

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 aluminosilicate 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).

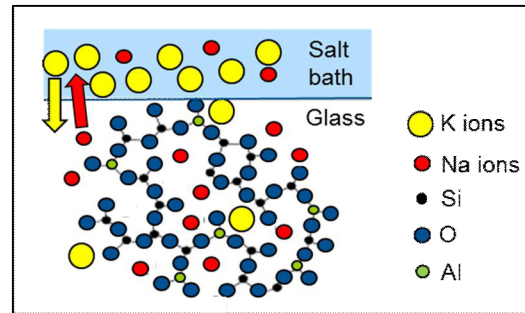


Figure 2. A schematic of the GGfA ion-exchange process.

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.

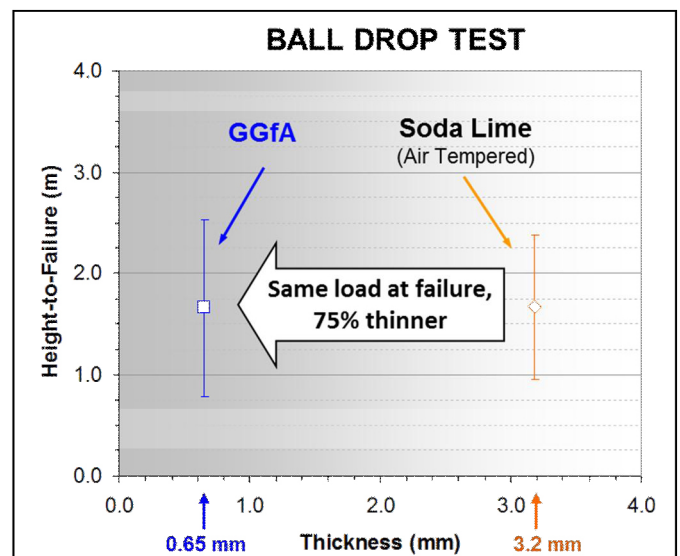


Figure 3. Ball drop test results of GGfA and fully air-tempered SLG.

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 m². 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.

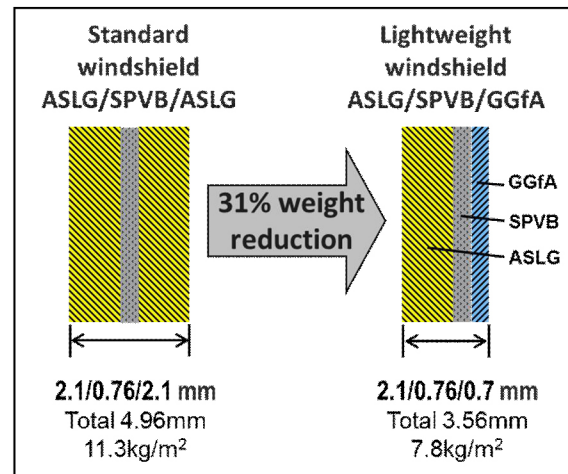


Figure 4. Standard and proposed lightweight windshield construction.

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.