Analysis of Carbon Fiber Composites Used in BMW i3 Automobiles

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Abstract

BMW is developing an electric automobile, the i3, which will extensively incorporate carbon fiber composites in order to provide consumers with a lighter, higher-performing, and more efficient vehicle. In order to produce enough carbon fiber for these automobiles, BMW formed a joint venture with SGL Group Carbon Company. However, even though this material is supposed to provide many benefits, some believe issues such as resource intensive production methods, high cost, and problems recycling are associated. Therefore, investigation on the properties of carbon fiber, the outcome it produces, and the problems involved is necessary in order to determine how beneficial the use of this material actually is with respect to BMW’s mass production lines. After extensive research, this study concluded that even though the overall opinion on incorporating carbon fiber into BMW’s new vehicles will vary, there is irrefutable evidence that proves incorporating this material into the i3 is beneficial. This evidence concludes that carbon fiber has the preferred properties when compared to other common materials used in automobiles, will be a sufficient material to provide safety to the vehicles, and has an energy efficient production method.
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Introduction and Literature Review

Carbon fiber composites have been elusive and rare materials for the automotive industry ever since its introduction in the late 1950’s. Many studies have analyzed the advantages of carbon fiber composites in various industries, but not extensively in the automotive industry in the context of mass production. This material has always failed to be produced on a large volume scale because of its high price and complications that are associated with manufacturing it. However, as technology started to advance, automobile companies were able to successfully produce simple components made of carbon fiber to include in their vehicles, such as bumper supports and roofs. This was considered a contributive achievement as the oil crisis was worsening because the use of this lightweight material can make a car more efficient without sacrificing strength. (Brosius, 2004). As a result, many automobile companies were striving to discover a way to circumvent the problems involved with carbon fiber in order to manufacture the material in large volumes. In 2010, BMW announced that they would be the first automobile company to use carbon fiber in large volume production, and they claim that they are the only car maker “with the experience necessary” to do this. (Jacob, 2010). In order to make this possible, BMW formed a joint venture with SGL Group Carbon Company and will be using the carbon fiber produced for their new car known as the i3. (“Carbon age begins”, 2010). Carbon fiber composites have been extensively researched on their properties and strength to weight ratios. However, since carbon fiber has had a troublesome history, the incorporation of this material into the BMW’s vehicles should be analyzed to determine if the use of the material would be beneficial to their company and society as a whole. For this reason, carbon fiber and the problems associated will be analyzed with respect to economics, the environment, and its
physical properties. This study aims to thoroughly examine the long-term pros and cons of the extensive use of carbon fiber composites in BMW’s vehicles to determine if they are making a strong business decision and if society will benefit.

**Data Collection**

Understanding the properties of carbon fiber is helpful when determining whether or not it will be beneficial to include in the BMW’s first vehicle to be made extensively from carbon fiber composites -- the i3. This is because the properties of a material used extensively will directly influence the efficiency, safety, and performance of a vehicle. For carbon fiber, the most striking properties are that it is strong and lightweight. However, there are different types of carbon fiber, and the properties of each will vary depending on the production method used. For BMW, the carbon fiber produced is reported to be “at least as strong as steel and around 50% lighter”. (Jacob, 2010). Since the BMW i3 will be significantly lighter compared to other automobiles, it will not need use as much energy during transportation. Also, the carbon fiber-based lighter vehicle will have improved performance because it will ‘accelerate faster, will be more agile through corners, and will brake to a standstill more quickly” (Megacity Article). In addition to being strong and lightweight, carbon fiber is also corrosion resistant. This is beneficial because the i3 will not rust, which will give the vehicle a longer lifespan and will make complex protection methods unnecessary. (Jacob, 2010). Even though all of these properties described will foster the i3’s performance, consumers are often interested in the safety of a vehicle as well. A vehicle’s safety rating is derived from different factors, one being the
rigidity and strength of the material used for the body of the vehicle. ("BMW Sauber", 2008). The rigidity of a material is directly proportional to its structure. As shown in Figure 1, carbon fiber has a similar structure to graphite, with sheets of carbon arranged in a hexagonal pattern. (Callister, 2007). However, carbon fiber is much more rigid than graphite because of the way the sheets interlock. In graphite, the sheets run parallel to one another and possess weak Van der Waals forces between them. Carbon fiber’s sheets are instead “crumbled” together, which is why it has such high strength. (Callister, 2007). In addition to its structure, researchers also claim it to be a safe material, commenting how it is “significantly lighter in weight than aluminum, yet it offers the same stability and crash safety as steel”. ("Carbon Fiber Composite", 2005). Professional Formula One drivers are also witnessing carbon fiber’s ability to provide protection since they experience high-impact crashes at speeds around 200 mph and survive. ("BMW Sauber", 2008). Even though the properties of carbon fiber are impressive, a further analysis on how carbon fiber compares to other materials aids to further determine how beneficial this material actually is.

