperature of 216°C (420°F). Once the glass reaches the control temperature, it shall be maintained at this temperature for 15 minutes. The glass should then be immersed into a water tank at 21°C (70°F). The glass shall not fracture as a result of the thermal shock exposure.

E. Edge Preparation

E.1 Edge preparation should always take place prior to tempering.

E.1.1 For edge finish reference, see Appendix 5.

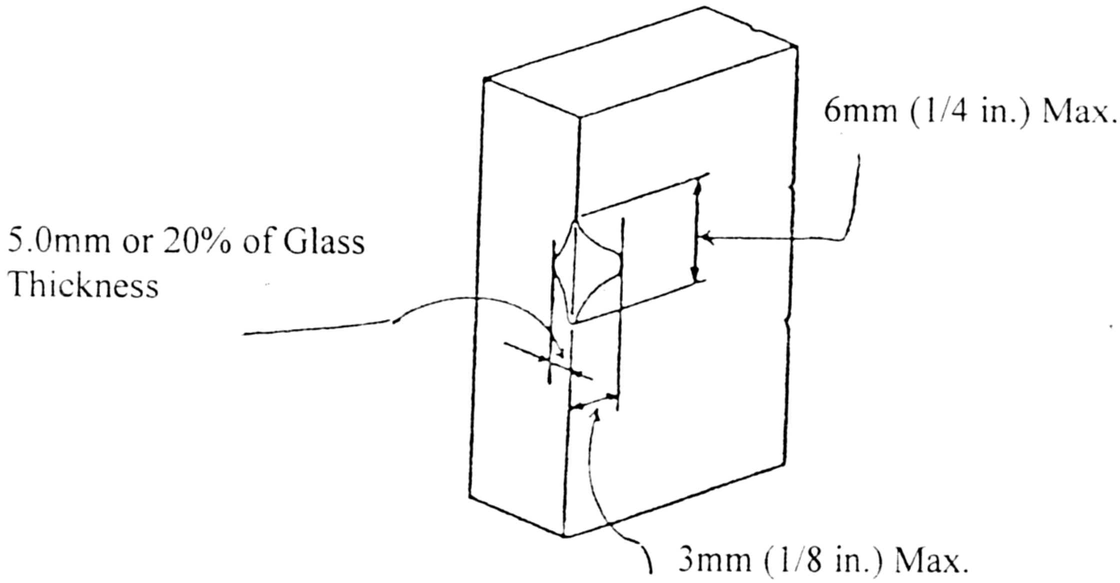
E.2 The seamed, ground, shaped or polished edge should always remove enough material to remove any sub-surface fissures that may have been introduced into the glass during the glass cutting process. The size of this seam, chamfer, or shaped edge should be enough to remove these potential flaws, especially on the score side edge of the glass.

E.3 Edge chips need not exist, but if they do, they should never interfere with the aesthetics, functionality, strength of the glass, or the strength of the edges on the glass.

E.3.1 V-Chips are not permitted, per ASTM C1036.

FIGURE 4

Shell Clip



E.3.2 Shell chip width shall be ≥ glass thickness or 6 mm (¼ in.), whichever is greater, length shall be ≥ 2 times the chip width, and depth ≥ 50 percent of the glass thickness, per ASTM C1036.

F. Labeling

The manufacturer's symbol or trademark may be permanently and legibly affixed to each glass. The marking should indicate the glass is fully tempered to distinguish it from ordinary glass. The marking shall be along the edge of the glass, visible after installation but within 38 mm (1.5 in.) of the edge. The marking should not exceed 12.7 mm (.5 in.) in width and 38 mm (1.5 in.) in length. It should be applied by etching, ceramic frit or sandblasting before the tempering operation.

G. Methods of Sampling

NGA endorses the general concept that satisfactory sampling programs should be developed by manufacturers in the absence of specific sampling programs required by applicable laws, regulations, codes and practices to which tempered glass shall conform.

SECTION 4— SPECIFICATION NO. 95-1-31 REV #2

Specification for Screen Printed Ceramic Enameled Architectural Flat Glass

A. Scope

This specification covers the manufacture of monolithic decorative architectural glass products manufactured by the screen-printing process with fired-on ceramic enamel.

B. Applicable Specifications

ASTM C1036	Standard Specification for Flat Glass
ASTM C1048	Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass
GANA 66-9-20 Rev. #7	Specification for Heat-Strengthened or Fully-Tempered Ceramic Enameled Spandrel Glass for Use in Building Window/Curtain Walls and Other Architectural Applications

Engineering Standards Manual Specification No. 66-9-20 Rev #8 (Section 2)

C. Objective

It is the objective of this document to provide the user with visual inspection requirements for evaluation of monolithic decorative glass products created with fired-on ceramic enamels as defined in Appendix 3, Section 2.

D. General Requirements

Unless otherwise specified, the decorative glass panel shall be viewed from the non-printed side. Color and appearance may vary somewhat from lot to lot but will fall within a commercial match from a mutually accepted proof or sample. Reference manufacturer's specification. Variation of ceramic frit thickness or other process parameters may result in varying color, opacity and appearance. Please consult with the manufacturer.

D.1 Pattern Registration Tolerances
Pattern may be located up to 1.6 mm (0.063 in.) off parallel from "locating glass edge" as identified on customer's engineering or shop drawings.

Patterns may be located up to 3.0 mm (0.125 in.) off parallel from edges other than the "locating glass edge."

For line patterns, the maximum variation in line width or distance between lines may be up to 0.8 mm (0.031 in).

The pattern may cover the entire glass panel up to a clear edge border of 3.0 mm (0.125 in.) or less. For structural silicone glazing applications, the pattern may extend to 0.8 mm (0.031 in.) or less but must be specified on the order.

Interior Applications
Unless otherwise specified or agreed upon, the requirements for interior applications shall be specified in D.1.2.1, D.1.2.2 and D.1.2.3:

TABLE 3

Screen Printed Ceramic Enamel Architectural Flat Glass

Recommended Standards for Aesthetic Appearance

	Interior Applications Viewed from at least 1 m (39 in.)	**Exterior Applications** Viewed from at least 3 m (10 ft.)
Blemishes**	**Column 1**	**Column 2**
Craters	Craters cannot be larger than 1.6 mm (0.0625 in.) and no closer than 50 mm (2 in.) on center	None Detectable
Fisheyes	Fisheyes cannot be larger than 1.6 mm (0.0625 in.) and no closer than 50 mm (2 in.) on center	None Detectable
Ghost	None Detectable	None Detectable
Hickey	Hickeys cannot be larger than 1.6 mm (0.0625 in.) and no closer than 50 mm (2 in.) on center	None Detectable
Mottle	None Detectable	None Detectable
Pinholes	Scattered pinholes are permissible	None Detectable
Sawtooth	None Detectable	None Detectable
Smear	None Detectable	None Detectable
Streak	None Detectable	None Detectable
Voids	Voids cannot be larger than 1.6 mm (0.0625 in.) and no closer than 50 mm (2 in.) on center	None Detectable

*For widths >1.5 m (~ 60 in.), contact manufacturer.
**Definitions of blemishes can be found in Appendix 3, Section 2.

D.1.2.1 The illumination under which a color evaluation is made shall be daylighting (without direct sunlight) or other uniform diffused background lighting that simulates daylight.

D.1.2.2 The glass shall be viewed with the naked eye in a vertical position at a distance of 1 m (39 in.).

D.1.2.3 The appearance quality shall conform to the requirements listed in Table 1, Column 1.

D.1.3 Exterior Applications
Unless otherwise specified or agreed upon, the requirements for exterior applications shall be specified in D.1.3.1, D.1.3.2 and D.1.3.3:

D.1.3.1 The illumination under which a color evaluation is made shall be daylighting (without direct sunlight) or other uniform diffused background lighting that simulates daylight.

D.1.3.2 The glass shall be viewed with the naked eye in a vertical position at a distance of 3 m (10 ft.).

D.1.3.3 The appearance quality shall conform to the requirements listed in Table 1, Column 2.

SECTION 5— SPECIFICATION NO. 65-5-13 REV. #5

Specification for Fully Tempered Glass for Use in Appliances

A. Scope

This specification covers flat and curved fully tempered glass, both plain and decorated, for use in appliances.

B. Applicable Specifications

ASTM C724	Standard Test Method for Acid Resistance of Ceramic Decorations for Architectural-type Glass
ASTM C1036	Standard Specification for Flat Glass
ASTM C1048	Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass
ASTM C1279	Standard Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat- Strengthened, and Fully Tempered Flat Glass
ASTM C1464	Standard Specification for Bent Glass
ASTM D3359	Standard Test Methods for Measuring Adhesion by Tape Test
CAN/CGSB-12.1	Tempered or Laminated Safety Glass
CAN/CGSB-12.3	Flat, Clear Float Glass

Underwriters Laboratories Standards 858
Standard for Safety Household Electric Ranges

Underwriters Laboratories Standards 471
Standard for Safety Commercial Refrigerators and Freezers

Underwriters Laboratories Standards 250
Standard for Safety Household Refrigerators and Freezers

C. General Requirements

C.1 Fully tempered glass may not be cut, drilled, edged, abraded or etched after tempering.

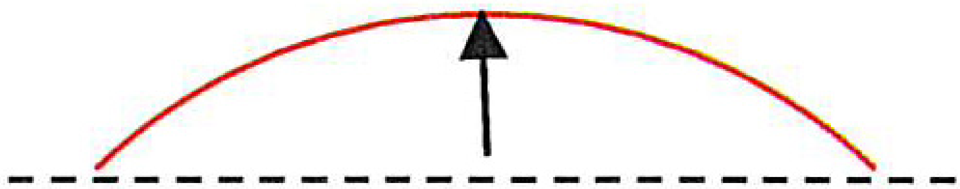
C.2 When used where temperature resistance is required, fully tempered glass will lose a percentage of its temper when held at over 260°C (500°F) for any appreciable length of time. See Time-Temperature curve in Appendix 2 for guidance.

C.3 Dimensional Tolerances, unless otherwise agreed to by the fabricator

C.3.1 The dimensions of fully tempered glass shall be within a tolerance of +/-1.6 mm (+/- 0.063 in.).

FIGURE 5

Chord of Height Tolerance



C.3.2 The fully tempered glass thicknesses are 3.0 mm (0.125 in.) through 6.0 mm (0.25 in.). Thickness tolerances shall be as specified in ASTM C1036.

C.3.3 The shape accuracy (contour) of bent glass shall be within +/- 3.2 mm (+/- 0.125 in) of the checking fixture at any point within 12.0 mm (0.5 in.) of the edge of the glass. The tolerance at the center point of the chord to height shall be +/- 2.4 mm (+/- 0.093 in) measured from the concave side. See illustration for chord to height tolerance for appliance glass.

C.3.4 Flat tempered glass shall not show warpage greater than 1.6 mm per 305 mm (0.063 in. per lineal foot) as measured within 12.0 mm (0.5 in.) of the glass edge.

C.3.5 Any localized kink centered at any tong location shall not exceed 1.6 mm (0.063 in.) in a 50.0 mm (2 in.) span.

C.3.6 There shall be no irregularities more than 3.0 mm (0.125 in.) from the edge of the glass, except tong marks, glass support marks and warpage to the extent specified in paragraph C.3.4.

C.3.7 Tong marks or support marks, unless otherwise agreed to by the fabricator, shall be within 12.7 mm (0.5 in.) of the edge of the glass. This distance should be measured from the center of the tong mark to the edge of the glass.

C.3.8 Hole Condition

C.3.8.1 Size

C.3.8.1.1 Minimum hole diameter shall be 6.0 mm (0.25 in.) or 1 times glass thickness, whichever is greater.

C.3.8.1.2 Hole diameter shall be specified a minimum of 3.0 mm (0.125 in.) larger in diameter than the part it is to accommodate.

C.3.8.2 Location, unless otherwise agreed to by the fabricator:

C.3.8.2.1 Holes shall be located to a reference corner (datum).

C.3.8.2.2 Minimum distance from edge of glass to periphery of hole shall be equal to or greater than 6.0 mm (0.25 in.) or 2 times glass thickness, whichever is greater.

C.3.8.2.3 Minimum distance between hole peripheries shall be 10 mm (0.40 in.) or 2 times glass thickness, whichever is greater.

C.3.8.2.4 Minimum distance from corner to periphery of hole shall be equal to or greater than 6-½ times glass thickness.

C.3.8.3 Tolerances, unless otherwise agreed to by the fabricator:

C.3.8.3.1 Chips and flakes at holes shall be less than 1.6 mm (0.063 in.).

C.3.8.3.2 Location of holes: +1.6 mm (+0.063 in.) with respect to distance from a specified glass edge.

C.3.8.3.3 Diameter of holes: +/- 1.6 mm (+/- 0.063 in).

C.3.8.3.4 Distance between holes or to datum corner: +/- 1.6 mm (+/- 0.063 in).

C.3.9 Decorations

C.3.9.1 Location, unless otherwise agreed to by fabricator:
The location and tolerance for decorating shall be as shown on the applicable drawings and/or master template within the following limits:

C.3.9.1.1 Decorations should not be placed within 0.8 mm (0.031 in.) of holes or glass edges.

C.3.9.1.2 Decorations should be registered parallel to a guide edge of the glass within +0.8 mm per 305 mm (+0.031 in. per 12 in.) of length, but not less than +0.8 mm (+0.031 in.).

C.3.9.1.3 The minimum width of screened letters, numbers and short lines should be 0.5 mm (0.020 in.). Minimum width of long or continuous lines should be 0.8 mm (0.030 in.).

C.4 Strength

C.4.1 When tested as described in Break Pattern Test No. D.1, glass weight of the ten largest crack-free particles shall not exceed the equivalent weight of 6452 sq. mm (10 sq. in.) of glass for that thickness.

C.4.2 Thermal Endurance

C.4.2.1 Glass uncoated or with ceramic decoration not covering more than 20 percent of any single surface area shall withstand a thermal downshock differential of 195°C (350°F), when tested as described in Test Procedure No. D.2.1 and sampled in accordance with paragraph G of this specification.

C.4.2.2 Glass with ceramic decoration exceeding 20 percent of a single surface area or containing one or more holes shall withstand a thermal downshock differential of 139°C (250°F), when tested as described in Test Procedure No. D.2.2 and sampled in accordance with paragraph G of this specification.

C.5 Surface and Interior Quality

C.5.1 Fully tempered glass shall be at least Q3 quality, sheet or glazing quality float, complying with the requirements of ASTM C1036.

C.5.2 Appearance
The decorated panel should be viewed at a distance of 1 meter (39.4 in.) to judge overall appearance. The following criteria should be used to determine acceptability:

C.5.2.1 Scattered pinholes and small opaque particles are permissible as long as they do not detract from overall appearances.

C.5.2.2 "Saw Tooth" edges of decorations are characteristic of decorative patterns and designs but shall not be of such magnitude as to be materially discernible when judging the overall appearance.

C.5.2.3 Color shall be within a reasonable commercial match of a mutually acceptable finished sample.

C.5.2.3.1 An approved color system or mutually acceptable individual samples can be used.

C.5.2.3.2 Minor color variations can be expected. These variations shall not be of a nature to prevent the part from harmonizing with other features of the appliance nor be limited by mutually acceptable limit samples.

C.5.2.4 Gloss shall be within a reasonable commercial match of a mutually acceptable finished sample.

C.5.2.4.1 Tolerance on gloss will be specified if necessary, by use of a standard gloss measuring method or by limit samples.

C.5.3 Durability

The durability of the decorations is dependent on the type of decorating materials used. Three general classes are considered: ceramic enamels, organic enamels and metallics.

C.5.3.1 Ceramic Enamels

Ceramic enamels are nearly as durable as the glass surface with the exception of the metallics (silver and gold). These exceptions shall be considered under paragraph C.5.3.3.

C.5.3.1.1 Ceramic Enamel Maturity Tests

In order to assess the maturity of the ceramic enamel, one or more of the following tests should be employed: D.3.1.1 India Ink Test, D.3.1.2 Moisture Penetration Test or D.3.1.3 Permanent Marker Pen Test.

C.5.3.1.1.1 India Ink Test: When tested as described in D.3.1.1 India Ink Test, if any ink remains on the enamel surface, it indicates porosity or insufficient cure which results in lowered adhesion, abrasion resistance and stain resistance.

C.5.3.1.1.2 Moisture Penetration Test: When tested as described in D.3.1.2 Moisture Penetration Test, by using an intense light, observe the enamel from the non-decorated side. If a wet spot can be observed from the non-decorated side the enamel fails or is not mature. This indicates an insufficient cure, which results in lowered adhesion and abrasion resistance.

C.5.3.1.1.3 Permanent Marker Pen Test: When tested as described in D.3.1.3 Permanent Marker Pen Test, the glass enamel is insufficiently cured if, when viewed through the glass, the marker ink can be seen to have migrated through the enamel to the enamel-substrate interface.

Darker inks may be visible through the glass; however, this may indicate incomplete opacity, rather than lack of enamel maturation. The ink must be seen to have migrated to the enamel-substrate interface in order to indicate an insufficient cure.

C.5.3.1.2 Ceramic Enamel Test for Acid Resistance
When tested as described in Ceramic Enamel Test for Chemical Resistance Procedure No. D.3.2, check for degree of stain on treated spot.

In the case of first surface decoration: limit acceptability to Grades 1 through 3 for leaded enamels; Grades 1 through 4 for non-leaded enamels.

In the case of second surface decoration: limit acceptability to Grades 1 through 3 for leaded enamels; Grades 1 through 5 for non-leaded enamels.

C.5.3.2 Organic Enamels
These decorative enamels should be used only in areas where low mechanical abrasion, minimum solvent action and low temperatures are expected.

The following test results should be used to determine the acceptability of an organic enamel part:

C.5.3.2.1 Adhesion: When tested, as described in D.3.3 Organic Enamels Adhesion Test Procedure, the coating should not lift. Please reference ASTM D3359.

C.5.3.2.2 Adhesion After Water Immersion
When tested, as described in D.3.4 Organic Enamels Adhesion After Water Immersion Test Procedure, the coating should not blister or bubble after 24 hours of immersion. After immersion and the coating dries, there should be 100 percent retention of the crosshatched area after the tape pull test. Please reference ASTM D3359.

C.5.3.2.3 When tested as described below in Organic Enamels Humidity Resistance Test Procedure, paragraph D.3.5, the coating should show no adverse effects upon drying. (Fine blister and poor adhesion will likely be noted initially on removal from humidity exposure.)

C.5.3.3 Metallics
These films are porous and demonstrate low durability. They should not be used in areas of exposure to abrasion or corrosive atmospheres. Although overcoating the metallics with an overcoating material imparts the durability of the overcoating material, this may result in discoloration and loss of metallic luster.

D. Test Procedures

D.1 Break Pattern Test
Glass selected for impact test shall be broken by means of a center punch hit with a hammer at a point 25.0 mm (1 in.) from edge and 50.0 mm (2 in.) from any corner. A spring-loaded center punch may also be used.

Note: Area within a 100.0 mm (4 in.) radius of the point of impact shall not be used for break pattern requirements in paragraph C.4.1.

D.2 Non-Destructive Evaluation of Temper Level
In certain instances, measurement of residual surface and/or edge stress following Standard Test Method ASTM C1279, Procedures A or B, may be used in addition to break pattern testing to confirm that temper level meets the minimum standards for fully tempered glass (Kind FT) mandated by ASTM C1048; this is not a substitute for break pattern testing.

D.3 Thermal Shock Resistance

D.3.1
A full-size panel shall be heated in a temperature-controlled oven at a temperature of 216°C (420°F). Once the glass reaches the control temperature, it shall be maintained at this temperature for 15 minutes. The glass should then be immersed into a water tank of 21°C (70°F). The glass shall not fracture as a result of the thermal shock exposure.

D.3.2
A full-size panel shall be heated in a temperature-controlled oven at a temperature of 160°C (320°F). Once the glass reaches the control temperature, it shall be maintained at this temperature for 15 minutes. The glass should then be immersed into a water tank at 21°C (70°F). The glass shall not fracture as a result of the thermal shock exposure.

D.4 Durability Test for Decorations

D.4.1 Ceramic Enamel Maturity Tests
Select either D.3.1.1 (India Ink Test), D.3.1.2 (Moisture Penetration Test) or D.3.1.3 (Permanent Marker Pen Test) to test for ceramic enamel maturity.

D.4.1.1 India Ink Test
The part must be at ambient temperature. On the surface of the enamel, at points approximately 50 mm (2 in.) from each outer edge of the decoration and again at a point on the enamel near the geometric center of the part, lightly scrape the fired surface with a razor blade. Draw a line on the enamel with India ink and allow to dry for 15 minutes. Then scrub with an assay brush and "Bon Ami" (feldspar) paste. The India ink should wash off without any deterioration of the enamel.

D.4.1.2 Moisture Penetration Test
The part must be at ambient temperature. On the surface of the enamel, at points approximately 50 mm (2 in.) from each outer edge of the decoration and again at a point on the enamel near the geometric center of the part, apply a drop of water to the enamel or touch the enamel with a damp cloth, paper towel or cotton ball.

D.4.1.3 Permanent Marker Pen Test
The part must be at ambient temperature. On the surface of the enamel, at points approximately 50 mm (2 in.) from each outer edge of the decoration and again at a point on the enamel near the geometric center of the part, draw a line at least 25 mm (1 in.) in length parallel to the edge of the part. It may be necessary to overprint this line one or more times in order to ensure an adequate deposit of ink. The marker should be a fine point or thicker grade [such as a "Sharpie" brand or equivalent]. On white or light-colored enamels, yellow provides the best contrast between fully matured and not matured conditions. Black or other color marker pens may also be used.

D.4.2 Ceramic Enamel Test for Chemical Resistance
Place several drops of a 10 percent citric acid solution (must be freshly prepared) on a normally glossed enamel surface at room temperature and cover with a 25 mm (1 in.) diameter watch glass. After 15 minutes, rinse in water and dry.

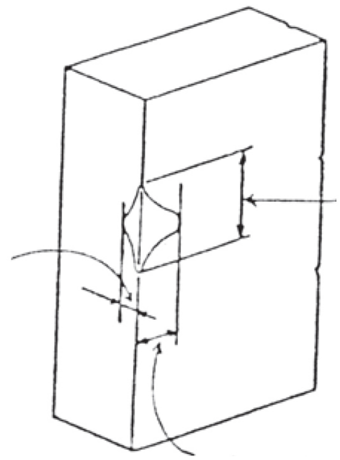
Ratings

Grade 1	No attack apparent.
Grade 2	Appearance of iridescence or visible stain on the exposed surface when viewed at a 45° angle but not apparent at angles less than 30°.
Grade 3	Definite stain which does not blur reflected images and is visible at angles less than 30°.
Grade 4	Definite stain with a gross color change or strongly iridescent surface visible at angles less than 30° and which may blur reflected images.
Grade 5	Surface dull or matte with chalking possible.
Grade 6	Significant removal of enamel with pinholing evident.
Grade 7	Complete removal of enamel in exposed area.

D.4.3 Onic Enamel Adhesion Test – bond of cured, dry enamel to substrate
The cured organic coating is scored in a crosshatched pattern with a sharp knife or razor blade. In an area on the cured surface free of blemishes, make at least 5 or 6 parallel cuts about 20 mm (.80 in.) long that are 1 mm (.04 in.) apart. Perpendicular to the first set of cuts, make a second set of at least 5 or 6 parallel cuts 1 mm (.04 in.) apart. Make sure the cuts go completely through the organic coating to the substrate. Permacel 99 tape is pressed tightly over markings. Tape is lifted rapidly. None of the enamel should be lifted off with the tape.

FIGURE 6

Edge Preparation



D.4.4 Organic Enamel Adhesion Test After Water Immersion – bond of cured enamel after water immersion
Sample should be immersed in water at 21°C (70°F) for 24 hours and allowed to air dry for a minimum of 30 minutes. After immersion and the coating has dried, a crosshatched pattern is made on the organic coating following the procedure described in D.3.3. Permacel 99 tape is pressed over the crosshatched pattern; one to two minutes after application the tape is removed with a rapid pull. None of the enamel should be lifted off with the tape.

D.4.5 Organic Enamel Humidity Resistance Test
Coated samples are exposed to 95+ percent RH 49°C (120°F) for 120 hours, and then allowed to air dry for a minimum of 30 minutes.

E. Edge Finish

E.1 Unless otherwise specified, all glass edges shall be swiped, seamed or ground prior to tempering.

E.2 Chips
Edge chips shall not exceed the greater of glass thickness or 6 mm (.24 in.) in width (W), length (L) ≤ 2 times the width, and depth (D) ≤ 50 percent of the glass thickness (see Figure 5 above).

F. Labeling

The manufacturer’s symbol or trademark may be permanently and legibly affixed to each glass.

G. Methods of Sampling

The frequency of sampling shall be sufficient to provide adequate control of the quality commensurate with production volume and recognized statistical quality control practices. In the event of rejects, they shall be properly identified and handled in accordance with accepted good practices and maintained in equal condition as received until inspected and released by the vendor of the parts.

SECTION 6— SPECIFICATION NO. 64-3-16A REV. #7

Specification for Fully Tempered Safety Glass for General Construction Usage: Consumer Products Safety Commission (CPSC 16 CFR 1201)

A. Scope

This specification shall cover flat glass that has been fully tempered to be used in general construction requiring conformity to CPSC 16 CFR 1201. Heat-strengthened and ceramic enameled spandrel glasses are not covered by this specification.

B. Applicable Specifications

The following specifications form a part of this specification to the extent specified herein:

ASTM C1036	Standard Specification for Flat Glass
ASTM C1048	Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass
CPSC 16 CFR 1201	Safety Standard for Architectural Glazing Materials
CAN/CGSB – 12.3	Flat, Clear Float Glass
CAN/CGSB – 12.20	Structural Design of Glass for Buildings

C. Objective

In many applications, fully tempered glass is the logical choice for a “safety” glass, due to its considerable resistance to impact, pressure and torsional forces, plus its characteristic break pattern. It is the objective of the specification to provide a means by which glass sold and identified as being “Tempered Safety Glass” can be shown to be fully tempered, as required by CPSC 16 CFR 1201. This standard does not include heat-strengthened glass.

