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Engineering Plastics and Plastic Composites

In Automotive Applications

Kalyan Sehanobish

Engineering Plastics and Plastic Composites in Automotive Applications

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Introduction

Before the 1970s, plastics were considered primarily as non-engineering materials and were used in applications such as belts, hoses, gaskets, carpet backing, sealing, adhesives, tires, and so forth as a part of an engineering solution. Those individuals who are not materials scientists presumably won't classify elastomers (i.e., natural and synthetic rubbers) and adhesives used in these applications as engineering plastics, although those materials have enabled the engineering function since their inception. It wasn't until plastics started to replace metals that they began to be considered as engineering materials.

Today, plastics have penetrated into engineering applications within the automotive industry, replacing traditional materials at a significant rate in only the past 30 years. By themselves, plastics are poor choices for engineering applications because of their poor strength-to-density ratio.[1] The introduction of plastics containing inorganic fillers and of plastic composite systems with cross-linkable resins as binders advanced the growth of plastics as structural materials in engineering applications. This book will not only cover some of the current applications of plastics and their advantages but also will address what may be foreseen in terms of new applications for plastics in automotive engineering.

However, before going any further, let's share some actual data (Table 1) compiled from various sources on the penetration of plastics and plastic composites into passenger vehicles.[2,3] From Table 1, it is evident that the use of plastics in engineering applications has crept upward from approximately 4.6% of the overall vehicle body weight in 1977 to approximately 7.6% in 2003. At first glance, this may not seem impressive, until you consider the increases in the variety of equipment and accessories added to vehicles during the past 30 years. In fact, these lightweight materials have allowed the industry to maintain the overall weight of vehicles at the same level as a basic new car in 1977. Today, plastics comprise almost 50% of the material volume in most new cars. Studies show that each 100 pounds of plastics can replace approximately 200 to 300 pounds of mass from traditional material.[2,3]

TABLE 1
PLASTICS IN A TYPICAL PASSENGER VEHICLE*

Year	Weight of Plastics and Plastic Composites (lb)	Total Vehicle Weight (lb)	Percentage of Plastics and Plastic Composites (%)
2003	255.0	3358.5	7.6
2002	255.0	3339.5, 3357.5[3]	7.6
2001	253.0	3309.0	7.6
2000	248.5	3286.0	7.6
1999	245.0	3274.0	7.5
1998	243.5	3261.5	7.5
1997	242.0	3248.0	7.5
1992	243.0	3135.5	7.7
1991	238.0	3059.0	7.8
1990	222.0, 229[3]	2896.0, 3140.5[3]	7.7, 7.3[3]
1989	224.5	3140.0	7.1
1988	219.5	3010.0	7.3
1987	221.5	3178.0	7.0
1986	216.0	3118.0	6.9
1985	211.5	3187.5	6.6
1984	206.5	3141.5	6.6
1983	200.0	3192.0	6.3
1982	202.5	3101.5	6.5
1980	196.5	3309.0	5.9
1978	176.0, 180[3]	3494.0, 3569.5[3]	5.0, 5.0[3]
1977	168.0	3665.5	4.6

*This table is taken from publicly available data in Reference 2, with some exceptions in Reference 3 as noted.

Let's start by classifying the plastics found in various segments of an automobile. (The use of plastics as foams and fabrics for noise absorption and comfort will not be addressed here.) To begin, we find examples of plastics primarily in decorative, safety, noise, vibration, and harshness applications for the interior parts of the vehicle. These applications include the cockpit systems (e.g., instrument panels [IPs], structural portions of IPs, and dashmats), headliners, seat systems (e.g., seat backs and seat bases), soft and hard trim (e.g., door trim and pillars), interior door handles, gloveboxes, and packaging trays. Steering wheels, door handles, and mirror housings are other interior items that are built from plastics. Plastics have even entered critical safety-oriented applications such as airbags and airbag covers.

Plastics are making modest advances in all horizontal and vertical body panel parts in the exterior of the vehicle or behind the cockpit, thereby replacing metals. These applications include door panels, roofs, floors, fenders, back panels, hoods, and mud plates often used as part of the firewall. Greater penetration of plastics into these parts is expected to occur in the future. Other panels that will be considered here as exterior parts include the bumper fascia, quarter panels, underbody shields, drag panels, exterior door handles, and mirror housings. Improved performance and lightness of weight will drive more plastics in these applications.

