Engineering Plastics and Plastic Composites in Automotive Applications

Kalyan Sehanobish

SAE International™
Warrendale, Pa.

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Warrendale, PA 15096-0001 USA
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Tel: 724-772-4028
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Chapter One

Why Choose Plastics for Automotive Applications?

"Plastics" is a broad term utilized primarily by the end users of these materials. In technical terms, the scientific nomenclature that more commonly defines plastics is that they are polymers composed of long covalent-bonded molecules.

Plastics often are classified into three groups:

1. Thermoplastics
2. Rubbers
3. Thermosets

Thermoplastics can be melted or softened and then reformed, and they demonstrate very little elastic recovery below their glass transition temperature. By comparison, rubbers exhibit large extensions and will spring back easily upon release. Thermosets are heavily cross-linked polymers that normally are rigid and intractable. The use of both thermosets and thermoplastics in passenger vehicles has grown to the point where a wide variety of plastics now are used in vehicles. Figure 1 shows the top ten types of plastics used in automotive applications in North America.[4]

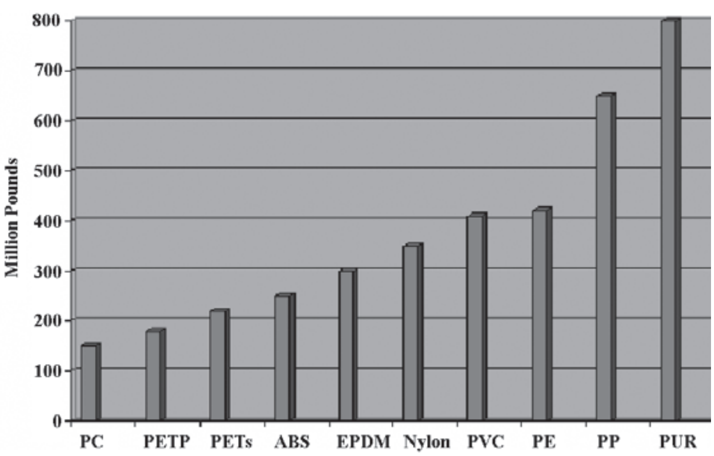


Figure 1 The use of plastics in automotive applications in North America.

Plastics offer several advantages in terms of their performance characteristics when used individually, as highly formulated filled plastic blends, and as reinforced plastic composites. For example, plastics are durable, strong, and lightweight, and they can be made transparent, translucent, or opaque. Likewise, plastics can be soft, flexible, or hard, and they can be formed into almost any shape, size, or color. Plastics can provide resistance to heat, chemicals, and corrosion, depending on how they are formulated. Furthermore, plastics are excellent thermal and electrical insulators and can be formulated to impart both thermal and electrical conductivity to a certain extent. In most cases, plastics are cost effective while providing automakers with the design freedom to incorporate safety, styling, and comfort into vehicles. Over the past decade, significant progress has been made in the recovery and recycling capabilities for automotive plastics, but much more remains to be done.

Thus, there are many good reasons that automotive engineers find plastics to be an attractive and beneficial material for use in the design of vehicles. As concerns about safety and lightness of weight unfold, plastics will continue to be a key player in the automotive industry.

Chapter Two

Plastics in the Interior of the Vehicle

Today, interior components account for the largest share of plastics in vehicles. This fact is not expected to change dramatically as plastics continue to gain acceptance for use elsewhere in vehicles. Traditionally, instrument panels (IPs) were made from several metal components that had to be painted and were held together by a steel supporting structure. Plastics initially entered the IP market to improve aesthetics on top of the steel structure. With the progression of time, thermoplastics have been expanding further into this application segment, facilitating complex designs and a reduction in both cost and weight. These thermoplastics include the following:

- Acrylonitrile-butadiene-styrene (ABS)
- High-heat ABS (HHABS)
- Blends of polycarbonate (PC) and ABS
- Modified polyphenylene ether (PPE)
- Modified polypropylene (thermoplastic polyolefin [TPO])
- Long-glass-filled polypropylene (LGF PP) and ABS
- Styrene maleic anhydride (SMA)

Designs that utilize thermoplastics could enable the integration of airbag housings, instrument housings, and so forth with structural needs (i.e., structural portions of IPs), allowing for the elimination of steel beams. However, the cost advantages remain debatable.

Let’s take a closer look at some of the plastics in interior applications and their performance characteristics. Figure 2 shows some of the typical interior applications for which plastics are predominantly the material of choice.

Because of their useful combination of toughness, stiffness, solvent resistance, and processability, ABS polymers began to appear in interior applications

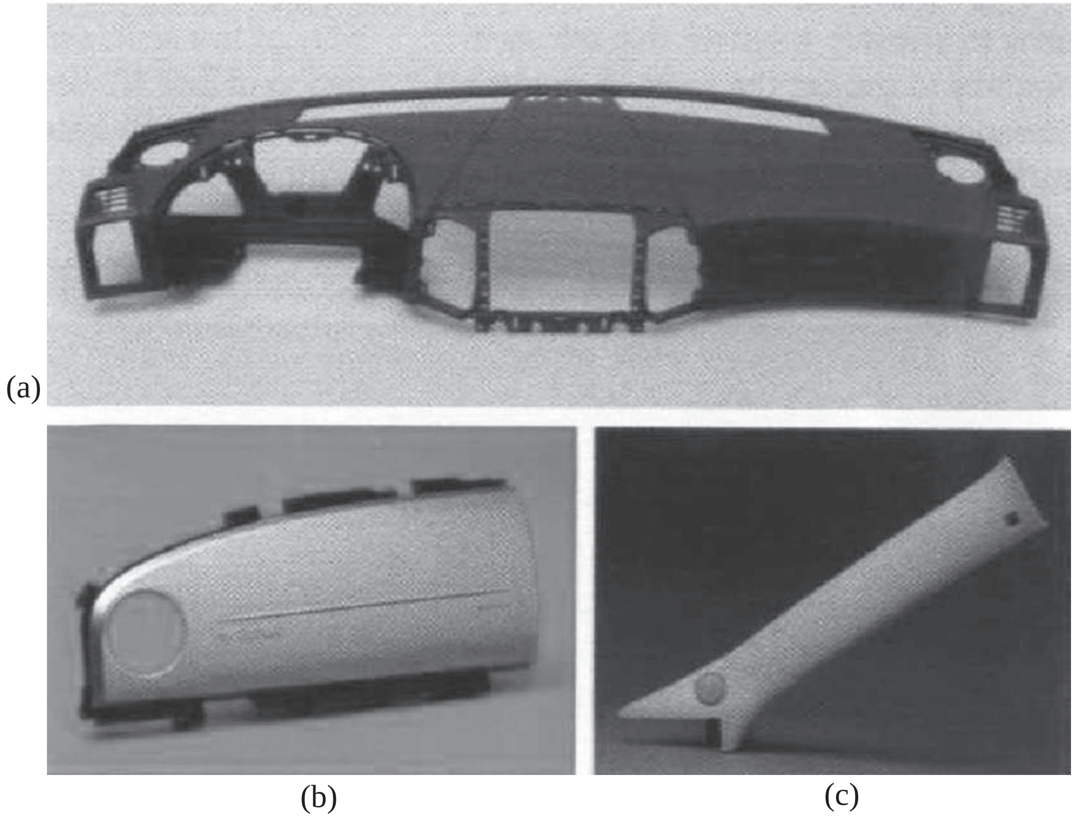


Figure 2 Various interior parts made from plastics: (a) instrument panel retainer, (b) door trim, and (c) A-pillar hard trim. (Courtesy of LyondellBasell Advanced Polyolefins)

during the 1980s. These materials are created by the polymerization of acrylonitrile, butadiene, and styrene. The quantity of each of these three monomers plays an important role in the ultimate properties of the resulting copolymer. Resin suppliers can tailor resins for particular applications and markets by varying the ratios of these three monomers and the morphologies of the dispersed phases in subsequent processing. In 2008, the worldwide capacity of ABS had been estimated to be 8 million metric tons per year (18 billion pounds per year). In North America and Europe, the major suppliers of ABS are BASF, Bayer AG, and The Dow Chemical Company.

