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Novel Lightweight Laminate Concept with Ultrathin Chemically Strengthened Glass for Automotive Windshields

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ABSTRACT

This paper proposes a novel concept for lightweight vehicle design, offering a step change in weight reduction for automotive glazing. Reducing window weight can be achieved by decreasing the thickness of the glass plies used to form vehicle windows. However, reducing the thickness of conventional automotive windows also decreases its effective strength; therefore, concerns about glass breakage become a limiting factor for weight reduction.

Chemically strengthened ultrathin Corning® Gorilla® Glass offers the potential to go beyond existing thickness limitations. Its higher strength compared to standard soda lime window glass allows the design of thin, low weight window constructions. In addition, its unique manufacturing process delivers pristine glass surfaces and precise thickness control for high quality window optics.

While this concept can be applied to all vehicle openings, this study focuses on automotive windshield design. By replacing the thick inner ply of a windshield laminate with an ultrathin Gorilla Glass ply, a significant weight reduction can be achieved. An overall reduction in windshield weight of more than 30% can be achieved with the proposed constructions in comparison to conventional designs. Test results will be discussed to demonstrate concept feasibility under consideration of regulatory and OEM vehicle design criteria. Benefits, as well as trade-offs, will be reviewed.

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INTRODUCTION

The worldwide trend towards tightening emission legislation and improved fuel consumption continues to drive innovation in the space of automotive vehicle design. Additionally, consumers' demand for higher vehicle performance and better drive dynamics is increasing.

OEMs are pursuing various technical paths in parallel to meet these targets. As such, lightweight design is becoming increasingly important, and automotive glazing is an attractive option for vehicle weight reduction. Removing mass above the vehicle belt line not only improves fuel consumption and vehicle performance, but also lowers the center of gravity, which leads to better drive dynamics and stability.

Laminates made from two plies of annealed soda-lime glass (ASLG) have been the standard material of choice for automotive windscreen glazing. The windshield mass can be reduced by decreasing the thickness of the glass plies used in the laminate.

However, effective glazing strength is decreased when the thickness of conventional window glass is reduced. Concerns about potential glass breakage during window manufacturing processes throughout the supply chain, installation at the vehicle assembly lines and, in particular, during in-vehicle use have defined the lower limits of window glass sheet thickness [1].

Gorilla Glass for Automotive (GGfA) offers a solution to these challenges. GGfA is a chemically strengthened alumino-silicate glass. When used in an automotive window laminate, its higher strength compared to soda-lime glass (SLG) enables a decrease in glass ply thickness down to 0.7 mm and below, while current standard window glass sheets range from 1.6-2.5 mm for the majority of applications. A significant weight reduction can be achieved by replacing the relatively thick SLG plies with thin GGfA.

In addition to meeting regulatory requirements, trade-offs need to be considered when designing thinner lightweight glazing. Impact resistance, acoustic performance, window stiffness, and optical performance are functions that must be considered.

In 2014 GGfA was introduced into a first automotive series application by a leading OEM for an interior acoustic partition [2]. In parallel, several OEMs interested in lightweight innovations are evaluating GGfA for external vehicle openings. This paper will explore the rationale for using GGfA in a windshield application.

WINDSHIELD DESIGN WITH GORILLA GLASS FOR AUTOMOTIVE

In 2007 Gorilla Glass was introduced as a cover glass for consumer electronic devices. It has been used in billions of devices worldwide and has demonstrated improved damage resistance to protect electronic devices from every day wear and tear [3]. As customer needs have evolved over time, the glass has been optimized to meet new requirements for consumer electronics. A similar evolution is expected for GGfA in automotive glazing applications.

GGfA Manufacturing Process

GGfA is made using a Corning proprietary fusion draw process. It yields thin sheet glass with pristine surface quality, high optical clarity, and inherent dimensional stability.

The raw materials are blended into a glass composition that is melted and conditioned. The molten glass is fed into a trough, overfilling it until the glass flows evenly over both sides. It then rejoins, or fuses, at the bottom, where it is drawn down to form a continuous sheet of flat glass. The glass is untouched by human hands or anything else that may introduce flaws into the surface.

Figure 1. A schematic of the fusion draw process.

The GGfA composition is engineered for deep chemical strengthening through an ion-exchange process [4]. In this process the glass is placed in a hot bath of molten salt at a temperature of approximately 400 °C. Smaller sodium ions leave the glass, which are replaced by larger potassium ions from the salt bath. These larger ions take up more volume and are pressed together when the glass cools, resulting in a layer of compressive stress on the surface of the glass (Figure 2).

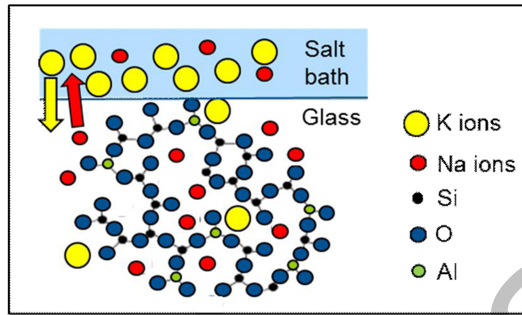

Figure 2. A schematic of the GGfA ion-exchange process.

