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PLASTIC MANUFACTURING PROCESSES FOR AUTOMOTIVE APPLICATIONS

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Abstract. The automotive industry has used plastics almost since the beginning. Plastics are employed in a variety of automotive parts, ranging from exterior components like bumpers and body panels to interior elements such as dashboards, seating materials, and trim. The manufacturing of these parts involves advanced plastic processing techniques, including injection molding, blow molding, thermoforming, rotational molding, compression molding, and extrusion. Each process offers unique advantages, such as high-volume production, complex part formation, and material consistency, contributing to the efficiency of automotive production. Plastic materials are widely used in the automotive industry due to their versatility, durability, and lightweight properties. These materials, often synthetic, are engineered to meet specific needs such as resistance to heat, chemicals, and physical stress. They can be molded into various shapes, making them ideal for creating complex parts used in vehicle manufacturing. Overall, plastics are crucial in modern automotive manufacturing, playing a significant role in producing efficient, lightweight, and cost-effective vehicles.

Keywords: plastic materials, automotive, manufacturing processes, molding, cost-effective vehicles.

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1. Introduction

Plastics encompass a broad category of synthetic and semisynthetic materials, with polymers as their primary component. Their flexibility allows them to be molded, extruded, or shaped into solid objects of various forms. This versatility, combined with properties such as being lightweight, durable, flexible, non-toxic, and cost-effective to manufacture, has contributed to their widespread global use (Elias and Mülhaupt, 2015).

In developed economies, approximately one-third of plastic is used in packaging, with a similar proportion used in construction for piping, plumbing, and vinyl siding. Other significant uses include the automotive industry (where plastic accounts for up to 20% of vehicle materials), furniture, and toys (Andrady and Neal, 1977).

Since 1950, an estimated 9.2 billion metric tons of plastic have been produced, with more than half of this total manufactured since 2004. Preliminary data for 2023 suggests that global plastic production exceeded 400 million metric tons. If current demand trends persist, annual plastic production will surpass 1.2 billion metric tons by 2060 (Fig. 1).

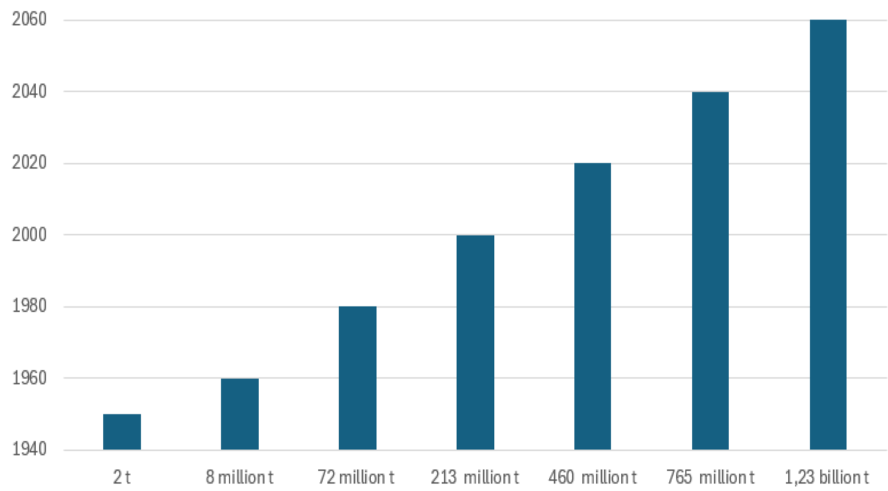

Fig. 1 – Global plastic production with projections, 1950 to 2060 *adapted after* (Geyer *et al*., 2017).

The use of man-made plastics dates back over 150 years. In 1862, chemist and inventor Alexander Parkes introduced the first synthetic plastic, known as Parkesine, at the International Exhibition in London. Made from cellulose, Parkesine could be heated, molded into various shapes, and would retain its form once cooled.