D. General Requirements

In order to assure that the manufacturing methods produce the desired safety properties, the following tests are prescribed for fully tempered glass in commercially available thicknesses.

D.1 Impact Test

D.1.1 Specimens to be Tested

D.1.1.1 Condition of Specimens
All specimens shall be tested as supplied by the manufacturer, following removal of any temporary protective masking materials. No tests shall be commenced before the specimens have been stored in the laboratory for four hours. Specimens shall be arranged to permit free circulation of air to all surfaces during this period.

D.1.1.2 Impact Specimens
Impact specimens shall be of the largest size manufactured up to a maximum width of 0.86 m (34 in.) and a maximum height of 1.9 m (76 in.). Specimens shall be tested for each nominal thickness offered by the manufacturer.

D.1.2 Test Apparatus
The test apparatus consists of two basic parts: 1) the test frame and 2) the impactor.

D.1.2.1 Test Frame (see Figures 1, 2 and 3)
The impact test shall be constructed to minimize movement and deflection of its members during testing. For this purpose, the structural framing and bracing members shall be steel angles 7.7 cm by 12.7 cm by 0.7 cm (3 in. by 5 in. by .025 in.) or other sections and materials of equal or greater rigidity.

The structural framing shall be welded or securely bolted at the corners and braced by one of the alternate methods shown in Figure 1 and shall be securely bolted to the floor.

The subframe for securing the test specimen on all four edges shall be reinforced at each corner. The material is shown as wood in Figure 3, but other materials may be used provided the test specimen will contact only the neoprene strips.

Any reasonable means may be used to secure the subframe to the test frame so long as the mounting is secure and the pressure on the glazing in the subframe is not significantly altered when the subframe is removed.

Pressures on the test specimen shall be controlled and the compression of the neoprene strips shall be between 10 and 15 percent of the original thickness of the neoprene. Securing methods such as wind bolts and clamps shall be uniformly spaced no greater than 45 cm (18 in.) apart, with no fewer than two on any edge. To limit the compression of the neoprene and prevent distortion of the subframe, metal shims of an appropriate thickness shall be used as shown in Figure 3.

D.1.2.2 Impactor (see Figure 4)
The impactor shall be a leather punching bag as shown in Figure 4 of this section. The bag shall be filled with No. 7-½ chilled lead shot to a total weight of completed assembly after taping, as shown in Figure 4, of 45.36 ± 0.11 kilograms (100 pounds ± 4 ounces). The rubber bladder shall be left in place and filled through a hole cut into the upper part. After filling the rubber bladder, the top should be either twisted around the threaded metal rod below the metal sleeve or pulled over the metal sleeve and tied with a cord or leather thong. Note that the hanging strap must be removed. The bag should be laced in the normal manner. The exterior of the bag shall be completely covered by 12.7 mm (0.50 in.) wide glass filament reinforced pressure-sensitive tape.

The impactor shall be supported as shown in Figure 2. Provisions shall be made for raising the impactor to drop heights of up to 1.22 m (48 in.). At its release, it shall have been supported so that the pin going through its center was in line with the steel cable. The impactor shall not wobble or oscillate after its release.

D.1.3 Test Procedures
Each specimen shall be struck within 50.8 mm (2 in.) of its geometric center with the impactor dropped from a single height, designated according to the product category. Specimens for Category I shall be impacted one time from a drop height of 458 m to 470 mm (18 in. to 18-½ in.). Specimens for Category II shall be impacted one time from drop height of 1.22 m to 1.23 m (48 in. to 48.5 in.). For all specimens that are not symmetric from surface to surface, an equal number of specimens shall be impacted on each side.

D.1.4 Interpretation of Results
A glazing material may be qualified for use in both Category I and Category II products if it meets the impact requirements for Category II. A glazing material shall be judged to pass the impact test if the specimen tested meets any one of the criteria listed below.

D.1.4.1 When breakage occurs, what appear to be the 10 largest crack-free particles shall be selected within 5 minutes subsequent to the test and shall weigh no more than the equivalent weight of 64 sq. cm (10 sq. in.) of the original specimen. For the purposes of this section, “particle” means a portion of a broken test specimen which is determined by identifying the smallest possible perimeter around all points in the portion of the broken test specimen, always passing along cracks or exposed surfaces.

D.1.4.2 The specimen does not break.

D.1.5 Certificate of Compliance
Manufacturers and private labelers of glazing materials covered by Part 1201 shall comply with the requirements of Section 14 of the Consumer Product Safety Act (15 U.S.C. 2063) and regulations issued under Section 14.

D.2 Dimensional Tolerances

D.2.1 Thickness

TABLE 4

Thickness for Transparent Flat Glass (Sheet, Plate and Float)

Thickness			Tolerance Thickness Range			
Metric Designation	Traditional Designation	Nominal Decimal Inch	Min. (mm)	Max. (mm)	Min. (in.)	Max (in.)
3.0 mm	Double ⅛ in.	0.12	2.92	3.40	0.115	0.134
4.0 mm	5⁄32 in.	0.16	3.78	4.19	0.149	0.165
5.0 mm	3⁄16 in.	0.19	4.57	5.05	0.180	0.199
6.0 mm	¼ in.	0.23	5.56	6.20	0.219	0.244
8.0 mm	5⁄16 in.	0.32	7.42	8.43	0.292	0.332
10.0 mm	⅜ in.	0.39	9.02	10.31	0.355	0.406
12.0 mm	½ in.	0.49	11.91	13.49	0.469	0.531
16.0 mm	⅝ in.	0.63	15.09	16.66	0.595	0.656
19.0 mm	¾ in.	0.75	18.26	19.84	0.719	0.781
22.0 mm	⅞ in.	0.87	21.44	23.01	0.844	0.906
25.0 mm	1 in.	1.00	24.61	26.19	0.969	1.031

Note: For tolerances of thicknesses not shown and for patterned glass, consult ASTM C1036.

D.2.2 Canadian Standards CAN/CGSB-12.2-M91 and CAN/CGSB-1⅔-M91 thickness and tolerance requirements are as follows:

TABLE 5

CAN/CGSB Thickness and Tolerance Requirements

Thickness				
Designation	Sheet (12.2-M91) Min.	Max.	Plate and Float (12.2-M91) Min.	Max.
3 mm	2.5 mm	3.5 mm	2.5 mm	3.5 mm
4 mm	3.5 mm	4.5 mm	3.5 mm	4.5 mm
5 mm	4.5 mm	5.5 mm	4.5 mm	5.5 mm
6 mm	5.5 mm	6.5 mm	5.5 mm	6.5 mm
8 mm	7.2 mm	8.8 mm	7.2 mm	8.8 mm
10 mm	9.0 mm	11.0 mm	9.0 mm	11.0 mm
12 mm	11.0 mm	13.0 mm	11.0 mm	13.0 mm
15 mm	14.0 mm	16.0 mm	14.0 mm	16.0 mm
19 mm	18.0 mm	20.0 mm	18.0 mm	20.0 mm
22 mm			21.0 mm	23.0 mm
25 mm			24.0 mm	26.0 mm

D.2.3 Rectilinear Tolerances
Dimensions not over 2.44 m (96 in.) or +1.6 mm (+0.0625 in.)

Not over 3.716 m² (40 sq. ft.) -3.0 mm (-0.125 in.)

Dimensions over 2.44 m (96 in.) or +1.6 mm (+0.0625 in.)

Over 3.716 m² (40 sq. ft.) -5.0 mm (-0.188 in.)

Strips up to 2.44 m (96 in.) ±3.0 mm (± 0.125 in.)

Strips over 2.44 m (96 in.) ±5.0 mm (±0.188 in.)

A strip shall be determined by the following table:
Up to 1.83 m (72 in.) length: If the width is equal to or less than the length, divided by 8.

From 1.83-2.44 m (72 to 96 in.) length: If the width is equal to or less than the length, divided by 7.

Over 2.44 m (96 in.) length: If the width is equal to or less than the length, divided by 5.

TABLE 6

Overall Bow, Maximum

Nominal Thickness Designation mm (in.)	0–50 (0–20)	>50–90 (>20–35)	>90–120 (>35–47)	>120–150 (>47–59)	>150–180 (>59–71)	>180–210 (>71–83)	>210–240 (>83–94)	>240–270 (>94–106)	>270–300 (>106–118)	>300–330 (>118–130)	>330–370 (>130–146)	>370–400 (>146–158)
	Maximum Bow, mm (in.)											
3 (1/8)	3.0 (0.12)	4.0 (0.18)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.87)	19.0 (0.75)	--	--	--
3 (1/8) Alternate Method*	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	3.0 (0.12)	5.0 (0.20)	6.0 (0.24)	7.0 (0.28)	8.0 (0.31)	10.0 (0.39)	--	--	--
4 (5/32)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.26)	9.0 (0.35)	12.0 (0.47)	14.0 (0.56)	17.0 (0.67)	19.0 (0.75)			
5 (3/16)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.26)	9.0 (0.35)	12.0 (0.47)	14.0 (0.56)	17.0 (0.67)	19.0 (0.75)			
6 (1/4)	2.0 (0.08)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.26)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	21.0 (0.83)	24.0 (0.94)
8 (5/16)	2.0 (0.08)	2.0 (0.08)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	6.0 (0.24)	8.0 (0.31)	10.0 (0.39)	13.0 (0.51)	15.0 (0.59)	18.0 (0.71)	20.0 (0.79)
10 (3/8)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	5.0 (0.20)	6.0 (0.24)	7.0 (0.26)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)
12 22 (1/2 7/8)	1.0 (0.04)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	5.0 (0.20)	5.0 (0.20)	7.0 (0.26)	10.0 (0.39)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)

*Values apply to 3 mm (1/8 in.) thickness only when the alternative checking procedure in 10.7.2 is used.

D.2.4 Flatness

D.2.4.1 Localized Bow – 1.6 mm per 300 mm of length (0.0625 in. per linear foot) span permissible.

D.2.4.2 Any localized kink centered at any tong location shall not exceed 1.6 mm (0.0625 in.) over a 50 mm (2 in.) span.

D.2.4.3 Overall bow tolerances for flat fully tempered glass are determined with the glass placed in a freestanding, vertical position, resting on supports at three quarter points. With the glass in this position, place a straight edge across the concave surface parallel to and within one inch from the edge and measure the maximum deviation with a taper or feeler gauge, or a dial indicator may be used. Maximum tolerances are shown in Table 6.

D.3 Surface and Interior Visible Quality

D.3.1 As specified by ASTM C1036 for the quality level ordered.

D.3.2 All edge or surface treatment should be done before tempering.

E. Edge Finish

Fully tempered glass can be furnished with edges clean cut, sawed, seamed, ground, polished, penciled or shaped.

F. Labeling

Fully tempered safety glass meeting the above requirements shall be permanently marked with manufacturers' distinctive marks, including any other marking required for its intended use by any responsible regulatory body including the Consumer Product Safety Commission, and may include the Specification No. 64-3-16a. The marking can be accomplished by sandblasting, etching, ceramic paint stenciling, or by other means that are permanent and cannot be removed intact. The mark should be located so as to be visible when the glass is installed in its final position, and should indicate in some manner that the glass is fully tempered.

G. Sampling Program

In accordance with CPSC 16 CFR 1201, all manufacturers must issue a certificate of compliance and be based on a reasonable testing program. The certificate may take the form of the label on the glass.

NGA endorses the general concept that satisfactory sampling programs should be developed by cooperative effort of manufacturers and purchasers, in the absence of any specific requirements in state or federal regulations.

FIGURE 7

Glass Impact Test Structure and Frame

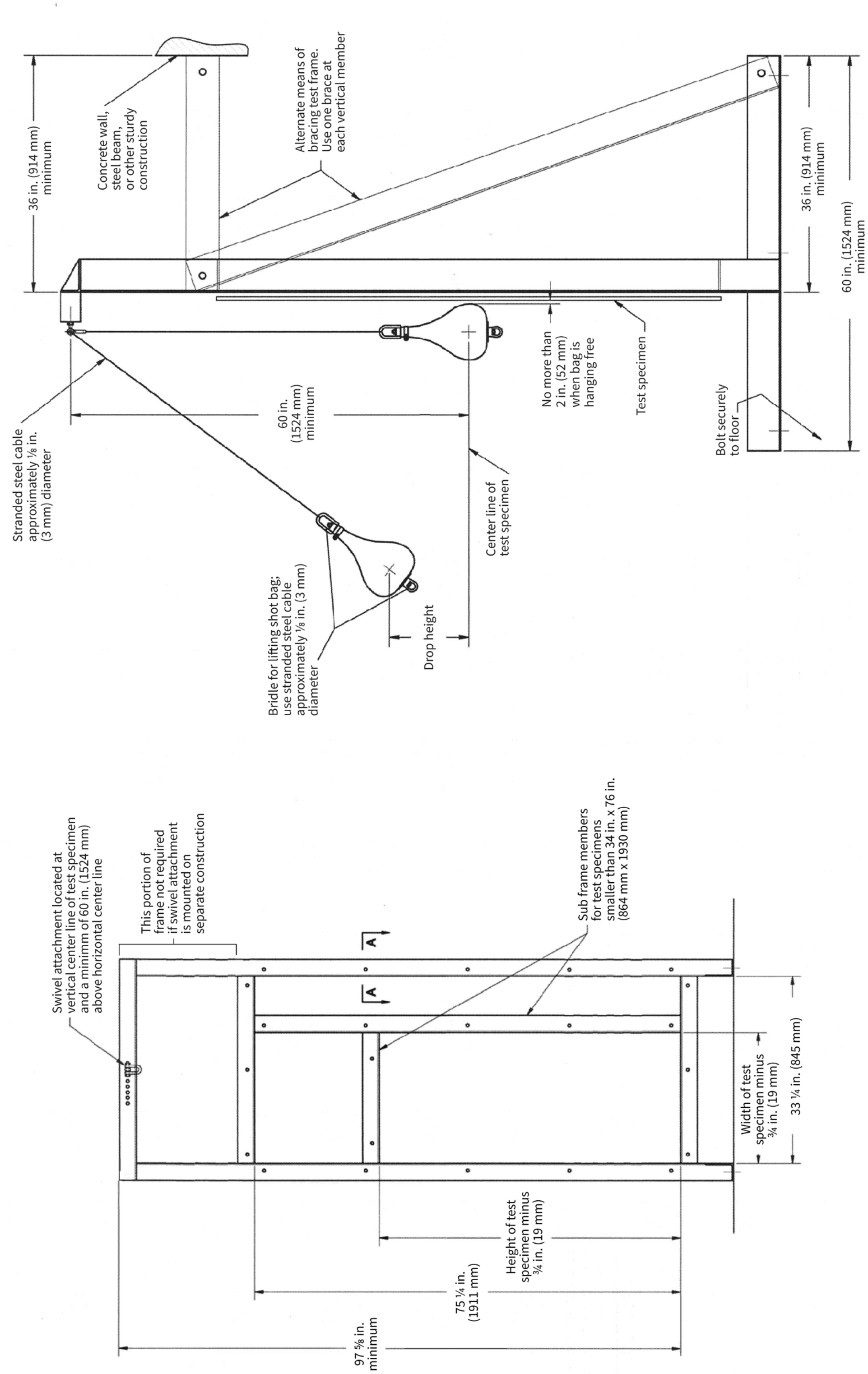


FIGURE 8

Glass Impact Test Structure

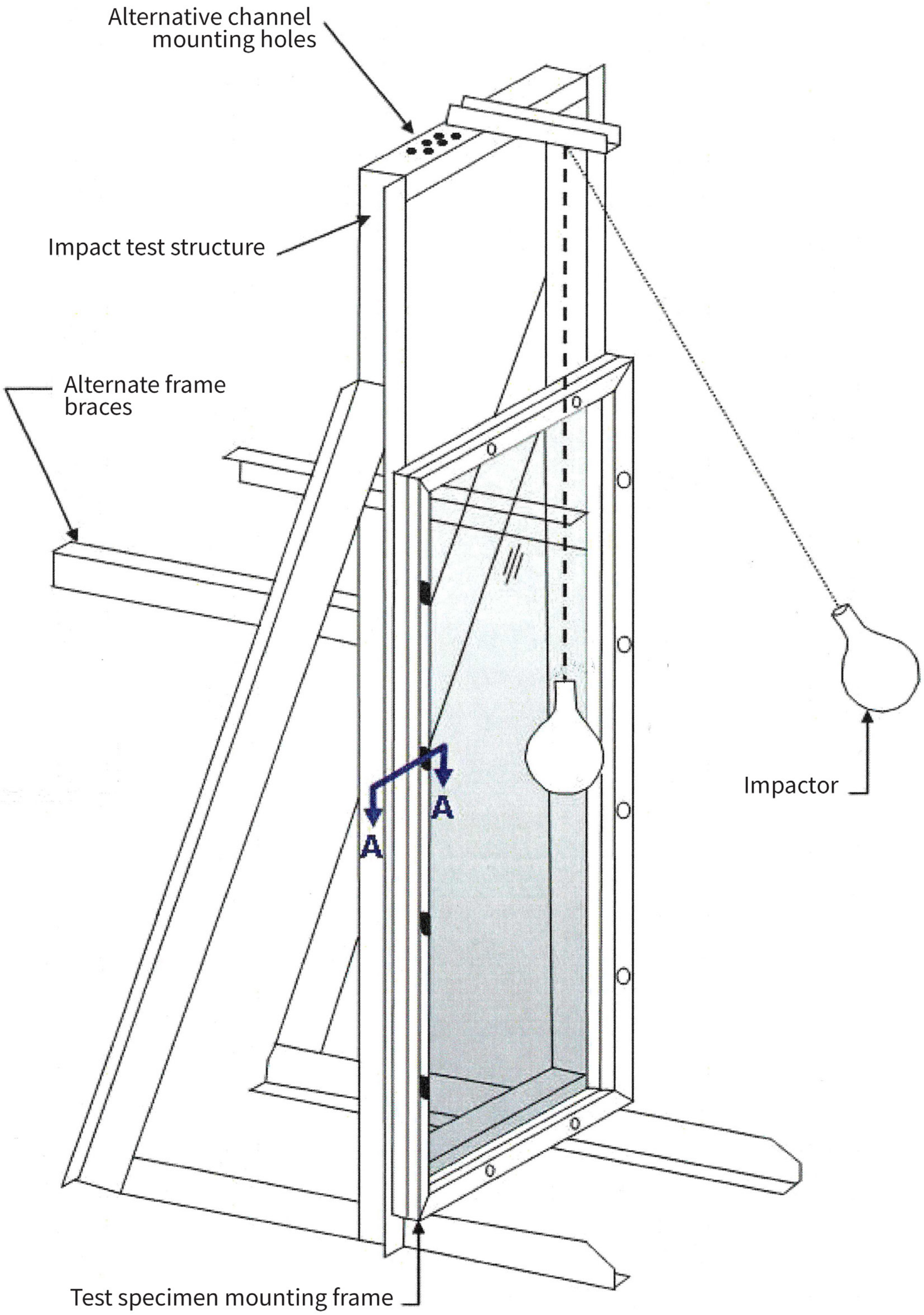


FIGURE 9

Impactor
Note: for metric values, refer to D.12

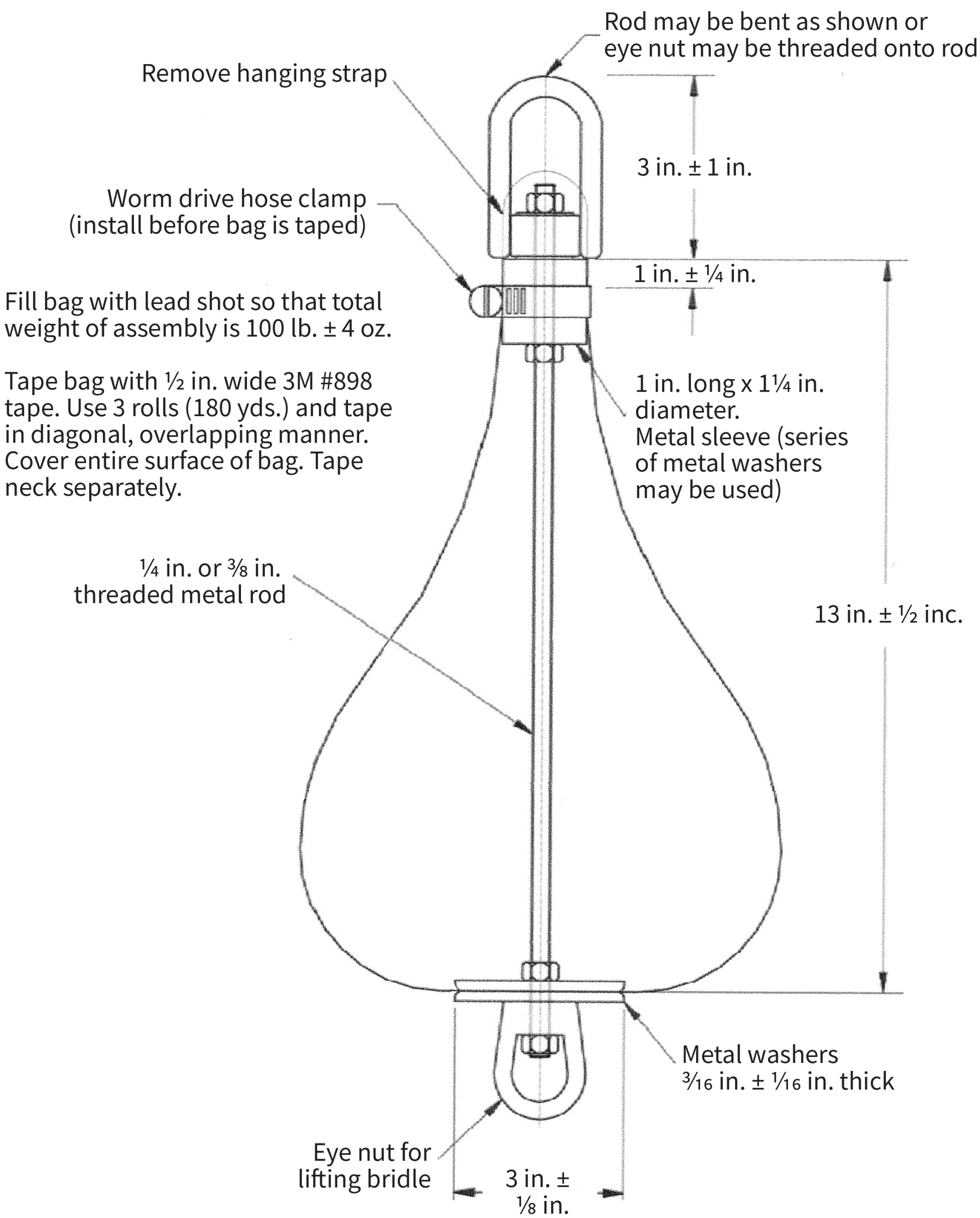
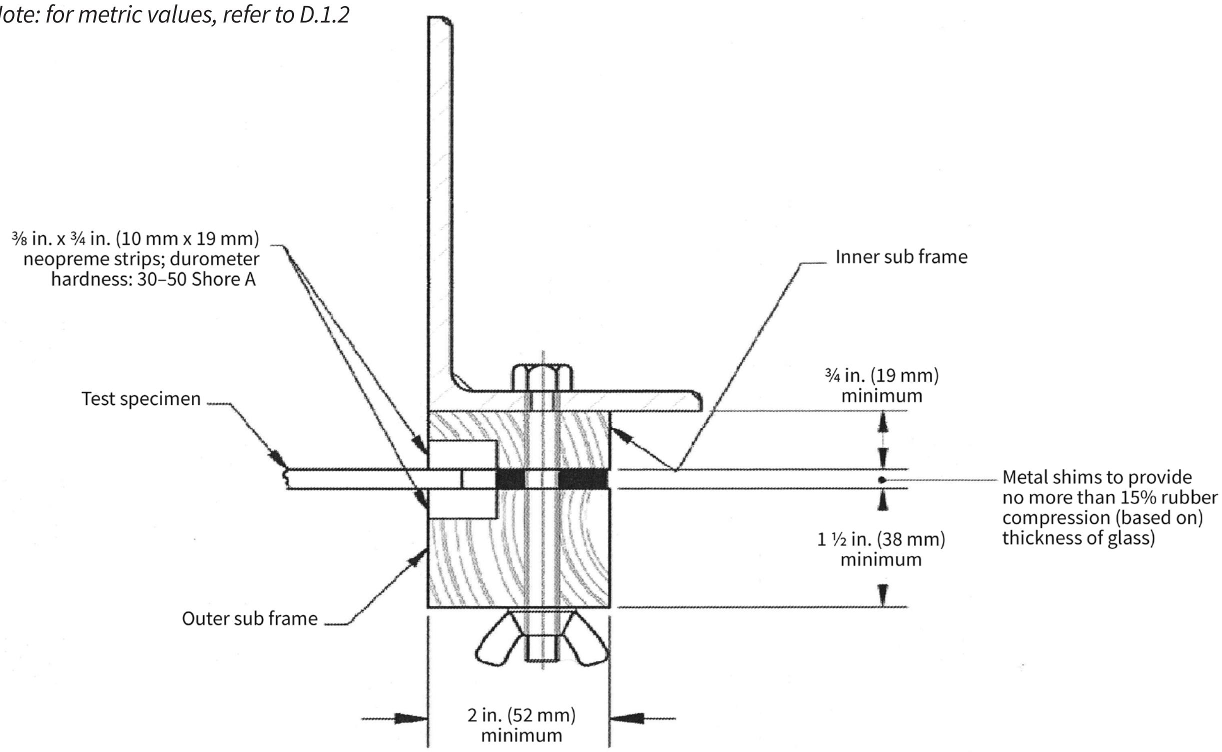


FIGURE 10

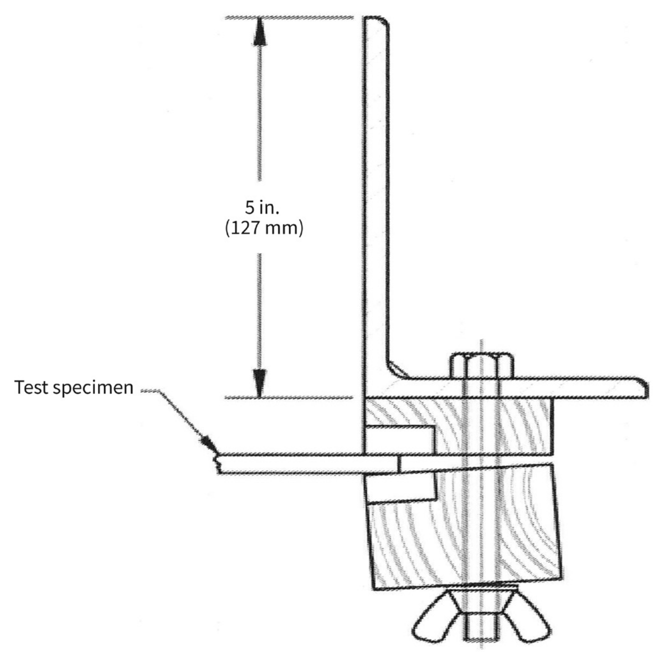
Properly & Improperly Clamped

Note: for metric values, refer to D.1.2

CORRECT



INCORRECT



SECTION 6.1— SPECIFICATION NO. 64-3-16B REV. #5

Specification for Fully Tempered Safety Glass for General Construction Usage: American National Standards Institute (ANSI Z97.1 – 2015)

A. Scope

This specification shall cover flat glass that has been fully tempered to be used in general construction requiring conformity to ANSI Z97.1-2015. Heat-strengthened and ceramic enameled spandrel glasses are not considered safety glazing materials and are not covered by this specification.