Many different materials are used for an automobile’s body, some common ones being steel and aluminum alloys. (Callister, 2007). In Figure 2, carbon fiber, steel, and aluminum are compared. Carbon fiber is superior in all categories, most important being the specific strength and specific modulus. The strength to weight ratio for carbon fiber is significantly greater, meaning that it has the highest ratio between its strength and weight. Also, the specific modulus for carbon fiber is approximately 18% greater than aluminum and 14% greater than steel. This proves that carbon fiber has the highest resistivity to deformation while having a low weight at the same time. Overall, carbon fiber has impressive characteristics, even when compared to other
Carbon Fiber Analysis

materials used in automobiles by providing the highest stiffness and strength per unit weight, resulting in a more efficient car without sacrificing any strength.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Strength (KN•m/kg)</th>
<th>Ultimate Tensile Strength (GPa)</th>
<th>Modulus of Elasticity (GPa)</th>
<th>Specific Modulus (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Fiber (60/40 fiber/matrix)</td>
<td>2457</td>
<td>3.5</td>
<td>210</td>
<td>10'</td>
</tr>
<tr>
<td>Aluminum Alloy (2024-T3)</td>
<td>254</td>
<td>.448</td>
<td>70</td>
<td>8.5x10^6</td>
</tr>
<tr>
<td>Steel Alloy (4130)</td>
<td>222</td>
<td>.862</td>
<td>207</td>
<td>8.8x10^6</td>
</tr>
</tbody>
</table>


Looking into how BMW produces its carbon fiber is indicative of the natural resources and energy means used to make this material. Some believe that after the large volume production and incorporation of carbon fiber into vehicles, oil will actually be lost because the amount of oil used to produce it is greater than what you would save driving a vehicle made out of lightweight carbon fiber. (Deaton, 2011). However, once the production process of carbon fiber by BMW is fully understood, it becomes conclusive that this process is actually energy efficient. The first step in producing BMW’s carbon fiber originates in Otake, Japan, where oil is refined to produce the polymeric feedstock known as the precursor. (Naskar). Then, this precursor is sent to Moses, Lake Washington where the next steps take place, which include oxidation, carbonization, heat treatment, and sizing. (McConnel, 2008). Lastly, the material is wound and shipped to Germany for its final preparations. Out of all of these steps, the only one that is using oil is the precursor material. However, it is a miniscule quantity in comparison to other technologies that run on oil. According to Figure 3, gasoline makes up 41.5% of the
average barrel of oil in the United States while “other refined products”, such as carbon fiber, make up only 1.5%. (“Petroleum Products”, 2006). In addition, BMW uses hydroelectric power to run the plant in Washington, which uses water instead of oil to produce electricity. And lastly, the BMW i3 will be an electric vehicle and therefore will not be using gasoline as its primary source of energy. Even though electric vehicles require another source of energy, they are not nearly as oil dependent as cars with gasoline-powered engines are. Overall, BMW’s process for incorporating carbon fiber into its i3 is not oil intensive.

<table>
<thead>
<tr>
<th>Product</th>
<th>Percent of oil used in average barrel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finished Motor Gasoline</td>
<td>51.4%</td>
</tr>
<tr>
<td>Distillate Fuel Oil</td>
<td>15.3%</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>12.3%</td>
</tr>
<tr>
<td>Still Gas</td>
<td>5.4%</td>
</tr>
<tr>
<td>Marketable Coke</td>
<td>5.0%</td>
</tr>
<tr>
<td>Residual Fuel Oil</td>
<td>3.3%</td>
</tr>
<tr>
<td>Liquefied Refinery Gas</td>
<td>2.8%</td>
</tr>
<tr>
<td>Asphalt and Road Oil</td>
<td>1.7%</td>
</tr>
<tr>
<td>Other Refined Products</td>
<td>1.5%</td>
</tr>
<tr>
<td>Lubricants</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