What set Parkesine apart was its ability to be transparent and shaped into countless designs. As the earliest manufactured plastic, it offered a colorful and affordable alternative to materials like ivory and tortoiseshell. It quickly found use in the production of small, everyday consumer goods such as buttons and brush handles, making these items more accessible to the general public (Freinkel, 2011).

In automobiles, plastic materials play a major role, widely used in exterior body panels, interior features, and various internal mechanical components. However, plastics have played a role in car manufacturing since as early as 1907, when Leo Baekeland invented Bakelite in New York. This synthetic plastic was lightweight, durable, non-conductive, and resistant to heat—qualities that made it ideal for early automotive components like instrument panels, control knobs, and some engine parts. Although Bakelite is no longer used in modern vehicle production, it paved the way for a broad range of advanced plastics that are now driving innovation in the automotive industry. These advanced materials enhance vehicle safety and reliability. To fully grasp their impact, it is important to understand the specific plastics involved (Piedmont Plastics, 2022).

Plastics are a preferred choice for modern vehicle manufacturers due to their lightweight nature and cost-effectiveness. Reducing vehicle weight aligns with consumer demand for improved fuel efficiency, while plastics' inherent durability and resistance to corrosion enhance safety. Additionally, their design flexibility makes them a more practical and economical alternative to metal.

To ensure that materials used in production are both durable and industry-compliant, automotive manufacturers must follow a rigorous set of standards. This process, known as material qualification, is mandatory for all plastics used in vehicle manufacturing.

2. Classification of Materials

Depending on physical properties, plastics are divided into two types: thermoplastic and thermosets as is presented in Table 1.

Thermoplastic resins are composed of macromolecular chains that lack cross-links between them. These chains may feature randomly oriented side branches or form statistically distributed crystalline phases. The chemical composition and molecular structure of thermoplastics significantly influence their resistance to chemicals and environmental factors such as UV radiation. Depending on their formulation, thermoplastics can range from optically transparent to fully opaque. In opaque variants, internal scattering caused by the molecular structure reduces light transmission, particularly as material thickness increases.

One of the key advantages of thermoplastics is their ability to be melted and re-solidified repeatedly through heating and cooling cycles without significant changes to their mechanical or optical properties. This makes them ideal for industrial manufacturing processes such as extrusion–used for producing films, sheets, and profiles–and molding of various components. Example: PVC, nylon, polythene, etc. (Stokes, 2020).

Thermosets are plastic resins with narrow crosslinked molecule chains. In the state of application thermosets are hard and brittle. Because of the strong resistance of molecular movement caused by the crosslinking, mechanical strength and elasticity are not temperature dependent, as with thermoplastics or elastomers.

Thermosets cannot be melted and joining by thermal processes like ultrasonic welding or laser welding is not possible. On exceeding the decomposition temperature Td, the material will be chemical decomposed. Examples of thermosets are epoxy resin, phenolic resin or polyester resin, Bakelite, melamine, polyimide etc. (Stokes, 2020).

Table 1
Different types of plastics, adaptation after (Maier, 2009)

Plastics			
Thermoplastics			**Thermosets**
Semi-crystalline	*Amorphous*	*Elastomeric*	
HDPE - High density polyethylene	ABS - acrylonitrile butadiene styrene	EPDM - ethylene-propylene-diene terpolymer	DAP - diallyl phthalate
LDPE - Low density polyethylene	CA - cellulose acetate	EPT - ethylene-propylene terpolymer	MF - melamine formaldehyde
LLDPE - Linear low density polyethylene	CAB - cellulose acetate butyrate	NBR - nitrile butadiene rubber	PF - phenol formaldehyde
PA - polyamide (nylon)	CP - cellulose proprionate	PEBA - polyether block amide	UF - urea formaldehyde
PBT - polybutylene terephthalate	PC - polycarbonate	SBS styrene-butadiene-styrene	EP - epoxy
PEEK - polyether ether ketone	PES - polyether sulphone	TPU - thermoplastic polyurethane	UP - unsaturated polyester
POM-polyoxymethylene (acetal)	PET - polyethylene terephthalate		
PP - polypropylene	PMMA - polymethyl methacrylate		
PPS - polyphenylene sulphide	PPO - polyphenylene oxide		
	PS - polystyrene		
	PUS - polysulphone		
	PVC - polyvinyl Chloride		
	SAN - styrene acrylonitrile		

