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Evaluation and Comparison of Glazing Performance in Impact Tests

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16. Abstract
FMVSS No. 205, *Glazing materials*, uses impact test methods specified in ANSI/SAE Z26.1-1996. NHTSA's Vehicle Research and Test Center initiated research to evaluate a subset of test methods from ANSI Z26.1-1996 including the 227-gram ball, shot bag impact tests, fracture test on tempered glass, and the ball and dart tests on laminated glass. Additional research was completed to learn about potential changes to tempered glass strength due to the ceramic paint area (CPA), and to compare the performance of 12-by- 12-inch flat samples and full-size production parts. Glass evaluated included tempered rear quarter, sunroof, and backlight glazing and laminated windshield glazing. Sample and production parts with and without paint were evaluated in equivalent impact tests. Several impact points were selected for comparison. Standard height impact tests were completed along with testing to identify the minimum height that the glazing begins to break. A modified shot bag with stiffened sidewalls was compared to the ANSI standard shot bag. Fracture testing was completed using both ANSI and ECE R43 methods and impact locations. High-speed video and pre- and post-test images were recorded for each test. More than 1,200 tests covering the various test conditions outlined above were completed. Overall trends showed a decrease in glazing strength due to the CPA when struck with the 227-gram ball. The modified shot bag concentrated the impact force, resulting in more glass breakages than with the ANSI bag. The ECE R43 fracture test location produced larger pieces than the ANSI fracture location. Laminated ball tests and dart tests produced similar results. Sample and production tests also generally had similar results for both the tempered and laminated glazing.

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Executive Summary

Federal Motor Vehicle Safety Standard (FMVSS) No. 205, *Glazing materials*, specifies performance requirements for glazing installed in motor vehicles. It incorporates by reference impact test methods specified in the American National Standard for Safety Glazing Materials (ANSI/SAE Z26.1-1996) (SAE International, 1997). In the June 2012 Notice of Proposed Rulemaking (NPRM) for FMVSS No. 205 (2012), NHTSA proposed changes to harmonize the current FMVSS No. 205 with the United Nations Economic Commission for Europe's Global Technical Regulation on automotive glazing (GTR No. 6) (UNECE, 2008). The changes proposed in the NPRM included

- eliminating the shot bag test for tempered glazing,
- lowering the 227-gram ball drop height to 2.0 m (6.6 ft) from the current 3.1 m (10 ft),
- altering the fracture test for tempered glazing from a single breaking point to two breaking points,
- eliminating the dart test for laminated glazing and relying solely on the 227-gram ball drop onto laminated test specimens, and
- lowering the 227-gram ball drop for laminated glazing to 9.0 m (29.5 ft) from the current 9.14 m (30 ft).

More than 1,200 glazing performance tests were completed to

- evaluate the NPRM-proposed changes to the mechanical property requirement tests for tempered and laminated glazing,
- learn about potential changes to tempered glass strength due to the CPA, and
- evaluate differences in the ANSI Z26.1 12-by- 12-inch flat specimens and full-size production parts.

Three types of tempered glass (rear quarter, sunroof, and backlight) and one type of laminated glass (windshield) were assessed. Both flat samples and corresponding full-size production parts were tested.

Equipment to complete testing was either purchased or fabricated at NHTSA's Vehicle Research and Test Center (VRTC). Equipment used included a drop tower, pneumatic gun fixture, impact items, and custom holding frames. Impact objects for the testing included a 1.5-inch, 0.5-lb (227-gram) smooth steel sphere ball, an 11-lb shot bag and modified version of the shot bag with stiffer side walls, and a 7-oz steel dart. Impact points were selected on both the sample and production glazing and included locations at the center, corner, painted to clear glass transition zone, and on the edge of the CPA. Standard height impact tests were completed along with testing to identify the minimum height that the glazing begins to break. Fracture testing was completed using both ANSI and ECE R43 methods of weight and count, respectively, at the impact locations from both standards. High-speed video and pre- and post-test images were recorded for each test.

Impact tests were completed on tempered glazing comparing 10-ft ball drops to 6.6-ft ball drops and the standard ANSI shot bag to a modified shot bag with stiffer sidewalls. The 6.6-ft ball drop test does not capture the effect of paint as well as the 10 ft drop at the edge location where the paint makes the glass the weakest. At the current standard location (center) the drop height differences did not change glass performance results. Shot bag results showed that the stiffer side walled bag (MSB) concentrates the force and stresses the glass differently than the ANSI bag (ASB). Because of this greater force concentration, the MSB is a test condition more severe for the glass than the ASB. In the tempered glass fracture test, the geometric center (ECE R43) location created larger fragments with greater weight and smaller count than the mid-point of the longest edge (ANSI) impact location.

The effect of CPA on tempered glazing was observed in ball tests on the exterior surface where the paint weakened the glass. However, in shot bag tests on the interior surface, the paint strengthened the glass. Impact side plays a role in the glass performance since the exterior of glass is generally stronger than the interior. The paint creates localized weak spots in the areas where it is applied but also influences the overall glass strength. The paint did not have as large an effect on performance of the glass in the fracture test as it did in other test modes.

Impact tests on laminated glazing of both the 30-ft ball drop and 30-ft dart drop were completed. Additional ball tests on unpainted sample glass conditioned to different temperatures were also completed. In the standard ball and dart tests similar results were seen between test modes at all but the edge location. In the temperature conditioned tests, the cold tests withstood higher impacts than ambient tests, which withstood similar or higher impacts than hot tests.

Generally, in the standard height ball tests the sample and production glass had consistent results. However, in the break height tests on tempered glass the production glass tended to be similar or stronger, especially at the areas away from the paint including fully unpainted glass. In shot bag tests, sample and production had inconsistent results with breaks occurring on the sample glass that did not occur on the production glass. In laminated standard height tests the sample and production glass had consistent results. In laminated break height tests with the ball and dart, the samples were generally similar or slightly stronger than the production glass.

Key findings from this research as they relate to the original objectives include:

- the shot bag stressed the glass differently than the ball, with the stiffened bag being a more severe test than the ANSI bag, different results were observed with the 227-gram ball test at 10 ft versus 6.6 ft, the two impact points in the fracture test produced different size pieces, and the ball and dart tests on laminated glass had similar performance results.
- the CPA reduces tempered glass strength, and
- ANSI Z26.1 12-by- 12-inch flat specimens and full-size production parts have similar performance in impact tests.

Introduction

FMVSS No. 205, *Glazing materials* (2012), specifies performance requirements for glazing installed in motor vehicles. It incorporates by reference impact test methods specified in the American National Standard for Safety Glazing Materials (ANSI/SAE Z26.1-1996). The purpose of FMVSS No. 205 includes reducing injuries from impact to glazing surfaces (e.g., lacerations) and minimizing the possibility of occupants being ejected through vehicle windshields. Glazing commonly used in motor vehicles includes laminated glass (i.e., windshields) and tempered (or toughened) safety glass. Tempered glass uses a heat-treating process so that the glass breaks into small pieces without jagged edges when broken. Ceramic paint is applied to the glazing during the heat-treating process to create the ceramic paint area (CPA), also known as frit.[1] The CPA on tempered glazing is thought to weaken the mechanical properties of the glass by creating an area of unstable stress distribution on the painted surface during the tempering process (KATRI, 2015). With the increasing size of sunroofs (e.g., panoramic sunroofs) and glass panes in vehicles, the area of CPA has also increased. Breakage of glass with CPA, including spontaneous breakage of sunroofs, both during vehicle motion and when vehicles are stationary, has been reported (Informal Working Group on PSG, 2019). This can result in glass falling into the occupant space and causing minor injuries (e.g., cuts and scratches) to occupants.

In the June 2012 Notice of Proposed Rulemaking (NPRM) for FMVSS No. 205, NHTSA proposed changes to harmonize the current FMVSS No. 205 with the United Nations Economic Commission of Europe's (UNECE) Global Technical Regulation (GTR) on automotive glazing (GTR No.6) (UNECE, 2008). The changes proposed in the NPRM included

- eliminating the shot bag test for tempered glazing,
- lowering the 227-gram ball drop height to 2.0 m (6.6 ft) from the current 3.1 m (10 ft),
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- eliminating the dart test for laminated glazing and relying solely on the 227-gram ball drop onto laminated test specimens, and
- lowering the 227-gram ball drop for laminated glazing to 9.0 m (29.5 ft) from the current 9.14 m (30 ft).

In April 2019, NHTSA withdrew the NPRM citing its belief that current glazing materials are performing acceptably and that it could not conclude at the time whether harmonizing would increase or decrease safety (FMVSS, 84 F.R. 65, 2019). Also, NHTSA noted that it did not have sufficient data to evaluate the safety of harmonization and that it would be conducting a glazing research study to better inform future decisions.

In 2019 NHTSA started a research study at the VRTC with three main objectives (Rains, 2024). The first objective was to evaluate the NPRM-proposed changes to the mechanical property requirement tests for tempered glazing. The second objective was to learn about potential changes to tempered glass strength due to the CPA. The third objective was to evaluate differences in the ANSI Z26.1 12-by- 12-inch flat specimens (i.e., samples) and full-size production parts. Five different tests from the ANSI/SAE Z26.1-1996 standard were used to

[1] Frit is important for bonding the glass to the frame, shading and protection of components, as well as used for aesthetically hiding glue lines or other components.

complete the above objectives. Additional tests from UNECE Regulation 43 (UN ECE R43) (UNECE, 2014) were also conducted for comparisons. Tests are listed in Table 1.

Table 1. Test Types

Object	ANSI Z26.1-1996 Test	ECE R43 Test
224-230g (0.5lb±0.1 oz) smooth, steel sphere	5.6 Impact, Test 6 (Ball Drop, 3.05 m [10 ft])	Annex 5 Uniformly toughened glass panes, Section 3 – Mechanical strength test, 227 g ball test [2 m]
Centerpunch	5.7 Fracture, Test 7	Annex 5 Uniformly toughened glass panes, Section 2 – Fragmentation test
4.99 kg (11 lb) shot bag	5.8 Impact, Test 8 (Shot Bag)	N/A
196-201g (7oz±0.1 oz) steel dart	5.9 Impact, Test 9 (Dart Drop, 9.14 m [30 ft])	N/A
224-230g (0.5lb±0.1 oz) smooth, steel sphere	5.12 Impact, Test 12 (Ball Drop, 9.14 m [30 ft])	Annex 7 Laminated-glass panes, Section 3 – Mechanical strength test 227 g ball test [9 m]
224-230g (0.5lb±0.1oz) smooth, steel sphere	N/A	Annex 6 Ordinary laminated glass windscreens, Section 4.3, 227 g ball test (hot and cold)

Test Setup and Methods

Equipment to complete testing was either purchased or fabricated at VRTC. Equipment used included a drop tower, pneumatic gun fixture, drop items, and custom holding frames. The maximum height available for a drop tower at VRTC was 16 ft for the 227-gram ball and 14 ft for the shot bag. To complete the higher drops from 30 ft and greater, a separate fixture was created. The fixture was a pneumatic gun designed to impart an initial velocity on the object so that velocity at impact was equivalent to a 30-ft drop. Also, to compare sample glass with production glass, custom holding fixtures were created to hold production glass pieces. Fixtures were fabricated at VRTC specific to glazing obtained for the testing. Further details for the drop tower, pneumatic gun and production holding fixtures will be described in the subsequent sections.

Glazing

Glazing obtained included flat samples and corresponding full-size production parts. Three tempered type glazing (sunroof (SR), backlight (BL) and rear quarter (RQ) panels) and one laminated type glazing (windshield (WS)) were selected. Both CPA painted glass and unpainted glass were obtained for both sample and production parts (Table 2).

Table 2. Glazing Description

TYPE	SIZE	PAINT	THICKNESS	DESCRIPTION
Rear Quarter (RQ)	Sample (305 mm x 305 mm)	No Paint	3.5 mm	Tempered
	Production	No Paint	3.5 mm	Tempered
	Sample (305 mm x 305 mm)	Paint (50 mm Black Band)	3.5 mm	Tempered
	Production	Paint	3.5 mm	Tempered
Sunroof (SR)	Sample (305 mm x 305 mm)	No Paint	4.0 mm	Tempered
	Production	No Paint	4.0 mm	Tempered
	Sample (305 mm x 305 mm)	Paint (50 mm Black Band)	4.0 mm	Tempered
	Production	Paint	4.0 mm	Tempered
Backlight (BL)	Sample (305 mm x 305 mm)	No Paint	3.5 mm	Tempered
	Production	No Paint	3.5 mm	Tempered
	Sample (305 mm x 305 mm)	Paint (50 mm Black Band)	3.5 mm	Tempered
	Sample (305 mm x 305 mm)	Paint (50 mm Black Band) and Silver Paint Lines	3.5 mm	Tempered
	Production	Paint and Silver Paint Lines	3.5 mm	Tempered
Windshield (WS)	Sample (305 mm x 305 mm)	No Paint	2.1 mm+PVB[2]+2.1 mm	Laminated
	Production	No Paint	2.1 mm+PVB+2.1mm	Laminated
	Sample (305 mm x 305 mm)	Paint (50 mm Black Band)	2.1mm+PVB+2.1mm	Laminated
	Production	Paint	2.1mm+PVB+2.1mm	Laminated

Figure 1 shows an example of each type of sample glass obtained. Two BL sample glass types with paint were tested, one with just the 50 mm black band around the periphery of the glass, and the other with both the black band and silver painted lines. The silver paint lines represent heater lines and give a direct comparison to the production BL glass.

[2] Polyvinyl butyral

Figure 1. Sample with Black Band (Left), Unpainted (Center), and Black Band and Silver Lines (Right)

Glazing Conditioning

Glass was stored in wooden crates in the test bay. Temperature and humidity in the bay were monitored and recorded while the glass was being stored. The ambient temperature for testing, per ANSI Z26.1-1996, was 20° C to 29° C (70° F to 85° F). The humidity in the test bay was monitored and recorded but not controlled for each test. Prior to testing, temperature and humidity were checked and recorded. If the temperature was out of the specified range, the glass was soaked using a temperature control box for four hours before testing. Temperature and humidity of the control box was 20° C to 29° C (70° F to 85° F) and 60 ± 20 percent.[3]

For the hot and cold testing of the laminated glass, a furnace and freezer were used for conditioning the glass. The desired hot temperature was 40° ± 2° C (104° F) and the desired cold temperature was -20° ± 2° C (-4° F). Sample glass test pieces were placed in the conditioning environment for a minimum of four hours prior to testing. Time from removal from the conditioning environment to test was recorded. For information purposes, for a subset of the hot and cold tests the temperature of the glass immediately preceding impact was compared to the temperature in the conditioning environment. The temperature of the glass at impact was measured using a temperature gun pointed at the impact location on the glass immediately before running the test. The soak time, time between removal from the conditioning environment and test, and the temperatures recorded by the temperature gun were all recorded. Appendix A contains information related to these measurements.

Impact Objects

Impact objects obtained for the testing included a 1.5-inch, 0.5-lb (227 gram) smooth steel sphere (ball), an 11-lb shot bag and a 7±0.1 oz steel dart per specifications in ANSI Z26.1-1996 (Figure 2).

[3] Humidity maintained per UNECE R43 specification. ANSI Z26.1-1996 only specifies temperature for testing.

Figure 2. Ball, Shot Bag, and Steel Dart

An additional shot bag was acquired and modified by adding layers of one-inch strapping tape to the side walls. This was to stiffen the sidewalls to create a more repeatable drop by limiting expansion and keeping the specified diameter throughout the impact. Twelve layers of the strapping tape were wrapped around the base of the bag at the seam line. The tape extended a quarter inch below to the seam line to help the bag hold its shape. This bag is referred to as the modified shot bag (MSB) and the unmodified version is referred to as the ANSI shot bag (ASB) in this report (Figure 3).

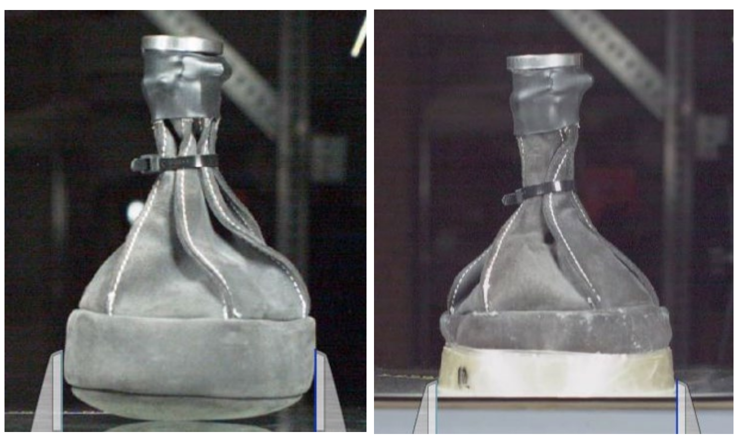


Figure 3. ANSI (Left) and Modified (Right) Shot Bag

The dart was modified for use in the pneumatic gun fixture. The modification allowed the dart to be shot out of the gun repeatably. The back fins of the dart were replaced with a cylindrical garolite block with a similar shape but solid structure. Garolite is a fiberglass and epoxy composite. Three darts were created (Figure 4). One of the darts had a smaller back end that was the same diameter as the largest diameter at the front end of the dart. The second dart had the same fin shape as the original but made of the garolite block. The third dart was the same shape as dart two but the height of the block on the back end was greater to increase the surface area interacting with the barrel. Shot within the dart was removed to keep the weight within the tolerance.

Figure 4. Dart Modifications

After trials with the three fin types, the final version of the dart used for testing was decided to be the dart with same fin shape as the original but made of the garolite block (Figure 5). This dart was the most consistent in the trials and most like the original fin shape. A drawing of the fabricated tail fin can be found in Appendix B.

Figure 5. Final Version of Modified Dart

Data Collection

High-speed video was recorded for each test. Video cameras were set up to view the glazing from the top, to capture crack propagation and waves, and from the side, to capture impact of the object onto the glazing. High-speed video of the impact was captured using a super-high-speed camera that could record up to 200,000 frames per second (fps). For production glass, the frame rate was captured at 110- to 130-thousand fps and for sample glass, was captured at 200,000 fps. The side view camera captured video at a rate of 1,000 fps. Digital photographs were also taken to document pre- and post-test results.

Holding Fixtures

A 305 mm x 305 mm sample holding fixture box was obtained conforming with ANSI Z26.1-1996.[4] However, the sample frame was modified from the standard fixture box to raise the glass and allow for lighting underneath to be able to capture video (Figure 6). The dimensions of the steel frame and rubber gasket supporting the glass were the same as the standard fixture from ANSI Z26.1-1996 but the glass was raised 725 mm from the ground. The feet of the raised support frame have rubber on the base like the support box.

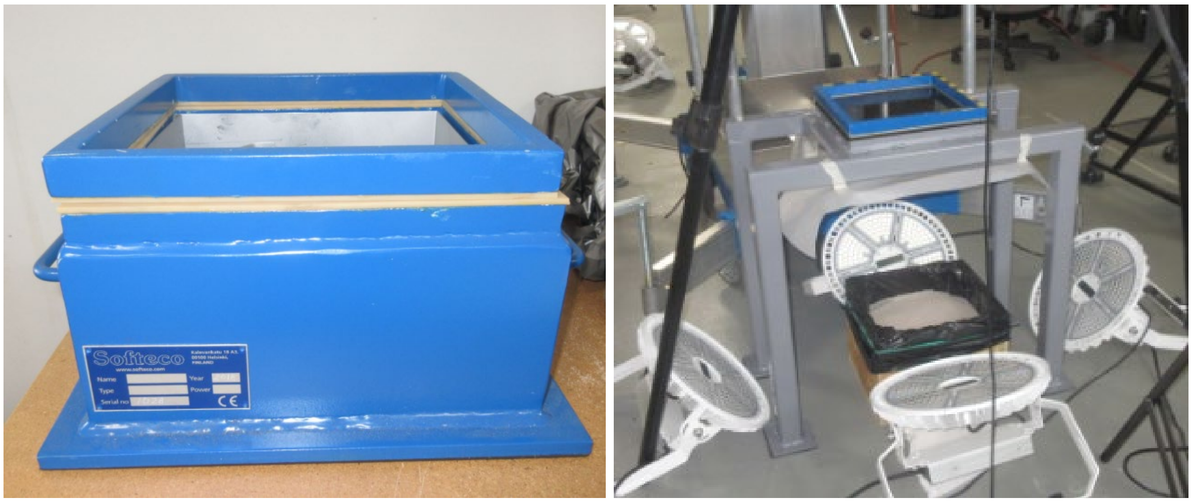


Figure 6. ANSI Sample Frame and Raised Frame

[4] ANSI Z26.1-1996 specifies a holding fixture consisting of a steel frame with rubber gaskets that sandwiches the glass and supports the specimen to be horizontal. The top frame is not secured to the bottom frame but sits on top of the glass surface.

Custom holding frames were fabricated for the production glazing. The custom frames used a single base fixture with replaceable custom-made frames for each type of production glazing. It consisted of a base fixture, glass frame fixture, and glass frame. Figures 7 to 10 show the setup for the rear quarter glazing. The full assembly is shown in Figure 7.

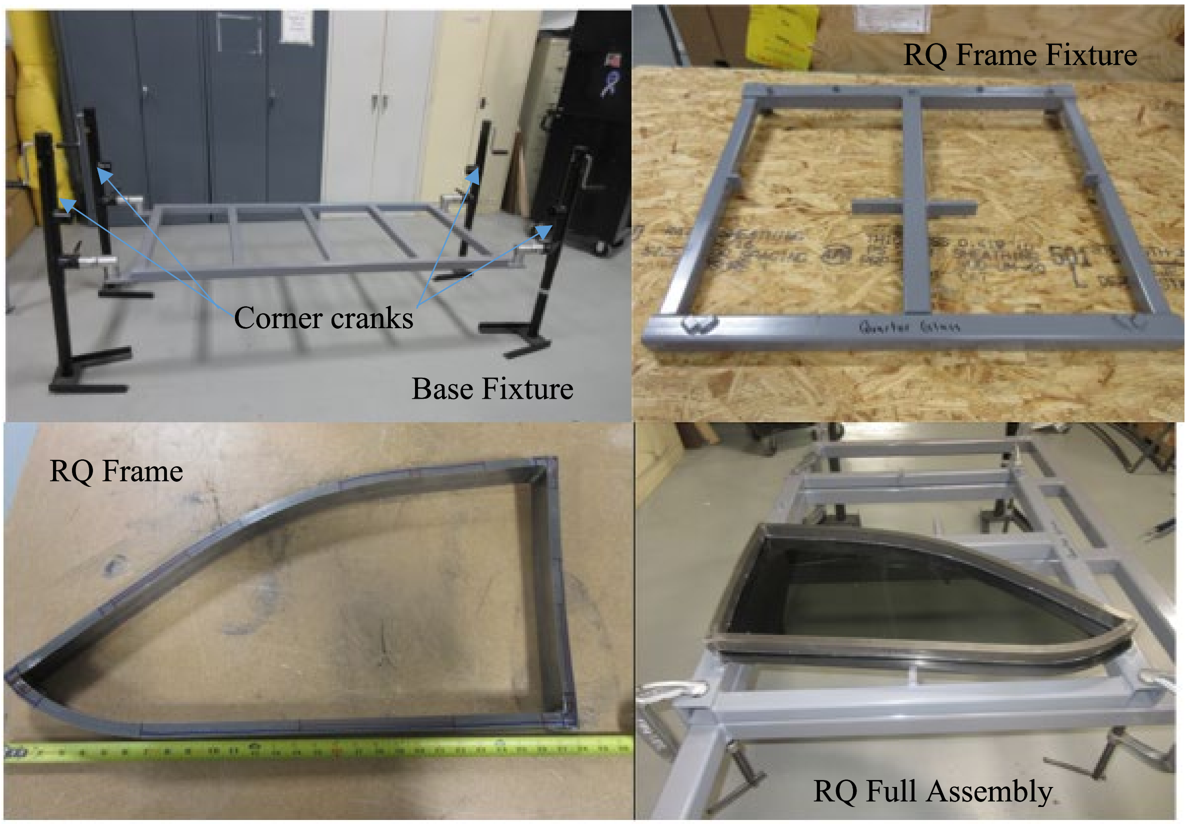


Figure 7. Rear Quarter Production Frame Assembly

Top and bottom glass frames were fabricated for each type of production glass using a metal bender to match as close as possible the curvature of the glazing and used the same dimensions for the steel as the ANSI standard fixture. Rubber was added to the bottom and top frames using the same rubber specification from the ANSI standard. The bottom glass frame was attached to the frame fixture using screws (Figure 8).

Figure 8. Screws Hold Frame to Frame Fixture

The frame fixture was then clamped to the base fixture. This setup allowed the glass to be held so that either an exterior or interior impact could be completed (Figure 9). In the figure, the left side is for an exterior impact and the frame on the right becomes the top frame, and vise-versa for an interior impact.

Figure 9. Interior or Exterior Impact on RQ Glazing

The base fixture has full adjustability to move the glazing up and down and tilt to create angles for perpendicular impacts on curved glass using the cranks on each corner. Additional supports for the base fixture were fabricated to keep the middle beams from flexing during testing. These supports clamped to the base fixture and were adjustable to fit the gap between the base fixture and floor. A target was placed on the side of the frame and monitored for any flexing of the base (Figure 10).

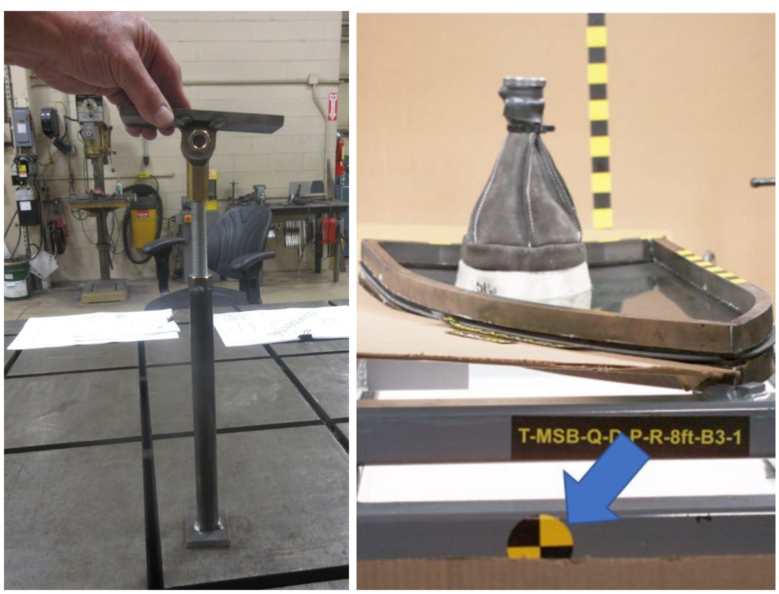


Figure 10. Base Frame Support

Drop Tower

The drop tower was fabricated to hang from the ceiling and consisted of a beam that hangs down and an electromagnet attached to an adjustable mount that moves up or down the beam depending on the height needed for the testing (Figure 11).