The powertrain segment is the most complicated and challenging application of plastics. As modern plastics meet these challenges, the presence of plastics will continue to grow. Plastics have already found their way into air induction systems (e.g., intake manifolds, ducts, air cleaners, air filters, and snorkels), cooling systems (e.g., hoses), side and front engine covers, engine fans, turbo systems (e.g., turbo impellers and housings), valve covers, oil pans, oil filters, and belly pans.

Fuel systems have already experienced an invasion by plastics. The use of plastics can be seen in fuel tanks, fuel rails, fuel pump parts, connectors, hoses, and fuel filters. Furthermore, external and internal lighting systems have already gone primarily to plastics. Wheel systems have adopted plastics much earlier in the construction of tires, wheel covers, and wheel house liners, although wheel systems remain primarily the domain of metals.

In spite of such frequent use of plastics, the automobile remains largely a metal play with sheet metal, cast iron, aluminum, magnesium, and so forth. According to the Society of the Plastics Industry's 1998 edition of *Facts and Figures*, the land transportation industry consumes only approximately 5% of the total plastics consumed in millions of pounds and remained unchanged between 1993 and 2008. The packaging industry consumes approximately 25% of all plastics made today. Although more new applications for plastics will be introduced in the transportation industry, a similar increase in the use of plastics in other industries will tend to maintain the ratio of plastics consumed as fairly constant. A dramatic change in this ratio can occur only if regulatory mandates for lowering the weight of vehicles pushes plastics further into the horizontal and vertical body parts of vehicles, coupled with innovation in plastic composites that addresses both the temperature-related expansion issues and the high-temperature baking issues of plastics. The use of plastics as structural beams and rails remains far from reality and only a dream for the plastics industry and fabricators within that industry.

Although the field of plastics and plastic composites in the transportation industry is vast, this book will focus on plastics that have already made entry into the automotive segments mentioned in the preceding paragraphs. It will conclude by projecting the future of plastics in the automotive industry in light of predicted global trends.

Executive Summary

Plastics have entered engineering applications within the automotive industry at a significant rate during the last 30 years. Although plastics have a poor strength-to-density ratio by themselves, plastics with inorganic fillers and plastic composite systems have advanced as structural materials while offering many advantages over metal. This book focuses on some of the various types of plastics and plastic composites and their applications within passenger vehicles. It also discusses the future of plastics in the automotive industry.

Plastics are classified as thermoplastics, rubbers, or thermosets. Available in a variety of forms and blends, their advantages include durability, strength, lightness of weight, and excellent thermal and electrical insulating properties. Progress made in the recycling of plastics has added to the acceptance of plastics.

Interior components make up the largest use of plastics in automotive vehicles, in applications such as instrument panels (IPs), body panels, door panels, dashmats, seat backs, seat bases, steering wheels, and airbag covers.

The use of plastics in exterior horizontal and vertical body panels of vehicles has been difficult, but some have found their way into the body panels, hoods, and especially fenders of vehicles. Plastics are commonly used in bumpers and are appearing as underbody shields and exterior door handles. Environmental conditions and stresses have limited the use of plastics in the exterior parts of vehicles.

While once viewed as unsuitable for the extreme environment found near engines, plastics now are being used under the hood as replacements for metal parts. These plastics meet the requirements for strength, high temperatures, and even flame resistance needed for powertrain applications while offering the advantages of lower weight and cost, improved air flow, and corrosion resistance.

Plastics also are used in fuel systems, with the largest application being fuel tanks. They are the predominant material today for headlight lenses and other automotive lighting. However, wheel systems remain primarily metal, except for decorative uses of plastics such as found on hubcaps.

Plastics will continue to permeate automotive applications, and hybrid polymer–metal technologies are expected to be developed in the years ahead. Increased use of airbags also will translate into the need for more plastic solutions. Acceptance of plastics engineering into vehicles will be driven by the need for lightness of weight, fuel efficiency, freedom from petroleum dependence, and improved methods of reuse and recycling of plastics. The future of plastics in the automotive industry depends largely on technological and manufacturing innovation, as well as economic and environmental factors.

