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Exploring the Role of Advanced Composite Materials in Current Electric Vehicles

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Abstract

This paper examines the pivotal role of advanced composite materials in the realm of current electric vehicles (EVs). With their exceptional qualities and lightweight nature, composites have become the preferred material across diverse industries. Conventional internal combustion cars, notorious for their heavy and inefficient design, have exacerbated pollution levels, particularly in urban areas. In response, lightweight composite materials are gradually replacing heavier metals in vehicle production, offering enhanced durability, fatigue resistance, and shape ability. However, the selection of advanced composite materials involves a tradeoff between price and performance. This paper explores the latest developments in the global automotive composites market and their profound impact on industry trends. Moreover, the global drive towards sustainable transportation and carbon reduction is closely aligned with the use of composite materials in automobiles. The paper concludes by proposing avenues for future research aimed at overcoming challenges and maximizing the utilization of composite materials in automotive applications, particularly in the context of electric vehicles.

Keywords: Electric Vehicles, Recyclable Polymers, Composites, Sustainability, India, Automotive Industry

INTRODUCTION

A lot of people are worried about pollution and energy efficiency right now. Greenhouse gas emissions are high in developing countries because their energy generation is highly dependent on fossil fuels. Figure 1 shows how these emissions are distributed by sector. Due to its strong reliance on fossil fuels, the dependability of grid energy supply is under question. Twenty to twenty-five percent of the world's energy goes into transportation, with half of that going into individual cars. Consequently, the car industry, which is worth around USD 2 trillion per year, puts a lot of strain on energy supplies and the environment. The sector is booming, and by 2020, 77 million vehicles will be produced each year [1–3] and Worldwide car sales grew to around 75.3 million automobiles in 2023, up from around 67.3 million units in 2022 [9].

Efforts are being made to minimize pollutants and increase energy efficiency by making cars lighter in order to lessen the environmental effect of this expansion. More and more, shoppers are looking for affordable cars with improved safety features, more efficiency, and more comfortable interiors. Adopting lightweight materials may decrease energy usage, increase vehicle performance, and extend travel range. Composite materials provide weight savings of 10-30%, and estimates indicate that a 25% decrease in vehicle weight might save around 250 million barrels of

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crude oil [2, 4, 5]. The remarkable performance and low weight of composite materials, especially carbon fiber composites, have led to their meteoric rise in popularity. The high cost of these materials compared to metals limits their acceptance in vehicles, even though they are mostly employed in sports goods, military, aerospace, and automotive industries [6, 7]. Weight reductions, specific strength, impact resistance, and stiffness are just a few of the ways carbon fiber composites excel above traditional metals. These materials have piqued the curiosity of the automotive industry for many years. The most popular types of fibers used are carbon, glass, and aramid. When it comes to high-performance applications, carbon fibers are chosen since they are lighter and more rigid than the other two [8–10]. Figure 1. illustrates the relationship between greenhouse gas (GHG) emissions and the consumption of Carbon Fiber Reinforced Polymer (CFRP) materials in various industries, highlighting sectors where CFRP usage potentially reduces emissions [11]. Figure 2 details the different composite material components used in the automotive sector to achieve lightweighting, a strategy aimed at enhancing fuel efficiency and reducing emissions by incorporating advanced materials like CFRPs [35]. In order to reduce weight, conventional and new electric passenger vehicles use a wide variety of composite materials. This study will examine these materials worldwide. It highlights the importance of electric cars—and the need for a new generation of automobiles overall—being more fuel-efficient, lighter, and less polluting than current models, particularly in poorer countries.