Figure 11. Drop Tower With Electromagnet and Laser for Alignment

A laser measuring device was used to set the height of the tower (Figure 12). The device was placed on the glass at the impact point. The distance of the drop was measured from the base of the drop object to the top surface of the glass; therefore, when the drop tower was set, the height of the drop object had to be included in the height determination. The ball height used was 0.125 ft (38 mm) and the shot bag height used was 0.663 ft (202 mm). For example, for a 10 ft drop with the ball, the height of the drop tower was set to 10.125 ft. The height range available with the tower is up to 16 ft (4.88 m) with the ball and up to 13 ft (3.96 m) with the shot bag. Before placing the test object, the electromagnet was leveled to horizontal ±1°, then the object was attached to the electromagnet. The magnet is manually switched off by the operator to release the drop item.

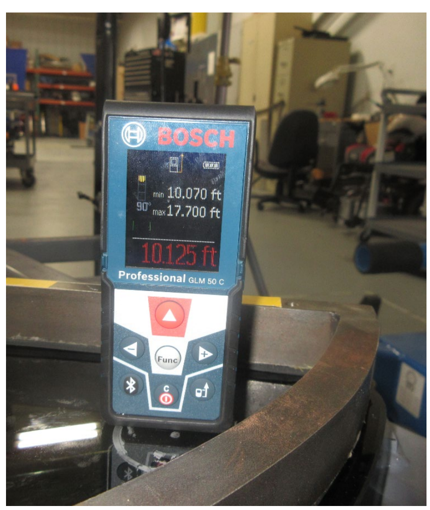


Figure 12. Drop Height Set from Glass Surface to Drop Magnet

Pneumatic Gun

A pneumatic gun fixture was fabricated to provide the additional energy needed to simulate higher drops, including the 30-ft drop, due to the maximum ceiling height available using the drop tower being only 16 ft. The gun fixture consisted of a support frame, gun barrel setups for the dart and ball, and a velocity laser (Figure 13). Two separate barrels were fabricated, one for the ball and the other for the dart. The barrels were interchanged into the fixture depending on the impact object being used.

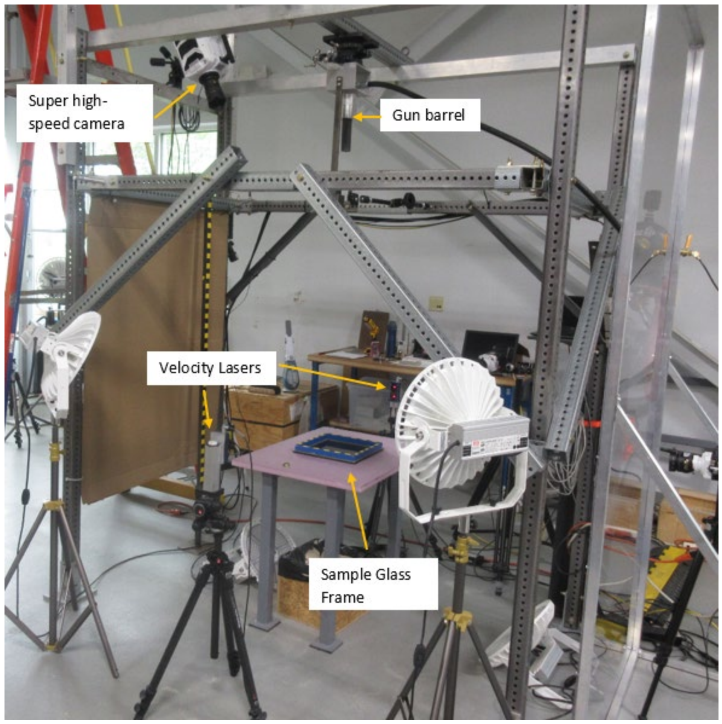


Figure 13. Pneumatic Gun Fixture

The gun imparted an initial velocity on the object so that velocity at impact was equivalent to the desired height (e.g., 30 ft (9.14 m) would produce a 13.39 m/s impact). As outlined in ECE R43, when a device is used to project the ball, the velocity tolerance is 1 percent of the impact velocity from the equivalent height drop. This tolerance was used for the testing that used the pneumatic gun. A velocity measuring laser light trap device (IES 2206 Velocity Measuring Laser Light Trap,[5] Figure 14) was used to measure the speed of the drop object prior to impact.

[5] EUROAMERICA LLC, North Rushsylvania, OH. https://euroamerica-llc.com/wp-content/uploads/2020/12/IES-2206e.pdf

Figure 14. IES 2206 Velocity Measuring Light Trap Device

Prior to selecting this speed device for testing, its speed readout was verified by completing a series of free fall drops from the drop tower down through the lasers and comparing the calculated drop speed based on the drop height with the experimental speed that the lasers outputted during the trials. This speed device gave very consistent results with little to no difference in the output from repeated drops (see Appendix C).

The speed device was mounted vertically so that the drop object passed between the two lasers during free fall (Figure 15). The center of the barrel was lined up with the center of the lasers of the speed device.

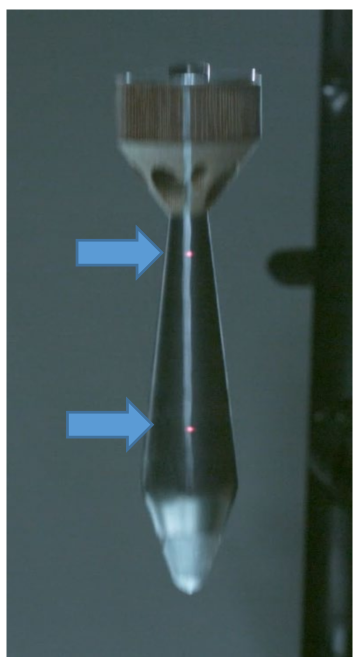


Figure 15. Drop Object Passing Between Velocity Device Lasers

The distance from the top laser down to the glass was recorded and used to find the velocity needed at the lasers for an equivalent height free fall drop (Figure 16). The equation used to determine the velocity needed at the light trap for an equivalent height impact is shown in Equation (1), where h = distance from glass to 1.25 cm below the top laser.

$$Velocity\ at\ light\ trap = \sqrt{Desired\ impact\ velocity^2 - 2gh} \qquad (1)$$

where $h = H - 1.25\ cm$

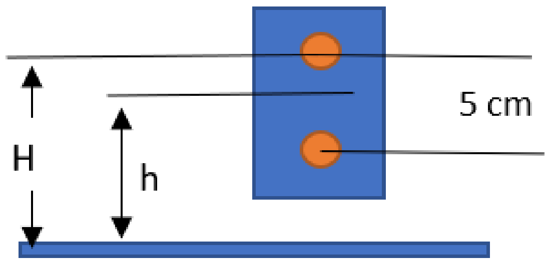


Figure 16. Velocity Calculation Diagram

After the speed needed for the specific height was calculated, speed shots were run to determine the pressure needed to achieve the desired velocity at impact. Each day of testing, speed shots were run to verify the speed. Pressure was adjusted as needed on the day of the testing. Speed at the lasers was collected and recorded for each test.

Laser Targeting

To ensure that the impact object was going to hit accurately and reliably within the 25-millimeter circle specified in the ANSI Z26.1-1996 standard, a laser was used for targeting. The laser was mounted to the drop tower or gun fixture and aligned with the center of the magnet or center of the barrel and with the impact location. The glass to be tested was adjusted to align the desired impact location with the downward beam of the laser. The laser was also used to set up the production glass so that the drop object hit perpendicular to the glass surface. This was done by shining the laser on the impact location and adjusting the glass using the four cranks on the base fixture so that the laser beam reflected upward onto a reflectance board with concentric circles (Figure 17). Each concentric circle on the reflectance board was a half inch in diameter. The red circle represents approximately 3° from vertical for the impact angle. The targeted goal for impacts was within the first concentric circle. All tests stayed within the red circle.

Figure 17. Reflectance Board

Impact Locations

Impact locations were selected based on the ANSI Z26.1 standard and to evaluate the effect of the CPA.

Sample Impact Locations

Impact points on the sample with the ball included the center (in the fully tempered area), in a corner tangent to both painted edges, in the transition zone between the non-painted glass and CPA, and on the edge of the CPA (Figure 18). Ball impacts were made on the exterior surface. Impact locations with the shot bag, shown in Figure 19, include center, tangent to the frame at the mid-point, and in the corner tangent to the frame edges. Impacts with the shot bag were on the interior surface of the glass.

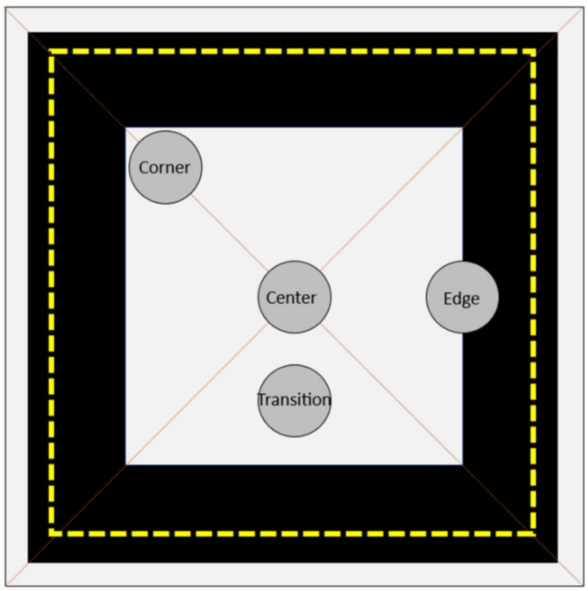


Figure 18. Ball and Dart Sample Impact Locations

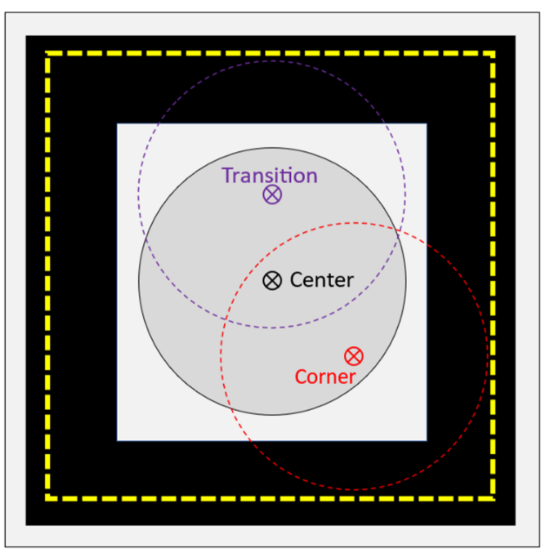


Figure 19. Shot Bag Sample Impact Locations

Tempered Production Glass Impact Locations

The production glazing impact locations selected were at the same type regions as used for the sample. Impact points on the production glass with the ball included the center (in the fully tempered area), in a corner tangent to both painted edges, in the transition zone between the non-painted glass and CPA, and on the edge of the CPA. Impact locations for the RQ, SR and BL are shown in Figures 20 to 22. Two additional locations were struck on the production glass and were in the fully painted area halfway between the CPA edge and frame edge and in the corner of the fully painted area, equidistant from the frame edges. All impacts with the ball were made on the exterior surface.

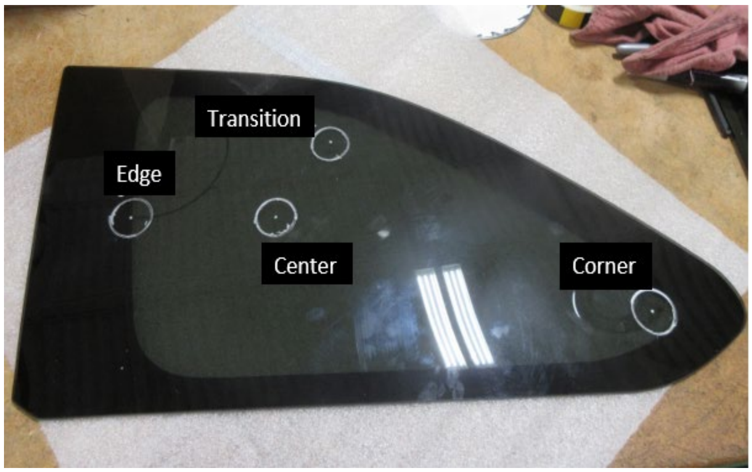


Figure 20. Ball RQ Production Impact Locations

Figure 21. Ball SR Production Impact Locations

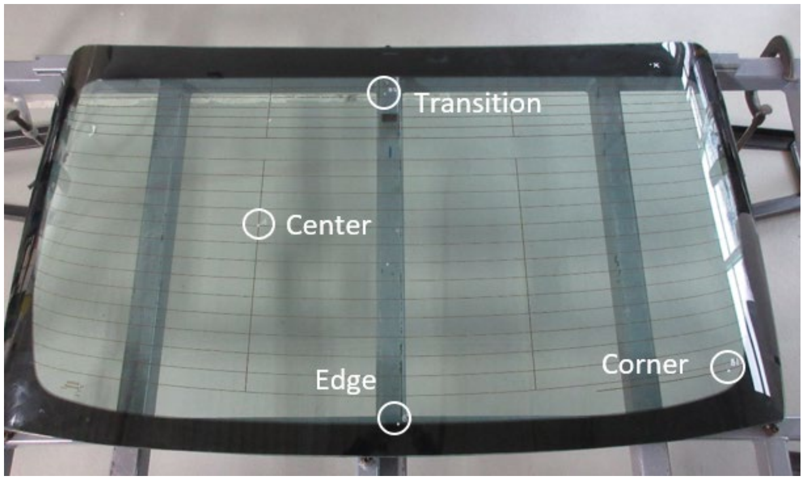


Figure 22. Ball BL Production Impact Locations

Impact points for the shot bag tests on production glass included in the center of the fully tempered portion, in the transition zone between the glass and CPA, and in the corner and on the edge of the CPA (Figures 23 to 25). Two additional locations on RQ were selected at the edge of the CPA in the corners. An SR additional location was selected in the opposite corner. This location assumed that there was symmetry left and right but not top to bottom of the sunroof. All impacts with the shot bag were made on the interior surface.

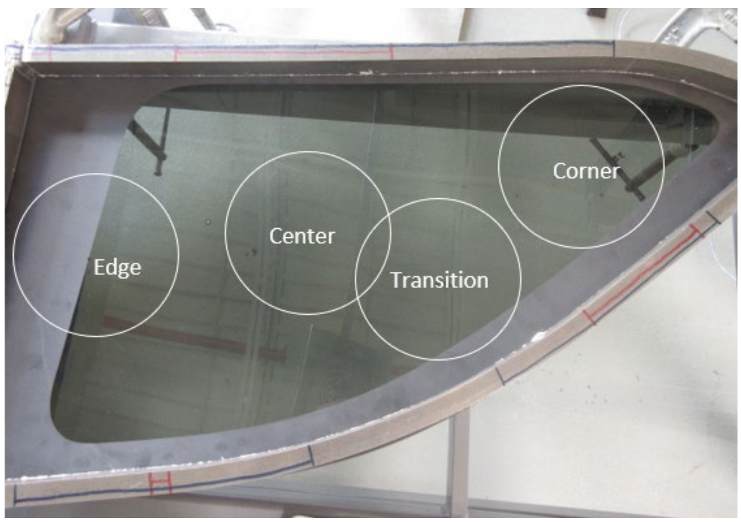


Figure 23. Shot Bag RQ Production Impact Locations

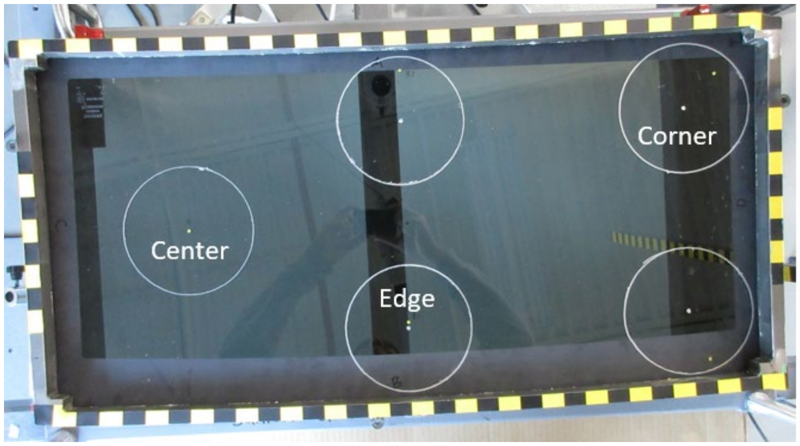


Figure 24. Shot Bag SR Production Impact Locations

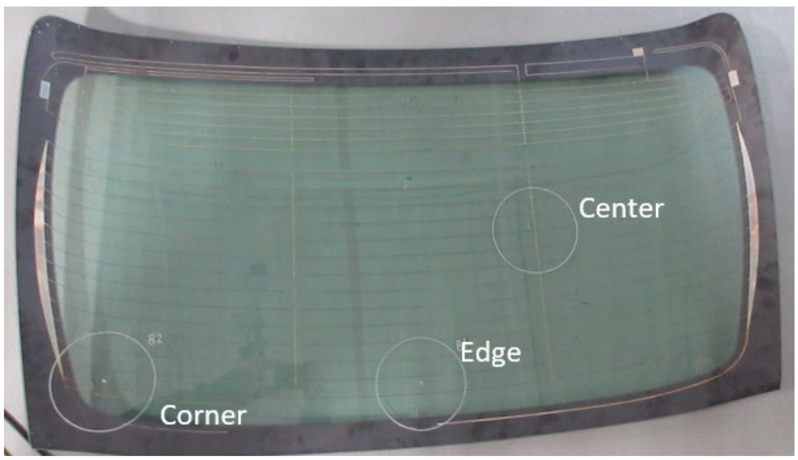


Figure 25. Shot Bag BL Production Impact Locations

Laminated Production Glass Impact Locations

The ball and dart impact locations on the laminated sample WS glass were the same locations as described in the *Sample Impact Locations* section. Impact points on the WS production glass were selected as similar locations to those used for the sample. In Figure 26 the center is one-third of maximum windshield width and half height of unpainted area, transition is a sphere radius from the CPA edge, one-quarter of the top edge width, corner is the corner of CPA edge with the sphere tangent to CPA, and edge is half the maximum width on the CPA bottom edge.

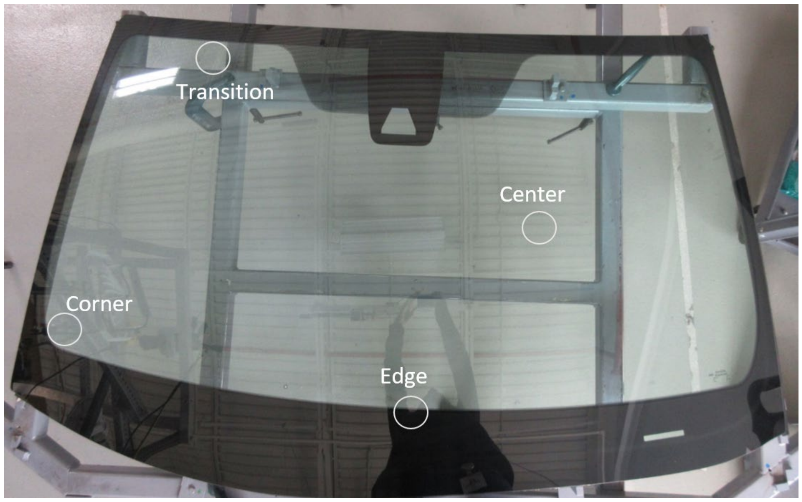


Figure 26. Ball and Dart WS Production Impact Locations

Fracture Test

The fracture test of ANSI Z26.1-1996 and fragmentation test of ECE R43 specify requirements for the glazing once it breaks. The purpose is to verify that the fragments produced minimize risk of injury. The ANSI standard requires that no individual fragment obtained within 3 minutes following the test shall weigh more than 4.25 g (0.15 oz). The ECE requirement is that any 5-by-5-centimeter square shall not have less than 40 fragments. Testing was completed using both ANSI and ECE methods of weight and count, respectively, at the impact locations from both standards.

The test was set up by placing the test piece on top of an identical glass piece and taping around the periphery of the glass. Clear packaging tape was used to hold the two pieces together and had approximately one inch of overlap onto the glass. The glass was placed concave down, so that the impact would be on the exterior surface of the glass, onto the support frame (Figure 27). This setup allowed for imaging of the glass during testing. A digital single-lens reflex (DSLR) camera was placed so that it was perpendicular to the support frame. Four 5-by-5 cm squares were placed onto the glass. The glazing was broken at specified impact locations using a spring-loaded center punch with a point having a radius of curvature of 0.2 mm +/- 0.05 mm per the ANSI and ECE R43 protocols.

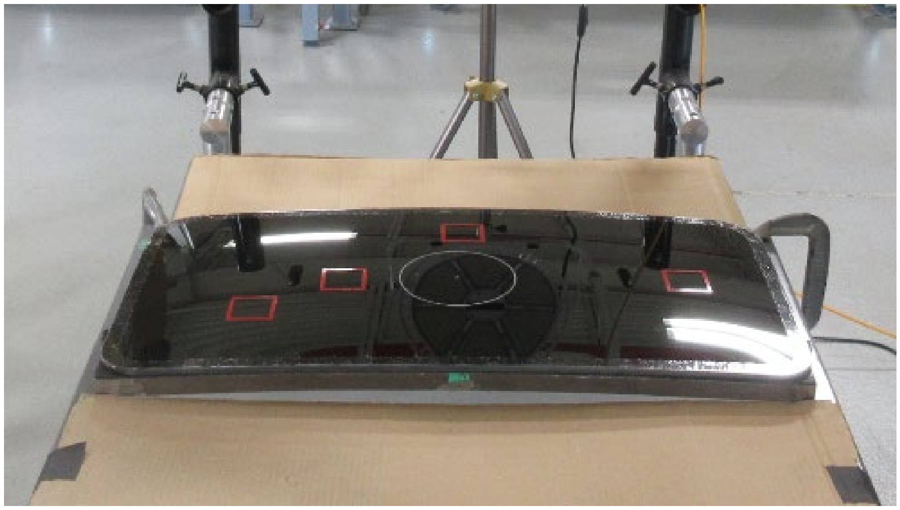


Figure 27. Fracture Test Setup

Fracture Impact Locations

Impact locations were determined following ANSI Z26.1 and ECE R43 and are shown in Figures 28 to 30 for each glass type tested. The ANSI location is 25 mm (1 in) inboard of the edge at the mid-point of the longest edge. The ECE R43 points are geometric center (point 1) and a point on the largest median in that area of the pane where the radius of curvature is smallest (point 2). Point 2 is only taken on curved glass panes having a minimum radius of curvature of less than 200 mm. None of the glass selected for this testing had a radius of curvature less than 200 mm; therefore, no point 2 locations were tested.

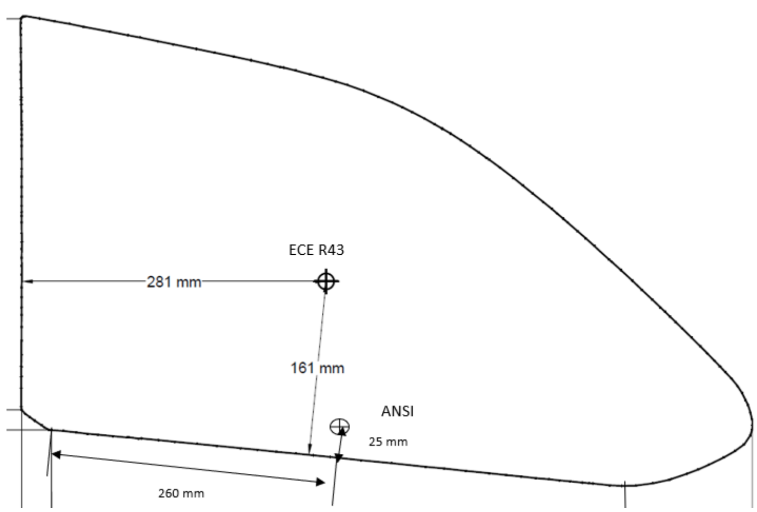


Figure 28. RQ Fracture Test Impact Locations

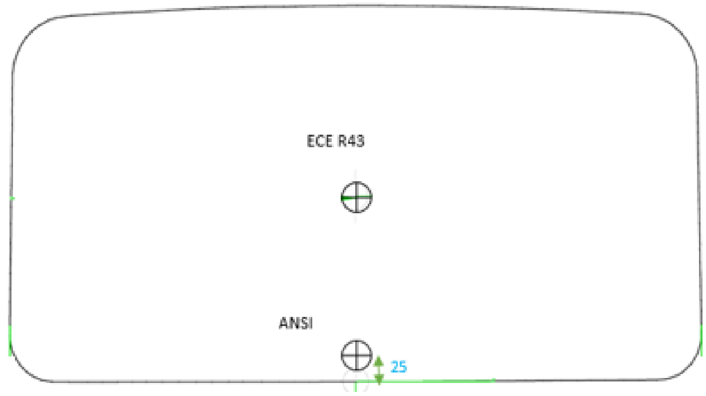


Figure 29. SR Fracture Test Impact Locations

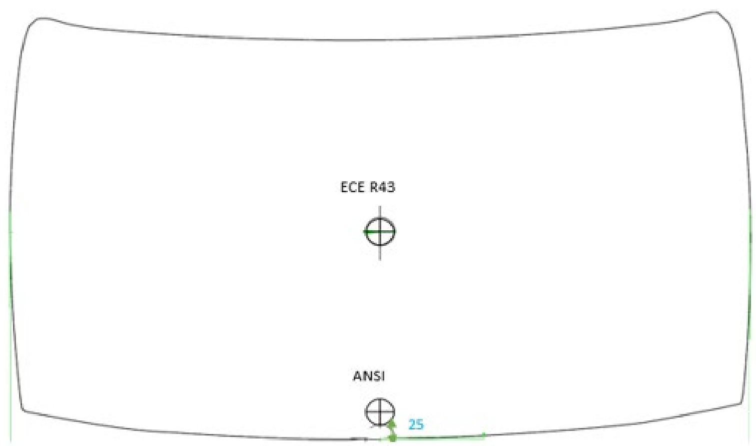


Figure 30. BL Fracture Test Impact Locations

Fracture Data Collection Methods

Within 10 seconds and 3 minutes of impacting the glazing, pieces were identified for weighing and images were taken for counting. Images of the fracture pattern were taken at 10 seconds, 1 minute, 2 minutes and 3 minutes after the punch. During this time the largest pieces of glass were identified and marked. Once imaging was completed at 3 minutes, the identified piece was removed and weighed. Counting was completed using manual counting with the same technician counting all tests. Methods for counting were per the standard, which was to count the number of fragments within a 5-by-5 cm square. Any fragments that intersected the edge of the square were counted as half a fragment.