The recent introduction of thermoplastic polyolefin (TPO) into the same application space has offered a considerable challenge to ABS suppliers in terms of improving gloss. Although ABS has better mechanical properties than most compounded TPOs, the lower gloss of TPO offers the benefit of molded-in-color parts for use by the fabricators and ultimately the original equipment manufacturers (OEMs). Recently, some manufacturers claim to have reduced the gloss of ABS to that of the level of TPOs by adjusting the morphology, but commercial acceptance of such materials is only in an early stage.[5] Figure 3 displays one example of a part that typically is made from TPO. The 60° gloss measurements shown at all locations in Figure 3 are plotted as a graph in Figure 4.

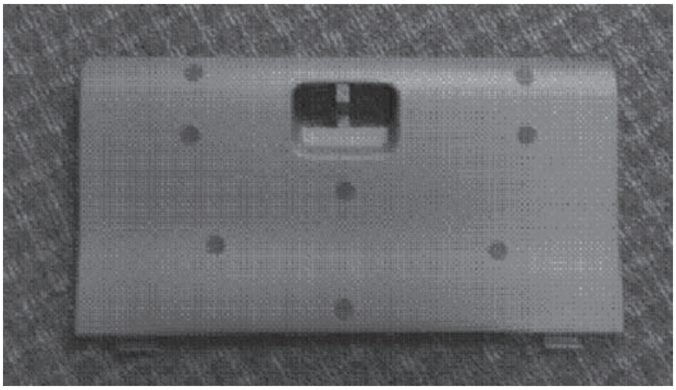


Figure 3 60° gloss measurement locations in an injection-molded glovebox.

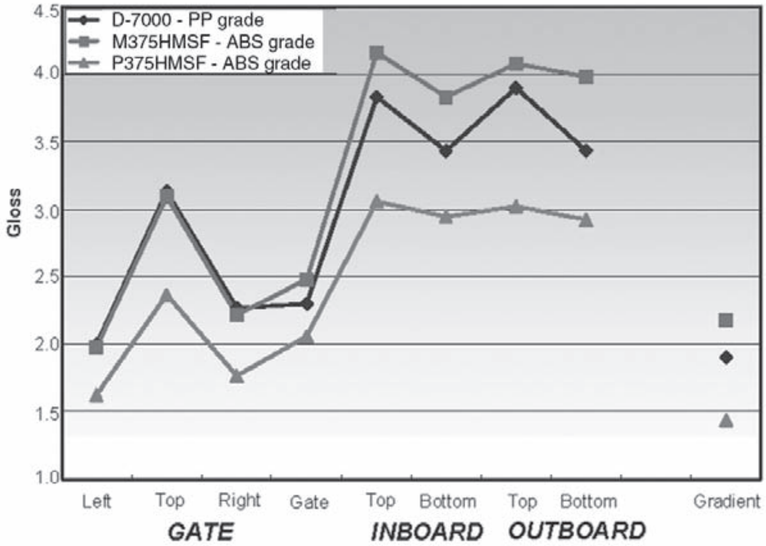


Figure 4 60° gloss measurements at all locations presented in Figure 3.

At all locations on Figure 3, the gloss numbers of the new ABS grade as molded undoubtedly are lower and even better than a competitive TPO considered for the specific application.

The need to balance superior stiffness and toughness over that of existing ABS led to the introduction of PC/ABS blends in the automotive industry. Polymer blends have always played an important role in automotive applications by providing additional properties that cannot be achieved with only a single material. Based on its versatility, PC/ABS blends are considered a mainstay engineering material for applications such as automotive IPs and body panels.

Although ABS and PC are extremely useful amorphous resins (see the discussion of PCs in Chapter 7 on car lighting systems), they have some limitations that can be resolved only by using them as blends. For example, PC offers exceptional clarity, toughness, and heat resistance. Likewise, it is notch sensitive and is more difficult to process than ABS resins. Similarly, ABS is a tough material, is readily processed, and adheres well to paint and foams. Because of the exceptional compatibility between these phases, an alloy of these two resins results in a resin with a unique combination of their properties. Blends of PC and ABS are noted for offering high heat resistance, stiffness, toughness with less notch sensitivity, improved processability, and versatile surface characteristics.

Figure 5 shows the notched Izod impact-resistance response as a function of weight percentage of PC in the blend, measured in a typical part both perpendicular and parallel to the flow direction to the mold. (The notched Izod impact resistance is a standardized measure of practical fracture toughness of material, ASTM D256, ISO 180.) Clearly, the notched Izod impact is optimum near 70% weight of PC in the blend composition (or 65% PC and 35% ABS by weight). Most PC/ABS blends sold in the market today are formulated from the optimum blend composition. These PC/ABS blends are available in four grades, based on performance needs:

1. General purpose
2. High flow
3. Blow molding
4. Low gloss

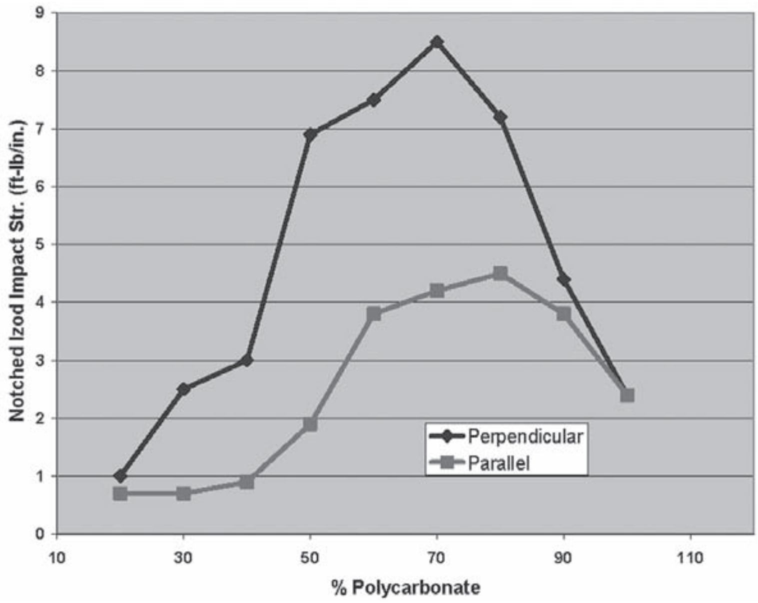


Figure 5 Impact resistance versus blend composition in a PC/ABS blend.

All four grades are formulated by incorporating mineral fillers, glass fibers, carbon fibers, and so forth to meet the performance need for rigid applications with very little sacrifice of toughness.

Modified polyphenylene ether (PPE), more accurately named poly-(2,6-dimethyl-p-phenylene ether), is made by the oxidation of substituted phenols. It is characterized by regular, closely spaced groups of phenyls.[6] (Phenol is an aromatic chemical compound derived from benzene.) General Electric Plastics (now SABIC) made this polymer available commercially as polyphenylene oxide (PPO). It often is modified by blending with a second polymer that usually is a polystyrene (PS). This high-performance polymer offers high heat-deflection temperatures and good flame resistance, and it provides good flow and impact resistance only when combined with high-impact polystyrene. It is sold by SABIC in the automotive market under the commercial name of Noryl® PPO. However, a lack of chemical resistance, ultraviolet (UV) resistance, and color stability mean that items made of this polymer must be painted frequently when used in some demanding interior applications. For IPs, UV resistance and color stability are critical and often are preferred over high heat resistance (e.g., heat resistance values of approximately 208°C for PPE, compared to approximately 145°C for PC and even lower for general-purpose ABS).

This polymer is also blended with nylon and is commercialized under the name of Noryl. Nylons are one type of the early polymers developed by Carothers in the 1930s. Most nylons are synthesized by repeatedly adding two molecules of a diamine and two molecules of an acid. Depending on the type of molecule, nylon can have wide range of properties.

