Chapter 10
Role of Composite Materials in Automotive Sector: Potential Applications

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Abstract In the 21stcentury, researchers have turned their attention towards composite materials (CMs) concerning lightweight applications in the automobile sector. Researchers have found a way to achieve better fuel efficiency by substituting conventional materials with novel variants. The history and state-of-the-art applications of composite materials in the automotive sector are presented. Material characteristics required for the substitution of composite materials over traditional automobile components are also discussed. The application of novel composite variants for automobiles offers significant advancements in material properties in terms of lightweight, cost, sustainability, and crashworthiness. Weight reduction in an automobile component exhibited by composite materials increased the fuel efficiency with reduced automobile emission. In addition, composite materials offered safety and comfort with improved vehicle performance due to the superior mechanical properties over conventional materials. Bio-composites comprised of natural material in metals and polymers have revealed a positive impact on environmental friendliness retaining its exceptional material properties for desired automotive application.

Keywords Composite materials · Automobile applications · FRPC

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10.1 Introduction

The development of the human species is contingent on its characteristic of desire to explore which is strongly associated with individual mobility. Long-distance travel was achieved by riding animals such as horses, camels, elephants, etc., in ancient times until the invention of vehicles in lateral years. The ease in travel, commute, and transportation is predominantly thrived by automobiles these days. An automobile provides mobility, comfort, and safety by means of consuming fossil fuels. Amidst the twentieth century, rapid industrialization swells the automobile sector and subsequently increases the demand for fossil fuels to a large extend. Sudden downfall in the oil prices was also accountable for such great need. Consequently, more people desired to get access to automobiles, which raised more vehicles for the attainment of the demand. Optimum production techniques were developed to reduce the cycle time and cost of an automobile. Most of the vehicles back then make use of conventional materials withdrawn from non-renewable resources. Considering the limited source of such materials, researchers seek sustainable, biodegradable materials for automotive applications, which predominantly increased the utilization of aluminum and its alloys over steel and iron for various automotive components. Further introduction of composite materials changed the whole picture in the automotive sector. Since evolution in the automotive sector prompted a serious global concern of pollution, these high-performance composite materials enhanced the overall efficiency of a vehicle following reduced emissions. The advancement in the efficiency and performance of the vehicle is mainly achieved owing to the material properties offered by the composites (Sinha et al. 2018; Rajak et al. 2019a).

10.1.1 History/Background

Amid World War II, the shortfall of aluminum compels researchers to seek an alternative material for aircraft components, while the automobile sector encountered similar consequences. Therefore, utilization of alternative materials instead of aluminum and steel components in the automobile sector was first undertaken by researchers at Ford Motor Co. in 1941. They used soybean fiber reinforced plastic for automobile body parts which reduced the weight of a car by great means (White 1945). General Motors introduced exterior body panels made of fiberglass in 1953 for their Chevrolet Corvette model. Total 46 components of fiberglass in polyester resin were fabricated, which enhanced vehicle performance through reducing overall weight and superior mechanical properties of material comparing conventional steel and aluminum counterparts. In 1957 Trabant car was made of a monocoque frame structure manufactured in East Germany, which employed cotton fibers reinforced thermoset polymer composite material for the vehicle body. Further introduction of sheet molded composite body panels was substantially employed by premium car manufacturers since the late 1960s (Flax 1991).

The automotive industry flourished in the late 20thcentury as a consequence of the drop in petroleum prices. The numbers of people acquiring an automobile were outbursting. As a result, automobile manufacturers were competing to develop vehicles to entice new buyers. Various big companies gushed into the automotive sector and started introducing novel technologies. Reduction in consumption of fuel or carbon emission was not the primary motive behind developing lightweight vehicles back then; it was rather to attain maximum speed. Daimler Chrysler also started implementing natural fiber composites in 1991. Jute fiber reinforced plastics were applied for the interior door panels of their Mercedes-Benz E-Class model in 1994, and it continued for several succeeding years. Later total 27 number of interior components made of natural fiber-based composites were employed in the 2006 Mercedes Benz S-class. Dutch company Van Eko in the year 2016, developed a battery-operated scooter called 'Be.e', which utilized most of their components made from bio-based materials (Verma and Sharma 2017). Figure 10.1 shows different automobile models in which composite materials are deployed.

The automobile industry is the most influencing industry concerning the global economy. Therefore, novel researches are emerging out to flourish development in the automobile industry. This incorporates improvement in vehicle performance by proposing the optimum structural design of a vehicle, introducing advanced manufacturing techniques to minimize production time, and applying new materials. In this

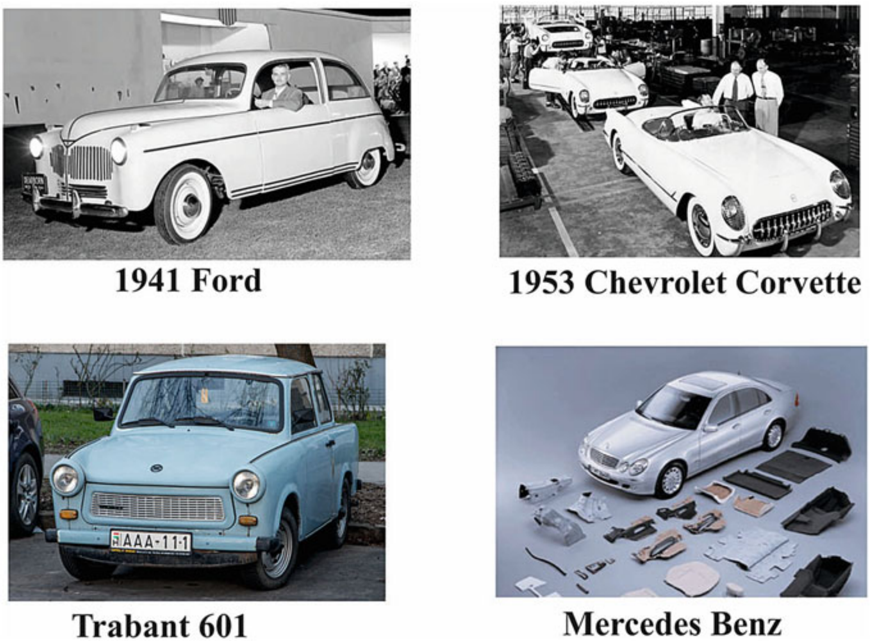

Fig. 10.1 Application of composite materials in different automobiles (Cape Cod Curmudgeon 2018; Tony Borroz 2009; Maximilian et al. 2020; Mohammed et al. 2015)

context, state-of-the-art composite materials employed in automobile applications since primitive times are presented to understand the advancements and emerging trends in the automotive sector.

