

Seat Belt Restraint Evidence Generated in the Presence of Fractured Glass

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ABSTRACT

Physical evidence on the seat belt restraint system is one source of data used by investigators to determine whether or not an occupant was wearing their seat belt during a crash. Evidence of occupant loading on seat belts generated during crash events has been thoroughly researched and is well documented in the literature. However, there is a paucity of data regarding the physical evidence produced when fractured glass is introduced into the restraint system during occupant loading events. The objective of this study is to characterize the physical evidence generated by glass-to-seat belt interaction during low-level impact loading, and compare this evidence with the types of seat belt marks that can be generated inadvertently by accident scene bystanders, emergency responders, and crash investigators. The presence of glass particles in and around the vehicle at the end of a crash event may contribute to the inadvertent generation of physical evidence.

Movable side windows composed of tempered safety glass and laminated safety glass were fractured via impactor loading representative of occupant impact. The resulting glass fracture fragments were separated by size using a series of sieves, and the distribution of glass fragments size was quantified.

New service-replacement seat belt retractor assemblies (including D-ring, latch plate, anchor, and webbing) were tested using a Seat Belt Load Simulator (SBLS) fixture, which simulates occupant loading by applying a repeatable load pulse to the restraint system. Each retractor assembly was mounted onto the SBLS fixture in a position representative of belt routing when installed in a vehicle. A repeatable lap-shoulder belt stroke pulse, representative of low-level restraint loading and consistent in magnitude and duration with loads produced during rollover, was applied using the SBLS with glass fragments of varying sizes introduced onto the webbing surface adjacent to the D-ring and latch plate surfaces.

Additional test series were run to investigate the types of physical evidence generated in the presence of glass under non-crash loading scenarios. These scenarios included the extraction of webbing with glass fragments present adjacent to the D-ring and latch plate, extraction of webbing over glass fragments captured or fixed in a window seal, and the compression of webbing with various sizes of glass fragments interposed between the webbing and a reaction surface.

Documentation of each restraint system was performed post-test. Seat belt loading events that occurred in the presence of fractured safety glass produced characteristic markings on the restraint system hardware and webbing. The tests conducted to examine non-crash loading evidence generated in the presence of fractured safety glass revealed markings on the restraint system that differed from those generated in a simulated loading event.

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INTRODUCTION

When a seat belt is worn by an occupant in a motor vehicle collision of sufficient severity, the forces imparted on the restrained occupant can produce physical evidence on the seat belt assembly indicating usage. Common characteristics of such evidence have previously been discussed in the

scientific literature [1,2,3]. Examples of physical evidence from crash loading include melting of the polymer-coated latch plate and D-ring routing loop in the impression of the web pattern; transfer of the polymer-coated surfaces onto the webbing; and webbing abrasions arising from interaction with vehicle components - such as the seat or trim - during a

collision. In the event of glass fracture during a motor vehicle collision, glass fragments may also be introduced into the occupant compartment and seat belt assembly during occupant loading events, generating other types of distinctive evidence on the seat belt assembly.

Bready, et al. [3] presented an example of a D-ring from a real-world accident with glass cuts and lacerations on the plastic surface. The evidence on the D-ring was attributed to glass fragments being pulled with the webbing through the D-ring web slot. Raphael, et al. [4] characterized a similar example of D-ring evidence as having "large glass particle-like scratches". Bready, et al. noted that the types of cuts or lacerations observed on the D-ring could occur at lower forces where melted plastic may not be seen, and required relative motion between the webbing and D-ring.

Moffatt, et al. [1] noted the importance of identifying the presence and distribution of glass particles on webbing as part of an accident investigator's restraint documentation. Meyer, et al. [5] presented a photograph of a segment of webbing with linear striations, said to be caused by glass fragment contamination of the D-ring. Bready, et al. [3] presented a case study of webbing with distinct, sharp surface cuts. Full analysis of the case study evidence indicated that several glass fragments were interposed with the webbing between the driver's shoulder and the B-pillar trim panel during the collision. The authors cautioned that careful evaluation was needed to identify the source of cuts and to distinguish them from damage that may have been produced post-accident.

Glass fragments found loose within the interior of a vehicle, or exposed along a window perimeter, present the opportunity for marks to be inadvertently generated on a restraint system after a collision. While several studies have compared occupant load marks with marks produced by non-collision events after an accident [6-7], the authors are not aware of any studies that have demonstrated the types of non-collision marks that can be produced by glass fragments.