B. Applicable Specifications

The following specifications form a part of this specification to the extent specified herein:

ASTM C1036	Standard Specification for Flat Glass
ASTM C1048	Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass
ANSI Z97.1-2015	Safety Glazing Materials Used in Buildings—Safety Performance Specifications and Methods of Test
CAN/CGSB – 12.3	Flat, Clear Float Glass
CAN/CGSB– 12.20	Structural Design of Glass for Buildings

C. Objective

In many applications, fully tempered glass is the logical choice for a "safety" glass, due to its considerable resistance to impact, pressure and torsional forces, plus its characteristic "break pattern." It is the objective of the specification to provide a means by which glass sold and identified as being "Tempered Safety Glass" can be shown to be fully tempered, as required by ANSI Z97.1.

D. General Requirements

In order to assure the manufacturing methods produce the desired safety properties, the following tests are prescribed for fully tempered glass in commercially available thicknesses.

D.1 Impact Test

D.1.1 Specimens to be Tested

D.1.1.1 Condition of Specimens
Tests shall be applied to four specimens as submitted by the manufacturer, except that any temporary protective masking material shall be removed prior to test. The specimens shall be separated and allowed to rest for at least four hours at temperatures between 18°C (65°F) and 29°C (85°F) to ensure uniform temperatures throughout each specimen at the time of test.

D.1.1.2 Thickness
The thickness of the specimens to be tested shall be recorded as a nominal thickness in accordance with accepted industry practice for glass, as set forth in the most recent issue ASTM C1036 and/or Canadian Standard CAN/CGSB-

12.2-M91 and CAN/CGSB-12.3-M91. No manufacturer shall mark or advertise as passing the tests, herein described, any product of different nominal thickness than the samples passing the tests.

D.1.1.3 Classification
Safety glazing panels used in buildings may be of relatively large or small size, and many manufacturers limit their manufacturing activities to special product lines that require only the relatively small panels. A description of the specimens to be tested is set forth in Table 7.

TABLE 7

Description of Specimens

Approval Classification	**Specimen Dimensions**
Limited (for all sizes up to and including dimension of specimens tested) x 1.9 m (76 in.)	Largest size commercially produced by the manufacturer up to 86 cm (34 in.)
Unlimited (for all sizes)	86 cm (34 in.) x 1.9 m (76 in.)

No manufacturer submitting specimens that are only in the Limited Classification shall mark or advertise as passing the tests, herein described, for any product with either dimension greater than those of the specimens passing the tests.

D.1.2 Test Apparatus
The test apparatus consists of two basic parts: 1) the test frame, and 2) the impactor.

D.1.2.1 Test Frame
The test frame shall be designed to minimize movement and deflection of its members during testing. For this purpose, the structural framing and bracing members shall be steel channels (4U7.25), or other sections and materials of equal or greater rigidity. This channel has a moment of inertia of 11.43 mm (4.5 in.) when used as shown in Figure 10.

This structural framing shall be welded or securely bolted at the corners to minimize racking or twisting during testing. Also, it shall be securely bolted to the floor and braced by one of the alternate methods shown in Figure 10.

The clamping frame for securing the test specimen on all four edges may be fastened at the corners or may be separate members. This is shown in wood in Figure 10. Other materials may be used, providing there is positive assurance that the test specimen will only contact the neoprene strips.

To allow for adjustability of the clamping frame members to accommodate samples of varying widths, the horizontal clamping frame members may be 70 mm (2.75 in.) shorter than the specimen width. This would allow a non-supporting area of less than 25 mm (1 in.) at each corner. The vertical clamping frame members shall be as long as the specimen height to give full support to the vertical edge of the sample.

The wing bolt shown in Figure 10 indicates one method of securing the clamping frame to the test frame. Alternate methods such as toggle clamps or C clamps may be used. To provide and limit elastomeric rubber compression and avoid sub-frame distortion, non-compressible shims appropriate to glazing thickness shall be used to separate the inner and outer parts of the sub-frame.

The elastomeric rubber strip, the only element of the sub-frame that the test specimen shall come in contact with, shall be 20 mm (0.8 in.) wide by 10 mm (0.4 in.) thick and have a Shore-A hardness of 40 ± 10 (ASTM D2240, Standard Test Method for Rubber Property - Durometer Hardness). Secured methods such as wing bolts and clamps shall be uniformly spaced no greater than 45.7 cm (18 in.) apart with no fewer than two on an edge.

Other modifications which clearly do not alter the function or performance of the test frame are acceptable.

D.1.2.2 Impactor
The impactor shall be a standard leather punching bag modified as shown in Figure 11 or Figure 12. The bag shall be filled with No. 7-½ chilled lead shot to a total weight of completed assembly of 45.36 + 0.11 kg (100 lbs. + 4 oz.). The rubber bladder shall be left in place and filled through a hole cut into the upper part. After filling the rubber bladder, the top should be either twisted around the threaded metal rod or chain below the metal sleeve or pulled over the metal sleeve and tied with a cord or leather thong. Note that the hanging strap must be removed. The bag should be laced in the normal manner. The exterior of the bag shall be completely covered with 13 mm (.5 in.) tape as indicated in Figures 11 and 12.

During testing, the impacting object (bag), shall be covered with a loosely draped terry-cloth towel, or terry-cloth towel shall be loosely hung directly in front of the impact area on the glazing material.

D.1.3 Test Procedure
The impacting object (shot bag) constructed in accordance with Figure 11 or 12, shall be suspended from an overhead support, so located that the impactor when at rest will, at its maximum diameter, be no more than 13 mm (.5 in.) from the surface of the specimen and no more than 51 mm (2 in.) from the center of the specimen (see Figure 10).

Each specimen shall be centered within the neoprene mounting strips before impacting, such that approximately 10 mm (.375 in.) grip is provided on each edge of the specimen.

Select a drop height classification of Class A (48-48.5 in.) or Class B (18-18.5 in.). Each specimen shall be struck at the center with the impacting object swinging in a pendulum arc from the appropriate drop height.

Materials that are asymmetrical from surface to surface shall be impacted by two specimens on one surface and two specimens on the other surface.

D.1.4 Interpretation of Results
The impact test shall be judged to have been satisfactorily completed if any one of the following safety criteria shall be met by each of the four specimens tested:

D.1.4.1 When disintegration occurs at 457 mm (18 in.), or 1.219 m (48 in.), the 10 largest crack-free particles selected within 5 minutes subsequent to test shall weigh no more than the equivalent weight of 65 sq. cm (10 sq. in.) of the original test specimen.

D.1.4.2 If the specimen does not break after impact, the Center Punch Fragmentation Test shall be performed (D.2).

D.1.4.3 Specimen is classified as safety glazing Type II.

D.2 Center Punch Fragmentation Test

D.2.1 Equipment
- A sharp impactor such as a point hammer of about 75 g (2.65 ounces) mass, or a spring-loaded center punch or similar appliance can be used.
- A means of specimen support to prevent scattering of fragments.
- A calibrated scale.
- A calibrated micrometer.

D.2.2 Procedure
Strike the test specimen 25 mm (1 in.) inboard of the longest edge at its midpoint until fracture occurs. Within five minutes after fracture, select and weigh the 10 largest crack-free particles. Measure the thickness of the largest particle.

D.2.3 Interpretation of Results
The total weight of the 10 largest crack-free particles shall weigh no more than the equivalent weight of 65 sq. cm (10 sq. in.) of the original test specimen. No one particle shall be longer than 102 mm (4 in.)—excluding an area of radius of 102 mm (4 in.) around the point of impact and 25 mm (1 in.) around the perimeter of the specimen.

D.3 Certificate of Compliance
Each manufacturer of fully tempered glass intended for use in general construction shall have its product sampled and tested in the manner described herein by a recognized independent certification program at intervals not exceeding six months. Results of such tests shall be produced upon demand.

D.4 Dimensional Tolerances

D.4.1 Thickness
(See table 8).

D.4.2 Rectilinear Tolerances
Dimensions not over 2.44 m (96 in.) or + 1.6 mm (+.0625 in.)

Not over 3.716 m² (40 sq. ft.) -3 mm (-.125 in.)

Dimensions over 2.44 m (96 in.) or +1.6 mm (+.0625 in.)

over 3.716 m² (40 sq. ft.) -5 mm (-.1875 in.)

Strips up to 2.44 m (96 in.)	+3 mm (+.375 in.)
Strips over 2.44 m + .1875 in.	(+ 5 mm)

A strip shall be determined as follows:

Up to 1.83 m (72 in.) length: If the width is equal to or less than the length, divided by 8.

From 1.83 - 2.44 m (72 – 96 in.) length: If the width is equal to or less than the length, divided by 7.

Over 2.44 m (96 in.) length: If the width is equal to or less than the length, divided by 5.

D.4.3 Flatness

D.4.3.1 Localized Bow 1.6 mm per 300 mm of length (–.0625 in. per linear foot) span permissible.

D.4.3.2 Any localized kink centered at any tong location shall not exceed 1.6 mm (.625 in.) over a 50 mm (2 in.) span. points. With the glass in this position, place a straight edge across the concave surface parallel to and within 25.4 mm (1 in.) from the edge and measure the maximum deviation with a taper or feeler gauge, or a dial indicator. Maximum tolerances are shown in Table 6.

D.5 Surface and Interior Visible Quality

D.5.1 As specified by ASTM C1036 for the quality level ordered.

D.5.2 All edge or surface treatment should be done before tempering.

TABLE 8

Thickness for Transparent Flat Glass (Sheet, Plate and Float)

Thickness			Tolerance Thickness Range			
Metric Designation	Traditional Designation	Nominal Decimal Inch	Min. (mm)	Max. (mm)	Min. (in.)	Max (in.)
3.0 mm	Double ⅛ in.	0.12	2.92	3.40	0.115	0.134
4.0 mm	5⁄32 in.	0.16	3.78	4.19	0.149	0.165
5.0 mm	3⁄16 in.	0.19	4.57	5.05	0.180	0.199
6.0 mm	¼ in.	0.23	5.56	6.20	0.219	0.244
8.0 mm	5⁄16 in.	0.32	7.42	8.43	0.292	0.332
10.0 mm	⅜ in.	0.39	9.02	10.31	0.355	0.406
12.0 mm	½ in.	0.49	11.91	13.49	0.469	0.531
16.0 mm	⅝ in.	0.63	15.09	16.66	0.595	0.656
19.0 mm	¾ in.	0.75	18.26	19.84	0.719	0.781
22.0 mm	⅞ in.	0.87	21.44	23.01	0.844	0.906
25.0 mm	1 in.	1.00	24.61	26.19	0.969	1.031

Note: For tolerances of thicknesses not shown and for patterned glass, consult ASTM C1036.

E. Edge Finish

Fully tempered glass can be furnished with edges clean cut, sawed, seamed, ground, polished, penciled, beveled or shaped.

F. Labeling

Fully tempered safety glass meeting the above requirements shall be permanently marked with manufacturers' distinctive marks, including any other marking required for its intended use by any responsible regulatory body, and may include the Specification No. 64-3-16b. The marking can be accomplished by sandblasting, etching, ceramic paint stenciling, or by other means that are permanent and cannot be removed intact. The mark should be located so as to be visible when the glass is installed in its final position.

G. Sampling Program

NGA endorses the concept that satisfactory sampling programs should be developed by manufacturers in the absence of any specific requirements in state or federal regulations.

FIGURE 11

Glass Impact Test Structure and Frame

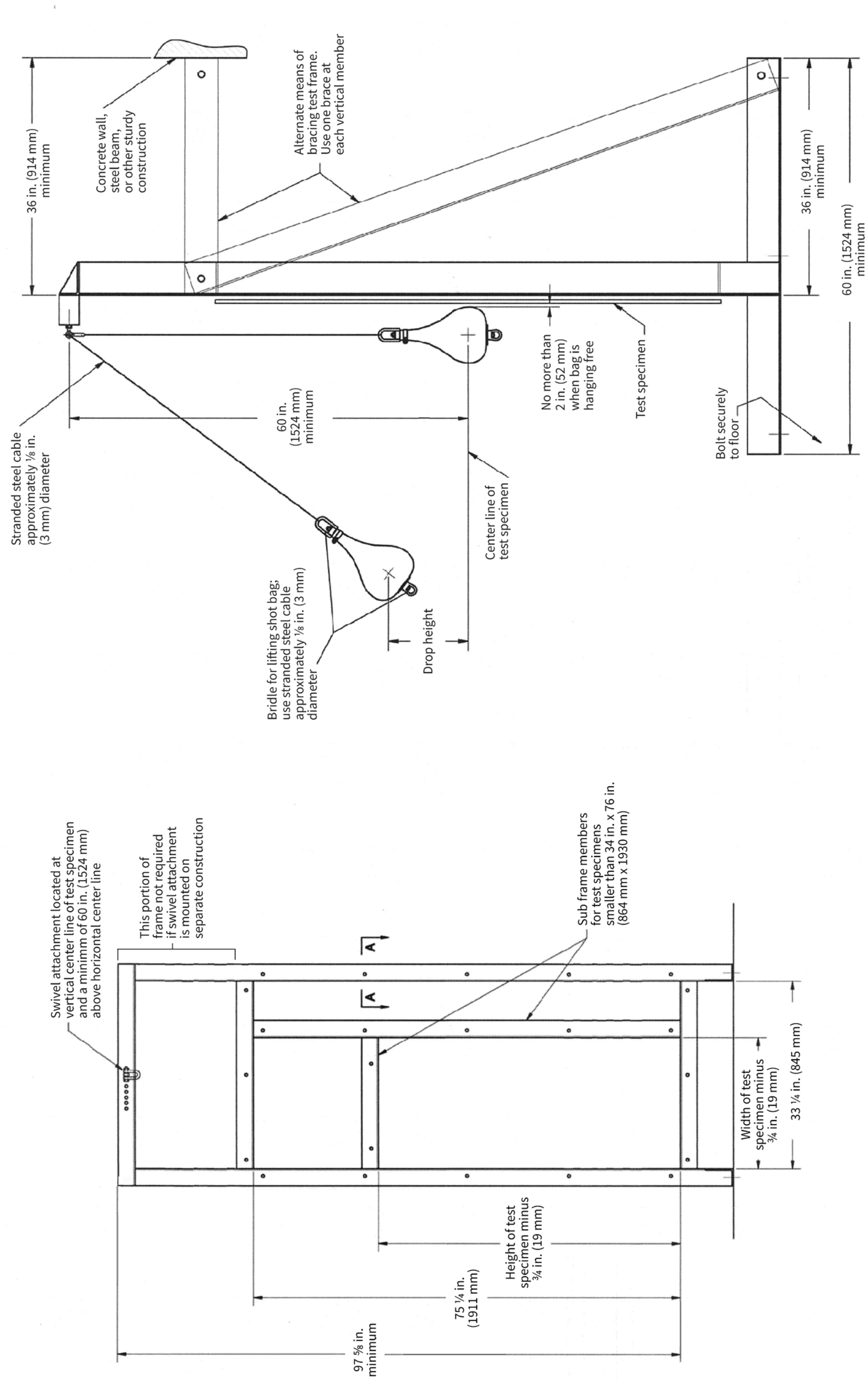


FIGURE 12

Clamping Mechanism

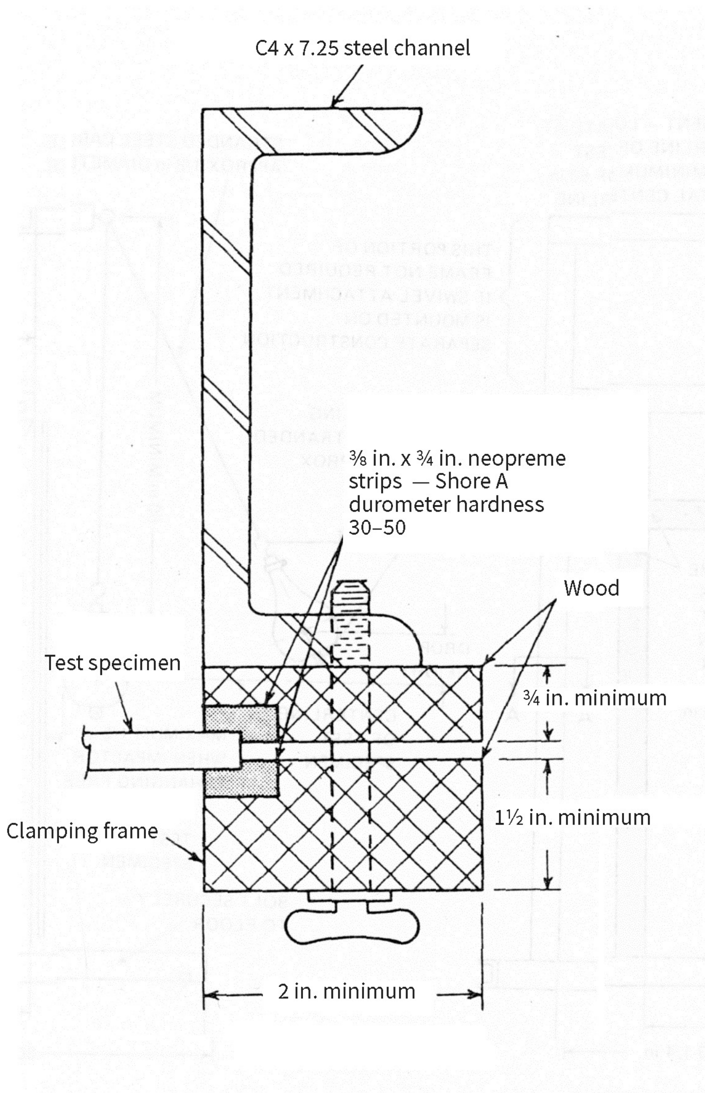


FIGURE 13

Impactor
Note: Refer to D.1.2 for metric values

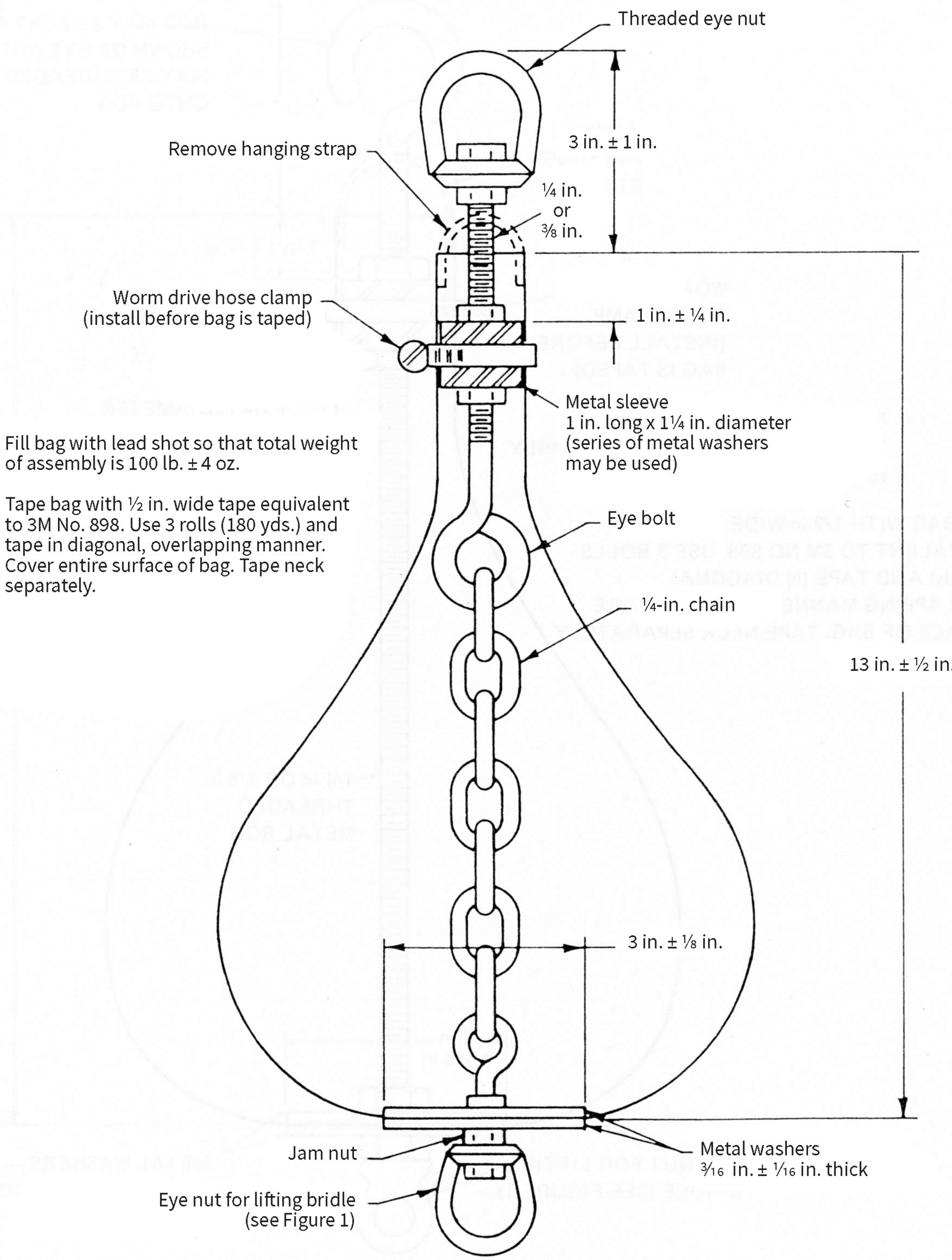


TABLE 9

Overall Bow, Maximum

Nominal Thickness Designation mm (in.)	0–50 (0–20)	>50–90 (>20–35)	>90–120 (>35–47)	>120–150 (>47–59)	>150–180 (>59–71)	>180–210 (>71–83)	>210–240 (>83–94)	>240–270 (>94–106)	>270–300 (>106–118)	>300–330 (>118–130)	>330–370 (>130–146)	>370–400 (>146–158)
	Maximum Bow, mm (in.)											
3 (1/8)	3.0 (0.12)	4.0 (0.18)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.87)	19.0 (0.75)	--	--	--
3 (1/8) Alternate Method*	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	3.0 (0.12)	5.0 (0.20)	6.0 (0.24)	7.0 (0.28)	8.0 (0.31)	10.0 (0.39)	--	--	--
4 (5/32)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.26)	9.0 (0.35)	12.0 (0.47)	14.0 (0.56)	17.0 (0.67)	19.0 (0.75)			
5 (3/16)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.26)	9.0 (0.35)	12.0 (0.47)	14.0 (0.56)	17.0 (0.67)	19.0 (0.75)			
6 (1/4)	2.0 (0.08)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.26)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	21.0 (0.83)	24.0 (0.94)
8 (5/16)	2.0 (0.08)	2.0 (0.08)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	6.0 (0.24)	8.0 (0.31)	10.0 (0.39)	13.0 (0.51)	15.0 (0.59)	18.0 (0.71)	20.0 (0.79)
10 (3/8)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	5.0 (0.20)	6.0 (0.24)	7.0 (0.26)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)
12 22 (1/2 7/8)	1.0 (0.04)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	5.0 (0.20)	5.0 (0.20)	7.0 (0.26)	10.0 (0.39)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)

*Values apply to 3 mm (1/8 in.) thickness only when the alternative checking procedure in 10.7.2 is used.

SECTION 6.2—SPECIFICATION NO. 86-8-11 REV #2

Specification for Fully Tempered Safety Glass for Overhead and Sloped Glazing Locations

A. Scope

This specification covers fully tempered safety glass for use in overhead and sloped glazing locations subject to the limitations and restrictions of local building codes and regulations.

B. Applicable Specifications

The following codes, specifications and standards form a part of this specification to the extent referenced herein:

ASTM C1036 Standard Specification for Flat Glass

ASTM C1048 Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass

Canadian Standard CAN/CGSB-12.2 Flat, Clear Sheet Glass

CAN/CGSB – 12.3 Flat, Clear Float Glass

CAN/CGSB – 12.20 Structural Design of Glass for Buildings

This test method is not a substitute for safety glazing test requirements of CPSC 16 CFR 1201.

C. Objective

In this application fully tempered safety glass is a proper choice because of its strength and resistance to fracture as a result of impact, pressure and torsional forces. When fracture occurs, fully tempered safety glass breaks into small granular pieces. It is the objective of this specification to provide a means to demonstrate that fully tempered safety glass possesses this degree of strength and fracture characteristics. This specification is not applicable to heat strengthened glass.