10.1.2 Characteristics of Automotive Material

As the world strives to find ways to improve the fuel efficiency of an automobile by ensuring its safety and sustainability, reducing the weight of a vehicle is imperative. Selection of superior material replacing the traditional ones is one of the effective ways of achieving it. In automobile material needs to withstand extreme environments, such as high temperature and pressure, sudden impact, and variable loads. Certainly, it is not always feasible for solitary material to possess such exceptional material properties. Composite material finds extensive applications in the automotive sector, as it combines two or more desirable materials to overcome the demerits of one another. For substituting a composite material, the following aspects need to take into consideration (Todor and Kiss 2016).

Light weight

In an automobile curtailing its overall weight by 10% leads to increased fuel efficiency by approximately 7%, whichis also followed by reduced carbon emissions. In addition, reduced overall vehicle weight aids in overcoming inertia forces, consequently saving the power required for accelerating and braking. This further allows designing smaller engines, transmission, and braking systems offering improved vehicle performance by means of rapid acceleration and smaller braking distances. One of the favorable effects of light-weight in automobiles observed was a decline in vehicle drag as its directly proportionate with the weight of the vehicle. Reducing vehicle weight also serves additional gains over vehicle stability and control. Researchers have achieved light-weight in automobiles without losing its functionality by substituting steel components with materials such as aluminum, alloys of aluminum, composite materials, and metallic foams. The only obstruction in employing these light-weight materials with superior mechanical properties over traditional materials is their high cost. The issue can be subdued by seeking advanced manufacturing techniques (Sinha et al. 2018; Ghassemieh 2011).

Sustainability

Researchers these days are obligated to develop environment-friendly products considering the depletion of non-renewable resources. The automobile sector encompasses a large share in the consumption of the world's raw materials. Materials required for the production of an automobile majorly include steel, aluminum, glass as well as various petroleum products. Making use of sustainable materials that are biodegradable or acquired from recycled materials is imperative and such criteria have been set by many countries concerning pollution and limited stock. Aluminum is the most widely recycled material and so is iron and steel, yet natural fibers reinforced composite materials exhibit remarkable biodegradability. All of these materials are widely implemented in the production of automotive components (Faruk et al. 2017; Muhammad et al. 2021). Moreover, material capability to resist wear and corrosion increases its fatigue life to withstand undesirable environmental conditions.

Cost-effectiveness

The material cost has lion's share in determining the best-fit substitute material for the desired application. Cost of material for automobile component sums up procurement cost, processing cost, and material testing cost. The utilization of naturally occurring substances reduces procurement and processing costs as synthetic materials are intricate and expensive. On the other hand, natural materials are available in abundance, require simple and fewer treatments, and are environment friendly as well. Sometimes it is not always feasible to use cost-effective materials independently considering their functional requirements for desired automotive application. This can be resolved by hybridizing inexpensive materials with finer materials in a certain fraction. Composite materials are accustomed to a similar principle and therefore substantially employed for automobile components (Ghassemieh 2011).

Crashworthiness

Material behavior to exhibit resistance to the deformation on collision to offer occupant safety in an automobile defines the crashworthiness of the material. It is the measure of a material to absorb impact energy retaining its structure against plastic deformation. Meaning material needed to possess high elastic modulus. Nearly 1.35 million people die in a road car accident each year, according to WHO reports. Automobile manufacturers these days are focusing on the safety, comfort, and eco-friendliness of the vehicle (Mallick 2020).Composite materials possess high strength, toughness, and stiffness owing to the combination of their constituents. Compressive loads are taken by the matrix material while tensile loads are carried by the reinforcement materials in a composite structure. This provides resistance to sudden impact during collisions maintaining the high elastic strength of a material.

Moreover with increasing tailpipe emissions have deleterious effects on both environment and human health. Therefore, improving fuel economy is the topmost priority for automobile manufacturers around the world these days. Application of composite materials offers exceptional mechanical, thermal, chemical properties with reduced weight over traditional materials to improve vehicle performance. These properties are tailorable according to the operating conditions of the desired application.

10.1.3 Materials Used for Automotive Applications

As the evolution in automotive materials began, researchers were putting efforts to improvematerial properties of existing materials (iron and steel) used for automobile fabrication. Cost-effective lamellar cast iron possessing good strength and energy-absorbing characteristics was developed to compete with steel with better tensile properties. However, immanent characteristics of steel and its variants served ease in fabrication and forming ability, which displayed numerous applications in vehicle body applications. Remarkable crashworthiness of high-strength steels (HSS) was observed in vehicle chassis application. Further betterment in steel variants gave rise to anti-corrosive, light-weight yet stronger material called stainless steel. The application of stainless steel can be seen in exhaust systems, fuel tanks, and several other parts. The introduction of aluminum and its alloys have changed the whole picture in the field of automotive applications. Ranging from engine, transmission, and axles, chassis to an exterior body part such as fenders, door panels, hood, and bumper all are made of aluminum alloys (Wilhelm 1993; Sadagopan et al. 2018).

Polymer matrix composite

Usually, polymer matrix materials used for the fabrication of composites are thermosetting or thermoplastic polymers with the inclusion of fibers, particles, preform, or sheets in it. The bond between the matrix material and reinforcements determines the properties of composite materials.

