Finishing options for polycarbonate automotive glazing

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Abstract
For automotive glazing, polycarbonate offers unique creativity options for styling and design, significant weight reduction, and advantages in passenger safety and security. New coating systems for polycarbonate provide resistance to more than 10 years of outdoor exposure, which is one of the most important quality criteria for polycarbonate windows. Additionally, glass-like abrasion performance is secured with plasma-enhanced chemical vapor deposition (PECVD) technology. These coating technologies as well as predictive weathering models will be presented. Options for automotive original equipment manufacturers (OEMs) such as defrosters, integrated panoramic roof systems, highly curved backlights, ambient lighting, and innovative door modules will also be reviewed.

Factors Impacting PC Glazing
Although polycarbonate for automotive glazing is compelling, many obstacles had to be overcome to meet the established standards. The development of complementary coating technologies was critical. The coating systems had to offer specific properties, primarily optical clarity, adhesion to the plastic substrate, abrasion resistance and weathering resistance. Although multiple coatings technology options exist, the primary options are siloxane hardcoats and a coating system incorporating a plasma-enhanced chemical vapor deposition (PECVD) layer. Siloxane coatings are well-known in the automotive headlamp market. PECVD systems are commonly found in industrial markets but are now gaining acceptance in the automotive market as a realistic option for glazing. This is particularly true for driver visibility applications, which require a higher level of abrasion resistance.

Approvals
Polycarbonate glazing systems need to pass the stringent requirements of the automotive companies and regulators. Examples of such regulations for driver visibility are FMVSS 205, ECE R 43 and JIS R 3211 in the United States, Europe, and Japan, respectively.

Technology to Make Real Parts
Molding technology needed to evolve for the injection molding of large, low-stress optical parts to be possible. Alternative printing and defroster technologies needed to be developed to allow application to three-dimensional parts. The defroster materials also had to take into consideration the different thermal characteristics of polycarbonate. Glazing technologies now exist to overcome these barriers.

Introduction
The automotive industry has a distinguished history of utilizing innovative solutions in the design and manufacture of motor vehicles. Vehicle development teams seek novel yet commercially viable options to meet the growing demands for improved styling, performance, safety, fuel economy and environmental impact. An increasing number of automotive companies are considering polycarbonate as a replacement for glass in glazing applications. This area represents one of the largest untapped opportunities for vehicle weight reduction. Polycarbonate, enhanced with a new coating system, opens new avenues for the automotive industry to meet the challenges of today and of the future. Moreover, life cycle and fuel economy analyses quantify environmental benefits, moving the polycarbonate glazing story from the realm of folklore to the reality.

Main Text
Why Polycarbonate (PC) Glazing?
In the automotive glazing world, polycarbonate offers some well-known advantages compared to glass. Some may not be so obvious.

Increased Styling and Design Freedom
Approximately 20 years ago, a trend started in the automotive headlamp market. Polycarbonate was introduced, and automotive designers recognized the opportunities for differentiation through styling. Today virtually all of the automotive headlamp assemblies utilize polycarbonate. Fast-forwarding to today’s glazing applications, injection molded polycarbonate can be made into complex shapes with integrated features, opening similar design opportunities. Many concept vehicles presented at auto shows around the world feature glazing styles that can only be accomplished with polycarbonate, indicating that this opportunity is already being seized.

Weight Reduction
For vehicle development teams one of today’s most important challenges is to take weight out of vehicles. A large potential area in this regard is glazing where polycarbonate is a viable alternative to glass. Polycarbonate is a clear, durable thermoplastic, which offers the possibility of a 40-60% reduction in integrated part weight, depending on the application and on the degree of integration. This leads to improved fuel economy, which reduces greenhouse gas emissions and decreases the dependence on fossil fuels. Additionally, weight reduction high in the vehicle lowers the vehicle’s center of gravity, which is especially meaningful for large sport utility vehicles and high-performance cars most susceptible to roll-over.

Improved Safety and Security
The toughness and impact resistance of polycarbonate enhances safety and security; safety through occupant retention [1] and security of vehicle contents through prevention of “smash and grab” thefts.

Cost Reduction by Means of Part Integration
Injection molding also makes it possible to incorporate integrated features through two-component and film-insert molding techniques. Some examples are hinge and gas strut attachment points for backlights, door handles, fractal antennas and electroluminescence (subdued interior lighting).

Coating Systems
The development of complementary coating technologies was critical. The coating systems had to offer specific properties, primarily optical clarity, adhesion to the plastic substrate, abrasion resistance and weathering resistance. Although multiple coatings technology options exist, the primary options are siloxane hardcoats and a coating system incorporating a plasma-enhanced chemical vapor deposition (PECVD) layer. Siloxane coatings are well-known in the automotive headlamp market. PECVD systems are commonly found in industrial markets but are now gaining acceptance in the automotive market as a realistic option for glazing. This is particularly true for driver visibility applications, which require a higher level of abrasion resistance.

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Plasma Enhanced Chemical Vapor Deposition Coating System
Only one coating system applied to polycarbonate has gained approval for driver visibility applications globally. That system comprises multi-layers,
involving an essential top coat (a PECVD layer) that is thinner than a human hair. This layer is designed to confer abrasion resistance and enables glazing systems to meet the 2% delta haze requirement in the Taber® Abrasion Test. Test results indicate that the PECVD layer is both a significant extension of the polycarbonate substrate and a siloxane hardcoat. This primer enhances adhesion between the polycarbonate and the hardcoat. The hardcoat provides for long-term weathering protection of the polycarbonate by incorporating an ultraviolet ray absorber commonly referred to as UVA. The complete glazing system is designed to provide a minimum of 10 years of Florida weathering.