D. General Requirements

In order to assure that manufacturers produce fully tempered safety glass with the desired safety performance properties, fully tempered safety glass for overhead and sloped glazing locations shall be tested according to and shall meet the requirements of the following impact tests:

D.1 Impact Test

D.1.1 Specimens to be Tested

D.1.1.1 Conditions of Specimens
Tests shall be applied to four specimens as submitted by the manufacturer, except that any temporary protective masking material shall be removed prior to test. The specimens shall be separated and allowed to rest for at least four hours at temperatures between 18 °C (65 °F) and 29 °C (85 °F) to ensure uniform temperatures throughout each specimen at the time of test.

D.1.1.2 Thickness
The thickness of the specimens to be tested shall be recorded as a nominal thickness in accordance with accepted industry practice for glass, as set forth in the most recent issue ASTM C1036 and/or Canadian Standards CAN/CGSB-12.2 and CAN/CGSB-12-3. No manufacturer shall mark or advertise as passing the tests, herein described, any product of different nominal thickness than the samples passing the tests.

D.1.1.3 Classification
Safety glazing panels used in building may be of relatively large or small size, and many manufacturers limit their manufacturing activities to special product lines that require only the relatively small panels. A description of the specimens to be tested is set forth in Table I.

TABLE 10

Description of Specimens

Approval Classification	Specimen Dimensions
Limited (for all sizes up to and including dimension of specimens tested)	Largest size commercially produced by the manufacturer up to 86 cm (34 in.) x 1.9 m (76 in.)
Unlimited (for all sizes)	86 cm (34 in.) x 1.9 m (76 in.)

No manufacturer submitting specimens defined by the Limited Classification shall mark or advertise as passing the tests, herein described, any product with either dimension greater than those of the specimens passing the tests.

D.1.2 Test Apparatus
The test apparatus consists of two basic parts: 1) the test frame, and 2) the impactor.

D.1.2.1 Test Frame
The test frame (See Figure 1) shall be designed to minimize movement and deflection of its members during testing. For this purpose, the structural framing and bracing member shall be steel channels (4U7.25), or other sections and materials of equal or greater rigidity. This structural framing shall be welded or securely bolted at the corners to minimize racking or twisting during testing. Also, it shall be securely bolted to the floor and braced by one of the alternate methods shown in Figure 1.

The clamping frame for securing the test specimen on all four edges may be fastened at the corners or may be separate members. This is shown in wood in Figure 1 (continued). Other materials may be used, providing there is positive assurance that the test specimen will only contact the neoprene strips.

To allow for adjustability of the clamping frame members to accommodate samples of varying widths, the horizontal clamping frame members may be 70 mm (2.75 in.) shorter than the specimen width. This would allow an un-supporting area of less than 25.4 mm (1 in.) at each corner. The vertical clamping frame members shall be as long as the specimen height to give full support to the vertical edge of the sample.

The wing bolt shown in Figure 1 indicates one method of securing the clamping frame to the test frame. Alternate methods such as toggle clamps or C clamps may be used. Pressures on the test specimen shall be controlled so as to compress the neoprene strips not more than 25 percent of the original depth of the neoprene. Secured methods such as wing bolts and clamps shall be uniformly spaced no greater than 45.7 cm (18 in.) apart with no fewer than two on an edge.

Other modifications which clearly do not alter the function or performance of the test frame are acceptable.

D.1.2.2 Impactor
The impactor shall be standard leather punching bag modified as shown in Figure 2 or Figure 3. The bag shall be filled with number 7-½ chilled lead shot to a total weight of completed assembly of 45.36 ± 0.11 kilograms (100 lbs. ± 4 oz.). The rubber bladder shall be left in place and filled through a hole cut into the upper part. After filling the rubber bladder, the top should either be twisted around the threaded metal rod below the metal sleeve or pulled over the metal sleeve and tied with a cord or leather thong. Note that the hanging strap must be removed. The bag should be laced in the normal manner. The exterior of the bag shall be completely covered with 13 mm (5 in.) tape as indicated in Figures 2 and 3.

During testing, the impacting object (bag) shall be covered with a loosely draped terry-cloth towel, or a terry-cloth towel shall be loosely hung directly in front of the impact area on the glazing material.

D.1.3 Test Procedure
The impacting object (shot bag) constructed in accordance with Figures 2 or 3, shall be suspended from an overhead support, so located that the impactor when at rest will, at its maximum diameter, be no more than 13 mm (5 in.) from the surface of the specimen and no more than 51 mm (2 in.) from the center of the specimen (see Figure 1).

Each specimen shall be centered within the neoprene mounting strips before impacting, such that approximately 10 mm (375 in.) grip is provided on each edge of the specimen.

Select a drop height classification of Class A (48.0-48.5 in.), Class B (18.0-18.5 in.) or Class C (12.0-12.5 in.). Each specimen shall be struck at the center with the impacting object swinging in a pendulum arc from the appropriate drop height.

Glazed units constructed of dissimilar glazing materials that are asymmetrical from surface to surface shall be impacted two specimens on one surface and two specimens on the other surface.

D.1.4 Interpretation of Results
The impact test shall be judged to have been satisfactorily completed if any one of the following safety criteria shall be met by each of the four specimens tested:

D.1.4.1 When disintegration occurs at 305 mm (12 in.), 45.7 cm (18 in.), or 1.219 m (48 in.), the ten largest crack-free particles selected within 5 minutes subsequent to test shall weigh no more than the equivalent weight of 65 sq. cm (10 sq. in.) of the original test specimen.

D.1.4.2 If the specimen does not break after impact, the Center Punch Fragmentation Test shall be performed (D.2).

<u>D.2 Center Punch Fragmentation Test</u>

D.2.1 Equipment
1. A sharp impactor such as a point hammer of about 75 g (2.65 ounces) mass, or a spring loaded center punch or similar appliance can be used.

2. A means of specimen support to prevent scattering of fragments

3. A calibrated scale

4. A calibrated micrometer

D.2.2 Procedure
Strike the test specimen 25 mm (1 in.) inboard of the longest edge at its midpoint until fracture occurs. Within five minutes after fracture select and weigh the ten largest crack-free particles. Measure the thickness of the largest particle.

D.2.3 Interpretation of Results
The total weight of the 10 largest crack-free particles shall weigh no more than the equivalent weight of 65 sq. cm (10 sq. in.) of the original test specimen. No one particle shall be longer than 102 mm (4 in.) – excluding an area of radius of 102 mm (4 in.) around the point of impact and 25 mm (1 in.) around the perimeter of the specimen.

D.3 Certificate of Conformity

Each manufacturer of fully tempered glass intended for use in general construction should have its product sampled and tested in the manner described herein by a recognized independent certification program at intervals not exceeding six months. Results of such tests shall be produced upon demand.

D.4 Dimensional Tolerances

D.4.1 Thickness

TABLE 11

Thickness			Tolerance Thickness Range			
Metric Designation	Traditional Designation	Nominal Decimal Inch	Min. (mm)	Max. (mm)	Min. (in.)	Max (in.)
3.0 mm	Double ⅛ in.	0.12	2.92	3.40	0.115	0.134
4.0 mm	5/32 in.	0.16	3.78	4.19	0.149	0.165
5.0 mm	3/16 in.	0.19	4.57	5.05	0.180	0.199
5.5 mm	7/32 in.	0.21	5.08	5.54	0.200	0.218
6.0 mm	¼ in.	0.23	5.56	6.20	0.219	0.244

Note: For tolerances of thicknesses not shown and for patterned glass, consult ASTM C1036.

D.4.2 Rectilinear Tolerances
Dimensions not over 2.44 m (96 in.) +1.6 mm (+.0625 in.)

and not over 3.716 m² (40 sq. ft.) -3.0 mm (-.375 in.)

A strip shall be determined by the following table:

Up to 1.83 m (72 in.) length If the width is equal to or less than the length divided by 8.

From 1.83-2.44 m (72 – 96 in.) length If the width is equal to or less than the length divided by 7.

D.4.3 Flatness

D.4.3.1 Localized Bow – 1.6 mm per 300 mm of length (.0625 in. per linear) span permissible.

D.4.3.2 Any localized kink centered at any tong location shall not exceed 1.6 mm (.0625 in.) over a 50 mm (2 in.) span.

D.4.3.3 Overall bow tolerances for flat fully tempered glass are measured while the glass is placed in a free-standing, vertical position, resting on supports at the quarter points. With the glass in this position, place a straight edge across the concave surface parallel to and within 25.4 mm (1 in.) from the edge and measure the maximum deviation with a taper or feeler gauge, or a dial indicator. Maximum tolerances are shown in Table III.

D.5 Surface and Interior Visible Quality
As specified by ASTM C1036 for the quality level ordered.

E. Edge and Surface Finish

All edge or surface treatment must be done before tempering. Fully tempered glass can be furnished with edges clean cut, sawed, seamed, ground, polished, penciled, beveled or shaped.

F. Labeling

Fully tempered safety glass meeting the above requirements shall be permanently marked with manufacturers' distinctive marks, including any other marking required for its intended use by any regulatory body, and may include the GANA Specification No. 86-8-11. The marking can be accomplished by sandblasting, etching, ceramic paint stenciling or by other means that are permanent and cannot be removed intact. The mark should be located so as to be visible when the glass is installed in its final position, and should indicate in some manner that the glass is fully tempered.

G. Sampling Program

The Glass Association of North America endorses the concept that satisfactory sampling programs should be developed by manufacturers in the absence of any specific requirements in state or federal regulations.

H. Diagrams and Figures

See Figures 14, 15 and 16.

FIGURE 14

Glass Impact Test Structure and Frame

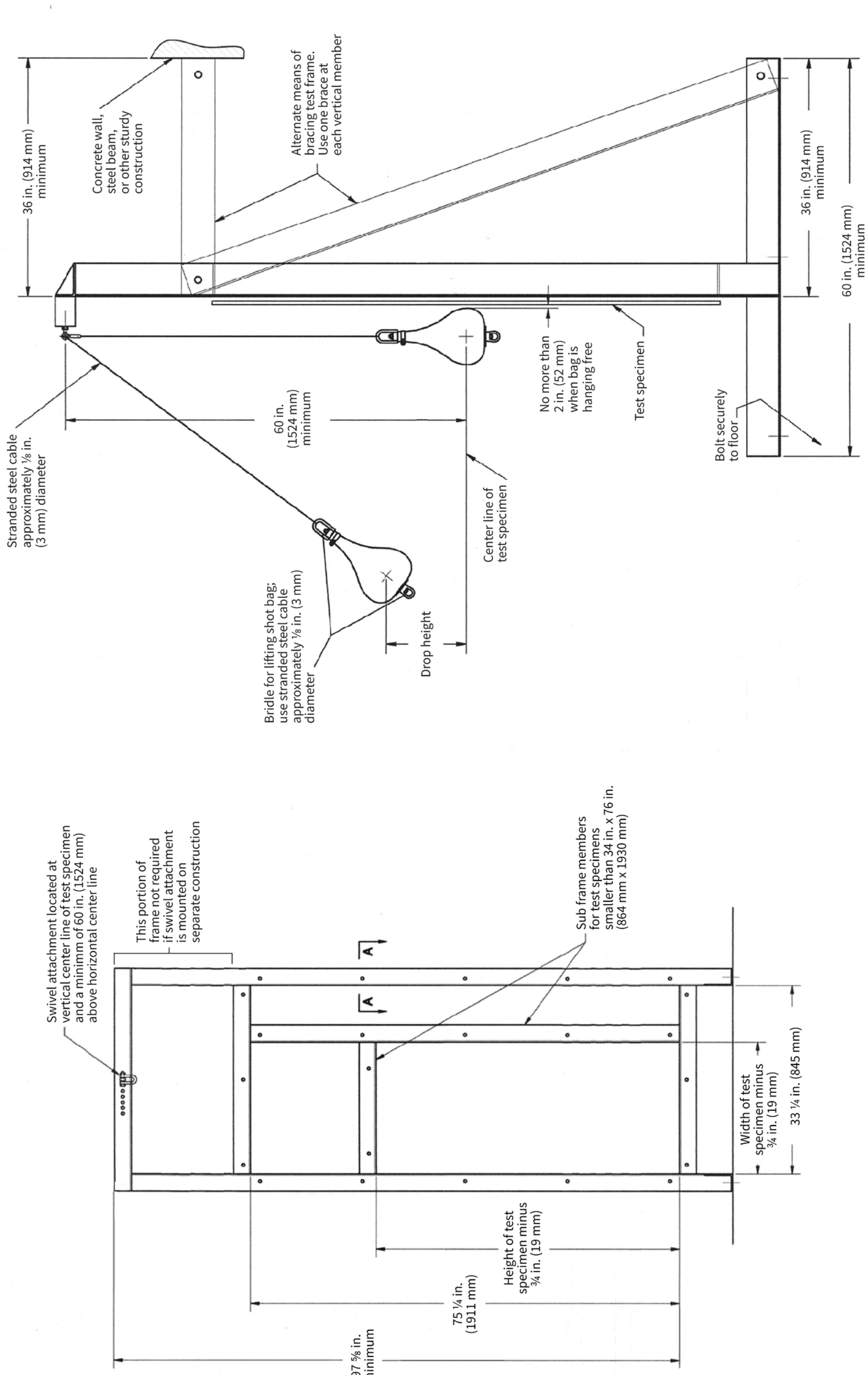


FIGURE 15

Clamping Mechanism

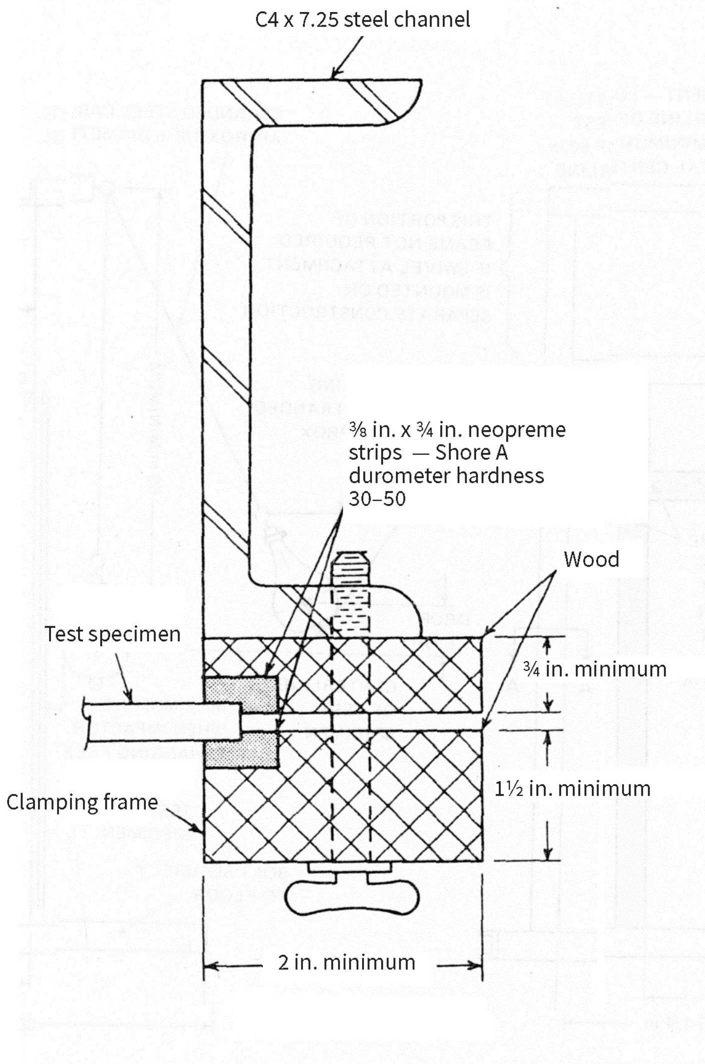
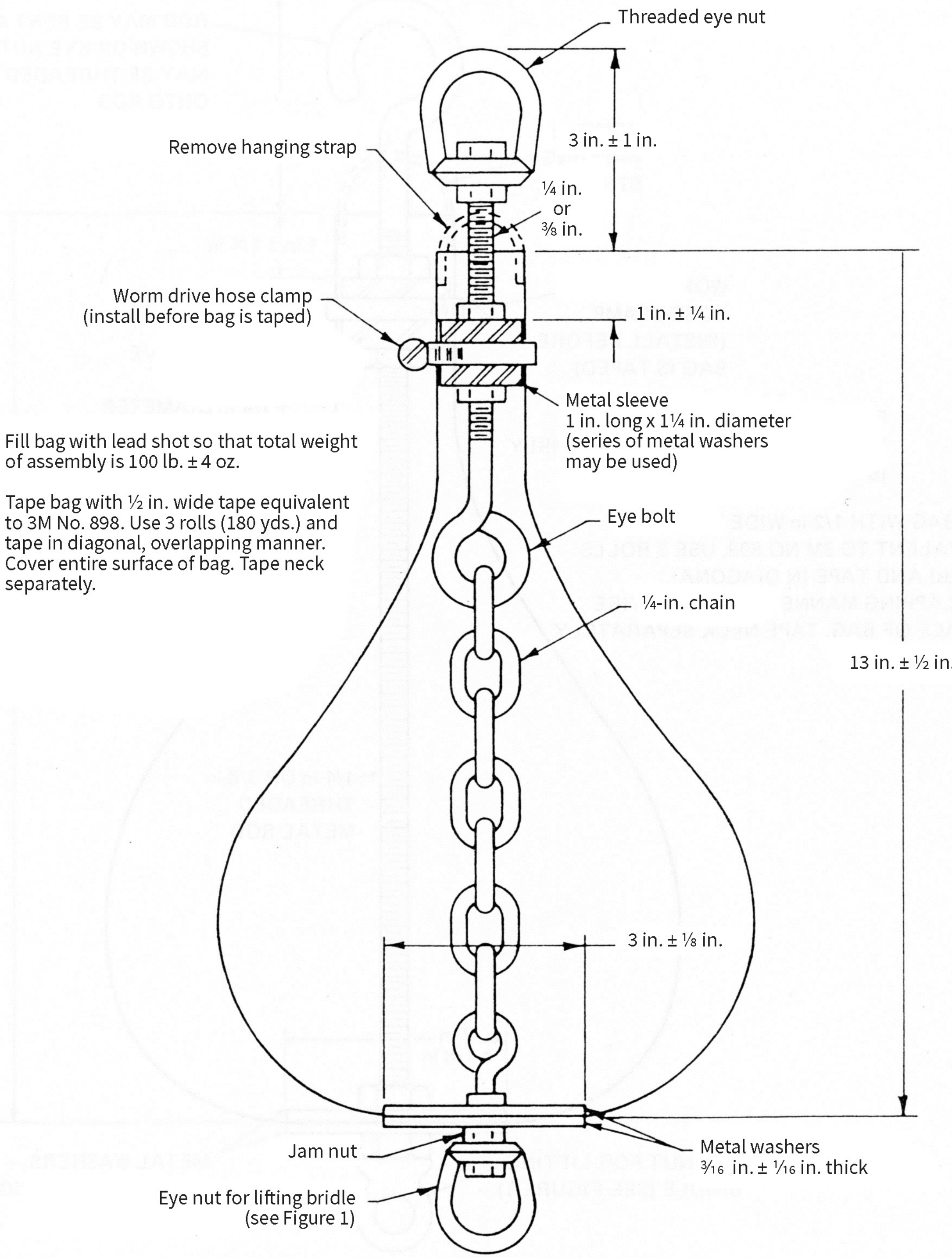


FIGURE 16

Impactor
Note: Refer to D.1.2 for metric values



SECTION 7—SPECIFICATION NO. 76-12-10B REV. #3

Specification for Tempered Safety Glass for Use in Motor Vehicles and Motor Vehicle Equipment Operating On and Off Land Highways

A. Scope

This specification applies to tempered safety glass for use in motor vehicles and motor vehicle equipment operating on and off land highways in the United States of America.

B. Applicable Specifications

Title 49 of the Code of Federal Regulations, Part 571.205	Glazing Materials
ANSI/SAEZ26.1-1996	American National Standard for Safety Glazing Materials for Glazing Motor Vehicles and Motor Vehicle Equipment Operating on Land Highways – Safety Standard
SAE J673 OCT2005	Automotive Safety Glasses

Note: Tempered safety glass used in motor vehicles and motor vehicle equipment, pursuant to statute, shall comply with 49 CFR 571.205 – the so-called "Implementing regulation." The "Implementing regulation" adopts, by reference, ANSI/SAE Z26.1, SAE J673 and other standards and specifications. NGA recommends that fabricators of tempered safety glass, for use in motor vehicles and motor vehicle equipment, consult these standards and specifications to determine their applicability.

C. Definitions

C.1 Safety Glass
Safety glazing materials, predominately ceramic in character, including (but not limited to) tempered glass.

C.2 Tempered Glass
A single piece of specially-treated float glass possessing mechanical strength substantially higher than annealed glass. When broken at any point, the entire piece breaks into small pieces that have relatively dull edges as compared to those of broken pieces of annealed glass.

D. General Requirements

Note: Fabricators of tempered safety glass, for use in motor vehicles and motor vehicle equipment, should refer to SAE J673 for more detailed information concerning commercial tolerance information and other requirements.

D.1 Dimensional Tolerances

D.1.1 Overall Size
Overall size tolerance for flat tempered safety glass is ± 0.8 mm (± 0.03 in), except for vertically sliding door glass where the height dimension may be ± 1.5 mm (± 0.06 in), unless otherwise specified.

Overall size tolerance for curved tempered safety glass is affected by pattern and degree of curvature.

D.1.2 Thickness
Commercially available flat or curved tempered safety glass ordinarily has a thickness tolerance of ± 0.1 x (n) mm ('n' being the number of layers of glass).

D.1.3 The center of tong marks may be located 8.0 mm (0.315 in) maximum from edge of glass, unless otherwise specified.

D.1.4 Mold marks may extend 8.0 mm (0.315 in) maximum from edge of glass depending on the size and complexity of the curved part, unless otherwise specified.

D.1.5 Curved Glass

D.1.5.1 Tolerances on the physical dimensions of curved tempered safety glass parts shall be specified as follows:

Size – maximum size (plus zero), with specified minimum size.

Thickness – nominal thickness, with acceptable commercial ranges.

Curvature – Peripheral or edge contour may be specified in terms of maximum departure from the peripheral face of the desired surface. Central area surface contour may be specified in terms of possible deviations of curvature from the designed contour.

Note: Manufacturing tolerances on size and curvature will vary with design and should be established by conference between the motor vehicle manufacturer and the glass fabricator. Designs for complex curved parts should recognize and accommodate necessary tolerances on size and shape.

D.1.5.2 Curved tempered safety glass is generally checked for size and curvature on a checking gauge made to receive the desired surfaces of the glass.

D.1.5.3 Peripheral or edge contour is usually checked by inserting a thickness feeler gauge, taper gauge or dial indicator (where possible) between the face of the checking ledge and the glass.

D.1.6 Flat Glass

D.1.6.1 Warp
Flat tempered safety glass may have 0.8 mm (0.03 in) maximum total bow per each lineal 305 mm (12 in) and each part may have a maximum overall bow in millimeters of 0.03 times the length of the part in millimeters (0.03 times the length of the part in feet).

D.2 All fabrication, such as cutting to overall dimensions, edgework, drilled holes, notching, grinding, sandblasting and etching, shall be performed before tempering.

E. Tests, Test Procedures and Equipment

Tests, test procedures and interpretation of test results shall be in accordance with 49 CFR 571.205 and ANSI/SAE Z26.1.

F. Edge Finish

Edge finish of tempered safety glass shall be in accordance with SAE J673 OCT2005.

G. Markings

Markings are to be in accordance with all applicable laws, regulations, codes, copyrights and practices to which tempered safety glass, for use in motor vehicles and motor vehicle equipment, is required to conform—e.g., 49 CFR 571.205 and ANSI/SAE Z26.1.

H. Sampling Program

NGA endorses the general concept that satisfactory sampling programs should be developed by manufacturers in the absence of specific sampling programs required by applicable laws, regulations, codes and practices to which tempered safety glass for use in motor vehicles and motor vehicle equipment shall conform.

SECTION 7.1—SPECIFICATION NO. 76-12-10B REV. #3

Specification for Tempered Safety Glass for Use in Marine Craft and Marine Craft Equipment

A. Scope

This specification applies to tempered safety glass for use in marine craft and marine craft equipment.

B. Applicable Specifications

ANSI/SAE Z-26.1-1996	American National Standard for Safety Glazing Materials for Glazing Motor Vehicles and Motor Vehicle Equipment Operating on Land Highways – Safety Standard
SAE J673 OCT2005	Automotive Safety Glasses

Note: Tempered safety glass, used in marine craft and marine craft equipment, should comply with ANSI/SAE Z-26.1 and SAE J673. ANSI/SAE Z26.1 references other standards and specifications. NGA recommends that fabricators of tempered safety glass, for use in marine craft and marine craft equipment, consult these standards and specifications to determine their applicability.

C. Definitions

C.1 Safety Glass
Safety glazing materials, predominately ceramic in character, including (but not limited to) tempered glass.

C.2 Tempered Glass
A single piece of specially-treated float glass possessing mechanical strength substantially higher than annealed glass. When broken at any point, the entire piece breaks into small pieces that have relatively dull edges as compared to those of broken pieces of annealed glass.

D. General Requirements

Note: Fabricators of tempered safety glass, for use in marine craft and marine craft equipment, should refer to SAE J673 for more detailed information concerning commercial tolerance information and other requirements.

D.1 Dimensional Tolerances

D.1.1 Overall Size
Overall size tolerance for flat tempered safety glass is ± 0.8 mm (± 0.03 in), except for vertically sliding door glass where the height dimension may be ± 1.5 mm (± 0.06 in), unless otherwise specified.

Overall size tolerance for curved tempered safety glass is affected by pattern and degree of curvature.

D.1.2 Thickness
Commercially available flat or curved tempered safety glass ordinarily has a thickness tolerance of ± 0.1 x (n) mm ('n' being the number of layers of glass).

D.1.3 The center of tong marks may be located 8.0 mm (0.315 in) maximum from edge of glass, unless otherwise specified.

D.1.4 Mold marks may extend 8.0 mm (0.315 in) maximum from edge of glass depending on the size and complexity of the curved part, unless otherwise specified.

