V-Grooving

In 1996 Vitro (formerly PPG Industries) issued Technical Service Recommendation 96-1, "Fabrication of Heat Treated Glass". TSR 96-1 was a reaffirmation of Vitro's long-standing recommendations against the post-heat treatment fabrication of glass. One of the reasons that Vitro reaffirmed its recommendations was the popularity of v-grooved glass, particularly in doors and sidelights where the glass must also be tempered to meet safety glazing requirements.

While data exists that confirms that significant reduction in glass strength occurs when glass is sand blasted or etched after heat treatment and while it is reasonable to assume that comparable, or even greater strength reductions occur if the glass is grooved after heat treatment, Vitro conducted tests to verify this assumption. Testing included both Uniform Pressure Destructive Tests and Impact Resistance Tests. The following glass types were tested in both 3.3mm and 5mm thickness:

- Annealed - no grooves
- Annealed with grooves **(5mm thickness only)**
- Tempered - no grooves
- Tempered - grooved before tempering
- Tempered - grooved after tempering

Test results, which are summarized in this TD, support the following conclusions:

When the glass is subjected to Uniform Pressure Destructive Tests:

- The strength of the grooved surface of annealed glass is approximately 59% less than the strength of annealed glass without grooves.
- The strength of the grooved surface of glass that was grooved after tempering is approximately 58% less than the strength of tempered glass without grooves.
- The strength of the grooved surface of glass that was grooved before tempering is approximately 33% less than the strength of tempered glass without grooves.
- The strength of the grooved surface of glass that was grooved after tempering was approximately equal to the strength of annealed glass without grooves.

When the glass is subjected to 1/2 pound steel ball impact bending stress conditions:

- The strength of the grooved surface of annealed glass is approximately 79% less than the strength of annealed glass without grooves.
- The strength of the grooved surface of glass that is grooved after tempering is approximately 76% less than the strength of tempered glass without grooves.

V-Grooving

- The strength of the grooved surface of glass that is grooved before tempering is approximately 60% less than the strength of tempered glass without grooves.
- The strength of the grooved surface of glass that is grooved after tempering is approximately 66% less than the strength of annealed glass without grooves.

These test results also support Vitro's long standing recommendations, as restated in Technical Services Recommendation 96-1, against the further fabrication of glass once it has been heat treated.

SUMMARY OF TEST RESULTS – Grooved and Non-Grooved Glass

Significance

The performance of any glass product will be influenced by many factors, including lite geometry, surface and edge conditions, and the methodology used to perform the test. Glass that has been V-grooved introduces additional influencing factors, including the geometry of the groove, groove pattern, and additional surface damage caused by the grooving process.

The results presented in this document pertain to samples with V-grooves as described in Sketches 1 & 2. Photograph 1 shows a typical test sample. While a reduction in strength is to be expected with any grooved glass, the magnitude of such reductions will vary, depending on the geometry of the groove, the groove pattern and the quality of the grooving process.

Uniform Pressure Tests

A total of 68 lites of glass were tested. These included 3.3mm and 5mm thickness, grooved and non-grooved, and both annealed and tempered. The average groove depth on 3.3mm thick lites was 0.035"; the average groove depth on 5mm thick lites was 0.025". The 3mm and 5mm tempered lites had average surface compression values of 14,100 psi and 19,800 psi respectively.

The glass lites were tested on an aluminum test fixture with approximate simple support edge boundary conditions and were subjected to a progressive ramp uniformly distributed pressure equivalent to 1,000 and 10,000 psi per minute for the annealed and tempered plates, respectively, until breakage occurred. The applied pressure to cause glass breakage was then recorded.

Using the recorded pressure at failure and the rate of loading, the BIHAR Finite Difference computer analysis program was then used to calculate the effective basic strength of the glass lite and the maximum stress induced by the applied pressure. For tempered and grooved glass, the BIHAR program was also used to calculate the total performance strength of the glass by assuming a mean basic strength based on mirror radius breaking stress values or a measured mean surface compression value and then iteratively solving for an

V-Grooving

effective mean surface compression or mean basic strength, respectively, until a predicted breakage rate of 50% was achieved.
The results of the uniform pressure testing are summarized in Table 1; charts 1 and 2 present the data graphically.

Impact Resistance Test Results

A total of 71- 22" x 36" lites of glass were tested. These included 3.3mm and 5mm thickness, grooved and non-grooved, and both annealed and tempered. The average groove depth on 3.3mm thick lites was 0.035"; the average groove depth on 5mm thick lites was 0.025".