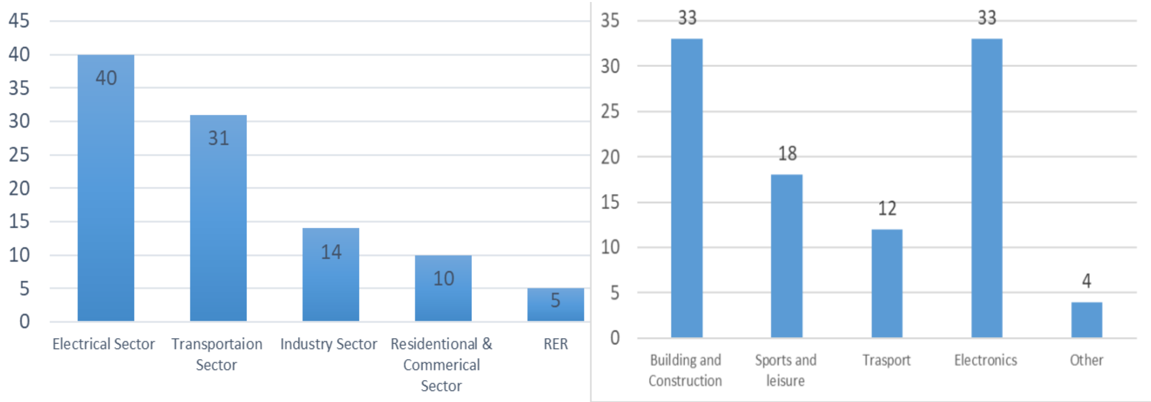


Figure 1. GHG Emissions and CFRP Material Consumption across Different Sectors.

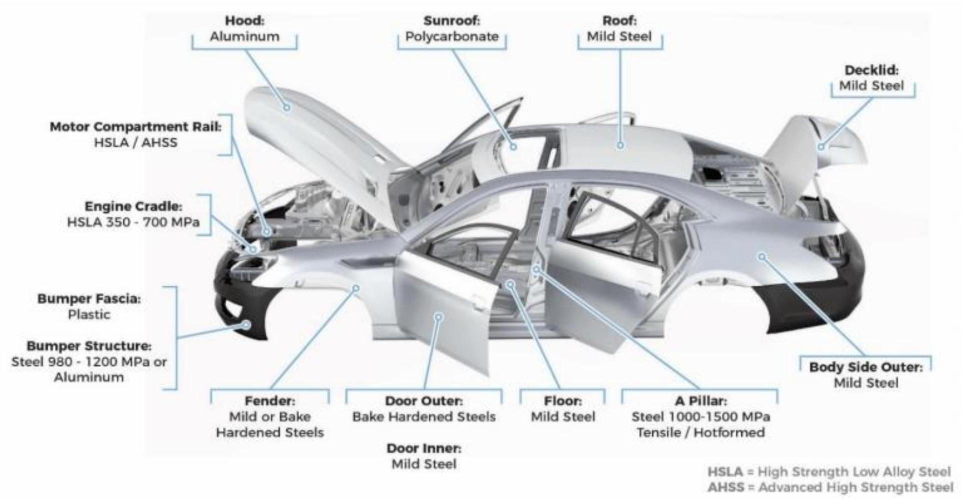
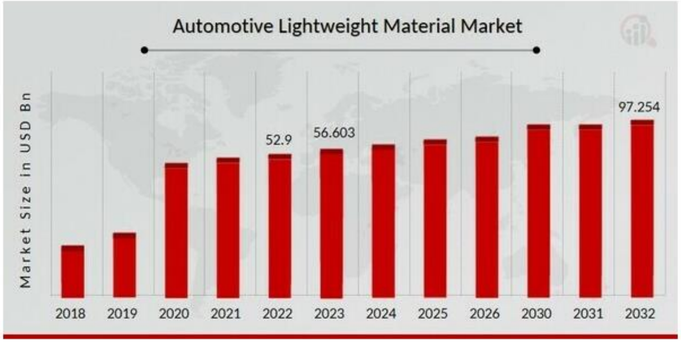


Figure 2. Composite Material Components for Light weighting in the Automation Sector

RATE OF GROWTH IN THE INDIAN COMPOSITE MARKET

In the world of composite materials, India is a major participant, especially when it comes to producing top-notch motorbikes and cars. According to recent data from the World Bank, the number of motor cars in India is 18 per 1000 people, which is far lower than the North American average of 786 and China's 69. This disparity notwithstanding, the analysis concludes that India's transportation sector has good room to develop. The Indian Railways have been heavy users of composite materials, consuming about 10,000 metric tons for a variety of uses. A commitment to local sourcing is highlighted by government laws that mandate 30% of aircraft components to originate from Indian industry. With a consumption of over 3 lakh metric tons in 2015 and forecasts of 4.18 lakh metric tons by 2020, representing a noteworthy compound annual growth rate (CAGR) of 5.8%, the composite sector in India has been steadily growing over the past several years. A similar 3.6% CAGR was seen by the industry between 2011 and 2015 [11–14]. The demand for lightweight materials in the automotive sector is expected 2025-32 driven by changing worldwide trends (see Figure 3 (a) & (b) [11–15]).