GGfA is specially designed to maximize ion exchange. The increase in retained strength of the glass is achieved by creating a deep layer of surface compression, while the core of the glass experiences residual tension. Compared to ion-exchanged SLG, a much deeper compressive layer can be achieved with GGfA, resulting in significantly higher damage tolerance at the same glass thickness than for chemically strengthened SLG.

For non-windshield automotive glazing applications, SLG is typically strengthened in a thermal tempering process. A rapid cool down of the molten glass sheet's surface creates a compression zone in the outer glass surfaces as the inner core cools down slowly. This method relies on thermal gradients during cool down and is most effective above 3 mm glass thickness to achieve a full temper. The ability to achieve significant thermal gradients through the glass becomes limited with thinner SLG glass and therefore, the ability to strengthen the product is significantly reduced. Therefore, a strength increase through thermal strengthening is typically limited to glass thickness greater than 1.5 mm for SLG.

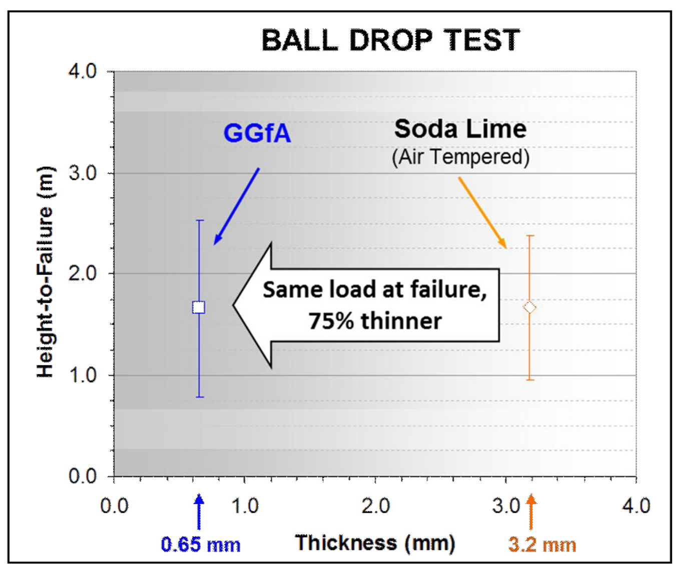

Figure 3. Ball drop test results of GGfA and fully air-tempered SLG.

Figure 3 shows the results of a ball drop test, which compares the impact resistance of GGfA with fully strengthened SLG (air-tempered). In this test a 128 g steel ball was dropped onto 4 inch × 4 inch glass samples. The height to failure was recorded and represents the energy needed to fracture the glass. Fully tempered SLG has to be 4-times thicker to achieve the same performance as 0.65 mm GGfA.

Laminate Windshield Design

Conventional Windshield Constructions

Windshields currently in use are designed as laminates due to regulatory safety requirements. Laminates offer additional advantages versus monolithic windows, including improved acoustics for better comfort inside the car, better solar management, theft control, passenger retention in case of accidents, and others. Indeed, a trend towards using laminate windows for all other car openings can be observed in the automotive industry.

The basic windshield laminate construction consists of two glass plies laminated with a Poly Vinyl Butyral (PVB) interlayer (Figure 4).

Typically, annealed SLG has been used for windshield laminates with a common configuration of two 2.1 mm-thick glass plies (2.1 ASLG/2.1 ASLG). Variations in ply thickness exist and some lighter weight technologies apply a configuration of 2.1mm as the outer ply that is paired with a sheet of 1.6 mm on the inner side of the windshield (2.1 ASLG/1.6 ASLG). For this study, 2.1 ASLG/2.1 ASLG was chosen as a benchmark for comparison against the proposed lightweight solutions.

The PVB interlayer delivers multiple functions. It retains glass particles in case of window breakage, enables passenger retention in accidents, dampens noise from wind and other sources, and can protect against UV and IR transmission into the vehicle. Tinted PVB versions are also available to reduce total light transmission. Acoustic PVB interlayers (APVB) can further reduce sound transmission compared to standard PVB (SPVB).

GGfA Windshield Design and Weight Savings

The inherent high strength of the GGfA material allows for the use of thinner glass for windshield glazing while mitigating risks for breakage and impact performance. In this paper we demonstrate that the preferred way to deploy GGfA in a windshield design is to use it as the inner ply in a ASLG/GGfA hybrid configuration (Figure 4).

The proposed lightweight windshield constructions in this study employ an inner ply of 0.7 mm thin GGfA, which enables window weight savings; 2.1mm SLG is used as the exterior ply of the windshield to provide stiffness and the desired breakage pattern in the event of road hazard-induced fracture.

Typical passenger car size windshields cover an aperture area of about 1.4 m^2. Replacing a 2.1 ASLG/2.1 ASLG windshield with 2.1 ASLG/0.7 GGfA reduces the weight by 4.9 kg (31%) from 15.8 kg to 10.9 kg, assuming a SPVB thickness of 0.76 mm.