The glass lites were tested on an aluminum test fixture (see Photograph 2) with approximate simple support edge boundary conditions and were impacted with a 1/2 pound steel ball dropped such that it impacted the glass lites within a 5-mm radius of its center. The sample was deemed to have passed if it did not break within 30 seconds of impact. The glass lites were impacted starting at 10 inches drop height, as measured from the underside of the steel impact ball and were successively impacted in 10 inch height increments until failure occurred.

The bending stress (σ in units of psi), which occurs on the opposite surface of the glass plate being impacted by a 1/2 pound steel ball, was calculated by using the equation:

$$\sigma_t = k_t \quad h$$

where h is the ball drop height in inches and k_t is an empirically derived coefficient, which varies with glass thickness. The average calculated maximum breaking stress was calculated using k_t coefficient values of 6,177.6 and 4,834.7 for the 3.3mm and 5.0mm thick glass, respectively.

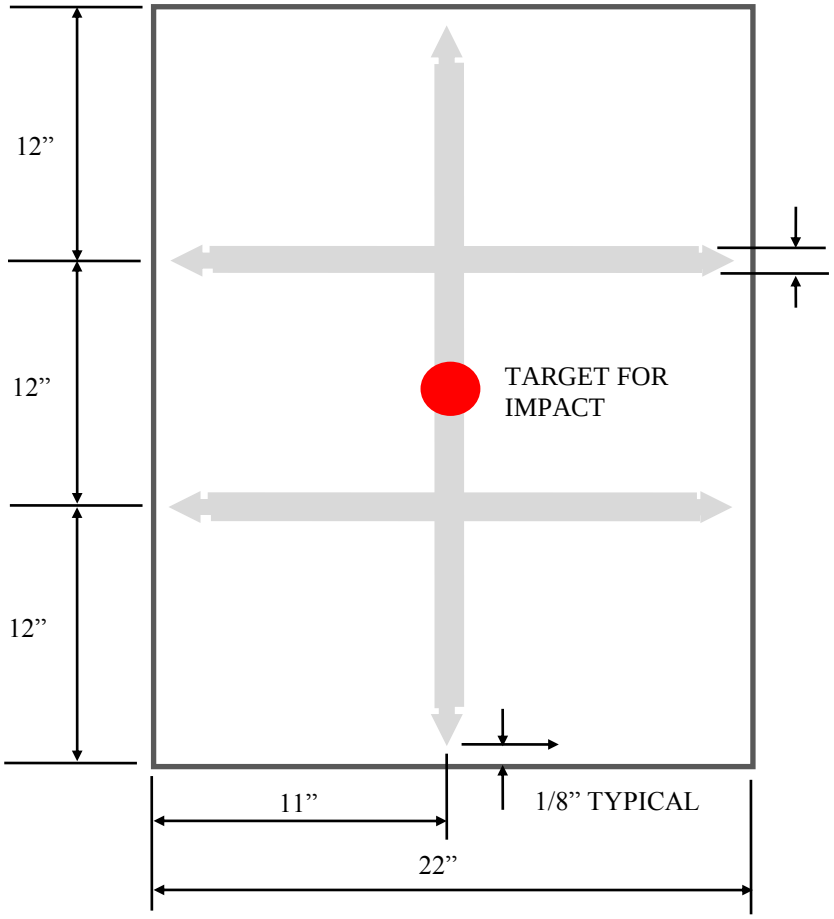
The results of the impact testing are summarized in Table 2; Charts 3 and 4 presents the data graphically.

SAFETY CONSIDERATIONS

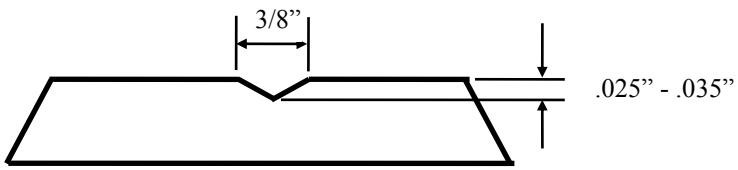
Users of annealed glass and unseamed tempered glass should be aware that these products can cause serious injuries by contact with the edge of the glass or from unanticipated breakage. Individuals handling unseamed tempered glass products and all annealed glass should exercise safe glass handling procedures and wear personal protective equipment (ppe) rated for antilacerative applications. This equipment should be worn over the body parts that could reasonably come in contact with these types of glass. Vitro experience shows that when worn as prescribed, antilacerative ppe eliminates many injuries and significantly reduces the severity of others. More detailed information is available from Vitro.