Test Matrix

A test matrix was developed to evaluate the glazing in different test configurations and compare results. Each set of tempered glass was tested per Table 3. Two test modes were completed on sample and production glazing (ball and shot bag), and one test mode was completed on production glazing only (fracture). All test modes were performed on both glass with CPA (painted) and without CPA (unpainted). Test procedures used are in Appendix D.

Tests modes using the defined drop heights of 10 ft and 6.6 ft for the ball and 8.0 ft for the shot bag will be referred to in this report as standard tests. For these test modes, unless otherwise indicated, three repeats of each test configuration were completed. For the 6.6 ft tests, it was assumed that if the glass did not break at 10 ft that it would not break at 6.6 ft. Therefore, no tests were completed at 6.6 ft if there were no breaks at 10 ft.

Break height testing, as indicated at a height followed by "+" in the table, was completed at select locations. Break height is defined as the height at which the glass first experiences a break. To determine break height, impact height was increased in 10 ft increments until a break occurred and then reduced to get a 5 ft range. The glass was reused for repeated impacts due to the number of pieces available. For example, 30, 40, and 50 ft tests were run on the same piece until failure, then the height was reduced to 45 ft on a new piece. Once a break height was found, a new piece was tested to confirm the break (e.g., test broke at 45 ft, a second 45 ft test on a new piece is run; the break was confirmed if the test on a new piece also broke). More than one repeat was done only if the result of the test on a new piece did not match the repeated height test. In this case, the result taken was the result of two of the three tests done at that height.

Table 3. Test Matrix

Glazing	Test Type			Height	# of Locations	Qty of Tests
Tempered (RQ, SR, BL)	Ball	Sample	painted & unpainted	10 ft	4	24
				6.6 ft	4	24
				10 ft +	4	36
		Production	painted & unpainted	10 ft	4	24
				6.6 ft	4	24
				10 ft +	4	36
	Shot Bag (ANSI)	Sample	painted & unpainted	8 ft	3	12
				8 ft +	3	24
		Production	painted & unpainted	8 ft +	6	24
	Shot Bag (Modified)	Sample	painted & unpainted	8 ft	3	12
				8 ft +	3	24
		Production	painted & unpainted	8 ft +	6	24
	Fracture	Production	painted & unpainted	ANSI	mid pt of edge	12
				ECE	center	12
Laminated (WS)	Dart	Sample	painted & unpainted	30 ft	4	24
				31 ft +	2	36
		Production	painted & unpainted	30 ft	4	24
				31 ft +	2	36
	Ball	Sample	painted & unpainted	30 ft	4	24
				31 ft +	2	36
		Production	painted & unpainted	30 ft	4	24
				31 ft +	2	36
		Sample (Cold)	unpainted	27.89 ft	4	12
				30 ft +	2	18
		Sample (Hot)	unpainted	29.53 ft	4	12
				30 ft +	2	18

Test Results

Results of comparisons between ANSI 12-by- 12-inch samples and production glass and painted and unpainted glazing are shown in the following sections. The three types of tempered glass were tested with the 227-gram ball from 10 ft, with the shot bag and modified shot bag from 8.0 ft and with the fracture test. The laminated glass was tested with the ball and dart from 30 ft.

Tempered Ball Standard Tests

Results from the 10 ft standard tests with the ball are shown in Figures 31 to 33. Each set of three tests is plotted for the RQ, SR and BL glass. The number of breaks was divided by the total number of tests to get the ratio of broken glass panes to unbroken glass panes. This ratio ranges from 0.0 (no glass pane broke) to 1.0 (all the glass panes broke). A table of these results can be found in Appendix E and F.

For the RQ and SR glass, the only location where the presence of paint produced a different result was at the edge of the CPA. At this location, the glass in all painted tests broke while all unpainted tests did not result in fracture. The BL glass had some other locations where the glass with paint broke while the glass without did not. At the standard (center) location, results for the RQ and SR glass were consistent between sample and production parts.

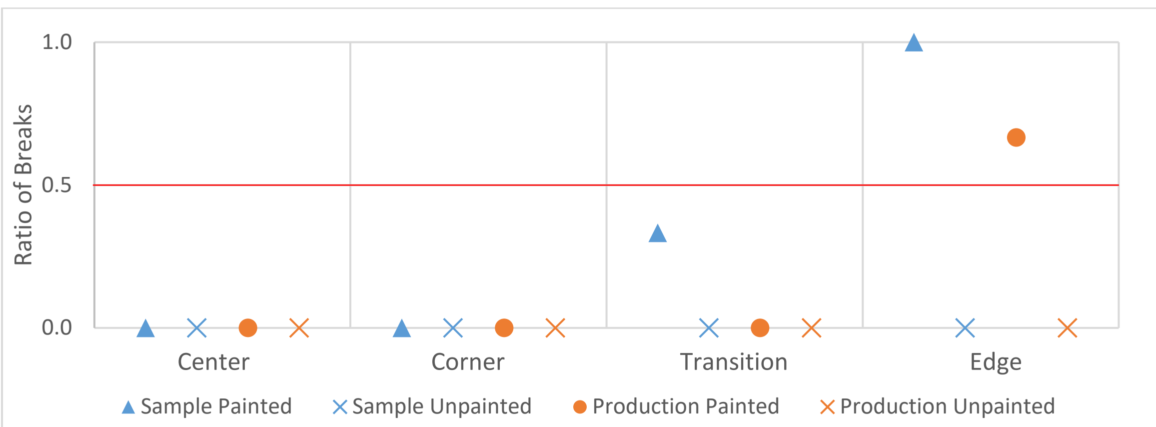


Figure 31. RQ Ball Standard Test Results

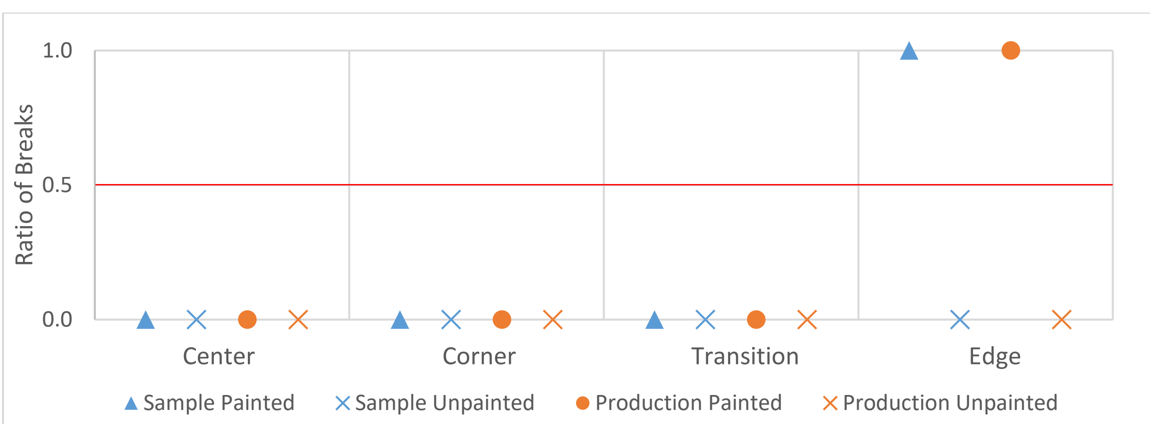


Figure 32. SR Ball Standard Test Results

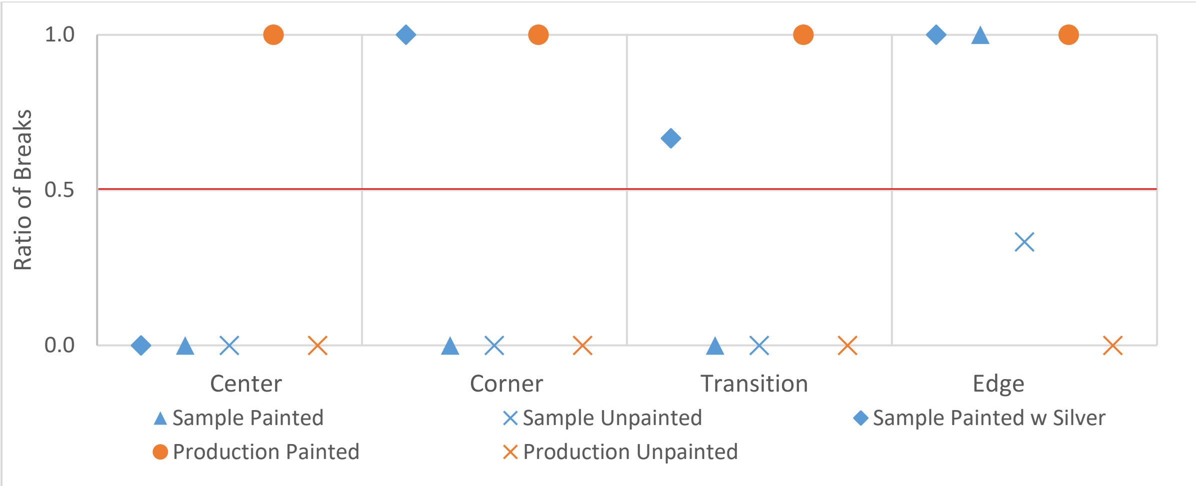


Figure 33. BL Ball Standard Tests Results

However, for the BL, results between sample and production differed as the production glass with paint broke in three locations while the sample glass with black band only did not break (center, corner, transition). Similarly, the sample glass with silver paint broke in two locations that the sample with black band only did not (corner, transition). Many breaks on the BL glass and differences in performance are likely due to the silver lines. For example, at the center location of the BL, impacts occurred directly on crosshairs of silver painted lines for production glass but between crosshairs for sample glass (Figure 34).

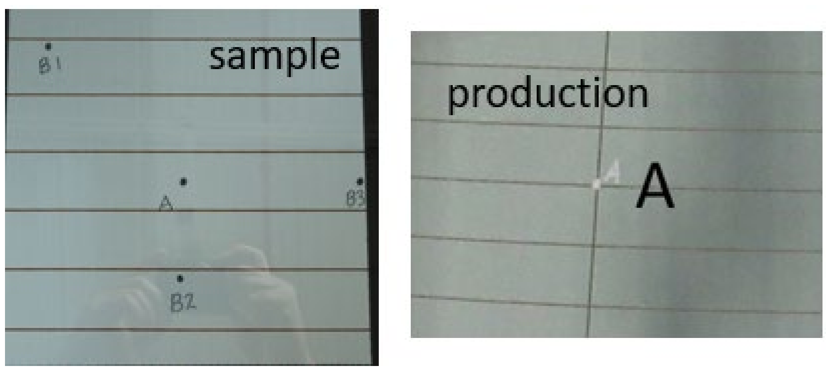


Figure 34. Impact Location Relative to Silver Lines

All production glass (and RQ sample glass) did not show different results between the 10 ft and 6.6 ft drops. On the SR and BL samples, the 6.6 ft had different results from 10 ft at three locations, all on painted glass – SR edge, BL transition and BL edge. No unpainted glass was tested at 6.6 ft due to all 10 ft tests having passing results. The 10 ft test better captures the effect of paint, as it had breaks occur at the edge location where the paint makes the glass the weakest while the 6.6 ft did not produce fracture at those locations.

Tempered Ball Break Height Tests

Break height testing with the 227-gram ball was completed following the steps previously described. Figures 35 to 37 show the results of each of the three glass types – RQ, SR, and BL. The break height shown is the lowest height where breaks started to occur.

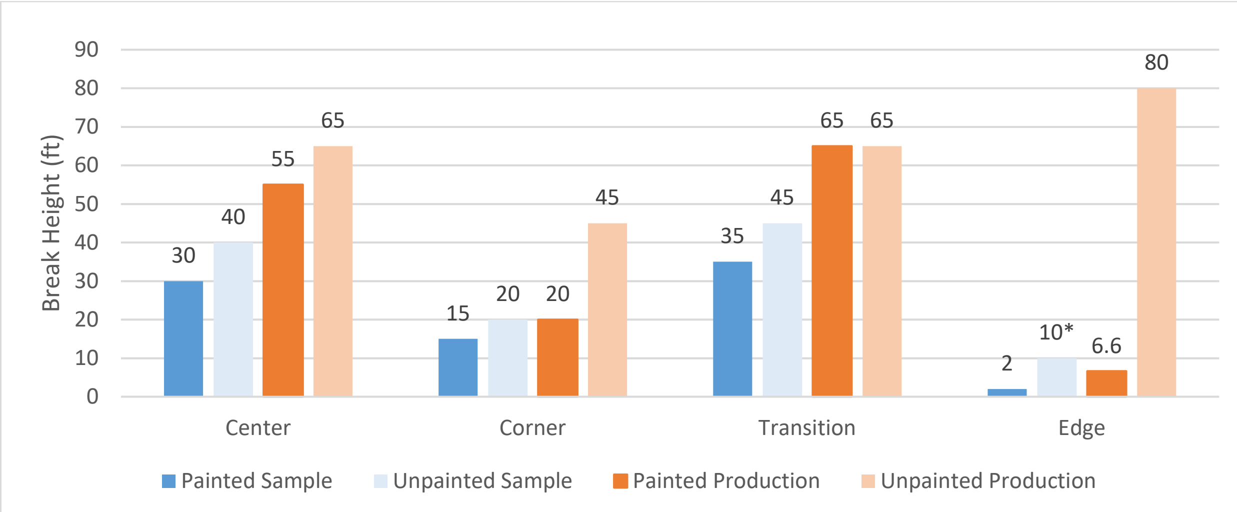


Figure 35. RQ Ball Break Height Results

RQ production glass was stronger, based on break height, than sample glass in all test conditions. Unpainted glass was stronger than painted in all conditions except for the transition location on production glass where strength was equal. Strength reduction due to the paint ranged from 0 percent (transition location, production glass) to 92 percent reduction in strength at the production glass edge location. This location also had the lowest break height at 2 ft for the painted sample glass. The paint creates localized weak spots, meaning it is more likely to break when struck near or on the paint edge. However, even when striking further away from the paint edge, such as at the center, the paint also caused weakening of the glass.

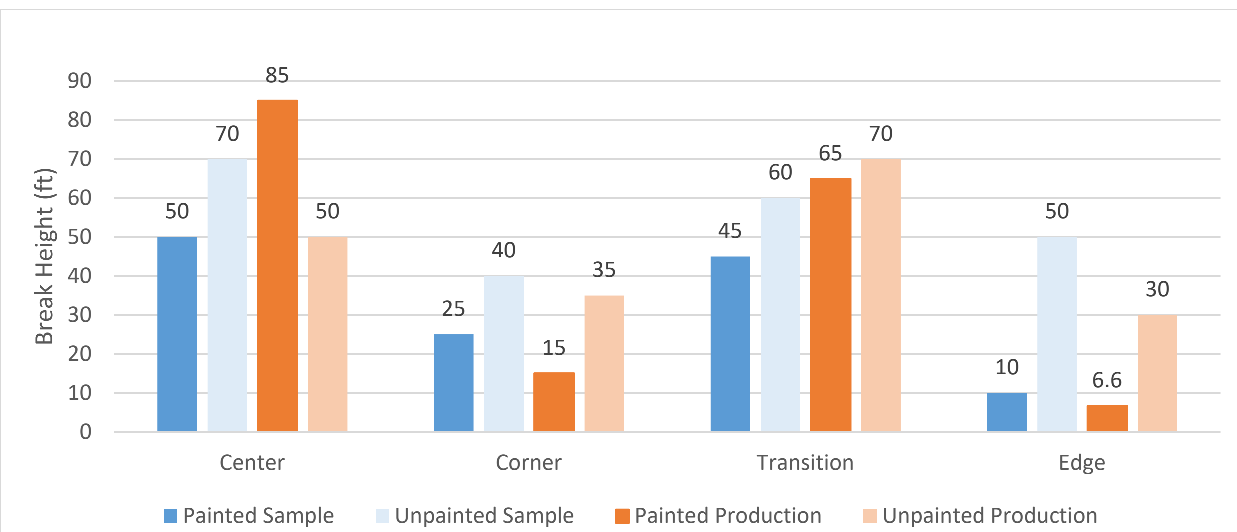


Figure 36. SR Ball Break Height Results

Unpainted SR glass was stronger than painted in every condition except for the center location on production glass where the painted was stronger. Two additional tests were completed on painted glass at the break height of this location to verify this result was not an anomaly. Both tests broke the glass confirming this break height. The painted edge location was the weakest with the corner location being a close second. Strength reduction due to the paint ranged from seven percent (transition location, production glass) to 80 percent reduction in strength at the sample glass edge location. Like the RQ glass, the SR showed that the paint creates localized weak spots.

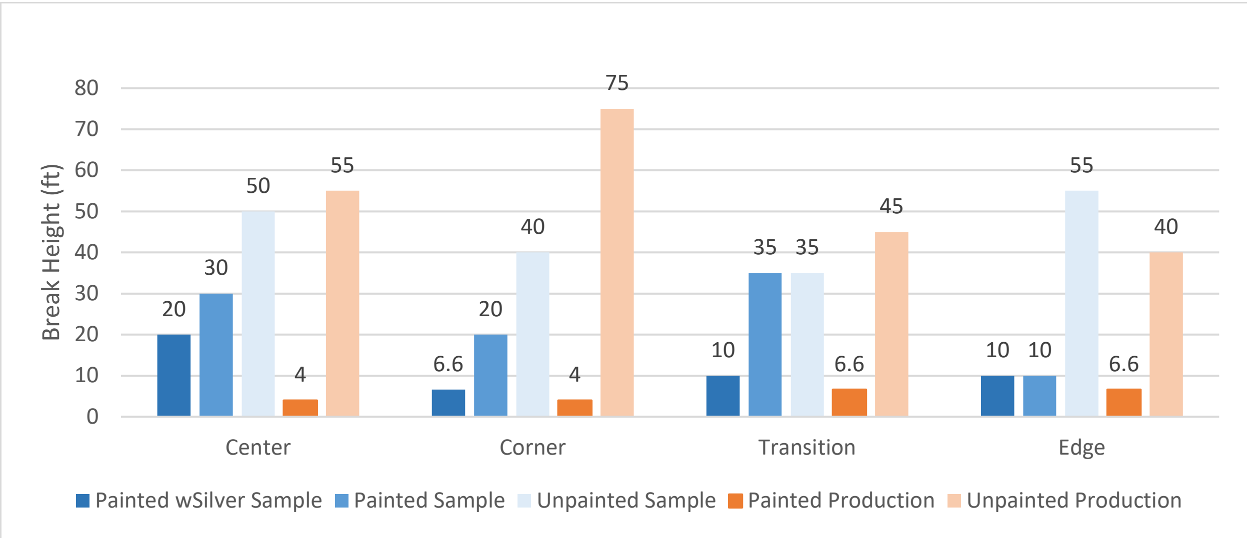


Figure 37. BL Ball Break Height Results

BL glass painted with silver lines was weaker than the unpainted for both sample and production parts. The painted sample glass was weaker than the unpainted sample but stronger than the sample glass painted with silver lines. Production glass exhibited a decrease in strength between 84 and 95 percent between unpainted and painted at all locations. The painted production glass had silver painted lines, which were expected to further decrease strength. Interestingly, the center and corner impact locations on the production glass were directly intersecting with a silver line which caused even more weakening of the glass when compared to the edge and transition locations where the impact was between or not near the silver lines. The painted sample glass with silver lines had the same or lower break height as painted sample glass without silver lines, again indicating that the silver lines further decreased strength. Like the other glass types, the sample BL exhibited the greatest decrease in strength between unpainted and painted at the edge location (82% decrease).

Tempered Shot Bag Standard Tests

Results from the 8 ft standard tests with the ANSI shot bag are shown in Figures 38 to 40. Each set of three tests is plotted for the RQ, SR and BL glass. The number of tests with breaks was divided by the total number of tests to get the ratio of broken glass panes to unbroken glass panes. This ratio ranges from 0.0 (no glass pane broke) to 1.0 (all the glass panes broke). A table of these results can be found in Appendix E and F.

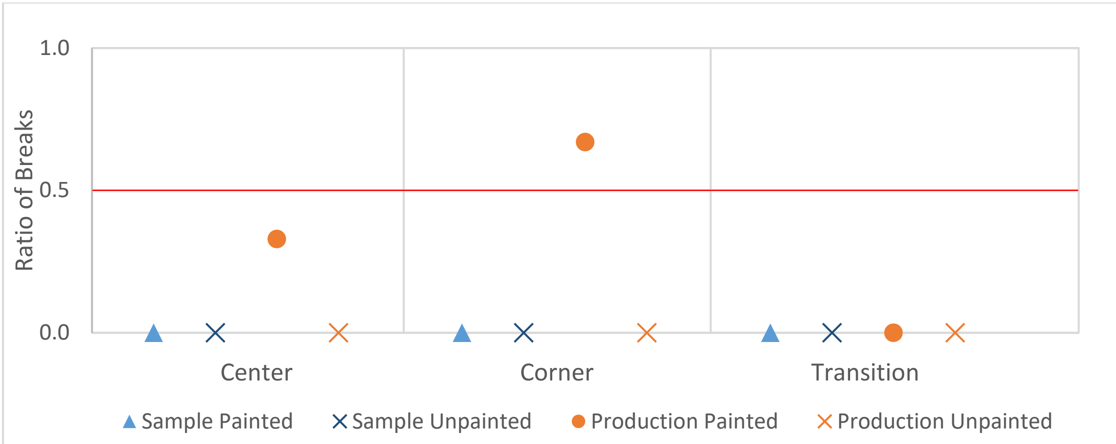


Figure 38. RQ Shot Bag Standard Test Results

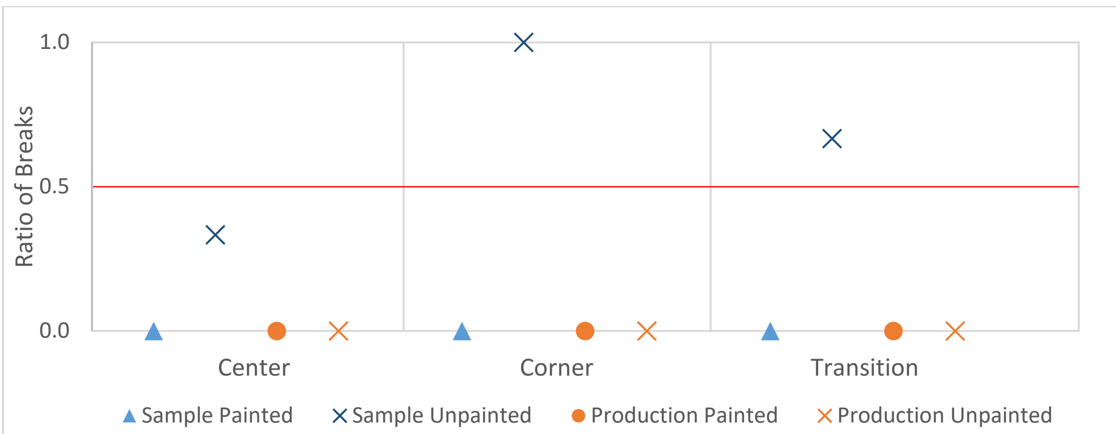


Figure 39. SR Shot Bag Standard Test Results

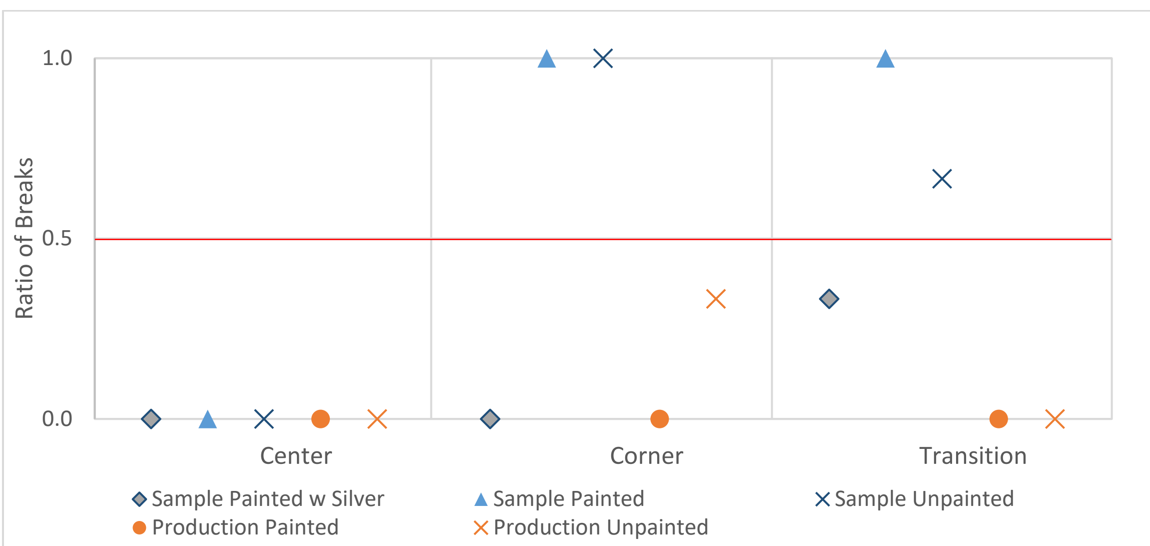


Figure 40. BL Shot Bag Standard Test Results

For the RQ glass, breaks only occurred on painted glass, with the corner and transition locations having the most breaks with both shot bags. However, for the SR glass, breaks were more likely to occur on unpainted glass. Only one location on the production glass resulted in a difference between painted and unpainted (RQ corner), while on the sample glass differences were observed in every location except for SR and BL center and all RQ tests, with the unpainted glass having more breaks than the painted glass. Also, fewer breaks occurred on glass with the silver paint applied. The SR and BL shot bag results indicate that the glass strength from interior shot bag impacts is increased with solid paint and painted silver lines applied, which is an opposite finding from the ball test results on the exterior where the paint reduced glass strength.