Thermoplastic polyolefin is a useful polymer blend of polypropylene (PP), filler, additives (e.g., slip agents and anti-oxidants), and a thermoplastic elastomer. In general, TPO can be classified into two broad categories:

1. High stiffness
2. High toughness

Today, TPOs are used increasingly in special automotive applications because of their lower specific gravity, injection moldability, economics, recyclability, and noise performance. Some variations of these essential ingredients either are compounded in extruders (other mixers) or are prepared in some combination of reactors (often referred to as reactor TPO) that can make both PP and the rubber followed by some post-reactor addition of other chemicals. Toyota Super Olefin Polymer (TSOP) is a special type of TPO offered primarily in Japan.[7] It is highly differentiated in its flow characteristics, modulus, and balance of low-temperature properties due to some unusual shared continuous morphology achieved through a unique fabrication route of PP and elastomer blend. The ratio of elastomer to PP in this blend can be adjusted to control the modulus and elastic recovery of a TPO.[8]

As already stated, typical TPO formulations can be classified for high-stiffness and high-toughness (low-modulus) applications.[7] High-toughness formulations are designed for low ductile-to-brittle transition temperature (DBTT) of –40°C as measured by a notched Izod impact test (test method ASTM D265), whereas the high-stiffness formulations are in the range of –20°C DBTT.

Recently, a Grupo Antolin door module made from TPO for the Dodge Caliber and Jeep Compass and Patriot received a Society of Plastics Engineers body interior award in 2006 (Figure 6). The door trim module combines all door hardware components plus the trim panel. It was injection molded by The Dow Chemical Company using a specific grade of TPO.

Figure 6 Door module made of TPO.

Long-glass-filled (LGF) PP and ABS are glass-reinforced blends of PP and ABS. Estimates are that approximately 30% of the 2 million metric tons of e-glass fiber consumed globally for polymer reinforcement is used in thermoplastic composites. (E-glass is a type of alkali-free glass originally used in electrical applications.) These composites have been growing at a healthy pace of 15 to 20% per year, largely fueled by automotive applications. Two key reasons that glass-reinforced thermoplastics are becoming so important are their recyclability and their fit with the injection-molding process. The incorporation of LGF reinforcement in PP has facilitated the use of a lower-cost polymer in semi-structural engineered applications in the automotive industry. Furthermore, LGF PP is especially interesting because the enhanced reinforcing abilities of the glass fiber and the cost and performance of PP make it an economical engineering material. This material is quickly gaining importance, as evidenced by its annual growth rate of more than 35% over the last four years. Although less versatile than LGF PP, LGF ABS was introduced recently and promises a better balance in impact performance. Figure 7 shows an IP retainer made from LGF ABS.

Another plastic called styrene maleic anhydride (SMA) was first introduced commercially under the trade name DYLARK® and currently is sold by NOVA Chemicals for the IP market segment as well. Styrene maleic anhydride copolymers were developed during the late 1960s. In the early

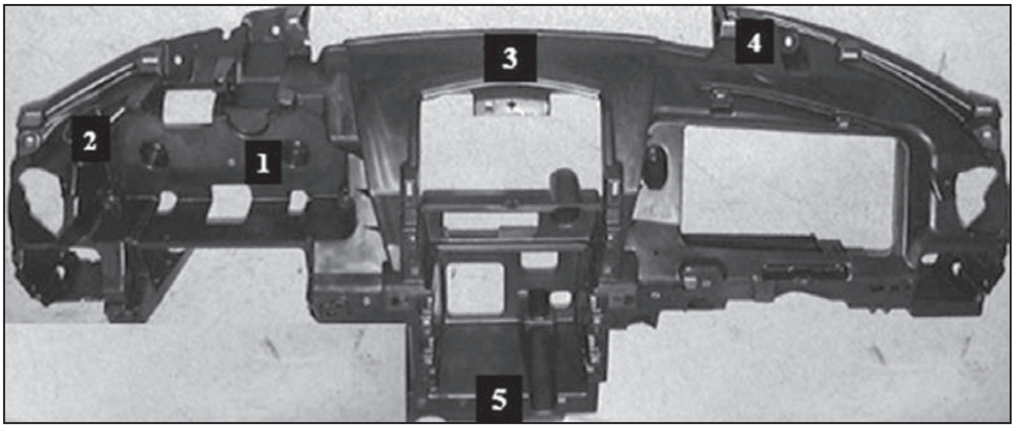


Figure 7 Instrument panel retainer made with LGF ABS.

1970s, elastomer-modified reactor and fiberglass-reinforced DYLARK grades offered enhanced heat resistance, impact resistance, tensile and flexural strength, and flexural modulus properties. These performance characteristics were adapted into a new and growing automotive application—injection-molded substrates for soft IPs.

In late 1970s, vehicle designs increased the slope of the windshield, which in turn increased the temperature on the top surface of the exposed IPs. Due to the thermal expansion of the cross-car beam, IPs using competitive substrates buckled and warped along the windshield edge. The thermal stability of DYLARK glass-reinforced resins demonstrated the physical properties required to withstand thermal expansion in the new designs. Glass-reinforced DYLARK also met U.S. government regulations for improved safety and head impact through greater energy management over a range of temperatures and speeds. Soft IPs progressed beyond carriers for polyurethane foam to include more intricate designs for one- and two-piece IP constructions. The new designs were more functional, had improved cross-car structure, and contained additional packaging compartments for the radio, heater, and speedometer openings. Variations of formulated thermoplastics discussed so far can be used in any soft or hard trim applications, gloveboxes, and packaging trays.

Dashmats are panels that are placed between the engine and the instrument panel to prevent engine noise and other airborne noises from reaching the ears of the occupants in an automobile. In the past few years, filled TPO has been formulated to function as a sound barrier with various porous sound absorbers. Rigid polyurethane (PU) thermosets also can be used as dashmat solutions. Headliners, another component of the interior segment, consist of many functional parts below the roof, and rigid PU is used most often as a backing for the underlying foams and fabrics. Thermoplastic solutions are found less frequently in this application.

Plastics recently have been used in seat backs through considerable design engineering modification. A push toward weight reduction made this change possible, and increasing numbers of OEMs are recognizing the advantage of plastics in this application. Seat backs are a highly regulated safety item, and plastics were first introduced by The Dow Chemical Company in 2000 for use in rear seat backs. Traditionally, steel has been the material of choice. However, the introduction of PC/ABS as a double-shell blow-molded structure led to a 20 to 25% weight savings.[9] This blend was first introduced successfully in the 2006 Audi TT in Europe (Figure 8). Subsequently, other North American OEMs adopted similar seat back designs made from PC/ABS for large vehicles, but TPO or reinforced TPO also could be used in this application.

Figure 8 Blow-molded seat back made for the 2006 Audi TT.

Seat bases are more demanding than seat backs. They must provide long-term creep resistance and must withstand low-speed crashes. They also must be able to accommodate various comfort features (e.g., reclining system, heating, and massaging). For high-end cars, the performance need often drives the choice of polymer composite (i.e., thermoplastic or thermoset). For low-end cars, LGF thermoplastic types of solutions may be adequate. Fabricators recently have been trying to introduce a one-piece seat with optional reclining features that would be suitable for low-cost cars. Engineers are trying to make seats thinner and lighter to improve fuel efficiency, but plastics have not yet appeared as the prime candidate.[10]

Interior door handles are less demanding than exterior door handles in terms of chemical resistance. Clearly, PC/ABS is a winner in this application.

Steering wheels are made either from molded and pigmented vinyl ester resins or from reaction-injection-molded[11–14] (RIM) pigmented urethane when a ductile material is required. Low-friction acetyl often is used for the switches, levers, and bearings of steering columns. It also is used in a variety of automotive applications due to its ability to withstand high mechanical and thermal stresses.

There are two types of vinyl ester resins:

1. Epoxy-based resins
2. Non-epoxy-based resins

A non-epoxy-based vinyl ester is simply a methacrylate terminated polyester. It has a reduced resistance to caustic and acids and can be used as a plastic composite binding resin in applications where high chemical resistance is not critical. Epoxy vinyl ester resins have not penetrated the automotive market because relatively inexpensive polyesters can meet most of the performance needs except chemical resistance. However, it is possible to imagine the introduction of epoxy vinyl ester resins into more corrosive or severe applications near the engine, batteries, external body parts, and so forth.