The objective of this study is to characterize the physical evidence generated by glass-to-seat belt interaction during low-level impact loading. Simulated load tests were performed on seat belt restraint assemblies with glass particles present between the webbing surface and restraint hardware. Additional testing was also performed to investigate the types of evidence that can be produced in non-crash loading events so that a comparison of the seat belt assembly physical evidence could be made.

METHODS

GLAZING

Glass Fracture

A service replacement tempered safety glass window for the moveable driver door position of a popular sport utility vehicle was obtained from an automotive supplier. The window glass was supported at the top, sides, and bottom

using contoured foam, and fractured via impactor loading. Using a similar protocol to that described by Pierce, et al. [8], an 18 kg [40 lb] ballasted headform impactor was dropped onto the interior aspect of the glass from a height of 2.29 m [7.5 ft], with an approximate impact speed of 24 km/h [15 mph]. This impactor mass, impact speed, and energy level have been previously described by the National Highway Traffic Safety Administration (NHTSA) to be "representative of the type, shape, and speed that could be expected during side impact and rollover crashes" [9], and are consistent with the test methodology more recently published by NHTSA [10]. The impactor was allowed to contact the glass and continued downward into a container located below the fixture, but was tethered so that it did not contact the bottom. The glass fragments were collected in the container and weighed. The pre-test window mass (including the attached metal regulator clips) was 3.70 kg [8.15 lb] and the post-test mass of the glass fragments and window hardware was 3.65 kg [8.05 lb], indicating 99% of the window glass assembly (glass and hardware) was recovered following fracture.

A second headform impactor test using the same speed, mass, and energy parameters was performed on a rear door-window assembly of a passenger car equipped with production heat-strengthened laminated safety glass. As in Pierce, et al. [8], the door-window assembly was supported at the hinges and rear latch area in a custom fixture and oriented such that the glass surface plane was horizontal (level) at the impact location. Plastic sheeting was used to enclose the test area and to contain glass fragments liberated following impact and fracture. The impactor was allowed to contact the glass and continued downward below the fixture, but was tethered so that it did not contact the ground. The glass fragments were collected and weighed. The pre-test window and affixed attachment hardware mass (i.e., including the metal regulator clip) was 3.76 kg [8.30 lb]. The post-test window, hardware, and glass fragment mass was 3.72 kg [8.20 lb], indicating 99% of the window glass assembly (glass and attachment hardware) was recovered following fracture.

Glass Sieve Analysis

The glass fragments recovered following fracture of the tempered safety glass and laminated safety glass side windows were separated into various particle size fractions using sieve analysis. The sieves utilized conform to the requirements of ASTM E11 [11] and their operation conforms to the requirements of ASTM D422 [12]. The set of sieves utilized in this analysis included the following opening sizes: 75 mm (3 in), 37.5 mm (1.5 in), 19 mm (0.75 in), 12.7 mm (0.5 in), 4.75 mm (No. 4), 2 mm (No. 10), 850 μ m (No. 20), 425 μ m (No. 40), 250 μ m (No. 60), 106 μ m (No. 140), and 75 μ m (No. 200).

Upon visual inspection of the various fragment size categories, it was determined that particles in the range of 2000 - 4750 μ m were of the size typically seen in police accident scene photographs and routinely encountered during post-crash inspections. The smaller fragments, specifically



those 850 μm or less, were of the size typically seen adhered to the vehicle interior, especially on exposed seat belt webbing, vehicle headliner material, and seat cushion fabric. Based on these observations, three particle or fragment size ranges were selected for testing with simulated seat belt loads: 106 to 250 μm ("small"), 250 to 425 μm ("intermediate"), and 425 to 850 μm ("large").

RESTRAINTS

Seat Belt Load Simulator (SBLS)

Laboratory tests were conducted to document the characteristics of seat belt webbing marks and marks generated by glass fragments when exposed to dynamic loads applied at the D-ring and latch plate using a Seat Belt Load Simulator (SBLS) machine. The machine is depicted in [Figure 1](#). New service replacement three-point restraint systems (including a plastic D-ring, single-slotted slide-through latch plate, retractor, anchors, and a continuous length of webbing) for the front outboard position of a popular sport utility vehicle were obtained from an automotive supplier. The buckle assembly was not utilized for this testing.