Thermoset

Reinforcements such as continuous or short fibers are easily combined with thermoset polymers at low-pressure conditions as these polymers have a very low viscosity. Therefore simple manufacturing techniques are employed to fabricate composites using thermosetting polymers as a matrix material. However, thermosets are non-reusable and cannot reform after being curing is done. Despite being the most popular matrix material in composites, Epoxy resins are not popular in the automotive industry. Epoxy has low shrinkage, good adhesion, and surface texture, but high-cost and prolonged curing cycles fail Epoxy to implement for mass production in the automobile industry. While Vinylester resins display better energy absorption abilities along with good resistance to temperature, creep, fatigue, and chemicals. On account of low curing time and excellent moldability, vinyl ester resins with glass fibers reinforcements are applied for a variety of large volume automotive applications (Holbery and Houston 2006). E-glass fiber reinforced PU plastic has demonstrated its ability to withstand under extended moisture and temperature conditions for automobile applications (Panaitescu et al. 2019). Reinforcements of carbon fibers in thermoset polymer matrix composites have shown superior properties with greater weight reduction than fiberglass reinforcements.

Thermoplastic

Thermoplastics are inexpensive, reusable, and best fit for mass productions, and they also exhibit longer storage life than thermoset polymers. Also, considering environmental friendliness, thermoplastic polymers are widely deployed for automotive applications. Some thermoplastics such as polystyrene, polyethylene exhibit resistance to certain chemicals, acts as an electrical insulator but are synthetic non-biodegradable plastic. Whereas thermoplastic polypropylene is being quite popular in automobile applications owing to its remarkable processability and dimensional stability. Polypropylene has a low mass per unit volume and shows resistance to deformation under high temperature and sudden impact loads. Polyesters such as poly(ethylene terephthalate) (PET) and poly(butylenes terephthalate) (PBT) have outstanding wear, abrasion, chemical, and thermal resistance with high strength and moldability when reinforced with fiberglass. Polycarbonate shows amazing light-transmitting ability while having transparency similar to acrylic. It shows resistance to creep, ultraviolet light and possesses good strength, formability and moldability together with dimensional stability. Polyvinylchlorides are low-cost, long-lasting, flame retardant, biodegradable polymers possessing excellent mechanical strength. These are present in amorphous form with great rigidity and hardness, but when combined with plasticizers PVC shows better flexibility and toughness. Polyamide-imides are amorphous polymers and can be categorized as either thermoset or thermoplastic polymers which show remarkable mechanical properties along with resistance to chemicals and temperature variations. Properties revealed by various polymers in composite materials are displayed in Table 10.1, along with their automobile applications (Hovorun et al. 2017). Wood-plastic composites (WPCs) are referred to as the combination of wood fibers or wood flour with thermoplastic resins. Fibers made of pine wood pulp are blended PLA have displayed superior mechanical properties, an outstanding sound absorption characteristic with the lowest density compared to several other thermoplastics blends (Stark and Cai 2021).

Nanocomposites

Nanocomposites are composites possessing one or more filler materials of dimensions in the nanometer range which is 10^{-9} m. Nanocomposite materials show remarkable physical and mechanical properties due to the high surface area per unit volume of nanoparticles. The incorporation of nano-scaled fillers in the matrix phase is categorized based on their dimensions. One dimensional structure consist of nanofibers or nanotubes such as carbon nanotubes (CNTs), two dimensional fillers contains sheets of graphene or silicate stacked in the matrix material. The third category contains three-dimensional nano-scaled particulates such as spherical silica. The nanofiller materials divert or shorten the cracks and prevent further widening of the crack. This property of nanofiller materials contributes to enhance the strength, fracture toughness, and flexibility of nanocomposites. The characteristics of a nanocomposite material are determined by the type of nanofiller used, the size of the nanoparticle, and the degree of dispersion of nanoparticles in the matrix phase (Stojanović and Ivanović 2015; Fu et al. 2019). Scratch-resistant coating is applied using Al_2O_3, SiO_2, ZrO_2, and TiO_2 nanoparticles. Silicate films, CNTs are used in automobile fabrics to acquire anti-stain and flame retardancy properties (Wu et al. 2020a; Chandra and Kumar 2017).

This state of art review displays various applications of composite materials in the automotive sector incorporating synthetic, natural fiber composite, wood plastic composite, ceramic composite, and metal matrix composites (MMCs).

Table 10.1 Variety of polymers utilizes for automobile applications with their improvement in PMC properties (Gowda et al. 2018; Bouzouita et al. 2017; Patil et al. 2017; Oliver-Ortega et al. 2019)

	Polymer	Properties	Application
Thermoset	Polyurethane (PU)	Improved moisture absorption, increased durability	Seat backrests, armrests, cushions, bumpers, fenders, steering wheels, door panels, hoods, and trunk lid
	Vinyl Ester Resin	Reduced weight	Wheels, seats, cooling rack, and engine valve sleeve
	Polyamides	Improved lifespan with material sustainability	Car door handle,gears, bushes, cams
	Polyamide-imides	High fatigue life, wear and corrosion resistant	Seals, bushings, pistons, and gears
Thermoplastic	Polyvinylchloride (PVC)	Incredible tensile strength	Upholstery, floor mats, auto tops, shields, grips, chemical tanks and electric cables sheathing
	Polypropylene (PP)	High flexural strength, improved fiber-matrix adhesion and insulation properties	Headlights, bumpers, battery boxes, carpets, steering wheels and partitions
	Poly-ethylene terephthalate (PET) & poly-butylene terephthalate (PBT)	Improved strength and rigidity	Housing material, door handles, engine covers, optical fiber cable and other electrical insulating application
	Poly Lactic Acid (PLA)	Heat resistant	Interior trims and door panels
	polyacrylates	Increased plasticity, oils resistance	Coatings, hoses, seals, gaskets, and dampers
	Polycarbonate (PC)	High thermal resistance, toughness, transparent and good processability	Headlamp lens, exterior panels, and wheel covers