Reaction-injection-molded PU offers a solution for the rapid production of complex plastic parts directly from low-viscosity monomers (single chemical unit) and oligomers (chain of multiple chemical units).[11–14] These liquids are combined by impingement mixing as they enter the mold.

Reaction-injection-molded PU chemistry specifically involves the mixing of polyoles (oligomers of alcohol units) and isocyanates (carbon-nitrogen compounds). Thorough mixing is required in the mixing phase to achieve uniform physical properties in the final manufactured part. For commercial applications, most RIM chemical reactions in the mold must take place in less than a minute. Non-reinforced RIM PU systems are soft and stretchy and can have a modulus close to 1000 MPa, a strength of approximately 30 MPa, and an average elongation to break that is close to 150%. The thermal expansion of non-reinforced PU systems can be reduced approximately tenfold in RIM PU composites by using appropriate fillers.

Nylon 6,6 is the primary polymer for airbag fabric today. It is a mature solution in which the airbag is coated with silicone to meet the requirements for permeability. Polychloroprene was the polymer of choice as a coating in the early development of airbags, but its inherent flaws made silicone the coating of choice. Airbags are sewn mainly with nylon 6,6 yarn. With consideration of alternative deployment approaches to the current azide-based pyrotechnique and the introduction of more airbags or inflated air curtains in vehicles, new material approaches will become more feasible.

Styrene-ethylene block (SEB) copolymers are the primary incumbent for airbag covers. They often are referred to as r-TPV (made by a reactive extrusion process with ethylene propylene diene monomer [EPDM], a cross-linker, and PP). The total global demand for SEBS is approximately 30 million pounds, divided almost equally among Japan, North America, and Europe.[6] Because of the fear of safety-related litigation, SEBS compounds associated with airbags are designed to have superior elongation, tensile, and tear strength over many other thermoplastic elastomers. SEBs are part of the styrene block copolymer (SBC) family. In a crude sense, SBCs possess strength properties that are equivalent to those of vulcanized elastomer systems without vulcanization.

Thus, the interior of vehicles is a key application for the use of plastics. These interior applications include IPs, body panels and door panels, dashmats, seat backs, seat bases, steering wheels, and airbag covers. The materials in use today can be individual polymers or blends that offer a variety of properties, including high impact resistance, high stiffness, injection moldability, and heat resistance. As materials science moves forward, plastics are expected to play an important role in the interior of vehicles.

Chapter Three

Plastics in Horizontal and Vertical Body Panels

The exterior body panels of vehicles include the door panels, roof, floor, fenders, hood, and back panels. These highly demanding applications require very strict and low coefficients of linear thermal expansion (CLTEs) comparable to those of metals, with high-temperature sag resistance to survive the high heat of the electrocoating bake ovens in the assembly lines of large car platforms. (High temperatures in the bake ovens are needed primarily to impart corrosion resistance to the rest of the steel structure.) This makes the entry of plastics difficult because plastics are always introduced with existing metals and therefore must match the specifications of the metal body panels. For example, a certain amount of surface conductivity is essential to allow painting side by side with metals in a single streamlined process.

The first major industrial use of thermoplastics (a filled blend of polycarbonate [PC] and acrylonitrile-butadiene-styrene [ABS]) in an automotive exterior door panel, rocker panel, and rear panel was introduced by The Dow Chemical Company in a special process developed for the General Motors Saturn line of vehicles. A formulated blend of nylon 6,6 and polyphenylene oxide (PPO), known as Noryl GTX, also was introduced at the same time in those same Saturn vehicles by General Electric Plastics (now SABIC) using a special assembly line procedure (Figures 9 and 10). Some European OEMs also lowered the temperature of the bake ovens to accommodate Noryl GTX to make exterior body panels. Most of the applications are found in vehicle fenders. The absorption of moisture by nylon remains a critical issue to be resolved in order to meet the performance need. Some of the special requirements to accommodate plastics often have driven the OEMs back to metal as a solution.

Apart from thermoplastics, two other materials labeled as SMC (sheet molding compound) and reaction-injection-molded (RIM) were utilized as body panels (Figure 11). This type of body panel has higher material costs

Figure 9 Door panel made of filled PC/ABS; fenders and quarter panels made of Noryl GTX.

Figure 10 Rear panel made of filled PC/ABS.

Figure 11 RIM fenders in the C6 GMX 245 Corvette.

than steel but lower tooling costs and is used primarily when build volumes are less than 200,000 vehicles per year.

Of the total market for body panels, such composite vertical body panels enjoyed a share of 6%, aluminum encompassed 3%, and steel encompassed 91% until 1998.[14] Of that, SMC enjoys the largest portion. A fiberglass-reinforced thermosetting compound, SMC usually is available in sheet form that is rolled into coils interleaved with plastic film to prevent adhesion. It is made by dispensing mixed resin (generally a polyester), fillers, maturation agent, catalyst, and mold release agent onto two moving sheets of polyethylene (PE) film. The lower film also contains chopped glass roving or glass mat. In this way, SMC can be molded into complex shapes with little scrap.

Apart from the disadvantage of the build volume, recyclability had been an Achilles' heel for thermosets and often prevented them from entering this relatively large market segment. It is interesting to note that the paint systems used on thermoplastics limit their true recyclability as well. Recently, for some offline and at-line fender applications, both PP-talc and thermoplastic polyolefin (TPO)-based solutions have been attempted. These had been essentially proven in very small car platforms.

Floor and roof panels have not been penetrated yet by plastics due to various engineering shortcomings. However, many efforts to change this are underway in concept cars such as the Toyota Sienna, which featured a sliding roof system that uses the SABIC Lexan GLX PC resin and is coated with Exatec 900vt plasma. On the other hand, plastic composites have been considered for application in hoods for a long time with only selective penetration into the market. These include both glass fiber and carbon fiber composite with a thermosetting matrix, but they are far from competing in cost with metal solutions. Mud plates are a small panel often designed into the IP to allow cockpit devices to be installed. These are made mostly of SMC to meet the requirements for stiffness.

In summary, the entry of plastics into the exterior body panels of vehicles has been difficult, but plastics are found in the panels, fenders, and hoods of certain vehicles. Some panels, such as floor and roof panels, have yet to utilize plastics, but concept cars are incorporating plastics into these areas.

Chapter Four

Plastics in the Exterior of the Vehicle

In 1925, front and rear bumpers became standard equipment on all cars. What were simple metal beams at that time evolved into complex engineering components that are integral to the protection of vehicles in low-speed collisions. Plastics entered these applications in the 1980s because of advantages such as their aesthetically pleasing appearance, corrosion resistance, lightness of weight, and ease of design. The expansion rate of plastics is delimited by metals, but the designers can work around that shortcoming. Bumpers do not have to be included in the assembly line with metals and thus can be painted separately and then assembled onto the vehicle later. Molded-in-color bumpers also have been considered in the past but were difficult to match to the color of the rest of the exterior body panels.

Highly filled reformulated versions of thermoplastic polyolefin (TPO), acrylonitrile-butadiene-styrene (ABS), and polycarbonate (PC)/ABS blends are found in bumper applications around the world. Today, TPO dominates this market worldwide. Other than these polymers and blends, thermosets often enter into this market as reaction-injection-molded (RIM) products. In fact, RIM was the first plastic to be approved for bumper fascia in North America to meet the low-temperature crashworthiness demanded by some OEMs. Unfortunately, due to process complexity, RIM could not be fabricated at a high enough rate to meet the demands of large car platforms. Faster cycle time for part production is delimited by the speed of curing chemistry and the ability of the resin to flow into molds. Furthermore, the automotive industry wanted to move away from the use of thermoset polymer systems that cannot be remelted. This attribute of thermosets was labeled by the industry as non-recyclable, and the industry made room for other thermoplastics such as TPO that can be remelted. Reaction-injection-molded parts are made from urethane epoxies, polyesters, and polyamides. A study of cost versus performance reported that RIM gives the best cost–performance characteristic for composite materials and is competitive with steel.[13]

