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

CARBON FIBERS OFFER GREAT POTENTIAL IN THE AUTOMOTIVE INDUSTRY

Abstract

New materials, including the use of carbon fibers, play a critical role in reducing vehicle weights. With a lighter carbon fiber body, car manufacturers can build smaller cars with more efficient engines, bringing even more fuel savings. The main advantage offered by the automotive industry is their potential to reduce car masses, resulting in lower carbon emissions. Carbon fiber is the perfect material for automotive parts. Because of its high flexibility, carbon fiber can match any contour so it is used for any automotive application. It provides high strength and low weight, factors influencing automobile performance. Carbon fiber is comprised primarily of carbon atom which is lighter than metal atom making a part of carbon fibers much lighter than a metal part.

This study provides more insight about carbon fiber and what makes this material different from others, as well as what benefits are possible by replacing metal parts with carbon fiber. For this purpose the properties of carbon fibers should be compared to traditional metals (steel, aluminum). Carbon fiber is stronger than steel but lighter than aluminum. The component made from carbon fiber of the same dimensions will be 50% lighter than an aluminum one and more than 5 times lighter than a steel one. Replacing steel components with carbon fiber would reduce the weight of

most cars by 60 percent. That 60 percent drop in weight would, in turn, reduce that car's fuel consumption by 30 percent and cut greenhouse gas and other emissions by 10 to 20 percent. That's a huge fuel savings, even without changing the car's engine. A 10% reduction in vehicle weight can improve fuel efficiency by 6%–8% for conventional internal combustion engines, or increase the range of a battery-electric vehicle by up to 10%.

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

Introduction

Carbon fiber is a polymer and is sometimes known as graphite fiber. It is a very strong and very lightweight material. Carbon fiber is five-times stronger than steel and twice as stiff. Though carbon fiber is stronger and stiffer than steel, it is lighter than steel; making it the ideal manufacturing material for many parts. Carbon fiber car parts could provide important benefits for automakers. It is a super strong material that's also extremely lightweight. Engineers and designers use it because it's five times as strong as steel, two times as stiff, yet weighs about two-thirds less. It's difficult to make gasoline powered engines significantly more efficient, and electric vehicles typically rely on heavy and expensive battery packs. Weight reduction could provide an easier way to make cars more efficient. New fuel economy and emissions standards are driving significant changes across the industry. Carbon fiber is a flexible fabric-like material that, when combined with a polymer, can be molded into the shape of a car part that is stronger and lighter than today's steel and aluminum parts. The fiber carbon reinforced composites present major light weighting opportunities for structural vehicle components. With advantages that align directly with the automotive industry's needs carbon fiber reinforced composites can be a major part of the solution for automakers.

Replacing traditional steel components with lightweight materials such as high-strength steel, magnesium (Mg) alloys, aluminum (Al) alloys, carbon fiber, and polymer composites can directly reduce the weight of a vehicle's body and chassis by up to 50 percent, and therefore reduce a vehicle's fuel consumption. Replacing a steel part with a carbon fiber part can reduce a car's final weight by more than the difference between the two parts. According to the logic of mass decompounding, a lighter car requires a lighter suspension, which requires a smaller motor to accelerate. A series of part replacements could make a car much lighter. This concept doesn't just affect the car's weight. If the automaker can replace several vehicle parts with smaller substitutes, then it could mean higher margins or a more price-competitive vehicle, which could be a major selling point for the carbon fiber companies. The weight difference between a carbon fiber part and a standard steel part could increase in the future. The Department of Energy funds research on several lightweight materials, and carbon fiber composites could potentially provide more weight savings than other materials.

Carbon fiber composites could eventually provide 50%-70% mass reduction, although the 30%-70% range for magnesium and the 30%-60% range for aluminum also show promise. Carbon fiber, despite being expensive for manufacturers at the moment, is one of the materials that are being left wanting for an industry that seeks maximum efficiency. Its lightness allows the whole car to be less heavy and, therefore, it is not necessary to use mechanics of larger size and higher consumption. The modulus of elasticity against metal parts is also superior. Faced with temperature variations, it also retains its shape. Reductions in weight, fuel economy and other performance benefits of carbon fiber are projected to drive the carbon fiber market in the coming years. Europe and other regions are also showing significant interest in carbon fiber applications in the automotive industry. It is the most promising application and offers the highest growth potential