10.2 Application of Composite Materials in Automotive Components

10.2.1 Engine Parts

Piston-Cylinder

Engine blocks and heads were previously manufactured of cast iron material on account of their durability. Since piston and cylinder material operate at extremely high pressure and temperature conditions, the coefficient of thermal expansion has to be minimum. Materials with higher thermal expansion coefficient needed more clearance between piston and cylinder which creates more vibrations at high loading conditions leading to failure of the component. Also both cylinder and piston materials needed to be designed to attain operating temperatures as quickly as possible to overcome cold start emission. With the introduction of aluminum, the weight of cylinders drops by more than half as that of cast iron with improved wear properties and thermal conductivity. Piston and cylinder material also encounters acute wear and fatigue failure under cyclic loading. The inclusion of boron nitride, silicon carbide (SiC), graphite, and carbon fibers in the aluminum matrix provides enhanced wear properties by offering solid lubrication. Figure 2a shows the microstructure of graphite inclusions in aluminum matrix composite (AMC). Self-lubricating characteristics of such filler materials in AMCs avoid engine seizure under boundary layer conditions by producing a protective film between moving components (Hassan et al. 2021; Macke et al. 2013; Omrani et al. 2017; Menezes et al. 2018, 2012a, 2013). SiC particles with good forming and machining ability, when added to aluminum alloy matrix, served excellent fatigue strength, wear properties, and thermal stability at high temperatures. Moreover, these composites are light in weight and have low manufacturing costs (Falsafi et al. 2017).

The former cast iron cylinder liner was replaced by aluminium matrix composite (AMC) with the inclusion of nano reinforcement particles of zirconium dioxide (ZrO_2), silicon carbide (SiC), and graphite (Gr). Improvement in the efficiency of diesel engine due to higher cylinder pressure and decline in pollutant emissions of carbon monoxide (CO), hydrocarbons (HC) and smoke was observed along with 43.75% of reduction in weight (Tiruvenkadam et al. 2015).

Driveshaft

In an automobile, drive shafts are referred to power transmitting device which delivers power to the axles from the engine. The Driveshaft is a hollow transverse component carrying torque that produces radial shear stresses. Usually, it is made of steel material due to its prerequisite higher yield strength and toughness values. However, the steel shaft is seen to be heftier in performance and corrosive, which led to consuming additional fuel due to its weight. When it was substituted by the drive shaft made of carbon fiber-reinforced polymer (CFRP) composite material, it showed better perseverance against torsional loading under prolonged cycle time without fracture. The improvement by means of strength, fatigue life, light-weight in the CFRP composite shaft was observed (Liu et al. 2016). Steel shaft was replaced by an intertwined polymer matrix of vinyl ester and polyurethane reinforced with E-glass fiber mat composite. The result showed increased static torque carrying capacity of the component at 50% reinforcement (Suresh et al. 2020).

Catalytic converter

As mentioned earlier, car manufacturers from the late twentieth century were building high-performance vehicles to attain maximum top speed, disregarding fuel efficiency and pollutants emission. Therefore there was a significantneed to set regulations and standards to minimize fuel consumptions and exhaust gas emission causing an environmental hazard. In the United States, the Clean Air Act enacted in 1963 restricted the emission of harmful gases to control national air pollution considering Ozone layer depletion. It compels car manufacturers to reduce emissions by 75% which executed the use of catalytic converter in the exhaust system of a vehicle by the year 1975 in the US. In 1975 United States also commanded Corporate Average Fuel Economy (CAFE) standards to curtail the country's dependency on petroleum imports. As a result, they started penalizing car manufacturers for developing substandard vehicles.

Automobile operates by burning fuel in an internal combustion engine (ICE). The emissions of several types of pollutants from automobiles share more than 60% of air pollution in urban regions. These pollutants include harmful gases liberated by ICEs such as carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx) and particulates of sulfur oxide (SOx), and lead (Pb). Air pollution is one of the major concern of countries worldwide as it severely devastate the environment causing global warming and causes dreadful effects on human health. One of the effective ways of battling air pollution is to mitigate automobile emissions. The catalytic converter was initially invented in 1930 by a French researcher and later implemented in automobiles by 1975 in the United States in response to government regulation for restraining tailpipe emissions. A catalytic converter is an apparatus installed in the exhaust system to convert poisonous harmful gases causing greenhouse gas effects into less harmful ones. Inside a catalytic converter, a honeycomb structure coated with porous material provides greater surface area for the redox reactions. The honeycomb structure in a catalytic converter is shown in Fig. 10.2b. The coating material is selected according to the fuel type used for the vehicle ((Mallick 2020; Dey and Mehta 2020)). The ability to disintegrate pollutants emitted from automobiles under visible light is known as the purification efficiency of the catalyst. Hydrocarbons are transformed into hydroxyl radicals to produce CO_2 and water molecules. TiO_2 nanoparticles are commonly used in photogenerated catalysis for the generation of hydroxyl radicals. Tradition metallic semi-conductor material when replaced by non-metallic graphite carbon nitride (g-C_3N_4) catalyst it showed an increase in the efficiency of the converter to purify exhaust gases by a significant amount. The ability of g-C_3N_4 to absorb visible light results in the highest purification efficiency for oxides of nitrogen (Cui et al. 2020). Bismuth vanadate ($BiVO_4$) photocatalystis

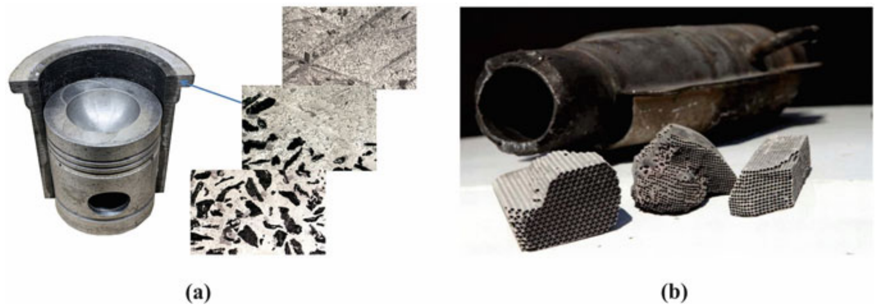

Fig. 10.2 **a** Graphite reinforced AMC for piston-cylinder application (Prateemak—Taken By Dr Pradeep Rohatgi 2012) **b** Honeycomb structure in catalytic converter (Kumar et al. 2015).