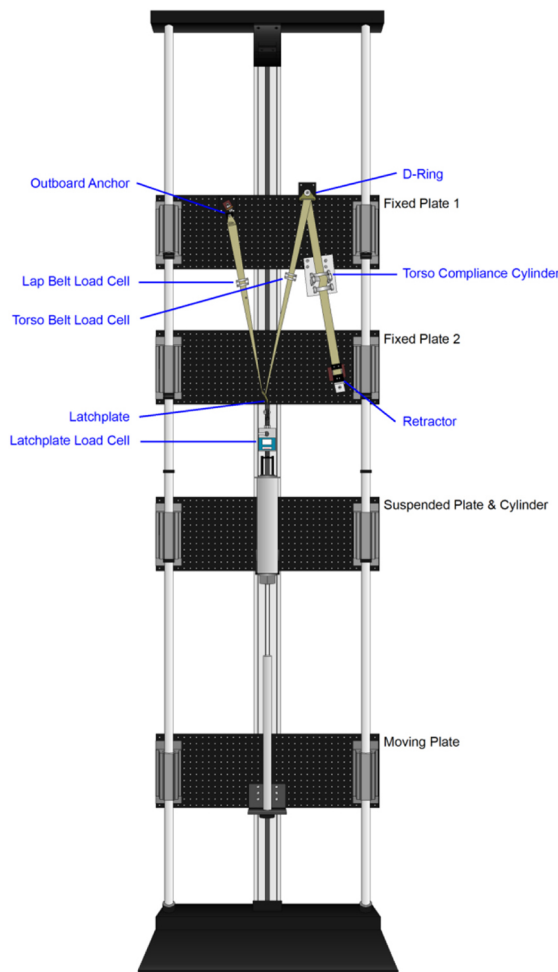


Figure 1. Seat Belt Load Simulator (SBLS)

The outboard anchor and D-ring were mounted to Fixed Plate 1 and the retractor was mounted to Fixed Plate 2 in a configuration consistent with the in-vehicle geometry of the restraint system. A pneumatic cylinder was mounted to another guided plate, which was suspended from the latch plate via a load cell. The weight of the suspended plate and cylinder served as a preload to the restraint system.

Each test was initiated by allowing the moving plate to drop through a pre-selected height. A mechanism mounted on the moving plate engages the end of the cylinder rod, which stops the moving plate in a controlled manner. The latch plate load cell (Interface SM-1000) monitored the load applied to the latch plate. The SBLS allows for the amplitude and duration of the dynamic load to be varied by selecting different amounts of rod extension and drop height. The cylinder functions as a pneumatic spring with the rod extension and initial pressure controlling the load pulse duration. The peak load imparted on the latch plate is controlled by the combination of: (i) rod extension, and therefore the gas volume on the rod side of the cylinder, (ii) drop height, and (iii) drop weight. Using these variables, the SBLS can produce pulses of 10 to 200 msec in duration with 89 to 6672 N [20 to 1500 lb] peak force.

A series of rollers can be attached to the webbing along the section between any two anchorage points to control the degree of lap-shoulder belt loading asymmetry that occurs during actuation of the SBLS. This compliance system uses another pneumatic cylinder, again functioning as a pneumatic spring, to allow a controlled amount of webbing to be transferred through the system. This unit has a total range of 30.5 cm [12 in] of webbing transfer. In this research, the compliance system was mounted between the retractor and the D-ring to facilitate transfer of approximately 6.1 and 3.1 cm [2.4 and 1.2 in] of webbing across the D-ring and latch plate, respectively. Load cells mounted on the lap and torso sections of the seat belt webbing (Denton 3255) monitored the loads in the two sections of the belt, and a string potentiometer (Celesco, SM2-25) measured motion at the roller attached to the compliance system. Geometric analysis was used to relate compliance roller displacement to web motion at the D-ring and latch plate.

The dynamic load pulse utilized in this study was designed to subject the seat belt components to low-level loading, consistent with that observed during a rollover event. The dynamic load pulse targeted in the current study involved a duration of approximately 100 msec and average lap and shoulder belt loads of 800 N [180 lb] and 400 N [90 lb], respectively. These pulse parameters are within the range of lap and shoulder loading pulses observed during recent rollover crash testing [13] ([Figure 2](#) and [Table 1](#)).