The future of the front-end systems of vehicles will depend on how innovative and plastics-friendly OEM engineers are willing to become. An example of such an innovative step is the design of a hybrid front-end carrier (FEC) system (Figure 12). The design and performance of such a hybrid system, in which long-glass-filled polyphenylene (LGF PP) specifically designed for the application was bonded with electrocoated metal, compared successfully with a traditional FEC built from steel and bolted or welded to the body-in-white.[15]

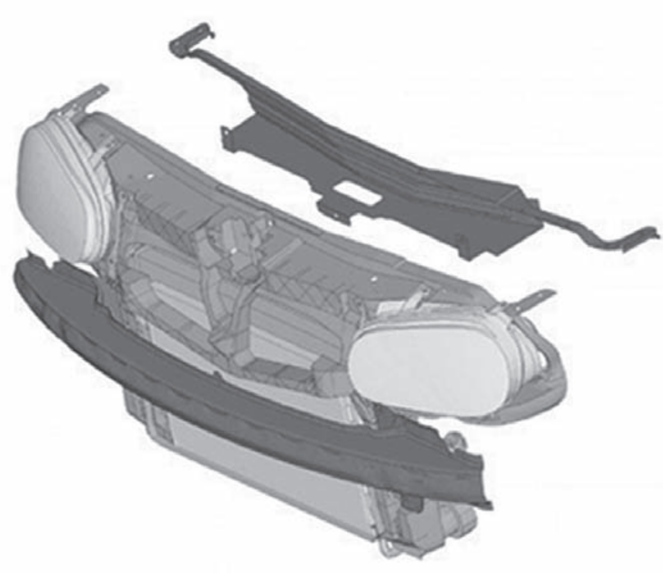


Figure 12 Bonded FEC made from LGF PP.

Figure 13 displays the assembled prototype in which a newly invented acrylic-based adhesive was used for bonding plastics with plastics and metals. Subsequently, Volkswagen of Mexico has introduced other thermoplastic composite solutions for its FEC systems in the Golf, Jetta, and Bora, using different methods to join to the body-in-white.[16]

Quarter panels have seen some plastics solutions but have been a difficult application for PC-based materials due to the need for the environmental stress crack resistance associated with fuel exposure. Nylon-based solutions have been implemented in a few cars but suffer from dimensional stability issues caused by fuel vapor absorption. Plastics also have been introduced

Figure 13 Assembled prototype for testing at Volkswagen.

as underbody shields to protect metals from corrosion. Due to the nature of the application, this part must have strong resistance to cracking from stone chips and similar abuses. However, with new technology to protect metal parts, this application has reached a plateau in some geographical areas. Here in the United States, LGF PP and ABS are the two predominant plastics in use. New designs with multifunctional capabilities will make some of the present solutions obsolete in the future. However, plastics will always play a significant role under the car body.

Exterior door handles are another application that has turned to plastics to balance chemical resistance and mechanical properties. Many filled thermoplastics such as blends of PC and polybutylene terephthalate (PBT), polyethylene terephthalate (PET), and nylon have been tried or used in this application, with nylon as the clear winner. Exterior mirror housings likewise use many thermoplastic solutions such as ABS, PC/ABS, blends of polyphenylene oxide (PPO) and polystyrene (PS), nylon, blends of PP and ethylene propylene diene monomer (EPDM), and weatherable ABS. Again, nylon clearly dominates this application in terms of volume. Many other exterior parts continue to adopt thermoplastic solutions. Figure 14 shows an impingement shield constructed from LGF PP.

As explained in this chapter, plastics have made their way into the exterior of vehicles, particularly in bumper applications but also as underbody shields and exterior door handles. However, environmental conditions and stresses have limited the use of plastics in some exterior parts of vehicles. New automotive applications for plastics continue to be found, and their future will depend on the innovation of designers and OEMs.

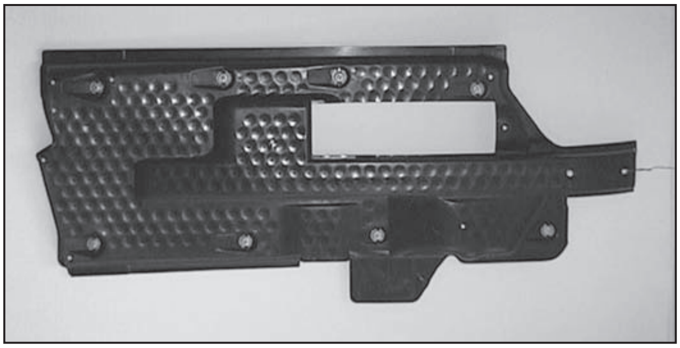


Figure 14 This impingement shield illustrates an underbody application made from LGF PP.

Chapter Five

Plastics in the Powertrain

The initial rate of market penetration of plastics under the hood of vehicles had been slowed by the fact that as recently as a decade or two ago, engineers felt that only metallic materials could meet the demanding conditions found near engines. After a long period of plastics proving themselves in designs optimized for metals, the automotive community finally started designing parts with plastic properties in mind from the onset. As a result, under-the-hood connectors, radiator grilles, and end caps are a relatively new application segment for plastics. Nylon (PA12, PA6) and polybutylene terephthalate (PBT) are the polymers predominant in this segment.

Polybutylene terephthalate is used primarily under the hood or close to the electrical and electronic connectors of the engine and in smart network interface devices, power plugs and electrical components, switches and controls, circuit breaker enclosures, and various housings, especially under the hood.

SABIC, DuPont, and Ticona are the biggest manufacturers of PBT, with products sold under the brand names of Valox® (SABIC), Crastin®, (DuPont™), and Celanex® and Vander® (Ticona). These products usually range from 100% unmodified PBT resins to combinations of glass-fiber-reinforced, mineral-filled, mineral-/glass-reinforced, and flame-resistant grades.

In the automotive industry, there is no known application of unmodified PBT. However, PBT and modified resins offer chemical resistance, outstanding dielectric strength, electrical properties, low-temperature performance down to –40°C, strength and modulus at elevated temperatures, good processability (long flow in thin sections), and, last but not least, flame resistance.

Heating and air conditioning ducts and consoles now provide temperature regulation to both the rear and front passenger seats. The consoles typically are manufactured from acrylonitrile-butadiene-styrene (ABS) resins, as well as polypropylene (PP) and styrene maleic anhydride (SMA) resins. The driving force for plastic intake manifolds is not only weight and cost reduction but also to provide improved air flow, corrosion resistance, packaging flexibility, noise reduction, and charge densities.[17] Air intake manifolds also allow more runners to the cylinders for improved performance. Nylon had been a fairly common material of choice for air intake manifolds (Figure 15). Plastics enabled improved air flow in ways that have been unobtainable with cast metal, such as exceptionally smooth interior walls with all runners directed toward the incoming air. Stylists also like the uniform matte finish and the coordinated under-the-hood theme of plastics. Figure 15 shows a prototype air intake manifold constructed from a nylon blend.

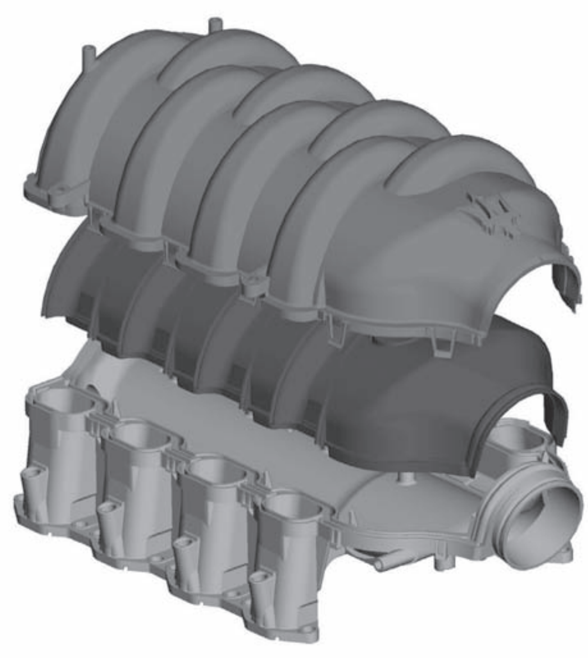


Figure 15 An example of a plastic air intake manifold.

