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Glass Breakage Performance Comparison Between Laminated and Tempered Glass: A Matter of Safety

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INTRODUCTION

The Baker Company has for years, standardized on the use of laminated glass in its products because of the belief that tempered glass could shatter into tiny pieces upon impact thereby causing a safety hazard to personnel; whereas laminated glass would stay intact. Purely from a safety standpoint, it was thought that shards of broken tempered glass, large and small, would become projectiles that could jeopardize the safety of lab personnel in proximity to the BSC. Although tempered glass is less expensive than laminated glass of a comparable size, the position of the Baker Company has been that laminated glass was much less hazardous than tempered, in the event of an object impacting it. Therefore, the extra premium in cost of laminated glass is significantly outweighed by the superior protection offered in lab safety.

This paper presents the results of tests to empirically affirm Baker's claim that laminated glass is safer for use on BSCs than tempered glass.

TEST FIXTURE

It was decided to obtain data for glass breakage comparison, by referring to the ASTM Standard F3007 – 19, "Standard Test Method for Ball Drop Impact Resistance of Laminated Architectural Flat Glass (ASTM), 2019)." Because this study was of internal interest to The Baker Company, the ASTM standard was used as a guideline rather than following it rigorously as typically required for compliance testing.

A metal test stand was constructed as shown in **Figure 1**. The inside dimensions of the upper rails of this fixture were 10.25 inch x 10.25 inch so that 10.25 inch x 10.25 inch open area of glass was presented to a falling steel ball.

FIGURE 1.
Glass Breakage Test Stand

To avoid point loading of any side rail on the glass (by an unintentionally applied force due to a local high point or prominence in a side rail), a layer of rubber was laid down between the glass piece and the metal support frame.

Samples of laminated architectural glass and tempered glass measuring 12 inch square were procured from the vendor. It was preferred to have the test samples cut to size by a professional cutting process so they would be absent of edge defects and anomalies within the 12 inch x 12 inch area.

During testing each glass sample was placed on the test fixture so that even margins of glass on all sides extended beyond the outside of the frame. The test was conducted by dropping a five (5) pound, 3.25 inch diameter steel ball on a single pane of glass. The glass and the frame were positioned so the steel ball would impact the glass in its center. For each ball drop event, several parameters characterizing the glass were measured, including the height of the ball above the glass surface. Measurements taken were the thickness of the glass at locations 6 inch along each side of the 12 inch x 12 inch glass sample, the weight and its temperature. This test of comparison was conducted with twelve (12) samples of laminated and twelve (12) samples of tempered glass.

TEST SAMPLES

There are several differences between laminated and tempered glass. Tempered glass is significantly stronger than laminated glass and derives its strength from chemical or annealing processes that put the surface of the glass in compression. Laminated glass derives its strength from the interlayer or resin between two pieces of glass bonded together by pressure or heat. All glass can be broken, so the question is which type of glass is better for minimizing damage and injury to personnel if the glass is impacted by a sharp blow?

As previously mentioned, prior to the ball drop test, the glass characteristics were measured and recorded. A summary of the physical properties is presented in Table 1 which shows the nominal thickness and weight of each type of glass. As can be observed, tempered glass is thinner and lighter in weight than the laminated glass.

TABLE 1.

Comparison of Physical Properties

Description	Parameter	Tempered	Laminated	Difference	%Difference	Comment
Material Property	Nominal Thickness [inch]	0.22	0.26	0.04	16%	Stock laminated glass is 16% thicker than tempered glass.
Material Property	Nominal Weight [lb]	2.90	3.16	0.26	8%	Stock laminated glass is 8% heavier than tempered glass.

Looking closer at Table 1, it is observed that the average thickness of laminated glass is 0.26 inch or 16% thicker than tempered glass. In addition, laminated glass is 8% heavier than tempered glass. In both cases, these comparisons are made with readily available, standard stock pieces of glass.

METHOD

Glass samples were laid on the rubber gasketed test fixture as previously described. The steel ball was suspended above the center of the test fixture and glass by a fishline. When all was ready, the fishline was cut so the 5-pound steel ball would fall and impact the glass on centerline. **Figure 2** shows the steel ball in motion, just after the fishline holding it was cut. In this picture, the 5-pound ball is falling toward a glass test sample.

This procedure of dropping the 5-pound steel ball onto samples of tempered and laminated glass was repeated twenty-four (24) times, once for each of the twelve (12) samples of tempered glass and once for each of the twelve (12) samples of laminated glass.

FIGURE 2.