2.1. Plastic Materials used in Automotive Industry

The automotive industry leverages the full spectrum of performance benefits provided by various polymer and plastic families. Elastomeric and cellular materials enhance seating comfort, absorb vibrations from the powertrain and suspension, and dissipate impact energy to improve safety. On the other end of the performance scale, structural plastics and composites serve as lightweight alternatives to metal, offering load-bearing support for vehicle bodies. These advanced materials play a crucial role in helping the industry meet strict emissions regulations and improve fuel efficiency.

Major plastics used in automotive applications:

ABS - Acrylonitrile butadiene styrene;
FP - Fluoropolymers;
HDPE - High density polyethylene;
LCP - Liquid crystal polymers;
LDPE - Low density polyethylene;
PA-4,6 - Polyamide-4,6;
PA-6/6,6 - Polyamide-6/6,6;
PAI - Polyamideimide;
PAR - Polyarylate;
PBT - Polybutylene terephthalate;
PC - Polycarbonate;
PE-UHMW - Ultrahigh molecular weight polyethylene;
PEEK - Polyetheretherketone;
PEI - Polyetherimide;
PES - Polyethersulfone;
PET - Polyethylene terephthalate;
PI - Polyimide;
PMMA - Polymethyl methacrylate;
POM - Polyoxymethylene;
PP - Polypropylene;
PPA - Polyphthalamide;
PPC - Polyphthalate carbonate;
PPO - Polyphenylene oxide;
PPS - Polyphenylene sulfide;
PPSU - Polyphenylsulfone;
PS - Polystyrene;
PSF - Polysulfone;
PVC - Polyvinyl chloride;
PVDF - Polyvinylidene fluoride;
SAN - Styrene acrylonitrile;
SMA - Styrene maleic anhydride;
TPI - Thermoplastic polyimide.

The plastics mentioned above represent only a small portion of the wide array of materials used in vehicle manufacturing. While they are among the most commonly found in automotive components, vehicles themselves differ greatly in size, shape, and intended use–whether for daily commuting, construction, cargo transport, or emergency services. As a result, selecting the appropriate plastic for each specific application is essential to ensure optimal performance and durability.

2.2. Plastics Manufacturing Processes

Plastics manufacturing processes are used to create objects of various shapes and sizes, from toys and appliances to parts for vehicles. There are a few different methods for producing plastics parts, including injection molding, blow molding, extrusion, rotational molding, 3D printing, polymer casting, CNC machining and thermoforming/ vacuum forming (Flying Precision, 2023).

Injection molding is a manufacturing process that involves injecting molten plastic into a mold cavity (Fig. 2). The process has an incredibly efficient way of producing large numbers of identical parts, making it ideal for mass production.

And, it can be a relatively inexpensive process with cost implications being based on materials and labor costs. It also has a relatively low environmental impact when compared to other plastic production processes. Furthermore, injection molding can create complex parts with excellent detail and high strength. Nowdays, injection molding is one of the most popular and versatile methods of plastics production despite the its drawbacks, like the need for intricate tooling and the high cost of tooling production.

