

Composite Materials for Automotive Body: Balancing Weight Reduction and Safety

Sen Liu

Changan Dublin International College of Transportation Changan University, Xi'an, China

Abstract

With the growing number of automobiles, the demands from both government and consumers for fuel economy and automotive safety are also on the rise. To meet these requirements, the article outlines some key properties required for automotive body materials. It delves into the characteristics of fiber-reinforced composites and sandwich structures. For example, it provides data on the impact strength and Young's modulus of Carbon Fiber Reinforced Polymer (CFRP), which is highly useful in selecting materials for the vehicle body. Finally, the article highlights several applications of composite materials in automotive body components, including support structures, bumpers, hoods, and chassis. This article primarily summarizes past research and provides direction for future studies.

Keywords

Composite Material, Properties, Applications, Material Selection, Safety, Lightweight.

1. Introduction

With the advancement of the automotive industry, more people now own automobiles. Figure 1 (a) demonstrates automobile sales revenue in China from 2005 to 2022 [1]. This trend is also observed in other developing countries.

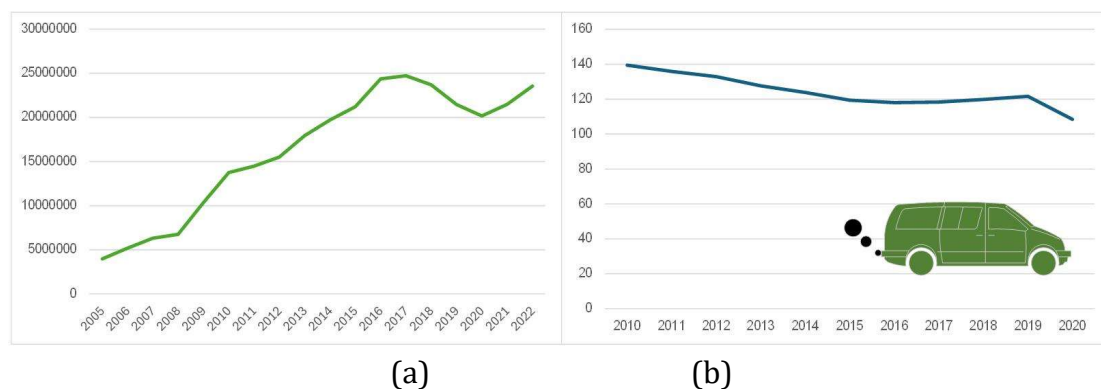


Figure 1. Change of Automobile Sales in China and CO₂ emissions in the EU (2010-2020) (from Global Automotive Sales Data and Association des Constructeurs Européens)

As a result, people have higher demands for vehicles. Also, today's average car weighs 200kg more than 25 years ago [1]. However, to protect the environment, governments impose strict requirements on fuel efficiency and CO₂ emissions. Additionally, consumers also seek high fuel economy to reduce costs [2]. To meet the standards of governments and the needs of consumers, achieving automotive lightweight is crucial. Reducing a vehicle's weight by 10% can lead to a 3% to 7% decrease in fuel consumption [3]. While, metal and alloy materials have been used for a long time, and the development potential is limited [4]. Due to this situation, more

and more scientists are putting their experiences into composite materials, which are made by combining two or more materials with different properties [1].

Meanwhile, safety must also be ensured. The safety of vehicle bodies includes various properties, such as tensile strength, impact strength, and corrosion resistance. Vehicle bumpers, as part of the vehicle body, must have sufficient strength to protect vehicles and passengers from injury [5]. The study illustrates that the strength of composite materials is significantly higher than conventional materials [6]. Above all, composite materials hold great potential and are crucial for future vehicle development. In 1947, the first composite material was used in vehicles. Furthermore, in 1974, Japan used composite material to reduce weight and enhance fuel economy [7]. Currently, some vehicles on the market already incorporate composite materials. However, due to their high cost, these materials are primarily used in high-performance and luxury vehicles. For example, fiber-reinforced composites have already been adopted by several leading automobile brands, including Mercedes-Benz, Toyota, and Ford. [8]. This essay focuses on comparing different materials used in vehicle bodies from weight, and safety, and gives some advice for application.