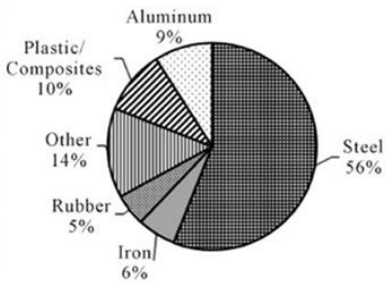


Figure 3. (a) Global CAGR Growth of Lightweight Materials. **Figure 3.** (b) Material Distribution in Conventional Vehicles.

USES OF COMPOSITES IN THE ELECTRONICS SECTOR

Composites are becoming increasingly valuable in the electronics sector due to their exceptional mechanical properties, thermal stability, and lightweight nature. One of the primary uses of composites in electronics is in the production of printed circuit boards (PCBs). High-performance composites, such as those reinforced with glass fibers or carbon fibers, are used to enhance the durability and thermal management of PCBs, ensuring reliable performance in demanding environments.

Additionally, composites are utilized in the manufacturing of enclosures and housings for electronic devices. These materials offer excellent protection against electromagnetic interference (EMI) and radiofrequency interference (RFI), which is crucial for maintaining the functionality of sensitive electronic components. The use of composites also contributes to the overall reduction in weight and size of electronic devices, which is a significant advantage in the consumer electronics market, where compact and portable devices are highly valued [16–20].

Another notable application of composites in the electronics sector is in the production of thermal management solutions. Advanced composite materials with high thermal conductivity are employed to create heat sinks and thermal interface materials that effectively dissipate heat away from critical components, thereby enhancing the performance and lifespan of electronic devices [21].

COMPOSITE MATERIALS USED IN MOTOR RACING

Motor racing demands materials that offer superior strength, stiffness, and weight reduction to optimize vehicle performance. One of the most commonly used composite materials in motor racing is carbon fiber reinforced polymer (CFRP). CFRP is renowned for its high strength-to-weight ratio, which significantly improves the speed and agility of racing cars while maintaining structural integrity and safety.

In addition to CFRP, other composite materials such as glass fiber reinforced polymer (GFRP) and aramid fiber composites are also utilized in various components of racing vehicles. GFRP is often used in body panels and aerodynamic parts due to its cost-effectiveness and good mechanical properties. Aramid fibers, known for their excellent impact resistance and toughness, are used in safety-critical components such as helmets and body armor, providing enhanced protection for drivers [22].

The adoption of composite materials in motor racing extends to the manufacturing of suspension components, chassis structures, and interior parts. These materials not only contribute to weight reduction but also improve the overall performance and handling of the vehicles. The ability to customize the properties of composite materials through different fiber orientations and resin formulations allows engineers to design components that meet the specific demands of motor racing, ensuring optimal performance on the track [34, 35].

CONVENTIONAL USE OF COMPOSITE MATERIALS IN AUTOMOTIVE MANUFACTURING

In the last few years there have been tendencies in the car industry to make cars lighter through steel and cast iron which have to supply their needs. Some of the vital components like cylinder heads, engine blocks, transmission system, valve body, cases, and channel plates, which have been made from steel alloy, magnesium alloy, and aluminum, in the previous era make the kits complete. This development in polymers' usage has been shown due to the increased usage of advanced polymers, both unreinforced and reinforced with carbon and glass fibers that have taken different tasks inside automobile applications. With the usage of MMC or the Metal Matrix Composites, the automotive sector has achieved a cheaper and acceptable replacement criterion. MMCs, characterized by the combination of metallic matrixes with non-metallic particles or fibers, give a better mechanical, thermal and physical properties compared to the aluminum alloys simply. To cite, Toyota has used the MMCs in trials ranging from pistons and engine block cylinder liners implying that they are not refutable. With the aim to increase the engine performance, these improvements are in the direction of enhancing efficiency and upgrading on heat transfer rates, in which the results from aluminum materials are very promising [15–17].