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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]

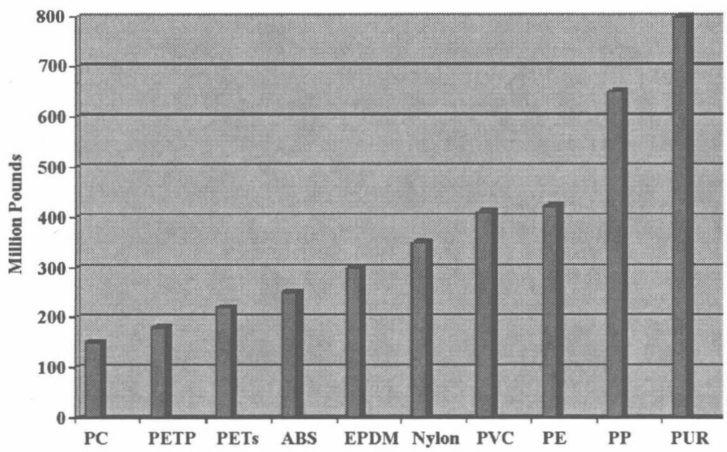


Figure 1 The use of plastics in automotive applications in North America.

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:

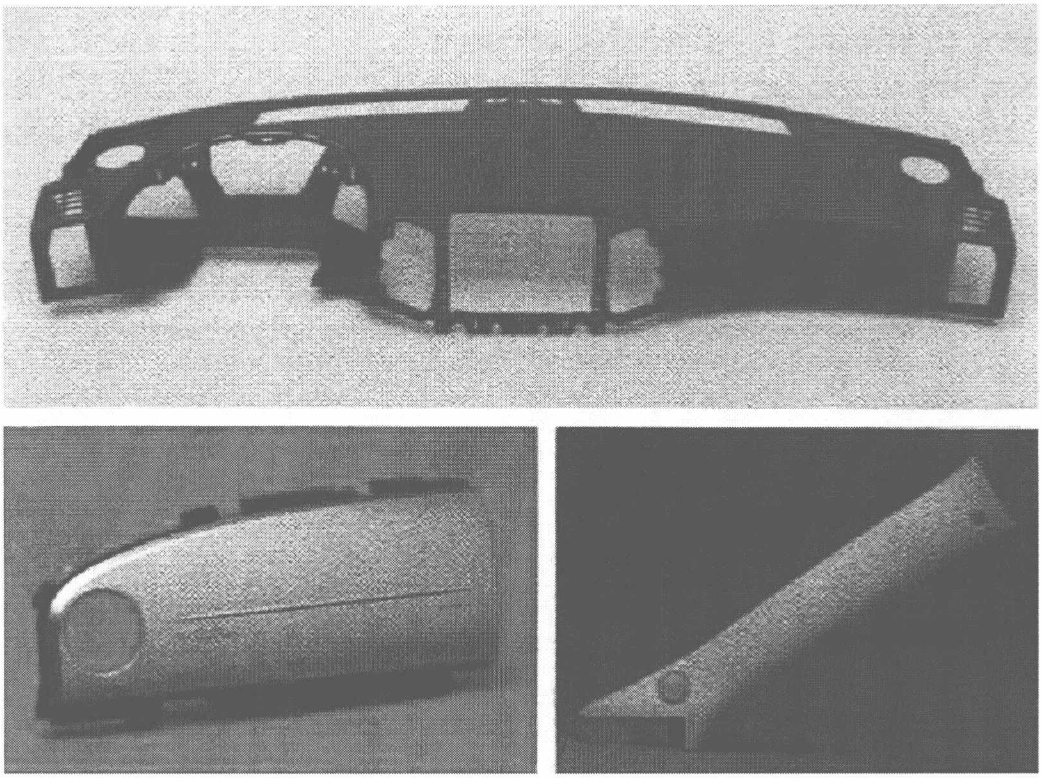
- Acrylonitrile-butadiene-styrene (ABS)
- High-heat ABS (HHABS)
- Blends of polycarbonate (PC) and ABS
- Modified polyphenylene ether (PPE)
- Modified polypropylene (thermoplastic polyolefin [TPO])
- Long-glass-filled polypropylene (LGF PP) and ABS
- Styrene maleic anhydride (SMA)

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

(a)



(b) (c)

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.

