**Msc.Ing.Luiza Lluri, Msc.Ing.Blerta Gërmënji, Msc.Ing.Drita Hima**

# CARBON FIBERS OFFER GREAT POTENTIAL IN THE AUTOMOTIVE INDUSTRY


## Abstract

New materials, like carbon fibers, reduce the vehicle's weight and the car becomes even more fuel-efficient. The most significant benefit of the automobile industry is that it can lower car masses, consequently releasing less carbon into the atmosphere. Carbon fibers are best suited for the making of automotive parts because carbon fiber parts are far lighter when compared with their metal parts. The extreme elasticity of carbon fiber makes it versatile in various automobile purposes where excellent strength with low weight, enhancing vehicle performance. This research explores the unique properties of carbon fiber and its potential benefits for replacing metalparts. Carbon fiber parts are 50% lighter for the same size as aluminum and more than 5 times lighter as steel. Carbon fiber is stronger than steel, but lighter than aluminum. If the steel parts of most cars were replaced with carbon fiber, the weight would be reduced by 60%. A weight reduction of 60% in a car will lead to a 30% reduction in fuel consumption and 10-20% in greenhouse gas emissions. This will immensely reduce fuel consumption without necessarily changing the car's engine. For every 10% in vehicle weight reduction, there comes an improvement in fuel economy by 6%-8% in internal combustion.


***Keywords:*** *carbon fiber, traditional metal, reduce weight, fuel economy, reduction of emissions, automotive industry.*

## Introduction

Carbon fiber is a polymer, and more normally known as graphite fiber. The material is strong and yet lightweight. Compared to steel, carbon fiber is five times as strong and twice as rigid. Carbon fiber has strengths and rigidity than that of steel yet lighter, making the material perfect to produce various items. Carbon fiber is composed of carbon atoms, which are lighter than metal atoms, making this material lightweight and extremely strong. Engineers and designers utilize it because it is five times stronger than steel, twice as rigid, and weighs around two-thirds less. Reducing car weight may simplify the process of improving efficiency. New fuel economy and pollution rules are causing big changes across the industry. If mixed with a polymer, carbon fiber is moldable into automotive parts, stronger and yet lighter than those made of the traditional metals like steel and aluminum. Carbon fiber-reinforced composites offer a great opportunity to reduce the structural weight of vehicle components and have advantages that correspond with the requirements of the automotive industry. They are one of the ideal choices for original equipment manufacturers.

Traditional steel components could be substituted by lightweight materials, such as high-strength steel, magnesium alloys, aluminum alloys, carbon fiber, and polymer composites to significantly decrease a vehicle's weight. Reducing body and chassis can result in a saving of as much as 50% in fuel consumption. The weight difference between carbon fiber and ordinary steel parts could be expanded in the future. Carbon fiber composite can reduce the mass by 50%-70%, while magnesium and aluminum exhibit promising results in the range of 30%-60% percent. Given that the industry is focused on efficiency, carbon fiber is a highly underutilized material given its high cost. Its lightweight reduces the overall weight of the car and its modulus of elasticity against metal parts is higher. It retains its shape irrespective of fluctuations in temperature. Performance benefits of carbon fiber, such as weight reduction and fuel economy, will power the future of the industry. Carbon fiber applications are increasingly being used in the automotive industry. This is the most promising application with the highest growth potential.

## Methodology

The objective is to outline the advantages of carbon fiber and how it is different from other materials, and the possible advantages of replacing metal parts with it. Comparison of Carbon fiber qualities is to be done. The stiffness and strength of standard metals (steel, aluminum) and alternative materials at equal weights were compared. Other properties compared include thermal expansion and heat conduction. Carbon fiber parts of similar size are 50% lighter than aluminum and over 5 times lighter than steel. If carbon fibers were used instead of steel, the weight of cars would be reduced by 60%.