V-Grooving

SKETCH 1
TEST SAMPLE FOR UNIFORM PRESSURE AND IMPACT TESTING



SKETCH 2
V-GROOVE GEOMETRY



V-Grooving

TABLE 1
SUMMARY OF RESULTS OF UNIFORM PRESSURE TESTS

Glass Thickness and Type Tested	Average Pressure at Failure (psf)	Average Calculated Maximum Breaking Stress (psi)	Effective Basic Strength (psi)	Effective Temper Level (psi)	Total Performance Strength (psi)
3.3mm Thickness					
Annealed - no grooves	222	10,218	10,570	na	10,570
Annealed - with grooves	not tested	not tested	not tested	not tested	not tested
Tempered - no grooves	861	34,695	14,426	14,126	28,552
Tempered - grooved before tempering					
Grooved surface in tension	500	21,368	10,938	6,680	17,618
Non-grooved surface in tension	612	25,740	7,244	14,097	21,341
Tempered - grooved after tempering					
Grooved surface in tension	341	15,043	10,446	2,425	12,871
Non-grooved surface in tension	854	35,156	14,775	13,631	28,406
5mm Thickness					
Annealed - no grooves	478	11,899	14,663	-	14,663
Annealed - with grooves					
Grooved surface in tension	142	5,844	5,978	-	5,978
Non-grooved surface in tension	366	10,111	12,054	-	12,054
Tempered - no grooves	>1,920	>39,934	15,020	19,800	>34,820
Tempered - grooved before tempering					
Grooved surface in tension	1278	27,871	11,759	12,810	24,569
Non-grooved surface in tension	1661	35,165	11,270	19,572	30,842
Tempered - grooved after tempering					
Grooved surface in tension	577	13,735	11,341	2,715	14,056
Non-grooved surface in tension	>1,920	>39,934	>15,020	19,800	>34,820

1 Calculated using the BIHAR computer program based on "Nonlinear Analysis of Rectangular Glass Plates by Finite Difference Method", C.V.G. Vallabhan and Bob Yao-Ting Wang, Institute for Disaster Research, Texas Tech University, June 1981