Results from the 8 ft standard tests with the modified shot bag are shown in Figures 41 to 43. Each set of three tests is plotted for the RQ, SR and BL glass. The number of tests with breaks was divided by the total number of tests to get the ratio of broken glass panes to unbroken glass panes. This ratio ranges from 0.0 (no glass pane broke) to 1.0 (all the glass panes broke).

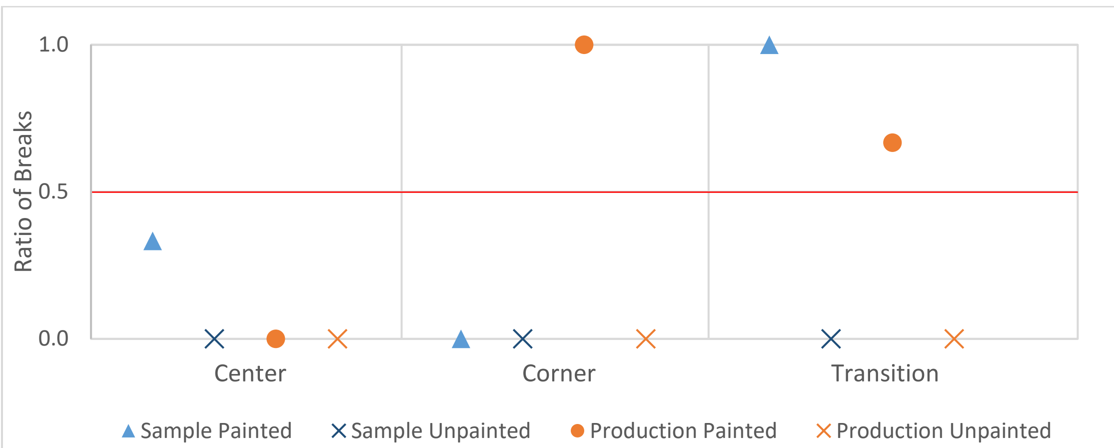


Figure 41. RQ Modified Shot Bag Standard Test Results

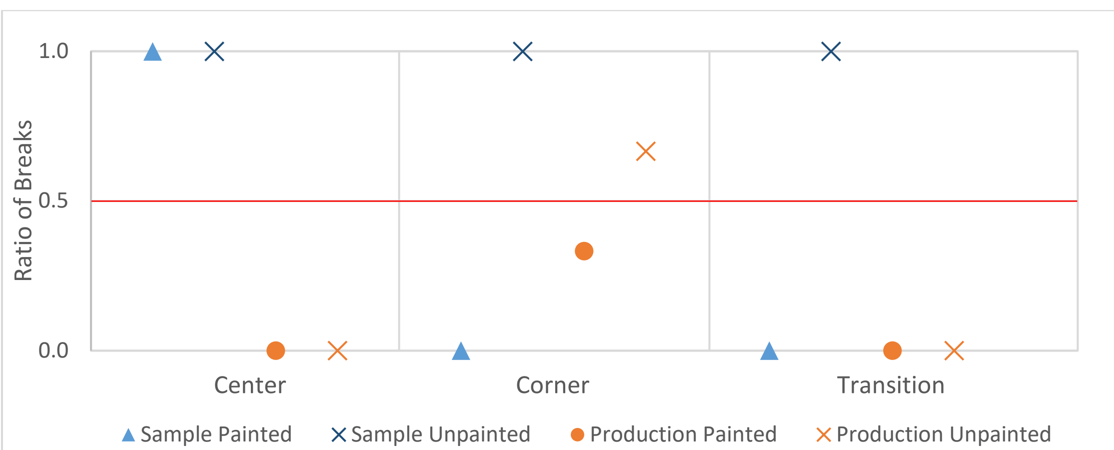


Figure 42. SR Modified Shot Bag Standard Test Results

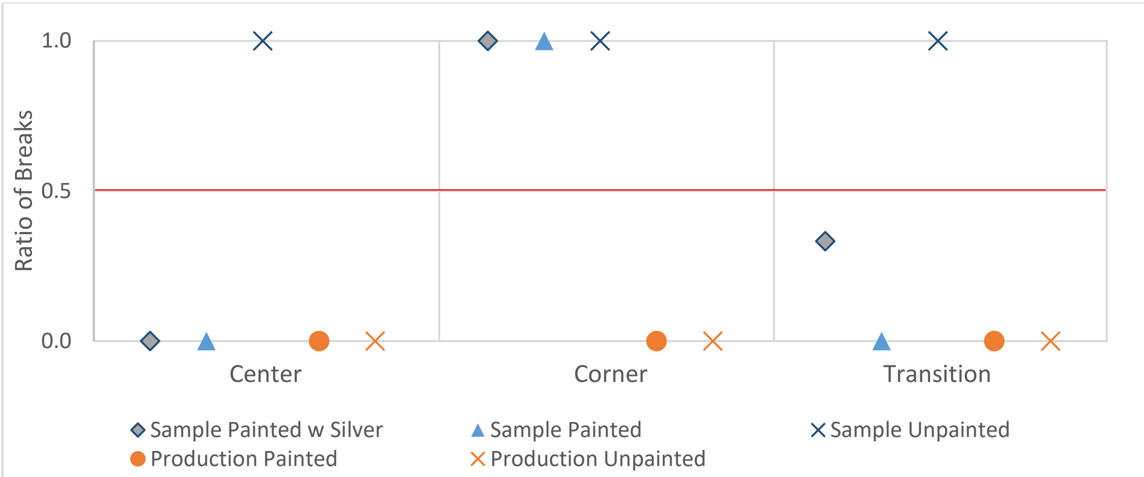


Figure 43. BL Shot Bag Standard Test Results

When comparing the ASB and MSB, only a few locations showed differences. At these locations the MSB produced breaks while the ASB did not, except for the transition location of the painted BL sample glass where the ASB produced more breaks than the MSB. This location may have shown differences due to the silver lines or may be an anomaly as one of the three MSB tests did break. Overall, these results show that the MSB concentrates the force and stresses the glass differently than the ASB.

Tempered Shot Bag Break Height Tests

Break height testing was completed with the shot bags following the same method as the ball break height tests, except that the shot bag test break heights were determined within a 1-foot range. Results are shown in Figures 44 to 46.

Break heights could not be determined at the center and transition locations of the RQ glass due to the height constraint of the tower. However, breaks did occur at the corner location with the MSB, indicating that location was the weakest on this glass type. At this location the paint created a 15 percent reduction in strength compared to unpainted glass.

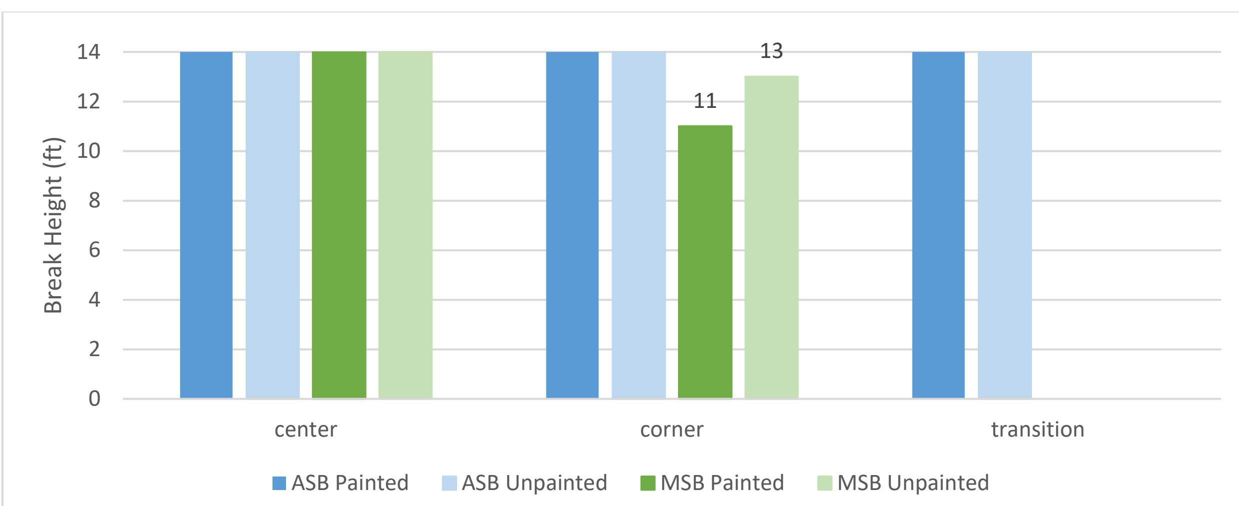


Figure 44. RQ Shot Bag Break Height Results

The SR glass showed that the paint slightly increased the strength compared to the unpainted at all locations. The greatest change in strength due to paint was at the transition location where there was a 25 percent increase with the ASB and a 43 percent increase with the MSB.

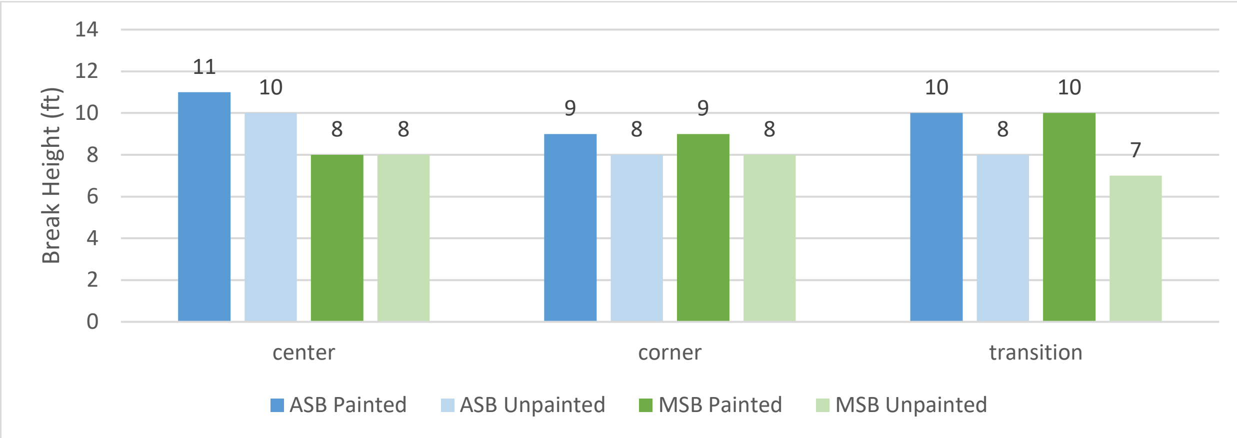


Figure 45. SR Shot Bag Break Height Results

On the BL glass, paint increased strength by 44 percent over unpainted at the center location with the ASB. At other locations with the ASB there was no change in strength due to the paint, but the paint with silver lines increased the strength of the glass.

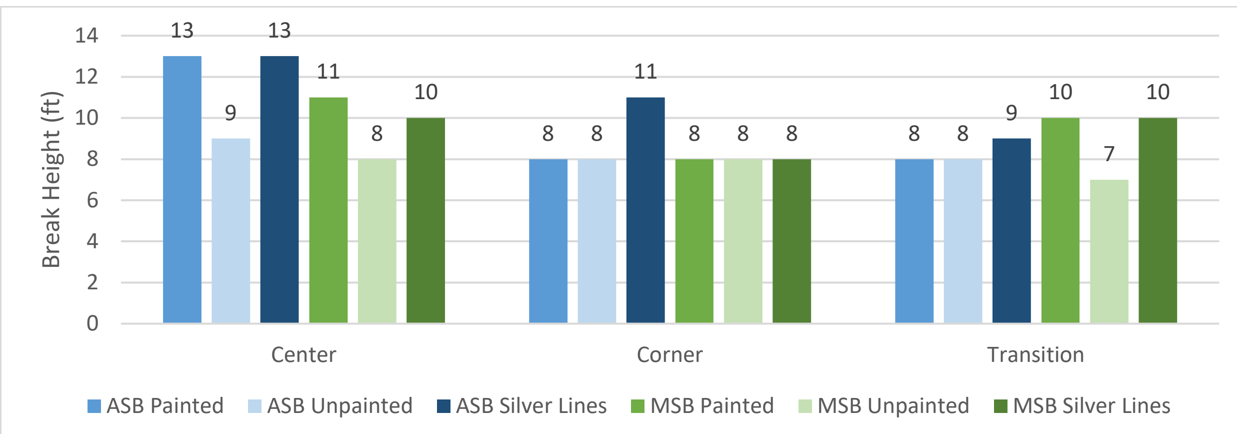


Figure 46. BL Shot Bag Break Height Results

Tempered Fracture Test

Two impact points were evaluated as part of the fracture test. At each of the impact points the weight of the pieces and the count of the pieces was collected following the methods from the ANSI standard and the ECE R43 standard, respectively.

Fracture test weight and count results for production glass are shown in Figure 47 as the average of three tests. Standard deviation of each set is also shown. Two results marked in the plots with an asterisk (*) are the average of only two tests. Red lines on the plots show the test requirement limits. Counts were taken at two locations, one close to the impact location (solid bars) and one in a corner area away from the impact location (hatched bars). The counts presented are at the 3-minute time stamp. A greater weight and smaller count mean that fragments were larger as indicated on the plots. A table of these results can be found in Appendix E.

Figure 47. Fracture Test Results

Overall, the geometric center (ECE R43) location created larger fragments with greater weight and smaller count than the mid-point of the longest edge (ANSI) impact location. All count and weight averages met the criteria. However, one BL test failed the ANSI weight criteria (painted at ECE location) and another BL test passed by .05 grams (unpainted at ECE location), but both met the ECE count criteria. Paint and silver lines did not have as large of an effect on the performance of the glass in the fracture test as it did in other test modes.

Laminated Ball Standard Height Results

Criteria for the 30-ft (9.14 m) ball drop test followed that from ANSI Z26.1-1996, section 5.12, Impact, Test 12, which states that “the test shall be considered to have given a satisfactory result if the following conditions are met (a) the ball does not pass through the test piece; (b) the laminate shall not break into separate pieces; (c) at the point immediately opposite the point of impact, small fragments of the glass may leave the specimen, but the small area thus affected shall expose less than 645 mm² of reinforcing or strengthening material, the surface of which shall always be well covered with tiny particles of tightly adhering glass. Total separation of glass from the reinforcing or strengthening material shall not exceed 1,935 mm² on either side. Spalling of the outer glass surface opposite the point of impact and adjacent to the area of impact is not to be considered a failure.” For the analysis, the point opposite of impact that was measured for area of exposed laminate was the vehicle interior side of the glass which was the opposite of the impact side (vehicle exterior).

In the ball standard height testing from 30 ft, three repeats were completed at each impact location. All sample WS glass met the performance criteria. Production WS glass met the performance criteria at all but the edge location. At this location the failure mode was the area of exposed laminate (Figure 48). A table of these results can be found in Appendix E.

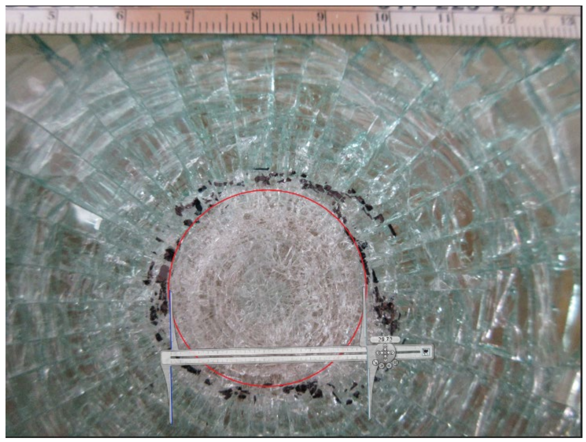


Figure 48. Area of Exposed Laminate on Opposite Side of Impact

Impact locations at corner and transition zone on production windshields had similar results to the respective windshield sample tests. Also, no differences were observed in break patterns between the painted and unpainted sample glass. An example of the break pattern from the ball test on the WS sample and production glass is shown in Figure 49.

Figure 49. Example of Break Pattern From 30-ft Ball Test at Corner

The center location had different fracture patterns between the production and sample tests. On the production glass the center impact location impact pattern looked more like a spiral compared to other locations (Figure 50). There was no major difference in the impact patter at the other impact locations.

Figure 50. Example of Break Pattern From 30-ft Ball Test at Center

The edge of the CPA also had some differences in fracture pattern between production and sample glass. The painted edge location on the production glass had a less centralized impact break pattern when compared to the unpainted (Figure 51). The other impact locations had similar results between the painted and unpainted glass.

Figure 51. Comparison of Sample and Production WS at Painted Edge Location (30-ft Ball)

Laminated Ball Break Height Results

Ball break height testing on the laminated glass was completed at two locations (center and edge). The results of the break height testing are shown in Figure 52, with results for sample glass in blue and production in orange and with results for the painted glass in the darker shade and unpainted glass in the lighter shade. For these break height tests, the failure mode was the area of exposed laminate. A table of these results can be found in Appendix E.

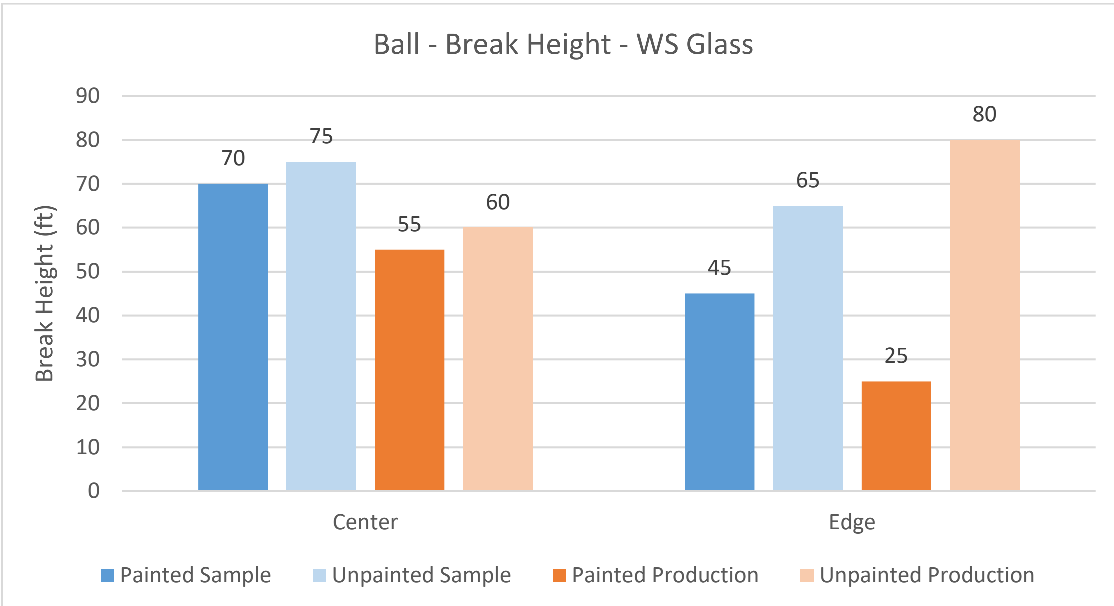


Figure 52. Laminated Ball Break Height Results

Overall, the unpainted glass was stronger than the painted, with the difference being more distinct at the edge location near the paint than at the center location. Similar trends can be observed between the sample and production glass.

Laminated Ball Hot and Cold Results

Drop heights for the hot and cold tests were determined following UN ECE R43 Annex 6, section 4.3. The drop height for the hot test was targeted to a 29.53 ft (9.0 m) equivalent height and the cold test was targeted to a 27.89 ft (8.5 m) equivalent height. Three repeats were completed at each impact location. All tests met the performance criteria. A table of these results can be found in Appendix E.

Results from the hot and cold break height tests were compared with the unpainted and painted ambient temperature tests (Figure 53). The asterisk (*) in the figure indicates that the failure mode was ball pass through.

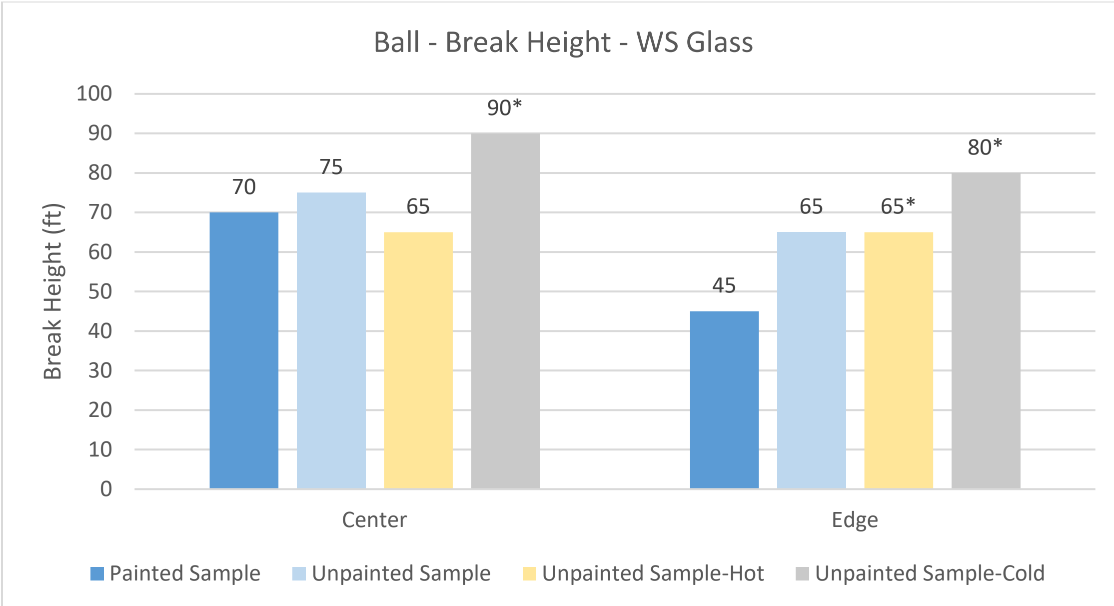


Figure 53. Tempered Ball – Hot and Cold Results

At the center location the hot and ambient results were similar. Cold tests had a greater break height, although the failure at the break height identified was more severe as the failures were of ball pass through as opposed to failure of area of exposed laminate for the other test types. At the edge location the hot and ambient were similar; however, the failure mode for the hot test was the more severe ball pass through. The cold test had a greater break height but again the failure mode was ball pass through.

When comparing the glass patterns from the temperature tests, the hot test produced more defined corner splines, with breakage concentrated around center impact point while there was more breaking of glass into smaller pieces in the cold test, radiating outward from center. Additionally, there was more stretch of the film layer in the hot test than in ambient and cold tests (Figure 54).

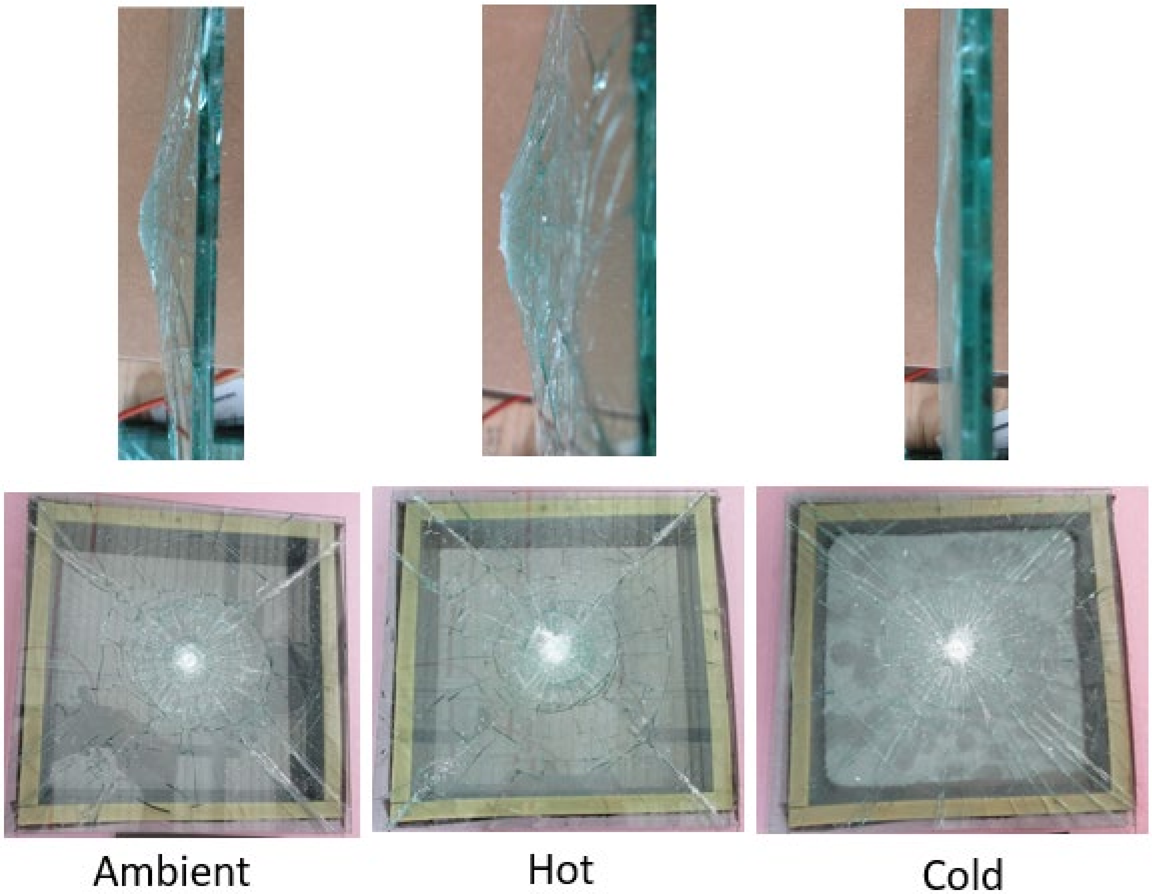


Figure 54. Examples of Glass Performance in Temperature Tests

Laminated Dart Standard Height Results

Criteria for the 30-ft dart drop test from ANSI Z26.1-1996 states that "the dart may crack the safety glazing material and may puncture the specimen. However, the hole produced in the specimen shall not be sufficiently large to permit passage of the body of the dart completely through the specimen. Small particles may disengage themselves from both sides of the specimen at and immediately around the point of impact, but no loose or detached pieces shall leave any area of the specimen exclusive to the area punctured by the dart. Furthermore, the glass on adjacent sides of each crack extending from the area punctured by the dart shall be held in place by the reinforcing or strengthening material, and no glass shall be freed from the reinforcing or strengthening material for a distance greater than 38mm (1½ inch) from a crack. Spalling of the outer glass surface opposite the point of impact and adjacent to the area of impact is not to be considered a failure." These criteria were followed for analysis of the dart testing results.