generally used for the oxygen evolution combined with graphite carbon nitride (g-C_3N_4) along with the inclusion of 25% by weight of tourmaline powder to form g-C_3N_4/$BiVO_4$/tourmaline powder composite. Purification efficiency for hydrocarbons (HC) and carbon monoxide (CO) to break them down into free radicals to form carbon dioxide (CO_2) and water molecules (H_2O) was increased by 70 percent and that for the oxides of nitrogen by 150 percent compared topure g-C_3N_4 (Li et al. 2020).

Transmission gears

To produce efficacious power transmission in automobiles, gears are the most reliant components. Gears regulate the power output from the IC engine to the drive system. It undergoes repetitive cyclic loading, which causes wear and induces variable stresses significantly affecting the fatigue life of a gear component. Conventional steel gears are substituted with polymer composite gears to attain better durability with minimum noise and vibrations. These gears are inexpensive, less noisy, and provides self-lubricity, high damping resistance, ease in design and fabrication. The addition of nearly 30% by weight glass fibers in polyamide 66 and polyoxymethylene polymers for spur gears have shown a significant decrease in wear rates (Jena 2019). Minimum developments of stresses were observed in composite spur gear fabricated using an aluminum alloy matrix with the inclusion of fly-ash (Rohatgi et al. 2012; Kasar et al. 2020). Compared to the cast steel gear component, composite spur gear displayed enhanced strength and stiffness values with low weight (Saleem et al. 2020). Spur gear made of fiberglass reinforced polymer composite revealed better damping properties compared to gears made of steel alloy and AMC (Aggarwal 2017). For the efficient running performance of electric vehicles, reduction in the weight of automobile components is imperative. Therefore most of the components in electric vehicles are deployed with lightweight components. The gear teeth and the hub part of an electric car were designed of steel to reserve the torque transmission, while the portion in between was introduced of aramid fiber reinforced phenolic composite as shown in Fig. 10.3. A reduction in the weight of the hybrid gear component was achieved with a 43.2% decrease in noise levels against whole steel gear (Kim et al. 2019). Besides engine gears, several other components in the automobile utilize

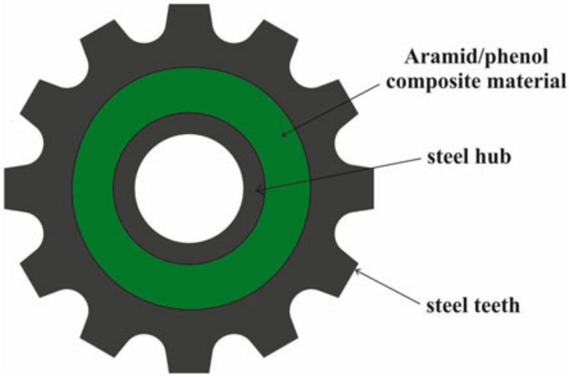

Fig. 10.3 Hybrid gear made of steel and aramid fiber reinforced phenolic composite (Kim et al. 2019)

gearing mechanisms such as rack and pinion gear pair in the steering mechanism. Thermoplastic polymer nylon 66 was reinforced with glass fibers to manufacture rack and pinion gear pair for the SAE formula supra car steering mechanism. It offered reduced noise, friction, and weight along with better corrosion resistance and self-lubricity (Chopane et al. 2018).

10.2.2 Braking System

Brake material

The braking unit needs to endure frictional torque and heat dissipation. The material employed for the brake rotor has to sustain in high temperatures and wear environment against thermoplastic deformation. Failure in the braking system is predominantly caused due to heat generation on account of friction between the rotor and braking pads (in the case of a disc braking system) or braking shoe (in case of drum braking system). Any sort of brake material failure will lead to accidents and consequently create a threat to the occupant's life. Formerly asbestos was extensively utilized as a brake material owing to its exceptional heat-absorbing property and abrasive nature. But its carcinogenic nature has later prohibited the use of asbestos and substituted by organic materials (Menezes et al. 2012b). The use of copper was also terminated due to its hazardous effects on marine life. Therefore the implementation of ceramic, aluminum and steel alloys was commonplace for succeeding years until composites were introduced. Composite materials made of fibers of carbon, glass or aramid as reinforcements in graphite or phenolic resins were gaining popularity as an alternative to asbestos for brake pads and brake linings in automobile applications (Jena 2019). Graphite and phenolic resins exhibit superior binding properties while the inclusion of carbon fiber yielded to enhancement in the hardness and specific strength of the brake material. Carbon fibers also provide thermal stability,

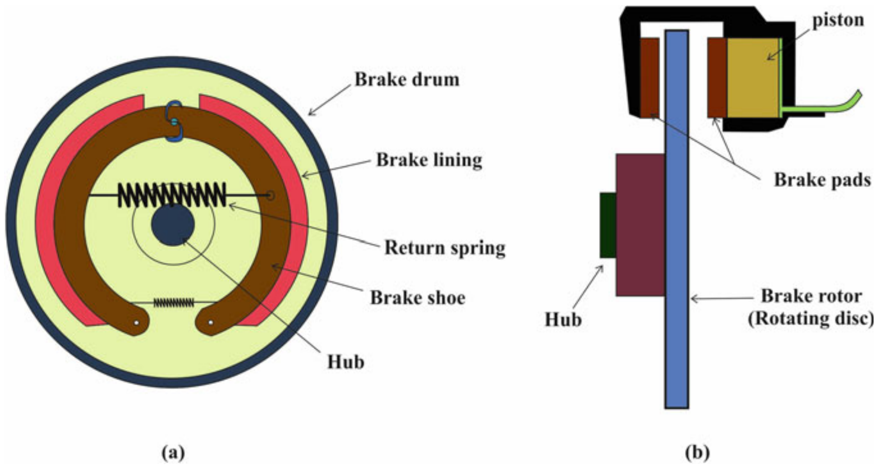

Fig. 10.4 Brake mechanism **a** Drum brake (Padmavathy et al. 2020) **b** Disc brake(Sadagopan et al. 2018)

wear-resistance and less curing time for better heat dissipation (Ahmadijokani et al. 2019).