D.1.5 Curved Glass

D.1.5.1 Tolerances on the physical dimensions of curved tempered safety glass parts shall be specified as follows:

Size: maximum size (plus zero), with specified minimum size.

Thickness: nominal thickness, with acceptable commercial ranges.

Curvature: peripheral or edge contour may be specified in terms of maximum departure from the peripheral face of the desired surface. Central area surface contour may be specified in terms of possible deviations of curvature from the designed contour.

Note: Manufacturing tolerances on size and curvature will vary with design and should be established by conference between the marine craft manufacturer and the glass fabricator. Designs for complex curved parts should recognize and accommodate necessary tolerances on size and shape.

D.1.5.2 Contour
Curved tempered safety glass is generally checked for size and curvature on a checking gauge made to receive the desired surfaces of glass.

D.1.5.2.1 Peripheral or edge contour is usually checked by inserting a thickness feeler gauge, taper gauge or dial indicator (where possible) between the face of the checking ledge and the glass.

D.1.6 Flat Glass

D.1.6.1 Warp
Flat tempered safety glass may have 0.8 mm (0.03 in.) maximum total bow per each lineal 305 mm (12 in.) and each part may have a maximum overall bow in millimeters of 0.03 times the length of the part in millimeters (0.03 times the length of the part in feet).

D.2 All fabrication, such as cutting to overall dimensions, edgework, drilled holes, notching, grinding, sandblasting and etching, shall be performed before tempering.

E. Tests, Test Procedures and Equipment

Tests, test procedures and interpretation of test results shall be in accordance with ANSI/SAE Z26.1.

F. Edge Finish

Edge finish of tempered safety glass shall be in accordance with SAE J673 OCT2005.

G. Labeling

Markings are to be in accordance with all applicable laws, regulations, codes and practices to which tempered safety glass, for use in marine craft and marine craft equipment, is required to conform – e.g., ANSI/SAE Z26.1.

H. Sampling Program

NGA endorses the general concept that satisfactory sampling programs should be developed by manufacturers in the absence of any sampling programs required by applicable laws, regulations, codes and practices to which tempered safety glass, for use in marine craft and marine craft equipment, shall conform.

SECTION 8—
Tempered Glass for Fireplace Screens
Precautions for Attachment on Glass Intended for Fireplace Screens

This Bulletin addresses fully tempered glass intended for use in fireplace screens. Such glass shall comply with applicable specifications of the National Glass Assocation (NGA), with GANA as detailed in its *Engineering Standards Manual*, Section 3 and Appendix 2. No other specifications apply unless approved in writing by the fabricator of the tempered glass. Tempered glass used in fireplace screen applications is not considered Safety Tempered Glass nor is the Fireplace Screen door considered a Safety Glass Required Application according to the Consumer Products Safety Commission CPSC 16 CFR 1201 as published June 28, 1982.

Fully tempered glass has increased resistance to impact, thermal stress and most other forces compared to regular untreated glass. It is, however, not unbreakable and certain precautions are recommended in its use to minimize the possibility of breakage in severe applications. For fully tempered glass used in fireplace screens, these precautions include the following:

In the design and fabrication of the fireplace screen, the glass should not contact any point metal or other hard materials.

Clearances between the edge of the glass and the frame should be at least 4.8 mm (3⁄16 in.). This can be accomplished at the bottom edge by using two fire-resisting setting blocks set at equal distance from the center of the edge. These must be of a material much softer than glass and fire resistant and must not degrade over the life of the glass. Temperatures of 426°C (800°F) have been measured on glass used as fireplace screens and setting block materials should be resistant to at least this temperature.

Clearances between the face of the glass and the framing should be at least 1.6 mm (1⁄16 in.). A fire-resisting cushioning material should be used to fill the void. This material should be installed in a manner that ensures that it will remain permanently in place for the life cycle of the glass.

Fire-resistant side blocks (similar to setting blocks) should be installed at the sides of the glass if there is a possibility the glass may shift laterally during shipment or in use. These blocks should not be installed tightly between the glass and the framing. A 1.6 mm to 3.0 mm (1⁄16 in. to 1⁄8 in.) clearance should be provided between the side block and the edge of the glass.

Failure to observe the preceding guidelines may result in scratching or chipping of the glass surface or edge and cause localized weaknesses in the glass. Glass-to-metal contact may also cause severe localized thermal stresses. Both conditions contribute to glass breakage.

Unique designs of fireplace screens may require additional precautions to prevent damage or major stresses being imposed to the glass. The manufacturer of the fireplace screens is responsible for incorporating these measures in his/her design.

The consumer should be cautioned to observe two rules. Each screen should have an appropriate notice attached.

For fireplaces that have operational doors of soda lime tempered glass, it is recommended that these doors be left open to reduce the risk of removing the temper level. Removal of the temper level in the glass can result in thermal stress breakage. The use of a low thermal expansion glass like Borosilicate reduces the risk of thermal stress breakage in fireplace glass doors.

If the glass doors need to be closed it is important to have the metal spark screen also closed to reduce the risk for direct contact of sparks to the glass. Efforts should be made to prevent contact of the metal screen door to the glass door. A minimum clearance of 200 mm to 300 mm (8 in. to 12 in.) is recommended between the fire and the glass doors.

Failure to observe these precautions may result in high thermal stresses in the glass, which may cause glass breakage. Prolonged exposure to temperatures above 260°C (500°F) may remove the temper from the glass. The temper gives the glass its high strength and thermal shock resistance.

SECTION 9—

Guidelines for Fully Tempered Glass Interior Butt Glazed Fixed Glass Panels

Minimum Thickness Guidelines for Fully Tempered Glass used in two-side simply supported interior panels and mounted or restrained at top and bottom only

Tempered glass lites used for interior glass partitions and walls supported or restrained on only two sides (top and bottom) require special design considerations. Two of these are addressed in this document: Glass Strength and Glass Deflection.

Fully tempered glass has been used for interior butt glazed glass panels in many applications because it meets the safety glass requirements per the following documents: Consumer Product Safety Commission (CPSC) standard 16 CFR 1201 – Safety Standard for Architectural Glazing Materials and ANSI Z97.1 American National Standard for Safety Glazing Materials Used in Buildings – Safety Performance Specifications and Methods of Test. Fully tempered glass shall meet the requirements as specified in ASTM C1048 – Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass.

Two columns in the following table show recommended minimum thicknesses of FULLY TEMPERED glass required to meet the IBC code for lites that are not linked together. The recommendations are based on analysis of tempered glass for conditions as required to meet prescribed loading requirements for stress, deflection and code stipulations as referenced in the current 2018 International Building Code (IBC).

International Building Code Section 2403.4 states:

> **"Interior Glazed Areas.** Where interior glazing is installed adjacent to a walking surface, the differential deflection of two adjacent unsupported edges shall not be greater than the thickness of the panels when a force of 50 pounds per linear foot (plf) (730N/m) is applied horizontally to one panel at a point up to 42 inches (1067mm) above the walking surface."
>
> **Section 2403.4 commentary states:** "This provision addresses the installation of glass panels in interior locations adjacent to walking surfaces, such as storefronts within covered mall buildings. Unlike exterior locations, interior installations do not require the placement of mullions individual glass panels are free to move independently of each other. When only one panel is subjected to horizontal pressure, the deflection of the panel may cause gaps between adjacent panels. These gaps pose a potential pinching hazard to anyone who may contact the glass panels and cause the differential deflection. This hazard is greater when the glass panels are not mounted in the same plane and the meeting edges form an angle.
>
> The design criteria provided in this section limit the use of glass panels to those that will not deflect more than the thickness of the glass panel itself when the specified force is applied at a height up to 42 inches (1067 mm) above the walking surface. This limitation protects against the occurrence of gaps between adjacent panels that would otherwise create a pinching hazard. The 42 inch (1067 mm) dimension represents the height range in which a person's body will likely contact the glass. The load must be assumed to occur at the point anywhere within the 42 inch (1067 mm) range that will cause the greatest differential deflection between the glass panels."
>
> International Building Code Section 1607.15 states:
>
> "Interior walls and partitions that exceed 6 feet (1829 mm) in height, including their finish materials, shall have adequate strength and stiffness to resist the loads to which they are subjected but not less than a horizontal load of 5 psf (0.240 kN/m2)."

Section 1607.15 commentary states:

"The minimum lateral live load is intended to provide sufficient strength and durability of the wall framing and of the finished construction to provide a minimum level of resistance to nominal impact loads that commonly occur in the use of a facility, such as impacts from moving furniture or equipment, as well as to resist heating, ventilating and air-conditioning (HVAC) pressurization."

Based on contact with a senior staff engineer at IBC, the following interpretation was rendered:

"While not specifically stated in the code, in my opinion, the glass panels are to be designed using the criteria of Sections 1607.15 and 2403.4 separately and independently rather than a combination of the loads."

Table 12 is based on calculations for the referenced loads individually 5psf (0.240 kN/m2) for section IBC 1607.15 and 50plf (730N/m) for IBC 2403.4.

The loads established by the IBC are minimum design criteria, however, and they may be combined for specific glass thickness selection. When design requirements are beyond these guidelines, please refer to engineering analysis.

The stress analysis for the various glass thicknesses, heights and loads was carried out based on the latest information in the ASTM E1300 – Standard Practice for Determining Load Resistance of Glass in Buildings, Appendices X6 and X7. Appendix X6 "Approximate maximum surface stress to be used with independent stress analysis," in part X6.2 uses a conservative allowable surface stress for fully tempered glass of 13,500 psi (93.1 MPa) for fully tempered (FT) glass. Appendix X7 "Approximate maximum edge stress for glass," part X7.2 used an allowable edge stress for fully tempered glass of 10,600 psi (73.0 MPa) for seamed and polished edges as noted in Table X7.1 of E1300.

The stresses calculated in the development of Table 1 are less than those allowed by ASTM E1300.

Deflection characteristics were calculated using a modulus of elasticity of soda lime silica glass to be 10.4 x 106 psi (71.7 x 106 kPa) and geometric structural properties based on minimum glass thicknesses as referenced in the ASTM C1036 – Standard Specification for Flat Glass. Since glass is a perfectly elastic material up to the point of rupture, when glass is deflected from a load, it will return to its original shape after the load is removed.

Glass Strength

The thickness of glass required to provide adequate strength in these applications varies with the length of the unsupported span and applied loading.

Table 12 below shows recommended minimum thicknesses of FULLY TEMPERED glass for various glass heights used in interior two-edge supported butt-glazed glass applications.

It is recognized that glass strength is the primary concern relating to proper design of glass. Deflection characteristics are also important and should be considered with regards to design considerations. When glass movement exceeds reasonable deflection criteria under loading, a review of the glazing system's ability to maintain the glass engagement should be closely examined. The proper glass bite should be used to maintain glass engagement in the glazing system.

Glass Deflection

Tempered glass supported on two sides is more flexible than glass supported on all four sides. If the glass is too thin, small fluctuations of interior air pressure can cause the glass to have noticeable movement or shimmer. People pushing or leaning on glass that is too thin will cause noticeable deflection of the glass. As the unsupported span or height of the glass lite increases, the glass thickness must also increase to maintain a reasonable stiffness.

Open narrow joints between butt glazed glass lites may catch or pinch fingers. The best preventative is to avoid open joints by filling them with silicone. An alternative is to install permanent clips at a spacing of approximately 4 feet to couple the adjoining lites together to prevent relative movement between panels. The gap between lites without

TABLE 12

Minimum Thickness Guidelines for Fully Tempered Glass
Used in two-side simply supported interior panels and mounted or restrained at top and bottom only

	IBC 1607.14[1,2]	IBC 1607.14[1,3]	IBC 2403.4[1,4]	IBC 2403.4[1,3]
	Load - 5 lb/sq.ft.	**Load - 5 lb/sq.ft.**	**Load - 50 lb/ft**	**Load - 50 lb/ft**
Unsupported span from top to bottom of glass	when open joints	when linked with silicone or permanent fastener	when open joints	when linked with silicone or permanent fastener
Up to 5 ft (1.5m)	3/8" (9mm)	3/8" (9mm)	1/2" (12mm)	3/8" (9mm)
Over 5 ft (1.5m) up to 6 ft (1.8m)	3/8" (9mm)	3/8" (9mm)	1/2" (12mm)	3/8" (9mm)
Over 6 ft (1.8m) up to 7 ft (2.1m)	1/2" (12mm)	3/8" (9mm)	5/8" (15mm)	3/8" (9mm)
Over 7 ft (2.1m) up to 8 ft (2.4m)	1/2" (12mm)	1/2" (12mm)	5/8" (15mm)	1/2" (12mm)
Over 8 ft (2.4m) up to 9 ft (2.7m)	5/8" (15mm)	1/2" (12mm)	5/8" (15mm)	1/2" (12mm)
Over 9 ft (2.7m) up to 10 ft (3m)	5/8" (15mm)	1/2" (12mm)	3/4" (19mm)	1/2" (12mm)
Over 10 ft (3m) up to 11 ft (3.4m)	3/4" (19mm)	5/8" (15mm)	3/4" (19mm)	5/8" (15mm)
Over 11 ft (3.4m) up to 12 ft (3.7m)	3/4" (19mm)	5/8" (15mm)	3/4" (19mm)	5/8" (15mm)
Over 12 ft (3.7m) up to 13 ft (4m)	7/8" (22mm)	5/8" (15mm)	7/8" (22mm)	5/8" (15mm)
Over 13 ft (4m) up to 14 ft (4.3m)	7/8" (22mm)	3/4" (19mm)	7/8" (22mm)	3/4" (19mm)
Over 14 ft (4.3m) up to 15 ft (4.6m)	1" (25mm)	3/4" (19mm)	7/8" (22mm)	3/4" (19mm)
Over 15 ft (4.6m) up to 16 ft (4.9m)	1" (25mm)	3/4" (19mm)	7/8" (22mm)	3/4" (19mm)
Over 16 ft (4.9m) up to 17 ft (5.2m)	1" (25mm)	7/8" (22mm)	7/8" (22mm)	7/8" (22mm)
Over 17 ft (5.2m) up to 18 ft (5.5m)	use engineering analysis	7/8" (22mm)	1" (25mm)	7/8" (22mm)
Over 18 ft (5.5m)	use engineering analysis	use engineering analysis	use engineering analysis	use engineering analysis
1. These numbers are based on the assumption that bottom of the glass attachment is at the same height as the walking surface.				
2. Guidelines based on IBC 2403.4 deflection limit of the thickness of the glass panel.				
3. Guidelines for spans up to 10' are based on a deflection limit of 1.5" (based on pullout of less than 1/16"); guidelines for spans greater than 10' are based on a deflection limit of 2" (based on pullout of 3/32"). Larger deflections should be reviewed by designer.				
4. Guidelines based on IBC 2403.4 deflection limit of the thickness of the glass panel and loading from IBC 2403.4.				

silicone or clips should be such that fingers cannot be inserted and trapped. Silicone joints or panel clips do not add to the structural strength or rigidity of the assembly.

SECTION 10—SPECIFICATION NO. FB13-07 (2018) (FORMERLY TD 04-1207)

The Importance of Fabrication Prior to Heat-Treatment

Glass applications frequently require a variety of glass edge and/or surface fabrication. Some common fabrication processes include: edge seaming, grinding, polishing, hole-drilling, notch-cutting, surface-grooving, sand-blasting, and etching. NGA does not recommend glass fabrication after heat-treatment because it may weaken the glass and/or cause it to break. This recommendation is confirmed in Section 7 of ASTM C1048, Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass, which states, "All fabrication, such as cutting to overall dimensions, edgework, drilled holes, notching, grinding, sandblasting, and etching, shall be performed before heat-strengthening or tempering and shall be as specified."

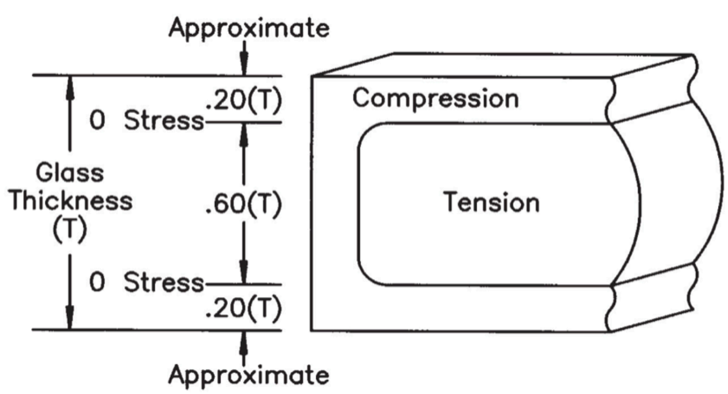
The Heat Treating Process

In order to provide greater resistance to thermal and mechanical stresses, and to achieve required break patterns for safety glazing applications, annealed float glass and patterned glass can be strengthened through a thermal process known as heat-treating. The most commonly used process for heat-treating architectural products calls for glass to be cut to the desired size and shape, and edges prepared to the specified condition. The glass is washed and then transported through a tempering furnace where it is uniformly heated to approximately 621 °C (1150 °F). Upon exiting the furnace, the glass is rapidly cooled (quenched) by blowing air onto all surfaces simultaneously.

The cooling process places the surfaces of the heat-treated glass into a state of high compression and the central core in tension. As shown in Figure 17, each surface compression zone is approximately 20% of the glass thickness and the middle 60 % of the glass thickness is the tension zone.

FIGURE 17

Heat-Treated Glass Compression and Tension Zones



Alteration of Surface Stress - Brought About by Fabrication After the Heat-Treatment Process

Fabricating glass after it has been heat-treated, such as grinding, sandblasting or etching, may compromise the compression and tension zones of the glass resulting in a weaker or broken piece of glass. Cutting and drilling heat-treated glass will result in breakage. Compromising the surface compression zones of fully tempered glass may also negatively affect its ability to comply with the industry safety glazing standards.

Penetration of a surface compression layer is a cause of heat-strengthened and fully tempered glass breakage. For example, each compression layer in a lite of heat-treated glass is approximately 20% of the glass thickness, penetration can occur in as little as 0.64 mm (0.025 in.) for 3 mm (.125 in.) thick glass and 1.02 mm (0.040 in.) for 6 mm (.25 in.) thick glass.

Heat-treated glass can be further fabricated by any process that does not alter the surface compression layer such as sputtered (vacuum deposition) coatings onto the surface; assembly of laminates and insulating glass units; and adding films and coatings for opacification.

Heat-Treated Laminated Glass

Two or more lites of heat-treated glass can be laminated when glass retention after breakage is desired to meet performance or building code requirements. Typical applications include canopies, skylights, railings, glass floors, curtain wall and storefront systems. Unlike annealed laminates, heat-treated laminates cannot undergo additional fabrication after laminating.

Similar to monolithic heat-treated glass, ASTM C1172 Standard Specification for Laminated Architectural Flat Glass states, "All dimensional fabrication, such as cutting to overall dimensions, edgework, drilling, notching, grinding, sandblasting, and etching on laminates containing heat-strengthened, chemically strengthened, or fully tempered glass shall be performed prior to strengthening or tempering."

In addition, ASTM C1172 gives length and width tolerances for rectangular shapes of symmetrically laminated glass including mismatch. These tolerances are shown below:

Laminate Thickness Designation, *t*	**Heat-strengthened/Tempered Glass Tolerance**
t < ¼ in (6.4 mm)	+7/32 in, -3/32 in (+5.6mm – 2.4mm)
¼ in < ½ in (6.4mm< 12.7mm)	+¼ in, -⅛ in (+6.4mm, -3.2mm)
½ in < 1 in (12.7mm < 25.4mm)	+5/16 in, - ⅛ in (+7.9mm, -3.2mm)

APPENDIX 1

Specification for Edge Stress Estimation Using Polarized Light (Strain Viewer)

A. Scope

This specification covers edge stress estimation using polarized light.

B. Applicable Documents

ASTM C1048	Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass
ASTM C1279	Standard Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat-Strengthened, and Fully Tempered Flat Glass.

C. Objective

It is the objective of this document to provide the user with a mechanism to estimate edge stress using polarized light.

D. General Requirements

An estimation of the level of residual stress in heat-treated glass at the edges can be accomplished using photoelastic color scale interpretation and two crossed polarizers or a simple strain viewer (polariscope). Magnification may or may not be required, depending on sample geometry and stress magnitude.

A quantitative measurement of residual stress in heat-treated glass requires the use of specialized polarimeters as described in ASTM C1279, Procedure B.

E. Principles

When polarized light rays travel through a strained material, they divide into slow and fast fronts, vibrating in the plane of maximum and minimum strain. The difference in speed between these fronts (called retardation) is proportional to strain/stress. As a result of the difference in speed of the slow and fast rays when they pass through a second polarizer positioned at 90° (crossed) to the first polarizer, an interference pattern is created and color “fringes” can be observed (Figure 18).

The colors (more correctly, lack of colors) can be used to evaluate the stresses in fully annealed glass since most residual stress has been relieved. However, in thermally processed glass, there are laminar stresses through the thickness that are ideally in equilibrium, namely compressive stresses (-) on the surfaces and tensile stresses (+) in the mid-plane. This, along with the fact that the direction of the stresses is not known, makes it impossible to determine temper level simply by color scale observation. (Heat-treated glass will show a distinctive “quench” pattern when viewed in polarized light; however, this only indicates that the glass has undergone heat treating. It cannot be used to determine temper level, mechanical strength or expected break pattern.)

At the edges of glass, however, it is possible to estimate stress values for two reasons:

(1) The edge of the glass is effectively a surface and its compressive stress is roughly comparable with the level of surface compression at the top and bottom surfaces (assuming cooling rate and heat flow are the same).

FIGURE 18

Edge Stress Color Pattern Typical of Tempered Glass Under Polarized Light (Magnified)

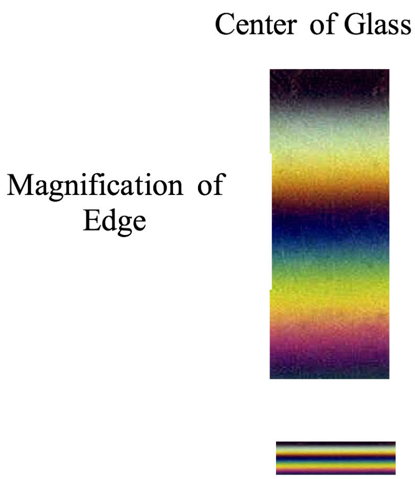


FIGURE 19

Portable Strain Viewer (Strainoptics, Inc.)

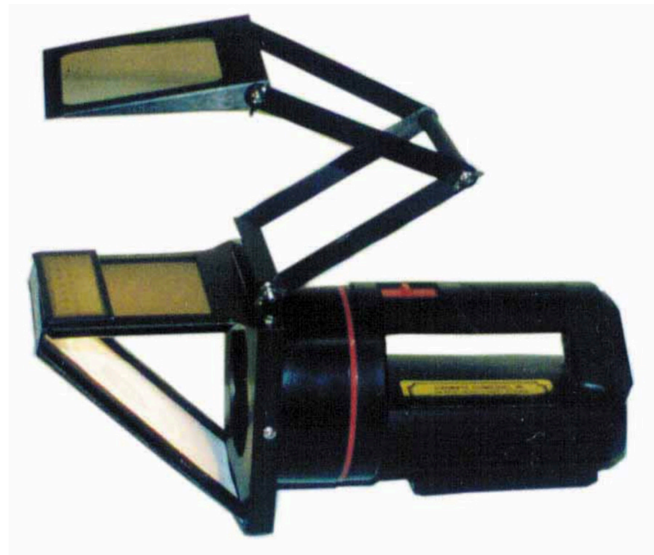


FIGURE 20

Polarizer

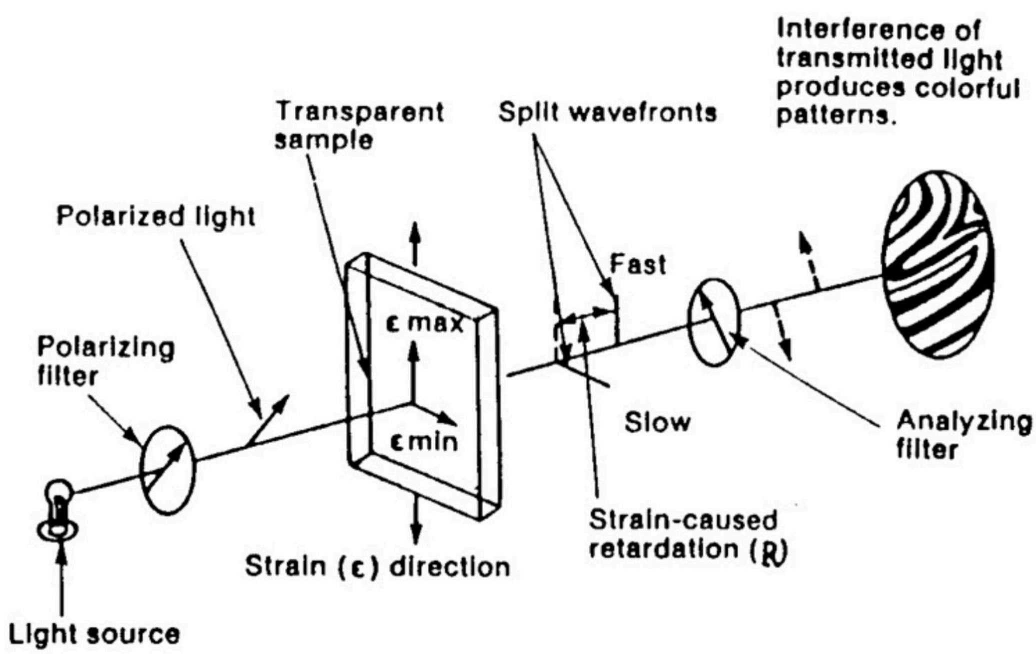


FIGURE 21

Portable Edge Stress Meter (Strainoptics, Inc.)

(2) Stress along the edge is parallel to the edge. Unlike regions away from the edge, this provides a known direction of principal stresses.

