

LIFE CYCLE COST ANALYSIS FOR PASSENGER CARS: STEEL VERSUS COMPOSITES

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Abstract

In today's car industry, companies are focused on higher performance cars with lower cost in order to attract the customer. In other words, the winner of this competitive market is the company which offers a high performance car with lower price and reasonable maintenance cost. For this reason, many companies are trying to identify customer needs and market demands for developing new products based on these desires. For making this happen, using life cycle cost analysis will help the manufacturer in order to find the best way for reducing unnecessary costs and developing new products that fit the market.

As an important part of the life cycle cost assessment, the usage of different resources such as raw material and fuel consumption should be evaluated. This will also help the manufacturer to design a car with lower end cost and reasonable maintenance cost.

In this project, life cycle cost assessment for an ordinary steel car has been compared with a carbon fiber car. For this reason, a life cycle cost model is designed for encompassing the cost of crucial elements that have major influence on cost. Hence, the pre manufacturing cost, manufacturing cost, use and post use costs have been evaluated.

According to the assessment, the cost of raw material for carbon fiber composites is more than steel. However, the total life cycle cost for a carbon fiber BIW is less than the steel one because of the fact that manufacturing costs as well as use costs are lower for carbon fiber car. Consequently, composite cars could make their way towards the market with the assistance of car industries. According to that, designers and manufacturers should focus on new concepts with this generation of materials in order to achieve and develop new technologies for mass production of composite passenger cars.

This assessment might help the car manufacturers in decision making for material replacement in a new generation of passenger cars.

Introduction

Referring to the history of industries, the car industry has accepted many changes during the history. Developing new technologies, robotics, new complex designs, improving passenger safety, and applying new alloys and materials have been helpful for the manufacturers to improve vehicles day by day. Focusing on the market, the car industry is one of the most cost sensitive markets with a lot of compulsory factors. Customer demands, safety issues, cost efficiency, environmental issues, fuel consumption, and update technologies are some of the key factors which the manufacturer should consider them in order to produce a compatible product. On the other hand, the competitive market has made a challenge for developing new technologies and producing high performance cars at lower cost. Therefore, R&D sections are always working for challenging technologies in order to find new acceptable manufacturing technologies.

According to the fact that car industries should focus on developing high performance cars at lower costs, developing lightweight cars using new materials are significantly considered in R&D sections. In fact, lightweight cars will reduce the fuel consumption remarkably so that the running costs will be decreased. Furthermore, lower fuel consumption will reduce the emission of perilous gases to the air as well as saving a lot of energy.

By analyzing today's vehicles, steel is the seminal material for almost every part of the car. In spite of the fact that steel has been widely used for fabricating body parts, car manufacturers have developed new lightweight concepts using aluminum and composites instead of steel. Although composites have been used for manufacturing expensive sport cars, these materials have not been widely used for mass production for economic reasons. One of the important factors that prevent releasing composite cars is the cost.

In this project, life cycle cost of a composite car will be compared to a steel car in order to find impressible elements. For this reason, different aspects for manufacturing a car have been considered and different costs have been estimated.

Theories

The Need for Material Selection

As a matter of fact, material is the most important item in production. In other words, the performance of the product is directly dependent on the type of material which has been used for production and design. Therefore, the designer should evaluate the properties of a suitable material for manufacturing and choose the best option from many available materials. Accordingly, the design, processing, cost, quality, and performance of the future product will be affected by this selection.

In addition to the importance of selecting the best material for manufacturing and design, it should be mentioned that material cost comprises of about 50% of the total cost of the product. Thus, selecting a suitable material with applicable properties is a major step in product design.

On the other hand, material choosing could be done for two purposes:

1. Redesign:

Sometimes, a product has been designed and manufactured but it hasn't got the optimized operation. Therefore, the redesigning process will be done in order to achieve better performance, higher reliability, lower cost, and lower weight. In this case, fixed and variable costs should be assessed and evaluated before the redesigned product released.

2. New design:

For new designs, the selection will be done for a new product with specific characteristics. So, the specifications of that product will help the designer to choose the right material.

In both of these procedures, different aspects should be considered. For instance, governmental laws, safety issues, environmental laws, cost, durability, and other relevant items should be assessed carefully. However, the decision making will be on the basis of life cycle cost analysis. In this project, the material choosing has been made for redesigning an ordinary steel made car [1].