CUTTING-EDGE MATERIAL ADVANCEMENTS IN HYBRID ELECTRIC VEHICLES FOR AUTOMOTIVE INDUSTRY

Figure 3(b) shows that metals, plastic composites, and glass have traditionally been used in the production of automobiles. Aluminum and magnesium alloys have replaced steel in the automation industry due to their lightweight properties. Composites have recently made significant strides, making them an ideal material for use in vehicle light weighting initiatives. Composites have recently emerged as a popular material choice in the aerospace and automotive sectors due to its increased safety features and increased stiffness and strength over traditional materials. A 10% reduction in vehicle weight is possible via the use of composite materials in the automation industry. Composites are 61% lighter than steel and 36% lighter than aluminum. Composite materials can save tooling costs by 50–70% when used to make automotive components. Despite its higher price tag, carbon fibers have found uses in high-end sports cars and luxury vehicles due to their 30% lower weight and reputed outstanding strength [18–21]. According to Table 1, these eco-friendly fiber composites are finding more and more uses in the structural and non-structural parts of automobiles made by manufacturers.

INNOVATIVE COMPOSITE MATERIALS FEATURING GRAPHENE

Emerging composite materials will rely heavily on graphene-fabricated items to fulfill future needs. Graphene is used as a nano-scale filler material in these composites, which are examples of polymer matrix composites and polymer nano composites in the automation industry. Incredibly, when contrasted with conventional polymer composites such as glass or carbon fibers, these materials provide substantial property improvements at noticeably lower loadings. Their primary use in the automobile industry is due to the fact that they make processing components easier and lighter. In addition, using nano composites with different compositions allows for the improvement of multifunctional properties in the fabrication of automotive components. Research shows that composites with even a little quantity of graphene spread in them have markedly better mechanical, thermal, electrical, gas barrier, and flame retardant characteristics. By incorporating graphene into polymer matrices, the structural and functional uses of graphene composites may be maximized, and these composites find use in various kinds of industries. The qualities of the source materials and the interfacial properties determine the ultimate attributes of graphene-based composites. Accurately capturing the interfacial behavior between the graphene and the polymer matrix is crucial for ensuring that these materials respond uniformly through reliability testing. Figure 4 shows how graphene-based composites are used in the car industry [23, 24].

Table 1. Integration of Natural Fiber Components Across Automotive Industries.

Company Name	Model Name	Component
BMW	Series 3, 5, and 7	Components include headliner panels, seat backings, door panels, and noise insulation boards.
Ford	Mondeo CD 162, FOCUS	Products encompass boot liners, pillars, and door paneling.
Toyota	Brevis, Harrier, Celsior, RAUM	Items consist of tire covers, door paneling, and seat backs.
Volkswagen	Passat, Bora, Fox, Polo, Golf	Offerings include boot liners, seat backs, boot lid finishing panels, and door paneling.
Mercedes-Benz	Trucks	Items include internal engine covers, engine insulation, sun visors, interior insulation, bumpers, wheel boxes, and roof covers.
Audi	A2, A3, Avant, A6	Products include hat tracks, seat backs, door panels, and boot linings.

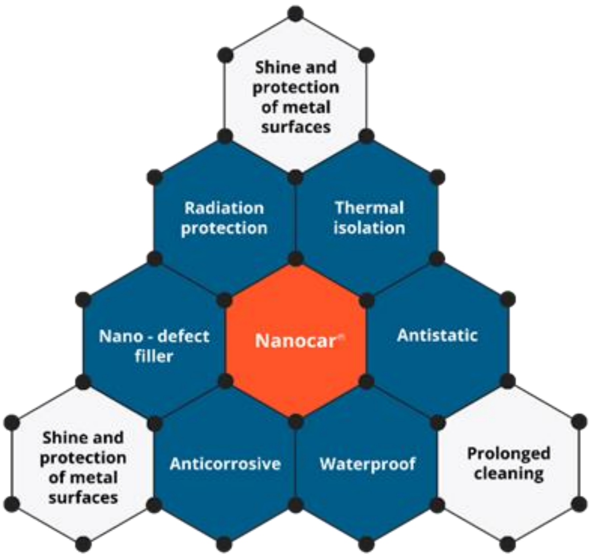


Figure 4. Applications of Graphene Composite Materials in the Automotive Sector and Their Objectives.

