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Carbon fiber comparison to traditional materials for the automotive industry

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Abstract. As automotive technology continues to advance; the industry is confronted with the ongoing challenge of improving car performance while maintaining safety and structural integrity. This long-standing challenge in the field of automotive technology may soon find a solution through the emergence of carbon fiber composite materials, potentially ushering in a new era of material dominance. Carbon fiber composites possess exceptional strength and extreme stiffness compared to metals, yet they exhibit a much lower density— 80% less than steel. This unique combination of properties makes carbon fiber a possible alternative for automobile materials. Moreover, carbon fiber is a more sustainable material compared to traditional metals, offering environmental benefits. It also enables more efficient manufacturing techniques, contributing to reduced energy consumption and waste production. The present study investigates the feasibility of utilizing carbon fiber as the primary material for future automobiles, exploring the intricate aspects of its manufacturing process and examining the wide range of applications associated with this new material. By investigating carbon fiber's potential, the automotive industry could unlock many new opportunities for improved vehicle performance, fuel efficiency, and sustainability.

Keywords: carbon fiber, Automotive, materials.

1. Introduction

Automobiles are the world's primary way to move around, providing the convenience of travel, speed, and independence. The automotive industry is one of the world's top 10 largest industries producing more than 150,000 cars a day. The design of our cities and world is largely influenced by roads and highways to accommodate automotive transport. During the evolution of the automobile industry, there have been two main themes of changes. There has been a constant race to increase vehicle performance thereby increasing range, fuel efficiency, and power by reducing weight while maintaining safety standards. “Replacing high density ones (such as steel) with low-density materials to manufacture different parts of e is one of the issues that are pursued to achieve foregoing goals” [1]. There have been significant sustainability improvements designed around “tightening environmental regulations” [2]. It is important for modern materials to be both strong and light as a lighter car will “consume less fuel and emit less harmful substances.” [3].

To ensure safety of passengers, automotive materials must have rigorous mechanical properties including high stiffness, impact resistance, and strength. Traditional automotive materials include cast iron, steel, and aluminum. However recently, the modern material carbon fiber has been adopted in a variety of fields. In aerospace, it has been used to make fuel tanks, nosecones, and other structural parts [4]. Sports industries have used it for performance golf clubs, ski poles, and bicycles [5]. Racing cars, most notably the f1 extensively use carbon fiber to increase performance [6]. The commercial automotive industry should be next.

This paper will compare traditional materials to carbon fiber's performance and practicability to be used as a primary material for automotive structures for modern commercial vehicles.

2. Manufacturing

Carbon fiber is a material made with yarn that is oxidized, then carbonized, then graphitized. These fibers consist of thin strands of carbon atoms that are woven together and then molded into shape. These thin fibers are lightweight and incredibly strong due to its strong carbon chains in its chemistry (Table 1). Currently, carbon fibers are made from several precursors including, PAN, cellulosic, pitch, lignin, and poly (vinylidene chloride) [7]. The most widely used precursor used today is polyacrylonitrile (PAN). Lignin is a new precursor of carbon fiber with promising applications in the automotive industry. It shows a "reduction in the cost of CFRP and reduction of CO_2 emissions during carbon fiber production" [8] compared to other precursors.

Table 1. Carbon fiber mechanical properties (single fiber tow) [9-10].

Fillament (count)	Density (g/cm³)	Tensile strength (GPa)	Tensile modulus (GPa)	Failure strain (%)
12,000	1.80	5.69	291	2.06
3,000	1.76	3.20	221	146

Thousands of these fibers are combines to form tows. These tows are then weaved to form a fabric like material. Composites come in a variety of weaves changing the direction of fibers. Different weaves may be stronger in different directions and may be easier to be molded to complex shapes than others. Tows that are aligned parallel and perpendicular to each other in a plain weave in a "checkerboard" pattern are known as Pain weaves. Weaves with a 0-45-0-degree angle called a "twill weave". Plain weaves are the strongest and are good for parts that do not contain complex curvature, twill weaves are used for parts where geometry is more complex sacrificing strength. Other weaves include a spread tow, which is similar to a twill but wider, a unidirectional weave, when fibers are all aligned in one direction, and a multiaxial weave, where fibers are oriented in different axes.

These weaves are then shaped onto a mold and held in shape by an epoxy. This can be done in three main processes, wet layup, prepreg, and infusion. The wet layup process starts by placing strips of carbon fiber weaves onto a mold and then using a tool to apply epoxy over the surface. These create low-cost parts however it is time-consuming and produces weaker parts and is not practical for large parts such as the body of a car. Prepreg is a process that uses carbon fiber cloth that is pre-impregnated with epoxy resin. These prepreg sheets are stored in the cold to prevent the epoxy from curing and forming a shape. Then sheets are laid onto a mold. This process skips the need to manually apply epoxy to wet layups. This is good for larger parts when the cost is a driving factor and when high structural performance is needed. The prepreg method is most widespread and has developed rapidly [11] use. Infusion is a process that places dry carbon fiber cloth onto a mold then uses a vacuum bag to press down against the mold surface. Resin is then inserted into the bag infusion the carbon fiber weave with resin. This method has high repeatability and has the best quality parts at a lower cost compared to prepregs. Different resins also offer different advantages and disadvantages. The individual carbon fibers are extremely strong so the epoxy bond is limiting factor of the strength of carbon fiber. Polyester, vinyl ester, polyurethane, and epoxy are typical resins used with carbon fiber. Phenolic resin can be used when a part is exposed to heat as it has "superior fire, smoke and toxicity properties." [12]. During assembly is possible to induction and resistance weld carbon fiber reinforced thermoplastic composites (CFRTP).

