Journal of the National Academy of Forensic Engineers®

NATIONAL ACADEMY OF FORENSIC ENGINEERS

http://www.nafe.org
ISSN: 2379-3252

Vol. XXVI No. 2 December 2009

Forensic Engineering Investigation of Side Glazing Failure in Rollover Collisions

By Stephen A. Batzer, Ph.D., P.E. (NAFE 677M)

Abstract

During automotive rollover collisions, full containment is critical to occupant safety. Conventional 3-point safety belts cannot ensure full containment. Tempered glazing failure results in open portals, leading to numerous avoidable deaths and serious injuries as occupant heads, shoulders, arms, and even legs are ejected and interact with the environment and vehicle exterior. This paper surveys the forensic aspects of side window glazing during rollover collisions, to include failure mechanisms, fractography, and legal aspects. Both the level of expected duty and current state of technology are reviewed. Occupant retention glazing design is discussed along with case studies.

Keywords

Automotive glazing, laminated glass, rollover, crash worthiness, occupant retention

Legal / Regulatory Aspects

In 1957, Chrysler, Rambler and Studebaker started using tempered side glass in their model year 1958 vehicles, which gave them a cost advantage over their competitors. This substitution reversed the long-standing practice of using only laminated glass in the vehicle except for the backlight, for which some models had used tempered since 1937. It was recognized at the time that tempered glass had less retention capability than did laminated, but there was no regulatory authority in place to oppose the change. Years later, the newly created National Highway Traffic Safety Administration (NHTSA) proposed a passive safety technology requirement for windows in their FMVSS 208 Docket 69-7 of 1971.[1] This proposed standard required containment of unrestrained occupants during various planar impacts and 30 mph dolly rollovers for model year 1976 passenger vehicles forward. The requirement stated under S6-1: "All portions of the test device shall be contained within the outer surfaces of the vehicle passenger compartment throughout the test." It was obvious that tempered glass could not be used for relatively large moveable windows in vehicles that would be FMVSS-208 compliant, and the automotive industry resisted. Shortly thereafter, the NHTSA standard FMVSS-216, *Roof Crush Resistance*[2], was enacted and provided a substitute requirement, such that if a passenger vehicle met the modest 1.5X strength to weight ratio roof requirement, then the passive containment requirement of FMVSS-208 would not be enforced.

Stephen A. Batzer, Ph.D., P.E., PO Box 1276, Prairie Grove, AR 72753-1276

Since 1973, all manufacturers have chosen to use the FMVSS-216 standard rather than comply with the passive containment standard of FMVSS-208. However, this does not exempt them from all glazing regulation. The American regulation governing the choice of automobile glazing material is found in the Code of Federal Regulation, 49 CFR Ch. V, 571.205 Standard 205; *Glazing Materials*[3], which indicates (enumeration and italics added):

"The purpose of this standard is to:

1. *reduce* injuries resulting from impact to glazing surfaces, to
2. *ensure* a necessary degree of transparency in motor vehicle windows for driver visibility, and to
3. *minimize* the possibility of occupants being thrown through the vehicle windows in collisions."

This regulation, in part, codifies the ANSI/SAE Z26.1, *Safety Code for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways*,was last updated in 1996[4], and is currently under revision. Through the referenced standard, only laminated safety glass can be used for the windshields of passenger vehicles, and this material choice is deliberate to aid occupant retention in frontal collisions. For all other glazing applications, various types of tempered and laminated glass are currently allowed. As early as 1968, laminated side glazing has been described as "state of the art" for occupant containment[5].

Figure 1 documents that there has been a thirty-plus year contradiction within the federal regulations. Automotive glazing is regulated because of its profound influence on occupant safety, and an explicit goal of regulation is that all glazing minimize partial and full ejection of belted and unbelted occupants during collisions. However, the stated goal of the FMVSS-205 regulation does not distinguish between window type, ejection type, belt status, and collision type. Further, the referenced standard, ANSI/SAE Z26.1, has never required that laminated glass be used in any position other than the windshield. Thus, the federal regulation has not been consistent, and manufacturers have been free to produce vehicles with large, tempered glass side windows that do not have the inherent capability to protect occupants the way that laminated glass can.