2. Properties of Materials Required for Vehicle Body

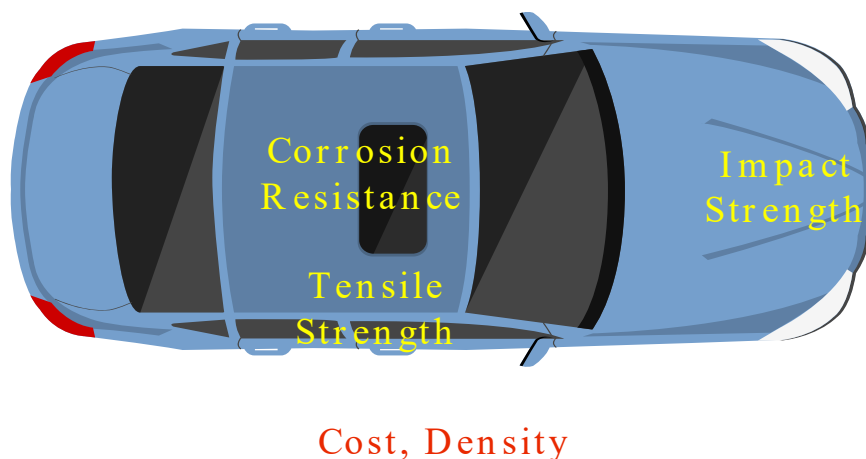


Figure 2. Properties vehicles needed

2.1. Density

Cars require the use of low-density materials to achieve lightweight designs. Lightweight vehicles can improve fuel economy and reduce carbon emissions [9,10]. Most metals and alloys have higher densities than composite materials [10]. For instance, [7] compares the density of steel (S355) and carbon fiber, showing that carbon fiber has a significantly lower density.

2.2. Safety

Safety depends on multiple factors, including impact strength, corrosion resistance, and plastic deformation capacity.

2.2.1. Impact Strength

When a material is subjected to a sudden impact or collision, it can absorb energy and resist fracture, which is called impact strength. The higher the impact strength, the better the car can absorb energy when it is impacted, thereby enhancing passenger safety. Composites are commonly used in bulletproof vests, which can protect soldiers from impact [10]. The same principle can be applied to vehicles.

2.2.2. Corrosion Resistance

Corrosion resistance is very important for vehicle longevity. The body is exposed for a long time and is susceptible to rain and air. [7] shows that composite materials have great advantages in resisting air and rain corrosion. However, corrosion resistance depends on the components of the matrix and reinforcement materials. The experiment concludes that the base Al alloys have better corrosion resistance than Al – B₄C composite material [11]. [12] compares different materials in many properties, and Titanium alloys, carbon fiber reinforced polymer (CFRP), and glass fiber reinforced polymer (GFRP) are good in corrosion resistance, which demonstrates people are more serious when choosing material.

2.2.3. Plastic Deformation Capacity

In this aspect, yield strength, tensile strength, Young's modulus, and ultimate strain. Yield strength and tensile strength can indirectly provide insights into the behavior of materials during the plastic deformation phase, ultimate strain reflects the maximum extent of plastic deformation that vehicle body materials can undergo, and Young's modulus quantifies a material's resistance to deformation.

2.2.4. Thermal Conductivity

Thermal conductivity is a critical factor in material selection as it affects cooling efficiency, component longevity, and overall vehicle performance [13]. People can add various thermal conductivity into the composite material to ensure the prospective thermal conductivity of materials [7].

2.3. Cost

Prices of the material are significant to consider. If the cost of material is expensive this material cannot be used in automobile manufacturing, it only can be used in high-performance vehicles and concept vehicles. However, the composite material is not expensive. For instance, the thermoset material is cheaper than most wood and metal, which can be used in vehicles [7].

3. Material Chosen

Different materials are being discussed according to their classification.