## Carbon fibers and traditional materials

Carbon fiber consists of very fine, tough crystalline filaments that impart extreme strength to materials. Carbon fiber is a stiff, strong, lightweight material with low density compared to aluminum and steel offers a number of practical benefits. The strength of a section is not only dependent on the material and thickness but also on its geometry. A relationship between the stiffness and weight of a material enables comparison and analysis across different materials in a much easier way. The most design engineers consider the stiffness and weight as the most important elements to determine material rigidity, so the stiffness-weight relationship is the most effective method. Design engineers usually seek materials that match the dimensions and thickness of aluminum components. Carbon fiber is 70% lighter than steel, and 40% lighter than aluminum. The properties of carbon fiber, steel, aluminum and plastic are compared in the table below (Table 1).

Table 1

| **Property** | **Fibers of Carbon** | **Steel** | **Aluminum** | **Plastic** |
|---|---|---|---|---|
| **Weight** | extremely lightweight; 1.6–2.0 g/cm³. | heavy; 7.8 g/cm³ | heavier than carbon fibers; 2.7 g/cm³ | lighter than most metals but weaker than fibers of carbon |
| **Resistance to Corrosion** | highly resistant to corrosion and chemical degradation. | prone to corrosion unless treated | naturally corrosion-resistant but can degrade in environments with saltwater | resistant to corrosion but less durable overall. |
| **Conductivity of heat** | high | high | high | low |
| **Sturdiness** | high but brittle | high and ductile | moderate | low |
| **Strength** | highest | high | moderate | low |
| **Stiffness** | very stiff, maintaining structural integrity under stress. | high stiffness but less efficient due to weight | lower stiffness than steel or carbon fibers | very low stiffness |
| **Price** | significantly more expensive than steel, aluminum, and plastic | inexpensive and widely available | more expensive than steel but cheaper than carbon fibers | generally the cheapest option |

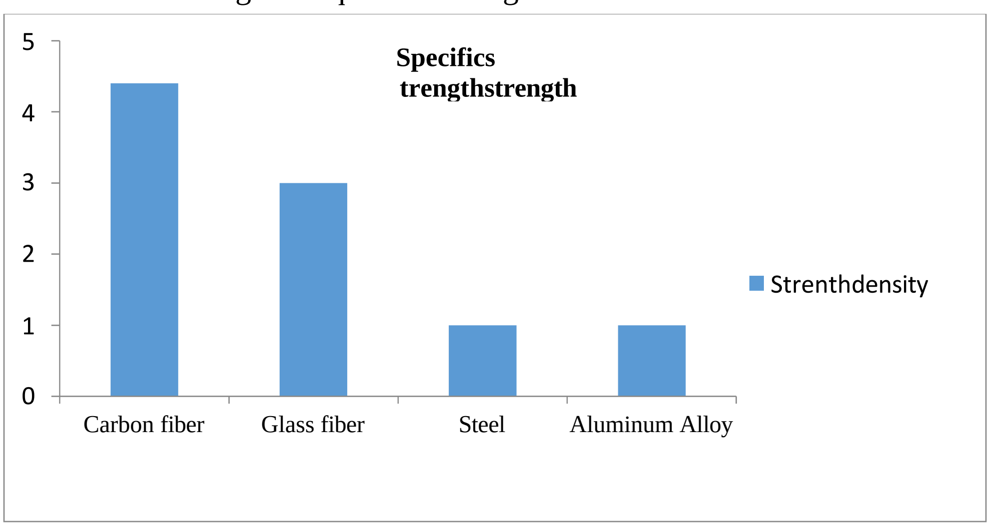
Table 2 lists the materials fibers of carbon, steel, aluminum and plastic with their areas of use.

