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ANALYSIS OF CARBON FIBER USAGE IN THE AUTOMOTIVE INDUSTRY

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Abstract. The increasing competition in markets encourages the search for innovative solutions that help stand out and attract customers. Carbon fiber, which is gaining popularity due to its excellent properties, holds great potential for this purpose. This article outlines the physical and technical properties of carbon fiber that can be applied in the automotive industry. It compares the properties of composite materials and alloys and explains why using carbon fiber in automotive parts manufacturing results in components with superior qualities compared to those made from steel or aluminum. Examples of automotive parts suitable for carbon fiber manufacturing are provided, along with descriptions of how carbon fiber components achieve better characteristics than those made from other materials. The article also analyzes the drawbacks of carbon fiber, including why it may be challenging and costly for the automotive industry to integrate carbon fiber manufacturing, and discusses the factors that drive up the cost of carbon fiber and make its recycling difficult.

Keywords: carbon fiber; automobiles; automotive industry

INTRODUCTION

The developing automotive industry, aiming to design and produce reliable products, is seeking alternative materials with improved properties. In automotive manufacturing, priority is given to vehicle safety, creating a demand for strong materials. Carbon fiber has become popular in the aviation, automotive, and electrical sectors due to its excellent tensile properties, bending strength, strength-to-weight ratio, lightness, low density, thermal conductivity, electrical conductivity, chemical resistance, and resistance to creep (Azad et al., 2024). With the growing demand for cars and rising competition, there is a continuous search for ways to create higher-quality products that can stand out in the market.

In vehicles, metal is replaced by carbon fiber and various composites of carbon and other materials wherever possible. Composite materials are used to manufacture car body elements, brake and clutch discs, and trim parts, as they are durable, lightweight, and more resistant to abrasion and corrosion (Valiulis, 2010). For example, a sports car's body must be lighter to offset the weight of the engine and other components, while maintaining safety—a requirement well met by carbon fiber.

THE RESEARCH METHOD

The aim of the study is to analyze the use of carbon fiber in the automotive industry.

Objectives of the study:

1. To identify the physical and technical properties of carbon fiber.
2. To present the applications of carbon fiber in automobiles.
3. To evaluate the drawbacks of carbon fiber.

Methodology of the study: The main research methods used include analysis of scientific sources, comparative analysis, systematization, and summarization. To ensure a thorough literature review, research data published in the Science Direct and Taylor & Francis databases were analyzed. Information was searched using keywords such as 'carbon fiber' and 'carbon fiber in the automotive industry.' Articles were selected from 2018 onward to ensure the information was current and relevant. These databases were chosen due to their reliable and relevant information aligned with the selected topic.

PHYSICAL AND TECHNICAL PROPERTIES OF CARBON FIBER

The automotive industry is one of the most competitive industries worldwide (Vasco, 2021). With the rapid development of the automotive sector, reducing fuel consumption and emissions has become a critical issue that requires urgent solutions (Azad et al., 2024). Carbon fiber composites offer low weight, high strength, high stiffness, good resistance to vibration, fatigue, corrosion, and many other advantages (Ahmad et al., 2020). Composite materials, including carbon fiber, glass fiber, and fast-curing resins, possess properties that resist corrosion from oxygen, moisture, corrosive substances, saltwater, and humid environments (Khan et al., 2024). A comparison of the properties of traditional metals and composites is shown in Table 1.

Table 1

Comparison of the Strength of Various Types of Composites and Alloy Materials

Material Name	Material Type	Tensile Strength Σu (MPa)	Density ρ (kg/m3)	Elastic Modulus E (GPa)	Material Name
Steel (S355)	Alloy	500	7850	210	**Steel (S355)**
Carbon Fiber (High Strength)	Composite	7060	1820	294	**Carbon Fiber (High Strength)**
Aluminum (AA6082)	Alloy	150	2710	71	**Aluminum (AA6082)**
Laminated Glass Fiber (FR4)	Composite	317	2000	24	**Laminated Glass Fiber (FR4)**

According to Table 1, carbon fiber and laminated glass fiber have higher tensile strength than steel and aluminum. The elastic modulus of metals is also higher. Although their density is lower, steel and aluminum can be replaced by carbon fiber and laminated glass fiber, respectively (Khan et al., 2024).