Steel Ball is Falling Toward Glass Sample

RESULTS

TABLE 2.
Drop Ball Test Results

The outcome of the ball dropping exercise was recorded in Table 2 which shows the physical properties again, the order of the runs during the experiment and the drop ball height. Lastly it summarizes the glass breakage results by describing the steel ball retention characteristics with notes in the rightmost column. **Table 3** accompanies **Table 2** for interpretation of glass retention characteristics indicated with the letters, *A*, *B*, *C* and *D*.

Test	Date	Glass Type	Glass Thickness (Inches)	Glass Weight (lbs)	Glass Temp (°F)	Ball Height (Inches)	Retention Characteristics	Notes
1	16/12/2020	Tempered	0.223	2.88	72	23	A	Glass unbroken, no visual breaks
2	16/12/2020	Tempered	0.224	2.90	72	25	D	Glass Broken-Shattered into pieces
3	16/12/2020	Tempered	0.224	2.90	72	25	D	Glass Broken-Shattered into pieces
4	16/12/2020	Tempered	0.225	2.92	72	25	D	Glass Broken-Shattered into pieces
5	16/12/2020	Laminated	0.264	3.18	72	25	B, C	Glass broken but remained whole, intact.
6	16/12/2020	Laminated	0.263	3.16	72	25	B, C	Glass broken but remained whole, intact.
7	16/12/2020	Laminated	0.263	3.16	72	25	B, C	Glass broken but remained whole, intact.
8	16/12/2020	Laminated	0.263	3.16	72	25	A	Glass unbroken, no visual breaks
9	22/02/2021	Tempered	0.223	2.90	72	25	D	Glass Broken-Shattered into pieces
10	22/02/2021	Laminated	0.265	3.16	72	25	B, C	Glass broken but remained whole, intact.
11	22/02/2021	Tempered	0.224	2.90	72	25	A	Glass unbroken, no visual breaks
12	22/02/2021	Laminated	0.266	3.16	72	25	B, C	Glass broken but remained whole, intact.
13	22/02/2021	Tempered	0.223	2.90	72	25	A	Glass unbroken, no visual breaks
14	22/02/2021	Laminated	0.266	3.16	72	25	A	Glass unbroken, no visual breaks
15	22/02/2021	Tempered	0.222	2.90	72	25	A	Glass unbroken, no visual breaks
16	22/02/2021	Laminated	0.263	3.16	72	25	B, C	Glass broken but remained whole, intact.
17	22/02/2021	Tempered	0.223	2.90	72	25	D	Glass Broken-Shattered into pieces
18	22/02/2021	Laminated	0.263	3.16	72	25	A	Glass unbroken, no visual breaks
19	22/02/2021	Tempered	0.224	2.90	72	25	D	Glass Broken-Shattered into pieces
20	22/02/2021	Laminated	0.266	3.16	72	25	B, C	Glass broken but remained whole, intact.
21	22/02/2021	Tempered	0.223	2.90	72	25	D	Glass Broken-Shattered into pieces
22	22/02/2021	Laminated	0.267	3.16	72	25	A	Glass unbroken, no visual breaks
23	22/02/2021	Tempered	0.224	2.91	72	25	D	Glass Broken-Shattered into pieces
24	22/02/2021	Laminated	0.266	3.16	72	25	A	Glass unbroken, no visual breaks

TABLE 3.
Glass Retention Characteristics

A	Ball Held: Glass Unbroken
B	Ball Held: Glass broken, no tears in interlayer
C	Ball Held: Glass broken, tears in interlayer
D	Ball not retained

Visual inspection of **Tables 2** and **3** reveal some differences in response between tempered and laminated glass to the drop ball test.

- The ball was held by the laminated glass in all cases even though there were some tears in the polymer interlayer between the panes of glass. There were no instances of the ball breaking through the laminated glass.
- In eight out of eleven cases, the steel ball shattered the tempered glass, breaking completely through it.
- In tests 1, 11, 13 and 15 the tempered glass did not break. The ball was held and did not break the glass. It is to be noted that in test 1, the ball was dropped from a height of 23 inches onto the tempered glass, not 25 inches which lessened the impact force. The ball was dropped onto tempered glass from 25 inches for tests 11, 13 and 15.

Figures 3, 4, 5 and **6** present images of tempered and laminated glass after impact by the 5-pound, 3.25” diameter steel ball.

FIGURE 3.

Large Jagged Shard of Tempered Glass. Ball Resting in Pile of Smaller Tempered Glass Pieces

FIGURE 4.