Table 2

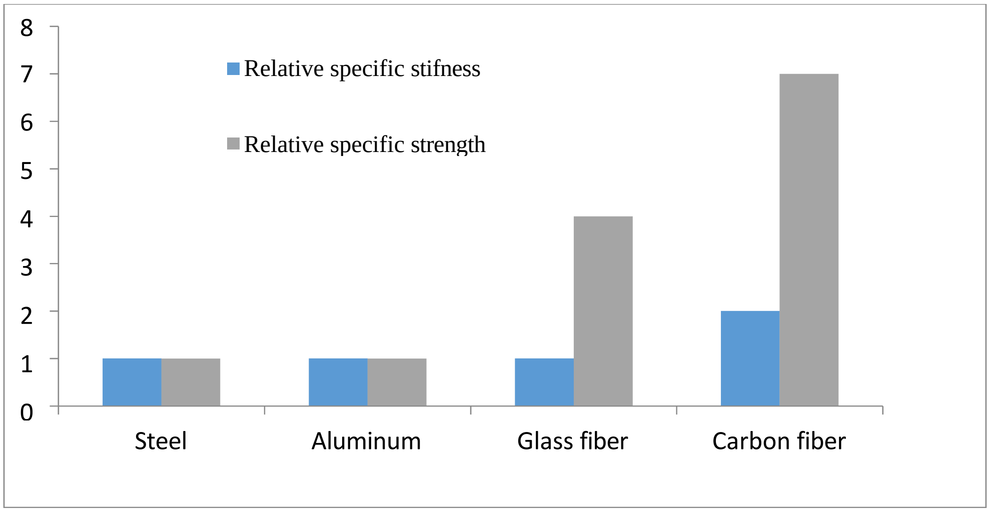
| Material | Applications |
|---|---|
| **Fibers of carbon** | Wind turbines, sports equipment, high-performance automobiles, and aircraft. |
| **Steel** | Structures, bridges, automobiles, tools, and large machinery. |
| **Aluminum** | Lightweight car parts, beverage cans, and airplanes. |
| **Plastic** | Consumer goods, packaging, and inexpensive parts. |

Carbon fiber is used where, although more expensive, light weight, high strength and corrosion resistance are required. Steel is used where high loads can be supported, but weight is less critical and low cost is an issue. For the same high loads, but lighter weight and high corrosion resistance, aluminum is the right choice. Plastic is suitable for low-load, non-structural elements

A carbon fiber component of the same thickness exhibits 31% higher stiffness, 50% less weight, and 60% more strength. For instance, steel has a tendency to possess a tensile modulus of about 29 million psi (200 million k Pa.). Carbon fibers have a tendency to be ten times stronger than steel and eight times stronger than aluminum, along with being substantially lighter, 5 and 1.5 times lighter, respectively (Graph 1, 2). Graph1 shows the relative merits of composite materials compared to steel and aluminum for stiffness and strength at equivalent weights.




Graph1 The merits of composite materials when compared to steel and aluminum in terms of stiffness and strength at equal weights




Graph2.Stiffness and specific strength of different materials

Carbon fibers are applied in industries where high quality and stiffness in relation to weight are needed. It is not so easy to compare the properties of carbon fibers with those of steel or aluminum, because, unlike carbon fibers, metals are usually uniform-isotropic, meaning that they have the same properties in every direction. A part made from standard carbon fibers with the same thickness as aluminum will provide 31% more stiffness than aluminum and at the same time have a weight of 50% less. The use of carbon fibers with a higher modulus and unidirectional structure can provide x 4 times the stiffness compared to aluminum with similar strength. By comparing aluminum with carbon fibers, the composition of carbon fibers has a density x 2 times less than aluminum and more than 5 times less than steel.

Consequently, in a component of the same dimensions, replacing aluminum with carbon fiber will reduce its weight by 50%. Replacing steel with carbon fiber will reduce the weight x 5 times. It is generally accepted that the use of carbon fiber will reduce the weight of a component by 30 to 50 percent of the original weight. Many products can, and are beneficial to, be made lighter in weight by using carbon fiber. Unlike most materials, significant directional strength can be achieved with carbon fiber. The strength of metals and composites is not the same in every direction. In fact, during production, the orientation of the fabric is determined - if unidirectional fabric is used - and which orientation provides the greatest strength compared to other areas. This solution allows for a further reduction in the weight of carbon fiber parts. For aesthetics and weight reduction, seat supports, dashboards, center consoles and trim pieces often use carbon fiber. Companies are researching recycled carbon fiber and cheaper production techniques that would bring down costs.

## Characteristics of materials

### Thermal expansion

Each material has different thermal expansion characteristics. Thermal Expansion is defined as the change in the dimensions a material undergoes because of a change in its temperature. Carbon fiber, however, shows almost zero heat expansion in practical usage and hence finds extensive application in devices including 3D scanners. Design engineers are increasingly being convinced by the many advantages that carbon fiber offers due to low heat expansion compared with traditional materials like steel or aluminum. Carbon fiber is a material with thermal expansion 6 times lower than that of aluminum and more than 3 times lower than that of steel. The table below considers the thermal expansion of selected materials per inch vs. degrees Fahrenheit (Table 3).