LCCA

LCCA or Life cycle cost analysis is a method for assessing the total cost of a product. The importance of assessing the cost of a product refers to the customer's financial status and the competitive price-based market [2]. In detail, this will consist of two types of costs [1]:

- Nonrecurring costs (fixed costs)
- Recurring costs (variable costs)

Nonrecurring costs:

According to "Business Dictionary" [3], nonrecurring costs or extraordinary costs include "write offs such as design, development, and investment costs" and also it covers "fire or theft losses, losses on sale of assets, and moving expenses".

Recurring costs:

According to "Business Dictionary" [4], recurring costs are "Regular cost incurred repeatedly, or for each item produced or each service performed".

According to these two definitions, the combination of recurring and nonrecurring costs in a product's life time including purchase prices, installation and operation costs, upgrade and maintenance costs, and the value of the product in the end of ownership should be considered. [5]

In spite of the fact that life cycle cost analysis must be considered as the basis of decision making, it might add more complexity to cost model. In other words, "operational costs, facilities, training, manpower, fuel or energy consumption, and maintenance costs as well as disposal costs" should be evaluated. In this process, some of the data must extract from historical data bases. For instance, operation costs, reliability, and maintenance costs should be gathered from customers so that the company should have a strategy to collect these data from them. [2]

From another perspective, the final product should be competitive in performance, aesthetics, on time release to market, quality, and cost [2]. Therefore, the customer demands will drive the market.

In spite of all these important issues, a design to cost approach consists of several steps. Some of these important steps are [2]:

- Inferring customer's affordability and competitive market price

- Reducing target costs to a manageable level
- Stable and manageable requirements in order to have a balance level between affordability and requirements
- Identifying the key factors that affect cost generally and focusing on them
- Modeling life cycle costs and product costs in order to use them in decision making
- Active consideration of cost especially during development processes and weighting it as an important decision making parameter
- Innovative Investigation for developing new concept and design choices as the foundation of developing lower cost design approaches

On the other hand, LCCA process includes problem or project definition, defining the cost model requirements, data collection (historical data, cost relation, cost data), defining the schedule, and developing the estimation before analyzing the results [6].

In this project, using a certain material will be assessed. Additionally, these costs are consist of production and manufacturing costs, use costs, and other relevant costs which is related to different stakeholders [7].

A final LCCA result should meet the following applications [6]:

- Predict the needed resources and identifying the potential problems
- Prove information for “preliminary design decision making”
- Evaluate the strategic planning and budgeting

During the life cycle cost analysis, some preventive errors may occurred which can affect the performance of the LCCA. Some of these errors are [6]:

- Data failure,
- Lack of a systematic structure or analysis,
- Misinterpretation of data,
- Wrong or misused estimating techniques,

- A concentration of wrong or insignificant facts,
- Failure to assess uncertainty,
- Failure to check work,
- Estimating the wrong items, and
- Using incorrect or inconsistent escalation data

Metals

Metals are the ordinary materials which have been used in a wide range of different industries. Iron, copper, magnesium, lead, nickel, and titanium as well as aluminum are some of the metallic materials that are used. The main characteristics of metals are:

- Stiffness
- Strength
- Thermal stability
- Higher temperature resistance than plastics
- Thermal and electrical conductivity
- Malleability

According to these characteristics, metals have the important properties, like malleability, for using them in production and manufacturing. However, pure metals have not been used in production because of the fact that they do not have high performance in comparison with alloys. Hence, alloys are widely used in different industrial productions because of better properties. For example, adding carbon and chromium to iron will make it corrosion resistant and tougher. On the other hand, alloys could be made by adding “non metallic elements” so that different properties could be reached. For the automotive industry, steel is the prevalent metal which has been used for many years. In fact, the properties of steel have made it suitable for manufacturing the body of the car. However, automotive manufacturers are investigating new generation of materials, such as composites, for making the body. [1]

Composites

Composites are a combination of two or more dissimilar ingredients which is stronger than each of them individually. These materials could be natural (like wood), or synthetic (like polymer wood). As a matter of fact, synthetic composites have been used since 1950's in many products especially when cosmetic finishing is required. These materials are helping the market with cost reduction and performance improvement in order to develop new products. As the most competitive industry in the world, composite manufacturing in The United States is the most advanced one with "five to seven thousand composite related manufacturing plants" and more than 236,000 employees. [8]

In addition, the benefit of using these materials have resulted in benefits for marketing, new applications in transportation, corrosion, resistance, marine, infrastructure, and consumer products as well as advanced industries including aerospace.