LIGHTWEIGHT COMPOSITE MATERIALS INCORPORATING CELLULOSE

Experiments performed by the Centre for Bio-composites and Biomaterials Processing (CBBP) on a variety of biomass sources demonstrated the practicality and feasibility of using Advanced Microfiber Technology (MF) to produce automotive parts. A novel microfiber-composite material was rapidly created using this approach [30, 31]. Composites and those with 40% glass fibers are compared in Table 2. Figure 5 shows the result of combining MF with Direct-Long Fiber Thermoplastic (DLFT) technology to create MF-DLFT composites, which are designed to have better impact performance. The production of car hoods might benefit from this integrated technology. The third table compares the properties of engine covers and cam covers made of cellulose microfiber hybrid composites. The MF-DLFT method is anticipated to make car parts 15% to 30% lighter, which might lead to a future fuel economy boost of 14% [25–28].

Comparative Analysis of Mechanical Properties and Fiber Utilization in Composite Materials for Automotive Applications

Using carbon fibers and microfibers made of cellulose, the CBBP has created a number of hybrid composites. Various comparative analysis is shown in Table 3 to Table 6 [29–35].

Table 2. Mechanical Testing of Polypropylene Composites Manufactured with MF Technology.

Property Test	**40% Glass Fiber Reinforced PP**	**MF Technology with Glass Fiber Composite**
Fiber Use (wt.%)	40	50
Tensile Strength (MPa)	Approximately 101	Around 90
Flexural Strength (MPa)	Roughly 160	About 135
Flexural Modulus (GPa)	Approximately 6.2	Approximately 6.5
Izod Impact Strength (J/m)	Approximately 214	Not specified
Density (g/cm3)	Approximately 1.14	Approximately 1.10

Table 3. Comparative Properties of Engine and Cam Covers Manufactured Using Cellulose-Based Microfiber Hybrid Composites.

Property Test	**Engine Cover**	**Cam Cover**	**CBBP MF-DLFT Hybrid Composite**
Tensile Strength (MPa)	Approximately 110	Around 85	Equivalent, with a slight increase for the hybrid composite
Flexural Modulus (GPa)	Approximately 7.10	Approximately 7.20	Equivalent, with a slight increase for the hybrid composite
Impact Strength (23°C) (kJ/m²)	Approximately 3.10	Approximately 4	Comparable, with a slight improvement for the cam cover
HDT at 1.82 MPa (°C)	Around 187	Around 170	Similar, with a slight variation for the cam cover
Flammability (mm/min)	Less than 100	Less than 100	No significant difference
Density (g/cm³)	Range: 1.320-1.420	Approximately 1.47	Slightly higher density for the cam cover

Table 4. Comparative Properties of Engine and Cam Covers Manufactured Using Cellulose-Based Microfiber Hybrid Composites.

Composite Name	**Common Name**	**Renewable Content (wt.%)**	**Proposed Application**	**Cost/lb (USD)**	**Model Use**	**Wt. Reduction (%)**
MiCelD210-PP	Cellulose Hybrid Fiber Polypropylene	20.0–30.0	Suitable for Door Panels, Engine Covers, Extension Panel Dash, Battery Housing, and Air Inlet Box	$1.32	Engine Cover	30
MiCelD215-PP	Cellulose Hybrid Fiber Polypropylene	20.0–35.0	Ideal for Camshaft Covers, Oil Pans, Intake Manifolds, and Engine Covers	$1.39	Oil Pan, Cam Cover	20
MiCelD112-PP	Cellulose Hybrid Fiber Polypropylene	20.0	Suited for Air Intake Boxes, Front Engine Covers, Extension Panel Dashboards, Battery Tray	$1.31	Battery Tray	25

			Lids, and Door Panels			

Figure 5. (A) Engine covers, (B) cam covers and (C) oil pan manufactured by CBBP

Table 5. Comparative Analysis of Fiber Mechanical Properties

Fiber Name	**Density (g/cm³)**	**Tensile Strength (MPa)**	**Modulus (GPa)**	**Elongation (%)**
Glass Fiber	2.54	3450	73	3.0–4.0
Carbon	1.78–1.81	3800–6530	230–400	1.78–1.81
Aramid Type	1.44	3600–4100	131	Not specified

Table 6. Comparative Analysis of Three Carbon Fiber/Epoxy Composite Products.