Table 3

| Material | Heat expansion |
|---|---|
| Aluminum | 13 |
| Steel | 7 |
| Glass fiber | 7-8 |
| Carbon fiber | 2 |

### Heat conductivity

Carbon fiber is a material of low heat conductivity. Heat conduction is the process of energy transfer from a high to a low temperature. Materials with high heat conductivity are far more effective in transferring temperature compared to those with poor conductivity. Composites made from carbon fiber and epoxy resin have heat conductivity 40 times lower than aluminum and 10 times lower than steel. Carbon fiber is normally considered an excellent insulator. Pure carbon fiber is considered an electrical insulator because the individual carbon fibers are coated in a protective polymer matrix which is non-conductive. Table 4 presents considerations about thermal conductivity of some chosen materials.

Table 4

| Material | Heat conductivity |
|---|---|
| Aluminum | 210 |
| Steel | 50 |
| Carbon fiber | 5-7 |

Fiber of carbon has the lower density and higher tensile strength that offers advantages compared to aluminum and allow steel (Table 5).

Table 5

| **Material** | **Modulus of elasticity** Metric G pa | **Tensile stremgth** Metric G pa | **Density g/cc** |
|---|---|---|---|
| Fiber of carbon | 120 | 2550 | 1,57 |
| Alloy steel | 205 | 1275 | 7.85 |
| Aluminum | 71.7 | 570 | 2.81 |

The straightforward comparison of carbon fiber, steel, and aluminum can be understood by examining the commonly used high-strength variations of these materials. Considering the properties of carbon fiber, these fibers can be categorized into:

- Ultra-high-modulus, designated as UHM (modulus >450Gpa)
- High-modulus, referred to as HM (modulus between 350-450Gpa)
- Intermediate-modulus, known as IM (modulus between 200-350Gpa)
- Low modulus and high-tensile, termed HT (modulus < 100Gpa, tensile strength > 3.0Gpa)
- Super high-tensile, classified as SHT (tensile strength > 4.5Gpa)

Carbon fiber composites are already used in the automotive industry to cut weight in vehicles and improve fuel economy. Exterior automotive components manufactured by using carbon fiber and its composites include panels, hoods, bonnets, and test plates. The carbon fiber-reinforced composite opens new design opportunities for the carrying of loads in the automobile and also brings many advantages to the automotive sector. For many years, car carbon fiber parts showed up only on $1-million-plus luxury supercars. Of late, these materials have emerged in an increasing range of somewhat more modestly priced variants- such as a BMW 7-series sedans, the Alfa Romeo 4C as well as sports cars including Corvette Z06 from Chevrolet.

Automotive engineers, car designers, experts in composites, material suppliers, and part manufacturers will have to work in even closer coordination to fully exploit the benefits of carbon fiber in automobiles. Large car manufacturers such as BMW and Mercedes plan to produce greater numbers of fuel-efficient cars by using carbon fiber to reduce their weight. They have managed to reduce the weight of their automobiles by

250 to 350 kgs which is 550 to 770 pounds, and thus increased fuel efficiency. This has motivated other automobile companies to develop their carbon fiber technologies. The BMW 7-series chassis comprises steel, aluminum, and carbon-fiber-reinforced plastic, where most of the components around the door frames and on the roof are made from carbon fiber. Car maker BMW uses carbon fiber for critical structures such as roof assemblies, structural pillars and door frames, mainly focusing its efforts on structures that are well above the ground. Among the different materials, carbon fibers provide the largest weight savings, as well as new design opportunities, but at a higher cost. At present, when lightweight material costs are high, benefits of weight savings are considerable. Table 6 shows some of the uses of various materials in automobile parts.