The fusion draw process allows production of GGfA in even thinner plies, offering additional weight savings potential. For example, a 2.1 ASLG/0.55 GGfA design will decrease the windshield weight by 5.4 kg to 10.4 kg, delivering a 34% weight reduction. Testing of that construct and more extreme constructions is underway. Preliminary data of 2.1 ASLG/0.55 GGfA is shown below.

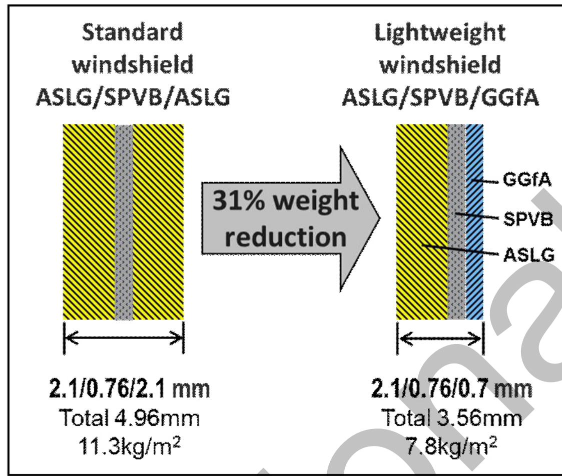

Figure 4. Standard and proposed lightweight windshield construction.

LIGHTWEIGHT WINDSHIELD EVALUATION

Thinner glass in automotive windows can be used to reduce weight; however, potential design trade-offs need to be considered. Regulatory requirements and external impact, acoustic, stiffness, and optical performance criteria must still be met with thinner constructs, which are addressed below.

Regulatory Requirements

The proposed lightweight windshield design was first evaluated in regards to compliance with regulations. Tests were conducted according to US regulations FMVSS 205 (ANSI Z26.1) and European requirements as defined in ECE R43 Rev. 3 for windshield applications.

The 2.1 ASLG/0.7 GGfA design passed all regulatory tests in the internal evaluation. Testing of the 2.1 ASLG/0.55 GGfA construction is ongoing; initial test results are positive.

Overall, test results indicate that these lightweight designs are likely to pass certification against these standards.

Beyond regulatory requirements, the breakage patterns in case of severe external impact was evaluated as well. In that evaluation, comparable visibility was observed for the proposed GGfA design and conventional ASLG constructions.

Impact Performance

Windshields are subjected to a wide variety of road hazard impact events, which is the greatest cause for windshield replacements. Breakage of the lightweight windows at various loads and speeds was explored. The goal was to achieve a similar performance as standard SLG constructs with the thinner windshield design.

A series of tests was performed to evaluate the robustness difference between standard SLG windshield constructions and the proposed GGfA lightweight design.

Ball Drop Test

Windows are subjected to a variety of events that introduce scratches and other flaws on the glass surface during window manufacturing processes, window assembly at the OEM lines, and in-vehicle use, which weaken the window. Glass breaks when sufficient tension is applied to these flaws and exceeds the material's critical stress intensity or fracture toughness.

To simulate these real life conditions and evaluate retained strength after abuse, the laminate test samples were abraded. The flaws were created on the side opposite to the area where the object hits the laminate because the tension is the highest at that location during an impact from the opposite side.

A 90 grit silicon carbide abrasive was applied at 4 psi pressure to abrade each sample surface with a 5 mm diameter circle in the center of the part to normalize flaw distribution between sample groups.

For the test a 227 g stainless steel ball was dropped on flat 12 inch × 12 inch laminate samples in accordance with ANSI standards (Figure 5).

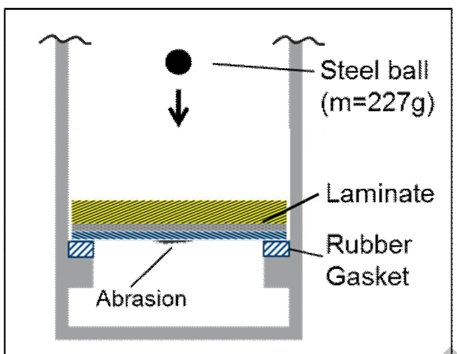

Figure 5. Ball drop test schematic (not to scale).

The ball drop height was incrementally increased until one of the glass plies in the laminate sample broke. The height to failure was recorded and plotted in a Weibull probability plot [5].

Both lightweight constructions exceeded the performance of the 2.1 ASLG/2.1 ASLG standard windshield construct (Figure 6). The thin ASLG/GGfA hybrid designs were 31-34% lighter yet still provided higher impact resistance than the SLG construction. Heights to failure at the 20th percentile Weibull value were 6-8 times higher for the lightweight constructions than for the thicker standard windshield.

The GGfA hybrids were not significantly different from each other in performance at a confidence interval of 95%. They exhibited a wider variability compared to ASLG/ASLG, which may be due to the difficulty of hitting the abraded spot from higher drop heights.