Methodology

To show the benefits of carbon fiber and what makes this material different from others, as well as what benefits are possible by replacing metal parts with carbon fiber. The properties of carbon fibers should be compared to traditional metals (steel, aluminum) and other materials in terms of stiffness and strength at equal weights. Also there are compared other properties as thermal expansion**,** heat conduction. As result carbon fiber is stronger than steel but lighter than aluminum. The component made from carbon fiber of the same dimensions will be 50% lighter than an aluminum one and more than 5 times lighter than a steel one. Replacing steel components with carbon fiber would reduce the weight of most cars by 60 percent.

Carbon fibers versus traditional materials

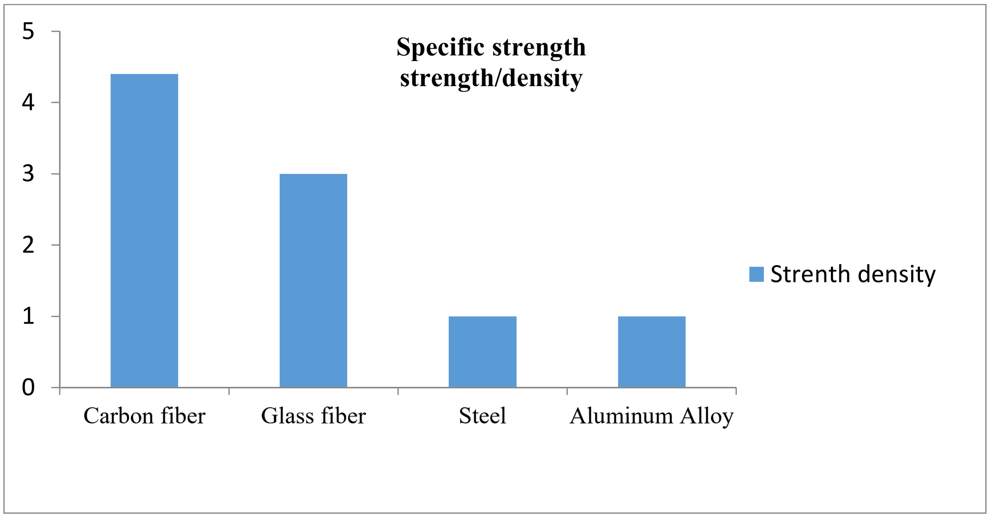
Carbon fiber is made of thin, strong crystalline filaments of carbon that is used to strengthen material. Carbon fiber is a material that offers stiffness and strength at low density– which is lighter than aluminum and steel that provides many practical benefits. Strength depends not only on the material and the thickness of a section but also on its geometry. The relation of a material's rigidity to its weight is the common denominator and simplifies comparison and analysis of different materials. The relation of stiffness to weight (namely a specific modulus) is in practice most effective to determine the rigidity of a material, as for most design engineers, stiffness and weight are the most crucial parameters.

Very often design engineers look for material that will enable them to manufacture a component identical to an aluminum one in all dimensions– including thickness. Carbon fiber is 70% lighter than steel, 40% lighter than aluminum. The tables below show comparisons regarding the stiffness and strength of a component of the same thickness made from aluminum, steel and carbon fiber (table 1).