On January 19, 2011, the Federal Register published their final rule on FMVSS 226, *Ejection Mitigation*, which addresses ejection from vehicle side windows during collisions[6]. This rule will require most windows of most vehicles to have on-board technology to passively eliminate ejections. Phase-in of the requirements begins September 1, 2013, and this regulation will be fully in effect on September 1, 2017. This new regulation only applies to the first three rows of those vehicles with a GVWR of 10,000 lbs or less. This rule does not address backlights or roof mounted glazing. This new rule followed the recent regulatory upgrades regarding side curtain airbags[7] and roof crush resistance[8]. NHTSA explicitly chose to optimize the side curtain airbags which they now require[7] rather than side glazing. According to NHTSA, "This final rule enhances the side curtain air bag systems installed pursuant to the FMVSS No. 214 side impact rulemaking." Thus, laminated glass may be the sole provider of ejection mitigation only

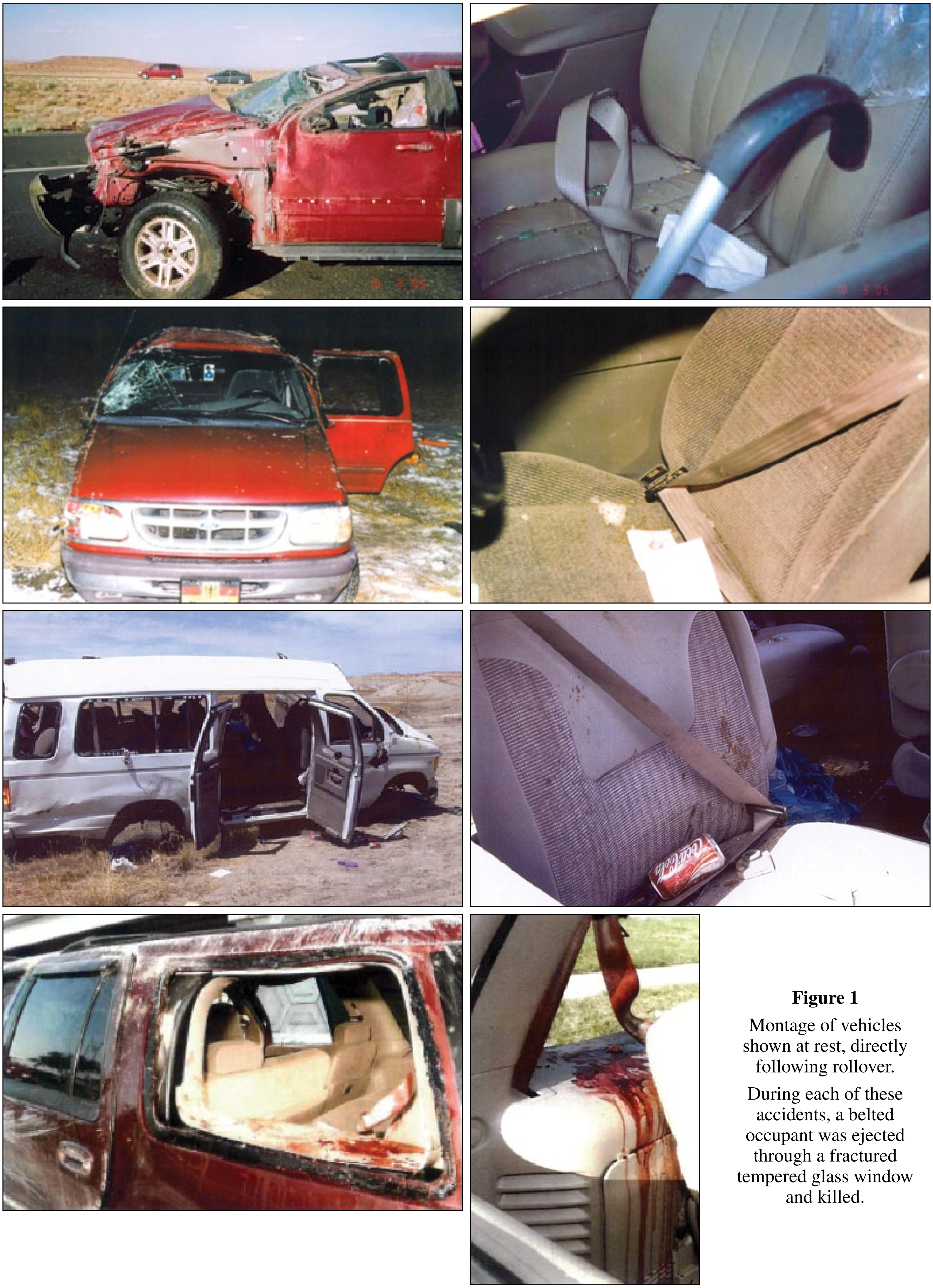

Figure 1

Montage of vehicles shown at rest, directly following rollover.