Traditional materials, such as steel, have a certain characteristics which could be reached in different conditions or alloys. However, composites can be produced according to specifications of the product. Additionally, synthetic composites have different characteristics due to their ingredients. For example, if corrosion resistance is needed, Isophthalic or Vinyl Ester Resin could be used and if the cost is crucial, Polyester Resin is suitable.

Although polyester resin is appropriate for cost oriented merchandise, it should be produced according to the needed properties. In detail, if the cosmetic is an important factor in that product, a relevant formula should be used but if the temperature is significant, there should be another formula.

According to the fact that each product should use a certain composite with a significant formula, component materials will be custom tailored. Therefore, the cost/benefit relations will be maximized.

Using composites instead of traditional materials have many considerable advantages. Reaching a higher strength with lower weight, forming complex shapes easier, durability for longer periods of time, and lower facility starting costs are factors which make composites more useful than traditional materials. A good example of these factors in the car industry is a resin part in the rear backseat of “BMW M3 CSL”. This specific part made from high temperature resin is not only 50% lighter than ordinary steel but also could be made fast. [8] So, it is obvious that lighter weight will reduce the fuel consumption of that car and faster manufacturing will reduce the cost for the producer. In other words, using composite parts will reduce the cost for both producer and customer.

Moreover, higher resistance to bending force could be reached by composites with thinner overall in comparison with metals. Therefore, using metal instead of composite will add weight which could be a negative factor for the product. In addition, composites have the capability of integration in order to reduce the number of parts. In other words, many metal parts could be substituted with only one composite part. [1] Thus, production costs including assembling costs will be reduced.

Consequently, composite products are durable, high quality and cost effective in comparison with traditional materials. In today’s industry and market, complex shapes with higher resistance, higher performance, and lower weight as well as lower cost could be produced in order to optimize the cost-benefit relations.

Metals versus Composites

According to previous descriptions, metals and composites have many properties in common which makes both of them suitable for manufacturing. Though, they have many differences from each other that make them useful in specific production. One of these differences is the weight.

Metals are mostly heavier than composites. For instance, steel is 4-7 times heavier than plastics. On the other hand, metals have to pass several processing steps, like sheeting, before using them in production line. Also, several machining operations need to be done for having a product made of steel. Complex items will consume more time and work for being produced. Additionally, the properties of these products could be changed during the usage so that the product will be timeworn soon. A good example of this is oxidization of iron which reduces the resistance of it and makes it brittle.

The fact is that composites are lighter and friendlier for use. These materials are flexible so that producing complex models is easier. In addition, using these materials will reduce the operational costs because of the fact that many of these operations are unnecessary. Also, the properties of the finished product will be more durable during the life span of the product [8]. This characteristic will prevent the user to pay extra costs for maintenance. For example, if a mudguard of the car has been made of metallic materials it will be destroyed after remaining in humid weather for a long time. Accordingly, extra costs should be paid in order to make this part rustproof. Although, this part will lose its resistance after a period of time that the customer needs to change this part with a new one. Hence, if the producer made this part from composites, these costs will be omitted.

Carbon Fiber Composites

Producing carbon fiber car parts are from “polymer PAN” with improved Sohia process. According to the reference [10], “This process involves an amonoxidation reaction between propene and ammonia, which gives the result of acrylonitrile, which can be transformed into polyacrylonitrile after polymerization. The first step is to stretch the polymer so that it is parallel to the axis of the fiber, which is then oxidized in the air between two hundred and three hundred Celsius. Here the hydrogen is removed and oxygen is added to the molecules that forms a hexagonal structure. Now, the white chain polymer becomes a black ring polymer, where it has to be purified by carbonization. This process involves heating up the polymer to twenty five hundred Celsius in a nitrogen rich environment, which expels the impurities until the polymer contains between ninety two and one hundred percent carbon, depending on required quality. The final process, which is known as sizing, involves weaving the fibers into sheets by embedding them into an epoxy resin.” After the primary stage of producing carbon fiber, almost every part for a car will be realized with a high gloss UV finish which prevents that part from fading.