Although plastics initially were viewed as unsuitable for the extreme environments found near engines in vehicles, they now are appearing in more areas under the hood as replacements for metals. Many plastics can meet the requirements for strength, high temperatures, and even flame resistance needed for powertrain applications while offering the advantages of low weight, low cost, improved air flow, and corrosion resistance.

Chapter Six

Plastics in Fuel Systems

In vehicle fuel systems, the fuel tank is the largest plastic component. For nonpolar fuels, high-density polyethylene (HDPE) is the most cost-effective material of choice. High molecular weight of HDPE with proper long-chain-branched architecture for high melt strength allowed companies such as Kautex (currently Kautex Textron) and Inergy L.P. to introduce blow-molded HDPE fuel tanks into the market more than a decade ago (Figure 16).

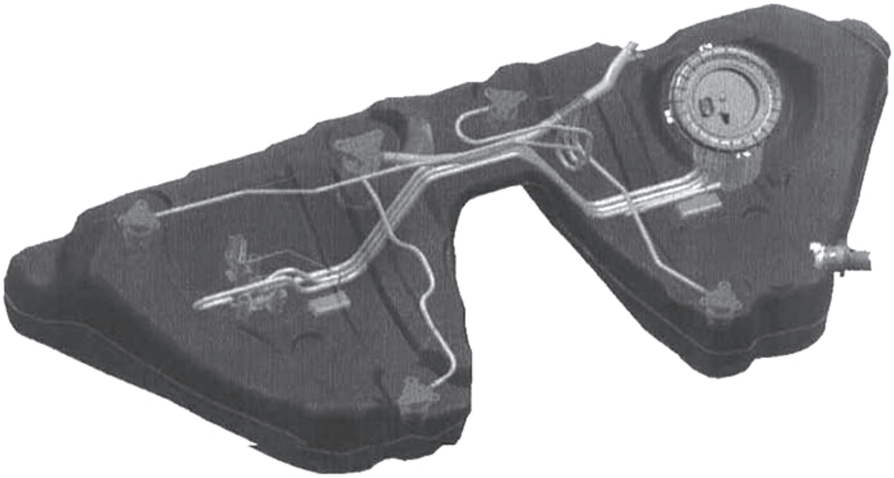


Figure 16 Typical example of a modern multilayer plastics fuel tank.

As the fuel mixture formulation changed in polarity and emissions regulations evolved, multilayer tank technology evolved as well, with HDPE as the primary layer and an ethylene vinyl alcohol (EVOH) copolymer layer for barrier properties. As even more stringent emissions regulations loom on the horizon, multilayer tanks are being fabricated with improved joints and pinch-off designs. These changes also have incorporated changes in the molecular architecture of the base HDPE resin. Some producers are responding to the challenge with material solutions based on nylon (also referred to as polyamide [PA], PA6, PA12, fluoroamides, and so forth).

Typical applications of nylon-based plastics also include fasteners for interior and exterior components, a host of connectors, holding fixtures (Figure 17), and radiator end caps. These applications rely on the ductility and toughness of impact-modified nylon 6,6 as a mechanism to connect assemblies or to attach components together.

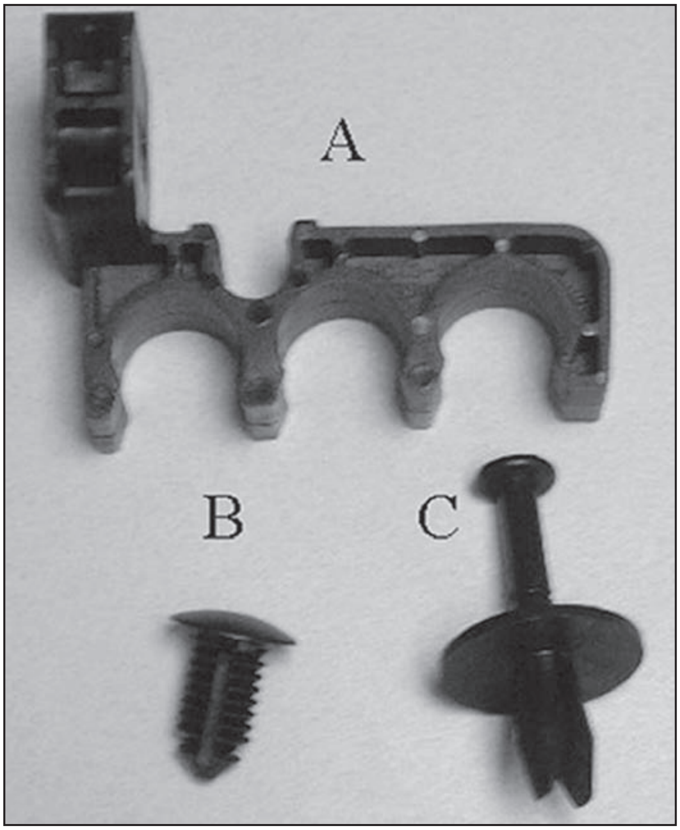


Figure 17 Typical injection-molded impact-modified nylon 6,6 components: (A) a fuel line connector, (B) a Christmas tree fastener, and (C) a Tufflock fastener.

Fuel vapor canisters represent a relatively new automotive application of molded impact-modified nylon 6,6 that is experiencing rapid growth (Figure 18). The material is an excellent choice for this application because of its inherent toughness and resistance to the combined effects of temperature

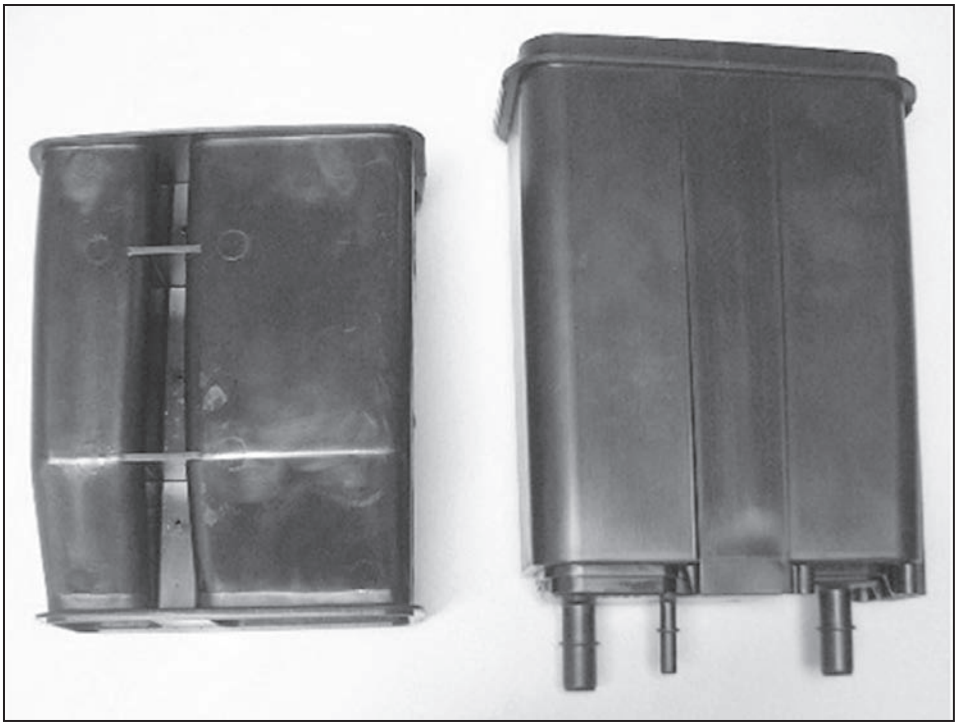


Figure 18 Two types of fuel vapor canisters molded from impact-modified nylon 6,6.

and gasoline vapor. The Clean Air Act of 1990 mandated that beginning with the 1998 model year, all new cars were required to make provisions to trap hydrocarbon (HC) fumes emitted from the fuel tank or dealing with the refueling process. DuPont leads the market in impact-modified nylon 6,6 with products that exhibit a range of impact and mechanical performance. The market is segmented into three performance categories:

1. Super toughness
2. Moderate toughness
3. Low toughness

The introduction of plastics into fuel rail applications in North America was driven by the need to accommodate alternative fuels. Now that this use of plastics has been accepted, engineers have started to consider plastics for all kinds of fuel rails to take advantage of the associated weight and cost benefits. This is a challenging application because of the need to balance flammability, dimensional stability, and mechanical properties. Methanol-containing fluids remain a challenge because they tend to soften the plastics and lower its mechanical properties.