During each of these accidents, a belted occupant was ejected through a fractured tempered glass window and killed.

for fixed window positions. This allowance for fixed window locations preserves technology already in place[9]. Moveable window locations must have side curtain airbags nominally providing retention, but may have laminated side glass as a supplementary or even *primary* retention mechanism. Remarkably, the technical requirements of the standard do not distinguish which technology, the glazing or the airbag, actually provides retention in side moveable window positions. If a manufacturer produced a vehicle which had exceptionally penetration resistant moveable side glass, and weak, essentially useless side curtain airbags, the technical standards for occupant retention could still be met, even though the intention of the standard was not met. In the end, NHTSA "…encourage[s] manufacturers to enhance ejection mitigation with [laminated] glazing" as a supplement to the full coverage side curtain airbags.

Testing and Validation

There are numerous methodologies to validate the efficacy of automotive side glass for occupant retention. Each of these involves a blunt object of reasonable mass interacting with the glass from the inboard side, either by quasi-static or impact loading. These methods include pushout tests, drop silo tests, high velocity (HYGE) sled tests, and full-scale rollover tests of the entire vehicle/window systems. These tests have been done by the automotive industry, and the author's testing progression has largely followed that of industry. Note that there are no universally accepted tests for occupant retention other than field performance. See Figure 2. Laboratory tests that predict collision performance must therefore be reasonable, consisting of a blunt impactor striking the daylight opening with a velocity and interac-

Figure 2
Laminated side glass laboratory testing montage[10-13].

tion mass that simulate an interaction level that is at least typical. Such a test, if not standard and universally agreed to, cannot be declared to be correct, but nonetheless can be reasonable and valuable.

Ideally, validation testing requires building a prototype that is functionally, if not cosmetically, ready for public sale, and then conducting a destructive test that is either industry standard, replicates an accident of interest, or is sufficiently severe that it exceeds the severity of occupant window interaction in the majority of rollovers. For occupant retention side glass, this means installing the alternative design onto a passenger vehicle, then rolling the vehicle with belted and unbelted Anthropomorphic Test Devices (ATDs).The photographs in Figure 3 show five rollover tests with no side glass ejection.

Figure 3
Occupant retention glazing design testing validating using robotic steering (1 roll,upper left); dolly (2.75 rolls, upper right); sled (4 rolls, lower left); sled (5.5 rolls, lower right); robotic steering (1/4 roll, bottom).

NHTSA and other organizations have run various tests of this sort. An illustration of how well this testing has gone is shown in Figure 4 below. Each vertical line represents one test condition (some with replicates), and the success rate in retaining unbelted occupants (top) and belted occupants (bottom). These charts give evidence that properly supported laminated side glass is sufficient to completely retain both belted and unbelted occupants in over 95% of turnovers.