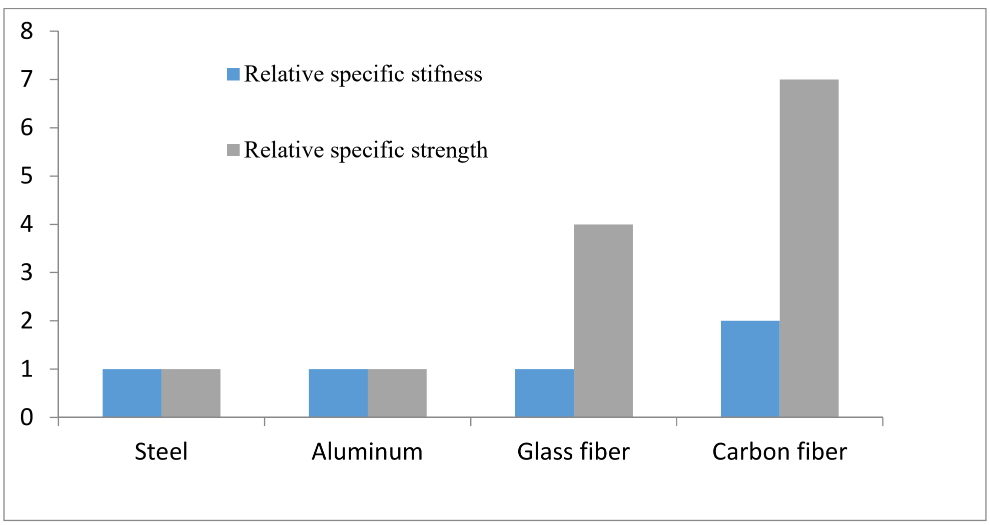
Table 1

Material	Aluminum	Steel	Two-direction carbon fiber – common modulus	Two-direction carbon fiber – improved modulus	Two-direction carbon fiber – highest modulus
Stiffness (Young's modulus)Unit: GPa	69	200	90,5	132	190
Ultimate strength (Tensile Strength – Ultimate Strength) Unit kN · m/kg	500	1000	800	368	126
Material	Aluminum	Steel	One - direction carbon fiber – common modulus	One - direction carbon fiber – improved modulus	One - direction carbon fiber – highest modulus
Ultimate strength (Tensile Strength – Ultimate Strength)Unit kN · m/kg	500	1000	1600	736	252
Stiffness (Young's modulus) Unit: GPa	69	200	181	264	380

A component made from standard carbon fiber of the same thickness as an aluminum one will offer 31% more rigidity than the aluminum one and at the same time weight 50% less and have 60% more strength. One square meter of sheet 6 mm thick has a weight of: 47.1 kg for a steel sheet. 16.2 kg for an aluminum sheet, 8.7 kg for a carbon fiber sheet. As a comparison, steel has a tensile modulus of about 29 million psi (200 million k Pa). Thus, the strongest carbon fibers are ten times stronger than steel and eight times that of aluminum, not to mention much lighter than both materials, 5 and 1.5 times respectively (graph 1, 2).



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



Graph 2. Stiffness and specific strength of different materials

Benefits of carbon fiber use

Carbon fiber is used in industries where high strength and rigidity are required in relation to weight. It is not easy to compare properties of carbon fiber against steel or aluminum. Unlike carbon fiber, metals are usually uniform– isotropic, which ensures the same properties in every direction. Aluminum is a material commonly used but carbon fiber provides a new solution for many construction engineers. Weight for weight, carbon fiber offers 2 to 5 times more rigidity (depending on the fiber used) than aluminum and steel. In the case of specific components that will be stressed only along one plane, made from one-direction carbon fiber, its stiffness will be 5-10 times more than steel or aluminum of the same weight. A component made from standard carbon fiber of the same thickness as an aluminum one will offer 31% more rigidity than the aluminum one and at the same time weight 50% less and have 60% more strength.

Use of carbon fiber of higher modulus and one-direction fabric may provide x 4 times the rigidity compared to aluminum at similar or improved ultimate strength. The more a component is reinforced with fabrics of highest modulus, the more it will be susceptible to breaking during bending. From the comparison of aluminum with carbon fiber we know that material density has a direct impact on its weight. Carbon fiber composite 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.

To illustrate this, imagine slabs 6mm thick of $1m^2$ area. One square meter of carbon fiber sheet 6 mm thick has a weight of:

- 47.1 kg for a steel sheet
- 16.2 kg for an aluminum sheet
- 8.7 kg for a carbon fiber sheet.

When designing products and at the point of material selection, rigidity shall be taken into account as well as the strength of a given material. In practice, possibilities regarding component weight reduction by replacing aluminum with carbon fiber required further tests and experiments. Each element relates to an individual case of unique geometry and parameters. Usually it is possible to reduce weight by 30-50 % by using carbon fiber. The carbon fiber car body enabled BMW to reduce the weight of each model by 300 kg. BMW launched production of complete car bodies made from carbon fiber for their I3 model. Every year, the company manufactures tens of thousands of these cars. Actually more clients are interested in this model than BMW originally predicted.