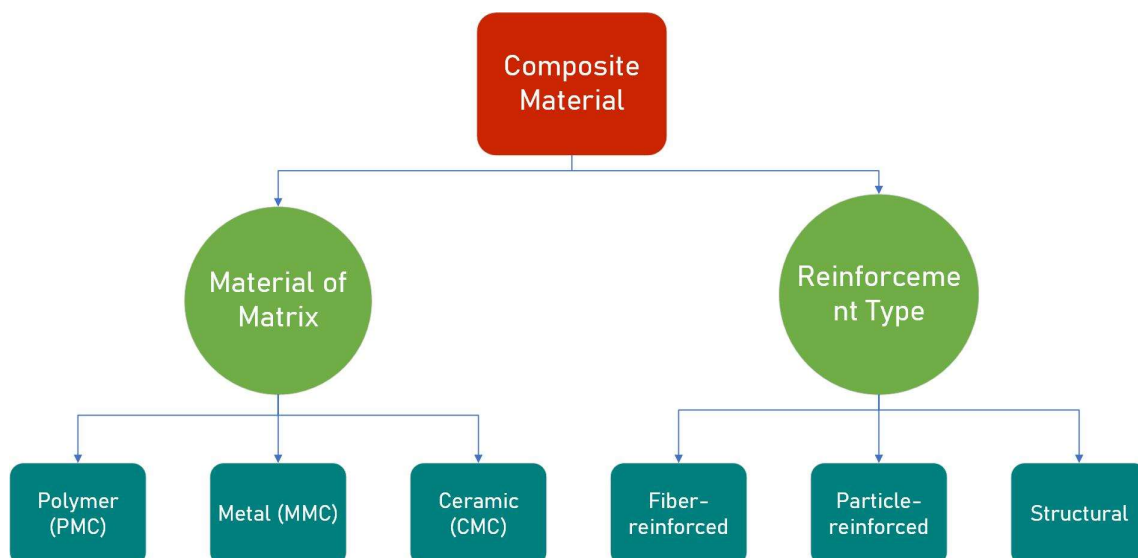


Figure 3. Classification of Composite Material

3.1. Fiber-reinforced

When individuals choose fiber-reinforced composites, they must think about the anisotropy. For example, the tensile strength of Carbon Fiber-reinforced polymer (CFRP) is determined by the direction of carbon fiber.

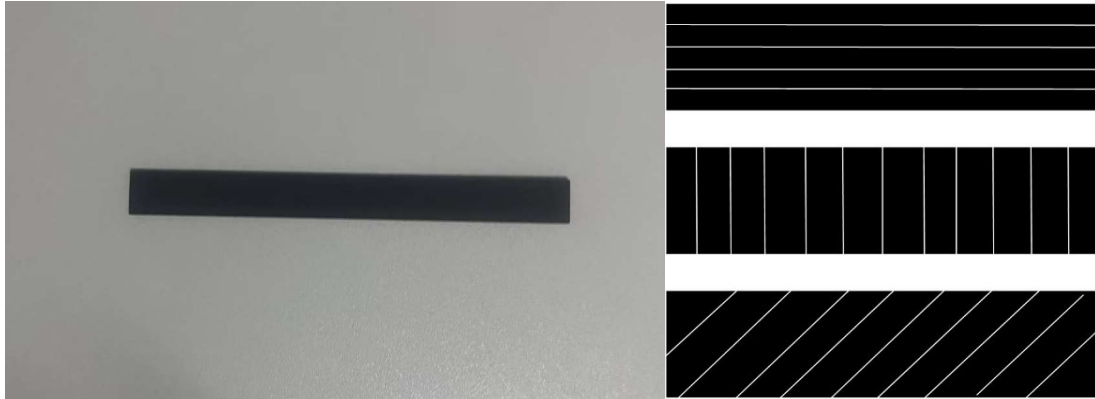


Figure 4. CFRP

If the carbon fiber in this figure is horizontal direction, tensile strength in the horizontal direction is larger than vertical direction. Moreover, if the fibers are 45 degrees, this material has higher isotropy. The direction should be chosen to align with the fibers, based on this essay.

3.1.1. Comparison between Carbon Fiber-reinforced Polymer (CFRP) and Glass Fiber-reinforced Polymer (GFRP)

CFRP shows lower density than metal and alloy which has good mechanical properties, it can be used in high-performance vehicles to increase the body's torsional rigidity [14].