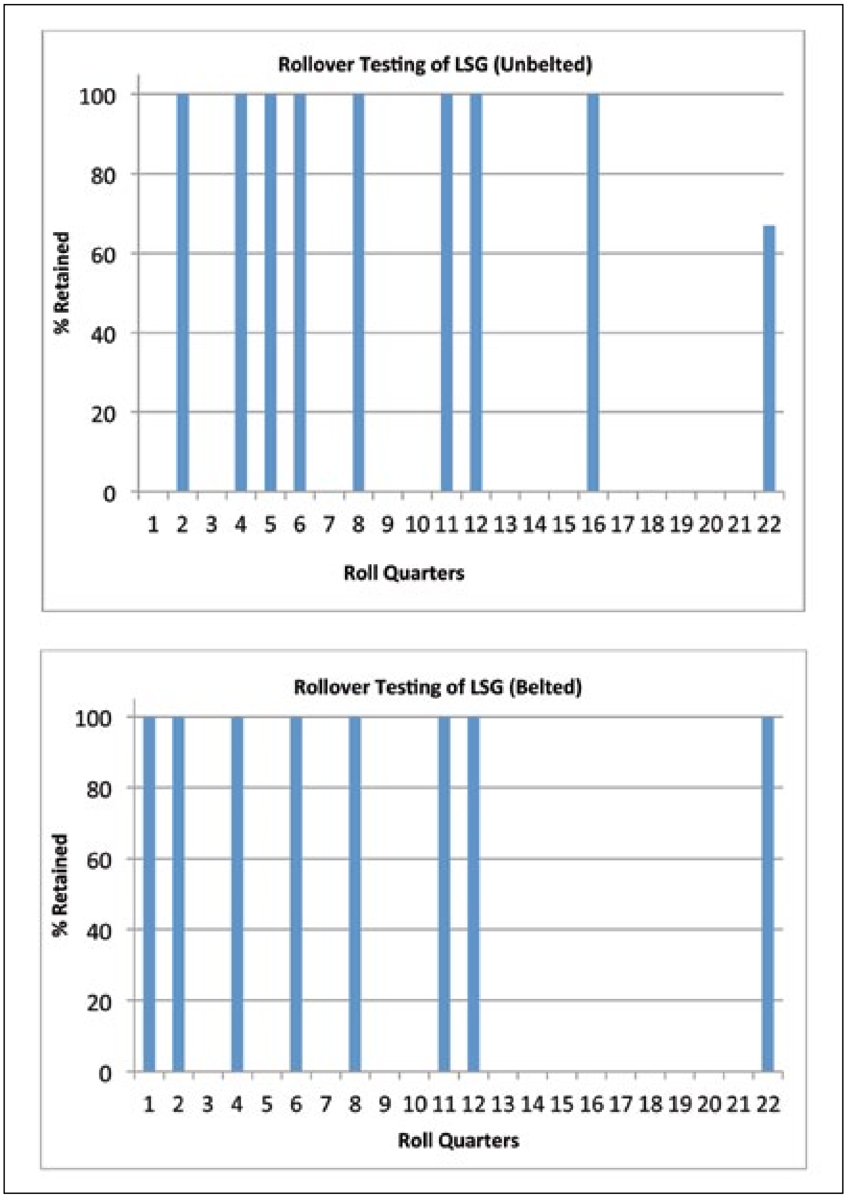

Figure 4
Testing success rate of laminated glass used to retain occupants in rollover collisions.
These two charts are based upon the data given in Table 1 below.

Table 1
Rollover Testing Relied Upon.

Roll Q's	Belt	% Retained	Type	Vehicle	Source / Reference
1	Yes	100	Dolly	88 Dodge Caravan	14
2	Yes	100	Friction	2006 XC90	15
4	Yes	100	Barrier	1995 Fiat Uno	16
4	Yes	100	Friction	01 Volvo V70XC	17
6	Yes	100	Dolly	88 Nissan Pickup	14
8	Yes	100	Dirt	Airflow	18
11	Yes	100	Dolly	2003 XC90	19
12	Yes	100	Dolly	1999 Navigator	20
22	Yes	100	Dolly	2004 XC90	21
2	No	100	Dolly	84 Honda Accord 4 dr	14
2	No	100	Dolly	88 Ford Bronco II	14
2	No	100	Dolly	79 Dodge Omni 4 dr	14
2	No	100	Dolly	82 Mercury Zephyr 4 dr	14
2	No	100	Friction	2006 XC90	15
4	No	100	Dolly	82 Chevy Celebrity 4 dr	14
4	No	100	Friction	01 Volvo V70XC	17
4	No	100	Dolly	88 Chevy CK-10 Pickup	14
5	No	100	Sled	Ford Aerostar	22
8	No	100	Dolly	1971 Pinto	23
11	No	100	Dolly	2003 XC90	19
16	No	100	Dolly	2006 XC90	24
22	No	67	Dolly	2004 XC90	21

Note that no ejections through the sunroof or windshield are tabulated, as the table represents testing of side glazing. Further, testing that is not representative of the alternative design or under inappropriate conditions purposing the glazing to fail is not considered to be relevant.

Table 2
Rollover Simulations Relied Upon.