A series of 9 tests were conducted, and new service replacement three-point restraint systems were utilized for each test. The first test (B1) was conducted to establish a baseline, and the restraint system was loaded in the absence of any glass fragments. For the remaining 8 tests, glass particles within one of the three size ranges identified were

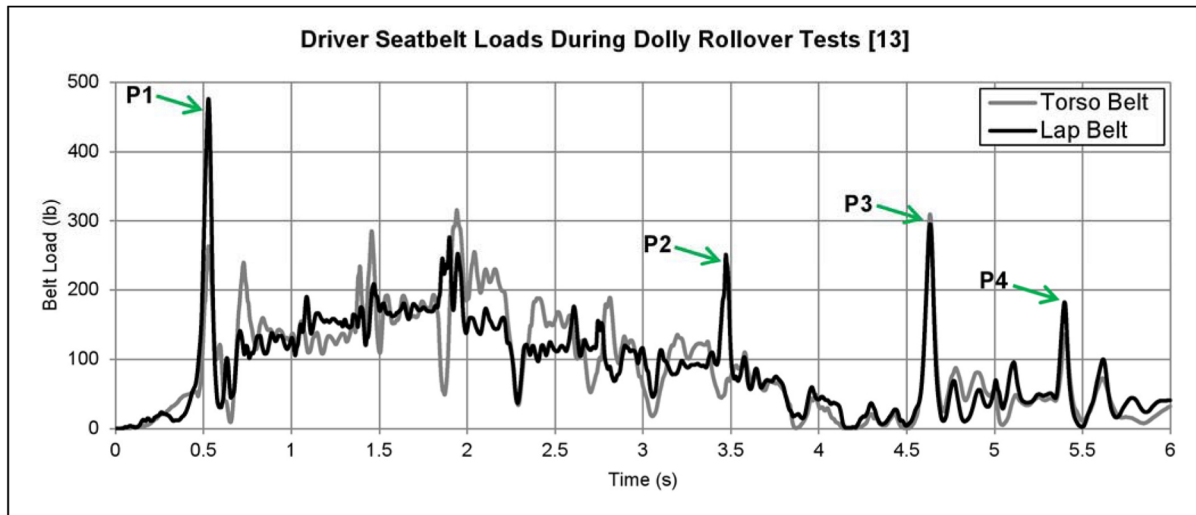


Figure 2. Driver lap and torso belt loads during dolly rollover testing of a Subaru Forester on dirt [13].

Table 1. Results at select belt loading points during dolly rollover testing of a Subaru Forester on dirt (Figure 2).

Peak ID	Lap Belt Load		Torso Belt Load		Torso:Lap Belt Load Ratio	Pulse Duration
	[lb]	[N]	[lb]	[N]		[msec]
P1	476	2117	263	1170	0.55	128
P2	251	1116	63	280	0.25	68
P3	295	1312	309	1374	1.05	122
P4	182	810	135	601	0.74	70

intentionally introduced: (i) onto the webbing load surface adjacent to the D-ring, and (ii) between the latch plate webbing and the lower latch plate load surface prior to application of the dynamic load (Figure 3). At the location adjacent to the D-ring, glass fragments were introduced by lightly brushing a sample of fragments transversely across the webbing; all fragments sizes utilized were sufficiently small that they generally adhered during this process. At the latch plate, the glass fragments were introduced between the body-facing side of the latch plate and the webbing with the assistance of gravity.

Of the 8 tests performed with glass fragments, 6 were performed using tempered safety glass fragments (G1 to G6), and 2 used glass fragments obtained from the fractured laminated safety glass (LG1 and LG2). A single torso belt compliance configuration was utilized for this series to facilitate approximately 5 cm [2 in] of webbing transfer at the D-ring. Load data was collected at 10 kHz from the three load cells using a DaqBook 2020 acquisition system with a 2 kHz anti-aliasing filter. Loads were processed in DIAdem with an SAE J211 CFC 60 compliant filter [14]. Load marks on the restraint system hardware (D-ring and latch plate) from the webbing and glass fragment interaction and evidence on the webbing from the glass fragments were photographically documented following the testing.