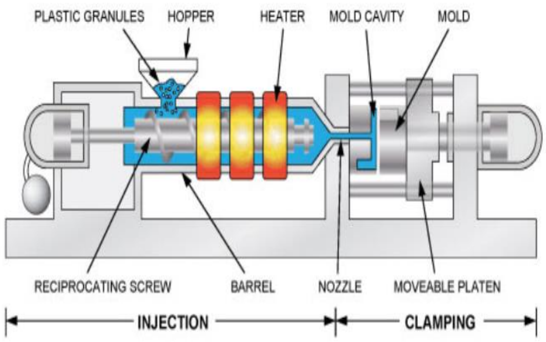

Fig. 2 – Injection molding machine (Chans Machining, 2024).

Extrusion molding is one of the most essential plastic molding processes, widely used in the industry for continuous profile production. This process involves forcing molten plastic through a die to create products such as pipes and sheets (Fig. 3). It highlights the complexity of plastic molding methods and demonstrates the adaptability of plastic manufacturing in meeting diverse industrial needs.

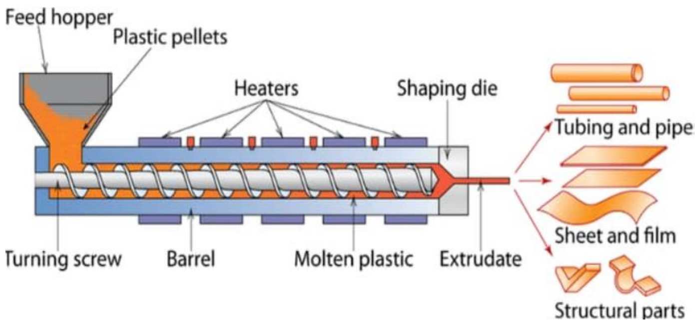

Fig. 3 – Extrusion molding (Chans Machining, 2024).

Blow molding is a specialized plastic forming process designed to produce high-quality hollow products, such as bottles. In this process, plastic is heated and then inflated within a mold to achieve the desired shape (Fig. 4). This method showcases the versatility of plastic molding, particularly in manufacturing plastic bottles, and exemplifies best practices in the plastic production industry.

Blow molding operates at significantly lower pressures compared to injection molding, which helps reduce tooling costs. Similar to injection molding and extrusion, it is a continuous and fully automatable process, enabling high production volumes and low per-unit costs.

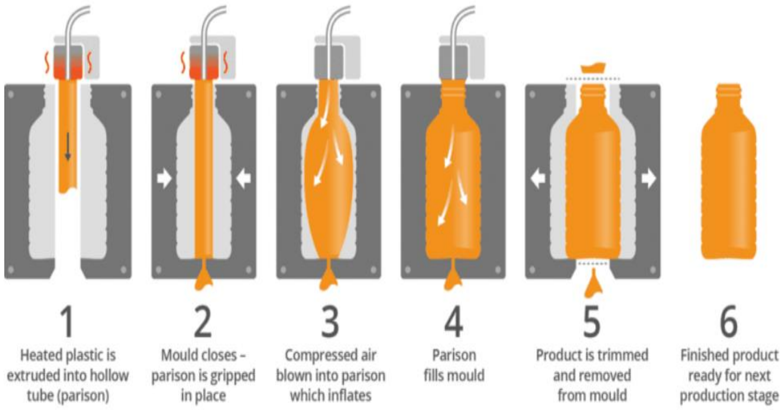

Fig. 4 – Plastic Blow Molding Process (Chans Machining, 2024).

Thermoforming, also known as vacuum forming, is a manufacturing process in which plastic is heated and shaped using a mold (Fig. 5). Vacuum forming machines range from simple, low-cost desktop units to advanced automated industrial systems. As a key plastic fabrication process, thermoforming is particularly useful for shaping large plastic parts by applying heat and forming plastic sheets over molds.