Glass	Vehicle	Roll Q's	Virtual Dummy	Belt	Containment	Reference
Laminated	See Technical Manuscript				Pass	25
Tempered					Fail	25
Laminated	See Technical Manuscript				Pass	25
Tempered					Fail	25
Laminated	Toyota Pickup	8	Driver - 50th H-III	Yes	Pass	26
Tempered	Toyota Pickup	8	Driver - 50th H-III	Yes	Fail	26
Laminated	Toyota Pickup	8	Driver - 50th H-III	No	Pass	26
Tempered	Toyota Pickup	8	Driver - 50th H-III	No	Fail	26
Laminated	86 Toyota Corolla	6	RF - 5th F H-III	No	Pass	26
Tempered	86 Toyota Corolla	6	RF - 5th F H-III	No	Fail	26
Laminated	86 Toyota Corolla	6	RF - 5th F H-III	Yes	Pass	26
Tempered	86 Toyota Corolla	6	RF - 5th F H-III	Yes	Fail	26
Laminated	86 Toyota Corolla	6	RF - 50th M H-III	No	Pass	26
Tempered	86 Toyota Corolla	6	RF - 50th M H-III	No	Fail	26
Laminated	86 Toyota Corolla	6	RF - 50th M H-III	Yes	Pass	26
Tempered	86 Toyota Corolla	6	RF - 50th M H-III	Yes	Fail	26
Laminated	85 VW Jetta	4	RF - 50th M H-III	No	Pass	26
Tempered	85 VW Jetta	4	RF - 50th M H-III	No	Fail	26
Laminated	85 VW Jetta	4	RF - 50th M H-III	Yes	Pass	26
Tempered	85 VW Jetta	4	RF - 50th M H-III	Yes	Fail	26

Table 2, shown above, gives the results of 10 paired simulations of reconstructed rollover accidents (20 total simulations) done by NHTSA in 1994 and 1995. The results of the simulations uniformly show that tempered glass fails and laminated glass gives containment in rollover collisions under the conditions studied.

Failure Mechanisms

Rollover ejection in which the door remained closed is predominantly through fractured tempered side glass, as tempered glass is the dominant side glazing material. A casual survey of vehicles on the roadway confirms that the glazing is almost always fully up to keep the cabin comfortable, clean, and quiet. Although ejections through the windshield do occur, they are rare. The failure mechanisms of side glass have been cataloged by Batzer[13,27,28] Analysis of tests and unplanned rollovers shows that crash forces deform the body and fracture the glass. Fracture due to occupant contact is uncommon as the severity of occupant-to-glazing impacts are insufficient to fracture the glazing. While tempered glass will fracture completely and become an open portal for ejection, laminated side glass, properly framed and supported, will remain in place and act as a barrier to ejection with only minimal laceration potential. This potential is less than contact with tempered glass or with the environment exterior to the vehicle.

Figure 5
2004 GMC Yukon. Second row right window is ejection portal for 140 lb occupant. No glass fragments remain in seal, a forensic indicator that crash forces dislodged the glass followed by cantilever failure. No divider bar present.

The poorest window designs do not even support their tempered side glass, see Figure 5. The use of flexible polymer at the outboard periphery allows the glass to dislodge, making the weatherstripping, not the glass, the weak mechanical link of the glazing system.

The likelihood of ejection is proportional to the window size. Smaller windows present a lower likelihood of ejection[29]. One technique for size reduction is the incorporation of a vertical divider bar at the position of the head/shoulders. This must be a *structural* divider bar that can absorb occupant impact loading. Conventional yellow school buses are a primary example of horizontal structural divider bars. Many vehicles have divider bars to separate fixed windows (sail lights) from the larger moveable windows, see Figure 6.

Figure 6
Two SUVs of different generations with passenger's side second row failed, non-load bearing, divider bars. Each window was the ejection portal during a fatal rollover.

Of interest, a rollover demonstration has shown that the low-cost, low-tech solution of a divider bar will contain some occupants. Figure 7 shows a Volvo XC90 equipped with structural divider bars that retained a 50th percentile male ATD during a high velocity dolly rollover. Note that the roll rate in this demonstration exceeded 600 degrees per second, and is not representative of the vast majority of real-world rollovers. This vehicle was rolled at 43 mph, rather than the FMVSS-208 standard 30 mph, amongst other protocol differences[24].

Figure 7
Images from the Exponent rollover of an XC90, showing containment of the second row right side ATD by the structural divider bar that separates the moveable and fixed door glazing.