Carbon fiber composites have the properties which make them suitable for manufacturing body parts. These properties will be discussed later.

Car Industry

The car industry is one of the important industries which have accepted composite materials in their manufacturing. . In the 2000's, about 144 million kilograms of these materials have been used in the car industry. "High quality surface finishing", "styling details", and "processing options" are three main factors which made these materials sufficient for choosing, especially for body items. Also, the plasticity of these materials has made them suitable for facelifts of sport cars [1].

Another important issue in car manufacturing is safety. According to experiments [10], carbon fiber body parts are as safe as steel so that there will be no danger in using them as the material for producing body parts of a passenger car. This has been realized by simulating crash tests for cars with composite parts and comparing the result with the ordinary crash test by a car made of steel. This has been achieved by customizing composites with less ductility for observing the impact without cracking.

"ALBOS" or Affordable Light-weight Body Systems is a project which has been held under the foundation of British Authorities for Aston Martin Lagonda in 2006. In ALBOS, supply chain, tools, and processes have been developed in a way that achieves higher industrial levels for making composite body parts for Aston Martin Lagonda.

Accordingly, other luxury car manufacturers have been attracted to this project. The fact is that composite parts are commercially attractive and reduces the tooling costs. In addition, the light-weight body part does not need any further finishing, sanding, patching, or polishing before painting. Consequently, higher standards will be reached with lower cost expenditure [11].

In addition to the fact that composites are suitable for all kinds of cars, they have been used in other vehicles such as trucks. It is obvious that the reason for using them is their characteristics including strength and durability.

In today's car industry, using recyclable materials with lower weight and shaping flexibility are considerable in order to reduce the costs before, during, and after a car has been made [7].

Despite of all the advantages, using composites in the car industry has been limited since [12]:

- Lack of knowledge and experience of design and production using advanced composites
- High cost of raw material
- Mass production of composite parts in the automotive industry has no affordable process for gaining the standards

In this project, the life cycle costs for a steel car will be compared to a fiber carbon one in order to identify and compare the advantages and disadvantages of using each of them.

Methodologies

Stakeholders

As a matter of fact, the consideration of this project is on the life cycle cost for a passenger car. Thus, stakeholders for a passenger car must be identified in order to have a scope for the analysis. The major stakeholders are:

1. Shareholders and manufacturers
2. Customers
3. Environment
4. Government
5. Workers
6. Suppliers

In this project, the life cycle cost analysis will be made with the consideration of shareholders or manufacturers. However, there are some parts of the analysis that may be related to more than one stakeholder so that it should be considered as well. For instance, the fuel consumption is an important factor for the customer. Although lower fuel consumption will benefit the customer, it will help the manufacturer to sell the car. In addition, higher fuel consumption will result in higher CO₂ emission. Another good example of this is the recycling cost. In fact, this cost is related to the environmental issues but it can help the producer to reuse the material for reducing the cost.

Scope

The data have been gathered previously in USA for other different case studies and extracted from several articles. Thus, this project is also takes place in USA and the assumptions will be on this basement. In detail, the labor cost, material cost, fuel cost, and bank interest rate as well as other related costs are calculated due to the manufacturing and use in USA. So, the currency is US dollars and all the cost have been calculated in this scale. Regarding to several bank resources, the bank interest rate in USA is 3%.

The cost for each level will have many differences in comparison with other countries. For example, the labor cost in USA is higher than developing countries. Therefore, if the manufacturing of the product takes place in a developing country, the total life cycle cost will be lower. Moreover, if the fuel is cheaper in a country, the total cost for use section will reduced so that it will affect the total life cycle cost.

Regarding to the fact that data have been extracted from other articles, there are several limitations for this project. Consequently, I tried to use several references for the primary assumptions in order to avoid using wrong data.