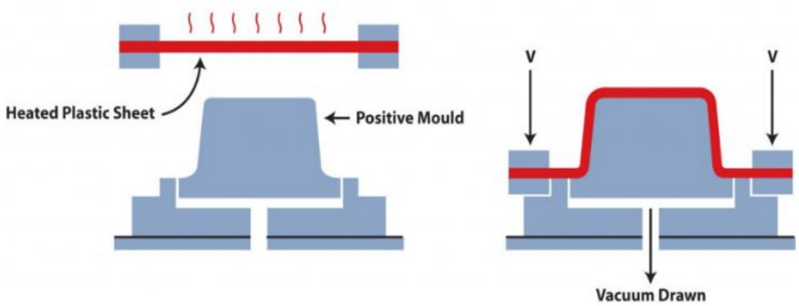

Fig. 5 – Thermoforming (Euro Extrusions Ltd, 2016).

Rotational molding stands out from other plastic molding processes due to its ability to produce large, hollow, and seamless parts. This method is essential in plastic manufacturing, as it involves rotating a heated mold to evenly distribute the material, ensuring uniform thickness and strength (Fig. 6).

Advantages of this process include cost efficiency, relatively short production times, and the ability to produce complex shapes. However, there are also potential disadvantages, such as the limited size of the part and a higher wall thickness than other processes.

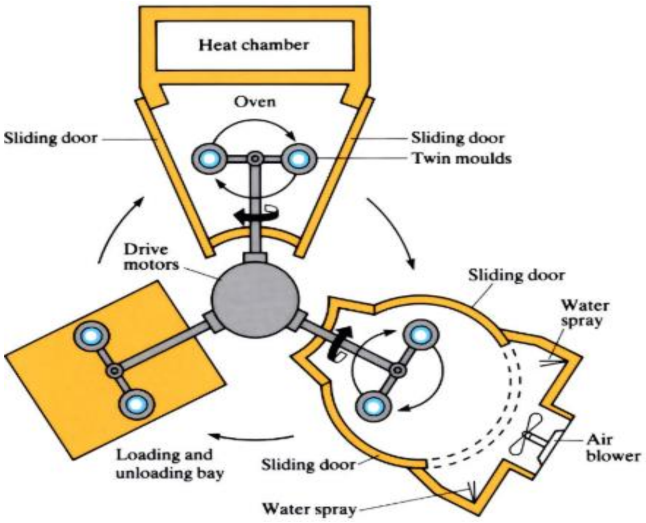

Fig. 6 – Rotational molding (Chans Machining, 2024).

CNC plastic machining utilizes computer-controlled tools to shape various plastic materials with precision and accuracy (Fig. 7). This method is a crucial aspect of plastic manufacturing, particularly for producing complex, custom forms that demand a high level of detail, reflecting advancements in modern manufacturing.

CNC machining, whether used for metal or plastic, relies on subtractive processes such as milling, turning, drilling, and grinding. It starts with solid blocks, bars, or rods that are precisely shaped by removing material. Unlike most plastic manufacturing process, CNC machining removes material either through a rotating tool acting on a stationary part (milling) or a rotating part shaped by a stationary tool (lathe).

This method is particularly well-suited for low-volume production of plastic parts, especially when complex geometries or tight tolerances make molding less practical. It’s commonly used for prototyping and manufacturing functional components like pulleys, gears, and bushings. CNC machining offers moderate setup costs and delivers high-quality, precision plastic parts.

Fig. 7 – CNC Plastic Machining (Dassault Systèmes, 2024).

While **3D printing** is a groundbreaking process, it doesn't yet match the scale and efficiency of traditional plastic manufacturing processes. This additive method, which is ideal for low-volume production, plays a crucial role in modern manufacturing. It enables rapid prototyping and the creation of customized plastic parts, reflecting the future of polymer process development. Professional 3D printers build parts layer by layer directly from CAD models, resulting in a fully formed physical object (Fig. 8). Since 3D printing requires no tooling and minimal setup for new designs, the cost of producing a custom part is far lower compared to conventional manufacturing methods. However, 3D printing is not typically used for large-scale mass production.