*Figure 3.* Petroleum Products Yielded from One Barrel of Crude Oil in California. Retrieved from http://energyalmanac.ca.gov/gasoline/whats_in_barrel_oil.html

Even though the production and incorporation of carbon in the BMW i3 does not heavily rely on the earth’s resources, it may still damage the environment in another way. There have always been issues involved with recycling carbon fiber since its discovery. This is a result of the complex composite structure it possesses. For example, it is relatively easy to recycle aluminum alloys: the molten elements separate and established processes can be used to reclaim those elements with predictable levels of purity. (Rush, 2007). However, since carbon fiber
composites have such a complex structure, it is difficult to separate the material, and it is also not possible to melt it down. Therefore, other recycling techniques are used. One method decomposes the material via thermal depolymerization in an oxygen free environment, which would allow reuse of the material’s monomers. (Suzuki, 2005). Another method to recycle carbon fiber shreds the carbon fiber at a low temperature in order to reclaim it. However, this method would result in a material with significantly less strength than previously has, and it would not be “strong enough to be used in another car”. (Deaton, 2011). This could potentially be harmful to the environment because it would generate a lot of waste. However, BMW states they have a firm grip on the situation and announced that they have “developed a concept for recycling production waste into commercial quality material” (Jacob, 2010). They believe that their recycled carbon fiber can be used for many applications, including primary fabric. However, even though BMW claims they have a use for recycled carbon fiber, it may be difficult to find a use for all of it since there are other materials that could easily be used. Therefore, this large volume production still has the potential to produce waste, which in turn would be negative for the environment and the image of BMW.

The use of carbon fiber in the BMW i3 should also be analyzed economically to determine if it is a beneficial investment. BMW has been rigorously studying and implementing carbon fiber into its vehicles for over ten years. (Sloan, 2011). They believe that its use will improve the vehicle’s efficiency, strength, and will also cut down the use of oil. However, the
use of this material is expensive, reported to be approximately $10 a pound in 2011. (Naskar). The most expensive part of manufacturing carbon fiber is making its precursor, as seen in Figure 4. Even though the price is high, BMW believes it will be a beneficial investment for they initially invested 100 million dollars, and it’s expected to reach approximately 300 million dollars by the end of the production process. It has been estimated that the i3 will be sold at around $35,000, and it’s ultimately up to the consumers to choose if they want to drive this electrically powered automobile. (Jacob, 2010). As far as the production of carbon fiber is concerned, the demand is predicted to rise, as seen in Figure 5. This will be beneficial for BMW since they have taken the first initiative when it comes to understanding the complexities carbon fiber. Even though it seems likely BMW will benefit economically from this investment, it is impossible to determine until consumers, other automobile corporations, and the economy itself respond.

Figure 5. The Projected Carbon Fiber Demand. Retrieved from http://www.ccrhq.org/publications_docs/CCR-Naskar_Presentation.pdf
Results and Discussion

When a new technology like carbon fiber is on the breakthrough, it is important to take a deeper look on how the technology will affect all aspects of society, instead of just one particular area. It was found that many studies only focused on a single factor of carbon fiber---cost, production, properties, etc. Therefore, it was beneficial to look at this technology in a more comparative and vast manner in order to truly understand it’s potential. After extensive research using this method, there is evidence that both supports and contests the use of carbon fibers in the BMW i3. The evidence that contests the use of this material includes the problems associated with recycling and an inevitably high price. On the contrary, there is also indisputable evidence that commends the use of this material in the i3, including the preferred properties it has when compared to other common materials used in automobiles, its ability to provide safety to the vehicles, and its energy efficient production method. Overall, in our opinion, it is concluded that the use of carbon fiber in the automotive industry will be more beneficial then it will be detrimental. The lighter automobiles that result and safety the material provides outweigh the cost and insignificant environmental factors.

Summary and Conclusion

Ultimately, the belief on whether or not incorporating carbon fibers will be beneficial is a subjective opinion. This study indicates that the use of carbon fiber composites can beneficial to society if recycling methods can be improved. With respect to the automotive industry, BMW believes that this is a beneficial decision because of the promising safety factors and better efficiency in a market striving for the highest quality product and the most gas mileage. As a result, they are paving a road towards a future for extensive use of carbon in not
only their vehicles, but many other aspects of peoples’ lives, which promises a more efficient 
and improved technological future.

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