Thus, the use of plastics in fuel systems has grown in recent years. While the largest application of plastics is fuel tanks, many other current applications include fasteners, connectors, radiator end caps, fuel vapor canisters, and fuel rails.

Chapter Seven

Plastics in Lighting and Wheel Systems

Glass headlight lenses have been replaced almost completely by transparent polycarbonate (PC) plastics. These PC plastics are designed to resist high levels of heat and shattering, and they can be molded into almost any shape. Another choice for this market is the use of acrylic plastics.

The first reported synthesis of aromatic polycarbonates from bisphenol-A can be traced back to Einhorn[18] in 1898. However, no additional investigations into this polymer were made for the next 50 years. Despite numerous investigations into PCs derived from other aromatic diols (a type of alcohol compund), the foundation of the PC industry lies on bisphenol-A (a type of alcohol compound). Today, it is estimated that the global PC manufacturing capacity is approximately 2.6 million metric tons. The major producers are General Electric Plastics (now SABIC) and Bayer AG, with a combined global capacity of 60%. Capacities are relatively balanced between Western Europe and the United States. Japan's share of the global capacity is approximately half that of the western regions. Between 2000 and 2010, global capacity growth is projected to be greater than 50%.[19] However, the regional shares should remain the same, except for some relative increase in capacity in Western Europe.

Polycarbonate was the first amorphous engineering polymer to be commercialized, and it possesses an enviable combination of performance attributes. Clearly, PC has the most advanced combination of properties such as impact resistance, ductility, clarity, dimensional stability, inherent ignition resistance, high-temperature resistance, rigidity, and creep resistance. On the other hand, the weaknesses of PC lie in its solvent resistance (organics), abrasion resistance, ultraviolet (UV) resistance (limited), notch sensitivity, and hydrolytic stability (limited).

Polycarbonate offers good resistance to UV light but displays yellowing. Ultraviolet stability can be extended with absorbers, coatings, and cap layers. Typical automotive exterior lighting applications rely on UV protection via proprietary coatings. Solvent resistance is an issue for some automotive applications that otherwise would use PC. For example, the use of PC and its blends in parts that can come into contact with gasoline is discouraged due to the potential stress cracking that might result in the part after exposure to gasoline.

The wheelbase is still considered a challenge for plastics, although plastics can make a significant improvement to the rotational mass in the car. No major OEM has introduced wheels made entirely of plastics yet. Vinyl ester-based composites had been attempted but with no commercial success.

On the other hand, plastics have served well in the decorative segment of the wheel. Wheel covers, also known as hubcaps, are decorative parts attached to the steel wheel that covers the lug nuts. Generally, painted acrylonitrile-butadiene-styrene (ABS) and thermoplastic polyolefin (TPO) are used most often in making hubcaps. Chrome-plated emulsion ABS also is used in this application for customers who prefer the appearance of chrome. Chrome plating is a finishing treatment utilizing the electrolytic deposition of chromium. Many other plastics such as mass ABS and TPO have been attempted in this application with limited success.

In summary, headlight lenses are one of the most common automotive applications for plastics, and polycarbonate was the first commercialized polymer to offer many beneficial performance characteristics for automotive lighting. Wheel systems remain within the domain of metals, except for decorative uses such as those found on hubcaps.

Chapter Eight

The Future of Plastics in Automotive Applications

Plastics will continue to follow a steady growth path in automotive applications, but that will not dramatically improve the total weight percentage of plastics consumed by the automotive industy. This scenario is likely to change only if fuel costs continue to rise and alternative fuels are not bringing any relief to the general public.

Market penetration by plastics either will be enabled by acceptance of more thermoset-based composite solutions or by part integration leveraged by advanced adhesive systems. Certainly many hybrid polymer–metal technologies are being considered and will surface in the market by the year 2025. Developing countries will look for lightweight and environmentally friendly cars, and in most cases, this will make plastics and plastic composites as well as bioplastic solutions attractive.

If a breakthrough occurs in the electrocoating process, there also is a good possibility that more plastics and plastic composites will find their way onto the car assembly line in body panels for large car platforms. This must be supported by significant technical innovation in fiber, resin, and fabrication technology of plastic composites to make their economic competitiveness comparable to that of metals.

Plastics had been struggling to get into the body panel segment since first introduced, with a few companies such as Renault maintaining interest with measured acceptance. Recently, it has been reported that plastic roof and liftgate modules will become mainstream in the next five to ten years. Plastic Omnium claims that its thermoset (composite) liftgate for the Buick Rendezvous weighs 10 to 20% less than its steel-based design.[20]

However, consideration of fuel costs is not significant enough to spark increased replacement of metal in vehicles. The People's Car, which was introduced by Tata Motors in 2007 as the least-expensive car in the world and has a high projected volume, is still made primarily of metals (Figure 19).

Figure 19 The $2,000 People's Car introduced by Tata Motors in 2007. (Courtesy Tata Motors)

Plastics solutions today still cannot meet the demands of frugal car designers such as Tata Motors. The need for fuel economy has driven expensive carbon fiber composite technology onto the automotive scene; however, questions remain regarding the need in the automotive segment and the average consumer's ability to pay for this technology. All composite bodies in some race cars have given OEMs a higher level of confidence in the approach. But the pocketbook rather than technology will drive the future.

As safety standards become more stringent, airbags will be considered elsewhere in vehicles, beyond the driver and passenger sides. This transformation is already in progress, with the need for thorax airbags, inflatable curtains, knee bags, and pedestrian safety front-end airbags. Plastics solutions probably are the only way to meet this need. However, intelligent electronic detector and interactive response systems will play a major role in all of these safety devices, dictating the need for more or fewer airbags. Innovative and smart polymer foams also will find a niche in this area.

Application areas such as exhaust systems, powertrain assemblies, and turbo impellers are only beginning to be explored and will be receptive to innovative plastics solutions.[21] The need for fuel efficiency also will drive the need for innovation of lightweight second-stage turbo impellers. Making such parts from plastic is largely a pipe dream today because of the requirement for 300°C or greater exposure over extended periods. Plastic gear systems are already being considered and will begin to appear in the market as better ways to deal with parts in friction are determined and as new lubrication technologies are brought to the market. Plastic composite wheels may be offered in the future as part of the drive to improve fuel efficiency and certainly will have a big impact in the reduction of rotational mass. The technology is feasible as long as the drive is there.

As seen in recent years, massive worldwide awareness to be free of the dependence on petroleum as an energy source also will impact alternative sources of plastics. If we learn from our past mistakes, multiple routes for making plastics will be found, rather than only one. Environmental concerns also will bring innovative recycled plastics solutions to market.[22] SABIC was able to convert polyethylene terephthalate (PET) from recycled bottles to polybutylene terephthalate (PBT) with virgin material properties for use in the automotive applications discussed in earlier chapters of this book. Other examples with recycled nylon and polyphenylene ether (PPE) demonstrated that plastic bumpers can be made from recycled parts simply by clever reformulation, without reclaiming the virgin material properties.[23] Recycling technology for all thermoplastics used in the automotive industry is being advanced continuously and refined.[24,25] Thermosets are a bigger challenge, and a fully formulated thermoset part at best can be burned for fuel value. The challenges associated with thermoplastics are not easy because many of our solutions involve thermosets used as paints or components of solutions. Separation techniques are neither easy nor affordable.