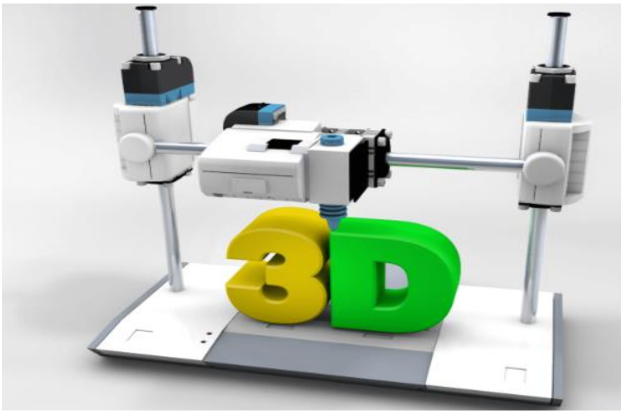

Fig. 8 – 3D Printing (Nitrile gloves info, 2024).

Compression molding is an efficient way of producing plastic parts quickly and cost-effectively, with some projects taking as little as 15 seconds to complete. This method is highly cost-effective and energy-efficient, making it a desirable option for manufacturers.

By using the correct mold and materials, the manufacturer can produce high-quality parts with little waste (Fig. 9). The process is also very flexible and can be used for a variety of different products. When compared to other plastic manufacturing processes, compression molding can require less energy, which can lead to cost savings for the manufacturer. Additionally, the process can be automated for larger production runs, leading to a more consistent product.

However, compression molding has some disadvantages. The process can be more expensive than other methods due to the need for special molds and the cost of the machinery required. Additionally, the process is limited to certain types of materials, so not all plastic parts can be produced this way. Despite these drawbacks, compression molding is still an efficient way to produce plastic parts quickly and cost-effectively.

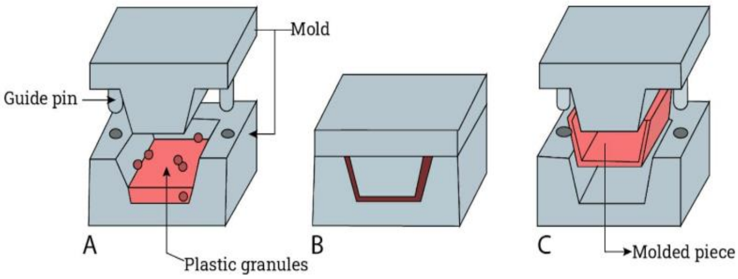

Fig. 9 – Compression Molding (Industrial Quick Search Manufacture Directory, 2024).

In **polymer casting**, a reactive liquid resin or rubber fills a mold which reacts chemically and solidifies (Fig. 10). Typical polymers for casting include silicone, polyurethane, epoxy and acrylic.

Flexible molds, typically made from latex rubber or room temperature vulcanized (RTV) silicone rubber, are more affordable than rigid tooling, though they can only produce a limited number of castings (usually between 25 to 100). This limitation occurs because the chemical reactions of materials like urethanes, epoxies, and acrylics degrade the mold over time.

RTV silicone molds are particularly effective at capturing intricate details, resulting in high-quality cast parts. Stereolithography (SLA) 3D printing is often used to create master patterns for molds directly from CAD designs, thanks to its high resolution and ability to reproduce fine features. While polymer casting is relatively inexpensive with minimal initial investment, it’s important to note that thermoset polymers tend to be more costly than thermoplastics. Additionally, the molding process is labor-intensive, with each part requiring post-processing, which increases the final cost per unit when compared to more automated methods like injection molding. Polymer casting is typically used for prototyping, small-batch production, and specialized applications such as dental or jewelry manufacturing.