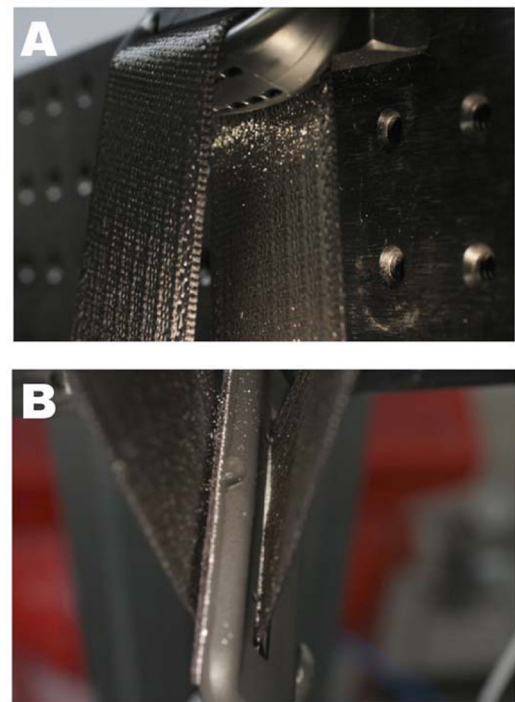


Figure 3. Photographs of glass fragments introduced on the webbing at D-ring (A) and latch plate (B).

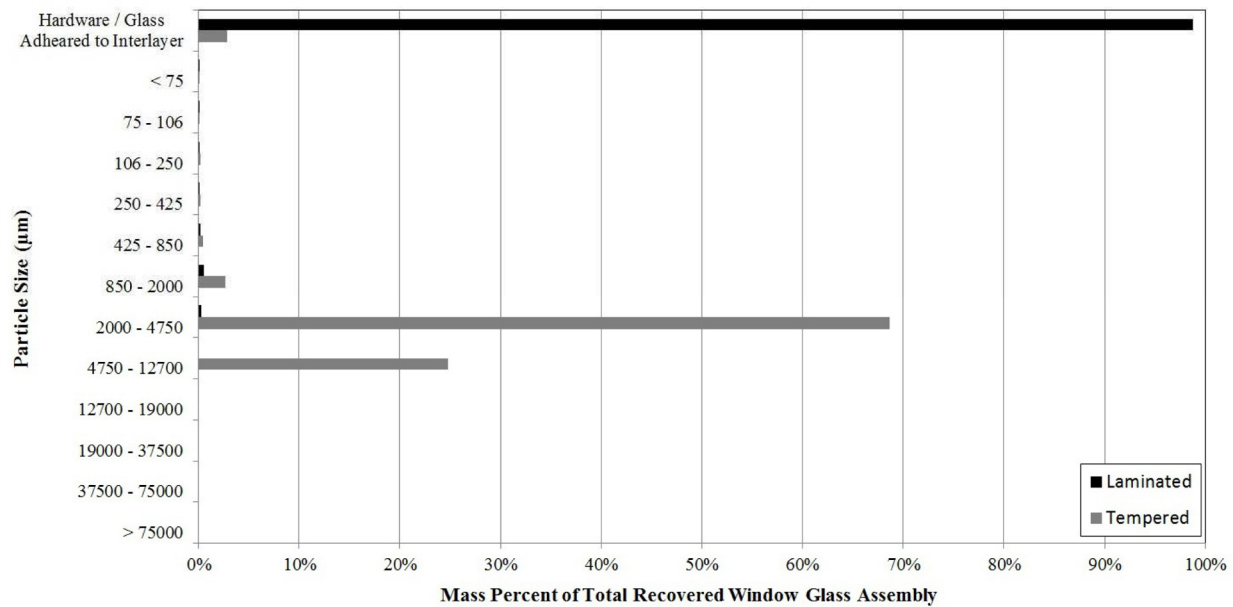


Figure 4. Bar chart depicting mass distribution of fracture fragments from window glass assemblies.

Manual Restraint Loading

Several additional test series were run to investigate the types of physical evidence generated in the presence of glass fragments under non-crash loading scenarios.

Test M1 was conducted in order to evaluate the evidence that can be generated on the seat belt webbing and hardware post-accident due to the presence of glass fragments on the restraint system components, such as when the webbing is pulled off of the retractor for inspection. A new service replacement three-point restraint system of a popular sport utility vehicle was installed on the SBLS, and tempered safety glass particles ranging in size from 250 - 425 µm were introduced on the webbing at the entrance to the D-ring and latch plate. The latch plate was then grasped by hand and pulled downward with a peak force of 65.7 N [14.8 lb], extracting the webbing off of the retractor. Evidence generated on the restraint system hardware (D-ring and latch plate) and webbing due to glass fragment interaction was photographically documented following the test.