Brake drum

The drum brake uses the principle where brake shoes or pads are pressed against the rotating drum to decelerate the speed of the drum on account of friction. The drum brake mechanism is displayed in Fig. 10.4a. Initially, brake drums were fabricated using cast iron which was heavyweight and corrodes easily yet displays good wear resistance. Later on, these were replaced by aluminum, a noncorrosive, much lighter, and thermally conductive material than iron. As aluminum wears out easily, brake drums made of aluminum with steel or iron lining on the inner surface were utilized for many years until MMC materials got introduced. Addition of abrasive particles such as alumina (Al_2O_3) and silicon carbide (SiC) into the aluminum matrix curbs the demerits of sole aluminum while retaining its boons. Combining effects of both reinforcement and matrix material revealed excellent strength and tribological properties along with reduced weight and better heat dissipation (Padmavathy et al. 2020; Rajak et al. 2020; Rajak and Menezes 2020; Chaudhary et al. 2020).

Brake rotor

Compressive forces deform the brake rotor profile which induces a vibration and ultimately results in failure. Motorcycle disc brake rotor cast from (AMC) with the 20% SiC reinforcement showed 56% reduction in weight compared to cast iron rotor. Reduced weight in brake rotors signifies lowered inertia forces (Sadagopan et al. 2018). Introducing graphite particles into aluminum alloy matrix manifests excellent wear properties attributed to the self-lubricating characteristic of graphite material. The composite material develops an anti-friction layer at elevated temperatures and

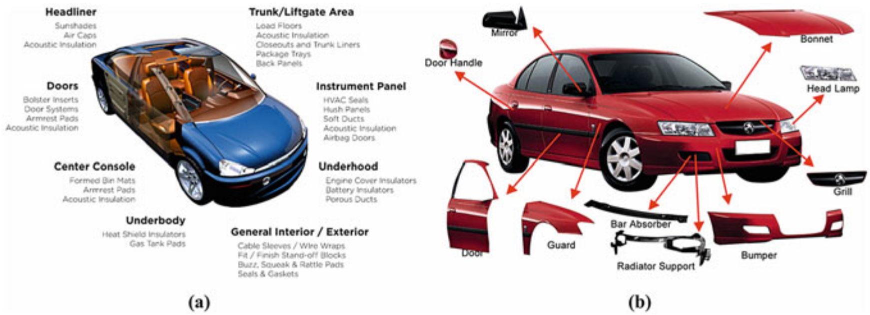

Fig. 10.5 **a** Interior trims (UFP Technologies 2021) and **b** Exterior trims of an automobile (Jasonstathamnz 2015).

gradually gets stronger, corresponding to further rise in temperature and volume percentage of graphite (Kumar and Kumar 2020).

Brake pads

In disc brakes, brake pads are pressed against the rotating disc under the action of the hydraulic piston, as shown in Fig. 10.4b. As long as operating conditions are concerned, friction and wear phenomenon in brake pads is inevitable. Without undermining the functionality of brake pad materials, wear can be alleviated by introducing composite materials with better performance than harmful asbestos. It is always feasible for the manufacturer to replace brake material despite altering the parameters of braking systems. Basalt fiber-reinforced composite (BFRC) material used as a brake pad material showed advancement in wear resistance and thermal stability as basalt fibers develop a tribo-layer between friction materials at high load conditions (Ilanko and Vijayaraghavan 2016).

When we consider the addition of natural fibers into a composite material to improve the biodegradability of the desired material, few treatments are needed to carry out on account of fiber-matrix compatibility. The selection of natural fibers primarily depends upon the desired characteristic required for the application as well as the availability of fibers in that geographical region which deduces cost with great means. DemostachyaBipinnata fibers were put through silane treatment in order to enhance fiber's surface characteristics for better fiber-matrix bonding and moisture resistance. Bipinnata fibers displayed great hardness number, and shear strength values together with exceptional wear resistance at high load and high-speed situations (Krishnan et al. 2021). Palm kernel fiber, Wheat fiber, and Nile rose fiber are desirable natural fibers combined with aluminum oxide (Al_2O_3) and graphite powder applicable for brake pads in order to enhance wear characteristics and hardness of material (Pujari and Srikiran 2019).

10.2.3 Suspension System

Automobile suspension systems are designed to restrain vertical displacements caused by road surface irregularities. The purpose is to provide comfort for occupants and protect the vehicle from getting damaged against shock loading. The suspension system serves its functionality through strain energy stored in its spring components and aids in making continuous contact with the road surface. Cast aluminum and steel material were broadly used as spring materials fora long time, although superior mechanical properties offered by the composite materials such as high specific strength, stiffness, anti-corrosive nature, high energy storing as well as absorbing capacity makes them the best fit for the spring material in automotive applications (Jena 2019).

Helical spring

Conventionally used steel helical springs as shock absorbing components in light motor vehicles (LMVs) are getting replaced by composite coil springs. About 50 to 80% reduction in weight is observed after substituting composite springs, which subsequently offers an overall decline in vehicle weight. It further offers corrosion resistance which eventually improves the life of the suspension component for a long number of cycles without failure. Various researches manifested the use of carbon fibers along with the glass fibers in epoxy resins have improved the stiffness and specific strength of a helical spring. Nevertheless, the use of basalt fibers instead of glass fibers in hybrid carbon/glass fiber composite has proven significantly better results concerning material sustainability and cost (Ke et al. 2020; Choi and Choi 2015). As fibers convey structural stiffness and strength to the composite material, increased fiber volume in the composite structure enhanced spring stiffness of carbon fiber reinforced epoxy resin composite helical spring. Further, twisted spring manifested minimum stress concentrations, unlike corresponding untwisted ones. It reveals that stress allocation is manageable by controlling twist angle (Wu et al. 2020b).