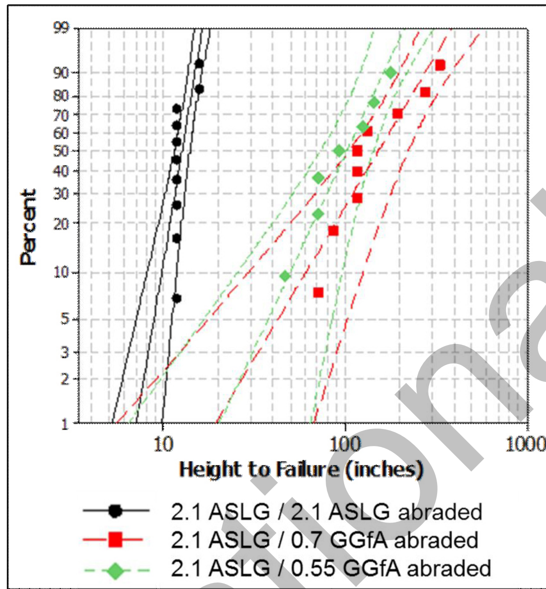

Figure 6. Ball drop test results of several laminate constructions (227g steel ball, Weibull with 95% confidence interval).

Ball Bearing Test

A ball bearing test was used to simulate stone impact at higher vehicle driving speeds. The impact object was a 1g stainless steel ball bearing with ¼ inch diameter. The ball bearing impacted the flat laminate samples at an angle of 45° (Figure 7). Samples were not abraded.

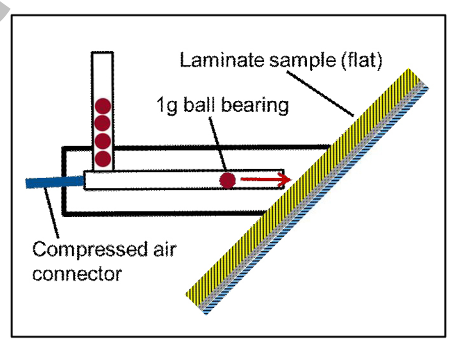

Figure 7. Ball bearing test apparatus (schematic).

The ball bearing velocity was increased in increments of about 5 mph until the test sample fractured. The threshold velocity at which fracture occurred was recorded and was plotted in a Weibull plot (Figure 8).

Based on 20th percentile Weibull values, the threshold break velocities of the thin ASLG/GGfA lightweight laminates were about 50% greater than the conventional ASLG laminates.

Again, 2.1 ASLG/0.7 GGfA and 2.1 ASLG/0.55 GGfA were not significantly different in performance, but both clearly performed better than the ASLG laminate.

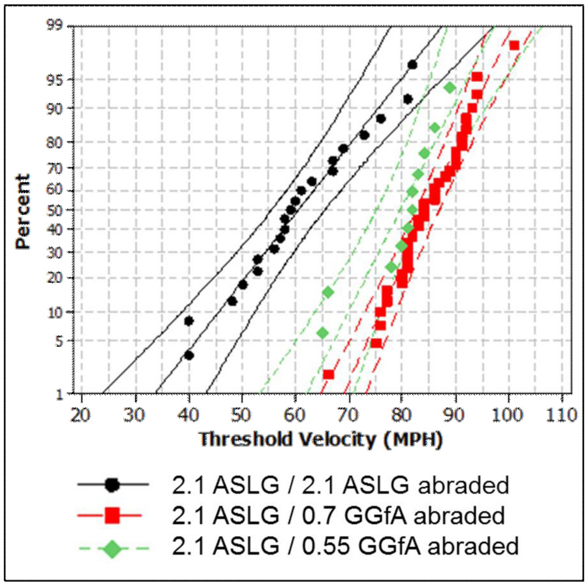

Figure 8. Ball bearing test results (45° incident angle, 1g ball bearing, Weibull with 95% confidence interval).

Hail Impact

Hail is another potential cause for windshield breakage in service. Ice balls (44 mm diameter) were shot against the samples at a 90° angle to evaluate the hail impact robustness of the lightweight laminates (Figure 9).

Figure 9. Hail impact test apparatus.

The impact speed was 72 mph, which represents the terminal velocity of hail this size falling through the atmosphere. The sample surface opposite of the impact side was abraded to obtain results on retained strength after simulation of real-life abuse.

Test groups included various constructions, while for each group the outer layer (where the impact occurred) was a ply of 2.1 ASLG. The inner ply was varied to make up the test groups. For the control group, standard 2.1 ASLG inner ply was used. For a second group, a very thin prototype glass sheet of 1.0 ASLG was used. A third and a fourth group utilizing GGfA inner plies were evaluated with thicknesses of 0.7 mm and 0.55 mm respectively.

The results are summarized in Table 1. Both ASLG/ASLG constructions fractured during the ice ball impact. As expected, the inner ply, which is opposite of the impacting ice ball, fractured as it experienced the highest tensile stresses during impact. ASLG strength was not sufficient to withstand these impact stresses.

Neither of the two ASLG/GGfA constructions broke from the hail impact. The strength of both GGfA constructions with 0.7 mm GGfA and the thinner 0.55 mm GGFA was greater than the stresses during impact.

Table 1. Hail impact test results.

Construction Tested		Breakage
ASLG/ASLG	2.1/2.1	Inner ply
	2.1/1.0	
ASLG/GGfA	2.1/0.7	None
	2.1/0.55	

High Velocity Impact on Windshields

To assess glass breakage and particle ejection behavior during very high impact speeds, a 1 gram, ¼ inch diameter stainless steel ball bearing was shot at the outer side of a windshield sample. The ball bearing velocity was approximately 120 mph with an impact angle of 90°.