2 No failures occurred when the maximum test load of 1,920 psf was applied and maintained for 5 minutes.

V-Grooving

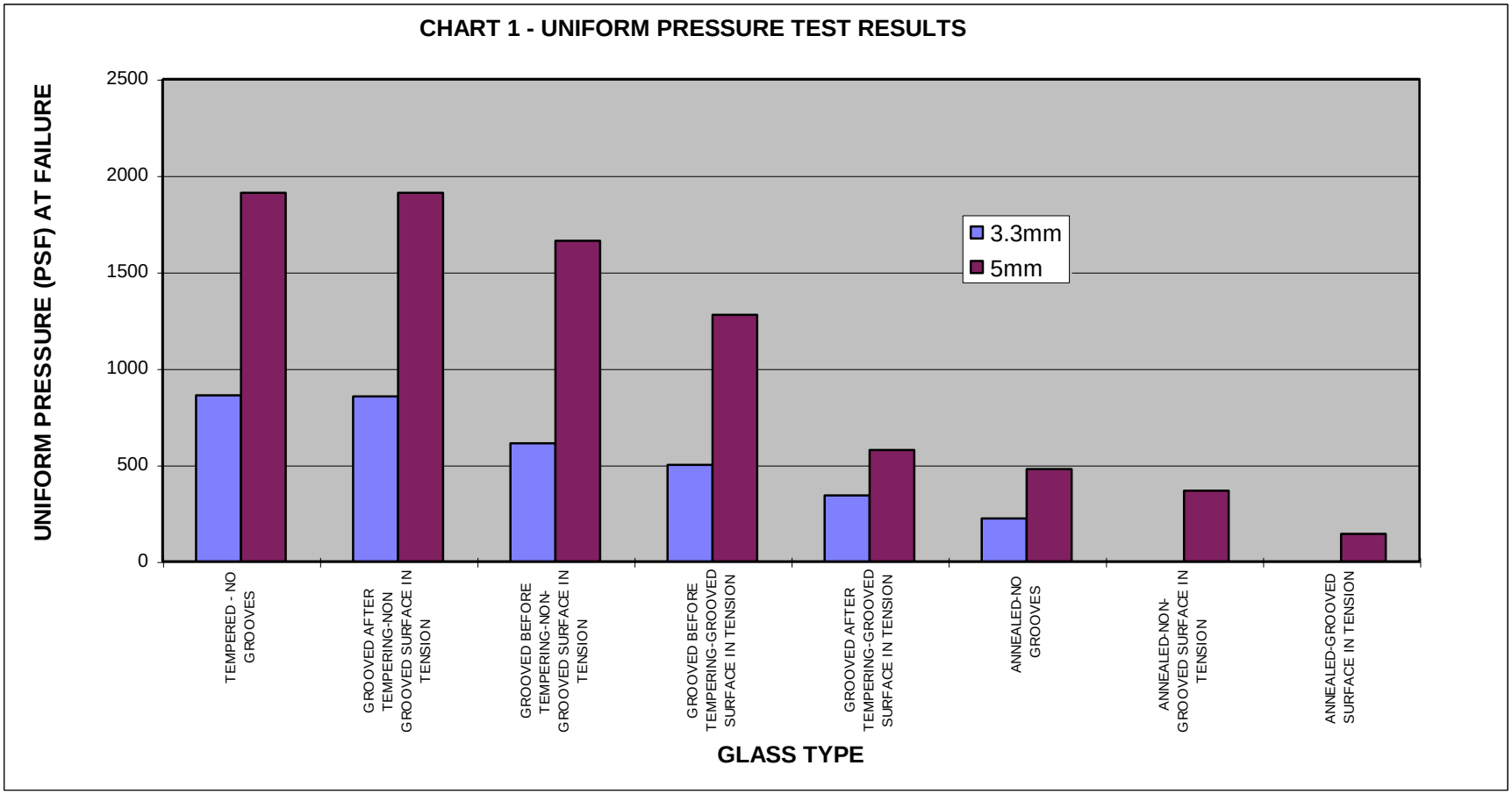


CHART 1 - UNIFORM PRESSURE TEST RESULTS
UNIFORM PRESSURE (PSF) AT FAILURE
2500
2000
1500
1000
500
0
3.3mm
5mm
TEMPERED - NO GROOVES
GROOVED AFTER TEMPERING-NON GROOVED SURFACE IN TENSION
GROOVED BEFORE TEMPERING-NON-GROOVED SURFACE IN TENSION
GROOVED BEFORE TEMPERING-GROOVED SURFACE IN TENSION
GROOVED AFTER TEMPERING-GROOVED SURFACE IN TENSION
ANNEALED-NO GROOVES
ANNEALED-NON-GROOVED SURFACE IN TENSION
ANNEALED-GROOVED SURFACE IN TENSION
GLASS TYPE

V-Grooving

TABLE 2
SUMMARY OF RESULTS OF IMPACT TESTING

Glass Thickness and Types Tested	Average Drop Height at Failure (inches)	Average Calculated Maximum Breaking Stress (psi)
3.3mm Thickness		
Annealed - no grooves	157.5	77,528
Annealed - with grooves	Not Tested	Not Tested
Tempered - no grooves	341.9	114,227
Tempered - grooved before tempering		
Grooved surface in tension	47.5	42,576
Non-grooved surface in tension	217.5	91,107
Tempered - grooved after tempering		
Grooved surface in tension	15.0	23,926
Non-grooved surface in tension	230.0	93,688
5mm Thickness		
Annealed - no grooves	261.3	78,151
Annealed - with grooves		
Grooved surface in tension	11.3	16,252
Non-grooved surface in tension	146.7	58,557
Tempered - no grooves	440.3	101,441
Tempered - grooved before tempering		
Grooved surface in tension	85.0	44,573
Non-grooved surface in tension	262.5	78,330
Tempered - grooved after tempering		
Grooved surface in tension	35.2	28,634
Non-grooved surface in tension	375.0	93,623