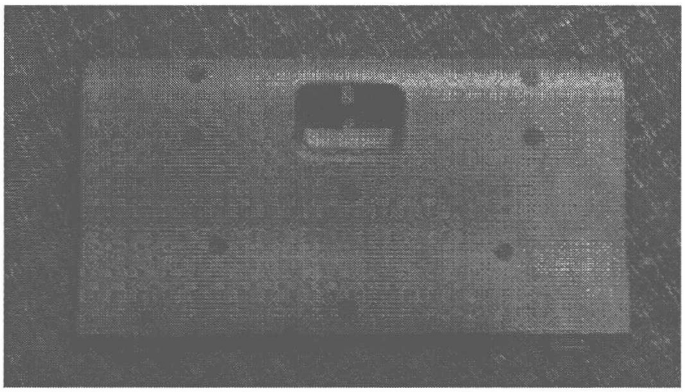


Figure 3 60° gloss measurement locations in an injection-molded glovebox.

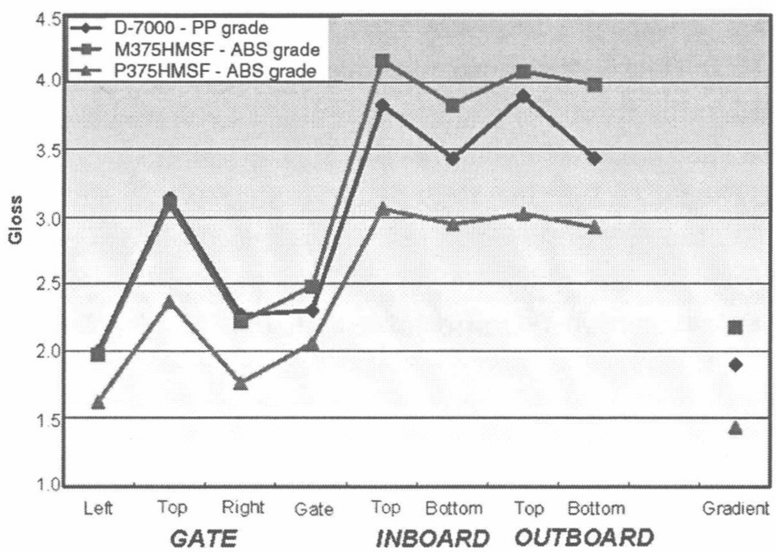


Figure 4 60° gloss measurements at all locations presented in Figure 3.

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

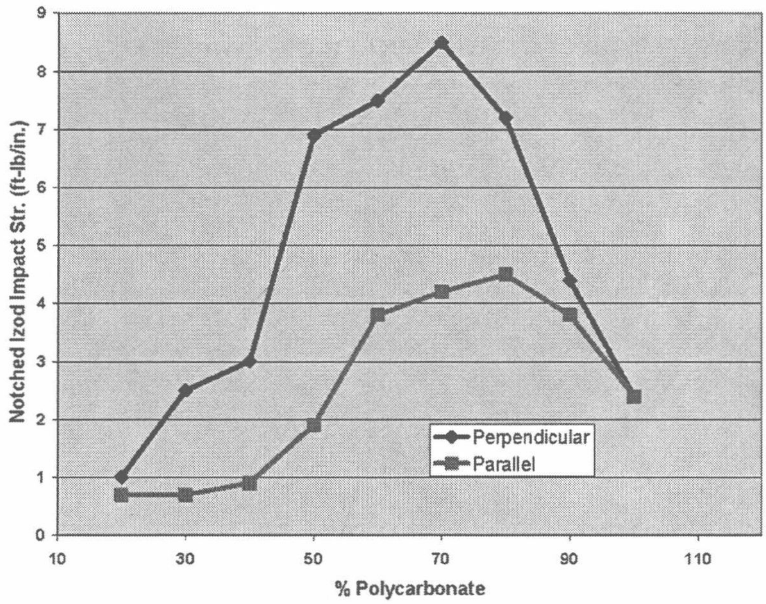


Figure 5 Impact resistance versus blend composition in a PC/ABS blend.

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).