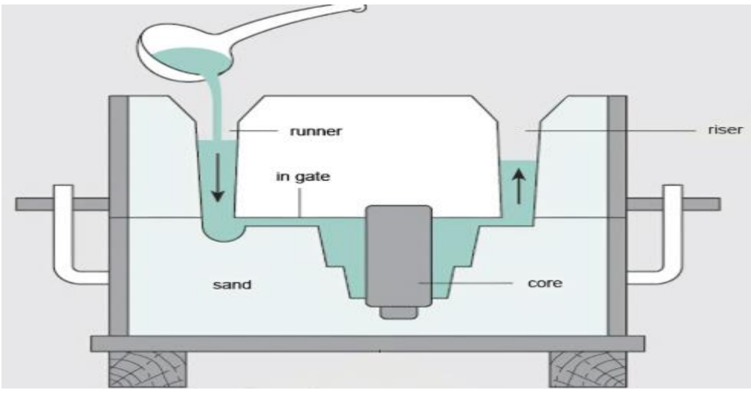

Fig. 10 – Polymer casting (Mechanical Engineering Portal, 2024).

In order to choose the optimal plastic manufacturing process, it is essential to consider the following factors:

– *the form of the part*. The decision is different depending on how complex the internal details are or their tolerance requirements. Also, the geometry of a part can limits the processes that can be applied or can make some economically unavailable to apply;

– *the volume of production*. In case of the high front costs for tooling and setup, it is important that the production volume or the price per-part allows these costs to be covered by high volume or high selling price;

– *costs for tooling and setup* of the manufacturing process;

– *cycle time*;

– *possibility of automation;*

– *lead time*. There are different processes and some of them can be applied in a single day or it takes month to create the environment for;

– *material of the part*. Usually, an optimal material exists for a given application and the choice is a compromise between the cost, stresses and strains etc.

2.3. Advantages and Disadvantages of Using Plastic in Automotive

Numerous car parts once made from metal or steel are now being manufactured with plastics because of their light weight, durability, and versatility. In addition to their safety and environmental advantages, plastics enhance design flexibility, improve aesthetic appeal, and provide cost savings for automotive manufacturers. They are used in various applications, including roof frames, dashboards, seat belts, door panels, steering wheels, car seats, airbags, electric vehicle charging points, car cables, seat belts, automotive chassis, etc. (Plastics Europe, 2025).

The key *advantages* of using automotive plastic parts:

– durability: automotive plastics are highly resilient and long-lasting. Unlike metal components, plastics are resistant to corrosion and wear, which helps preserve their strength over time. Their ability to absorb and dissipate impact energy enhances crash safety, making them ideal for applications ranging from bumpers to interior panels.

– cost-effectiveness: compared to metals, plastics offer a more economical solution. They are inexpensive to produce, easy to mold into complex shapes, and simple to replace. This reduces manufacturing and maintenance costs while still delivering high-quality components.

– lightweight: plastics significantly reduce the overall weight of a vehicle. Lighter vehicles consume less fuel, resulting in improved fuel efficiency and longer travel range per tank.

– versatility: plastics are exceptionally versatile, allowing designers to create complex, aerodynamic, and aesthetically appealing shapes. Their flexibility enables the production of customized, functional parts that meet both engineering and design requirements.

– corrosion resistance: one of the standout features of automotive plastics is their immunity to rust and corrosion. This leads to a longer lifespan for components throughout the vehicle–from the engine bay to the cabin–ensuring sustained performance and appearance over the years (Acharya, 2024).

The *disadvantages* of plastic parts compared to metal in automotive industry are presented below:

– higher initial tooling cost. Plastics have a disadvantage of the high cost of developing injection molding tools. Different parts require different injection molds, while machined metal parts do not require special tools.

– higher lead time for tool development. The development of injection molding tools has a longer lead time. But for smaller volumes, plastic prototyping process are used to get samples quicker. Therefore, plastic parts have a disadvantage of higher lead time compared to metal parts.

– electrical and thermal conductivity. Plastics are not good conductors of heat. Therefore, plastic parts cannot be used where high heat and thermal conductivity are required. To solve this problem, we can use plastic parts together with metal parts.