V-Grooving

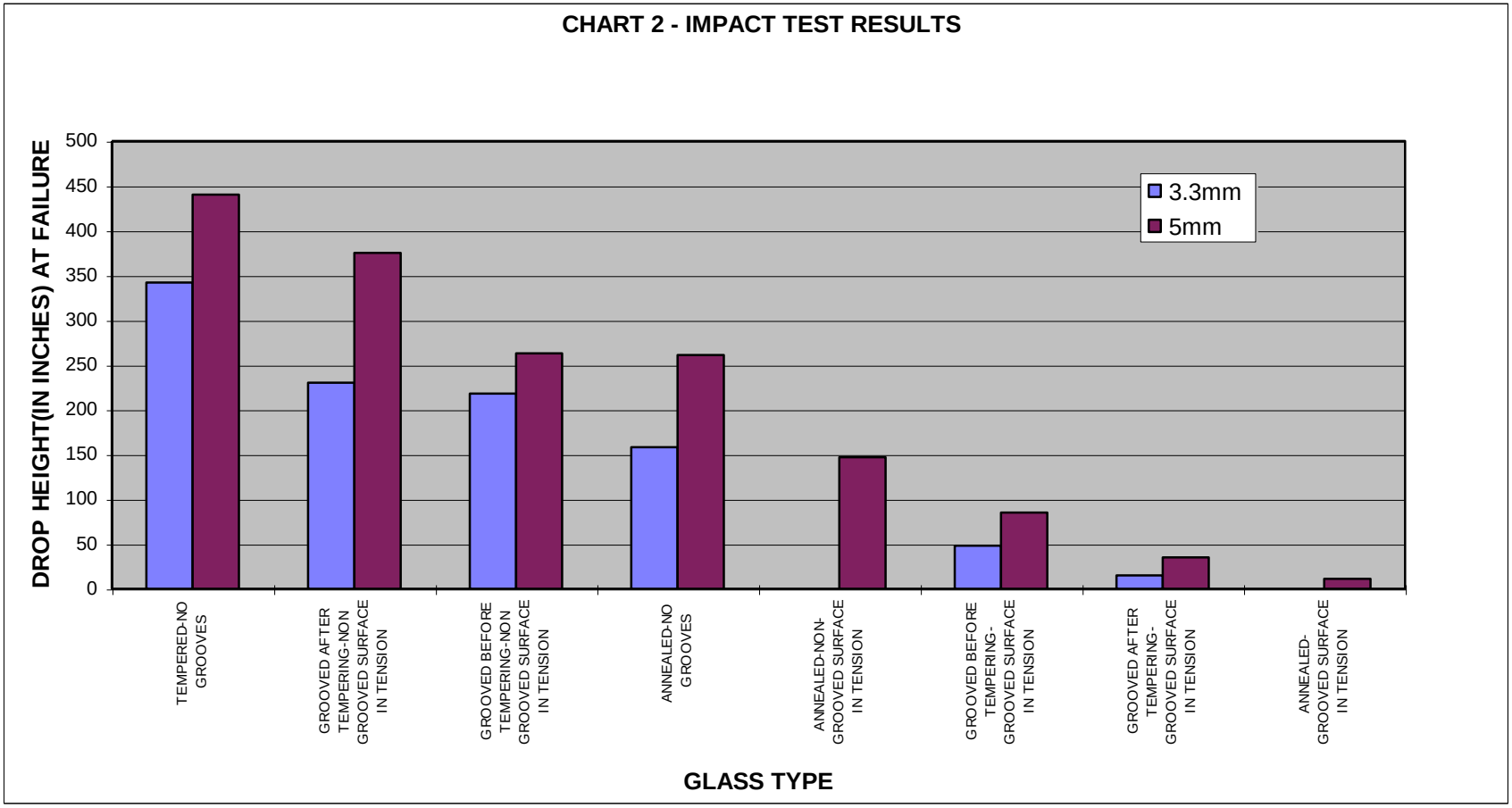


CHART 2 - IMPACT TEST RESULTS
DROP HEIGHT(IN INCHES) AT FAILURE
500
450
400
350
300
250
200
150
100
50
0
3.3mm
5mm
TEMPERED-NO GROOVES
GROOVED AFTER TEMPERING-NON GROOVED SURFACE IN TENSION
GROOVED BEFORE TEMPERING-NON GROOVED SURFACE IN TENSION
ANNEALED-NO GROOVES
ANNEALED-NON-GROOVED SURFACE IN TENSION
GROOVED BEFORE TEMPERING-GROOVED SURFACE IN TENSION
GROOVED AFTER TEMPERING-GROOVED SURFACE IN TENSION
ANNEALED-GROOVED SURFACE IN TENSION
GLASS TYPE

V-Grooving

HISTORY TABLE		
ITEM	DATE	DESCRIPTION
Inside Glass TSM 97-3	11/10/1997	V-Grooving: Glass Strength Test Results
TD-127	05/13/2002	Transferred to Internet
Revision 1	2016-10-04	Updated to Vitro Logo and format