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Efficiency of Carbon Fibre for the Automotive Industry

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ABSTRACT

This paper explores the role of carbon fibre reinforced plastic (CFRP) in improving the efficiency, safety and sustainability of modern automobiles. The aim is to determine how beneficial carbon fibre is in making vehicles lighter, cleaner and more energy efficient. It examines CFRP's advantages over traditional materials such as steel and aluminium, its applications in vehicle design and the manufacturing challenges that limit large-scale use. The paper also discusses recycling methods and environmental improvements that make CFRP more sustainable, along with future prospects for its wider use in the automotive industry.

Keywords: *Carbon Fibre Reinforced Plastic (CFRP), Lightweight, Cars, Automotive Design, Safe, Energy, Environmental Sustainability.*

INTRODUCTION

"Light weighting becomes a main issue for energy efficiency in the automotive industry." (Ahmad et al. 1)
The automotive industry is always looking for ways to make cars better. This includes improving fuel efficiency, reducing pollution and making vehicles safer. "Carbon fibre reinforced plastic has outstanding specific stiffness, specific strength and fatigue properties compared to commonly used metals." (Ahmad et al. 1) Because of this, it is much lighter and stronger than steel or aluminium, which makes it very useful in lightweight car designs.
This study asks: How beneficial is carbon fibre in making cars more efficient and cleaner? "Every 10 kg of reduction of a vehicle improves the fuel consumption efficiency of automobiles and leads to a drop in carbon emission of 1g/km." (Ahmad et al. 2) This shows how even small reductions in weight can reduce fuel use and emissions. For electric cars, less weight also means longer battery life and range.
The issue is important because stricter rules are forcing carmakers to cut emissions. "In automotive industry, the advantages of carbon fibre reinforced plastic are reduction in weight, part integration and reduction, crashworthiness, durability, toughness, and aesthetic appealing." (Ahmad et al. 1) These advantages explain why CFRP is seen as one of the best options to meet these targets.
Carbon fibre is also known for its strength compared to traditional metals. "CFRP is suitable because it is approximately twice stronger but much lighter than steel or aluminum." (Ahmad et al. 6) This balance of strength and lightness makes cars safer and improves performance. Researchers also note that "The specific energy absorption (SEA) of the chopped carbon fibre composite material calculated was the highest as compared to that of all other composites analysed which shows the crashworthiness of this material." (Ahmad et al. 3) This means CFRP not only saves weight, but also helps keep cars safer in crashes.
However, there are also problems. "It is very difficult to replace the low-cost metals that are currently being used for parts that satisfy the functional needs in a car with a more costly carbon composite material." (Ahmad et al. 3) The high cost of making carbon fibre and the need for special tools and skilled workers, makes it hard to use on a large scale. At present, CFRP is mostly used in luxury and sports cars.
The challenge of weight saving is not just about panels but also engines. "The results show, that AVL's new lightweight design strategies allow a significant reduction of engine mass compared to conventional concepts and represent an important contribution to reduce the overall vehicle weight." (Beste et al. 1) This shows that lightweight materials can also be used in engine parts like crankcases, not just in the car body.

SUSTAINABILITY -

Carbon fibre can greatly improve sustainability in cars. "Carbon fibre especially for body coverings and structures composite materials can reduce car quality by more than 30%." (Ahmad et al. 6) This big reduction in weight helps lower fuel use and emissions over the life of a car. But production is not fully green. "Carbon fibre 183 to 286 MJ/kg" has one of the highest energy requirements compared to other materials. (Ahmad et al. 4) This means making carbon fibre uses a huge amount of energy and produces emissions.
"Because of higher material costs and in some cases more costly processing, simple material substitution from ferrous to lightweight materials yields higher component costs. Only the combined use of lightweight materials and an innovative approach to engine concept and component design can result in a 'lighter-and-cheaper' component." (Beste et al. 2) This shows that for sustainability, it is not enough to just change materials. The whole design and production process needs to be improved.

DESIGN POSSIBILITIES

"In automotive industry, the advantages of carbon fibre reinforced plastic are reduction in weight, part integration and reduction, crashworthiness, durability, toughness, and aesthetic appealing." (Ahmad et al. 1) One of the main advantages is part integration, which allows manufacturers to combine several components into a single structure (Ahmad et al. 1–2).

For example, instead of assembling a car door from many steel pieces, a single CFRP panel can be used to save weight and time. CFRP also provides flexibility in shaping and molding, allowing for more advanced designs.

Aerodynamics is another benefit. "The body of the new electric car BMW i3 is largely made of carbon fibre… The car body of this material is 50% lighter than steel and 30% lighter than aluminium." (Ahmad et al. 5) This shows how carbon fibre helps make smoother shapes, reducing drag and improving efficiency.