For the standard height testing at 30 ft, three repeats were completed at each impact location. All the sample and production WS glass met the performance criteria. A table of these results can be found in Appendix E. The dart punctured or split the laminate in 20 of 24 tests (Figure 55). The dart punctured the glass in 2 of the painted tests and 6 of the unpainted tests, and there was a split in the laminate for 9 painted and 3 unpainted tests. However, all tests met the criteria according to ANSI Z26.1. For a failed result, the dart body would have had to fully pass through the glass

(Figure 56). There were no visible differences observed in painted versus unpainted results for sample or production glass with the dart.

Figure 55. Examples of Dart Puncture

Figure 56. Dart Body Pass Through

Laminated Dart Break Height Results

Results from the break height testing with the dart is shown in Figure 57. The sample results are shown in blue, and the production results are shown in orange. Only the center and edge locations were tested for break height and are identified in the figure. A table of these results can be found in Appendix E.

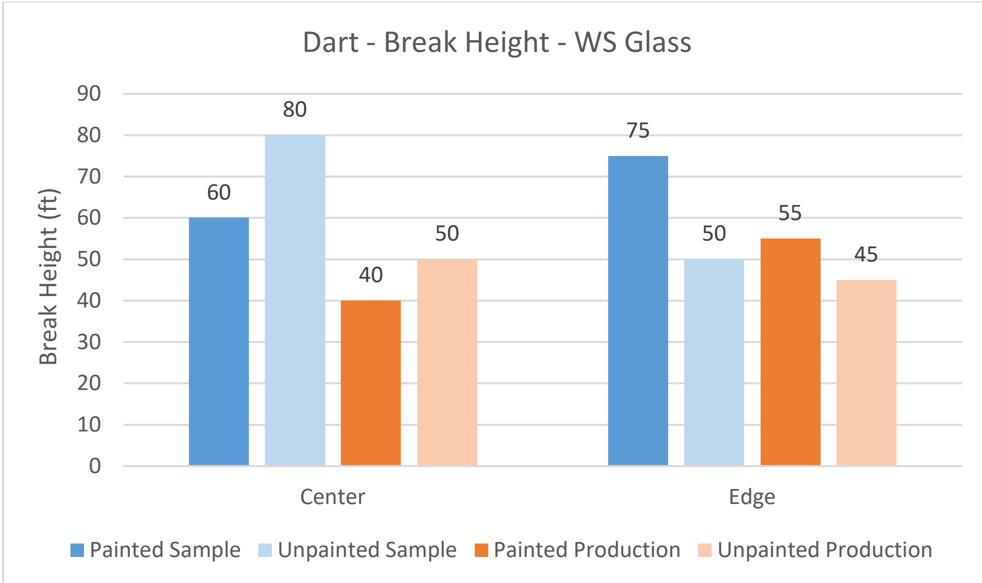


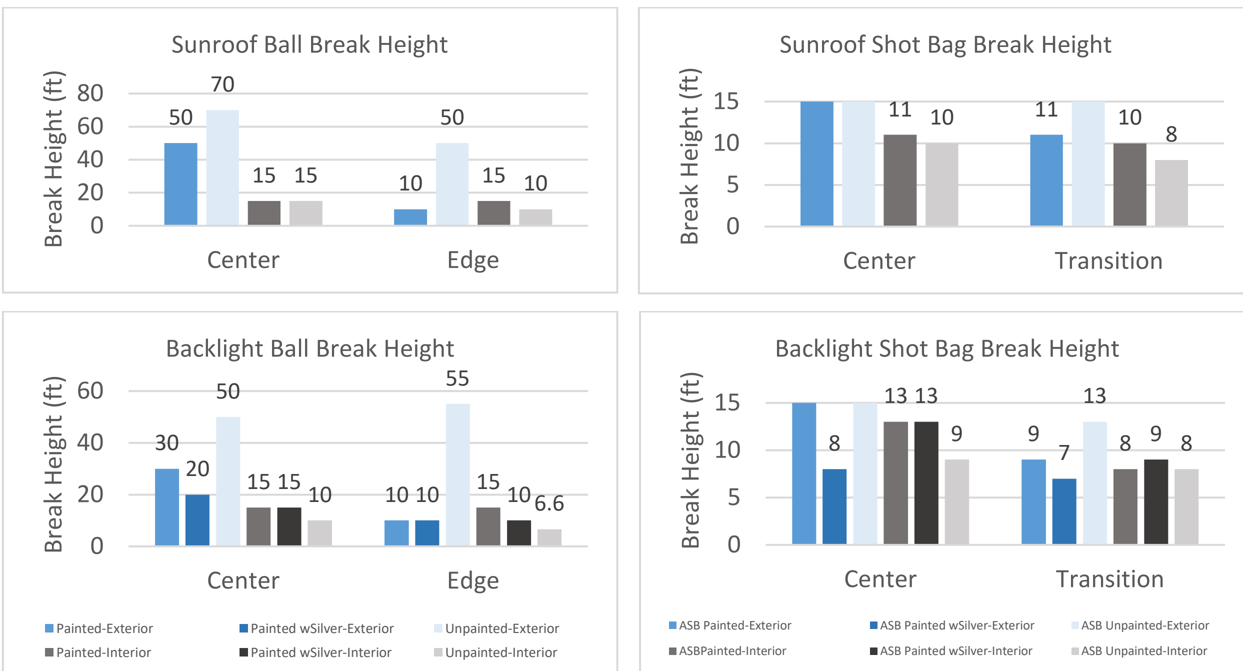
Figure 57. Dart Break Height Results

At both locations the sample glass had higher break heights than production glass. However, when looking at painted and unpainted results, the unpainted was stronger than the painted at the center location but the painted was stronger than unpainted at the edge location. Similar trends were observed for both sample and production glazing.

Discussion and Comparisons

Tempered – Ball and Shot Bag Comparison

The ball and shot bag tests had an inverse relationship in how the painted and unpainted glass performed. In the ball tests, the painted glass was weaker than the unpainted glass, while in the shot bag tests the unpainted glass was weaker than the painted glass. Because of this result, a small set of additional tests were completed to better understand the effect of impact side (i.e. exterior or interior) on the glass performance. These additional tests included completing break height tests impacting the interior surface with the ball and the exterior surface with the shot bag on sample glass only, both painted and unpainted. Results of the tests are shown in Figure 58. In the figure, the tests on the exterior surface are shown in shades of blue and the tests on the interior surface are shown in shades of grey.



Shades of Blue = exterior impact on sample
Shades of Grey = interior impact on sample

Figure 58. Break Height Testing on Glass Interior Versus Exterior

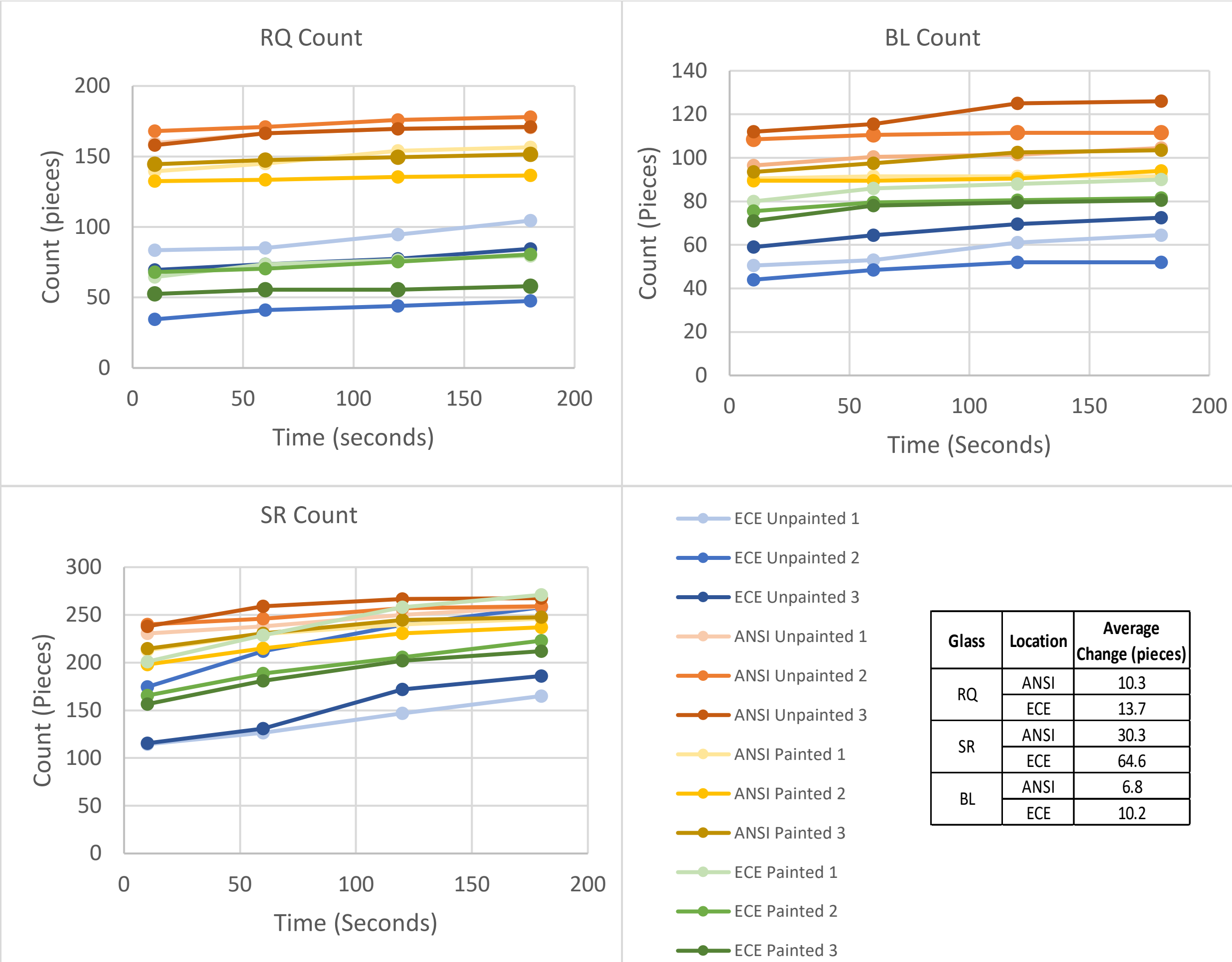
Results from the testing showed that the exterior of the glass is generally stronger than interior, as the ball and bag tests performed on the exterior had higher break heights than ball and bag tests on the interior. One exception to this is that the glass with silver lines had similar results for the ball test regardless of the surface struck. Results also showed that paint on the exterior weakens the glass. Meanwhile, paint has less effect on interior surface and, may make it slightly stronger.

The difference in results from the paint on the interior versus exterior may be due to the stress concentrations within the glass surfaces created during the tempering process. Paint is applied to the interior surface of the glass prior to it being tempered. For automotive glass, the tempering process creates high surface compression in the glass to strengthen it. On glass without CPA, both the interior and exterior surfaces of the glass are in their most stable condition, which is a compression state. When glass is tempered with the CPA applied, it creates a stress distribution that causes the painted surface to be in an unstable tension state where force from impact is more likely to cause fracture (Lee et al., 2015).

Tempered – Fracture Test Collection Time

Fracture test results were collected at 10 seconds, 1 minute, 2 minutes and 3 minutes. Count results were reported at the 3-minute timestamp.[6] Figure 59 shows the time profiles for each test per glass type. The counts increased over the 10-second to 3-minute time interval for both the ANSI location and ECE location, indicating that the glass continued to break into smaller pieces over time. The SR had the largest change from 10 seconds to 3 minutes with an average change of 64 pieces at the ECE location and 30 pieces at the ANSI location.[7] The RQ and BL had similar change over time of around 10 pieces. All tests met the criteria at the 3-minute timestamp. Only one test did not meet the count criteria at another time stamp (RQ ECE location test two, unpainted, 10-second mark). In this test, at the 10-second mark only 34.5 pieces were counted, which is below the minimum criteria. However, as time went on, the glass continued to break apart and the number of pieces increased to where the count exceeded the minimum requirement of 40.

[6] ECE R43 specifies that permanent recording shall start within 10 seconds and end within 3 minutes after impact.
[7] The average change is the average (n=3) of the change from 10 seconds to 3 minutes for each of the tests.



Glass	Location	Average Change (pieces)
RQ	ANSI	10.3
	ECE	13.7
SR	ANSI	30.3
	ECE	64.6
BL	ANSI	6.8
	ECE	10.2

Figure 59. Fracture Time Profiles

Table 4 shows the minimum, maximum, and average counts for the 10-second to 3-minute time range. These values differ from the values presented in the *Tempered Fracture Test* section as they are over the full range of collection time, not just at the 3-minute timestamp. Except for the RQ glass ECE location, all counts met the performance criteria. The BL glass ECE location minimum count met the criteria, but only by four pieces. Both the BL and RQ glass have a 3.5 mm thickness, while the SR has a 4.0 mm thickness. The thicker SR glass well exceeded the performance criteria at both ANSI and ECE locations.

Table 4. Fracture Test Counts (10 seconds to 3 minutes)

Glass	Thickness	Location	Min. Count	Max. Count	Average Count
RQ	3.5 mm	ANSI	132.5	178	156
		ECE	34.5	104.5	69
SR	4.0 mm	ANSI	198	267.5	240
		ECE	114.5	271	189
BL	3.5 mm	ANSI	89.5	126	102
		ECE	44	90	69

Laminated – Dart and Ball Comparison

The ball and dart standard tests onto laminated glass were completed from similar heights. In the standard height tests (30 ft) both ball and dart gave similar results. When looking at the break height test results completed at the center and edge location, some differences can be observed. Results of the break height tests are shown in Figure 60. Results between the two are comparable at the center location. However, at the edge location more irregular values and trends were seen. It should be noted that the measurement method for the ball test can be ambiguous at times in terms of determining how much laminate is exposed, and no ball pass through results were seen in the ambient condition testing that is being compared to test results using a dart, for which the failure mode is body pass through.

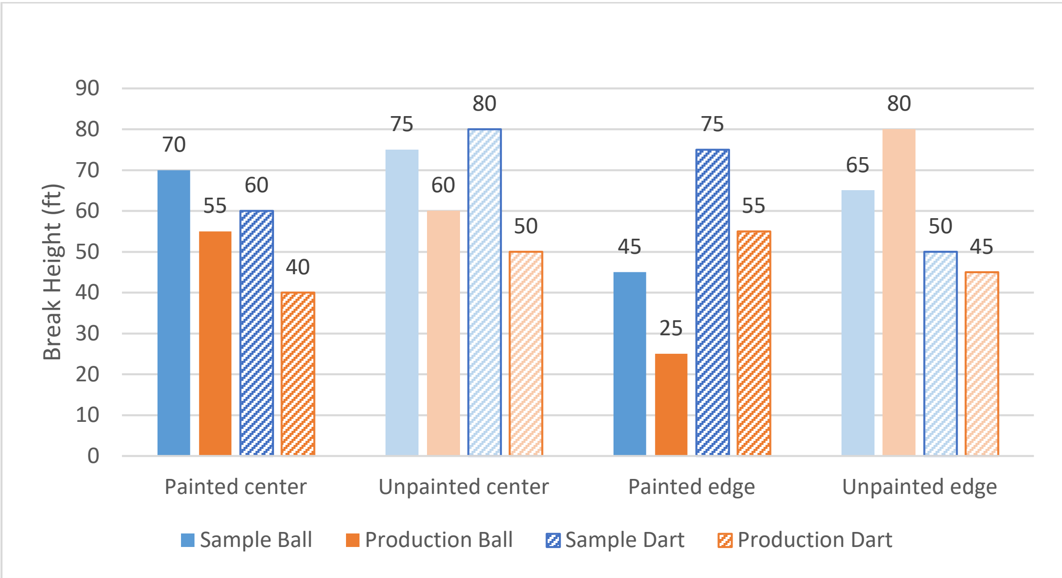


Figure 60. Ball and Dart Break Height Test Comparison

Limitations

While many tests were performed covering many different test modes, a limited number of tests were completed at each test mode. For standard tests only three repeats were done and for break height only one repeat was done to confirm the break. Also, tempered test pieces had to be struck several times for break height, which is not ideal for glass testing. However, results were always confirmed with an additional test on new pieces.

Another limitation of this study was the production frames not being exact match to the curvature of the production glass. Assessment of these frames and the effect of matching the curvature would need future work to establish an objective criterion for the fit of the frames to the glass.

A third limitation of this study was that only one type of glass per location type was assessed. The glass systems selected are representative of those types of glass found in motor vehicles but not comprehensive of all types of glazing that could be present. The data presented in this report is a qualitative assessment of the results. More data would need to be collected to complete a quantitative statistical analysis of the results. This data provides a starting point for future studies on this subject.

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Summary

More than 1,200 glazing performance tests were completed to fulfill three objectives: (1) evaluate the NPRM proposed changes to the mechanical property requirement tests for tempered and laminated glazing, (2) learn about potential changes to tempered glass strength due to the CPA, and (3) evaluate differences in the ANSI Z26.1 12-by- 12-inch flat specimens and full-size production parts. Three types of tempered glass (rear quarter, sunroof, and backlight) and one type of laminated glass (windshield) were assessed.

Impact tests were completed on tempered glazing comparing 10-ft ball drops to 6.6-ft ball drops and the standard ANSI shot bag to a modified shot bag with stiffer sidewalls. The 6.6-ft ball drop results differed from the 10-ft ball drop results at the painted sample glass edge location for SR and BL but were similar for RQ and all production glass. The 6.6-ft ball drop test does not capture the effect of paint at the edge location where the paint makes the glass the weakest. At the current standard location (center), the drop height differences did not change glass performance results. Shot bag results showed that the MSB concentrates the force and stresses the glass differently than the ASB. Because of this greater force concentration, the MSB is a more severe test condition for the glass than the ASB. In the tempered glass fracture test, the geometric center (ECE R43) location created larger fragments with greater weight and smaller count than the mid-point of the longest edge (ANSI) impact location.

In ball tests on the exterior surface, the paint weakened the glass while the silver paint lines decreased its strength even more. However, in shot bag tests on the interior surface, the paint strengthened the glass. The paint creates weak spots in areas where it is applied but also influences the overall glass strength. The paint and silver lines did not have as large of an effect on the performance of the glass in the fracture test as it did in other test modes.

Impact tests on laminated glazing of both the 30-ft ball drop and 30-ft dart drop were completed. Additional ball tests on unpainted sample glass conditioned to different temperatures were also completed. In the standard 30-ft ball and dart tests similar results were seen between test modes at all but the edge location. At the edge location the 30-ft ball tests did not meet the performance criteria, with the result exceeding the minimum amount of exposed laminate. In the temperature conditioned tests, the cold tests withstood higher impacts than ambient and ambient withstood similar or higher impacts than hot tests when tested on unpainted sample glass.

Sample and production glass had consistent results in the standard 10-ft ball tests on tempered glass. However, in the ball break height tests production glass tended to be similar or stronger, especially at the areas away from the paint, including fully unpainted glass. In shot bag tests, sample and production had inconsistent results with breaks occurring on the sample glass that did not occur on the production glass. No break height comparisons between sample and production glass systems were completed with the shot bag due to equipment height constraints. Sample and production glass had consistent results in the standard 30-ft ball test and dart tests on laminated glass. In laminated break height tests with the ball and dart, the samples were generally similar or slightly stronger than the production glass.

Key findings from this research as they relate to the original objectives include: (1) the shot bag stressed the glass differently than the ball, with the stiffened bag being a more severe test than the ANSI bag, different results were observed with the 227-gram ball test at 10 ft versus 6.6 ft, the two impact points in the fracture test produced different size pieces, and the ball test and dart tests on laminated glass had similar performance results. Other findings related to the objectives include (2) the CPA reduces tempered glass strength, and (3) ANSI Z26.1 12-by-12-inch flat specimens and full-size production parts have similar performance in impact tests.

References

Federal Motor Vehicle Safety Standards, Glazing materials, 77 F.R. 120, 37478, June 21, 2012. [Docket submission. Docket No. NHTSA-2012-0083 in Regulations.gov].

Federal Motor Vehicle Safety Standards; Glazing Materials, 84 F.R. 65, 13222, April 4, 2019. [Docket submission. Docket No. NHTSA-2019-0024].

Informal Working Group on PSG. (2019, October 11). *Mutual resolution No. [4] (M.R. [4]) of the 1958 and the 1998 agreements concerning panoramic sunroof glazing (PSG).* (Informal document GRSG-117-xx [117th GRSG, 8]). United Nations Economic Commission for Europe. https://wiki.unece.org/download/attachments/-87624151/PSG%20PCA%20MR%20No4-v3.pdf?api=v2

Korea Automobile Testing & Research Institute [KATRI]. (2015, September 29). *Overall review of CPA [ceramic printed area]*. [PowerPoint]. https://wiki.unece.org/download/attachments/26902754/PSG-02-04-Overall_Review_of_CPA.pdf?api=v2

Lee, K.-C., Kwon, H.-B., Ahn, H.-S., Jeon, S.-W., & Son, Y.-S. (2015, June 8-11). *A study on toughened glass used for vehicles and its testing methods*. 24th International Technical Conference on the Enhanced Safety of Vehicles, Gothenburg, Sweden. Also published in the Journal of Auto-vehicle[sic] Safety Association,7(3) (Paper Number 15-0152). https://www-nrd.nhtsa.dot.gov/departments/esv/24th/files/Session%2023%20Written.pdf

Rains, C. (2024, April 16-18). *NHTSA's evaluation of glazing performance testing* (Paper No. 2024-01-2491). WCX SAE World Congress Experience, Detroit, MI. doi:10.4271/2024-01-2491 . Also published as SAE Technical Paper 2024-01-2491, 2024.

SAE International. (1997, August 11). *American national standard for safety glazing motor vehicles and motor vehicle equipment operating on land highways* (ANSI/SAE Z26.1-1996). https://webstore.ansi.org/standards/sae/ansisaez261996?srsltid=AfmB-OorteozNTYZI1lyVJCwFLfRSvShYtfAVcVPFHZVI1RSr-E7TCjsL [Payment only]

United Nations Economic Commission for Europe. (2008, May 16). *Global Technical Regulation No. 6, Safety glazing materials for motor vehicles and motor vehicle equipment* (ECE/TRANS/180/Add.6). https://unece.org/fileadmin/DAM/trans/main/wp29/wp29wgs/wp29gen/wp29registry/ECE-TRANS-180a6e.pdf

UNECE. (2014). Regulation No 43 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of safety glazing materials and their installation on vehicles (Document 42014X0212(01). *Official Journal,* L 42, 1-126. http://data.europa.eu/eli/reg/2014/43(2)/oj[legislation]

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Appendix A: Windshield Glass Temperature Study

For the temperature study, the laminated sample glass was soaked in a temperature and humidity-controlled environment. Then, using an infrared temperature thermometer gun, the temperature of the glass was recorded immediately preceding the test being ran. The amount of time from when the glass was removed from the temperature environment to when the temperature was taken was also recorded. Ambient temperature in the lab was 68 to 70° F during the testing.