In this test, a series production full-size windshield was used as the reference. A commercially available lightweight version was chosen in 2.1 ASLG/1.6 ASLG. The GGfA design was a 2.1 ASLG/0.55 GGfA prototype windshield that was made with the same dimensions as the series windshield.

It was expected that the projectile would break the window at that high energy impact. However, differences in fracture behavior and particle ejection into the interior of the car towards the passenger compartment were observed.

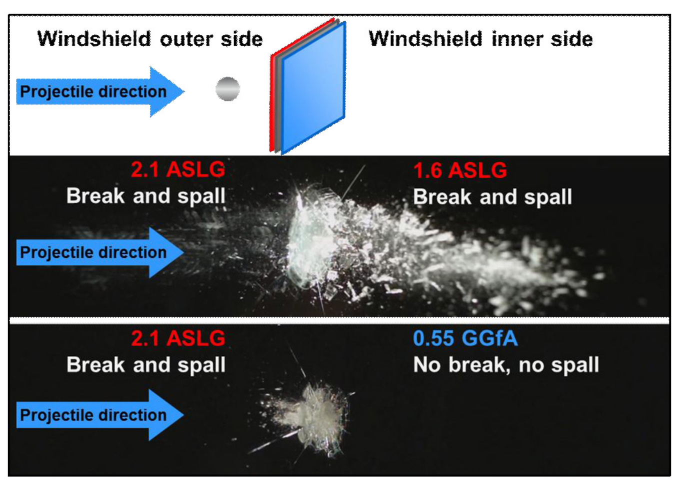

Figure 10. Photographs of high speed ball bearing windshield impact of two laminate constructions (1 gram, ¼ inch diameter projectile, 120 mph, 90° incidence angle).

A high speed camera was used to record the breakage behavior. Figure 10 shows the breakage milliseconds after the projectile had hit the windshield's outer side. The top picture shows the 2.1 ASLG/1.6 ASLG standard windshield, while the lower picture shows the 2.1 ASLG/0.55 GGfA construction.

To observe the impact by high speed video, the test set up, background, and light conditions had to be chosen such that the actual windshield cannot be seen in the pictures of Figure 10. The schematic at the top of the figure shows the orientation of the actual windshield.

For both constructions, the projectile did not penetrate the windshield; the projectile broke the outer 2.1 ALSG ply and was deflected. The inner ply was also broken in the all ASLG construct, and a significant number of particles were ejected in the direction of the interior of the car. In contrast, the GGfA ply did not break, and particle ejection towards the interior was not experienced. The fracture and particles shown in the bottom frame of Figure 10 are the result of the outer ply breakage.

In summary, the ASLG/GGfA lightweight constructions exceeded the performance of the standard ASLG/ASLG performance in all of the impact tests. Additional ball drop and ball bearing external impact tests of various hybrid laminate constructions showed that performance was better when GGfA was used as the inner ply as opposed to the outer ply.

Regulatory tests represent the minimum windshield requirements. The tests described here were chosen to provide complementary and broader information about the robustness of the proposed GGfA design in various potential impact situations.

Acoustic Performance

Reduced windshield thickness may increase perceived noise inside the vehicle. In general, higher comfort and low noise levels in the car interior is preferred by consumers; therefore, a perceivable noise increase is not desired.

It has been shown in a laboratory setting with flat window glass samples, that sound transmission is affected by the window design. Reducing the glass ply thickness at a constant PVB interlayer thickness will result in higher sound transmission. However, sound transmission can be reduced in the frequency range of most sensitive hearing by proper design of the viscoelastic PVB interlayer [6].

The noise levels passengers actually perceive in the interior of a car are also impacted by other factors. For example, noise source intensity at a particular window location and window area play a major role. An acoustic model was developed to estimate the perceived sound pressure levels (SPLs) in a vehicle. The model was calibrated against actual sound pressure levels measured inside of a high-end series sports utility vehicle.

The car's baseline glazing constructions are shown in Table 2. For the windshield a 2.1 ASLG/2.1 ASLG construction with an acoustic PVB interlayer was used. Monolithic tempered SLG was utilized for all other openings.

Table 2. Base glazing constructions used in acoustic modeling.

Glazing Position	Reference construction
Windshield	2.1 ASLG / APVB / 2.1 ASLG
Front side glass	3.85mm tempered SLG monolith
Rear side and cargo	3.15mm tempered SLG monolith
Backlight	3.15mm tempered SLG monolith
Sunroof	3.85mm tempered SLG monolith

Statistical energy analysis was used to model the effect of substituting the reference case windshield with our lighter ASLG/GGfA windshields, keeping all of the other glazing constructions unchanged. The constructions of the lightweight windshield substitutions were 2.1ASLG/APVB/0.7GGfA and 2.1ASLG/APVB/0.55GGfA.

Each of the noise sources (wind noise, reverberant or point source) were applied to all of the indicated glazing positions. In addition, a flanking (non-glazing) noise source was applied.