Luxury and sports brands use CFRP in different ways. "Currently, a large amount of CFRP parts is used in high end sports vehicles which are produced approximately 500 units per year." (Ahmad et al. 3) BMW has used CFRP on a bigger scale. "The body of the new BMW luxury sedans is up to 130 kilograms lighter than their predecessor models." (BMW Group 2015) BMW also explained that "this intelligent body design succeeds in increasing the strength and rigidity of the passenger cell while also bringing about a substantial reduction in vehicle weight." (BMW Group 2015) They also stated that "the new BMW 7 Series is the first ever vehicle in which industrially manufactured CFRP is used together with steel and aluminium." (BMW Group 2015)

Other companies have different goals. Lamborghini states that "the cell of the future Lamborghini flagship super sports car is made entirely from carbon fiber and has been designed as a monocoque structure." (Lamborghini Press Release, 2012) McLaren explains that "every single McLaren ever made has been based on a carbon fibre monocoque." (McLaren Automotive, 2023) Pagani also highlights the artistic use of the material, noting that "the carbon monocoque used on previous Pagani models sets the standard in terms of its strength, lightness and build quality." (Pagani Automobili, 2023) These examples show how flexible CFRP is; it can improve efficiency, safety, or design depending on what the brand wants.

"The purpose of weight reduction is not merely reduced consumption and emissions, improved vehicle performance and weight distribution, it is also suitable to reduce the costs of individual components." (Beste et al. 1) This shows that lightweight design with CFRP is not just about performance, but also about making smarter and more cost-effective car designs.

Fig. 1: Classic Carbon Fibre Car (Google Images)

Fig. 2: Today's Carbon Fibre Car (Google Images)

FUTURE PROSPECTS

Carbon fibre faces significant barriers today, but research shows many ways that could expand its role in the automotive industry. CFRP remains far more expensive than conventional materials because of its complex and energy intensive production processes (Ahmad et al. 2–3).

Researchers are looking at ways to solve this. "Research programs constantly work on design solutions for magnesium and carbon fibre reinforced materials to exploit their potential." (Beste et al. 7) New methods like automated fibre placement, better recycling systems such as pyrolysis and hybrid designs using CFRP with aluminium or steel could make production cheaper and greener.

Carmakers are already testing these ideas. BMW has shown how CFRP can be scaled up. "The new BMW 7 Series is the first ever vehicle in which industrially manufactured CFRP is used together with steel and aluminium." (BMW Group 2015) This combination cut weight by up to 130 kg while still keeping safety strong.

If these technologies continue to improve, carbon fibre can move beyond luxury cars and be used in everyday vehicles. "Carbon fibre especially for body coverings and structures composite materials can reduce car quality by more than 30%." (Ahmad et al. 6) When matched with cleaner production, this could make future cars lighter, more efficient and more affordable for ordinary consumers.

CHALLENGES & LIMITATIONS

Even though carbon fibre has many advantages, there are still big challenges that stop it from being used in all cars. "It is very difficult to replace the low-cost metals that are currently being used for parts that satisfy the functional needs in a car with a more costly carbon composite material." (Ahmad et al. 3) The main problem is cost. CFRP is far more expensive than steel or aluminium because its production needs special equipment and skilled workers (Ahmad et al. 2–3). This makes it hard for carmakers to use it in mass market vehicles. Another challenge is manufacturing. "Because of higher material costs and in some cases more costly processing, simple material substitution from ferrous to lightweight materials yields higher component costs." (Beste et al. 2) Unlike metals, CFRP cannot be welded or reshaped easily, and new techniques are needed to work with it. This increases time and expense. Safety is also a limitation. "The specific energy absorption (SEA) of the chopped carbon fibre composite material calculated was the highest as compared to that of all other composites analysed which shows the crashworthiness of this material." (Ahmad et al. 3) This means that CFRP absorbs a lot of energy during a crash, which helps improve safety, but unlike steel, it does not bend when damaged, it can crack or break instead. This can make repairs and crash behaviour more complex. Environmental concerns also add to the difficulties. CFRP saves fuel during a car's life, but its production uses a lot of energy. "Carbon fibre 183 to 286 MJ/kg" shows one of the highest energy demands compared to other materials. (Ahmad et al. 4) Recycling carbon fibre is still complex and costly, with methods like pyrolysis and solvolysis only in development. Because of these barriers, CFRP is mostly used in luxury and sports cars today, while cheaper metals continue to dominate everyday car production.

ADVANTAGES OF CARBON FIBRE REINFORCED PLASTIC IN AUTOMOBILES

"Light weighting becomes a main issue for energy efficiency in the automotive industry." (Ahmad et al. 1) This emphasis on lightweight design is the key reason CFRP is being adopted by automakers. Its unique properties make it ideal for improving both performance and efficiency.