Reduction of weight by use of carbon fiber is possible and advantageous especially for products where directional strength is significant. Unlike metals, composites do not demonstrate identical strength in any direction (not uniform). Actually it is during the production process where decisions are taken regarding the direction of fabrics (when using one-direction fabrics) and the direction that will offer the greatest strength, by reducing strength at other places. This solution makes it possible to reduce the weight of carbon fiber components even further.

Other properties

Thermal expansion

Each material displays different heat expansion characteristics. Heat expansion relates to the change in material dimensions due to temperature change. Carbon fiber, in practice, shows almost zero heat expansion and therefore it is widely used in devices including 3D scanners.

Design engineers are more and more often 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 heat expansion x 6 times less than aluminum and more than 3 times less that steel. The table below includes analysis regarding heat expansion of different materials, considering the ratio of inch/degree Fahrenheit. The specified units are for reference only with regard to differences between materials (table 2).

Table 2

Material	Heat expansion
Aluminum	13
Steel	7
Glass fiber– epoxy composite	7-8
Carbon fiber– epoxy composite	2

Heat conduction

Carbon fiber is a material with low heat conduction characteristics. Carbon fiber is a perfect insulator– the above photo shows a carbon fiber turbine inlet. Heat conduction mainly depends on transfer/conduction of energy from areas of high temperature to areas of low temperature. Highly heat conductive materials transfer temperature more easily than materials with low heat conductivity. Composite made from carbon fiber and epoxy resin is a material with heat conductivity x 40 times less than aluminum and 10 times less than steel. Therefore the assumption may be made that carbon fiber is a very good insulator.

The table 3 below compares heat conductivity of different materials (Unit W/m*)

Table 3

Material	**Heat conduction**
Aluminum	210
Steel	50
Carbon fiber– epoxy composite	5-7

Carbon fiber has corrosion resistance, which offers another advantage compared to aluminum (table 4).

Table 4

Material	Modulus of Elasticity		Tensile Stremgth		Density g/cc
	Metric G pa	English k si	Metric M pa	English k si	
Carbon fiber T700S	120	17.5	2550	370	1,57
Alloy steel AISI 5130	205	29,.7	1275	185	7.85
Aluminum	71.7	10.4	570	83	2.81

The simple comparison between carbon fiber, steel and aluminum can be understood using common forms of the high-strength versions of these materials.

Based on carbon fiber properties, carbon fibers can be grouped into:

- Ultra-high-modulus, type UHM (modulus >450Gpa)
- High-modulus, type HM (modulus between 350-450Gpa)
- Intermediate-modulus, type IM (modulus between 200-350Gpa)
- Low modulus and high-tensile, type HT (modulus < 100Gpa, tensile strength > 3.0Gpa)
- Super high-tensile, type SHT (tensile strength > 4.5Gpa)

Applications

Carbon fiber composites are primarily used in the automotive segment to reduce vehicle weight, thus increasing in fuel efficiency. The most common automotive components where carbon fiber and carbon fiber composites are used include exterior body parts, hoods, bonnets, and test plates.

Carbon fiber reinforced composites offer numerous new design possibilities for structural components in cars and a wide range of advantages to the automotive industry. Car parts made of carbon fiber have been used for decades in $1-million-plus European supercars, from the likes of Ferrari and McLaren. The new BMW 7-series sedan, Alfa Romeo 4C and Chevrolet Corvette Z06 sports cars use carbon fiber elements. Automotive engineers, car designers, composites experts, material suppliers and part fabricators will need to work much closer together to achieve optimum benefit from carbon fiber applications in automobile.

Many leading automotive manufacturers, such as BMW and Mercedes, are planning to scale up their production of fuel efficient cars through weight reduction by using carbon fiber. They achieved success to reduce the 250-350 kilos (550-770 lbs) weight of the car and increased the fuel efficiency. This encourages other car manufacturers to develop their technology around carbon fiber. The chassis of the BMW 7-series combines steel, aluminum, and carbon-fiber-reinforced plastic. In this model the most parts around the door frames and across the roof are carbon fibers. BMW is using carbon fiber in key roof elements, supporting roof pillars, and door frames essentially anything that's high off the road. A BMW 7-series, including carbon fiber in parts of the frame, is produced in Germany.