With this information, stress can be evaluated qualitatively with a strain viewer (Figure 19) and color scale interpretation (Figure 20) or quantitatively with a compensator-equipped polarimeter (Figure 21) as specified in ASTM C1279, Procedure B. This procedure is ideally suited to decorative glass with a clear area at the edge, such as spandrel glass, patterned glass, and other applications where direct measurement of surface stress using transmitted light polarimetry is not otherwise possible.

F. Evaluation of Retardation and Fringe Order Using a Color Scale

The retardation (R) is a distance and can be expressed in "nm" (nanometers), or "fringe orders." There is a simple relation between various length units commonly used for measuring retardation.

1 nm = 10-9 meters = 1 millimicron (mμ)

1 micron = 1000 nanometers = 1000 millimicron

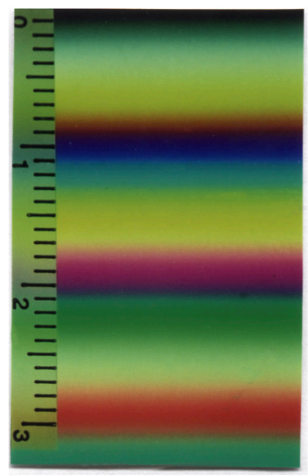
1 fringe = 565 nm* = 1 wavelength (λ)

The stress is constant along a constant color line or a color fringe. As the stress in the sample increases, the observed color changes. This color change follows a very predictive sequence.

TABLE 13

Color Sequence Observed versus Retardation Values

Observed Color	Retardation R (nm)	Fringe Order2, N
Black	0	0
Gray	150	
White-Yellow	250	
Yellow	300	1/2
Orange (Dark Yellow)	450	
Red	500	
Indigo-Violet (1st order)	565	1
Blue	600	
Blue-Green	650	
Green-Yellow	750	
Yellow	850	1 1/2
Orange (Dark Yellow)	950	
Red	1050	
Indigo-Violet (2nd order)	1130	
Green	1300	
Green-Yellow	1400	
Pink	1500	
Violet (3rd order)	1695	3
Green	1750	



* 565 nm is standard wavelength for glass.

The color sequence (yellow—red—green) repeats itself and if several color bands are observed, one must first identify fringe orders. The integers (N = 0, 1, 2…) appear as follows:

Zero Order Fringe	N = 0	Retardation, R = 0 mm	Black region or line
1st Order Fringe	N = 1	Retardation, R = 1130 mm	Indigo-Violet line between 2nd red (pink and green)
2nd Order Fringe	N = 2	Retardation, R = 1130 mm	Indigo-Violet line between 2nd red (pink and green)
3rd Order Fringe	N = 3	Retardation, R = 1695 mm	Violet between 3rd pink and light green
4th Order Fringe	N = 4	Retardation, R = 2825 mm	Violet between 4th pink and green

Along a constant color line, retardation remains the same, and can be approximately evaluated using the color chart above. For example, at the yellow line/area between the first order and second order, the “order” N = 1½ and the retardation R is 1.5 x 565 nm.

As a first step in evaluation of stresses, FULL FRINGE ORDERS (n = 1, 2, 3…) must be identified. When no color fringes are observed and only a black, gray, or yellow color is observed, the fringe order is less than 1. The edge stress can be obtained as follows:

$$\text{Stress: } \frac{N \times F}{T} \qquad \text{or } S = \frac{R \times F}{565 \times t}$$

where:
S is the stress (psi)

R is the retardation, expressed in nanometers from color pattern on Table 1.
N is the fringe order observed (ex., 1, 1½, 2, 3) from the color pattern and

Table 1. Note that the fringe order $N = \frac{R}{565}$

t is thickness (inches)
F is material constant (1270 psi for soda lime float glass)

For example, assume you are estimating edge stress in HS glass.

N = 1½ (yellow between first and second order) t = ¼ inch
F = 1270 psi

$$S = \frac{1.5 \times 1270}{0.25}$$

Stress = 7620 psi

G. Application Examples

Observation of Stress in Heat-Strengthened and Fully Tempered Glass

Edge pattern can be used to estimate edge stress. Determine fringe order N at the edge using Table 13 and figures illustrating ½, 1, 1½, 2, 3, 4. Knowing the fringe order N and the sample thickness t, use Table 14 on the following page to estimate the edge stress or calculate the approximate stress using the equation:

Stress = (N x F)/t

Table 14 provides the range of edge stress and fringe orders for several thicknesses of glass. Using Table 14, review and practice examples below.

Example 1

You have a ⅜ inch-thick glass and you observe approximately 1½ fringes on the edge. The edge stress is:

SEdge = (N x F)/t = (1.5 x 1270)/0.375 = 5080 psi (This sample can be considered “heat-strengthened.”)

Example 2

This time you have ⅛ inch-thick glass, and you see 1.5 fringes on the edge. The edge stress is above 10,000 psi and meets the fully tempered requirement of ASTM C1048.

Example 3

A ½ inch-thick glass shows 1½ fringes on the edge. Conclusion: The edge stress is in a “borderline situation” around 3800 psi. You cannot confidently state that this sample is sufficiently heat-strengthened.

TABLE 14

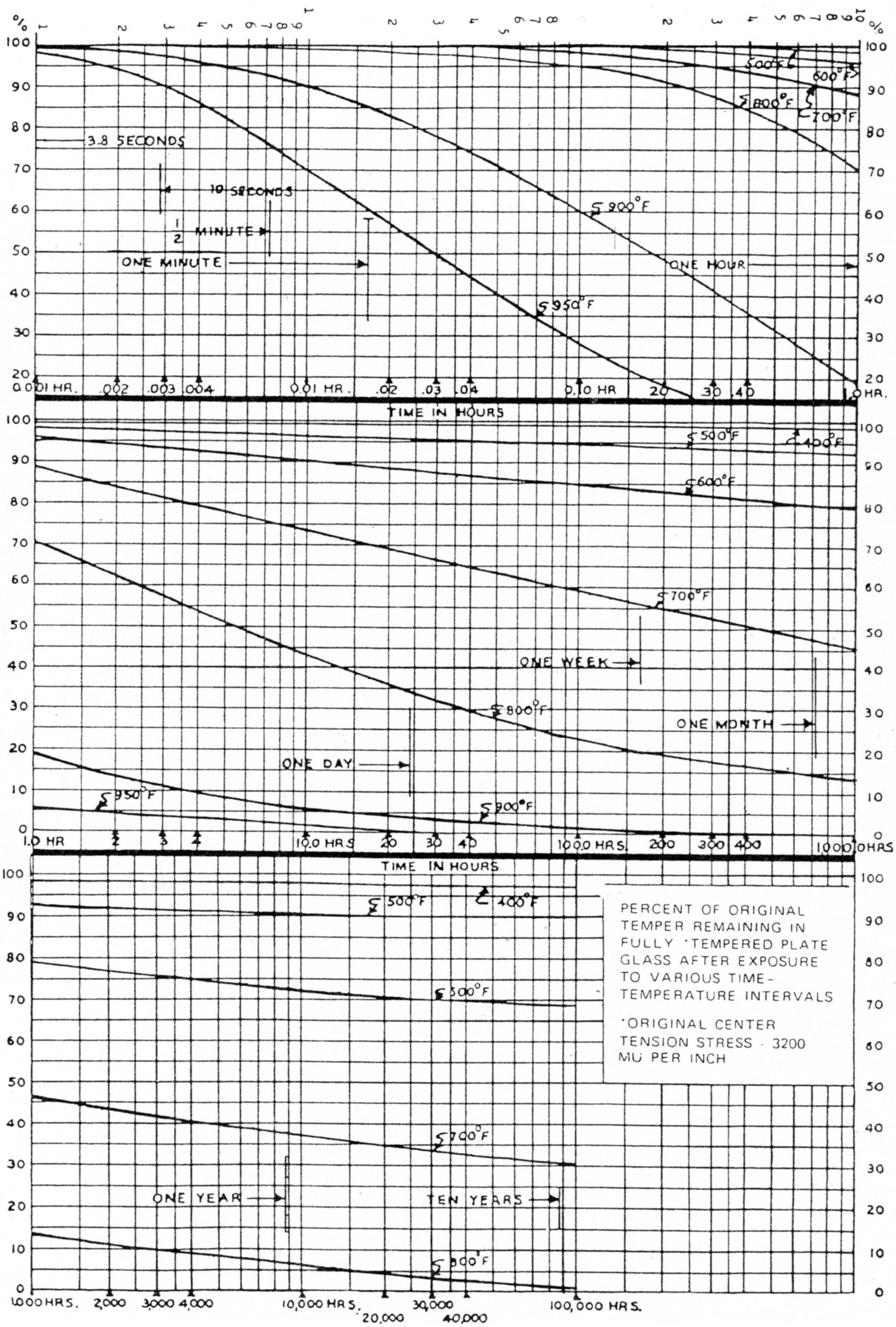
Estimating Edge Stress in Tempered and Heat-Strengthened Glass

Color Observed	Retardation (nm from Table 1)	Fringe Order (N)	Edge Stress, psi, for Glass Thickness				
			1/8 in. (O.125)	3/16 in. (0.188)	1/4 in. (0.250)	3/8 in. (0.375)	1/2 in. (0.500)
			3 mm	5 mm	6 mm	10 mm	12 mm
Yellow	300	0.5	5080	3378	2540	1693	1270
Orange	450	0.8	8128	5404	4064	2709	2032
Red	500	0.9	9144	6080	4572	3048	2286
1st Order Fringe	565	1	10160	6755	5080	3387	2540
Blue	600	1.1	11176	7431	5588	3725	2794
Blue-Green	650	1.2	12192	8106	6096	4064	3048
Green-Yellow	750	1.3	13208	8782	6604	4403	3302
Yellow	850	1.5	15240	10133	7620	5080	3810

APPENDIX 2

Thermal Endurance Curves, Time vs. Temperature

Percent of Original Temper Remaining in Fully Tempered Plate Glass After Exposure to Various Time - Temperature Intervals



APPENDIX 3

Glossary of Terms Related to Heat-Treated Glass

Section I: General Terms Related to Heat-Treated Glass

Annealed Glass: Float, plate, sheet or rolled glass with low residual internal stresses so that it can be easily cut. Annealed glass is sometimes referred to as ordinary, raw or unenhanced glass and may be flat or bent.

ANSI Z97.1: *American National Standard for Safety Glazing Materials Used in Buildings – Safety Performance Specifications and Methods of Test.* This standard establishes the specifications and methods of test for the safety properties of safety glazing materials as used for all building and architectural purposes. See related term **CPSC.**

ANSI Z26.1: *American National Standard for Safety Glazing Materials for Glazing Motor Vehicles and Motor Vehicle Equipment Operating on Land Highways – Safety Standard.* It contains specifications and test methods for the safety properties of glazing materials for automotive and other equipment used on highways.

ASTM C1048: Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass

ASTM C1172: Standard Specification for Laminated Architectural Flat Glass

ASTM C1422: Standard Specification for Chemically Strengthened Glass

ASTM C1464: Standard Specification for Bent Glass

Bent Glass: Flat glass that has been formed while hot into curved shapes.

Break Pattern: The resultant pattern formed by the cracks within an individual lite of glass when broken. Also called **Fracture Pattern.** *See* ***Dice*****.**

Bow: Departure from flatness that may occur in glass that has been heat-treated. Also known as **Warp.**

Center Tension: Tensile stress within the center portion of the thickness of heat-treated glass.

Chemically Strengthened Glass: Glass that has undergone an ion exchange process to impart a very thin, highly compressive stress at the treated surfaces.

Compression: *See* ***Edge Compression*** *and* ***Surface Compression.***

CPSC: Acronym for Consumer Product Safety Commission, a USA federal agency. The CPSC standard 16 CFR 1201 - *Safety Standard for Architectural Glazing Materials* requires safety glazing in certain hazardous locations and specifies the test criteria and certification for safety glazing materials. See related term **ANSI Z97.1.**

Dice: The individual fragments of broken fully tempered glass.

Distortion: Alteration of viewed images usually caused by variations in glass flatness, thickness, or inhomogeneous portions within the glass body. See related term **Roller Wave Distortion.**

DSR: Differential Surface Refractometer. An instrument commonly used to measure the surface compression of fully tempered glass.

Edge Compression: Compressive stresses at the edges of heat-treated glass.

Edge Finish: Specified finishes to the edges of glass. Sometimes called Edgework. See Appendix 5 for descriptions of types of Edge Finish.

Edgework: *See **Edge Finish.***

Figured Glass: *See **Patterned Glass.***

Flat Glass: A general term covering float glass, sheet glass, plate glass, rolled, patterned and wired glasses.

Float Glass: Flat glass that has been formed by floating on molten tin.

Fracture Pattern: The resultant pattern formed by the cracks within an individual lite of glass when broken. Also known as **Break Pattern.** *See **Dice.***

Fully Tempered Glass: Flat or bent glass that has been thermally tempered to a surface and/or edge compression to meet the requirements of ASTM C1048. Fully tempered glass may or may not meet the requirements for safety glass. *See related terms: **Safety Glass, ANSI Z26.1, ANSI Z97.1, ASTM C1048** and **CPSC.** Outside of North America, commonly called toughened glass.*

GASP®: Grazing Angle Surface Polarimeter. An instrument commonly used to measure the surface compression of annealed, heat-strengthened and fully tempered glass

Heat-Treated Glass: Glass which has been heated to near its softening point and quenched by rapidly cooling with air. Heat-treated glass may be either heat-strengthened or fully tempered.

Heat-Strengthened Glass: Flat or bent glass that has been heat-treated to a specific surface compression range to meet the requirements of ASTM C1048. Note: Heat-strengthened glass is not safety glass unless laminated to meet a safety glass standard.

Iridescence: *See **Strain Pattern.** Also known as **Quench Marks.***

Kink: An abrupt deviation from a flat plane or the normal contours of bow, and most commonly found near the leading and/or trailing edge of heat-treated glass.

Laminated Glass: In flat glass, an assembly consisting of two or more lites of glass bonded together by an interlayer. *See related terms:* ***Safety Glass, ANSI Z26.1, ANSI Z97.1, ASTM C1172*** *and* ***CPSC.***

Patterned Glass: Flat glass manufactured by forming a ribbon of glass with a pair of machined or engraved forming rolls. The rolls impress their surface pattern into the glass surfaces. *Also known as* ***Rolled Glass*** *or* ***Figured Glass.***

Plate Glass: Flat glass formed by rolling, grinding, and polishing both sides, with surfaces essentially plane and parallel. The plate glass process is obsolete and has been replaced by the float glass process.

Polariscope: An instrument for observing the degree of residual stress in glass using polarized light.

Polished Edge: Glass edgework in which the face of the edge is ground to a uniform flatness or other desired shape and then polished so that the surface is very smooth and reflective, similar to the surfaces of float glass. *See* ***Edge Finish.*** *Also See Appendix 5 for descriptions of types of Polished Edge.*

Quench or Quenching: To rapidly cool a lite of glass in the tempering process.

Quench Marks: *See* ***Strain Pattern.*** *Also known as* ***Iridescence.***

Roller Wave Distortion: Waviness or a variation in glass flatness imparted to horizontally heat-treated glass while the glass is transported through the tempering system on a roller conveyor. The waves produce distortion when the glass is viewed in reflection. Also known as **Roll Wave** or **Roller Wave.**

Rolled Glass: *See* ***Patterned Glass.***

Safety Glass: Fully Tempered Glass or Laminated Glass that complies with CPSC 16 CFR 1201, ANSI Z97.1 or ANSI Z26.1.

Seamed Edge: Glass edgework in which a small chamfer is roughly ground onto all edges, but the faces are left untouched. This process is typically performed with seaming belts, or diamond or carbide grinding wheels. The degree of grinding is greater than for a swiped edge. *See* ***Edge Finish.*** *Also see Appendix 5 for a description of Seamed Edge.*

Sheet Glass: Flat glass formed by vertically drawing a ribbon of glass from a pool of molten glass. Sheet glass has been almost completely replaced by float glass.

Spandrel Glass: Glass that has been rendered near opaque and glazed in wall areas designed to hide structural columns, floors, walls, or other building elements that are intended to be concealed.

Stain: Chemical corrosion on the surface of glass which manifests itself by an iridescence or whiteness. Stain is frequently caused by moisture trapped between adjoining sheets of glass that are in storage.

Strain Pattern: A specific geometric pattern of iridescence or darkish shadows that may appear under certain lighting conditions, particularly in the presence of polarized light. Strain Pattern is a characteristic of heat-treated glass and should not be mistaken as discoloration or non-uniform tint or color. *Also known as* ***Quench Marks.***

Surface Compression: Compressive stress at and beneath the surfaces of heat-treated or chemically-strengthened glass.

Swiped Edge: Glass edgework in which sharp edges or corners are removed, but the faces are left untouched. This process is typically performed with manual sanding pads or with seaming belts. The degree of grinding is less than for a seamed edge. *See* ***Edge Finish.*** *Also see Appendix 5 for a description of Swiped Edge.*

Tempered Glass: A common abbreviation for Fully Tempered Glass.

Tension: *See* ***Center Tension.*** *Also known as* ***Tension Zone.***

Tong Marks: Slight indentations along an edge of vertically heat-treated glass, resulting from the method of holding or supporting the glass with tongs.

Toughened Glass: International term for tempered glass. In North America, commonly called fully tempered glass. *See* ***Fully Tempered Glass.***

16 CFR 1201: *See* ***CPSC.***

Warp: *See* ***Bow.***

Section II: Decorative Glass Terms

Abrasion: A wearing, grinding or rubbing away by friction.

Abrasion Resistance: The inherent ability of a coating or substrate to resist degradation or destruction by friction.

Acuity: Sharpness.

Adhesion, Chemical: The bonding of two surfaces, such as some coatings to glass, where the molecules from one surface are chemically bonded to molecules of the other surface. Chemical adhesion can vary in strength depending on the type of chemical bonds present and may be accompanied by Mechanical Adhesion. *See* ***Adhesion, Mechanical.***

Adhesion, Mechanical: The bonding of two surfaces, such as some glues to wood, where one material fills small pores or voids in a substrate material. This interlocking of the materials may be accompanied by Chemical Adhesion. *See* ***Adhesion, Chemical.***

Artwork: A design developed primarily for reproduction.

Backlap: A heavy, uneven application of paint on one side of a screen-printed glass product.

Bleeding: Migration of color from the coating film onto or into a surface with which it comes in contact.

Blemish: A noticeable imperfection.

Blisters: A profusion of bubbles in a coating film that form during the heat-treating process and may remain after the film solidifies. Surface disruption, such as a break or hole in the film, can occur in extreme cases. May be accompanied by a slight color change or loss of adhesion.

Blur: Image lacks sharpness; out of focus. *See* ***Smear.***

Ceramic Enamel: An inorganic coating, to be fused to a substrate in a high temperature oven. Consists primarily of a glass frit and inorganic pigments. May be mixed with an organic vehicle. *Also known as* ***Ceramic Frit, Ceramic Paint*** or ***Glass Enamel.***

Ceramic Frit: *See* ***Ceramic Enamel.***

Checking: Fine hairline cracks in a dried coating film which begin at the surface and progress downward. *Also known as* ***Crazing.***

Chemical Adhesion: *See* ***Adhesion, Chemical.***

Color Variation: Noticeable color differences over the coated area on the same piece.

Crater: Small, shallow areas, circular in shape, in a coating film which may or may not expose the underlying substrate. Can vary in size from a tiny spot to an inch or more in diameter.

Crazing: *See* ***Checking.***

Decal: A specially prepared paper on which designs have been printed with ceramic enamels for the purpose of being later transferred to glass and fired onto the surface during the heat-treating process.

Devitrification: A change in a ceramic coating resulting in a loss of gloss due to crystallization. Usually caused by extreme over fire.

Dimple: A shallow depression in a coating film. *Related to* ***Crater.***

Expansion Fit: *See* ***Fit.***

Fisheye: Defect in coating film, generally a circular depression, usually resulting from contamination of the substrate surface; the coating flows away from the contaminant.

Fit: The stress relationship between the fired ceramic enamel and the glass substrate to which it has been applied. *Also known as* ***Expansion Fit.***

Flood Coat: The spreading of a layer of coating material over the image area of a printing screen without actually printing. This serves a dual purpose:

1) To provide an adequate supply of coating material for the printing stroke;
2) To keep the image area wet to reduce the possibility of dried paint clogging the screen.

Frit: A form of low melting glass which forms the permanent vehicle of glass enamels.

Ghost: An image of the printed pattern which extends beyond the boundary of the stencil.

Glass Enamel: *See* ***Ceramic Enamel.***

Gloss: The amount of reflected light relative to the amount of incident light from a surface at a given angle.

Half-Tone: The creation of gradations of color shades and/or transparency by printing dots of varying sizes and spacing.

Hickey: An imperfection in a screen-printed coating caused by contamination; i.e., dirt, lint, hardened specks of color, etc. Often small and circular in shape.

Matte: Without luster or gloss; dull.

Mechanical Adhesion: *See* ***Adhesion, Mechanical.***

Mesh:

1) The woven material that supports the pattern in screen printing.

2) The term that designates the number of openings per linear inch or centimeter in a screen-printing fabric.

Moire: An optical illusion, usually undesirable, that produces linear, circular or wavy patterns in a printed glass application. It occurs when one pattern of regularly spaced dots or lines is overlaid with or set in front of a similar pattern that differs slightly in size, spacing or orientation. This can be produced with two printed patterns, or with one pattern and its reflected image.

Mottle: A blotchy appearance in a coating film.

Negative: A negative image mode in photographic film; dark areas of the subject are clear on film; light areas of the subject are dark on film.

Off-Contact: The distance between the mounted screen and the surface of the substrate to be printed.

Opacity: The degree to which an object obscures a pattern or surface directly behind it. In paints or coatings, the ability of a material to reduce the transmission of light.

Orange Peel: A rough surface texture on a coating film having the appearance of an orange peel; it may be caused by an overly viscous paint or other coating material.

Parallelism: 1) The degree to which two surfaces (or lines) maintain equidistance apart over the entire length;

2) The degree to which a mounted screen and the substrate or printing table are equally spaced.

Pattern: An artistically or mechanically produced design for screen printing.

Pinholes: Tiny, transparent openings in a coating film that can be attributed to surface contamination, cracks, dirt, coating contamination, surface tension, static electricity, screen clogging, abrasion of the film, agglomerates in the coating, rapid solvent loss, etc. Any small hole that permits the passage of light.

Pock Marks: *See **Crater, Fisheye.***

Positive: A positive image made in photographic film; dark areas of subject are dark on film; light areas of subject are light on film.

Registration: The ability to print one or more colors and maintain pattern location on the substrate and alignment of each color to all others.

Sawtooth: Uneven edge definition in a screen-printed design caused by inadequate thickness of emulsion or insufficient exposure of the emulsion which results in the emulsion, during washout operations, to break free of an entire mesh opening, following the contour of the mesh instead of the contour of the image. Most obvious with coarser meshes where the pattern steps over a thread.

Scallop: A condition in which the edges of the coated area pull back, resulting in a scallop-like appearance.

Screen: An assembly of stretched screen mesh fabric on a rigid frame with a stencil attached, ready for printing.

Screen Snap: A defect in a printed film, usually in the shape of an arc, that appears at the trailing edge of the print stroke. Caused by the sudden release of the screen from the substrate before the peeling action is complete.

Scuff: An abrasion or dull area on a glass substrate usually caused by oven rolls or contact with other oven parts during heat treating cycle.

Scum: 1) A dull area in a glossy coating film;

2) A residue left in the image areas of a printing screen due to failure to adequately wash out the emulsion.

Shadow: *See **Ghost.***

Smear: A defect in a coating caused by accidental handling or movement of the printing screen or substrate during application of the coating film. May also be caused by momentary sticking of the printing screen to the printed substrate during the print stroke.

Smudge: *See **Smear.***

Snap-Off: *See **Off-Contact.***

Squeegee: The tool or blade used to force the printing ink through the screen and onto the substrate.

Streak: Elongated defect.

Substrate: The item or material to be printed.

Sulfide Stain: A metallic-appearing gray-like scum on a fired ceramic surface which develops during storage of the decorated product. It is caused by sulfur-containing packaging or atmospheric attack.

Translucent: The property of transmitting and diffusing light so objects beyond may not be viewed clearly.

Viscosity: The term used to designate the degree of fluidity of a coating material.

Voids: Holes or openings in a coating film.