Figure A-1. Cold Temperature

Test	Soak Temperature (°F)	Time From Removal to Test (minutes:seconds)	Glass Temperature During Impact (°F)	Temperature Difference (°F)
L-227g-W-L-N-C-27.9ft-b1-1	-4.0	2:32	14.2	18.2
L-227g-W-L-N-C-27.9ft-b1-2	-4.0	3:28	21.2	25.2
L-227g-W-L-N-C-27.9ft-b1-3	-4.0	2:52	15.7	19.7
L-227g-W-L-N-C-27.9ft-b2-1	-4.0	2:08	13.1	17.1
L-227g-W-L-N-C-27.9ft-b2-2	-4.0	2:15	12.8	16.8
L-227g-W-L-N-C-27.9ft-b2-3	-4.0	2:04	11.2	15.2
L-227g-W-L-N-C-27.9ft-b3-1	-4.0	2:13	14.4	18.4
L-227g-W-L-N-C-27.9ft-b3-2	-4.0	2:28	15.1	19.1
L-227g-W-L-N-C-27.9ft-b3-3	-4.0	2:08	13.7	17.7
L-227g-W-L-N-C-30ft-a-1	-3.4	2:48	19.3	22.7
L-227g-W-L-N-C-70ft-a-1	-3.3	3:02	24.8	28.1
L-227g-W-L-N-C-80ft-a-1	-3.2	3:16	20.5	23.7
L-227g-W-L-N-C-75ft-a-1	-3.1	3:26	21.8	24.9
L-227g-W-L-N-C-75ft-a-2	-3.2	2:40	19.8	23.0
L-227g-W-L-N-C-75ft-a-3	-3.4	3:08	19.4	22.8
L-227g-W-L-N-C-30ft-a-2	-3.3	2:34	20.9	24.2
L-227g-W-L-N-C-80ft-a-2	-4.6	2:00	13.9	18.5
L-227g-W-L-N-C-80ft-a-3	-3.9	2:03	17.3	21.2
L-227g-W-L-N-C-85ft-a-1	-3.6	2:13	16.6	20.2
L-227g-W-L-N-C-90ft-a-1	-3.7	2:10	15.3	19.0
L-227g-W-L-N-C-60ft-b3-1	-3.2	2:26	17.5	20.7
L-227g-W-L-N-C-50ft-b3-1	-3.2	2:46	16.2	19.4
L-227g-W-L-N-C-55ft-b3-1	-3.2	2:47	17.9	21.1
L-227g-W-L-N-C-55ft-b3-2	-3.2	2:58	18.4	21.6
L-227g-W-L-N-C-55ft-b3-3	-3.3	2:46	17.6	20.9
L-227g-W-L-N-C-60ft-b3-2	-3.2	3:02	18.4	21.6
L-227g-W-L-N-C-60ft-b3-3	-3.8	2:15	15.1	18.9
L-227g-W-L-N-C-65ft-b3-1	-3.4	2:36	16.7	20.1
L-227g-W-L-N-C-70t-b3-1	-3.4	3:03	17.6	21.0
L-227g-W-L-N-C-75ft-b3-1	-3.4	2:06	18.2	21.6
L-227g-W-L-N-C-80ft-b3-1	-3.5	2:06	16.4	19.9
MIN	-4.6	2:00	11.2	15.2
MAX	-3.1	3:28	24.8	28.1
AVERAGE	-3.6	2:35	17.1	20.7

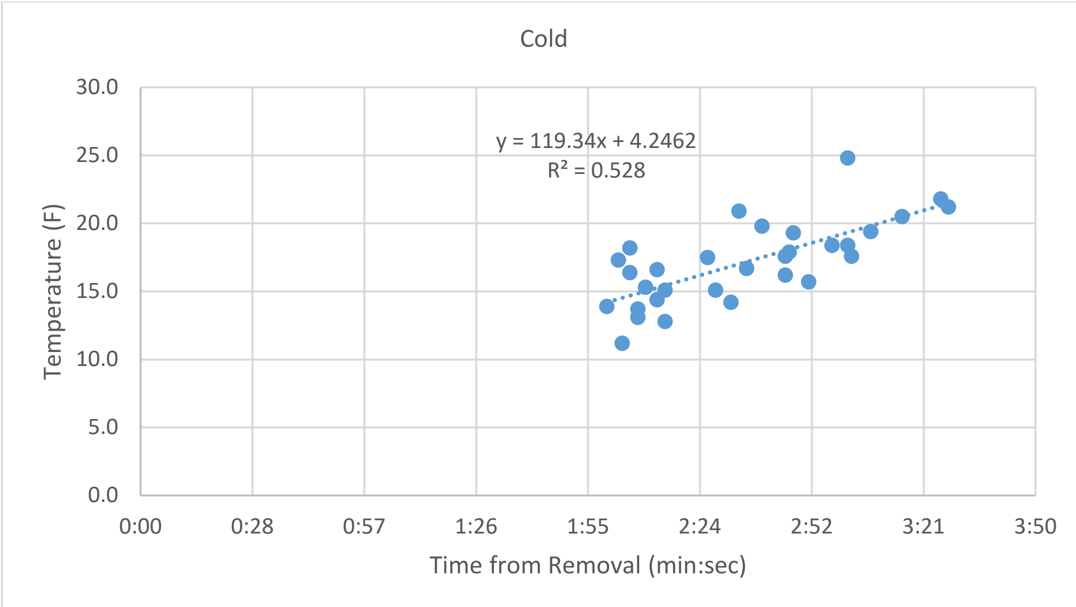
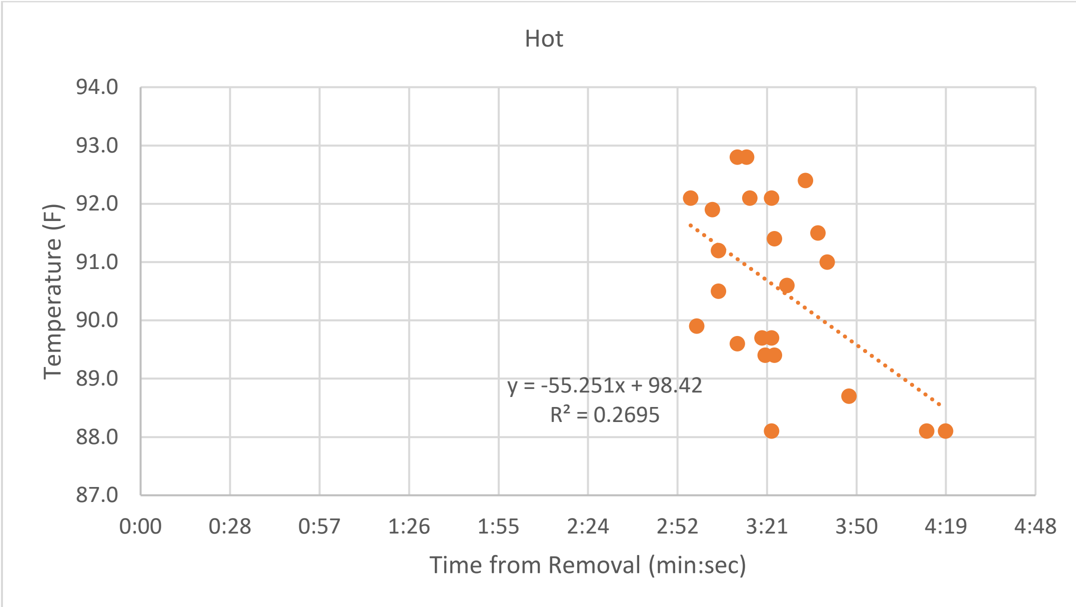


Figure A-2. Hot Temperature

Test	Soak Temperature (°F)	Time From Removal to Test (minutes:seconds)	Glass Temperature During Impact (°F)	Temperature Difference (°F)
L-227g-W-L-N-H-29.5ft-b1-1	104.0	3:06	91.2	-12.8
L-227g-W-L-N-H-29.5ft-b1-2	104.0	3:41	91.0	-13.0
L-227g-W-L-N-H-29.5ft-b1-3	104.0	3:38	91.5	-12.5
L-227g-W-L-N-H-29.5ft-b2-1	104.0	3:12	92.8	-11.2
L-227g-W-L-N-H-29.5ft-b2-2	104.0	3:23	92.1	-11.9
L-227g-W-L-N-H-29.5ft-b2-3	104.0	3:34	92.4	-11.6
L-227g-W-L-N-H-29.5ft-b3-1	104.0	2:57	92.1	-11.9
L-227g-W-L-N-H-29.5ft-b3-2	104.0	3:16	92.1	-11.9
L-227g-W-L-N-H-29.5ft-b3-3	104.0	3:15	92.8	-11.2
L-227g-W-L-N-H-70ft-a-1	105.3	3:24	91.4	-13.9
L-227g-W-L-N-H-60ft-a-1	105.5	4:13	88.1	-17.4
L-227g-W-L-N-H-65ft-a-1	105.9	3:28	90.6	-15.3
L-227g-W-L-N-H-65ft-a-2	105.8	3:12	89.6	-16.2
L-227g-W-L-N-H-65ft-a-3	105.8	3:24	89.4	-16.4
L-227g-W-L-N-H-60ft-a-2	105.6	3:20	89.7	-15.9
L-227g-W-L-N-H-60ft-b3-1	105.6	2:59	89.90	-15.7
L-227g-W-L-N-H-70ft-b3-1	105.6	3:06	90.50	-15.1
L-227g-W-L-N-H-65ft-b3-1	105.6	3:23	89.7	-15.9
L-227g-W-L-N-H-65ft-b3-2	105.6	3:21	89.4	-16.2
L-227g-W-L-N-H-60ft-b3-2	105.6	3:23	88.1	-17.5
L-227g-W-L-N-H-70ft-b3-2	105.6	3:48	88.7	-16.9
L-227g-W-L-N-H-65ft-b3-3	105.5	4:19	88.1	-17.4
L-227g-W-L-N-H-70ft-b3-3	105.5	3:04	91.9	-13.6
MIN	104.0	2:57	88.1	-17.5
MAX	105.9	4:19	92.8	-11.2
AVERAGE	105.0	3:24	90.6	-14.4



Hot
94.0
93.0
92.0
91.0
90.0
89.0
88.0
87.0
Temperature (F)
y = -55.251x + 98.42
R² = 0.2695
0:00
0:28
0:57
1:26
1:55
2:24
2:52
3:21
3:50
4:19
4:48
Time from Removal (min:sec)

Appendix B: Dart Tail Drawing

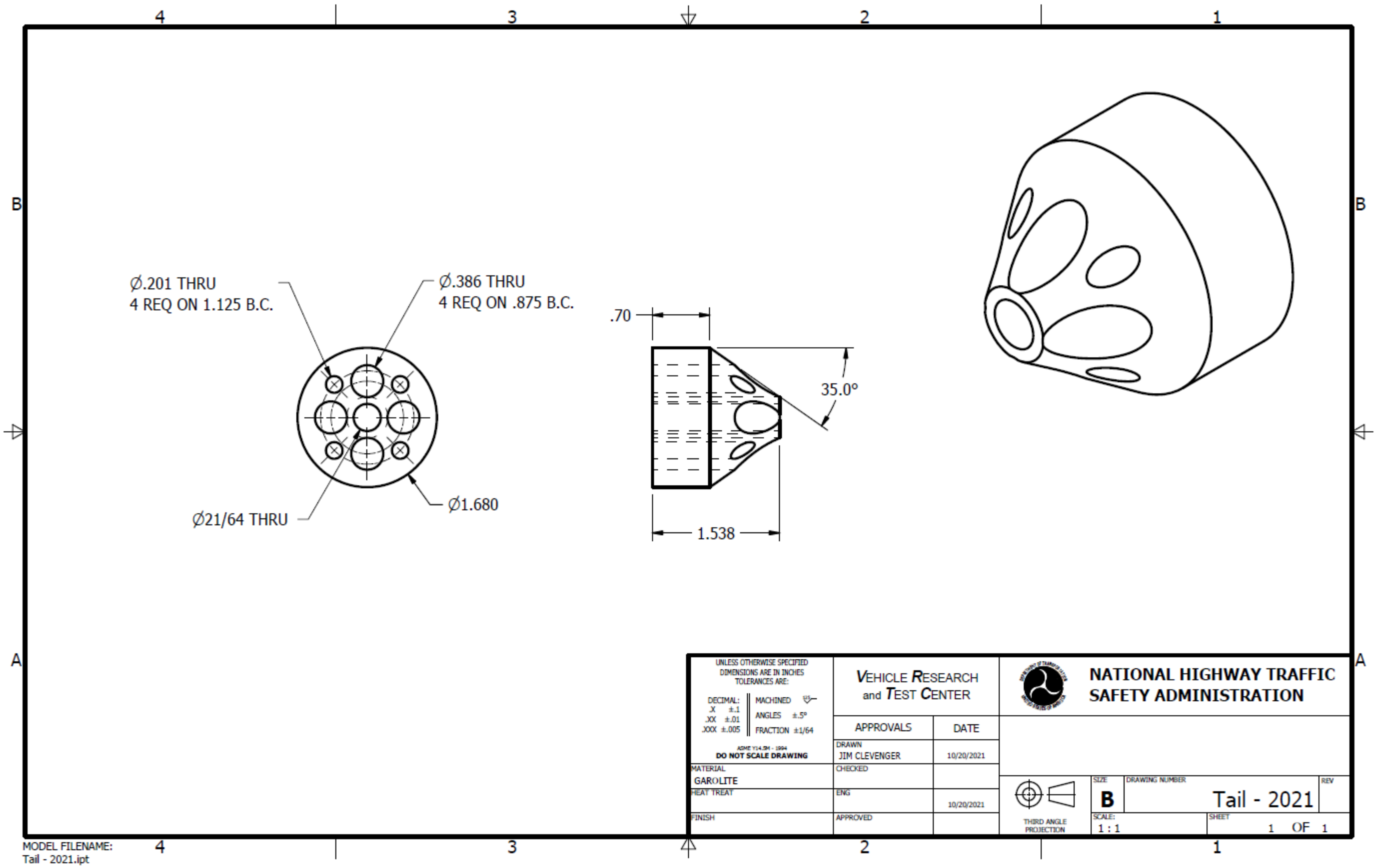


Figure B-1. Dart Tail Drawing

Appendix C: Verification of Glazing Test Fixture Setups

Drop Tower Reliability

The drop tower was fabricated to hang from the ceiling at VRTC. An electromagnet was attached to a sliding bar that could be moved up or down along the tower to achieve the desired drop heights. The release from the electromagnet was triggered with a switch. The electromagnet had a washer that was attached to it to aid in centering the ball on the magnet. The original washer was the size of the electromagnet (left image of Figure C-1). During initial setup testing, it was found that the electromagnet needed to be level within 1 degree of horizontal for the ball to fall within the 25 mm radius tolerance as specified in the ANSI/SAE Z26.1-1996 standard. The washer, which centers the ball on the electromagnet, also effects the reliability of the drop tower to drop the ball at the appropriate location. The size of the washer was changed from the original size to a smaller washer during the verification testing described in this appendix. This change aided in the ball dropping straight down from the tower and ensured it being centered on the magnet prior to release. The magnet with the smaller washer is shown in the right image in Figure C-1.

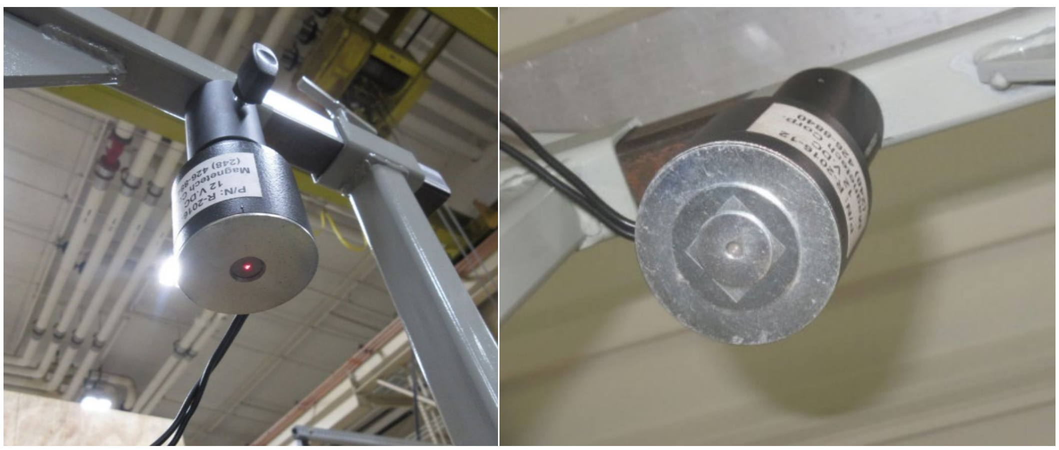


Figure C-1. Washer on drop tower, original size (left) and smaller size (right)

Light Trap Verification

Two light traps were procured as options to measure the speed of the ball when shot from the pneumatic gun (Figure C-2). The Smart Gate consists of a single unit that uses two photogate beams spaced 1.5 cm apart to calculate the velocity of an object passing between the beams. The IES 2206 Laser Light Trap is a set of two devices, a sender and receiver, which form a system using light beams to measure the velocity of an object passing between the two devices. Both light trap systems work by measuring the time between when the object breaks each beam and calculating the velocity using the known distance between beams and the change in time.

Figure C-2. Smart Gate (left) and IES 2206 Laser Light Trap (right)

Free fall drops were selected as the method for verifying the accuracy of the light traps as the height between the release point and contact with the top beam can be measured and used in calculation. Following a simple conservation of energy equation (1), and assuming that the initial velocity and final height were zero, the theoretical final velocity could be calculated using the equation (2):

$$\frac{1}{2}mv_o^2 + mgh_o = \frac{1}{2}mv_f^2 + mgh_f \quad (1)$$

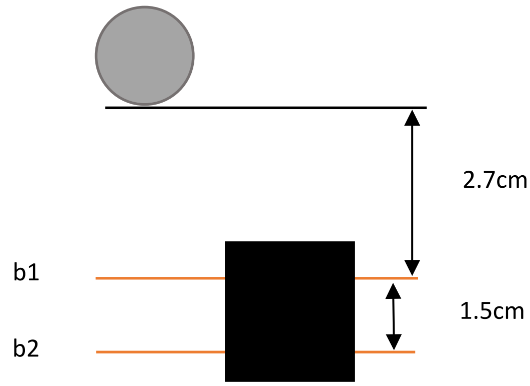
$$v_f = \sqrt{2}gh_o \quad (2)$$

The “theoretical average velocity” presented in this appendix is calculated by determining the final velocity at each beam of the light trap then averaging those two velocities. The “experimental average velocity” is calculated by averaging the results from the device output.

The Smart Gate was tested first with low height free fall drops. The ball was dropped from 27 cm above the top beam of the Smart Gate. Five trials were done. Results are shown in Figure C-3. An experimental average velocity of 2.32 m/s with a standard deviation of 0.005 m/s was reported. The calculated theoretical average velocity was found to be 2.33 m/s shown as the solid line in Figure C-3. The percentage error was 0.69 percent.

$v = \sqrt{2gh}$

	h (m)	g (m/s2)	v (m/s)
b1	0.27	9.8008	2.30
b2	0.285	9.8008	2.36
		AVG	2.33



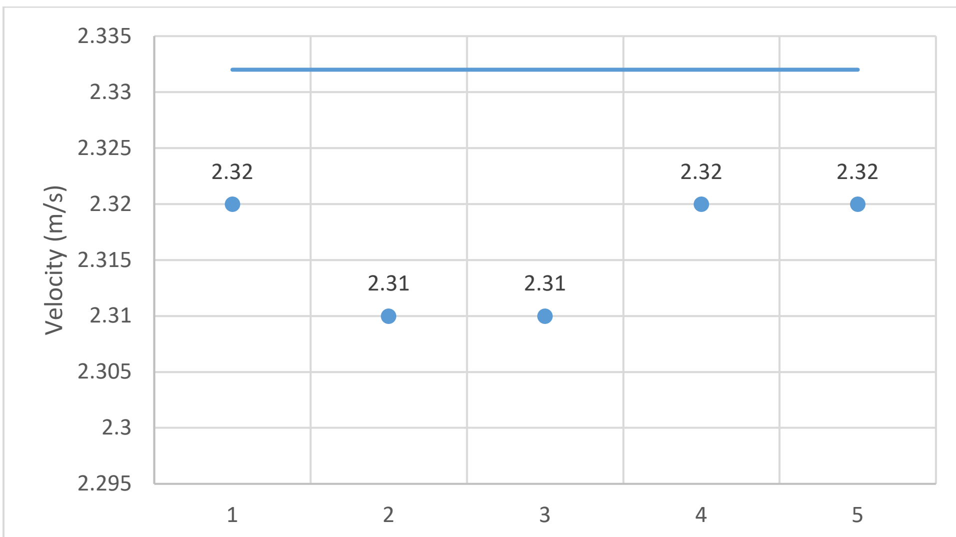


Figure C-3. Ball drop from 27 cm

To further evaluate the accuracy of the Smart Gate, the device was moved over to the drop tower to get a higher drop height. The ball was dropped from the tower at a height of 2.65 m (8.7 ft) from bottom of ball to top beam of light trap. The results are shown in Figure C-4. A table of the values can be found in tables at the end of this Appendix. The experimental average velocity was 7.13 m/s with a standard deviation of 0.18 m/s. The calculated theoretical average velocity was 7.24 m/s, shown as the solid line in Figure C-4. The percentage error for this setup was 1.63 percent.

These trials used the large washer on drop fixture. There were some misses when the device did not record any velocity. This unreliability of drop tower, thought to be due to the large washer, may have contributed to the error seen in this drop test series. Further drops were needed to verify the speed device.

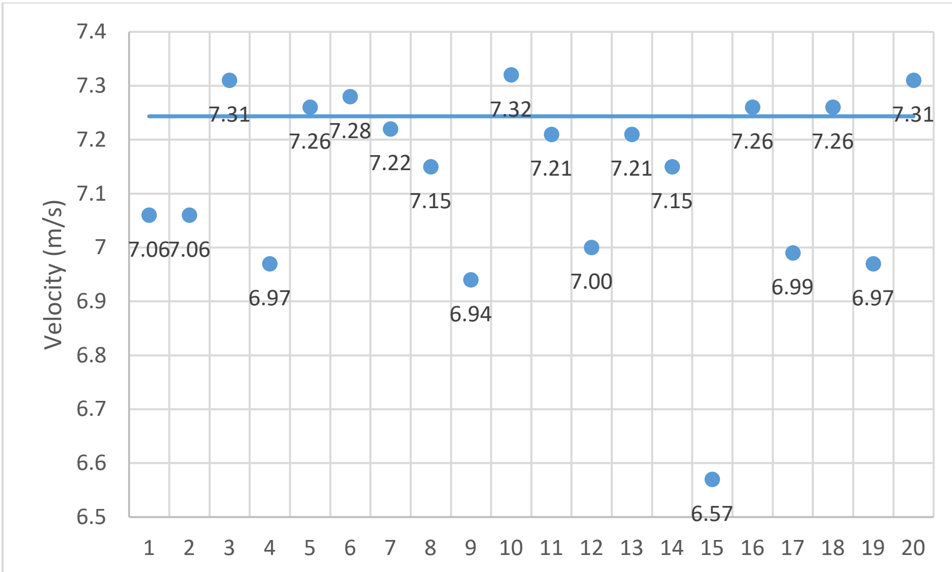


Figure C-4. Ball drop from 2.65m

The next series of drops moved the drop tower to a height of approximately 4.5 m (15 ft). The drop height from the bottom of the ball to the top beam of the Smart Gate was 4.38 m (14.38 ft). In addition to the Smart Gate, the IES 2206 Laser Light Trap was evaluated with this setup. The distance from the bottom of the ball to the top beam of this light trap was 4.13 m (13.55 ft). The setup of both light traps is shown in Figure C-5 below. The Smart Gate is circled in blue and the two devices for the IES Light Trap are circled in orange. This setup used the small washer on drop tower.

Figure C-5. Setup of Both Light Traps

The ball was dropped 20 times simultaneously through both the Smart Gate and IES 2206 device. Results of this setup are shown in Figure C-6. A table of the values can be found in the end of this Appendix. The Smart Gate recorded an experimental average velocity of 9.02 m/s with a standard deviation of 0.03 m/s. The calculated theoretical average velocity was 9.28 m/s, shown as the solid blue line in Figure C-6. The IES 2206 device recorded an experimental average velocity of 9.01 m/s with a standard deviation of 0.014 m/s. The calculated theoretical average velocity was 9.03 m/s shown as the orange line in Figure C-6.

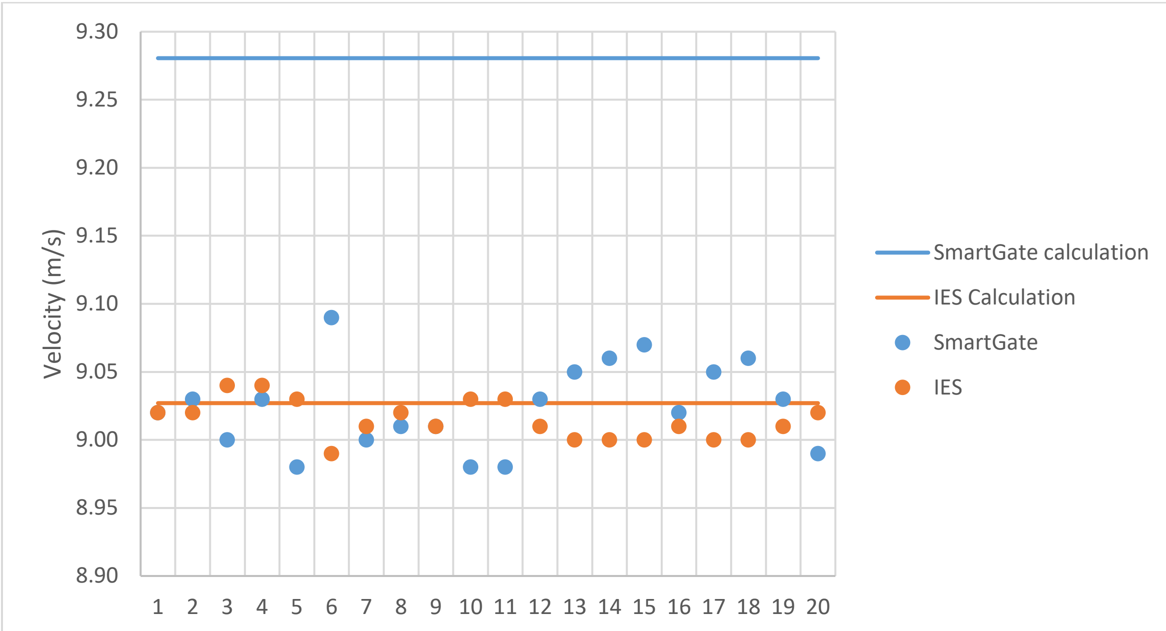


Figure C-6. Comparison of light trap results for 4.5 m (15 ft) ball drop

Additional drops were done to evaluate both light trap devices. The height of the drop tower was lowered to approximately 2 m (6.6 ft). The height from the bottom of the ball to the top beam of the Smart Gate was 1.91 m (6.27 ft) and the height from the bottom of the ball to the top beam of the IES device was 1.64 m (5.38 ft). The small washer was used for this setup.

The ball was dropped 20 times simultaneously through both the Smart Gate and IES 2206 device. The Smart Gate recorded an experimental average velocity of 5.97 m/s with a standard deviation of 0.02 m/s. The calculated theoretical average velocity was 6.13 m/s, shown as the solid blue line in Figure C-7. The IES 2206 device recorded an experimental average velocity of 5.71m/s with a standard deviation of 0.00 m/s. The calculated theoretical average velocity was 5.72 m/s shown as the orange line in Figure C-7.