The reference case was modeled with all glazing and flanking noise paths active, and then the windshield was replaced with each of the ASLG/GGfA laminates. The resulting effect on sound pressure level at the driver's ear was calculated as a function of sound frequency.

Frequency-dependent SPL results were converted to Sones using ISO 532 Method A adapted to 1/3 octave intervals. Sones are used to represent frequency-dependent SPL results in terms of a single number on a linear scale that approximates perceived loudness.

Turbulent (wind noise) load consists of an acoustic load excitation in the near field and a structural vibration excitation in the glass. For a reverberant load, a 100 dB acoustic load was applied to each glazing position to simulate a distributed and uniform reverberant acoustic load as experienced when driving through a tunnel.

For the point source load, a 110dB source located 2 meters from the car and 2 meters high was assumed. The acoustic loads calculated for each glazing position were based on the geometry of the test vehicle. This load is intended to simulate driving next to a truck.

Wind noise modeling results are shown in Figure 11. Despite replacing the thick 2.1ASLG/APVB/2.1ASLG series windshield with the thinner lightweight GGfA windshields, there was no perceived SPL difference for frequencies below 5000 Hz. Only a small difference was calculated above 5000 Hz; SPL in that region was 0.7 to 0.8 dB greater for GGfA laminates compared to the reference case.

It can be concluded that in the 1000 Hz to 5000 Hz range, where the human ear is most sensitive, there is no significant difference in perceived wind noise loudness.

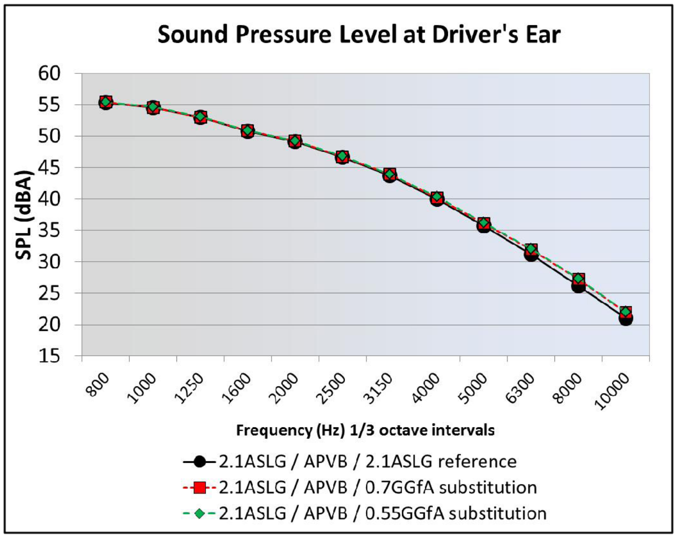

Figure 11. In-vehicle sound pressure level for lightweight windshields and standard reference (modeling results, wind noise).

While wind noise is present in most driving conditions, reverberant and point loads were also investigated, although they are less frequent in day-to-day vehicle use.

Figure 12 summarizes the effect of the windshield replacement for all three sources of noise using Sones to measure perceived loudness in the car over all frequencies. The model predicted only a small acoustic penalty with the reverberant and point sources for the thinner windshields.

Intuitively, referencing the standard measurement method of sound transmission loss, a penalty would also be expected in perceived sound levels inside a car. However, the presented model predicts no noticeable change in SPL in the vehicle when replacing the standard thicker windshield with the lightweight designs. Other openings and sources of noise are more dominant inside the vehicle.

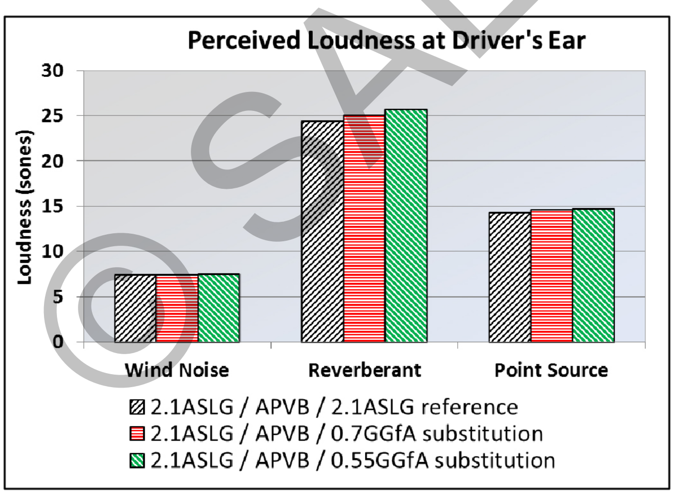

Figure 12. Modeling results for in-vehicle sound pressure level for different noise sources (in Sones).

Therefore, to evaluate the actual acoustic impact for a specific vehicle application, measuring the different window designs in a real test vehicle is recommended.

Stiffness

Windshield stiffness is an important design variable as it determines deflection under load conditions. For example, high deflection under wind load could compromise wiper contact under high speed driving conditions.