Steel Ball Resting in the Shards of Shattered Tempered Glass

Figure 5 shows the same steel ball, dropped from the same 25 inch height, as with the tempered glass cases, but the laminated glass remained whole, intact and did not let the ball go through it.

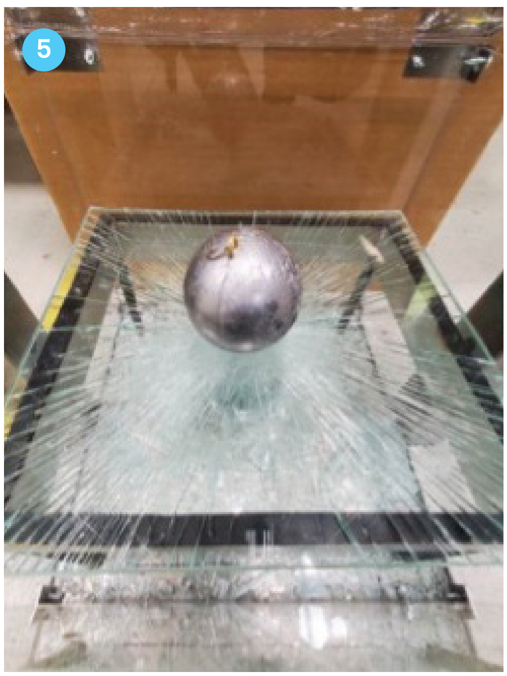

FIGURE 5.

Steel Ball Held by Unbroken Laminated Glass

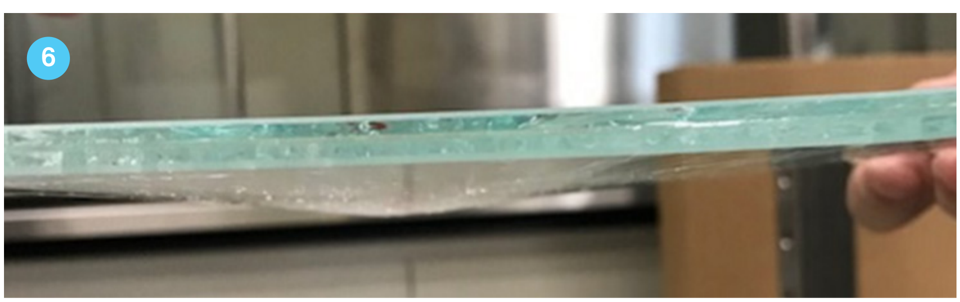

FIGURE 6.

Depression in Laminated Glass from Ball Impact. The Ball Did Not Break Through the Laminated Glass.

STATISTICAL COMPARISONS

(Charles Lipson and Narendra Sheth, 1973, pp. 240 - 261)

Observations of **Tables 2** and **3** in a previous section, offered an overview comparison of glass breakage performance between these two types of glass. Since personal observation is subjective, and open to bias, it was desired to gain further understanding rooted in more objective measures. For this purpose, statistical methods were used to learn whether tempered and laminated glass behave differently or not, when subjected to the drop ball test adapted from the ASTM standard.

The first step was to select the appropriate test of comparison. The form of the response variable influenced the type of statistical test because drop ball retention results were reported with the letters, *A, B, C* and *D* or written comments. This is qualitative data which suggested the need for applying Nonparametric Statistical methods to determine an objective answer to the question: Do tempered and laminated glass samples perform similarly to the drop ball test, or does one type of glass perform better than the other?

For clarity,Tempered glass and associated retention characteristic letters (*A, B, C* or *D*) have been indicated in red font.

TABLE 4.

Retention Characteristic Results Sorted into Run Sequences from D to A

Item #	Test #	Date	Glass Type	Retention Characteristics	Run Groups for Statistical Test
1	2	16/12/2020	Tempered	D	Run #1
2	3	16/12/2020	Tempered	D	
3	4	16/12/2020	Tempered	D	
7	9	22/02/2021	Tempered	D	
15	17	22/02/2021	Tempered	D	
17	19	22/02/2021	Tempered	D	
19	21	22/02/2021	Tempered	D	
21	23	22/02/2021	Tempered	D	
4	6	16/12/2020	Laminated	B, C	Run #2
5	7	16/12/2020	Laminated	B, C	
8	10	22/02/2021	Laminated	B, C	
10	12	22/02/2021	Laminated	B, C	
14	16	22/02/2021	Laminated	B, C	
18	20	22/02/2021	Laminated	B, C	
6	8	16/12/2020	Laminated	A	Run # 3
9	11	22/02/2021	Tempered	A	
11	13	22/02/2021	Tempered	A	
12	14	22/02/2021	Laminated	A	
13	15	22/02/2021	Tempered	A	
16	18	22/02/2021	Laminated	A	
20	22	22/02/2021	Laminated	A	
22	24	22/02/2021	Laminated	A	