Table 6

| **Material** | **Part weight** | **Part cost** | **Part applications in automotive** |
|---|---|---|---|
| Steel | 100 | 100 | Structural parts needed strength (side intrusion beams) |
| Plastic | 80 | 100 | Exterior and interior parts (fascias or covers) |
| Aluminum | 60 | 130 | Structural or functional parts, (sub-frames or beams) |
| Carbon fiber | 50 | 570 | Structural parts (frame, hood, or tailgates) |

A vehicle is made up of hundreds of materials, such as metals, plastics and rubber. Vehicles come in many sizes, and hence weights. The mass for a vehicle can range from 990 to 2000 kg. An average vehicle requires over 770 kg of steel, 180 kg of iron, 110 kg of plastic, 80 kg of metal and sixty kg of rubber, apart from small amounts of other materials. Allowable CO2 emissions = 130 + a × (M – M0)

Where::M = mass in kg, M0 = 1,289 kg, a = 0.0457 g $CO_2$/kg.

A saving of 100 kg in vehicle weight saves approximately 8.5 g $CO_2$ per 100 miles. The mass of a car plays an important role in the safety of its occupants. The mass and safety of an automobile are believed to be directly related such that a car weighing 2000 kg is considered to be twice as safe as one weighing 1000 kg. In the most conditions, the number of car crashes is precisely related to the mass difference between the two cars. According to the laws of motion, when two cars collide, their speeds change. The difference in speed generates the forces that kill and injure. Since carbon fiber is tough, for the same resistance, less material can be used compared to its metal counterpart. Less material of low density could save a few kilograms from the overall computation.

**Limited use of carbon fibers**

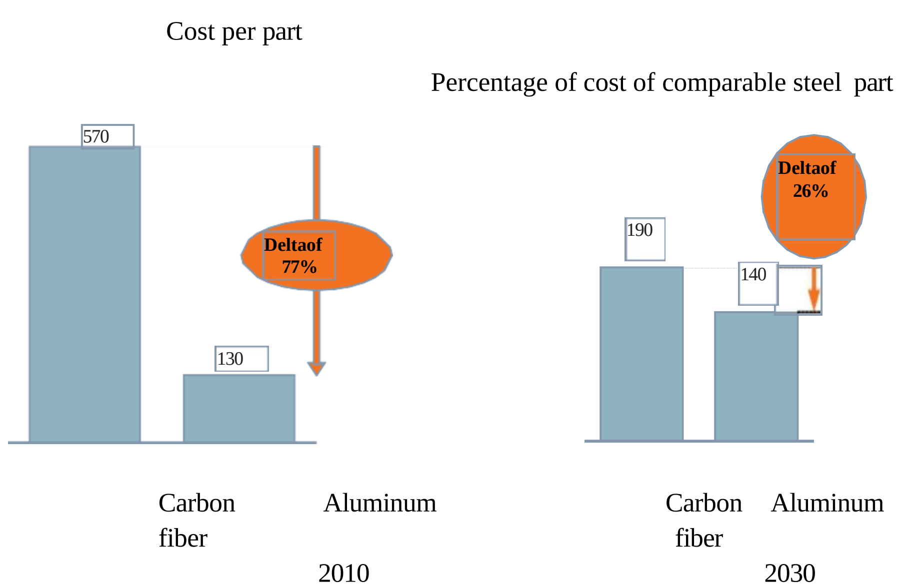
The most common reason is the price. Carbon fiber is pretty expensive. Carbon fiber parts are more expensive than aluminum parts because their production is more expensive and takes longer to make. Sometimes carbon fiber is cheaper and more economical for small runs where the production of aluminum would be too expensive. Little is actually known about carbon fiber and how it will outperform and service better than such traditional materials as aluminum and steel. "Its major drawback: Carbon fiber is very brittle. In other words, while it's strong, it tends to break catastrophically. Steel and aluminum bend, but carbon fiber shatters.

Since repairing the damage is hard and expensive, it brings us to the next point. The diameter of a carbon fiber is usually around 5-10 micrometers and is mainly composed of carbon atoms. Carbon fibers have plenty of advantages, such as high stiffness, high tensile strength, low weight, chemical resistance, temperature tolerance, and low thermal expansion. Because of its exceptional properties, carbon fiber is applied in aircraft, civil engineering, military, racing, and other competitive sports. They are, more costly than their equivalents made of glass and plastic.