Test M2 was conducted in order to evaluate the evidence generated on seat belt webbing when pulled across the surface of fractured tempered safety glass, such as when webbing is pulled off of the retractor and out of an adjacent window for inspection, interacting with the tempered safety glass fragments in the perimeter window seal. A three-point restraint system installed in the left rear seating position of a popular sport utility vehicle was pulled through an adjacent fractured window opening. The pull force was measured using an S-type load cell attached to the webbing. The webbing was pulled out of the window opening with a peak force of approximately 44 N [10 lb] and allowed to interact with the vertical portion of the window seal containing fractured tempered safety glass fragments. Evidence

generated on the webbing due to glass fragment interaction was photographically documented following the test.

Test M3 was conducted in order to evaluate the evidence generated on seat belt webbing when compressed between glass fragments and a contact surface, such as when a length of webbing is lying outside of a vehicle or on a vehicle floorboard in an area populated with fractured glass and is subsequently stepped on by emergency personnel, bystanders, or other individuals. The same sport utility vehicle used in Test M2 was utilized for this testing. Samples of glass fragments found in the vehicle were collected and placed on the floor in the area of the right rear seating position. Webbing was extended off of the right rear retractor and placed atop the sample of glass fragments. A male volunteer, 191 cm [75 in] tall and weighing 86.6 kg [191 lbs], wearing casual dress shoes then stepped onto the webbing simulating an inspection of the vehicle's roof. The webbing evidence due to glass fragment interaction was photographically documented post-test.

RESULTS

GLAZING

Glass Sieve Analysis

Following sieving of the fractured window glass, the mass distribution of glass fragments was determined (Figure 4). Fragments 850 µm or less were identified as the sizes typically seen adhered to the vehicle interior. Figure 5 depicts tempered and laminated glass samples of the three particle size ranges identified for testing.