– lower working temperature range. Plastic is not recommended for very high and low temperature applications.

– difficult manufacturing process. Controlling of the injection molding process may be challenging. Various plastic injection molding defects will come up if the plastic parts design is not as per guidelines, or the injection molding process is not controlled.

– environmental impact. One of the main disadvantages of plastic manufacturing is its significant environmental impact. Plastic waste and pollution is a major environmental problem, with the annual accumulation of millions of tons of plastic waste in our oceans and landfills (Smlease Design, 2024).

3. Conclusion

Plastic materials have become integral to the automotive industry due to their lightweight, with the average car containing between 150-200 kilograms of plastics (around 15% of its total weight) durable, and cost-effective nature. They play a crucial role in enhancing fuel efficiency, safety, reduced emissions, and design flexibility, while also reducing manufacturing costs. The process of manufacturing plastics for automotive applications involves various processes, such as injection molding, extrusion, and thermoforming, which allow for high precision and mass production. Each process offers a variety of benefits and challenges, so it's important to consider the specific application and desired outcome when selecting the right manufacturing process. Plastics also provide design flexibility, allowing for complex shapes and aesthetic features that metal parts cannot easily achieve. There is no one-size-fits-all approach to plastics parts manufacturing, but the tools and processes available make it possible to create quality parts and products.

However, there are also disadvantages to the widespread use of plastics in automotive manufacturing. One of the main concerns is their limited strength and impact resistance compared to metals, which may affect the overall safety of vehicles. Plastics can also be prone to degradation over time due to exposure to UV rays, heat, and chemicals, potentially leading to material failure. Furthermore, while plastics offer cost benefits, their manufacturing processes can be energy-intensive, and some types of plastic can be difficult to recycle, contributing to waste.

The benefits of using plastic in automotive manufacturing are clear. Plastic has revolutionized the industry and become an essential material for modern vehicles. Whether used for interior components or exterior features like shiplap cladding, plastic offers a wide range of advantages that make it an ideal choice for automotive applications. Additionally, they have resistance to corrosion, which can extend the lifespan of automotive parts.

To stand out, industry innovations emphasize design principles, mold considerations, and the impact of material selection on producing high-quality parts. As demand grows, these advancements ensure product functionality, durability, and aesthetics while driving the future of material science and engineering. Using plastics in automotive applications gives the vehicle efficiency and durability. With the right approach and a bit of creativity, plastics manufacturing can be a powerful tool for success.

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PROCESE DE FABRICAȚIE A PIESELOR DIN MATERIALE PLASTICE PENTRU APLICAȚII ÎN INDUSTRIA AUTO

(Rezumat)

Industria auto a folosit materiale plastice aproape de la început. Materialele plastice sunt folosite pentru o varietate mare de piese auto, precum componente exterioare, cum ar fi barele de protecție și panourile caroseriei, până la elemente interioare, cum ar fi tablourile de bord, materialele pentru scaune și ornamentele. Fabricarea acestor piese implică tehnici avansate de prelucrare a plasticului, inclusiv turnare prin injecție, suflare, termoformare, turnare rotațională, turnare prin compresie și extrudare. Fiecare proces oferă avantaje unice, cum ar fi producția în volum mare, formarea pieselor complexe și consistența materialului, contribuind la eficiența producției de automobile. Materialele plastice sunt utilizate pe scară largă în industria auto datorită versatilității, durabilității și proprietăților lor ușoare. Aceste materiale, adesea sintetice, sunt concepute pentru a satisface nevoi specifice, cum ar fi rezistența la căldură, substanțe chimice și stres fizic. Ele pot fi turnate în diferite forme, făcându-le ideale pentru crearea de piese complexe utilizate în fabricarea vehiculelor. În general, materialele plastice sunt esențiale în producția modernă de automobile, jucând un rol semnificativ în producerea de vehicule eficiente, ușoare și rentabile.