In a recent publication, a vision was presented by Tier 1 automotive solution providers. It stated, “Light weight, high-strength materials (including polymer-matrix composites) will be the focus for material development in the automotive industry for the next several years… The use of bio-based materials, such as poly(lactic acid), soybean oil derived materials, and the like are being investigated to cut our dependence on petroleum-based materials."[26]

High-performance polymer composites are not ready for mass-produced cars, regardless of whether they are made using glass fiber or carbon fiber, because fabrication techniques are limited to small car build volumes. Carbon fiber composites (CFCs) pose an additional problem because the purity needed for performance will drive the cost upward. Pundits predict that with adequate research funding, they could lower the cost to an affordable level within five to ten years. This is plausible if the purity level of these fibers is sacrificed to a certain extent or if the use of mixed glass and carbon fibers is considered. Furthermore, the development of a higher-throughput composite part production line will be necessary to enter the high-volume mass-produced car segment. Mid-luxury cars have started to use high-performance CFCs in selected body parts for lightness of weight, styling, and improved crash performance. For example, Figure 20 shows how BMW adopted a CFC roof segment in one of its car platforms. High-performance cars and race cars have already adopted the CFC route, as shown in Figure 21.

Thus, the future of plastics in the automotive industry depends largely on technological and manufacturing innovation, as well as economic and environmental factors and new ways to manufacture the plastics.

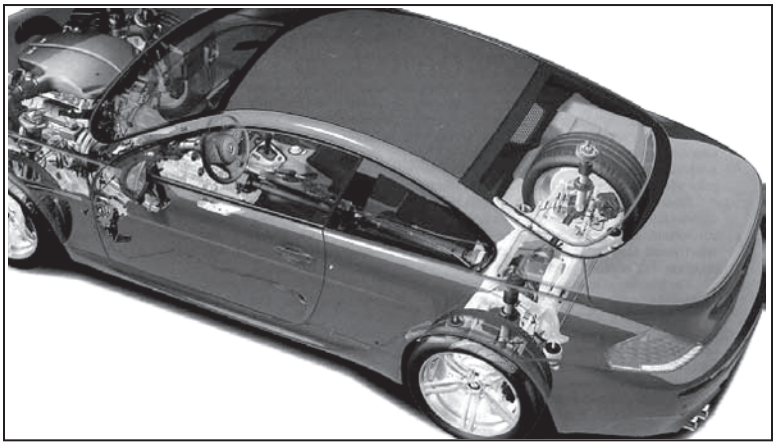


Figure 20 Roof segment made of CFC in the BMW MS CSL.

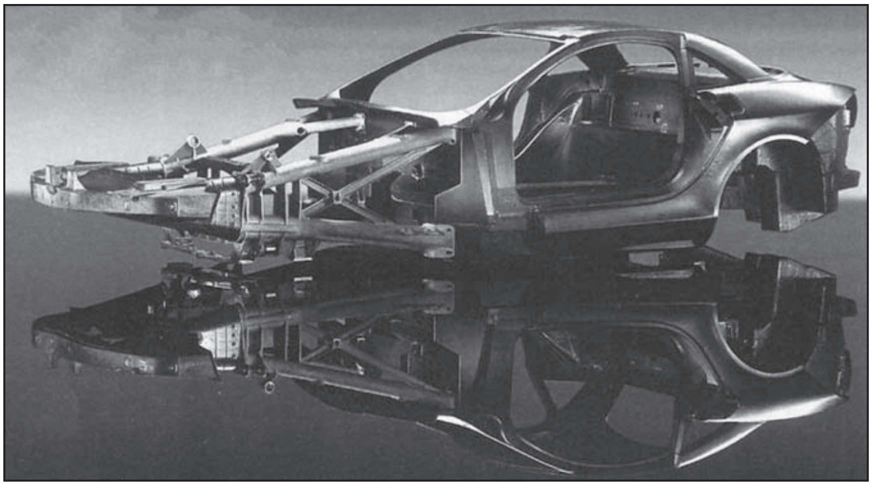
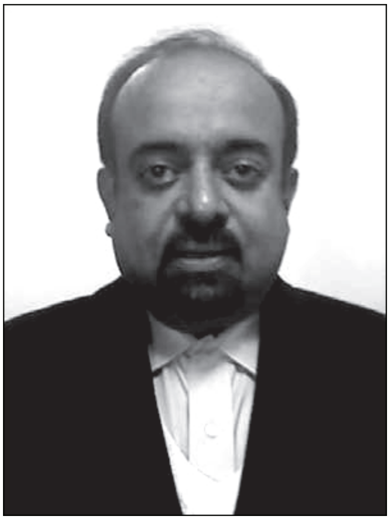


Figure 21 Front structure made completely of CFC in the Mercedes SLR McLaren.

About the Author



Dr. Kalyan Sehanobish is a leading expert in materials science, with particular emphasis on fracture behavior. He completed his undergraduate and graduate education in Chemical Engineering in India. He then came to the United States to attend Case Western Reserve University, where he graduated with a Ph.D. in Macromolecular Science.

Dr. Sehanobish currently is a senior scientist with Dow Automotive Research, a market-facing business unit of The Dow Chemical Company. He has technical responsibility for most of the new business opportunities for that company, with a primary focus on materials science aspects. This encompasses a broad range of technology solutions, such as intelligent foams for acoustics and crash management, new heat storage materials to improve powertrain efficiency, and identifying approaches to make crack-resistant ceramic filters.

During his 20-year career with The Dow Chemical Company, Dr. Sehanobish has been responsible for pioneering work in lifetime prediction modeling for polyolefin pipes, structure–property relationships of thermoplastic polymer blends, and the engineering materials science aspects of metals, ceramics, and hybrids.

Dr. Sehanobish was one of the early pioneers of developing applications for metallocene-catalyzed polyethylene resins, known as polyolefins, plastomers, and elastomers, starting from 1989. He was instrumental in developing a broad variety of applications of metallocene-catalyzed polyethylene resins. His efforts related to structure–properties relationships included pioneering work in the area of mechanical properties and tie-chain concentration over a broad range of crystallinity and the effect of processing on molecular orientation and film properties. Dr. Sehanobish was instrumental in developing applications of metallocene- and post-metallocene-catalyzed resins, such as impact modifiers for thermoplastic olefins (TPO) that are used today in almost all car bumper fascia applications, unique cast stretch films, hot water pipes, and blown films.

Dr. Sehanobish has authored a series of publications and holds more than 25 patents in the areas of polyethylene pipes, blown and cast films, speciality fibers and films, and TPOs. His research is the basis for the INSITE^{TM} technology platform and new resin families such as ENGAGE^{TM}, AFFINITY^{TM}, NORDEL^{TM} IP, and ELITE^{TM}. The INSITE technology received the *R&D* 100 Award in 1994 from *R&D Magazine*, and the ELITE enhanced polyethylenes received the *R&D* 100 Award in 1999. These efforts also resulted in currently more than one billion pounds per year of sales of metallocene-catalyzed polyethylene resins by The Dow Chemical Company.

Since joining the automotive industry in 2004–2005 as part of Dow Automotive Research, Dr. Sehanobish has worked on the development of plastics and composites for automotive applications, including several new products in safety, bonding, acoustics, and heat storage applications. Two of these products received the *R&D* 100 Award in 2005 and 2007. Dr. Sehanobish also has presented papers at numerous technical and industrial conferences, often as an invited speaker.

List of Acronyms

ABS	Acrylonitrile-butadiene-styrene
CFC	Carbon fiber composite
CLTE	Coefficient of linear thermal expansion
DBTT	Ductile-to-brittle transition temperature
EPDM	Ethylene propylene diene monomer
EVOH	Ethylene vinyl alcohol
FEC	Front-end carrier
HC	Hydrocarbon
HDPE	High-density polyethylene
HHABS	High-heat acrylonitrile-butadiene-styrene
IP	Instrument panel

LGF	Long-glass-filled
LGF PP	Long-glass-filled polyphenylene
OEM	Original equipment manufacturer
PA	Polyamide
PBT	Polybutylene terephthalate
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene terephthalate
PP	Polypropylene
PPE	Polyphenylene ether
PPO	Polyphenylene oxide
PS	Polystyrene
PU	Polyurethane
RIM	Reaction-injection-molded
r-TPV	Thermoplastics vulcanizate made by a reactive extrusion process with EPDM, a cross linker, and PP.

SBC	Styrene block copolymer
SEB	Styrene-ethylene block (copolymer)
SMA	Styrene maleic anhydride
SMC	Sheet molding compound
TPO	Thermoplastic polyolefin
TSOP	Toyota Super Olefin Polymer
UV	Ultraviolet

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