Further information

Various lightweight materials are in use, but the particular material used depends on its characteristics and the requirements of the application. For example, one lightweight material may offer superior stiffness while another is more malleable. The materials under consideration all offer a significant weight advantage but come at higher costs. High-strength steel, for example, offers a weight advantage of 20 percent over steel at an additional cost of 15 percent per part, and aluminum is 40 percent lighter but 30 percent more expensive. Cost considerations have so far often prohibited the use of lightweight materials. Since the introduction of CO_2 targets and resulting penalties, the use of lightweight materials now delivers a monetary benefit, which will justify an increased use of lightweight materials in the future. Carbon fibers versus other materials have biggest weight advantage, new design opportunities, but highest cost. Today lightweight materials are costly but offer significant weight advantages

Material	Part weight Percentage of steel	Part cost Percentage of steel	Part applications in automotive
Steel	100	100	Structural parts requiring strength and formability needed, e.g., side intrusion beams
Plastic	80	100	Exterior and interior parts with no requirements for structural strength, e.g., fascias or covers
Aluminum	60	130	Structural or functional parts, e.g., sub- frames or beams
Carbon fiber	50	570	Structural parts requiring high strength, e.g., frame, hood, or tailgates

A car is made out of many different kinds of materials, such as metals, plastics, and rubber. Cars greatly vary in size, and therefore in mass. A car's mass may vary in the range of 990 to 2000 kg. However, a typical car may require more than 770 kilograms of steel, 180 kilograms of iron, 110 kilograms of plastics, 80 kilograms of aluminum, and 60 kilograms of rubber, as well as, less significant amounts of different materials. Permitted specific emissions of $CO_2 = 130 + a \times (M - M0)$ Where::M = mass in kg, M0 = 1,289 kg, a = 0.0457 g CO_2/kg.

To reduce the vehicle weight by 100 kg, it saves approximately 8.5 g CO_2 per 100 km. One of the most important things about the mass of a car, is the fact that the heavier it is, the safer it for the occupants, and vice versa. In fact, the mass and safety of a car are said to be directly proportional, so a 2000 kg car is twice as safe as a 1000 kg car. In special studies, it was found out that in most cases, the numbers of crashes between cars are directly proportional to the difference in masses of the two cars. In case of two-car crashes, the effect flows directly from Newton's laws of motion, which require that when two objects collide, the speed change each undergoes is in inverse proportion to its mass. It is this speed change that generates the forces that lead to death and injury. Precisely, the carbon fiber being so resistant, which is another of its virtues, allows us to use a smaller amount of material for the same resistance that a metal piece would need. By using less material, and to be of a low density, it allows saving a few kilos that will be subtracted from the global calculation.

Restrictions on the use of carbon fibers

Most often they are caused by price. Carbon fiber is very expensive. The price has come down a great deal in recent years, but it is still very pricey. Carbon fiber elements cost more than aluminum ones because carbon fiber costs more and the manufacture of carbon products is more time consuming. On the other hand, when comparing costs related to implementation of aluminum and carbon fiber production, in many cases it is the production of the carbon fiber element that will be cheaper and, more importantly, affordable in case of a small run, for which implementation of aluminum element production would not be cost-effective. Finally we need to mention widespread lack of awareness regarding the advantages and benefits of carbon fiber over traditional materials including aluminum or steel. The big disadvantage is that carbon fiber is actually very brittle. This means that though it is strong, when it breaks it often breaks catastrophically. Steel and aluminum bend, carbon fiber shatters. This also means that when damage does occur, repairs can be very difficult and costly, which leads us to our next point.

Carbon fibers are fibers about 5–10 micrometers in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers.

The future of carbon fiber in the automotive industry

The future of carbon fiber in the automotive world is assured, even more when it is possible to implement the use of thermoplastic resins, which will be the breakthrough in this matter. Its production will be faster, it will produce more and, consequently, the price will decrease. Therefore, carbon fiber will end up being democratized. As we have already mentioned, with this technique of thermoplastic resins, recycling will also be easier, something vital in the automotive world. The increasing use of carbon fiber in automotive is driven by the need for light weight, helping manufacturers to meet emissions standards. The mass auto market demands robust, high-speed processes that, like traditional metal stamping, enable cycle times measured in minutes. So there are processing issues to address and pricing clearly remains a limiting factor.