[15] mentioned that GFRP and CFRP both have good strength-to-weight ratios and can be used in automobile manufacturing. Comparing the two materials and then identifying which part of the vehicle each material is more suitable for.

Table 1. Comparison of CFRP and GFRP [9,18,19,20]

Characteristic	GFRP	CFRP
Density, g/m^3	1.8-2.1	1.7-2.0
Young's modulus, GPa	70	140-145
Tensile strength, MPa	1700	800-1100
Thermal conductivity, $W/m\ ^\circ C$	0.75	0.5-0.1
Corrosion resistance	Resistant	Resistant
Impact strength	Good	Good
Price	Lower	Higher

[16] showed the density of GFRP is 1.8-1.9, and this data in [17] is 2.1. The data is merged. [16] mentioned that these two materials are resistant in line of Resistance to aggressive environments. [18] mentioned that C glass fiber shows good corrosion resistance in an acidic environment, however, it may have a lower capacity for corrosion resistance in an alkaline environment. [7] shows that the impact strength of these two materials is great which can be used in hood and bumper. Furthermore, this essay demonstrates impact strength is one of the advantages of composite material.

This table only shows a rough comparison of the two materials. When using these materials in vehicles' bodies, more data will be included, and doing experiments is a better choice. Nevertheless, these two materials can be recommended and used in some components.

3.2. Sandwich Structural

Some sandwich structures using carbon fiber and glass fiber are mentioned, and in this part, the aluminum or aluminum alloy sandwich is mainly focused on.

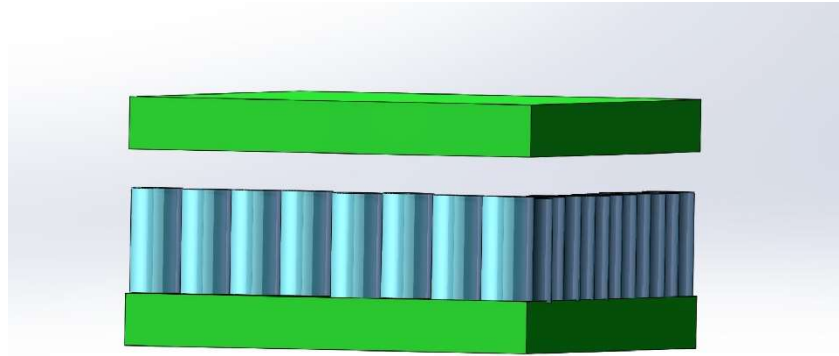


Figure 5. Aluminum Honeycomb Model in SolidWorks

3.2.1. Comparison of Foam Sandwich Structural and Honeycomb Sandwich Structural

The experiment in [19] compares the properties of cores of aluminum honeycomb, and aluminum foam and shows that aluminum honeycomb sandwich laminated box beams had the largest ratio of overall stiffness to mass and ultimate load to mass, which means that this material has advantages to lightweight.

Table 2. Comparison of aluminum sandwich laminated box beams [23]

Types	<i>Overall Stiffness</i> / <i>Mass</i>	<i>Ultimate load</i> / <i>Mass</i>
Al Honeycomb	32.42	69.51
Al Foam	21.25	56.74

The aluminum honeycomb is composed of many small, regularly arranged hexagonal honeycomb cells, with gaps existing between these cells. The density of this material is relatively low while maintaining strength, thereby achieving lightweight.

[20] also compares lots of composite materials combined with aluminum alloy. For honeycomb sandwich panels, scientists do experiments, and the result is that the Material front surface and honeycomb core have the same size damage. Moreover, aluminum foam-cored sandwich plates show the foamed core plays a significant role in energy absorption.

Table 3. Properties of Aluminum Foam Sandwich (AFS)

Types	AFS
Tensile strength, MPa	200
Young's modulus, GPa	21
Density, g/cm³	0.8
Costs, €/kg	10 (series)

The data in this table provides quantitative values for corresponding properties, which can help in better material selection.