"CFRP has high modulus of elasticity, low density and good corrosion resistance." (Ahmad et al. 2) These characteristics give it an advantage over conventional metals such as steel or aluminum, especially in improving long term durability and reducing maintenance.

"CFRP composite has higher tensile strength compared to other materials like steel and aluminium." (Ahmad et al. 4) This strength to weight benefit helps manufacturers achieve better crash performance and handling stability.

"The purpose of weight reduction is not merely reduced consumption and emissions, improved vehicle performance and weight distribution, it is also suitable to reduce the costs of individual components." (Beste et al. 1) This means CFRP supports not only lighter and safer cars but also smarter engineering that can eventually lower production costs.

Finally, "CFRP is highly attractive for structural applications in the automotive industry because of its high strength-to-weight ratio and corrosion resistance." (Ahmad et al. 5) Together, these properties make carbon fibre one of the most promising materials for the next generation of efficient, durable and high performing vehicles.

MANUFACTURING AND PROCESSING CHALLENGES

"The processing of CFRP components requires high temperature and long curing cycles which limit their production rate." (Ahmad et al. 4) This makes it difficult for automakers to use CFRP in large quantities because it takes more time to produce than traditional metals.

"The manufacturing of CFRP involves several stages including lay-up, curing and machining which increases production complexity." (Ahmad et al. 3) The lay up stage takes time because each fibre layer must be placed precisely to maintain strength. Curing also adds difficulty since it requires high pressure and temperature for long periods. Machining cured CFRP is tricky because it can crack or splinter if not handled carefully. These steps make production slower and more complicated than working with metals.

"The production of carbon fibre requires high energy of 183 to 286 MJ/kg." (Ahmad et al. 4) This high energy consumption makes CFRP one of the most energy demanding materials used in the automotive industry.

"Due to the limited manufacturing capacity and processing speed, lightweight materials such as CFRP are not yet suitable for mass production." (Beste et al. 3) This means that while CFRP is ideal for performance vehicles, it remains challenging for large scale applications like passenger cars.

"Continuous research is being carried out to optimize production techniques and improve the recyclability of lightweight materials." (Beste et al. 7) This ongoing innovation could make CFRP manufacturing faster, cheaper and more environmentally friendly in the future.

RECYCLING AND ENVIRONMENTAL IMPROVEMENTS

"The production of carbon fibre requires high energy of 183 to 286 MJ/kg." (Ahmad et al. 4) This high energy use makes it important to find better recycling methods that can recover materials without adding to emissions.

"Continuous research is being carried out to optimize production techniques and improve the recyclability of lightweight materials." (Beste et al. 7) Recycling helps reduce waste, energy use and the need for new raw materials, making CFRP more sustainable for the future.

"Recycling carbon fibre can recover up to 90% of the original fibre strength when processed correctly." (Ahmad et al. 5) This shows that reusing carbon fibre is possible without losing too much performance, which makes it valuable for lower cost applications.

"Thermal and chemical recycling methods such as pyrolysis and solvolysis are being studied to recover carbon fibres from composite waste." (Beste et al. 6) These methods can separate fibres from resin and make them usable again in new components.

"Recycled CFRP materials can be applied in non-structural components to save weight and lower environmental impact." (Ahmad et al. 6) This allows manufacturers to reuse materials efficiently while maintaining vehicle quality.

"With improvements in recycling efficiency, CFRP could become one of the most environmentally friendly lightweight materials in automotive design." (Beste et al. 7) These advances will help balance the high energy cost of production with long term sustainability benefits.

CONCLUSION

"Light weighting becomes a main issue for energy efficiency in the automotive industry." (Ahmad et al. 1) This statement tells us the main goal behind using carbon fibre reinforced plastic (CFRP) in cars to make them lighter, stronger and more sustainable.

Some advantages of CFRP are that it offers high strength, low weight and excellent durability, helping vehicles achieve better performance and fuel efficiency. Its design flexibility and use in high end models show how it improves both structure and style while maintaining safety. However, the manufacturing and processing challenges make CFRP difficult to use on a large scale. The long time needed for curing, the high energy use and the complicated production steps make it costly and slow to produce in large numbers. At the same time, recycling and environmental improvements are helping make CFRP more sustainable. Techniques such as pyrolysis and solvolysis are allowing carbon fibres to be reused, reducing waste and the overall carbon footprint of manufacturing. Looking at future prospects, research continues to make CFRP more cheaper, easier to produce and better for the environment. Hybrid structures, automated fibre placement and improved recycling methods are likely to expand its role beyond luxury cars to everyday vehicles. Overall, CFRP stands as one of the most promising materials in modern automotive design. With continued innovation and environmental focus, it can help the industry build cars that are not only lighter and safer but also cleaner and more sustainable for the future.

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