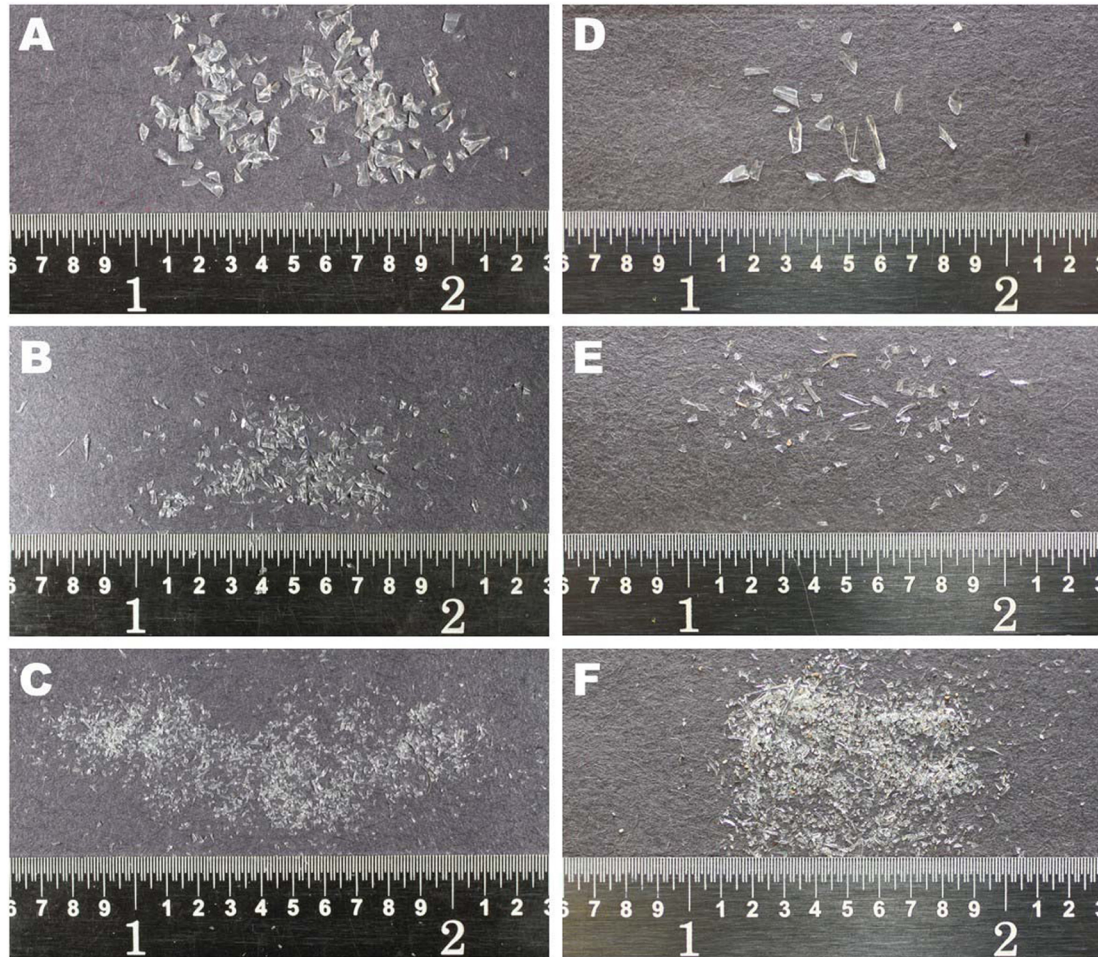


Figure 5. Glass fragments (depicted scale in inches). Tempered safety glass (A) 425-850 μm , (B) 250-425 μm , (C) 106-250 μm , and Laminated safety glass (D) 425-850 μm , (E) 250-425 μm , (F) 106-250 μm

Table 2. Results from restraints testing using SBLS machine.

Test ID	Pulse Characteristic			Peak Lap Belt Load		Peak Torso Belt Load		Glass Particle Size Range [μm]	Glass Particle Location		Restraint	
	Peak Latch Plate Load		Pulse Duration						Latch Plate	D-Ring	Manufacturer	Model
	[lb]	[N]	[msec]	[lb]	[N]	[lb]	[N]					
B1	241	1072	91	170	757	92	411	---	---	---	Key Safety Inc.	B9280
G1	241	1070	93	171	761	88	393	250 - 425	x	x	Key Safety Inc.	B9280
G2	245	1088	90	178	792	93	415	425 - 850	x	x	Key Safety Inc.	B9280
G3	244	1085	89	180	802	85	378	106 - 250	x	x	Key Safety Inc.	B9280
G4	253	1125	91	181	806	93	413	250 - 425	x	x	Key Safety Inc.	B9280
G5	250	1112	90	183	815	90	399	425 - 850	x	x	Key Safety Inc.	B9280
G6	265	1177	86	206	917	84	373	106 - 250	x	x	Key Safety Inc.	B9280
LG1	240	1066	82	176	782	87	389	425 - 850	x	x	Key Safety Inc.	B9280
LG2	250	1111	81	179	796	90	398	250 - 425	x	x	Key Safety Inc.	B9280

SEAT BELT LOAD SIMULATOR (SBLS)

Test parameters and results for the restraint testing conducted on the SBLS are summarized in [Table 2](#). For each

test, peak loads at the latch plate load cell and both webbing load cells are listed as well as the duration of the response pulse (defined at 10% of the peak). A representative plot of the belt loads is presented in [Figure 6](#).

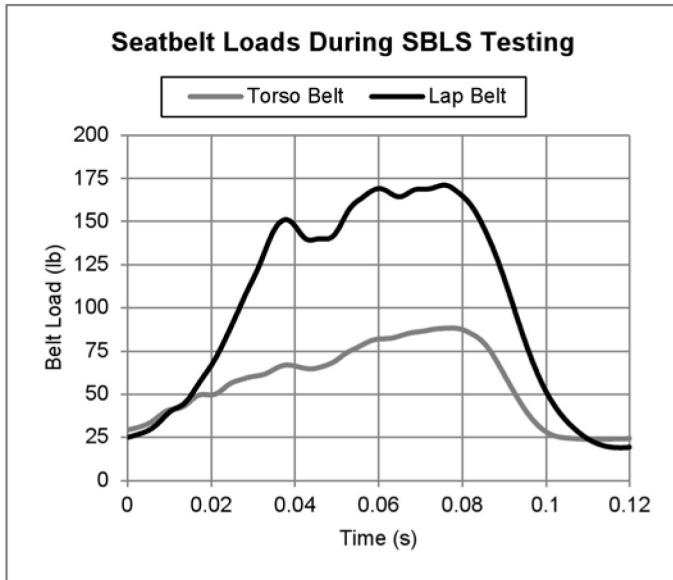


Figure 6. Representative plot of torso and lap belt loads from test G1 of the SBLS testing

An average of 5.9 ± 0.3 cm [2.3 ± 0.1 in] of webbing moved across the D-ring at an average peak rate of 1.8 ± 0.2 m/s [4.0 ± 0.4 mph]. An average of 3.0 ± 0.2 cm [1.2 ± 0.1 in] of webbing moved across the latch plate at an average peak rate of 0.9 ± 0.1 m/s [2.0 ± 0.2 mph]. Appendix A contains photographs comparing the post-test conditions of the D-rings, latch plates, and webbing for the SBLS tests.