Type	**55% CF SMC**	**Entry-Level Carbon Fiber Epoxy Fabric**	**Premium Grade Carbon Fiber Epoxy Fabric**	**Carbon Epoxy**
Carbon Fiber (%)	55	Not Applicable	Not Applicable	67
Density (g/cm³)	1.45	1.15	1.8	Not Applicable
Tensile Strength Ultimate (N/mm²)	289	50	2100	1362
Modulus of Elasticity (10^3 N/mm²)	55.1	6.6	520	140
Flexural Yield Strength (N/mm²)	613	110	1600	1383
Flexural Modulus (10^3 N/mm²)	34.5	6.41	125	122
Compressive Yield Strength (N/mm²)	275	50	1720	1084
Compressive Modulus (10^3 N/mm²)	31.7	8.2	140	136
Shear Strength (N/mm²)	65.6	0.8	120	87.4

CF RECYCLING VIA FLUIDIZED BED PROCESS

Composites made of carbon fiber are becoming more used in several industries, including aerospace and automobile manufacturing. Carbon fiber (CF) systems that combine recycling procedures to handle waste from manufacturing and old CF components will be able to fulfill future needs for CF materials. The importance of recycling carbon fiber material has grown in the past several years. About 68,000 metric tons of carbon fiber were needed in 2015; 18,000 metric tons were discarded from production, and the other 50,000 metric tons will likely end up as carbon fiber composites (CFCs) in 2–40 years, depending on their use. When it comes to recycling CFRP, the fluidized bed process is often the go-to for many industries.

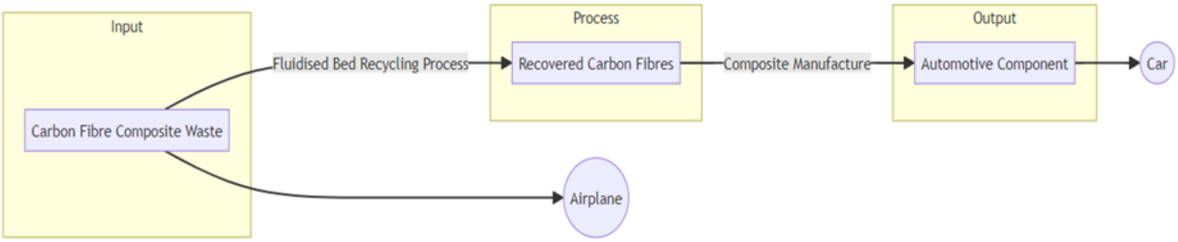


Figure 6. Recycling Technique for Carbon Fiber Composites in Aerospace and Automotive Industries.

The procedure involves oxidizing epoxy resins at 500 °C, which releases hot gases that extract CF components from fibers and transfer them to a fluidized sand bed. The byproducts of polymer breakdown are fully oxidized after fiber separation by directing the hot gases through a hot combustion chamber. There may be about 3,000 metric tons of carbon fiber trash produced yearly by 2030 as 6,000 to 8,000 commercial airplanes in the United States and Europe alone reach the end of their useful lives. The amount of carbon fiber composite materials that are accessible for recycling is anticipated to rise dramatically as older airplanes are decommissioned in the next several years. Reduced environmental impact and cheaper availability in lightweight material markets are two benefits of recovering carbon fiber. Carbon fiber composites are repurposed from the aircraft industry to the automobile sector, as seen in Figure 6 [9].

CONCLUSION

Exciting developments in composite materials used in a wide variety of automotive and other industrial components are highlighted in this paper. Increased consumer awareness about green mobility and energy security issues in metropolitan areas has spurred a major spike in the application of composite materials within the transportation sector over the past several years. These materials won't replace metals totally, but they have a lot of promise for the future of automation. The composites sector is now under pressure to prove that its materials are superior to metals in terms of their advanced characteristics. In addition, new composite materials are urgently needed to solve transportation industry problems with weight reduction, energy efficiency, and safety. The use of fiber-based hybrid composite materials in the production of different kinds of light cars is becoming more popular in the industry. Lightweight cars, both affordable and high-end, have seen a dramatic makeover because to recent technical developments, especially in the use of cellulose and carbon composite materials. Additionally, a promising future for the creation of hybrid composite lightweight materials is the accessibility of carbon fiber-based composites at lower prices through recycling procedures. cars constructed using lightweight composite materials have had encouraging outcomes in terms of improving fuel economy, with noticeable gains in mileage seen in these cars. In line with the goals of major environmental protection organizations, it is becoming more and more possible to achieve fuel economy standards through the extensive use of lightweight composite materials.

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