APPENDIX 4

Specification References

Copies of the specifications referenced throughout this manual are available through the appropriate agencies listed below:

ANSI Z26.1
American National Standard for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways

ANSI Z97.1 American National Standard for Safety Glazing Materials Used in Buildings

American National Standards Institute
1430 Broadway
New York, NY 10018

ASTM C346	*Standard Test Method for 45-deg Specular Glass of Ceramic Materials*
ASTM C724	*Standard Test Method for Acid Resistance of Ceramic Decorations on Architectural-Type Glass*
ASTM C978	*Standard Test Method for Photoelastic Determination of Residual Stress in a Transparent Glass Matrix Using a Polarizing Microscope and Optical Retardation Compensation Procedures*
ASTM C1036	*Standard Specification for Flat Glass (Replaces DD-G-451)*
ASTM C1048	*Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass (Replaces DD-G-1403)*
ASTM C1279	*Standard Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat-Strengthened, and Fully Tempered Flat Glass*
ASTM G153	*Standard Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials*
ASTM G154	*Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials*
ASTM G155	*Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials*

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

Canadian Standards:

CAN/CGSB-12.1	*Tempered or Laminated Safety Glass*
CAN/CGSB-12.3	*Flat, Clear Float Glass*
CAN/CSGB-12.4	*Glass, Heat Absorbing*
CAN/CSGB-12.9	*Spandrel Glass*
CAN/CSGB-12.10	*Glass, Light and Heat Reflecting*
CAN/CSGB-12.20	*Structural Design of Glass for Buildings*

Canadian General Standards Board

Portage III, 6B1
11 Laurier Street
Gatineau QC K1A 1G6
Canada

16 CFR 1201 *CPSC Standard on Architectural Glazing Materials*

Consumer Product Safety Commission
111 18th Street NW
Washington, DC 20207

GANA Glazing Manual

National Glass Association
1945 Old Gallows Rd. Ste. 750
Vienna, VA 22182

FMVSS-205 *Federal Motor Vehicle Safety Standard No. 205, Glazing Materials*

Superintendent of Documents
Government Printing Office
Washington, DC 20402

MIL-G-2857 *Glass, Heat-treated, Glazing, Rectangular (bridge windows)*

Commanding Officer
Naval Publications and Form Center
5801 Tabor Ave.
Philadelphia, PA 19120

SAE J673

SAE J674b

Society of Automotive Engineers, Inc.
Detroit Office
2100 West Big Beaver Road
Troy, MI 48098

UL 250 *Standard for Safety Household Refrigerators and Freezers*
UL 471 *Standard for Safety Commercial Refrigerators and Freezers*
UL 544 *Standard for Safety Electrical Medical and Dental Equipment*
UL 858 *Standard for Safety Household Electric Ranges*

Underwriters Laboratories, Inc.
Publications Stock
333 Pfingsten Road
Northbrook, IL 60062-2096

APPENDIX 5
Edge Finish

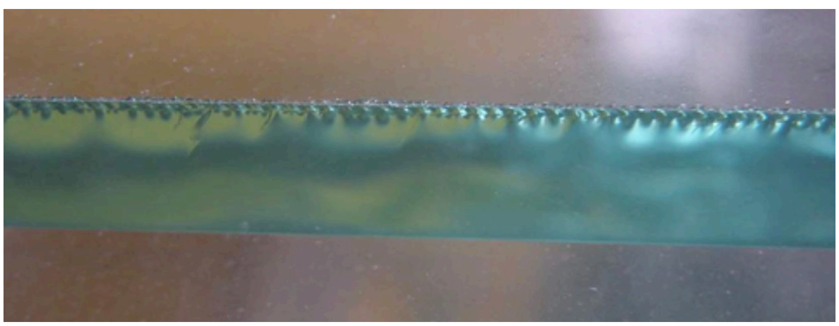
The surface and/or cut edges of glass are commonly subjected to grinding, smoothing and/or polishing by hand or machine processes. Specific applications may require different edge finishes, defined and illustrated below.

Raw Edge

Also known as a “clean cut” or “plain” edge, this is the condition of the edge immediately following a cutting operation. During the cutting process, sub-surface fissures and other flaws are introduced into the glass edge. Tempering and heat strengthening glass with a raw edge will result in lower process yields. Raw edges are usually sharp and more likely to cause cuts or abrasions if handled incorrectly.

FIGURE 22

Raw Edge



Processed, or Finished, Edges

Raw edges are often processed in order to improve safety, appearance and processability. Glass with a processed edge is less sharp and safer to handle. Glass with a processed edge will better withstand some form of heat processing such as heat strengthening, tempering or bending. Glass with processed edges is stronger than glass with raw edges. Processed edges are more aesthetically pleasing and are available in a variety of profiles.

Edge finishes fall under two broad categories: Partially Ground and Fully Ground.

Partially Ground, or Seamed, Edge
Partially ground edges are produced on glass that is cut to size and has minimal edge preparation requirements. Such glass is typically referred to as “seamed.”

Seamed glass has a small chamfer, roughly 45 degrees, that is roughly ground onto all edges, but the faces are left untouched. This process is typically performed with seaming belts, or diamond grinding wheels. The coarseness of the grinding material can have a significant impact on the quality of the edge (see Figures 2 & 3).

Seamed edges can be found on some laminated glass, windshields, insulated glass and glass that will be encapsulated or framed. Seamed edges are generally not meant to be exposed in the final installation.

FIGURE 23

Seamed edge, using 120 grit seaming belt

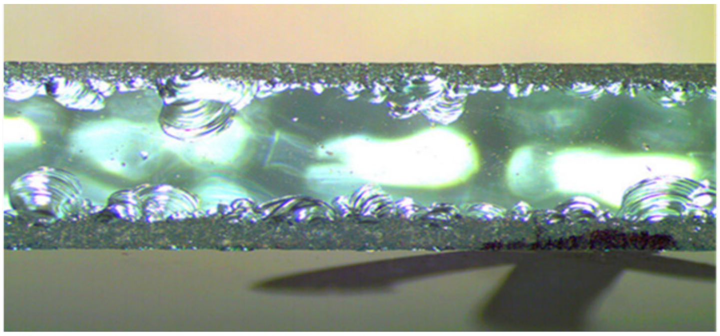
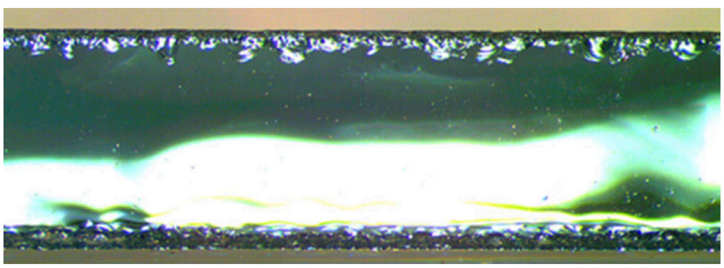


FIGURE 24

Seamed edge using 180 grit seaming belt



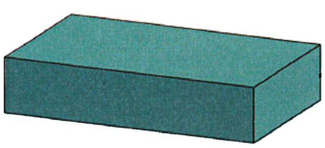
Fully Ground Edges

Fully ground edges are produced on glass that is cut and then ground to size. In fully ground edges, no part of the cut edge is unground. A number of profiles can be produced in a fully ground edge. A diamond grinding wheel is used in this process.

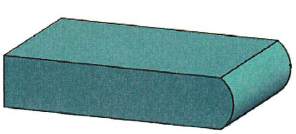
Applications include shower doors, commercial door walls, stair and balcony rails, furniture glass, appliance glass, certain automotive glass and solar glass.

FIGURE 25

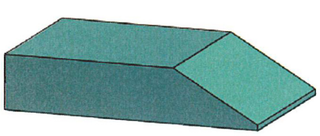
Fully-ground edge profiles



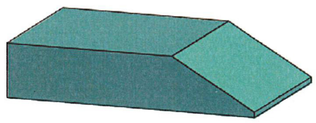
Flat Edge – The cut edge of the glass is ground flat and surface edges are arrissed. Arrissed edges are created by grinding a small chamfer at an angle of approximately 45° to the cut edge. The finished edges may be smooth ground or polished.



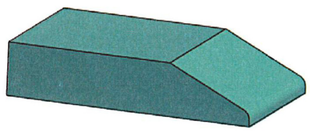
Round Edge – The cut edge of glass is curved to form an arc of a circle of selected radius. The degree of roundness depends on the profile of the grinding wheel. This edge can be smooth ground or polished. Variations and alternate names for Round Edges include Pencil, Weber, Crown, Semi-round, Half-moon and Diamond.



Bevel Edge – The cut edge of glass is beveled to ⅛" or more in width as required. The angle formed by intersection of the plane of the bevel with the face of glass is typically 3° to 10°. The nose of the bevel may be finished or left as cut depending on requirements, thickness and machining capabilities. This edge is most often polished.



Miter Edge – The cut edge of glass is beveled to a miter angle, typically 45°, 22.5° or 15°, or some other specified angle. The knife-edge point is slightly arrissed, left as is, or radiused, depending on requirements and machining capabilities. This edge may be smooth ground or polished.



Feather Edge – A beveled edge where the bevel is brought as close as practicable to the back edge of the glass. This edge is most often polished.

Surface Quality of Edge Finishes

The texture and appearance of the edge surface after finishing depends on the edging tool specifications and process used to machine the edges. Manual sanding pads or sanding belts will result in a rougher texture and less uniform appearance than high-speed, fine grinding or polishing wheels (see Figures 2 & 3). The quality of the finishing tools is also a factor, as worn grinding wheels may result in "burning" of edges and sub-surface cracks.

Definitions of the surfaces for edge finishes are as follows:

- **Ground, or Rough Ground** – Surface exhibits fine linear and random abrasion marks, rough in appearance.
- **Smoothed, or Smooth Ground** – Surface has uniform, frosted appearance which diffuses any reflected light.
- **Polished** – Surface is reflective in appearance similar to the major surface of glass.

Fully ground edges must be specified ground, smoothed or polished.

Bevel and Feather edges are generally polished unless otherwise specified.

APPENDIX 6

Method for Measuring the Surface Stress of Heat-Strengthened and Fully Tempered Float Glass Using Optical Refraction Techniques

A. Scope

This guideline offers recommendations for surface stress analysis of heat-strengthened and fully tempered glass. This guideline is applicable only to measurements made on the tin surface of essentially flat transparent float glass.[1] Examples of equipment such as the Gaertner Scientific DSR[2] and the GASP, a registered trademark of Strainoptics, Inc., are referred to for measuring certain stress ranges.[3] A reference table with recommendations for achieving various levels of accuracy in repeated readings will serve to allow measurements to be as precise as necessary. Guidelines for establishing precision of measurements were determined by ASTM E691 Method for Determining Precision and Accuracy of a Round Robin.[4]

B. Applicable Documents

ASTM C162	*Terminology of Glass and Glass Products.*
ASTM C770	*Standard Test Method for Measurement of Glass Stress Optical Coefficient.*
ASTM C1048	*Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass*
ASTM C1279	*Standard Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat-Strengthened, and Fully Tempered Flat Glass.*
ASTM E691	*Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method.*

Gaertner Scientific (DSR) operating manual

Strainoptics, Inc. (GASP) operation manual

C. Objective

It is the objective of this document to provide the user with guidelines for non-destructive testing to determine the average surface stress of a heat-strengthened or fully tempered flat glass surface. Specifically, this document provides recommendations regarding the number of readings and their locations for measuring surface stresses of heat-strengthened and fully tempered float glass of standard geometries. This document does not instruct the user in the operation of specific instruments. The method of operation, measuring range, and other limitations of the specific instruments may be obtained from the manufacturer.

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1 Float glass, when manufactured, is in direct contact with molten tin during the forming process. This results in a diffusion of tin atoms into the glass surface. The surface in contact with the molten tin is called the “tin surface.” Note: some instrumentation may have the capability to measure curved surfaces; refer to manufacturer’s statement of applicability in determining the suitability of the device for measuring stress on surfaces which are not essentially flat.

2 Contact the manufacturer if a particular instrument is needed to measure a specific reading.

3 The instruments referred to are used only as examples, and were chosen because of the availability of a useful statistical data base describing their precision and accuracy, and because of the convenient commercial availability of these instruments in the U.S. Suitable similar alternative equipment and procedures are also available.

4 The round robin was conducted in May 2000, under the auspices of the ASTM C14-08 Subcommittee to establish Precision and Bias of the C1279-94 Standard Test Method using 12″ X 12″ heat-strengthened and fully tempered ¼″ float glass.

D. General Requirements

Glass to be tested may be production glass or test samples for establishing process parameters. This guideline applies to flat and nearly flat glass surfaces. Glass must be at a uniform, ambient temperature, clean and placed in position with the "tin" side up. If not known, the tin side can be determined using a simple UV light (nominal 254 nm) per the manufacturer's instructions. The proper type and amount of index oil, as prescribed by the equipment manufacturer, should be used. It is important that the test specimen be fully supported in the horizontal plane during the measurement process, and that no weight be applied to the surface of the glass (except for the weight of the instrument) while measuring stresses.

D.1.1 Test Apparatus
To achieve optimal precision in measurements, follow the applicable stress range limitations recommended by the instrument manufacturer.

D.1.2 Stress Measurements
Following the measuring equipment manufacturer's procedure for calibration and operation of the stress measuring device; a set of measurements shall be made in five locations, and in two directions at 90° to each other at each location on each specimen to be tested (see Figure 26) for a total of ten readings per set:

- From an edge arbitrarily chosen (or leading edge if known) as Edge 1, locate point a, ⅛ the length of the specimen (L) at the midpoint of the width of the glass (W).
- From the midpoint of the edge opposite Edge 1, locate point b, ⅛ the length of the specimen (L) at the midpoint of the width of the glass (W).
- Locate point c, at the geometric center of the piece.
- From the midpoint of Edge 2, which would be an edge connecting to Edge 1, locate point d, halfway between the geometric center and Edge 2.
- From the midpoint of the edge opposite Edge 2, locate point e, ½ the distance from that edge to the geometric center.

If one set of two readings per point is taken at each point described above, the average of the data generated at each point can be expected with 95 percent confidence to have a precision of two readings, or ±1055 psi. If additional data sets are collected, the precision of the averages can be improved as described in D.1.2.1 below. The averages of two data sets (or 20 readings all together) should provide a precision of ±746 psi for the data. Any additional repeat measurements should be made at the same locations but at a 45° orientation to the previous positioning of the instrument.

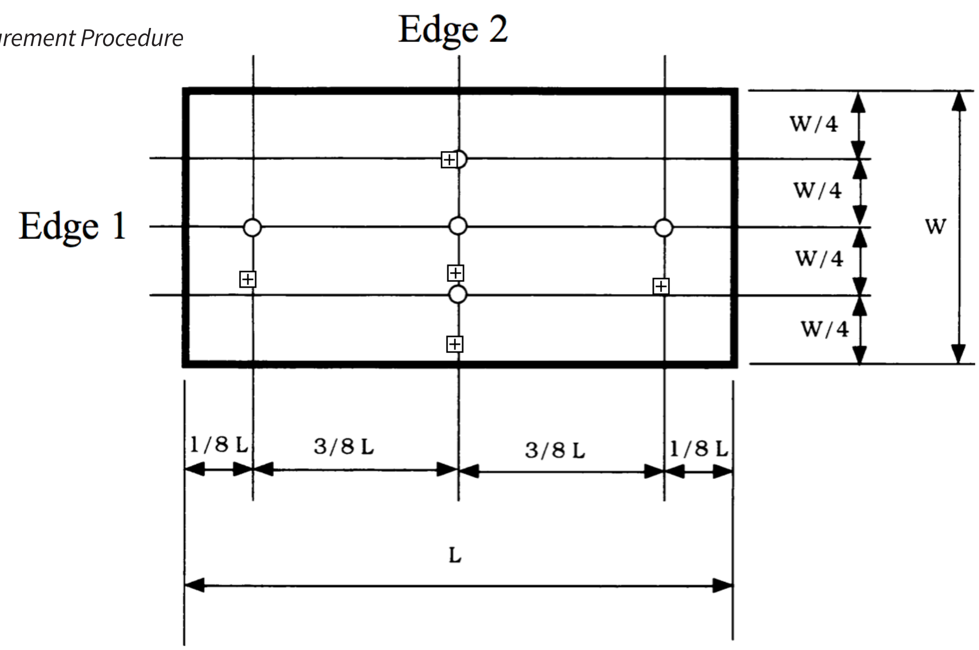
D.1.2.1 Precision of Stress Measurements
Based upon data collected in a round robin test series conducted by members of the ASTM C14-08 Subcommittee Task Group to establish Precision and Bias of the C1279 Standard Test Method, it has been determined that the precision of measurements can be improved by averaging repeated readings of stress at a given point. A table is calculated using the equation:

95 percent confidence limits = $1.96\ s / \sqrt{n}$

Where: s = average standard deviation of the process (which was 912 psi for the measurements provided by seven laboratories on six samples exhibiting a broad range of stress levels, from approximately 2,600 to 18,000 psi.) Measurement locations were as specified by ASTM C1048-97, comprising five points measured in two directions for a total of ten measurements per sample per laboratory. To provide reproducibility, three replicate measurements were made at each point, with the results being averaged. The average standard deviation for reproducibility among the six samples was 0.46.

FIGURE 26

Stress Measurement Procedure



n = number of readings at a single point (X, Y)

Using Table 15, based upon this equation, it is possible to determine statistically with 95 percent confidence, the precision of the average stress measurement at a specific point on the specimen when multiple readings are taken at a point.[1]

TABLE 15

Precision of Stress Measurements

Number of Readings	Precision
1	± 1788 psi
2	± 1268 psi
3	± 1034 psi
4	± 894 psi
5	± 798 psi
6	± 730 psi

D.1.3 Reporting Stress Measurements

Report the individual values for each measurement location and the average for all the readings. A form such as the example on the next page can be used to record results.

[1] This table represents total non-repeatability gauge error for averages of repeat readings with a 95% confidence level. Note that the analysis is based on variation (s = 912 psi) due to repeatability only, i.e., variation found by the same operator using the same gauge. Because this analysis assumes small error between operators and laboratories, and that gauge-to-gauge error is small, it is necessary that consistent procedures and calibration standards be established to assure that these statistics are valid.

Reading Location	a	b	c	d	e
Set 1:					
Stress Results (oriented @ 0° parallel to edge 1)	____,	____,	____,	____,	____
Stress Results (oriented @ 90° to edge 1)	____,	____,	____,	____,	____
Set 2:					
Stress Results (oriented @ 45° to edge 1)	____,	____,	____,	____,	____
Stress Results (oriented @ 135° to edge 1)	____,	____,	____,	____,	____
Average of Column	____,	____,	____,	____,	____

Average of all 5 column averages: ____

Maximum column average: ____

Minimum column average: ____

Precision value: ____

APPENDIX 7

Proper Procedures for Cleaning Architectural Glass Products

Glass Informational Bulletin FB01-00 (2016) (formerly TD 01-0116)

Written in conjuction with the International Window Cleaners Association (IWCA)

Proper Procedures for Cleaning Architectural Glass Products
Architectural glass products play a major role in the comfort of the living and working environment of today's homes and commercial office spaces by providing natural daylight, views of the surroundings, thermal comfort and design aesthetics. Glass usage and condition often affect our selection of where we live, work, shop, play and seek education.

This document describes procedures that generally apply to most architectural glass products. Certain glass types may require different procedures and care. Glass can be clear or tinted and have pyrolytic or sputtered low-E or reflective coatings, some of which may be on the exposed surface of the glass. Glass products can be monolithic (single lites), laminated glass or insulating glass units. (See Glass Informational Bulletin FB15-07 (2016) (formerly ID 01-0816) *Describing Architectural Glass Constructions.*) Glass can be of various strengths, i.e., annealed, heat-strengthened or fully tempered. There are also other decorative and functional glass types including spandrel, silk-screened, patterned, acid etch, and sand-blasted.

Architectural glass products should be properly cleaned and protected throughout the construction process using a program of regularly scheduled maintenance designed to maintain visual clarity and prevent glass surface damage. Since glass products can be permanently damaged if infrequently or improperly cleaned, glass producers and fabricators recommend strict compliance with the following procedures for cleaning glass surfaces.

Routine Cleaning & Maintenance
For routine maintenance, interior and exterior glass surfaces should be thoroughly cleaned as dirt and residue appear. Cleaning frequencies should be tailored to the individual characteristics inherent to the site conditions, as well as the severity of local environmental factors and atmospheric pollutants that vary from region to region. Before proceeding with cleaning, determine whether the glass is clear, tinted or reflective. Surface damage is more noticeable on reflective glass as compared with the other glass products. If the reflective surface is exposed, either on the exterior or interior surface, special care must be taken when cleaning, as damage to the reflective glass surface may result in coating removal and a visible change in light transmittance which is very noticeable. A simple test to determine the location of the reflective coating is to touch the point of a pencil to the glass surface. If the reflection of the pencil point meets the real pencil, the coating is exposed on that side. If there is a gap between the pencil point and the reflections, the coating is not exposed on that side of the glass. Cleaning tinted and reflective glass surfaces in direct sunlight should be avoided, as the surface temperature may be too hot for optimum cleaning. Exterior cleaning should begin at the top of the building and continue to the lower levels to reduce the risk of leaving residue and cleaning solution on glass that has already been cleaned. Cleaning procedures should also include checking that the wind is not blowing the cleaning solution and residue onto already cleaned glass.

Prior to beginning a cleaning project, it is strongly recommended that window cleaners test clean a small area of one window, then stop and examine the surface carefully for any damage to the glass and/or any exposed coating. The ability to detect certain surface damage, such as light scratches, may vary greatly with the lighting conditions. Daylight conditions are needed to properly evaluate a glass surface for damage. Scratches that are not easily seen with a dark or gray sky may be very noticeable when the sun is at a certain angle in the sky or when the sun is low in the sky. In addition, because different backgrounds may yield different observations, cleaning methods should be tested on all glass constructions on the building, including both vision and spandrel units.

Cleaning should begin by soaking the glass surfaces with clean water and a mild, non-abrasive glass cleaning solution. Apply generous amounts of solution to the glass surfaces with a brush, strip washer or other non-abrasive applicator, and lightly agitate to loosen the soil and debris. Immediately following the application of the cleaning solution, a window-cleaning squeegee should be used to remove all of the cleaning solution from the glass surface. During routine cleaning care should be taken to avoid metal contact with the glass surface; razor blades and metal scrapers should not be part of routine cleaning. The use of sufficient water will help prevent abrasive particles from being trapped between the glass and the cleaning tools being used. However, the window cleaner needs to be diligent in keeping all abrasive particles from scratching the glass.

The International Window Cleaning Association (IWCA) recognizes an additional glass cleaning technique being utilized by some professional window cleaning contractors. This technique employs the use of pure water delivered to the glass surface using a specialized extension pole. Gentle agitation with a non-scratching (non-abrasive) brush is followed by the final pure water rinse. Rinse water is generally allowed to evaporate from freshly cleaned surfaces. Therefore, the pure water used in both the wash and rinse must have a total dissolved solids content (TDS) of 20 parts per million (PPM) or less to prevent spotting and streaking of cleansed surfaces. The use of tap water is not acceptable. Effective water treatment, via ion exchange and/or reverse osmosis equipment, should be used in conjunction with delivery & rinse methods at all times. Water quality can be monitored with a handheld TDS or conductivity meter. A reading of 40 micro-Siemens/cm (0.025 Me ohm – cm) represents a TDS level of 20 PPM.

Non-Routine Post-Construction Cleaning & Restoration

Careful communication between the responsible parties should precede the use of aggressive cleaning techniques, as any non-routine cleaning carries a risk of irreparable damage to glass products.

During all stages of construction, the glass must be properly protected from construction debris such as cement, paint, varnish, adhesives and other construction material commonly found on jobsites. (See the NGA/IWCA Bulletin FB03-03 (2018) (formerly TD 03-1003 (2010)) *Construction Site Protection and Maintenance of Architectural Glass.)* Extended construction schedules may create the need for multiple cleanings to avoid the accumulation of significant amounts of soil and debris, and to avoid potential damage. In addition to ordinary techniques for protection from construction debris used by various trades, temporary protective window films may be applied to glass. Follow specific manufacturer instructions regarding film application and removal. If the film is removed prior to job completion, additional cleanings may still be needed to prevent glass damage. Failure to remove temporary protective films by the manufacturer's recommended date may result in aggressive methods being required to remove the film.

Glass that is improperly stored or left unprotected during construction may result in glass that cannot be successfully cleaned using routine cleaning procedures. In such situations, more aggressive cleaning and restoration techniques may become necessary, such as the use of razor blades, chemical cleaning and/or mechanical polishing. Glass surface conditions that may require more aggressive cleaning techniques would include, but not be limited to, the accumulation of paint, stain or varnish overspray; mortar, concrete or cement splashing on glass; silicone sealants and/or lubricants being smeared or sprayed onto glass and frames; and sealer overspray or run-off from adjacent masonry or stone waterproofing operations. In the process of removing tenacious contaminates from unprotected glass, particles may be trapped between the razor blade and the glass, resulting in fine scratches.

While members of NGA and GANA neither condone nor recommend scraping of glass surfaces with blades or scrapers for routine cleaning, it is recognized that window cleaners may choose more aggressive techniques, including the use of razor blades, in non-routine cleaning. In such cases, use of razor blades should be limited to the affected areas of the glass. Scraping should be done in one direction only with a new blade. Never scrape in a back and forth motion as this could trap particles under the blade that may cause scratches. These scratches may be visible at all times, but in some cases they may be visible only under certain lighting conditions. Significant care should be taken to ensure the glass is not scratched. Razor blades should never be used on coated glass surfaces. Contact a professional window cleaner proficient in construction window cleaning, such as a member of the IWCA for the most appropriate solution.

Glass Types

When cleaning the glass in architectural windows and doors, it is necessary to determine what type of glass is being cleaned and what, if any, type of coatings may be present on the exposed surfaces. In addition to reviewing the bulletins previously referenced, it is important to review the Glass Informational Bulletin FB02-02 (2018) (formerly TD

03-0402 (2018)) *Heat-Treated Glass Surfaces are Different* before initiating the window cleaning process, as glass may be heat-treated, i.e., heat-strengthened or fully tempered. Heat-treated glass is used in most architectural glass products today for a variety of strength and safety reasons, but it must be understood that heat-treated surfaces require greater care when cleaning as discussed in detail in the above referenced bulletin.

Some glass may contain a logo that may indicate the glass supplier and if the glass is tempered, heat-strengthened or laminated, but it typically will not indicate the glass type or if exposed coatings are present. A logo may not be visible or present on all heat-treated glass products, so the lack of a logo does not mean the glass is not heat-treated.

High performance windows may be produced with a coating on one or both exposed surfaces. Low-E coatings are typically neutral in color and very difficult to see. Reflective coatings increase the reflectivity of the glass and are normally obvious. Specific glass cleaning procedures must be adhered to when attempting to clean coated glass surfaces. Consult the glass manufacturer's guidelines for specific procedures.

The plastic interlayer in laminated glass is generally exposed around the periphery of the window glass; cleaning fluids and their vapors must be kept away from this area. For cleaning laminated glass, or windows and doors containing laminated glass, do not use anything that is corrosive such as solvents, acids, bases or other chemicals. Examples of some materials that may cause harm include, but are not limited to:

- Bleach (or other solutions containing sodium hypochlorite)
- Acids, especially muriatic/hydrochloric and hydrofluoric (often found in glass cleaning and restoration products)
- Ammonia
- Toluene
- Xylene
- Methyl Ethyl Ketone (a.k.a. MEK)
- Acetone
- Ethyl Acetate
- Mineral Spirits
- Turpentine
- Methanol
- Products with labeling that states they are flammable or corrosive

Contact the laminated glass supplier or interlayer manufacturers for additional recommendations and cautions.