Under a load F, the deflection δ of a glass sheet with a Youngs-Modulus E, length L, width b, and thickness t can be calculated as shown in Figure 13.

$$\delta = FL^3 / 4Ebt^3$$

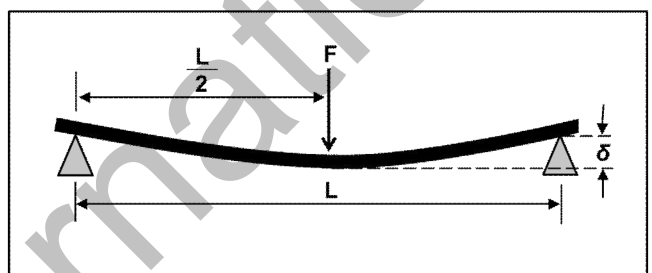

Figure 13. Schematic of glass sheet deflection.

As glass deflection is a function of its thickness cubed, reducing the thickness will significantly decrease stiffness. The Young's-Modulus of GGfA and SLG are similar. Therefore, that relation is equally valid for both materials. The difference, however, is that GGfA can withstand much higher stresses compared to SLG.

Applying that principle to laminates, a similar relation can be found. A ball-on-frame model was developed to estimate the deflection of laminates under load. It assumes a point load F (representing a steel ball) applied onto the center of a flat, square laminate sample (12 inch x12 inch) positioned in a frame and clamped at the edges. The model was validated using strain gauges with different laminate constructions.

Figure 14 shows the results of that model for a constant force F=100 N applied to flat laminates with different combinations of outer and inner ply thicknesses. Total glass thickness was kept constant to show the impact of the constructions' degree of asymmetry on deflection. The APVB at 0.81mm thickness was kept constant.

The results indicate that asymmetric constructions where one ply is thicker than the other deflect less than symmetric constructions where both plies have the same thickness. Based on above relationship of deflection and thickness of glass sheets, the thicker ply dominates the total laminate stiffness. For example, for a 2.1/0.7 configuration, the model estimates about 20% lower deflection compared to a 1.4/1.4 laminate.

When designing thin lightweight windshields, that result may become very important. A high degree of asymmetry helps to increase window stiffness at a given total laminate thickness target. In addition, other factors such as size and curvature need to be considered for actual windshields.

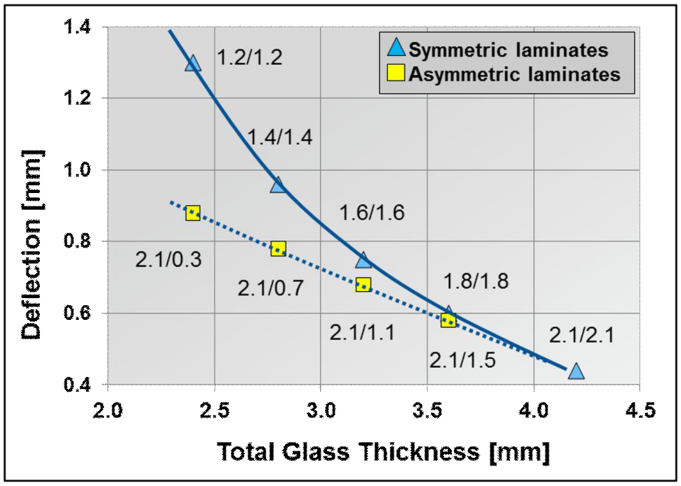

Figure 14. Modeling results for deflection for symmetric and asymmetric laminates (Ball-on-frame case).

Optical Performance

Standard SLG exhibits draw line distortion when produced in a typical float glass process [7]. Thin float glass is particularly prone to this feature due to the faster processing speeds required. Draw line distortion is a significant concern for windshield manufacturing. Draw line distortion can be observed under certain viewing angles, particularly when viewed in a cross-car perspective. In contrast, the GGfA fusion draw process produces glass with excellent optical quality at any thickness.

Figure 15 shows a side-by-side comparison of SLG and GGfA. Using a Xenon point light source at a 65° viewing angle, optical distortion due to the draw lines on SLG can be clearly seen, whereas the GGfA ply has no visible distortion. Therefore, less distortion is expected when looking through a windshield from an angle for the proposed GGfA lightweight constructions.

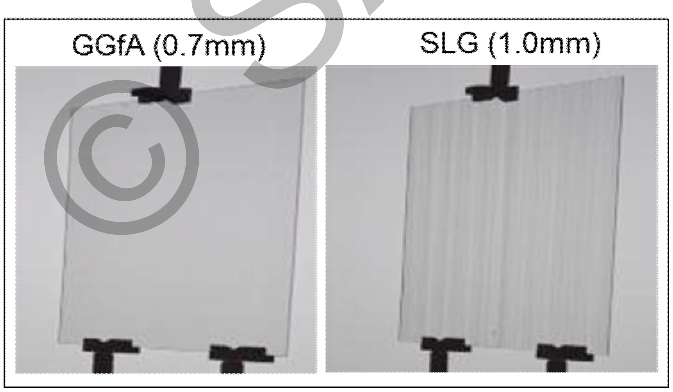

Figure 15. Photographs of optical distortion in GGfA and SLG (65° viewing angle, point light source).