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Welding overcomes some issues with traditional jointing techniques for carbon fiber reinforced polymers (CFRP) including stress concentration, and long curing cycles [13].

3. Mechanical properties

The biggest advantage of carbon fiber composites is its high stiffness-to-weight ratio compared to traditional metals such as steel or aluminum alloys. Carbon fiber composites can be "five times stronger than grade steel for structural parts, yet are still five times lighter." [14] .

Aluminum 6061 is a traditional metal currently widely used for similar benefits to carbon fiber. Aluminum which has a density of 2.7 g/cm³ has a much lower density than other traditional metals such as steel with a density of 7.86 g/cm³ or stainless steel which has a density around 8.03 g/cm³. Carbon fiber's density is even less than that of aluminum with a density of 2.7 g/cm³. Even though carbon fiber has a density much less than that of traditional materials, its strength is greater than aluminum. Carbon fibers tensile modulus is much greater than any metals. Because of this, by using carbon fiber as the primary material for an automotive it doses not sacrifice strength. The low density of the material would in fact increase collision safety as the impact would be less large with the reduced weight.

Table 2. Carbon fiber epoxy matrix vs 6061-t6 aluminum mechanical properties [15-16].

Density (g/cm³)	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation at break (%)	Material
1.79	569	291	2	Carbon fiber
2.7	310	68.9	12	6061 aluminum

4. Environmental impact

The lightness of carbon fiber materials extends the range and improves the fuel efficiency of the car. This reduces GHG (greenhouse gas) produced during the automotive's operation and the production and processing of fuel. Further, carbon fiber mass reductions open up pathways for electric vehicles as they have a stricter mass budget to accommodate for their batteries. Recycling is an issue gaining global traction, the EU has required that 95% of all vehicles mass must be recyclable. The recycling of carbon fiber is possible and is low energy relative to steel and other metals. A catalytic depolymerization process has been proven to recycle more than 90% of all carbon fiber. [17] The field of recycled carbon fiber's commercialization is emerging and could offer great environmental benefits to carbon fiber, many predictions have determined it to be financially viable. Carbon fiber reinforced thermoplastics have also been of discussion in the environmental impacts of carbon fiber. Currently 40% of carbon fiber is wasted in the production of carbon fiber reinforced plastic parts and only 10% of carbon fibre is wasted in the production of carbon fibre reinforced thermoplastics [18].

5. Conclusions

Carbon fiber composites have sufficient strength, and resistance against rough environments to be used on a car. It doses this while reducing the weight significantly compared to metals. If carbon fiber was to be used as the main material of a car including the main body components, and internal structural parts, cars could be much lighter while maintaining strength increasing both performance and safety.

- The density of carbon fiber composites is 1.75, whereas aluminum is 2.7. The same part geometry would be 35% lighter if it were carbon fiber as opposed to aluminum (Table 2).
- The tensile strength of carbon fiber composites is 329MPa, whereas a high-strength aluminum 6061-t6's tensile strength is only 290MPa. This would allow parts to be smaller while having the same strength hence decreasing weight (Table 2).

- The modulus of elasticity of carbon fiber is 27 MPa which is much higher than the 68.9 GPa of 6061-t6 aluminum. This stiffness of carbon fiber allows the material to resist deformation under load assuring consistent performance and stability (Table 2).

A lighter car will be more fuel-efficient driving down operational costs of gas cars. For electric vehicles, a lighter car will make room for the heavy battery. A car which is lighter is safer as it is more responsive decreasing the minimum breaking distance of cars. A carbon fiber car will be more environmentally sustainable as the materials could be recycled, and the car’s emissions are reduced.

More development in Carbon Fiber technologies will need to be done to overcome some issues with the material. Due to the nature of the fiber structure of carbon fiber, when one fiber is broken, all the long fiber is weakened. The current manufacturing costs and maintenance costs results in large-scale carbon fiber parts being impractical, so more research is required to reach the full potential of carbon fiber. The strength of carbon fiber is also greatly limited by the epoxy it is bonded by. More research needs to be done to the bonding material to increase the strength and other desirable properties of carbon fiber. Finally, increased research should be done to make recyclable carbon fiber more accessible. If recyclable carbon fiber is used commonly in automotive, this will greatly reduce the environmental damages produced by the automotive industry. However, due to its benefits, carbon fiber is an incredibly promising material for our future cars.

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