Insulating glass, laminated glass and decorative glass is glazed in many ways, utilizing glazing sealants, gaskets, and/or tapes. Glazing materials do not provide a sufficient barrier to prevent cleaning agents from entering the glazing pocket and damaging the edge of the glass product or affecting the insulating glass unit seal. The presence of weep holes is recommended but is also not sufficient to overcome the risk of improper cleaning materials coming in contact with the edge of glass products. Exposure to certain chemicals may affect the sealants of insulating glass units and the surface of decorative products. Insulating glass unit longevity may be negatively affected by exposure to certain chemicals. Contact the supplier for additional recommendations and cautions.

The glass industry takes extreme care to avoid glass scratches by protecting glass surfaces during manufacturing and fabrication, as well as during all shipping and handling required to deliver the glass to the end user. A large percentage of damaged glass results from non-glass trades working near glass. They may inadvertently lean tools against the glass, splash materials onto the glass and/or clean the glass incorrectly, any of which can permanently damage glass.

To ensure long-term performance of the glass in a building, NGA and IWCA encourage glazing contractors, general contractors, building management and owners to be diligent in preserving the integrity of glass products. It is important to be aware of conditions that can lead to glass damage, to follow the handling and cleaning guidelines provided by NGA/IWCA and the glass fabricator, and to adhere to a regular schedule of maintenance cleaning. Generally, twice per year cleaning is sufficient; however, specific regions may require more frequent cleaning due to environmental factors and atmospheric pollutants. Contact a professional window cleaner, such as members of the IWCA, to discuss recommended frequencies for your particular building.

Quick-Reference Guide to Cleaning Architectural Glass Products
The following "Do's" and "Don'ts" are offered as a supplement to the Glass Informational Bulletin FB01-00 (2016) (formerly TD 01-0116) Proper Procedures for Cleaning Architectural Glass Products:

The following are things to DO:
- DO clean glass when dirt and residue appear
- DO protect glass during all stages of construction
- DO determine if coated glass surfaces are exposed
- DO exercise special care when cleaning coated glass surfaces
- DO avoid cleaning tinted and coated glass surfaces in direct sunlight
- DO start cleaning at the top of the building and continue to lower levels
- DO soak the glass surface with a clean water and soap solution to loosen dirt and debris
- DO use a mild, non-abrasive commercial window cleaning solution
- DO use a window-cleaning squeegee to remove all of the cleaning solution
- DO clean one representative window and check to see if procedures have caused any damage
- DO be aware of and follow the glass supplier's specific cleaning recommendations
- DO caution other trades against allowing other materials to contact the glass
- DO watch for and prevent conditions that can damage the glass

The following are things NOT to do:
- DO NOT start cleaning without reading:

FB15-07 (2016) (formerly ID 01-0816)	*Describing Architectural Glass Constructions*
FB02-02 (2018) (formerly TD 02-0402 (2018))	*Heat-Treated Glass Surfaces Are Different*
FB03-03 (2018) (formerly TD 03-03)	*Construction Site Protection and Maintenance of Architectural Glass (in collaboration with IWCA)*
FB01-00 (2016) (formerly TD 01-0116)	*Proper Procedures for Cleaning Architectural Glass Products*

- DO NOT allow dirt and residue to remain on glass for an extended period of time
- DO NOT begin cleaning glass without knowing if a coated surface is exposed
- DO NOT clean tinted or coated glass in direct sunlight
- DO NOT allow water or cleaning residue to remain on the glass or adjacent materials
- DO NOT begin cleaning without rinsing excessive dirt and debris
- DO NOT use abrasive cleaning solutions or materials for maintenance cleaning
- DO NOT ever use razor blades on coated glass surfaces
- DO NOT allow metal parts of cleaning equipment to contact the glass
- DO NOT trap abrasive particles between the cleaning materials and the glass surface
- DO NOT allow other trades to lean tools or materials against the glass surface
- DO NOT allow splashed materials to dry on the glass surface

Consult either glasswebsite.com or iwca.org for additional information and links providing additional technical resources.

The National Glass Association (NGA), with GANA has produced this Glass Information Bulletin in cooperation with the International Window Cleaning Association (IWCA) solely to provide general information as to basic proper procedures for cleaning architectural glass products. The Bulletin does not purport to state that any one particular type of glass cleaning process or procedure should be used in all applications, or even in any specific application. The user of this Bulletin has the responsibility to ensure the cleaning instructions from the glass supplier are followed. NGA disclaims any responsibility for any specific results relating to the use of this Bulletin, for any errors or omissions contained in the Bulletin, and for any liability for loss or damage of any kind arising out of the use of this Bulletin.

APPENDIX 8

Units of Measure

A. Scope

This guide provides basic information and a cross reference for Units of Measure (UoM) while using the *Engineering Standards Manual* (ESM).

B. Objective

- Provide a means of consistency, clarification and convention for UoM.
- Provide the user of the ESM with constants to calculate various measures and weight.
- Provide basic conversion tables for English to Metric measurement.

C. Common Measurements

- Distance
- Weight/Mass
- Energy
- Pressure
- Temperature

D. General Information/Considerations

- Follow manufacturer's recommendation for safe and proper use of measurement tools.
- Always properly store and handle measurement tools to avoid loss of calibration.
- Select the measurement tool based upon the precision you wish to attain and do not report results to a greater precision than the measurement tool is capable.
- Operator skill and training in the use of selected tools should be considered to attain the proper result.
- For some measures, such as distance and weight, GR&R (Gage Repeatability and Reproducibility) is highly recommended for accuracy.
- Measurement accuracy is improved with certified and properly calibrated tools.
- Instrument limitations, scale graduations, observational angle, temperature change, measurement range, etc., should be considered in tool selection.
- Consider the coefficient of expansion when measuring distances on dissimilar materials.

E. Conversions

Dimensional

- 1 Millimeter = 0.03936996 Inch
- 1 Inch = 25.4 Millimeters
- 1 Centimeter = 0.3937008 Inch
- 1 Inch = 2.54 Centimeters
- 1 Meter = 39.36996 Inches

Weight

- 1 Ounce = 28.34952 Grams
- 1 Gram = 0.0352736 Ounce
- 1 Ounce = 0.0625 Pound
- 1 Pound = 16 Ounces
- 1 Ounce = 28.34952 Grams
- 1 Pound = 453.5924 Grams
- 1 Pound = 0.4535924 Kilogram
- 1 Gram = 0.0352736 Ounce
- 1 Kilogram = 35.27392 Ounces
- 1 Kilogram = 2.20462 Pounds
- 1 Kilogram = 1000 Grams

Pressure/Stress
- 1 P.S.I. = 0.006894757 MPa
- 1 MPa = 145.0377 P.S.I.

Energy
- 1 Foot-pound Force = 1.355818 Joule
- 1 Joule = 0.7375621 Pound Force-foot

Temperature
- (°F - 32) x $\frac{5}{9}$ = °C
- °C x $\frac{9}{5}$ + 32 = °F

Volume
- 1 Milliliter = 0.03381402 Ounce
- 1 Ounce = 29.57353 Milliliters
- 1 Liter = 33.81402 Ounces
- 1 Pint = 473.1765 Milliliters
- 1 Quart = 946.3529 Milliliters
- 1 Gallon = 3.78541 Liters

F. Tables: (see pages 103 through 109)

TABLE 16

Dimensional Conversion US Fraction to Inch to Millimeter

Inch (Fractional)	Inch (Decimal)	Millimeter (mm)	Inch (Fractional)	Inch (Decimal)	Millimeter (mm)	Millimeter (mm)	Inch (Decimal)
1/64	0.016	0.40	33/64	0.516	13.10	0.1	0.004
1/32	0.031	0.79	17/32	0.531	13.49	0.2	0.008
3/64	0.047	1.19	35/64	0.547	13.89	0.3	0.012
1/16	0.063	1.59	9/16	0.563	14.29	0.4	0.016
5/64	0.078	1.98	37/64	0.578	14.68	0.5	0.020
3/32	0.094	2.38	19/32	0.594	15.08	0.6	0.024
7/64	0.109	2.78	39/64	0.609	15.48	0.7	0.028
1/8	0.125	3.18	5/8	0.625	15.88	0.8	0.032
9/64	0.141	3.57	41/64	0.641	16.27	0.9	0.036
5/32	0.156	3.97	21/32	0.656	16.67	1	0.039
11/64	0.172	4.37	43/64	0.672	17.07	2	0.079
3/16	0.188	4.76	11/16	0.688	17.46	3	0.118
13/64	0.203	5.16	45/64	0.703	17.86	4	0.157
7/32	0.219	5.56	23/32	0.719	18.26	5	0.197
15/64	0.234	5.95	47/64	0.734	18.65	6	0.236
1/4	0.250	6.35	3/4	0.750	19.05	7	0.276
17/64	0.266	6.75	49/64	0.766	19.45	8	0.315
9/32	0.281	7.14	25/32	0.781	19.84	9	0.354
19/64	0.297	7.54	51/64	0.797	20.24	10	0.394
5/16	0.313	7.94	13/16	0.813	20.64	11	0.433
21/64	0.328	8.33	53/64	0.828	21.03	12	0.473
11/32	0.344	8.73	27/32	0.844	21.43	13	0.512
23/64	0.359	9.13	55/64	0.859	21.83	14	0.551
3/8	0.375	9.53	7/8	0.875	22.23	15	0.591
25/64	0.391	9.92	57/64	0.891	22.62	16	0.630
13/32	0.406	10.32	29/32	0.906	23.02	17	0.670
27/64	0.422	10.72	59/64	0.922	23.42	18	0.709
7/16	0.438	11.11	15/16	0.938	23.81	19	0.748
29/64	0.453	11.51	61/64	0.953	24.21	20	0.788
15/32	0.469	11.91	31/32	0.969	24.61	21	0.827
31/64	0.484	12.30	63/64	0.984	25.00	22	0.867
1/2	0.500	12.70	1	1.000	25.40	23	0.906
						24	0.945
						25	0.985

TABLE 17

Weight Conversion Ounce to Gram

Ounce	=	Gram	Gram	=	Ounce	Gram	=	Ounce
0.1	=	2.83	0.1	=	0.004	28.0	=	0.988
0.2	=	5.67	0.2	=	0.007	29.0	=	1.023
0.3	=	8.50	0.3	=	0.011	30.0	=	1.058
0.4	=	11.34	0.4	=	0.014	31.0	=	1.093
0.5	=	14.17	0.5	=	0.018	32.0	=	1.129
0.6	=	17.01	0.6	=	0.021	33.0	=	1.164
0.7	=	19.84	0.7	=	0.025	34.0	=	1.199
0.8	=	22.68	0.8	=	0.028	35.0	=	1.235
0.9	=	25.51	0.9	=	0.032	36.0	=	1.270
1.0	=	28.35	1.0	=	0.035	37.0	=	1.305
2.0	=	56.70	2.0	=	0.071	38.0	=	1.340
3.0	=	85.05	3.0	=	0.106	39.0	=	1.376
4.0	=	113.40	4.0	=	0.141	40.0	=	1.411
5.0	=	141.75	5.0	=	0.176	41.0	=	1.446
6.0	=	170.10	6.0	=	0.212	42.0	=	1.481
7.0	=	198.45	7.0	=	0.247	43.0	=	1.517
8.0	=	226.80	8.0	=	0.282	44.0	=	1.552
9.0	=	255.15	9.0	=	0.317	45.0	=	1.587
10.0	=	283.50	10.0	=	0.353	46.0	=	1.623
11.0	=	311.84	11.0	=	0.388	47.0	=	1.658
12.0	=	340.19	12.0	=	0.423	48.0	=	1.693
13.0	=	368.54	13.0	=	0.459	49.0	=	1.728
14.0	=	396.89	14.0	=	0.494	50.0	=	1.764
15.0	=	425.24	15.0	=	0.529	51.0	=	1.799
16.0	=	453.59	16.0	=	0.564	52.0	=	1.834
17.0	=	481.94	17.0	=	0.600	53.0	=	1.870
18.0	=	510.29	18.0	=	0.635	54.0	=	1.905
19.0	=	538.64	19.0	=	0.670	55.0	=	1.940
20.0	=	566.99	20.0	=	0.705	56.0	=	1.975
21.0	=	595.34	21.0	=	0.741	57.0	=	2.011
22.0	=	623.69	22.0	=	0.776	58.0	=	2.046
23.0	=	652.04	23.0	=	0.811	59.0	=	2.081
24.0	=	680.39	24.0	=	0.847	60.0	=	2.116
25.0	=	708.74	25.0	=	0.882	61.0	=	2.152
26.0	=	737.09	26.0	=	0.917			
27.0	=	765.44	27.0	=	0.952			

TABLE 18

Weight Conversion Ounce to Pound to Gram to Kilogram

Ounce	=	Pound	=	Gram	=	Kilogram
1	=	0.06	=	28.35	=	0.03
2	=	0.13	=	56.70	=	0.06
3	=	0.19	=	85.05	=	0.09
4	=	0.25	=	113.40	=	0.11
5	=	0.31	=	141.75	=	0.14
6	=	0.38	=	170.10	=	0.17
7	=	0.44	=	198.45	=	0.20
8	=	0.50	=	226.80	=	0.23
9	=	0.56	=	255.15	=	0.26
10	=	0.63	=	283.50	=	0.28
11	=	0.69	=	311.84	=	0.31
12	=	0.75	=	340.19	=	0.34
13	=	0.81	=	368.54	=	0.37
14	=	0.88	=	396.89	=	0.40
15	=	0.94	=	425.24	=	0.43
16	=	1.00	=	453.59	=	0.45
17	=	1.06	=	481.94	=	0.48
18	=	1.13	=	510.29	=	0.51
19	=	1.19	=	538.64	=	0.54
20	=	1.25	=	566.99	=	0.57
21	=	1.31	=	595.34	=	0.60
22	=	1.38	=	623.69	=	0.62
23	=	1.44	=	652.04	=	0.65
24	=	1.50	=	680.39	=	0.68
25	=	1.56	=	708.74	=	0.71
26	=	1.63	=	737.09	=	0.74
27	=	1.69	=	765.44	=	0.77
28	=	1.75	=	793.79	=	0.79
29	=	1.81	=	822.14	=	0.82
30	=	1.88	=	850.49	=	0.85
31	=	1.94	=	878.84	=	0.88
32	=	2.00	=	907.18	=	0.91
33	=	2.06	=	935.53	=	0.94
34	=	2.13	=	963.88	=	0.96
35	=	2.19	=	992.23	=	0.99
36	=	2.25	=	1020.58	=	1.02

TABLE 19

Conversion, P.S.I. to MPa

P.S.I.	=	MPa	P.S.I.	=	MPa	P.S.I.	=	MPa	P.S.I.	=	MPa
100	=	0.689	3700	=	25.511	7300	=	50.332	10900	=	75.153
200	=	1.379	3800	=	26.200	7400	=	51.021	11000	=	75.842
300	=	2.068	3900	=	26.890	7500	=	51.711	11100	=	76.532
400	=	2.758	4000	=	27.579	7600	=	52.400	11200	=	77.221
500	=	3.447	4100	=	28.269	7700	=	53.090	11300	=	77.911
600	=	4.137	4200	=	28.958	7800	=	53.779	11400	=	78.600
700	=	4.826	4300	=	29.647	7900	=	54.469	11500	=	79.290
800	=	5.516	4400	=	30.337	8000	=	55.158	11600	=	79.979
900	=	6.205	4500	=	31.026	8100	=	55.848	11700	=	80.669
1000	=	6.895	4600	=	31.716	8200	=	56.537	11800	=	81.358
1100	=	7.584	4700	=	32.405	8300	=	57.226	11900	=	82.048
1200	=	8.274	4800	=	33.095	8400	=	57.916	12000	=	82.737
1300	=	8.963	4900	=	33.784	8500	=	58.605	12100	=	83.427
1400	=	9.653	5000	=	34.474	8600	=	59.295	12200	=	84.116
1500	=	10.342	5100	=	35.163	8700	=	59.984	12300	=	84.806
1600	=	11.032	5200	=	35.853	8800	=	60.674	12400	=	85.495
1700	=	11.721	5300	=	36.542	8900	=	61.363	12500	=	86.184
1800	=	12.411	5400	=	37.232	9000	=	62.053	12600	=	86.874
1900	=	13.100	5500	=	37.921	9100	=	62.742	12700	=	87.563
2000	=	13.790	5600	=	38.611	9200	=	63.432	12800	=	88.253
2100	=	14.479	5700	=	39.300	9300	=	64.121	12900	=	88.942
2200	=	15.168	5800	=	39.990	9400	=	64.811	13000	=	89.632
2300	=	15.858	5900	=	40.679	9500	=	65.500	13100	=	90.321
2400	=	16.547	6000	=	41.369	9600	=	66.190	13200	=	91.011
2500	=	17.237	6100	=	42.058	9700	=	66.879	13300	=	91.700
2600	=	17.926	6200	=	42.747	9800	=	67.569	13400	=	92.390
2700	=	18.616	6300	=	43.437	9900	=	68.258	13500	=	93.079
2800	=	19.305	6400	=	44.126	10000	=	68.948	13600	=	93.769
2900	=	19.995	6500	=	44.816	10100	=	69.637	13700	=	94.458
3000	=	20.684	6600	=	45.505	10200	=	70.327	13800	=	95.148
3100	=	21.374	6700	=	46.195	10300	=	71.016	13900	=	95.837
3200	=	22.063	6800	=	46.884	10400	=	71.705	14000	=	96.527
3300	=	22.753	6900	=	47.574	10500	=	72.395	14100	=	97.216
3400	=	23.442	7000	=	48.263	10600	=	73.084	14200	=	97.906
3500	=	24.132	7100	=	48.953	10700	=	73.774	14300	=	98.595
3600	=	24.821	7200	=	49.642	10800	=	74.463	14400	=	99.285

TABLE 20

Energy Conversion Pound Feet to Joule

Lb-Ft	=	Joule	Lb-Ft	=	Joule	Lb-Ft	=	Joule	Lb-Ft	=	Joule
1	=	1.36	37	=	50.17	73	=	98.98	109	=	147.784
2	=	2.71	38	=	51.52	74	=	100.33	110	=	149.14
3	=	4.07	39	=	52.88	75	=	101.69	111	=	150.496
4	=	5.42	40	=	54.23	76	=	103.04	112	=	151.852
5	=	6.78	41	=	55.59	77	=	104.40	113	=	153.207
6	=	8.14	42	=	56.94	78	=	105.75	114	=	154.563
7	=	9.49	43	=	58.30	79	=	107.11	115	=	155.919
8	=	10.85	44	=	59.66	80	=	108.47	116	=	157.275
9	=	12.20	45	=	61.01	81	=	109.82	117	=	158.631
10	=	13.56	46	=	62.37	82	=	111.18	118	=	159.987
11	=	14.91	47	=	63.72	83	=	112.53	119	=	161.342
12	=	16.27	48	=	65.08	84	=	113.89	120	=	162.698
13	=	17.63	49	=	66.44	85	=	115.25	121	=	164.054
14	=	18.98	50	=	67.79	86	=	116.60	122	=	165.41
15	=	20.34	51	=	69.15	87	=	117.96	123	=	166.766
16	=	21.69	52	=	70.50	88	=	119.31	124	=	168.121
17	=	23.05	53	=	71.86	89	=	120.67	125	=	169.477
18	=	24.41	54	=	73.21	90	=	122.02	126	=	170.833
19	=	25.76	55	=	74.57	91	=	123.38	127	=	172.189
20	=	27.12	56	=	75.93	92	=	124.74	128	=	173.545
21	=	28.47	57	=	77.28	93	=	126.09	129	=	174.901
22	=	29.83	58	=	78.64	94	=	127.45	130	=	176.256
23	=	31.18	59	=	79.99	95	=	128.80	131	=	177.612
24	=	32.54	60	=	81.35	96	=	130.16	132	=	178.968
25	=	33.90	61	=	82.71	97	=	131.51	133	=	180.324
26	=	35.25	62	=	84.06	98	=	132.87	134	=	181.68
27	=	36.61	63	=	85.42	99	=	134.23	135	=	183.035
28	=	37.96	64	=	86.77	100	=	135.58	136	=	184.391
29	=	39.32	65	=	88.13	101	=	136.94	137	=	185.747
30	=	40.68	66	=	89.48	102	=	138.29	138	=	187.103
31	=	42.03	67	=	90.84	103	=	139.65	139	=	188.459
32	=	43.39	68	=	92.20	104	=	141.01	140	=	189.815
33	=	44.74	69	=	93.55	105	=	142.36	141	=	191.17
34	=	46.10	70	=	94.91	106	=	143.72	142	=	192.526
35	=	47.45	71	=	96.26	107	=	145.07	143	=	193.882
36	=	48.81	72	=	97.62	108	=	146.43	144	=	195.238

TABLE 21

Temperature Conversion F to C

F	=	C	F	=	C	F	=	C	F	=	C
-40	=	-40.00									
-30	=	-30.00									
-20	=	-28.89	330	=	165.56	690	=	365.56	1050	=	565.56
-10	=	-23.33	340	=	171.11	700	=	371.11	1060	=	571.11
0	=	-17.78	350	=	176.67	710	=	376.67	1070	=	576.67
10	=	-12.22	360	=	182.22	720	=	382.22	1080	=	582.22
20	=	-6.67	370	=	187.78	730	=	387.78	1090	=	587.78
30	=	-1.11	380	=	193.33	740	=	393.33	1100	=	593.33
32	=	0.00	390	=	198.89	750	=	398.89	1110	=	598.89
40	=	4.44	400	=	204.44	760	=	404.44	1120	=	604.44
50	=	10.00	410	=	210.00	770	=	410.00	1130	=	610.00
60	=	15.56	420	=	215.56	780	=	415.56	1140	=	615.56
70	=	21.11	430	=	221.11	790	=	421.11	1150	=	621.11
80	=	26.67	440	=	226.67	800	=	426.67	1160	=	626.67
90	=	32.22	450	=	232.22	810	=	432.22	1170	=	632.22
100	=	37.78	460	=	237.78	820	=	437.78	1180	=	637.78
110	=	43.33	470	=	243.33	830	=	443.33	1190	=	643.33
120	=	48.89	480	=	248.89	840	=	448.89	1200	=	648.89
130	=	54.44	490	=	254.44	850	=	454.44	1210	=	654.44
140	=	60.00	500	=	260.00	860	=	460.00	1220	=	660.00
150	=	65.56	510	=	265.56	870	=	465.56	1230	=	665.56
160	=	71.11	520	=	271.11	880	=	471.11	1240	=	671.11
170	=	76.67	530	=	276.67	890	=	476.67	1250	=	676.67
180	=	82.22	540	=	282.22	900	=	482.22	1260	=	682.22
190	=	87.78	550	=	287.78	910	=	487.78	1270	=	687.78
200	=	93.33	560	=	293.33	920	=	493.33	1280	=	693.33
210	=	98.89	570	=	298.89	930	=	498.89	1290	=	698.89
220	=	104.44	580	=	304.44	940	=	504.44	1300	=	704.45
230	=	110.00	590	=	310.00	950	=	510.00	1310	=	710.00
240	=	115.56	600	=	315.56	960	=	515.56	1320	=	715.56
250	=	121.11	610	=	321.11	970	=	521.11	1330	=	721.11
260	=	126.67	620	=	326.67	980	=	526.67	1340	=	726.67
270	=	132.22	630	=	332.22	990	=	532.22	1350	=	732.22
280	=	137.78	640	=	337.78	1000	=	537.78	1360	=	737.78
290	=	143.33	650	=	343.33	1010	=	543.33	1370	=	743.33
300	=	148.89	660	=	348.89	1020	=	548.89	1380	=	748.89
310	=	154.44	670	=	354.44	1030	=	554.44	1390	=	754.45
320	=	160.00	680	=	360.00	1040	=	560.00	1400	=	760.00

TABLE 22

Volume Conversion

Ounce	=	Quart	=	Gallon	=	Milliliter	=	Liter
1	=	0.031	=	0.008	=	29.57	=	0.03
10	=	0.313	=	0.078	=	295.74	=	0.30
20	=	0.625	=	0.156	=	591.47	=	0.59
30	=	0.938	=	0.234	=	887.21	=	0.89
40	=	1.250	=	0.313	=	1182.94	=	1.18
50	=	1.563	=	0.391	=	1478.68	=	1.48
60	=	1.875	=	0.469	=	1774.41	=	1.77
70	=	2.188	=	0.547	=	2070.15	=	2.07
80	=	2.500	=	0.625	=	2365.88	=	2.37
90	=	2.813	=	0.703	=	2661.62	=	2.66
100	=	3.125	=	0.781	=	2957.35	=	2.96
110	=	3.438	=	0.859	=	3253.09	=	3.25
120	=	3.750	=	0.938	=	3548.82	=	3.55
130	=	4.063	=	1.016	=	3844.56	=	3.84
140	=	4.375	=	1.094	=	4140.29	=	4.14
150	=	4.688	=	1.172	=	4436.03	=	4.44
160	=	5.000	=	1.250	=	4731.76	=	4.73
170	=	5.313	=	1.328	=	5027.50	=	5.03
180	=	5.625	=	1.406	=	5323.24	=	5.32
190	=	5.938	=	1.484	=	5618.97	=	5.62
200	=	6.250	=	1.563	=	5914.71	=	5.91
210	=	6.563	=	1.641	=	6210.44	=	6.21
220	=	6.875	=	1.719	=	6506.18	=	6.51
230	=	7.188	=	1.797	=	6801.91	=	6.80
240	=	7.500	=	1.875	=	7097.65	=	7.10
250	=	7.813	=	1.953	=	7393.38	=	7.39
260	=	8.125	=	2.031	=	7689.12	=	7.69
270	=	8.438	=	2.109	=	7984.85	=	7.98
280	=	8.750	=	2.188	=	8280.59	=	8.28
290	=	9.063	=	2.266	=	8576.32	=	8.58
300	=	9.375	=	2.344	=	8872.06	=	8.87
310	=	9.688	=	2.422	=	9167.79	=	9.17
320	=	10.000	=	2.500	=	9463.53	=	9.46
330	=	10.313	=	2.578	=	9759.26	=	9.76
340	=	10.625	=	2.656	=	10055.00	=	10.06
350	=	10.938	=	2.734	=	10350.74	=	10.35

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