The fractography of glazing failure during collisions has been done with marginal results. The tempered glass through which an ejection occurred is largely absent and unable to be examined. A fracture origin determination is often possible only when facture occurred at the periphery and fragments near to the failure remain. Looking at the fracture surfaces provides little information. Tempered glass contains residual stresses from the tempering process, and occupant induced stresses (i.e., inside to outside forces against the glass), cannot be reliably detected.

Case Study 1

On May 31st, 2003, a 2000 Ford Explorer was traveling east on FM 582, Zavala County, Texas, with four unbelted occupants. The roadway made a sharp 90° turn at the intersection with CR 2010, which continued straight. The driver of the vehicle failed to negotiate the curve and continued straight onto CR 2010. At this point the driver lost control and the vehicle initiated a driver-side leading roll onto the flat soil roadside. During the rollover sequence, the two second row females were ejected from the second row of the vehicle and suffered fatal injuries, see Figure 8.

Figure 8
Accident vehicle. Notice gross intrusion of roof.

This is the first case in which a vehicle was held by the jury to be defective because its side glazing did not retain the occupants during a rollover collision, contrary to the purpose statement of the governing FMVSS 205 regulation.

Case Study 2

On October 22, 2004, a mother was traveling with her nine year-old daughter in a 2004 Chevrolet Tahoe in Round Rock, TX. According to the Texas Peace Officer's Report, "Unit #1 was yielding to north bound traffic in the 2700 block of S. IH-35 on the East Frontage from the IH-35 south-to-north turn around lane. Driver Unit #1 stated she maintained visual of the North bound traffic behind her vehicle when attempting to enter the roadway. Driver Unit #1 did not see the guardrail dividing the East Frontage between two outer lanes for traffic use and two inner lines for construction. Unit #1's LF struck the guardrail, causing Unit #1 to roll to the right. Unit #1 then came to rest on the vehicle's right side."During this minimally severe overturn, the right front passenger, was partially ejected and received significant injuries to her right hand and arm. See Figure 9.

Figure 9
Accident vehicle. Notice complete lack of deformation to window framing.

Figure 10
Accident vehicle scene photographs. Driver's adjacent side glass is unfractured, and seat belt is still latched.

Case Study 3

According to the Indiana Officer's Standard Crash Report, "V1 was traveling S/B on I65 when V1 drove off of the west side of I65. V1 continued S/B as it traveled off of the west side of I65. V1 struck an earth embankment on the south side of C.R. 1000 south Bridge as it continued S/B over the bridge embankment striking two cement drainage structures. V1 became air born [sic] as it left the north side of C.R. 1000 south bridge embankment. When V1 landed it started to flip several times, ejecting D1 from the vehicle. V1 came to rest facing west off of the west side of I65. The seat belt for the driver's seat was still fastened. D1 was ejected through the sunroof of V1. D1 still had the window seal gasket from the sunroof wrapped around his feet when medical personal [sic] arrived. D1 was pronounced dead at the scene at 9:59 a.m." See Figure 10.

Case Study 4

On March 29, 2006, the Beaumont High School Girls Soccer team, comprising 23 students, was on their way to a match, accompanied by 2 school officials and a bus driver. The driver took evasive action to avoid debris to her front, and left the roadway. The vehicle rolled onto its left side, partially ejecting several occupants who interacted with the exterior. Two students were killed, and numerous others suffered life-altering injuries. This bus was not equipped with seatbelts for any occupant other than the driver. See Figure 11.

Figure 11
Accident vehicle. Notice the size of the tempered side windows.

Conclusions

The case studies discussed above represent automobile accidents in which unprotected windows contributed significantly to life-altering injury and death. Prior to the introduction of side curtain airbags, laminated safety glass in side window positions was the only technology available to ensure full occupant containment for passenger vehicles with large windows. Laminated glass provides an energy absorbing function during rollovers that tempered glazing simply cannot. Further, as detailed by Batzer[12,13], laminated glass provides superior performance over that of tempered glass for each of the three safety purposes stated within the preamble of the FMVSS 205, which is why its use is mandated in the windshield position. In 2001[29], the NHTSA opined that, “Advanced glazing systems could save 537 to 1,305 lives annually…In addition 235 to 575 serious (maximum abbreviated injury scale (MAIS) 3-5) injuries could be reduced annually.”While the overall safety difference between side curtain airbags and laminated side glass is not yet clear, it is apparent that these technologies provide superior occupant protection, and both provide vital protection to those vehicles involved in rollover collisions.