Carbon fiber materials are used as electrodes and as reinforcement for other materials due to their unique physical and chemical properties (Qiao et al., 2023). Therefore, they can be used in the production of electrically insulating components where this property is required. Composite materials have low thermal and electrical conductivity, making them good insulators for components that require insulation (Khan et al., 2024).The best way to improve fuel efficiency is to reduce the weight of vehicle parts (Ahmad et al., 2020). While carbon fiber is stronger and stiffer than steel and aluminum, it weighs about a quarter of the weight of steel and 70% of the weight of aluminum (Khan et al., 2024). Comparison of Composite and Pure Materials in Figure 1.

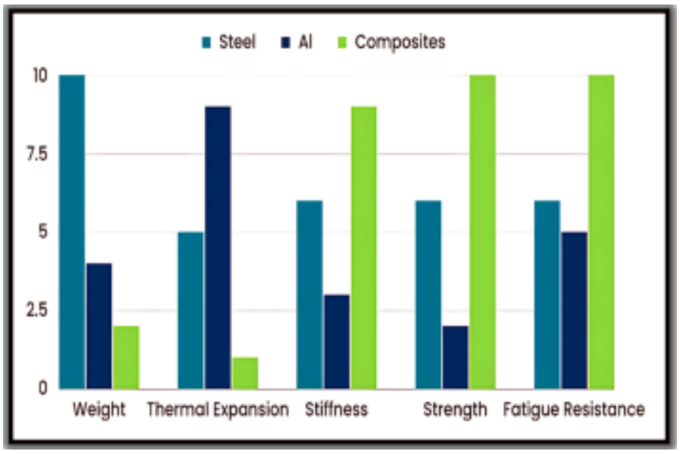

Figure 1. **Comparison between composite and pure materials**

When comparing carbon fiber to steel, aluminum, and laminated glass fiber, carbon fiber is lighter, which reduces fuel consumption as the vehicle becomes lighter. It is also stronger and stiffer, so the components do not break as easily, and in the event of a traffic accident, carbon fiber components can better perform their protective function for passengers. Carbon fiber is resistant to corrosion, fatigue, vibration, and moisture. These properties ensure a longer lifespan for the components as the impact of environmental factors is reduced. Therefore, carbon fiber has more suitable properties for the production of automotive components. Additionally, lighter vehicles can reduce road wear.

APPLICATION OF CARBON FIBER IN AUTOMOBILES

Carbon fibers can be used in various parts of a vehicle (Ahmad et al., 2020). Typically, composite materials used in automotive structures are limited to secondary external components such as body panels, wheel housings, or bumpers (Othman et al., 2018).

Chassis Frame: The use of composite materials in the chassis helps reduce the overall weight of the vehicle, improves handling, and increases fuel efficiency (Khan et al., 2024). The chassis, as the frame of the vehicle, must be rigid or strong enough to absorb and stop the movements and vibrations of the engine, suspension, and axles (Ahmad et al., 2020). Composites can offer excellent fatigue resistance, ensuring that the chassis maintains its performance and structural integrity over time (Khan et al., 2024). Carbon fiber-reinforced plastics are suitable because they are about twice as strong but much lighter than steel or aluminum. The carbon fiber frame is inflexible; for example, metals can be melted or welded, whereas a carbon fiber chassis will not bend and will break under sufficient force, unable to be joined again (Ahmad et al., 2020).

Hood: Composite hoods can help improve vehicle handling and accelerate faster due to reduced weight and an improved power-to-weight ratio (Khan et al., 2024). Composite hoods can provide greater impact resistance, enhancing passenger safety in the event of a collision. Composite materials offer more design freedom, enabling manufacturers to produce hoods with complex curves and shapes (Ngo, 2020). Natural flax fiber, glass fiber composites, and carbon fiber composites show significant research impact. Studies recognize that composite materials for the hood reduce weight by almost 30%, while strength remains nearly the same under torsion and bending stresses (Khan et al., 2024).

Bumper: Composite bumpers can be designed to efficiently absorb and distribute impact energy, reducing structural damage to the vehicle and minimizing injury severity at low speeds (Rangabashiam et al., 2020). In case of minor damage, composite bumpers can be repaired more simply and cost-effectively compared to traditional steel bumpers. Composites simplify the integration of various features, such as sensors, parking aids, and lighting components. This simplifies the bumper's design and improves overall design efficiency (Khan et al., 2024).

Doors: Composite materials are known for their high stiffness and strength, which improves the structural integrity and impact resistance of vehicle doors. Composites can withstand corrosion, wear, and fatigue more effectively than metals (Rajak et al., 2019). Engineering composites can create quieter cabins due to specific acoustic properties that help reduce noise transmission through the doors. Car manufacturers can produce lighter and stronger doors, which, by utilizing the advantages of composite materials, contribute to increased safety and aesthetics (Salifu et al., 2022). Epoxy resin-reinforced carbon fiber absorbs more deformational energy than steel, reducing weight by 65% (Khan et al., 2024).