A second optical advantage of the lightweight windshield design is related to the use of heads up displays (HUD). The HUD light source, which usually originates from the dash board, projects an image against the windshield at an angle so that the reflection from the windshield inner surface reaches the driver's eyes. However, since the light also travels through the windshield, it is reflected back a second time at the outer windshield surface, creating an undesired second “ghost” image for the driver. The gap between the desired image and the ghost image increases with increasing windshield thickness, which creates a blurred image for the driver.

Wedged PVB interlayers can be used to reduce the ghost effect. However, that adds significant cost to the windshield and may not consistently solve the problem for windows with a large ghost image offset.

The optical quality of the HUD display can be improved significantly by applying a thin GGfA ply in the lightweight windshield construction. The effect of the reduced total windshield thickness is shown in the HUD screen shot in Figure 16.

A 2.1 ASLG/2.1 ASLG windshield with a 0.22 mRad wedge PVB exhibited an undesired ghost image with a gap of about 10 pixels from the desired reflection. The 2.1 ASLG/0.55 GGfA laminate with the same 0.22mRad wedge PVB exhibited a ghost image with a gap of only approximately 3 pixels, indicating that the driver would experience a much clearer HUD picture.

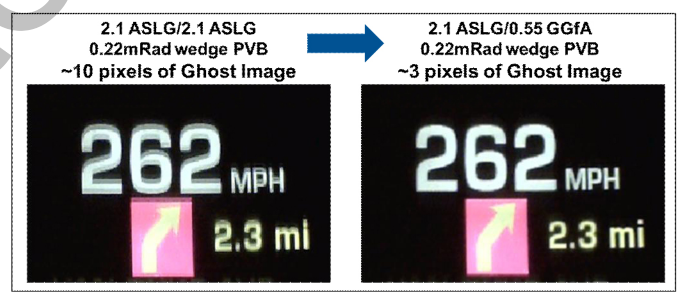

Figure 16. Images showing the improved HUD quality with the GGfA windshield design.

SUMMARY/CONCLUSIONS

A new automotive lightweight windshield laminate concept is proposed here, which is achieved by replacing the thicker 2.1 mm inner ply of annealed soda lime glass with an ultra-thin chemically strengthened Gorilla Glass for Automotive ply. Two GGfA thicknesses were described (0.7 mm and 0.55 mm), which result in a windshield weight reduction of 31-34%.

The higher strength of chemically tempered GGfA compared to standard SLG enables this design change, overcoming the concerns of glass breakage when reducing glass ply thickness with standard SLG.

Internal tests according to regulatory requirements were completed with the 2.1 ASLG/0.7 GGfA design. Results indicated that the proposed construction complied with certification requirements. Evaluation of the second 2.1 ASLG/0.55 GGfA design is underway, and initial data are promising.

Regulatory requirements represent the minimum performance criteria; therefore, additional tests were conducted to address other OEM design criteria. In particular, criteria that may be more challenging to thinner windshields were investigated.

A variety of impact tests showed superior performance of the thinner GGfA constructions compared to the standard 2.1 ASLG/2.1 ASLG design. While the goal was to demonstrate equivalent performance with reduced windshield thickness, the proposed GGfA designs showed higher robustness in the ball drop, ball bearing, and hail impact testing. Furthermore, an additional advantage was discovered in the high speed ball bearing test; while the inner ASLG ply broke and emitted glass particles into the passenger compartment, the GGfA ply did not break, and glass spalling was avoided.

The acoustic performance evaluation also showed promising results. The applied acoustic model suggested no significant difference in the perceived sound pressure levels in a vehicle when the thick standard 2.1 ASLG/2.1 ASLG windshield was replaced with the proposed 2.1 ASLG/0.7 GGfA or even 2.1 ASLG/0.55 GGfA constructions under the test conditions. Evaluation of actual perceived noise levels in a real test vehicle, rather than just relying on transmission loss measurements in lab conditions, is recommended when determining the acoustic performance of different windshield options.

Window stiffness was also investigated. Reducing the windshield thickness results in reduced stiffness; therefore, deflection in use may become a challenge. However, modeling shows that a higher degree of asymmetry helps to decrease the loss in rigidity. Indeed, a thick outer ply paired with a thin inner ply should have better stiffness than two plies with the same thickness.

In addition, optical performance of different windshield constructs was investigated. As the GGfA fusion draw manufacturing process delivers display quality glass, optical distortions are expected to be reduced compared to standard SLG constructions. Furthermore, for HUD display applications, the known ghost image issue can be improved with the proposed thinner constructions.

The presented windshield concept using ultrathin GGfA opens up new opportunities and flexibility for lightweight automotive vehicle design. While these constructions deliver significant weight savings, the limit of that technology has not yet been reached. Concepts with even thinner constructions are being evaluated for windshields and other vehicle openings.

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CONTACT INFORMATION

For information on Corning Gorilla Glass for automotive applications, please visit www.corninggorillaglass.com

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DEFINITIONS/ABBREVIATIONS

OEM - Original equipment manufacturer

GGfA - Corning® Gorilla® Glass for Automotive

SLG - Soda lime glass

ASLG - Annealed soda lime glass

PVB - Poly vinyl butyral

APVB - Acoustic PVB

SPVB - Standard PVB

UV - Ultraviolet light

IR - Infrared

SPL - Sound pressure level

HUD - Heads up display