References

1. FMVSS 208 Docket 69-7 of 1971.
2. 49 CFR Ch. V, 571.216 Standard 216, *Roof Crush Resistance*, 1973.
3. 49 CFR Ch. V, 571.205 Standard 205, *Glazing Materials*, 1968.
4. ANSI/SAE Z26.1-1996, American National Standard for Safety Glazing Materials for Glazing Motor Vehicles and Motor Vehicle Equipment Operation on Land Highways-Safety Standard.
5. Hill, G. P., "Occupant Protection … review of energy absorbing devices," SAE National Convention, 1969.
6. Federal Register, Federal Motor Vehicle Safety Standards, Ejection Mitigation; Phase-In Reporting Requirements; Incorporation by Reference. January 19, 2011.
7. 72 FR 51908, Docket No. NHTSA-29134, FMVSS-214 Final Rule, September 11, 2007.
8. 49 CFR Parts 571 and 585, Docket No. NHTSA-2009-0093, FMVSS-216 Final Rule, April 30, 2009.
9. PRNewswire, "PPG and Saflex Bond Together on Glazing System for New GM Vans," May 7, 2007.
10. Batzer, S. A., J. E. Evans, K. A. Allen, M. R. Martin, and D. R. Phillips, "Biomechanical Analysis of Headform Impacts into Automobile Side Glazing," ASME *2005 Summer Bioengineering Conference*, Vail Cascade Resort & Spa, Vail, Colorado, June 22-26, 2005.
11. Herndon, G. G., K. A. Allen, H. A. Roberts, D. R. Phillips, and S. A. Batzer, "Automotive Side Glazing Failure due to Simulated Human Interaction," *Engineering Failure Analysis*, Vol. 14, Issue 7, pp. 1701-1710, December, 2007.
12. Batzer, S. A., C. K. Thorbole, G. G. Herndon, and D. Beltran, "Injury Analysis of Laminated and Tempered Side Glazing," *20th International Safety Conference on the Enhanced Safety of Vehicles*, Paper No. 07-0101-W, Lyon, France, June 18-21, 2007.
13. Batzer, S. A., G. G. Herndon, C. K. Thorbole, H. Chamberlain, D. R. Phillips, and H. Yudenfriend, "Automotive Side Glazing for Primary and Secondary Occupant Retention," SAE 2007-01-1546, 2007.
14. Clark, C., and P. Sursi, "Rollover Crash and Laboratory Tests of Ejection Reduction by Glass-Plastic Side Windows and Windshields," SAE 890218, 1989.
15. Engineering Institute Testing - remotely piloted rollover of a 2006 Volvo XC90 SUV with 4 ATD occupants, July 23, 2009.
16. Giavotto, V., "Ejection Through Sidewindows: Relevance And Countermeasures," Paper No. 530, Proceedings, 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan, May, 2003.