The chosen statistical test was the Wald-Wolfowitz Runs test which required equality of sample sizes for the two groups being compared, as well as equality of test conditions for each group. The requirements for this test were achieved by eliminating run 1 due to its different ball drop height, and eliminating run 5 to equalize the quantity of laminated and tempered glass samples. Finally, sorting by Glass Type yields the results shown in Table 4. There are now a total of 22 runs comprised of 11 tempered and 11 laminated glass test runs all being tested under identical conditions.

Observations from Table 4:

1. "Run Sequences" 2 and 3 indicate laminated glass never once shattered into pieces and retained the ball in 100% of the cases.
2. Since the Weight Box is a counter balance for the weight of the front sash, a sash made with tempered glass would shatter into fragments as a result of an impact load, leaving an unequal weight to oppose that of the Weight Box. Thus, the Weight Box would fall, unchecked, possibly precipitating secondary damage within the BSC. The fact that laminated glass remains intact when fractured means avoidance of this secondary damage possibility.
3. Tempered glass is less expensive than laminated glass, however the value of personnel safety is limitless. Baker Products with laminated glass offer superior safety by lowering the risk of lab personnel being hurt by flying pieces of tempered glass in the event of a sharp impact force striking the glass.

| CONCLUSIONS

- ☑ Statistical analysis of results demonstrates that laminated glass is more resistant to breaking.
- ☑ Therefore, laminated glass is safer than tempered.

| HYPOTHESIS TESTING

The statistical test was performed by establishing the Null Hypothesis, symbolized by Ho, that claims there is no difference between glass breakage performance of both tempered and laminated glass.

The Alternate Hypothesis, symbolized by H_1, asserts that laminated glass breakage performance is better than tempered glass.

Then the number of "run sequences" were counted. A run sequence is an unbroken series of a given letter or an unbroken series of a pair of letters. There are eight "Ds" which form one run sequence. There are six "B, C" pairs that form a second run sequence. Finally, there are eight letter "As" that form a third sequence.

Hence the number of runs or run sequences is three. The details of this statistical test are summarized in the steps immediately below.

H_o: Laminated Glass Safety Performance = Tempered Glass Safety Performance

H_1: Laminated Glass Performance > Tempered Glass Performance

$R_{experiment}$ = Number of Run Sequences Determined Empirically = 3

$N_{tempered} = N_{laminated}$ = Number of Samples in Each Group = 11

$R_{table} = 6$

$R_{experiment} = 3 < R_{table} = 6$

For α = 0.01 (where 1 – α is the level of confidence) in the **Appendix Table** "Distribution of the total number of runs" page 247 Statistical Design and Analysis of Engineering Experiments by C. Lipson and N. Sheth/ McGraw-Hill Book Company, 1973.

Perform hypothesis testing and conclude with 99% confidence that the safety performance of laminated glass is superior to that of tempered glass, in terms of not shattering into small flying pieces due to an impact force. Laminated glass is significantly more likely to remain whole and in position in the sash of a BSC in the event of it receiving an impact load.

APPENDIX TABLE

Expected Number of Runs Based on Chance, Given Sample Size and Confidence Level

	Lower Percentage Points U'_α		Upper Percentage Points U'_α	
$n_1 = n_2$	$\alpha = 0.05$	$\alpha = 0.01$	$\alpha = 0.05$	$\alpha = 0.01$
5	3	2	9	10
6	3	2	11	12
7	4	3	12	13
8	5	4	13	14
9	6	4	14	16
10	6	5	16	17
11	7	6	17	18
12	8	7	18	19
13	9	7	19	21
14	10	8	20	22
15	11	9	21	23
16	11	10	23	24
17	12	10	24	26
18	13	11	25	27
19	14	12	26	28
20	15	13	27	29
21	16	14	28	30
22	17	14	29	32
23	17	15	31	33
24	18	16	32	34
25	19	17	33	35
26	20	18	34	36
27	21	19	35	37
28	22	19	36	39
29	23	20	37	40
30	24	21	38	41

Charles Lipson and Narendra Sheth. (1973). "*Statistical Design and Analysis of Engineering Experiments*", page 247, New York: McGraw-Hill Book Company.

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