Belleville springs also serve potential gains helical spring for automobile applications. Polymer composite made of epoxy resin prepreg displayed improvement in vehicle handling and comfort by means of reduced tyre contact patch load variations and acceleration (Foard et al. 2019).

Leaf spring

A leaf spring counts for 10–20% of the unsprung weight of an automobile. Therefore cutting down the weight of the leaf spring will consequently reduce the overall weight of the vehicle to improve its performance. Composite leaf spring comprised of basalt fibers and epoxy resin exhibited phenomenal deduction in weight by 82.27% to that of steel spring retaining its stiffness (Raut et al. 2020). Leaf spring manufactured by stacking 55% vol. of woven carbon fibers into epoxy resin showed an 88.43% reduction in weight comparing to steel counterparts (Raut and Katu 2016). Leaf spring also undergoes friction and wear as it is bolted and clamped to the chassis.

Thus spring material must possess good wear and damping properties. Epoxies resins composite revealed excellent tensile strength and wear resistance in unidirectional reinforcement, while high flexural strength owning to weft reinforcements in 3D woven E-glass prepregs (Khatkar et al. 2020). Two different materials were proposed for leaf spring, AMCwith 25% inclusion of boron carbide and carbon fiber reinforced epoxy composite. Both materials exhibited enhancement in mechanical properties with a reduced weight with higher manufacturing cost compared to steel leaf spring (Singh and Brar 2018).

Tyres

An automobile runs on account of friction between the road surface and tyres. Thus, tyres must hold outstanding wear resistance and durability to maintain their traction on wet or dry roads without skidding. Goodyear, a top tyre manufacturer, introduced corn starch inclusions into tyre material to lower carbon black and silica dependency. Remarkably it decreased the rolling resistance and weight of the tyre, which resulted in minimal noise and rolling inertia further improving fuel economy (Sandstrom et al. 2002). Corn starch, an alternative filler material,was introduced for the most commonly used carbon black to produce tyres. It is a low-cost filler material with outstanding reinforcement capabilities. Addition of corn stover biochar along with corn starch and cornflour in rubber improved tensile properties (Peterson 2012; Kurihara 1995; Akampumuza et al. 2017). Tyres made from graphene-based elastomeric nanocomposites are lightweight and exhibit advanced mechanical properties with decreased rolling resistance which consequently reduced fuel consumption (Mansor and Akop 2020).

10.2.4 Interior Trims

Interior trims refer to all the plastic components or panels that are present inside the automobile cabin. Unlike automobile IC engine components, these components do not undergo high pressure, high temperature, or cyclic loading conditions. The functions of interior trim components are mainly to reduce vibration and noise. Along with the sound absorption characteristic, interior trim material needs to display several other properties, such as flame retardancy, durability, anti-rust, anti-wear, high specific strength, etc. Kevlar fibers are employed for seat textiles because of their high melting point, high kindling point, and thermal resistivity. Nonetheless, a reduction in the weight of any component will improve the vehicle's performance. Reducing weight in interior body panels is achieved by deploying natural fiber composites. Coconut fibers are utilized to manufacture seat bottoms, back cushions, and head restraints, while wood fibers are utilized for backseat cushions and abaca fibers for under-floor body panels. Cotton fibers also offer good sound absorption. Natural fibers composites comprised of plant polyols hold better tear resistance than glass fiber reinforced PU composites. Furthermore, their greater toughness, formability, specific strength over glass fibers makes them a superior candidate for automobile door trims application (Dahlke et al. 1998; Rajak et al. 2019b; Kumar Rajak et al. 2021).

Interior door panels made of coir fiber in PP composite possessed better dimensional stability, hardness and flame retardancy than GFRP composite. As far as adding 60% of coir fibers resulted in advancement in flexural and tensile strengths of composite material by 26 and 35%, respectively (Ayrilmis et al. 2011). Three different natural fibers hemp, kenaf and flax along with their hybrid combination in epoxy resin were investigated to figure out the best suitable candidate for the fabrication of vehicle door panels. Reinforcement of Flax fiber in epoxy resin composite revealed superior tensile properties and showed better resistance to impact and plastic deformation when the load is applied (Prasad et al. 2021). PU foams are employed for automobile seat cushions and car door trims, while PU foam coated with nanomaterials such as graphene, graphene oxide, and carbon nanotubes exhibit high specific strength and stiffness values (Kausar 2018).

10.2.5 Exterior Trims

Exterior trims refer to plastic components outside the car cabin. They have to withstand impact loads, thermal degradation, and wear. The exterior body parts must hold enough strength and stiffness to resist impact loads on collision for the assurance of occupant safety. Exterior body panels were majorly made from sheet molding compounds (SMCs).

The bumper beam plays a vital role to bear sudden impact at the time of the head-on collision. Thus crashworthiness of the beam component determines occupant safety. By virtue of aramid fiber's incredible characteristics, such as toughness, tensile, flexural, and shear strengths with low density, a bumper beam made from aramid fibers in epoxy resin showed 20% enhancement in the tensile and impact properties to that of stainless steel (Selwyn 2021). Moreover, the combination of glass fibers with hemp fibers in epoxy resin also shows favorable impact strength and hardness requisite for automobile bumper application (Perumal et al. 2018). Kevlar fibers display great resistance to breakage under tensile loads compared to glass or carbon fibers. Former woven fiberglass thermoplastic was replaced by hybridized kevlar-date palm fibers in epoxy resin composite. Combined effects of reinforcing kevlar and date palm fibers raised tensile properties by a great extent which is best suitable for automobile bumper beam material concerning occupant as well as pedestrian safety (Muthalagu et al. 2020).