17. Engineering Institute Testing - remotely piloted rollover of a 2001 Volvo V70XC station wagon with 4 ATD occupants, September 24, 2008.
18. Video - 1934 Chrysler Airflow sedan rollover, undated; no documentation. Barrel rollover with 8 corner impacts of a sedan on a dirt field with no glazing fracture. The car drives away.
19. Engineering Institute Testing – SAE J2114 dolly rollover of a 2003 Volvo XC90 SUV with 6 ATD occupants, 3 belted, 3 unbelted, March 15, 2010.
20. Video and documentation - 1999 Lincoln Navigator rollover with laminated side glazing in the cargo area by Autoliv for the Ford Motor Company.
21. Engineering Institute Testing – Dolly rollover of a 2004 Volvo XC90 SUV with 6 ATD occupants, 3 belted, 3 unbelted, October 26, 2009.
22. Eliseco Systems sled rollover testing of a modified 1990 Ford Aerostar van, July 2, 2008.
23. Mark, J. A., Final Test Report – Crash Test 2661 of a Ford Pinto, September 18, 1973.
24. Batzer, S. A., G. G. Herndon, P. T. Semones, C. Thorbole, M. Ziejewski, and R. Hooker, "Automotive Side Glazing Ejection Mechanisms Part II – Review of Recent Glazing Literature," *ASME International Mechanical Engineering Congress & Exposition*, Boston, Massachusetts, IMECE2008-68483, 2008.
25. Digges, K., A. C. Malliaris, and H.J DeBlois, "Opportunities for Casualty Reduction in Rollover Crashes," 14th International ESV Conference, Munich, Germany, May, 1994.
26. NHTSA Advanced Glazing Research Team; "Ejection Mitigation Using Advanced Glazing: A Status Report," Docket 95-941-GR-002, November, 1995.
27. Batzer, S. A., "Performance of Automotive Side Glazing In Rollover Collisions," *Materials Science & Technology 2005 Conference and Exhibition*, Failure Analysis Symposium Proceedings, Pittsburgh, Pennsylvania, pp. 81-91, September 25-28, 2005.
28. Batzer, S. A., "Failure Mechanisms of Automotive Side Glazing in Rollover Collisions," *Journal of Failure Analysis and Prevention*, Vol. 6, No. 3, pp. 6-11 and 33-34, 2006.
29. NHTSA Advanced Glazing Research Team; "Ejection Mitigation Using Advanced Glazing: Final Report," August, 2001.
30. Johnston, D., and C. Moskowitz, "Glass Breakthrough Profitable for Volvo," Press Release, July 30, 2000.
31. Batzer, S. A., R. D. Burgess, and C. A. Brown, "Axiomatic Design of Automotive Roof Structures," SAE 2007-01-0685, 2007.
32. Chandrasekaran, V. C., "Essential Rubbery Formulary," William Andrew Publishing, 2007.

Appendix I: Occupant Retention Glazing Design

Occupant retention laminate side glazing must address three primary failure mechanisms. First, the window frame must not pull down in cantilever failure during rollover due to ground interaction. Second, the glazing material must be energy absorbing and resist loading perpendicular to the plane. Third, the window must have sufficient peripheral fixation to not pull out due to loading. Mercedes-Benz has recently addressed one additional aspect. Their newer vehicles will rapidly close side windows and the sun roof when the vehicle senses that a crash is imminent. The graphic below shows an occupant retention glazing design overview. The door shown is a Volvo S60, which is advertised to have an occupant retention feature on the window monogram.[30]

<table>
<tr><td>The run channel will be deep, providing approximately 0.5” of steel flange exterior overlap over the glass to provide a peripheral friction lock on the glass.</td><td>Roof that supports glass will be essentially non-deforming in rollover, approximately 4X strength to weight ratio when measured by FMVSS-216 protocol.[31]</td><td>Window frame is below roof rail to prevent cantilever failure as the roof rail interacts with the ground during turnover.</td></tr>
<tr><td>Outer and inner plies of glass will be soda-lime composition with iron oxide additions. Glass plies will be 2.1 mm thick, heat strengthened to 24-52 MPa. Edge grinding will conform to SAE Recommended Practice J673a, Automotive Glazing</td><td rowspan="3">
<u>Driver’s door and window</u>

Rear doors will incorporate a structural divider bar with the sail light having its characteristic dimension of less than 8”. That is, an 8” sphere will not be able to pass through the daylight opening with the glass removed.</td><td>Regulation (retraction / elevation) shall use a scissor or cable design within the door proper. Manual or electric regulation.</td></tr>
<tr><td>The laminated glass will have a 0.030” (0.76mm) PVB interlayer. This will be stiff formulation, similar to aircraft PVB, rather than conventional automotive windshield PVB.

Tempered glass will only be used in small windows unable to permit occupant ejection.</td><td>The door and window will maintain a conventional shape. An occupant retention window will not be distinguishable from one which is not by the casual user. This must be a framed design with a metal periphery surrounding the entire window.</td></tr>
<tr><td>Weather stripping uses conventional polymer per Chandresekaram.[32]</td><td>Window monogram per ANSI Z26.1, Marking of Safety Glazing Materials with St. Gobain/Sekurit pictogram indicating occupant retention.</td></tr>
<tr><td>Child-resistant regulation switches will prevent unwanted raising of the window when an unattended child rests his hands on the switches and the window is down.</td><td>Glazing will be affixed below the belt line using a wide (10” minimum engagement) aluminum U-channel.</td><td>The window will incompletely retract in order to discourage the occupant from resting his arm on the window during travel.</td></tr>
</table>

Figure 12
Occupant retention side glazing design for movable side windows.