**Carbon fiber perspective in the automotive industry**

Carbon fiber is so promising for the automobile industry, especially when thermoplastic polymers are being introduced. Carbon fiber will no more be that expensive. Carbon fiber is increasingly being used in the making of vehicles as it is lightweight and helps meet the emission rules. The mass vehicle market is interested in high-speed methods similar to traditional metal stamping for quicker cycle times measured in minutes. High-performance motorcar makers know carbon fiber does pay off. Its stiffness strengthens the chassis and improves suspension performance. Carbon fibers are improving automotive design, especially in electric vehicles and when high performance is required. Ongoing research and cost reductions are aiming for a wider adoption of carbon fibers in this industry. The future of the automotive industry is shifting towards sustainability and efficiency where carbon fibers will play an important role improving fuel efficiency and performance.

Carbon fiber is an in demand light weighted material as it reduces weight in several applications 3, 8. The costs at present - five to six times higher than steel (presuming 60,000 units per year- restrict market exploitation. In the following twenty years, automotive carbon fiber applications will widely reduce costs-from EUR 42 per kilogram now to respectively EUR 23 in a conservative scenario and to EUR 14 by the year 2030. It is expected that the cost decrease of carbon fibers will bring the material closer to aluminum parts, although a disparity of 20-30% is still predicted. The cars with greater freedom in design and performance have a beneficial impact on brand positioning and are expected to earn a large share in specific applications despite the high cost differential. The difference high on cost between aluminum and carbon fibers will decrease over time, as shown in Graph 3.




Graph 3 The difference on cost between aluminum and carbon fibers

As a result, the price for carbon fibers will decrease by the production of low-cost precursor materials such as textile PAN or lignin-based precursors. The raw material cost will be reduced about 30-50% due to the increased consumption of precursors other than oil/gas-based precursors. Fast-curing resins are on the market and pre- and part-forming processing costs have already decreased by 60-80% due to shorter cycle time and reduced investment and labor costs.

**Conclusions**

1. Carbon fiber provides stiffness and strength at low density, which is lighter compared to aluminum and steel, hence offering many advantages and practical benefits. Carbon fibers have several advantages, including high stiffness, tensile strength, low weight, chemical resistance, temperature tolerance, and minimal thermal expansion.

2. Carbon fiber parts are 50% lighter than aluminum and over 5 times lighter than steel of the same size. Replacing steel parts with carbon fibre can reduce the weight of most cars by 60%.

3. Utilizing lightweight material technologies such as high-strength steel, Mg alloys, Al alloys, carbon fiber, and polymer-based composites could significantly reduce vehicle weight. The carbon fibers have the largest weight-reduction potential of any lightweight material, being about 50% lighter than steel. Vehicle body and chassis reduction could result in as much as a 50% saving in fuel use.

4. Some of the major performance gains, like weight reduction and improved fuel efficiency, will increase demand for carbon fibers. This is the most promising application with the largest growth potential. Carbon fiber effectively impacts the cost of lowering $CO_2$: industrialization of carbon fibers is able to result in cost reductions by up to 70%, which is far more attractive.

**References**

1.Ahmad D. Vakili ZhongrenYue :"Low Cost Carbon Fiber Technology Development for Carbon Fiber Composite Applications"

2.Charlie Tacchi Zack Peters Cody Van Beek Philip Tran: " Carbon Fiber"

3.Mark Mauhar ,Jim Stike :"Low Cost Carbon Fiber Composites for Lightweight Vehicle Parts"

4.Dr. Ruth Heuss ,Dr. Nicolai Müller ":Carbon fiber and other lightweight materials will develop across industries and specifically in automotive"

5.Robert Crow: "Carbon Fiber In Mass Automotive Applications"

6.Petersson, Håkan; Motte, Damien; Bjärnemo, Robert: “Carbon Fiber Composite Materials In Modern Day Automotive “

7.Roland Berger :”Automotive Metal Components For Car Bodies And Chassis”

8.Tie Wang ,Yonggang Li::” Design And Analisysis Of Automotive Carbon Fiber Composite Bumper Beam Based On Finite Element Analysis”

9.V.Koncherry, P.Potluri, A.Fernand Multifunctional: “ Carbon Fiber Tapes for Automotive Composites”

10.Per Mårtensson, Dan Zenkert ,MalinÅkermo:: “Cost And Weight Effective Composite Design Of Automotive Body Structures “