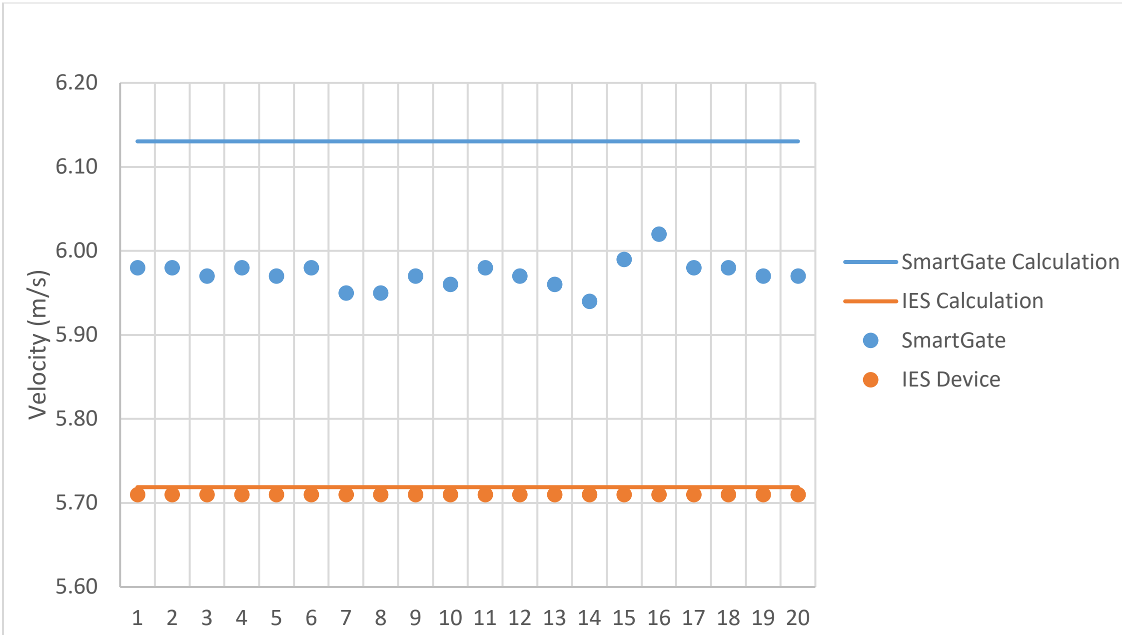


Figure C-7. Comparison of light trap results for 2 m (6.6 ft) ball drop

Table C-1 shows the comparison of the two devices at both heights tested. The percentage error of the Smart Gate for both setups was greater than the IES device. Also, for both devices, the percentage error did not change much between the higher and lower speed drops. The Smart Gate had a percentage error of -2.76 percent at the low drop height and -2.58 percent at the higher drop height. The IES device had a percentage error of -0.15 percent at the low drop height and -0.14 percent at the higher drop height. At the 30-ft drop height, which had an estimated impact speed of 13.4 m/s, the error due to the IES speed device is estimated to be about 0.02 m/s. Per this verification the IES 2206 Laser Light Trap was decided to be used as the velocity calculation device for the pneumatic gun testing.

Table C-1. Summary of Device Comparison Test Results

Drop Type	Speed Device	Theoretical Average (m/s)	Experimental Average (m/s)	Standard Dev	% Error
Ball Drop – 4.5m (15ft)	SmartGate	9.28	9.02	0.03	-2.76%
	IES	9.03	9.01	0.01	-0.14%
Ball Drop – 2m (6.6ft)	SmartGate	6.13	5.97	0.02	-2.58%
	IES	5.72	5.71	0.00	-0.15%

Conclusion

The drop tower after modification of the release, showed reliability in dropping and hitting within the 25 mm radius specified in ANSI/SAE Z26.1-1996. The IES 2206 Laser Light Trap was verified to be used as the light trap for testing, with a percentage error of about -0.15 percent. This velocity calculation device was used for all pneumatic gun testing, including for verification of the gun barrels and creation of speed-pressure tables.

Ball Free Fall Drop Test Results Tables

Height: 2.65 m (8.7ft)

Smart Gate

Number	Velocity (m/s)
1	7.06
2	7.06
3	7.31
4	6.97
5	7.26
6	7.28
7	7.22
8	7.15
9	6.94
10	7.32
11	7.21
12	7.00
13	7.21
14	7.15
15	6.57
16	7.26
17	6.99
18	7.26
19	6.97
20	7.31
AVERAGE	**7.13**
ST Dev	**0.18**

Ball Drops

Height to top beam:

Smart Gate: 4.38m (14.38ft)

IES 2206: 4.13m (13.55ft)

	Smart Gate	IES 2206
Number	Velocity (m/s)	Velocity (m/s)
1	9.02	9.02
2	9.03	9.02
3	9.00	9.04
4	9.03	9.04
5	8.98	9.03
6	9.09	8.99
7	9.00	9.01
8	9.01	9.02
9	9.01	9.01
10	8.98	9.03
11	8.98	9.03
12	9.03	9.01
13	9.05	9.00
14	9.06	9.00
15	9.07	9.00
16	9.02	9.01
17	9.05	9.00
18	9.06	9.00
19	9.03	9.01
20	8.99	9.02
AVERAGE	**9.025**	**9.015**
ST Dev	**0.032**	**0.014**

Ball Drops

Height to top beam:

Smart Gate: 1.95m (6.40ft)

IES 2206: 1.68m (5.51ft)

	Smart Gate	IES 2206
Number	Velocity (m/s)	Velocity (m/s)
1	5.98	5.71
2	5.98	5.71
3	5.97	5.71
4	5.98	5.71
5	5.97	5.71
6	5.98	5.71
7	5.95	5.71
8	5.95	5.71
9	5.97	5.71
10	5.96	5.71
11	5.98	5.71
12	5.97	5.71
13	5.96	5.71
14	5.94	5.71
15	5.99	5.71
16	6.02	5.71
17	5.98	5.71
18	5.98	5.71
19	5.97	5.71
20	5.97	5.71
Average	**5.97**	**5.71**
ST Dev	**0.02**	**0.00**

Appendix D: Test Procedures

Glazing Preparation

1. Condition selected glazing for testing per ANSI Z26.1-1996 at a temperature of 21° C to 29° C (70° F to 85° F) for at least 4 hours preceeding test. Humidity should be 40±20 percent.
    a. Use temperature/humidity box set at desired temperature range and humidity.
2. For hot or cold tests, place glass in either the furnace or freezer set at the specified temperature of 40° C (104° F), and -20° C (-4° F) for hot and cold tests, respectively. The average temperature over the soak time should be within ± 2° C of specified temperature. The glass should soak for a minimum of 4 hours preceeding the test.
    a. Record duration of soak, temperature of soak and the time from when the glass is removed to when the test is conducted.
3. Mark the glass at the desired impact location using a marker and corresponding impact circle.

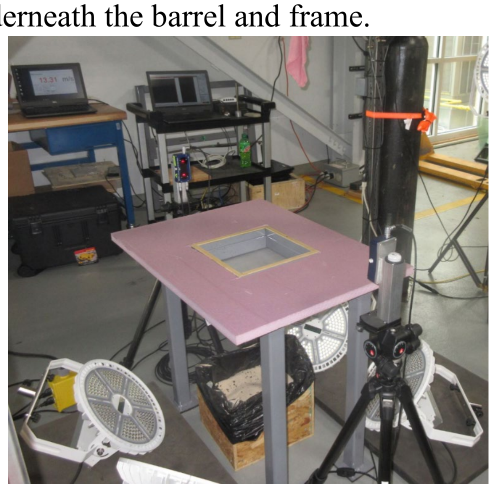
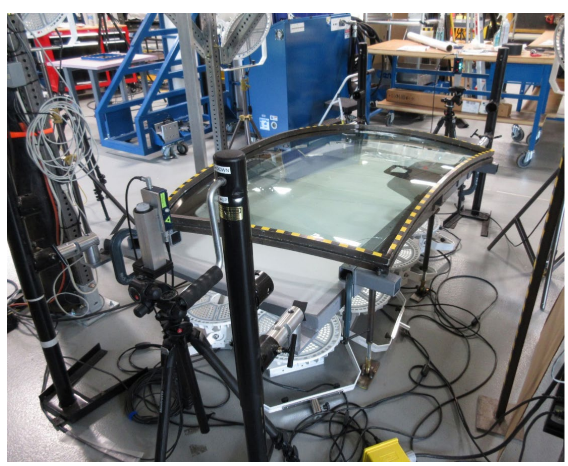
Drop Tower

1. Set the drop tower to the approximate test height using a laser measurer.
    a. The height is measured from the bottom of the drop object to the top of the glass.
    b. Tolerance: height -0/+0.25% total height
2. Level the electromagnet both directions +/- 1°.
3. Attach laser to laser mount on drop tower and align it to the center of the electromagnet.
4. Set the support frame underneath the laser with the frames in the correct orientation.
    a. Sample glass tests will use the same support frame, so no adjustments needed.
    b. Production glass support frames will have two orientations for interior or exterior impacts. Select and assemble frame per test type. Exterior impact for ball test and interior impact for shot bag test.
5. Place glass squarely on the support frame with exterior surface up for ball and interior surface up for shot bag. Align the impact target point with the laser by moving the fixture. Place top support on glass.
    a. Try to keep glass/frame as centered in both camera views as possible.
    b. May need to move entire base fixture rather than just the top support fixture.
    c. Make sure top and bottom frame are directly on top of each other.
6. For a production glazing test follow the procedure in "Production Frame Tilt Method" to align the impact location perpendicular within 3° to the incident direction of the impact object.
7. Clamp all the holding fixtures down.
8. Clamp the frame supports and adjust into place. Tighten so that they are snug but not pushing the base up.
9. Adjust the height of the tower to its final position using the laser measurer placed on the impact point. Take a photo of the measurement.
    a. Shot bag height: (8.66 ft) (bag is 8 in/202 mm)
    b. Ball height: 3.088m (10.12 ft) (ball is 38 mm/1.5 in)

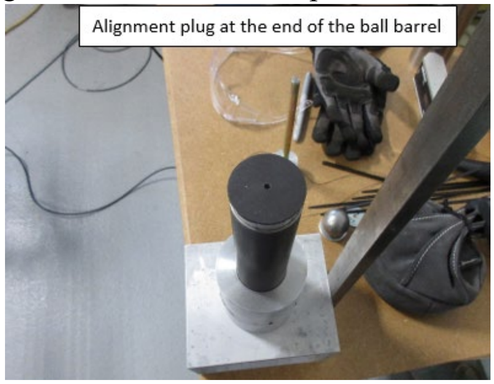
10. Adjust paper under glass as needed. Place cardboard to block extra light from shining up. Check cameras and lights for constant dispersion of light and that most/all glass surface is in view.
11. Print sign boards – one from top and one for side camera.
12. Record all pretest data:
    i. Test Number
    ii. ANSI Test Number
    iii. Impact Object
    iv. Glass Type
    v. Impact Location
    vi. Drop Number of the Set
    vii. Temperature & Humidity
    viii. Pretest Photos
13. Place object on electromagnet.
14. Turn on lights, select capture on cameras and run test by pressing the release switch to drop the object.
    a. Attempt to catch ball to prevent second bounce.
    b. Impact tolerance is within 25mm (1in) radius of impact location.
15. After the test is complete record all post test data.
    i. Save video.
    ii. Collect post-test photos.
    iii. Record if the glass cracked or broke.
    iv. Did object pass through? If only partially, measure amount and take picture.

<u>Pneumatic Gun</u>

1. Verify the correct barrel for designated test (ball or dart) is installed. Connect the air hose at the top of the barrel and attach targeting laser to laser mount underneath the barrel.
2. Setup the desired glass frame (sample or production) underneath the barrel.
3. Place the marked glass onto the frame and adjust the frame to the impact location using the targeting laser. Glass should be placed with exterior surface up. Verify the sand box is underneath the barrel and frame.

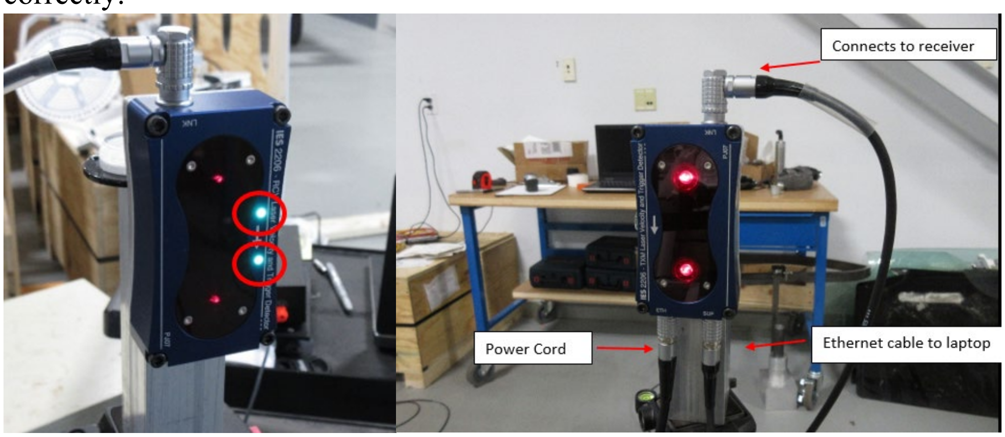
 

a. Align the targeting laser using the vertical beam to the center of the barrel using or the alignment plug for a ball test, or the tip of the dart loaded into the barrel.



b. For a production glass test follow the steps to tilt the glass for a perpendicular impact
c. Remove the alignment plug or dart from the barrel.

4. Set up and plug in the light traps. The light trap requires at least a 15-minute warm up time before alignment.
    a. Align the light approximately two ft from each other or as close as they can be aligned for the desired test. The two lasers from the transmitter align with the two holes in the receiver. If both solid green lights are on, it means the light trap is aligned correctly. If either light is flashing, then the light trap is not correctly aligned. The faster the lights are flashing the closer it is to being lined up correctly.

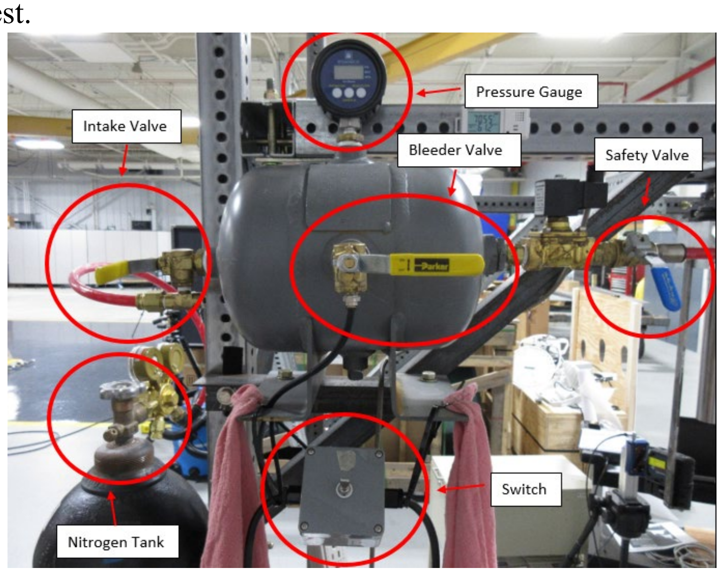


    b. The height of the lasers should be set up so that the item passes through them close to the glass.
    c. Verify the lasers are centered underneath the barrel using a plum bob or targeting laser.
5. Put a piece of tape over the bottom of the gun barrel and place the glass back on the frame. Measure and record the distance from the glass to the bottom of the barrel (tape) using the laser measurer. Measure the distance from the glass to the top beam of the light trap or distance from barrel to the top laser.
6. Input the distances into the velocity calculator to get the speed needed for the gun at the light traps.

7. Remove the glass, verify sand box is in place and run speed shots to generate PSI needed for the desired speed. Check the camera setup, including triggers during this step.
    a. Run speed shots each day of testing and at least once right before each test to verify pressure is giving same speed.

For each test:

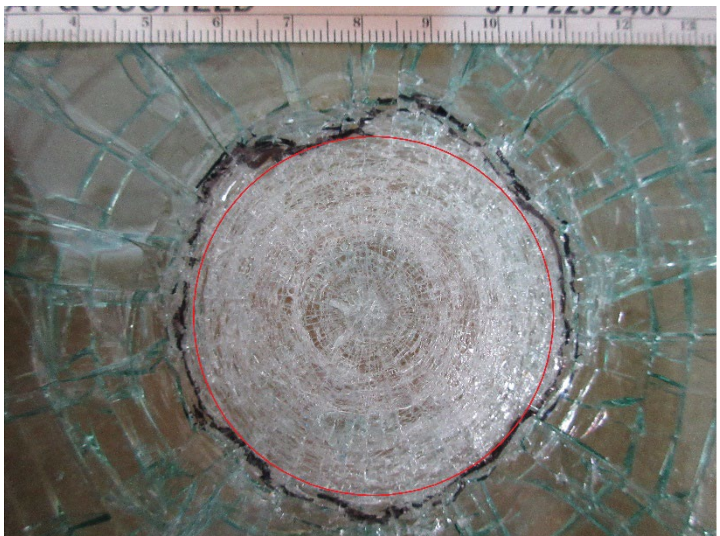
1. Mark test glass with impact location and place onto frame. Align glass with the targeting laser on the barrel. Move targeting laser out of the way.
2. Collect and record all pretest data:
    i. Test Number
    ii. ANSI Test Number
    iii. Target Velocity
    iv. Impact Object
    v. Glass Type
    vi. Impact Location
    vii. Drop Number of the Set
    viii. Temperature & Humidity
    ix. Pre-test Photos
3. Verify camera setup and turn on lights.
4. Load drop object into the barrel.
5. Open the nitrogen tank and turn on the pressure gauge. Set pressure to desired psi. When ready to fire open the safety valve and press the switch toward the taped side. Hold the switch toward the taped side to allow all the air to be released. Close the safety valve after every test.

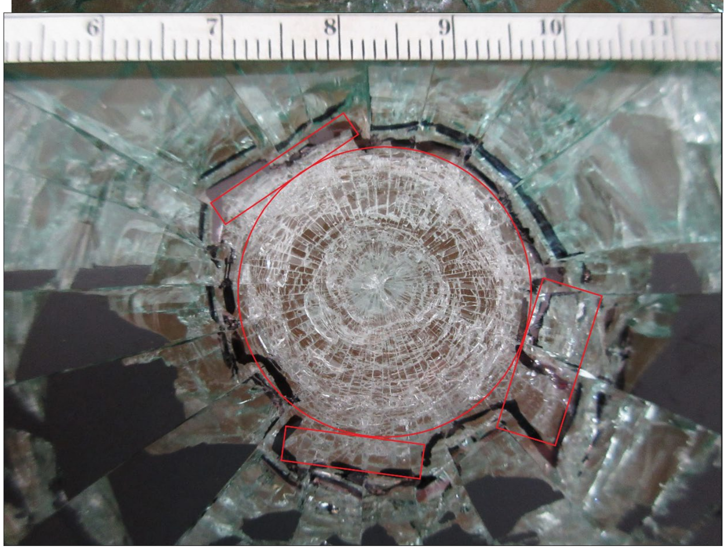


6. After the test is completed record all post test data
    i. Save both videos.
    ii. Collect post-test photos
    iii. Record Actual Velocity. Click "Update" on the VeloView program to view actual velocity. Tolerance on velocity is +/- 1% of target velocity.
    iv. Note if glass cracked or broke

v. Note if object passed through. If only partially measure amount and document with photos

vi. For laminated glass tests only: Is there more than 1-inch^2 (625 mm^2) of exposed laminate? If yes or unsure mark around the exposed laminate with a marker and take picture with ruler to measure with screen calipers. Fill in the marker circle with the biggest circle that can fit inside of the marker circle and measure that. If there is additional exposed laminate inside the impact location breakage area measure that as well.



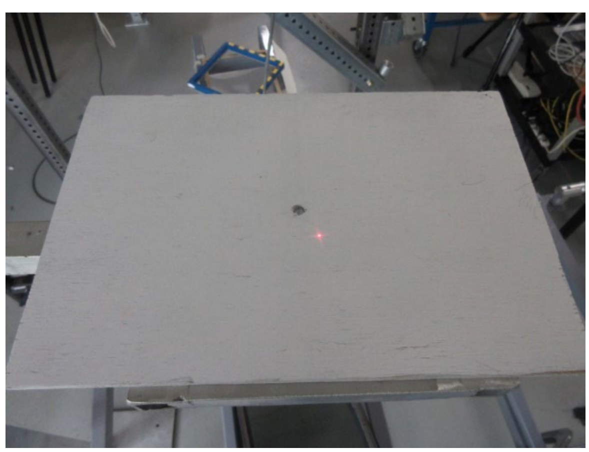


Production Frame Tilt Method

1. Set the production frame and base fixture in correct orientation (interior or exterior surface) and under the tower or pneumatic gun. Turn on alignment laser and align with magnet center or alignment plug/dart.

2. Align glass frame/fixture so impact object is roughly in line with impact location.
3. Place circle bubble level on impact point and turn the cranks on the base fixture so that bubble level is close to being at level.

4. Move the square reflectance board into position over glass so that laser shines down through hole in plate and onto impact location on glass.



(For demonstration only – laser not yet aligned)

5. Look at underside of board for reflectance of laser from glass.


6. Adjust the tilt of the frame to get the reflectance within the 2-inch circle (red) on the plate. Ideally, the laser is within the first concentric circle.
    c. Target is approximately 3° max tolerance from perpendicular impact (reference ECE R43 section 2.1.4.)
7. Take a photo of the laser reflectance on the underside of the reflectance board.
8. Record measurement of distance from glass to reflectance board.
9. Remove reflectance board and continue with test setup.

<u>Fracture Test</u>

1. Place test piece concave down onto an identical glass piece.
2. Tape around entire periphery along edges with approximately 20 mm (¾ inch) overlap of the tape on the glass.
    a. Clear packaging tape can be used.
3. Mark impact location with glass, draw the exclusion zone (area 75 mm (3/4 inch) radius around point of impact and a strip 20 mm (3/4 inch) around periphery of specimen on the glass.
    a. FMVSS No. 205: The fracture origin or breakpoint shall be 25 mm (1 in) inboard of the edge at the mid-point of the longest edge of the specimen. In the event that the specimen has two long edges of equal length, the edge nearer the manufacturer's trademark shall be chosen.
    b. ECE R43 Point 1: In the geometric center of the glass.
    c. ECE R43 Point 2: For curved glass panes having a minimum radius of curvature "r" of less than 200mm. The point shall be selected on the largest median in the part of the pane where the radius of curvature is smallest.
        i. Only will impact this point if minimum radius of curvature is less than 200mm.
4. Place holding glass piece (with taped test piece on top) concave down onto frame.
    a. Verify frame holding/base fixture is level (+/- 1° of horizontal).
    b. Do not place top frame on glass.
5. Verify DSLR (high resolution) camera is setup and armed.
    a. Camera setup perpendicular to frame and covering entire glass.

6. Place minimum of two, 5cm x 5cm square(s) randomly on glass, covering different areas of the glass.
7. Turn all lights on.
8. Punch glass using centerpunch at target location.
9. Immediately after punch start a timer.
10. After break, within 10 seconds and 3 minutes, take pictures with DSLR camera that is centered over the entire piece, looking straight down. Lighting should be uniform across the piece and glass should be in focus.
    a. Take photos post-break with DSLR camera at (+/- 5 seconds):
        i. 10 seconds
        ii. 60 seconds (1 minute)
        iii. 120 seconds (2 minutes)
        iv. 180 seconds (3 minutes)
11. While taking pictures with DSLR, within 3 minutes from punch, identify pieces of glass to be used for weight. Pieces identified as largest pieces not within exclusion zone.
    a. Mark pieces by <u>outlining them</u> with silver marker.
        i. Outlining is critical as pieces will continue to break apart after 3minute timeframe.
12. After 3 minutes, for **painted pieces only** change setup so that painted area can be imaged.
    a. Lower camera to focus on painted area, level camera to be perpendicular to frame and adjust lighting (1 light behind camera – see below image).
    b. Place the 5 cm × 5 cm squares into the painted area.
    c. Save image for counting and record amount of time after punching that image was taken.
13. Weigh pieces:
    a. FMVSS No. 205: (Weight) Largest piece selected and weighed within 3 minutes of test. No individual fragment, free from cracks shall weigh greater than 4.25 grams.
        i. Prior to removing pieces from glass take an overall picture of location of pieces identified.
        ii. Carefully remove pieces from glass and weigh using scale. Take picture of piece on scale and weight recorded.
14. Count pieces:
    a. ECE R43: (Count) Any 5 cm × 5 cm square on the glass shall not have less than 40 fragments.
        i. Count in both overall view and in painted area view by using computer software to mark pieces.
        ii. Save image of count.

Appendix E: Results Tables

The 227-gram ball was dropped from a height of 10 ft (3.05 meter) onto the exterior surface on both the sample and production glass. Any drops where the glass broke are highlighted in yellow.