Front fender

Automobile fenders generally do not go through much stress but need to design for their crashworthiness. Extensively available low-cost sisal fibers treated with alkali solution for the removal of moisture and cellulosic matter showed high surface roughness. The composite material consists of alkali-treated sisal fibers reinforced with polyester manifested superior tensile and flexural strength over steel counterparts. Alkali treatment offers anti-corrosive characteristics of the composite material, enhancing its fatigue life and rigidity of the component (Alemayehu et al. 2021).

Bonnet

Bonnet durability deteriorates as a consequence of vibrations developed in an automobile while driving. For this reason, automobile bonnet material is required to design for its stiffness against torsion and bending moment. Carbon fiber and glass fiber reinforced composite for an automobile bonnet displayed an increase in strength to weight ratio by 52% when compared with metallic bonnet (Ye et al. 2019). Glass fiber reinforced epoxy resin composite material manifested good tensile properties viable for engine hood material in automobiles (Wagh and Pagar 2018). Composite material's strength, stiffness, hardness, and thermal stability improved with the increased fraction of chopped carbon fibers in PP (Rezaei et al. 2008).

10.3 Other Automobile Applications

Automobile chassis has to sustain under various static and dynamic loads, including occupants and vehicle weight, torsion, and sudden impacts. Therefore, 10% weight reduction with improved rigidity was attained when carbon fiber reinforced thermoplastic composite chassis was substituted for Lotus Elise in place of aluminum chassis (Ishikawa et al. 2018). Glass was used for automobile headlamps and windows owing to its hardness and anti-scratch properties. However, it is replaced by lighter material called polycarbonate, which possesses higher impact resistance and toughness values. Furthermore, an anti-scratch, anti-smudging, hydrophobic coating was applied to polycarbonate by means of nano-particles of aluminum oxide, silica, and titanium oxide to ensure transparency and anti-fogging characteristic for automobile headlamps and windows (Bai et al. 2021). The increase in the percentage content of ZrO_2 in aluminium matrix composite resulted in improved hardness and wear resistance of connecting rod (Ramachandra et al. 2015). Aluminium matrix nanocomposites (AMNC) owing to their incredible strength, stiffness and creep resistance applicable for a variety of automobile components such as connecting rods, brakes, chassis, cylinder liner and exhaust valves (Singh et al. 2020). Ceramic matrix nanocomposites (CMNCs) are employed for nozzles and energy conversion systems where temperature and pressure conditions are extreme. Ceramic matrix incorporating carbon nanofibers displays durability at high temperatures, wear resistance, and are lightweight compared to steel or aluminum (Durowaye et al. 2017).

CFRP fuel pipe served as an outstanding barrier for terminating fuel evaporation and reducing weight by 83% compared to steel alloy (Sinha et al. 2018). Table 10.2 displays several different applications of composite materials in certain vehicles.

Table 10.2 Composite materials automobile applications

Refs	Year	Manufacturer/ Model	Material used	Application	Findings
Kurihara (1995)	1980	GM Corvette	GFRP	Leaf springs	Reduced weight by 80% to that of steel leaf spring
	1984	Renault Espace	PMC	Hood, roof	Improved corrosion resistance
	1985	Ford Econoline	CFRP	Propeller shafts	50% weight reduction compared to steel counterparts
Akampumuza et al. (2017)	1995	Opel Corsa	Flax fiber PP composite	Interior door panels	Better soundproofing
	2006	Mercedes Benz S-class	Wood fibers and flax fibers composite	Front door linings, parcel shelves and rear trunk covers	Extended the use of sustainable materials by 73%
	2011	Lexus-CT200	Bio-based polyethylene terephthalate (PET)	Luggage compartment	Increased temperature resistance, durability with reduced susceptibility to shrinkage
Airale et al. (2017)	1981	Chevrolet Corvette C4	Glass fiber reinforced epoxy composite	Leaf spring	Reduced 15 kg of unsprung weight
Sandstrom et al. (2002)	1999	Goodyear (Tyre manufacturer)	Corn starch/plasticizer composite	Tyres	Improved rolling resistance with reduced weight and noise
Carello and Airale (2014)	2012	XAM 2.0	Carbon fiber epoxy resin composite	Wishbone arm in a suspension system	Stiffness improved by 78% with a 5% weight reduction
Schmitt et al. (2017)	2012	Audi AG	GFRP composite	Suspension spring	Reduced weight by 40% compared to steel springs

(continued)

Table 10.2 (continued)

Refs	Year	Manufacturer/ Model	Material used	Application	Findings
Saleem et al. (2020)	2020	Tata Super Ace	Fly ash-AMC	Gears	Minimal stress development with improved strength and stiffness

10.4 Conclusions

The state-of-art review presents a potential application of composite materials in the automobile industry. Owing to their phenomenal advancement in mechanical, thermal and chemical properties over traditional cast iron, steel, and aluminum, composite materials nowadays found their extensive application in almost every automobile component ranging from engine parts to body panels. Leading automobile manufacturers and researchers around the globe are testing for more novel variants of fillers material in metal or polymer matrix to fabricate a composite material for a certain application. The global concern of utilizing more sustainable materials and reducing carbon waste has compelled us to employ natural materials over synthetic ones. Material cost puts significant relevance on a unit price of a vehicle considering mass production in the automobile industry. Bio-composites are cost-effective materials as their constituents are naturally available in abundance. Brittleness of matrix materials was overcome by optimizing the volume fraction of fibers, as natural fibers possess good tensile properties to sustain impact loads following improvement in crashworthiness of automobile components. Moreover, low specific gravity of biocomposite materials remarkably curtails the overall weight of the vehicle improving its fuel efficiency. All four aspects lightweight, sustainability, cost-effectiveness, and crashworthiness of natural composites, have made them the most viable material for automobile application.

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