Sunroof: Composite materials with unique properties are used in the construction of car sunroofs. Weight reduction is one of the main reasons for using composites in sunroofs. Due to the reduction in weight, the overall efficiency of the vehicle can be improved. Composites have a high strength-to-weight ratio, making them desirable for reducing overall weight while maintaining structural integrity (Mansor et al., 2019). Some sunroof glazing or exterior surfaces can be made from composite materials.

Engine cradle: Another application of composite materials in automobiles is in the engine frame, a structural element that holds the engine and other related components. One of the key subcomponents of the engine subsystem, the engine frame performs four main functions: holding the engine, transmission, and suspension, distributing large chassis loads, reducing vibrations and shocks, and helping manage rigidity and collisions (Fonseca et al., 2019). Due to their natural thermal insulating properties, composite materials can improve heat management by reducing heat transfer from the engine to other parts of the vehicle (Huang et al., 2022). Vehicle safety and impact resistance can be enhanced by designing composite engine frames that absorb and dissipate impact energy (Khan et al., 2024). Composite engine mounts can reduce collision forces and protect other critical vehicle parts during a crash (Mohammadi et al., 2022). Using composites in the engine frame can simplify the integration of other elements, such as suspension systems and mounting points, making the vehicle's design more unified and efficient (Sharma et al., 2022).

Therefore, by replacing certain materials used in the production of components with carbon fiber, we can achieve automotive parts with better properties. Due to its lightness and strength, carbon fiber is ideal for manufacturing chassis, sunroofs, hoods, and bumpers, and its thermal insulating properties make it suitable for engine frame (engine cradle) production. Carbon fiber-made car doors will be resistant to corrosion and reduce external noise.

DISADVANTAGES OF CARBON FIBER

Material Cost: One of the barriers contributing to the limited use of carbon fiber in the automotive industry is the cost of materials (Othman et al., 2019). However, it should also be understood that replacing cheaper metals, currently used for functional automotive parts, with more expensive carbon composite materials will be very difficult (Ahmad et al., 2018). Currently, a large portion of CFRP (carbon fiber reinforced polymer) parts are used in high-end sports vehicles, with approximately 500 units produced annually (Othman et al., 2018).

Recycling: Recycling multiple different resins increases the disassembly costs, thus reducing the car's residual value. These resins are generally not recyclable and are disposed of in landfills as shredded automotive waste. Disposal in landfills and incineration have been the dominant recycling methods for a long time. However, these are not sustainable methods as they fail to address issues related to waste accumulation (landfilling) or require intensive energy consumption (incineration) (Butenegro et al., 2021). A survey conducted by the University of Michigan's Transportation Research Institute states that one of the main barriers to using composite materials in vehicle components is their recycling (Othman et al., 2019).Although carbon fiber has many suitable properties for the automotive industry, its production requires newer technologies to reduce the cost of carbon fiber so that the automotive industry can create affordable products for consumers. Also, due to the complexity of its production, industries may face challenges in obtaining larger quantities, which limits its use to sports and luxury cars. Possibly, due to the complex recycling of carbon fiber, its repair is also complicated. This requires specialized skills and equipment, which increases the cost. Since carbon fiber has different properties in different directions, due to its fiber orientation (anisotropic properties), challenges may arise in designing components. The load direction must be carefully considered, which can complicate manufacturing and repairs.

CONCLUSIONS

1. After identifying the physical and technical properties of carbon fiber, we can conclude that carbon fiber has more suitable properties for automotive component manufacturing than commonly used materials such as steel, aluminum, or fiberglass. Carbon fiber is lightweight, yet strong and rigid.

2.Presenting the possibilities of carbon fiber usage, it was observed that many vehicle components can be made from carbon fiber to produce stronger, lighter, and higher-performance parts. Typically, carbon fiber is used to manufacture external automotive structures, as these parts are most exposed to external factors that shorten their lifespan. The produced components are resistant to corrosion, fatigue, vibration, and moisture.

3.Considering the drawbacks of carbon fiber, it is clear that the automotive industry could benefit from using carbon fiber, but the specifics of its production must be taken into account. In order to provide affordable products to consumers, the automotive industry must also consider the cost of the materials used. Additionally, the waste generated during production is difficult to remove because carbon fiber is hard to recycle. As a result, there is no circular economy, and environmental pollution occurs.

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