Likewise, the manufacturers of high performance cars have seen how carbon fiber is beneficial for their creations. Its rigidity also helps to create more rigid chassis that alloys the operation of the suspensions. We have already seen in some cases of sports cars not exaggeratedly expensive how these two advantages merge, as in the Alfa Romeo 4C. Currently, BMW is one of the most advanced manufacturers of its carbon fiber conversion process, and it already markets two vehicles with carbon chassis: the BMW 3 and 8. Carbon fiber is currently the most discussed lightweight material due to its high potential for weight reduction in certain applications. But current costs are enormous (five to six times as high as steel, already assuming a mass production of 60,000 units per year) and prohibit high penetration. Over the next two decades, however, we will observe a significant cost decline for automotive carbon fiber applications, from about EUR 42 per kilogram today down to EUR 23 in a conservative cost scenario and EUR 14 in an optimistic cost scenario by 2030.

The projected carbon fiber cost decrease will be mainly driven by:

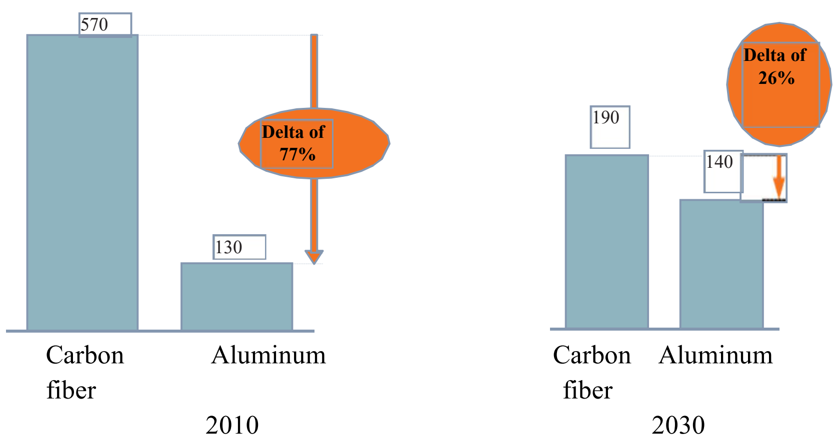
The development of a less expensive precursor material to produce the carbon fibers (textile PAN precursors or even lignin-based precursors instead of oil/gas based precursors to decouple the material price from oil price developments), resulting in a 30 to 50 percent cost decrease for the raw material.

A reduction in the processing cost for pre- and part forming of 60 to 80 percent due to radical reductions in cycle times driven by, for example, the development of fast- curing resins and the resulting reduction of investment and labor costs per part.

The difference high on cost between aluminum and carbon fibers will decrease over time (graph 3)

Cost per part

Percentage of cost of comparable steel par



This fall in cost will bring carbon fiber significantly nearer to comparable aluminum parts though a difference of 20 to 30 percent will remain. Since carbon fiber has the biggest weight advantage, offers a greater degree of freedom in car design and performance, and has positive effects on the brand positioning, it will gain a significant share in selected applications regardless of the difference high on cost.

Conclusions

1. Carbon fiber is a material that offers stiffness and strength at low density– which is lighter than aluminum and steel that provides many practical benefits. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion

2. The component made from carbon fiber of the same dimensions will be 50% lighter than an aluminum one and more than 5 times lighter than a steel one. Replacing steel components with carbon fiber would reduce the weight of most cars by 60 percent.

3. Replacing traditional steel components with lightweight materials such as high-strength steel, magnesium (Mg) alloys, aluminum (Al) alloys, carbon fiber, and polymer composites can directly reduce the weight of a vehicle's body and chassis by up to 50 percent, and therefore reduce a vehicle's fuel consumption.

4. Reductions in weight, fuel economy and other performance benefits of carbon fiber are projected to drive the carbon fiber market in the coming years. Europe and other regions are also showing significant interest in carbon fiber applications in the automotive industry. It is the most promising application and offers the highest growth potential.

5. Among of all the lightweight materials that offer weight reduction carbon fibers have the highest weight reduction potential (50 percent lighter than steel) but also by far the highest cost (570 percent the cost of steel today)..

6. Carbon fiber has an effective impact on the cost of reducing CO2, and the industrialization of carbon fibers can bring down cost savings of up to 70 percent, making it considerably more attractive.

REFERENCES

1.Ahmad D. Vakili Zhongren Yue :"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 ,Malin Åkermo:: "Cost And Weight Effective Composite Design Of Automotive Body Structures "