The SBLS pulse was of sufficient severity to produce loading evidence in the baseline test B1. The movement of the webbing across the D-ring produced abrasions from the webbing's finished edges at both ends of the D-ring's inboard load-bearing surface, and a few light abrasions between the edge striations (Figure 7A). No discernible abrasions or transfer of polymer were evident on the corresponding webbing surface that translated across the D-ring, although minor fiber disruption was seen (Figure 7B). Abrasions were observed on the body-facing side of the latch plate across the full webbing contact width. The abrasions were patterned in the form of the webbing weave, but did not exhibit any build-up (Figure 8A). No abrasions were observed on the non-body side of the latch plate. The corresponding webbing surface that translated across the latch plate exhibited linear abrasions and fiber disruptions (Figure 8B).



Figure 7. Baseline test B1 results - inboard side of D-ring (A) and corresponding webbing (B)



Figure 8. Baseline test B1 results - body side of latch plate (A) and corresponding webbing (B)

Tempered Safety Glass Particles

Two tests were conducted for each range of tempered safety glass particle size in order to establish repeatability of the method. The results indicate similar characteristics in the marks produced on the D-ring, latch plate, and webbing in tests using the same particle size range.

The particle size range dictated the number of individual particles that were introduced onto the webbing, such that the small size range tests had more fragments on the webbing as compared to the intermediate and large sizes. As a consequence, more glass-related abrasions were produced on the hardware (across the full webbing contact width) and webbing in the small fragment size tests (Tests G3 and G6, 106-250 μ m). The number of glass-related abrasions decreased with increased particle size - intermediate particle sizes (Tests G1 and G4, 250-425 μ m) and large particle sizes (Tests G2 and G5, 425-850 μ m).

The tempered safety glass particles generated distinctive abrasions on the D-ring load-bearing surfaces, on both the inboard and outboard sides. The characteristics of the abrasions in the small and intermediate particle size tests



Figure 9. D-ring abrasions generated by tempered glass fragments - (A) Small [Test G3], (B) Intermediate [Test G1], (C) Large [Test G2]

were consistent with the size of the individual particles. The smallest particle size generated fine abrasions as compared to the slightly deeper and wider abrasions produced by the intermediate particle size. The correlation between the size of individual abrasions and the particle size was not observed in tests with the large particle size, which appeared lighter than even the small particle size abrasions. Figure 9 shows a comparison of the abrasions produced on the inboard load-bearing surface on the D-ring from the three glass particle sizes.

The corresponding webbing that translated across the D-ring in each test exhibited diffuse abrasions where the glass particles were introduced. Several of the small glass particles were attached to the webbing post-test, a few intermediate-sized particles remained on the webbing, and one large-sized glass particle was seen on the webbing after Test G5. Figure 10 shows a sample of the glass particles that were attached to the webbing in the area of the D-ring contact post-test for the three particle size ranges tested.

Abrasions were produced on the latch plate load bearing surface by both tempered safety glass particles on the body-facing side of the latch plate and the patterned weave of the webbing. Additionally, in all tests several of the glass-related abrasions extended upward on the latch plate toward the area of the over-mold pin holes. Tests involving the small particle size range generated fine linear abrasions with some areas of irregularity most notably near the web slot (Figure 11A). These irregular areas were characterized by shaving and splaying of the polymer material as a result of interaction with the glass fragments, and subsequent melting of the displaced material back onto the latch plate surface. In some areas, shaving from the small particles produced a glossy appearance on the load-bearing surface of the latch plate. Similar observations of irregular glass-related abrasions characterized by displaced and subsequently melted polymer material were seen in the intermediate particle size tests (Figure 11B). Many of the intermediate particle size abrasions were deeper and wider than those generated by the