Weathering Resistance
Weathering failures manifest themselves in three primary ways: microcrazing, delamination and yellowing. Microcrazing (microcracking) is a common phenomenon, linked to degradation of the polycarbonate substrate by oxidative damage. The design of the coating system has to take into consideration over the desired life of the part. The primary lever in this regard is the thickness of the UVA-containing hardcoat, which can be adjusted to achieve the desired ultraviolet ray protection in order to prevent yellowing and delamination [1]. As mentioned earlier, the PECVD layer not only provides the abrasion resistance but also enhances the weatherability by placing the hardcoat under compression, thereby inhibiting microcrazing.

Waiting for natural weathering in Florida or Arizona to be completed is not practical for product development. In order to compress the development timelines, a new accelerated weathering method has been developed. This method is based on the ASTM method G155 Cycle 1 and is designated as GMD (G155 Cycle 1 modified). The GMD test has over double the irradiance of G155 Cycle 1, and in conjunction with a transfer function allows 10 year weathering performance predictions in two years or less. An additional tool that has been developed is a stochastic model for predictive weathering. This model predicts weathering performance by taking into account variables that impact weathering performance such as geographical location, shading, strain, glazing location, temperature, coating thickness and part orientation. The data from this model has been correlated with actual weathering results of glazing systems.

Abrasion Resistance
Another key performance criterion for automotive glazing applications is abrasion resistance. This can be tested using a variety of methods such as a simulated car wash, falling sand, Taber® abrasion and oscillating sand. One of the most commonly accepted test methods in the automotive industry is the Taber® Abrasion Test. This test is conducted by placing a flat sample on a small table, and rotating the sample under a pair of wheels containing abrasive media. The other tests identified result in various levels of scratching, pitting and roughening simulating a variety of field conditions. The results indicate that the hardcoat system with the PECVD layer meets the performance requirements originally specified for glass. This polycarbonate coating system also passes the Taber® Abrasion Test requirement for driver visibility applications of 1000 cycles with less than a 2% delta haze.

Application Example and Integration
An excellent application example that demonstrates the possibilities afforded by polycarbonate for glazing applications is the backlight. Injection-compression molding technology has been developed that enables the manufacture of such large optical parts with complex geometries. The part is made by using two-component technology where the clear polycarbonate is injection-molded first, followed by a thermoplastic, black second component, which forms the interior frame. The resultant low-stress part has excellent optical quality. The second shot contributes to high stiffness and rigidity - important qualities for that application. Injection molding also facilitates the integration of features such as attachment points, and openings for interior and rear safety lights.

Film-insert molding offers additional opportunities to integrate interesting and value-added features such as defrosters, electroluminescent films and fractal antennas.

Life Cycle Analysis
A firm specializing in environmental studies compiled a report regarding the life cycle of polycarbonate in comparison to glass in automotive glazing. They looked specifically at glazing production, use and waste in order to quantify the energy demand and greenhouse gas emissions in each case. In this study, the comparison was between 1 kilogram of polycarbonate and 2.2 kg of glass. The life cycle results indicated that each kilogram of polycarbonate used versus glass for automotive glazing saves an estimated 200 – 300 Mega joules of energy and 14 – 22 kilograms of CO2 equivalents. If the estimated 277 million square meters of annual glazing applications behind the “A” pillar were converted to polycarbonate, the total weight would be approximately 1.4 million metric tons of polycarbonate per year. The final calculations would highlight a significant savings in global energy and greenhouse gas emissions.

Further Translation to Everyday Life
Weight savings can be converted into annual environmental impact. As an example, using polycarbonate to replace glass behind the “A” pillar could mean a weight savings of approximately nine kilograms per vehicle. According to an European Automobile Manufacturers Association report [3], the total number of passenger vehicles in Europe in 2005 was almost 196 million. The Fraunhofer Institute published in their magazine in 2005 an estimate for fuel savings of 0.8 liters/100 kg per 100 kilometers [4]. These two numbers, combined with an estimated average annual European driving distance of 15,000 kilometers, yield a total potential fuel savings of 2200 million liters of fuel per year in Europe alone. This annual fuel savings can be converted into approximately 5.2 million metric tons of carbon dioxide emissions using conversion numbers located on the BP (British Petroleum) website [5]. What does this amount to in practical terms? The amount of trees needed to sequester the carbon [6] for this much carbon dioxide would fill approximately 5700 square kilometers, roughly 11 times the size of the city of Tampere, Finland, where this conference is taking place.

Conclusions and Summary
Vehicle design teams continue to explore opportunities to utilize the positive attributes of polycarbonate glazing systems, and automotive styling is beginning to reflect glazing designs that can only be realized with polycarbonate. The technologies have evolved to enable the manufacture of parts that meet the requirements for transparent panels (windows). The coating systems play a particularly important role here. Various coating options exist, and there is a system that meets the global requirements for driver visibility. This system is a multi-layer coating with a siloxane hardcoat combined with a PECVD layer, where the outer PECVD layer not only provides abrasion resistance but also enhances the weathering durability. Benefits of polycarbonate glazing extend beyond the carrier vehicle to the environment at large. Life cycle analysis shows a positive result in energy savings and reduced amount of greenhouse gas emissions. The effect of weight reduction on fuel savings amounts to a
significant reduction in carbon dioxide emissions. The technologies exist to make this a reality.

References