Table E-1. 10-ft ball Drop Results

Rear Quarter - ball drop							
Height: 10 ft							
Sample				Production			
Location	trial	Paint	No Paint	Location	trial	Paint	No Paint
a (center)	1	x	x	A (center)	1	x	x
	2	x	x		2	x	x
	3	x	x		3	x	x
	4	x	x	B1 (Corner)	1	x	x
	5	x	x		2	x	x
	6	x	x		3	x	x
b1 (corner)	1	x	x	B2 (Transition)	1	x	x
	2	x	x		2	x	x
b2 (transition)	1	x	x		3	x	x
	2	x	x	B3 (Edge)	1	x	x
	3	x			2	x	x
b3 (edge)	1	x	x		3	x	x
	2	x	x				

Sunroof - ball							
Height: 10 ft							
Sample				Production			
Location	trial	Paint	No Paint	Location	trial	Paint	No Paint
a (center)	1	x	x	A (center)	1	x	x
	2	x	x		2	x	x
	3	x	x		3	x	x
b1 (corner)	1	x	x	B2 (Corner)	1	x	x
	2	x	x		2	x	x
	3	x	x		3	x	x
b2 (transition)	1	x	x	B1 (Transition)	1	x	x
	2	x	x		2	x	x
	3	x	x		3	x	x
b3 (edge)	1	x	x	B3 (edge)	1	x	x
	2	x	x		2	x	x
	3	x	x		3	x	x

Backlight - ball								
Height: 10 ft								
Sample					Production			
Location	trial	Paint	No Paint	Paint w/ Silver Lines	Location	trial	Paint	No Paint
a (center)	1	x	x	x	A (center)	1	x	x
	2	x	x	x		2	x	x
	3	x	x	x		3	x	x
b1 (corner)	1	x	x	x	B1 (corner)	1	x	x
	2	x	x	x		2	x	x
	3	x	x	x		3	x	x
b2 (transition)	1	x	x	x	B2 (transition)	1	x	x
	2	x	x	x		2	x	x
	3	x	x	x		3	x	x
b3 (edge)	1	x	x	x	B3 (edge)	1	x	x
	2	x	x	x		2	x	x
	3	x	x	x		3	x	x

The ball was also dropped onto the sample and production glass from a height of 6.6 ft at locations where breaks occurred at 10 ft. Any drops where the glass broke are highlighted in yellow.

Table E-2. 6.6-ft ball Drop Results

Rear Quarter - ball drop							
Height: 6.6 ft							
Sample				Production			
Location	trial	Paint	No Paint	Location	trial	Paint	No Paint
b2 (transition)	1	x					
	2	x					
	3	x		B3 (corner)	1	x	
b3 (corner)	1	x			2	x	
	2	x			3	x	
	3	x			4	x	

Sunroof - ball							
Height: 6.6 ft							
Sample				Production			
Location	trial	Paint		Location	trial	Paint	
b3 (edge)	1	x		b3 (edge)	1	x	
	2	x			2	x	
	3	x			3	x	

Backlight - ball								
Height: 6.6 ft								
Sample					Production			
Location	trial	Paint	No Paint	Paint w/Silver Lines	Location	trial	Paint	No Paint
a (center)	1				A (center)	1	x	
	2					2	x	
	3					3	x	
b1 (corner)	1			x	B1 (corner)	1	x	
	2			x		2	x	
	3			x		3	x	
b2 (transition)	1			x	B2 (transition)	1	x	
	2			x		2	x	
	3			x		3	x	
b3 (edge)	1	x	x	x	B3 (edge)	1	x	
	2	x	x	x		2	x	
	3	x	x	x		3	x	

The ANSI shot bag was dropped from a height of 8 ft (2.44 meter) onto the interior surface on both the sample and production glass. Any drops where the glass broke are highlighted in yellow.

Table E-3. 8 ft Shot Bag Results

Rear Quarter - shot bag							
Height: 8 ft							
Sample				Production			
Location	trial	Paint	No Paint	Location	trial	Paint	No Paint
a (center)	1	x	x	A (center)	1	x	x
	2	x	x		2	x	x
b1 (transition)	1	x	x		3	x	x
	2	x	x	B1 (transition)	1	x	x
b2 (corner)	1	x	x		2	x	x
					3	x	x
				B2 (corner)	1	x	x
					2	x	x
					3	x	x
				B3 (edge)	1	x	x
					2	x	x
					3	x	x

Sunroof - ANSI shot bag							
Height: 8 ft							
Sample				Production			
Location	trial	Paint	No Paint	Location	trial	Paint	No Paint
a (center)	1	x	x	A (center)	1	x	x
	2	x	x		2	x	x
	3		x		3	x	x
b1 (transition)	1	x	x	B1 (Transition)	1	x	x
	2	x	x		2	x	x
	3		x		3	x	x
b2 (corner)	1	x	x	B2 (Corner)	1	x	x
					2	x	x
					3	x	x
				B3 (Edge)	1	x	x
					2	x	x
					3	x	x
				B4 (Corner)	1	x	x
					2	x	x
					3	x	x

Backlight - ANSI shot bag								
Height: 8 ft								
Sample					Production			
Location	trial	Paint	No Paint	Paint w/silver lines	Location	trial	Paint	No Paint
a (center)	1	x	x	x	A (center)	1	x	x
	2	x	x	x		2	x	x
b1 (transition)	1	x	x	x		3	x	x
	2	x	x	x	B1 (transition)	1	x	x
	3	NA	x	x		2	x	x
b2 (corner)	1	x	x	x		3	x	x
					B2 (corner)	1	x	x
						2	x	x
						3	x	x

The modified shot bag was dropped from a height of 8 ft onto the interior surface on both the sample and production glass.

Table E-4. 8 ft Modified Shot Bag Results

Rear Quarter - modified shot bag							
Height: 8 ft							
Sample				Production			
Location	trial	Paint	No Paint	Location	trial	Paint	No Paint
a (center)	1	x	x	A (center)	1	x	x
	2	x	x		2	x	x
	3	x			3	x	x
b1 (transition)	1	x	x	B1 (transition)	1	x	x
	2	x	x		2	x	x
b2 (corner)	1	x	x		3	x	x
				B2 (corner)	1	x	x
					2	x	x
					3	x	x
				B3 (edge)	1	x	x
					2	x	x
					3	x	x
				B4 (corner 2)	1	x	x
					2	x	x
					3	x	x
					4	x	x
				B5 (corner 3)	1	x	x
					2	x	x
					3	x	x
					4	x	x

Sunroof - modified shot bag							
Height: 8 ft							
Sample				Production			
Location	trial	Paint	No Paint	Location	trial	Paint	No Paint
a (center)	1	x	x	A (center)	1	x	x
	2	x	x		2	x	x
b1 (transition)	1	x	x		3	x	x
	2	x	x	B1 (Transition)	1	x	x
b2 (corner)	1	x	x		2	x	x
					3	x	x
				B2 (Corner)	1	x	x
					2	x	x
					3	x	x
				B3 (Edge)	1	x	x
					2	x	x
					3	x	x
				B4 (Corner)	1	x	x
					2	x	x
					3	x	x

Backlight - modified shot bag								
Height: 8 ft								
Sample					Production			
Location	trial	Paint	No Paint	Paint w/ silver lines	Location	trial	Paint	No Paint
a (center)	1	x	x	x	A (center)	1	x	x
	2	x	x	x		2	x	x
b1 (transition)	1	x	x	x		3	x	x
	2	x	x	x	B1 (transition)	1	x	x
	3	NA	NA	x		2	x	x
b2 (corner)	1	x	x	x		3	x	x
					B2 (corner)	1	x	x
						2	x	x
						3	x	x

An evaluation of break height was completed on sample glass. The max height available for the shot bags using the tower at VRTC was 13 ft. The glass was tested at increasing heights until the maximum height was reached, then repeats were completed on new glass samples. Any drops where the glass broke are highlighted in yellow.

Table E-5. RQ Glass Shot Bag Break Height Results

Rear Quarter - shot bag			
Height: break height (13ft+)			
Sample			
Location	trial	Paint	No Paint
a (center)	1	x	x
	2	x	x
	3	x	x
	4	x	x
	5	x	x
b1 (transition)	1	x	x
	2	x	x
	3	x	x
b2 (corner)	1	x	x
	2	x	x
	3	x	x

Rear Quarter - modified shot bag			
Height: break height (13ft+)			
Sample			
Location	trial	Paint	No Paint
a (center)	1	x	x
	2	x	x
	3	x	x
	4	x	x
	5	x	x
b2 (corner)	1	x (13)	x (13)
	2	x(13)	x (13)
	3	x(13)	x (13)
	4	x(12)	x(12)
	5	x(11)	x(11)
	6	x(11)	x(11)

Sunroof - shot bag					
Height: break height (13ft+)					
Sample					
Location	trial	Height (ft)	Paint	Height (ft)	No Paint
a (center)	1	8/9	x	8/9	x
	2	9	x	8/11	x
	3	9/11	x	11	x
	4	11	x	10	x
	5	10	x	10	x
b1 (transition)	1	8/9	x	6/7	x
	2	8/11	x		
	3	11	x		
	4	10	x		
b2 (corner)	1	8/9	x	6/7	x
	2	9/12/13	x		
	3	9	x		
	4	9/10	x		
	5	10/11	x		
	6	11	x		

Sunroof - modified shot bag					
Height: break height (13ft+)					
Sample					
Location	trial	Height (ft)	Paint	Height (ft)	No Paint
a (center)	1	6/7	x	6/7	x
b1 (transition)	1	8/9/10	x	6/7	x
	2	8/11	x	7*	x
	3	11	x		
	4	10	x		
b2 (corner)	1	8/9	x	6/7	x
	2	9	x		

Backlight - ANSI shot bag							
Height: break height (13ft+)							
Sample							
Location	trial	Height (ft)	Paint	Height (ft)	No Paint	Height (ft)	Paint w/ silver lines
a (center)	1	9	x	9	x	9/11/13	x
	2	9/11/13	x	9	x	13	x
		9	x				
	3	13	x				
b1 (transition)	1	6/7	x	6/7	x	9	x
	2					9	x
	3						
b2 (corner)	1	6/7	x	6/7	x	10	x
	2					9	x
	3					10	x
	4					10/11	x
	5					11	x

Backlight - modified shot bag							
Height: break height (13ft+)							
Sample							
Location	trial	Height (ft)	Paint	Height (ft)	No Paint	Height (ft)	Paint w/ silver lines
a (center)	1	8/9/10	x	6/7	x	8/9/10	x
	2	8/11	x			8/11	x
	3	11	x			11	x
	4					10	x
b1 (transition)	1	8/9/10	x	6	x	8/9/10	x
	2	8/11	x	4/5	x	8/11	x
	3	11	x	6	x	11	x
	4	10	x	6/7	x	10	x
	5			7	x		
b2 (corner)	1	6/7	x	6/7	x	6/7	x
	2						
	3						

Fracture Test Results

Weight results are shown below. Performance criteria is that the largest piece selected between 10 seconds and 3 minutes shall not weigh more than 4.25 grams.

In one RQ test, marked with an asterisk, the glass did not break on first impact with the centerpunch. The piece was punched a second time to break it.

Table E-6. RQ Glass Fracture Weight Comparison

Test Type	Glass Type	Weight (grams)	Average (grams)
ANSI location (mid-point of longest edge)	Unpainted	0.5	0.6
		0.6	
		0.8	
	Painted	1.1	1.2
		1.3	
		1.1	
ECE R43 Point #1 (geometric center)	Unpainted	0.9	1.0
		0.9 *	
		1.3	
	Painted	1.1	1.3
		1.5	
		1.4	

Table E-7. SR Glass Fracture Weight Comparison

Test Type	Glass Type	Weight (grams)	Average (grams)
ANSI location (mid-point of longest edge)	Unpainted	1.5	1.0
		0.7	
		0.7	
	Painted	0.7	0.6
		0.6	
		0.5	
ECE R43 Point #1 (geometric center)	Unpainted	1.7	1.6
		1.1	
		2.0	
	Painted	1.7	1.4
		1.7	
		0.9	

Table E-8. BL Glass Fracture Weight Comparison

Test Type	Glass Type	Weight (grams)	Average (grams)
ANSI location (mid-point of longest edge)	Unpainted	1.2	1.7
		-	
		2.2	
	Painted	1.3	1.1
		1	
		1.1	
ECE R43 Point #1 (geometric center)	Unpainted	2.5	3.0
		3.7	
		2.7	
	Painted	4.9	4.2
		3.5	
		4.2	

Counts were taken at both the spline area close to the impact location and in a corner area further away from the impact location. The ECE R43 performance requirement is that no 5 cm × 5 cm square shall contain less than 40 pieces.

In one RQ test, marked with an asterisk, the glass did not break on first impact with the centerpunch. The piece was punched a second time to break it. In another of the RQ tests, the area selected to be counted (i.e. spline area) was not able to be counted due to overexposure of the cracks in the photo collected. This was the first test performed and adjustments were made for the remainder of tests so all areas could clearly be counted.

Table E-9. RQ Fracture Count Comparison

Test Type	Glass Type	spline area			corner area		
		Count (pieces)	Location	Average	Count (pieces)	Location	Average
ANSI location (mid-point of longest edge)	Unpainted	170.5	A	173.2	189.5	B	198.7
		178	A		207.5	B	
		171	A		199	B	
	Painted	156.5	A	148.2	182.5	B	201.8
		136.5	A		213	B	
		151.5	A		210	B	
ECE R43 Point #1 (geometric center)	Unpainted	-	-	66.0	104.5	B	114.7
		47.5*	A		106.5	B	
		84.5	C		133	B	
	Painted	79.5	C	72.7	128	B	121.2
		80.5	C		119	A	
		58	C		116.5	A	

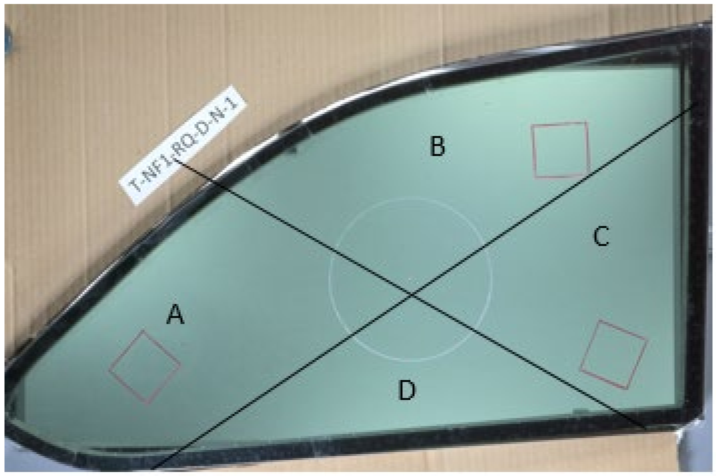


Table E-10. SR Fracture Count Comparison

Test Type	Glass Type	Primary			Secondary		
		Count	Location	Average	Count	Location	Average
ANSI location (mid-point of longest edge)	Unpainted	258.5	D	262	296.5	A	326
		259	D		340.5	A	
		267.5	D		342	A	
	Painted	246	D	244	390.5	A	375
		237	D		373.5	A	
		247.5	D		360	A	
ECE R43 Point #1 (geometric center)	Unpainted	165	A	203	229	B	225
		258	A		225	B	
		186	A		219.5	B	
	Painted	271	A	235	154.5	B	163
		223	A		181.5	B	
		212	A		153	B	

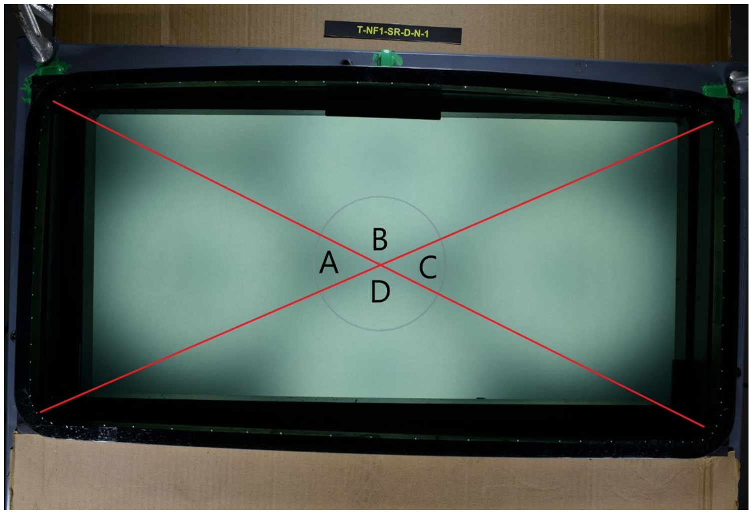
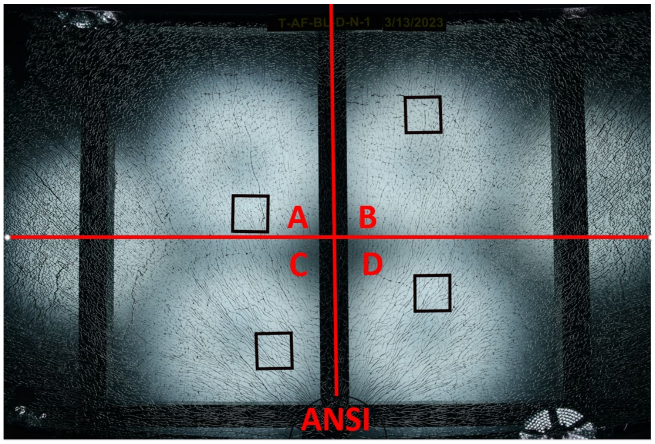


Table E-11. BL Fracture Count Comparison

Test Type	Glass Type	Primary			Secondary		
		Count	Location	Average	Count	Location	Average
ANSI location (mid-point of longest edge)	Unpainted	104.5	C	114	118	D	114
		111.5	C		104.5	D	
		126	C		120	D	
	Painted	91.5	C	96	106.5	D	109
		94	C		98.5	D	
		103.5	C		121	D	
ECE R43 Point #1 (geometric center)	Unpainted	64.5	A	63	73.5	D	72
		52	A		72.5	D	
		72.5	A		69.5	D	
	Painted	90	A	84	61.5	D	61
		81.5	A		65	D	
		80.5	A		55.5	D	



Laminated Glass Results

Three repeats were completed at each impact location. All tests, on both the sample and the production WS glass met the performance criteria. Boxes highlighted in yellow did not meet the criteria. Measurements of the area of exposed laminate are provided in the tables.

30ft Ball - Windshield							
Sample				Production			
Location	trial	Paint	No Paint	Location	trial	Paint	No Paint
Center (a)	1	x	x	Center (A)	1	x	x
	2	x	x		2	x	x
	3	x	x		3	x	x
Corner (b1)	1	x	x	Corner (B1)	1	x	x
	2	x	x		2	x	x
	3	x	x		3	x	x
Transition (b2)	1	x	x	Transition (B2)	1	x	x
	2	x	x		2	x	x
	3	x	x		3	x	x
Edge (b3)	1	x	x	Edge (B3)	1	x	x
	2	x	x		2	x	x
	3	x	x		3	x	x

Break Height Ball - Windshield							
Sample							
Location	trial	Paint			No Paint		
		Height (ft)	Result	Msmt (mm²)	Height (ft)	Result	Msmt (mm²)
center (a)	1	120	x	1592	60	x	347*
	2	90	x	1181	90	x	1250*
	3	90	x	459	90	x	2121
	4	90	x	652	80	x	1084
	5	100	x	2632	70	x	589
	6	95	x	2149	75	x	694
	7	95	x	1844	75	x	354
	8	85	x	1651	75	x	820
	9	75	x	489			
	10	65	x	513			
	11	80	x	2142			
	12	67.5	x	330			
	13	75	x	2047			
	14	70	x	1717			
edge (b3)	1	60	x	769	60	x	431
	2	50	x	632	70	x	1726
	3	55	x	843	65	x	834
	4	50	x	755	60	x	326
	5	50	x	687	65	x	216
	6	45	x	726	65	x	906
	7	40	x	337			
	8	45	x	822			

Break Height Ball - Windshield							
Production							
Location	trial	Paint			No Paint		
		Height (ft)	Result	Msmt (mm²)	Height (ft)	Result	Msmt (mm²)
center (A)	1	50	x	777	50	x	618
	2	40	x	444	60	x	863
	3	45	x	601	55	x	745
	4	50	x	611	55	x	552
	5	50	x	508	55	x	531
	6	40	x	518	60	x	716
	7	55	x	1237			
	8	55	x	1265			
edge (B3)	1	35	x	1201	40	x	0
	2	30	x	1355	50	x	470
	3	20	x	647	60	x	615
	4	20	x	141	70	x	494
	5	25	x	1764	80	x^	690
	6	20	x	313	75	x	503
	7	25	x	336	80	x	575
	8	25	x	649	80	x^	675

x^ = small split in laminate

Windshield - Ball - Cold				
Sample				
Location	Height (ft)	trial	No Paint	Msmt (mm²)
center (a)	27.89ft [8.5m]	1	x	-
		2	x	-
		3	x	-
corner (b1)	27.89ft [8.5m]	1	x	-
		2	x	-
		3	x	-
transition (b2)	27.89ft [8.5m]	1	x	-
		2	x	-
		3	x	-
edge (b3)	27.89ft [8.5m]	1	x	-
		2	x	-
		3	x	-
center (a)	30	1	x	0
	70	2	x	479
	80	3	x	1624
	75	4	x	705
	75	5	x	517
	75	6	x	433
	30	7	x	208
	80	8	x	451
	80	9	x	431
	85	10	x	547
	90	11	x	Pass through
edge (b3)	60	1	x	898
	50	2	x	352
	55	3	x	365
	55	4	x	736
	55	5	x	550
	60	6	x	610
	60	7	x	266
	65	8	x	467
	70	9	x	463
	75	10	x^	407
	80	11	x	Pass through

x^ = split in laminate

Windshield - Ball - Hot				
Sample				
Location	Height (ft)	trial	No Paint	Msmt (mm²)
center (a)	29.5ft [9.0m]	1	x	-
		2	x	-
		3	x	-
corner (b1)	29.5ft [9.0m]	1	x	-
		2	x	-
		3	x	-
transition (b2)	29.5ft [9.0m]	1	x	-
		2	x	-
		3	x	-
edge (b3)	29.5ft [9.0m]	1	x	-
		2	x	-
		3	x	-
center (a)	70	1	x	1638
	60	2	x	582
	65	3	x	403
	65	4	x	1548
	65	5	x	1116
	60	6	x	406
edge (b3)	60	1	x	438
	70	2	x	844
	65	3	x	Pass through
	65	4	x	Pass through
	60	5	x	423
	70	6	x	304
	65	7	x	322
	70	8	x	Pass through

Dart Break Height Tests

x	Tested (no puncture of film layer)
x	pass but dart punctured film layer (rip or dart stuck)
x	failure
x^	One or both glass panes did not break

31ft+ Dart - Windshield					
Sample					
Location	trial	Height (ft)	Paint	Height (ft)	No Paint
center (a)	1	34.393	x	34.393	x
	2	60	x	60	x
	3	50	x	70	x
	4	55	x	75	x
	5	60	x	80	x
	6	60	x	80	x
edge (b3)	1	34.393	x	34.393	x
	2	50	x	70	x
	3	60	x	60	x
	4	70	x	50	x
	5	70	x	40	x
	6	70	x	45	x
	7	75	x	50	x
	8	75	x	50	x

31ft+ Dart - Windshield					
Production					
Location	trial	Height (ft)	Paint	Height (ft)	No Paint
center (A)	1	60	x	34.393	x^
	2	55	x	40	x
	3	50	x	50	x
	4	40	x	45	x
	5	34.393	x	40	x
	6	40	x	45	x
	7	34.393	x^	45	x
	8	34.393	x^	50	x
	9			34.393	x
	10			34.393	x
edge (B3)	1	34.393	x	34.393	x
	2	40	x	40	x
	3	50	x	50	x
	4	60	x	45	x
	5	55	x	45	x
	6	55	x	45	x
	7	55	x		

Appendix F: Standard Test Comparison Tables

The below tables summarize the results from the standard tests. Each box represents a set of three tests, unless otherwise indicated, and the values are the number of breaks divided by number of tests ran. A zero means that none of the three tests broke, while a one means all tests in that set broke. The following key indicates the symbol used in the tables to indicate the number of tests if different than three:

Symbol	# of tests
*	6
^	4
+	2
!	1

Table F-1. Comparison of 10-ft Ball Standard Tests

227g ball - standard tests							
Type	**Location**	**Height (ft)**	**Sample Painted w Silver**	**Sample Painted**	**Sample Unpainted**	**Production Painted**	**Production Unpainted**
Rear Quarter	center	10		0*	0*	0	0
	corner	10		0+	0+	0	0
	transition	10		0.33	0+	0	0
	edge	10		1+	0+	0.67	0
Sunroof	center	10		0	0	0	0
	corner	10		0	0	0	0
	transition	10		0	0	0	0
	edge	10		1	0	1	0
Back Light	center	10	0	0	0	1	0
	corner	10	1	0	0	1	0
	transition	10	0.67	0	0	1	0
	edge	10	1	1	0.33	1	0

Table F-2. Comparison of 10 ft and 6.6 ft Drops on Sample Glass

227g ball - standard tests							
Type	**Location**	**Height (ft)**	**Sample Painted w Silver**	**Sample Painted**	**Sample Unpainted**	**Production Painted**	**Production Unpainted**
Rear Quarter	center	10		0*	0*	0	0
		6.6					
	corner	10		0+	0+	0	0
		6.6					
	transition	10		0.33	0+	0	0
		6.6		0			
	edge	10		1+	0+	0.67	0
		6.6		1		0.75^	
Sunroof	center	10		0	0	0	0
		6.6					
	corner	10		0	0	0	0
		6.6					
	transition	10		0	0	0	0
		6.6					
	edge	10		1	0	1	0
		6.6		0		1	
Back Light	center	10	0	0	0	1	0
		6.6				1	
	corner	10	1	0	0	1	0
		6.6	0.67			1	
	transition	10	0.67	0	0	1	0
		6.6	0			1	
	edge	10	1	1	0.33	1	0
		6.6	0	0	0	1	

Table F-3. Comparison of ASB and MSB Standard Tests

shot bag - 8ft							
Type	**Location**	**Bag type**	**Sample Painted w Silver**	**Sample Painted**	**Sample Unpainted**	**Production Painted**	**Production Unpainted**
Rear Quarter	center	ASB		0*	0*	0.33	0
		MSB		0.33	0*	0	0
	corner	ASB		0*	0*	0.67	0
		MSB		0*	0*	1	0
	transition	ASB		0*	0*	0	0
		MSB		1*	0*	0.67	0
Sunroof	center	ASB		0*	0.33	0	0
		MSB		1*	1*	0	0
	corner	ASB		0*	1*	0	0
		MSB		0*	1*	0.33	0.67
	transition	ASB		0*	0.67	0	0
		MSB		0*	1*	0	0
Back Light	center	ASB	0*	0*	0*	0	0
		MSB	0*	0*	1*	0	0
	corner	ASB	0*	1*	1*	0	0.33
		MSB	1*	1*	1*	0	0
	transition	ASB	0.33	1*	0.67	0	0
		MSB	0.33	0*	1*	0	0

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