3.3. Application

According to the properties of composite materials, their use can be come out.

3.3.1. Hood

[7] mentioned that CFRP and GFRP can be used in the hood. [21] shows a detailed structure of the hood, the different types of CFRP material (45, -45, and 0 degrees, respectively) combined to form composite laminates for the composite hood, which shows high impact strength. This result takes advantage of CFRP. CFRP and GFRP mix and get composite laminates which can be used for the hood. Meanwhile, these composite hoods are lightweight. These and the data above corroborate with each other, proving the merit of composite material.

3.3.2. Bumper

Mohammad Sakib Ul Abrar et.al modeled bumper mode, and the simulation analysis was done to analyze the damage degree of different materials at different speeds. The results illustrate that Glass Mat Reinforced Thermoplastics (GMT), which use thermoplastics as a matrix, and Carbon Fiber have good impact strength and can protect vehicles and passengers [5]. Moreover, [7] demonstrates that CFRP and GFRP are both good materials used for bumpers that can absorb energy from collision.

3.3.3. B-pillar

[22] raises a new composite combined with metal and CFRP. This new structure reduces weight and enhances strength. Authors use this material in B-pillar, causing a 44% weight reduction, and its crashworthiness increased by 10% compared to the tailor-welded steel pillar.

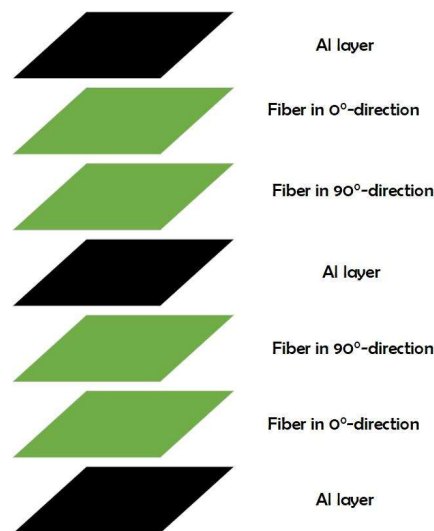


Figure 6. Fiber metal laminates

3.3.4. C-pillar

[23] mentioned that the sandwich structure can be used in a C-pillar. In this essay, a sandwich structure made of steel skins and a rigid foam core are used. Additionally, Al honeycomb and Al foam can be used in C-pillar manufacturing. Using these materials can achieve a high strength-to-weight ratio and keep the price in the same range.

3.3.5. Chassis

[24] mentioned that the materials of glass fiber, vinyl ester resin, and urethane foam are used in manufacturing floors for automotive structures. By finite element analysis, the safety of the two loading conditions is evaluated, and the structure shows that the maximum stress and

displacement of the two structures are within the safe range. At the same time, compared with steel material, the effect of weight reduction is also achieved.

In addition, sandwich structural material can be used in various components, such as doors, luggage lids, bonnets, battery boxes, and other support structures [4, 25].

4. Conclusion and Future work

The increasing number of automobiles has led to heightened demands from both the government and consumers regarding fuel economy and automotive safety. At the same time, as an emerging material that can be applied to automotive body structures, composite materials are well worth investigating. In response to these needs, this article explores the essential properties required for automotive body materials, with a particular focus on fiber-reinforced composites and sandwich structures, which are crucial for material selection in vehicle body design. Additionally, the article highlights various applications of composite materials in automotive components, including support structures, bumpers, etc. By summarizing past research findings, this article offers valuable insights and guidance for future research directions in the field of automotive materials. For future work, there is significant potential in exploring the combinations and improvements of the composite materials mentioned in this article. By doing so, individuals can not only achieve better weight reduction but also meet the stringent safety standards required for automotive applications. In terms of material selection, evaluation models such as the entropy weight method can be employed to provide a more objective and data-driven approach. For instance, when selecting materials for a specific automotive body component, the entropy weight method can help determine the optimal material based on various performance indicators. Additionally, the application of big data can further enhance the process by providing insights into the performance requirements and consumer preferences. This integration allows for more precise material selection and design, ultimately leading to vehicles that are not only lighter and safer but also better aligned with market demands.

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