Assumptions

Different stages of the life cycle in automotives should be considered so that the life cycle cost analysis should be made on all the levels of pre-manufacturing, manufacturing, use, and post use of the car [13]. Accordingly, some primary terms must be clarified before the analysis starts:

Body in white: Body in white or BIW are all the structures which have been ready before the body of the car goes for paint shop [14]. This process includes the operations which should be done to a metal sheet (or other primary materials) in order to make different parts of the body (i.e. doors, hood, etc) and assembling [15].

- Pre-manufacturing: all the operation before the material is gradated to a certain status with applicable properties and adequate shape. For instance, pre manufacturing for aluminum starts from the formulation of alloy towards making it to sheets.
- Manufacturing: includes different operations before assembling (like honing, sanding, finishing) and assembling.

- Use: this includes the costs for a car during its life span. [13]
- Post-use: costs for dismantling and recycling [13]

Regarding to the fact that achievement of lower weight BIW will be incontestable by using composite parts, the life cycle cost of composites will be assessed in this part. For this reason, fiber carbon composites will be compared to steel. The steel BIW which has been considered for this study is related to "Honda odyssey minivan" which approximately weight 370 kg [22]. In addition, it has assumed that there will be no interval time between manufacturing and use.

Firstly, the cost of raw material should be known. The cost of steel could be purchased with the cost of 0.77 - 1.3 \$/kg so that the average of them will be 1.03 [13] [19]. Secondly, the cost of carbon fiber has the range of value of 11 - 22 \$/kg [19] and the average cost will be 16.5 \$/kg. Also, the weight of carbon fiber is 60% less than steel [10]. Therefore, if the steel BIW weights 370 kg, carbon fiber composite BIW will be approximately 148 kg.

For fuel consumption, it has been assumed that %10 of weight reduction will consequence to %5 fuel efficiency [13]. In addition, a carbon fiber car will be approximately %60 lighter than an equivalent car made of steel [10]. Thus, the fuel economy of carbon fiber will be 30% more than steel. The fuel economy for steel BIW has been assumed to be 20 mpg [13] and for carbon composite BIW it has been assumed to be 26 mpg. The results are presented in Table I:

Table I: Primary assumptions for life cycle cost analysis

Parameter	value	Range
Gas price (\$/gal)	2.3	1.84 – 2.76
Price of steel (\$/kg)	1.03	0.77 – 1.3
Price of fiber carbon composite (\$/kg)	16.5	11 - 22
Fuel consumption(mpg)		
Steel BIW	20	
Carbon fiber BIW	26	
Total vehicle weight(kg)		
Steel BIW	1417	
Carbon fiber BIW	1195	
Body in white weight(kg)		
Steel	370	
Carbon fiber	148	
Life of the car (year)	14	
Life time mile driven	174,140	

According to “Life cycle cost analysis: Aluminum versus steel in passenger cars” [13], the estimate of annual miles which the car is going to be driven is presented in Table II:

Table II: Estimation of annual miles

years	Annual miles	Total miles
1	15,220	15,220
2 to 5	14,250	72,220
6 to 10	12,560	135,020
11 to 14	9,780	174,140

Life Cycle Cost Model

As a matter of fact, analyzing the life cycle cost with the consideration of nonrecurring and recurring costs is very general. In other words, a significant model is needed in order to identify the cost for the analysis. For this reason, the following cost model has been chosen [13]:

$$\text{Life cycle cost} = \text{Pre-manufacturing cost} + \text{Manufacturing cost} + \text{Use cost} + \text{Post use cost}$$

According to the fact that the exact delay time between manufacturing and use step is unknown, I assumed that pre manufacturing and manufacturing are in year 0. Therefore, the time delay between production and use are assumed to be marginal.

Pre-manufacturing

Concerning a body in white structures, the designer needs a reliable material in order to satisfy the needs of strength, safety, flexibility, and other important factors for a body part. In this case, a suitable composite which has the needed properties is Carbon Fiber. Unfortunately, carbon fiber is more expensive than steel and aluminum so that cost savings must be found in the structural design and manufacturing methods. For this reason, minimizing the total amount of material, high effective usage and integration of parts, simplifying assembling and tooling, simplifying part handling, inventory, and processing cost through design, and employing a novel manufacturing system for fabrication of parts could be useful in order to minimize the total cost [19].

The first step for manufacturing a component is designing. In addition, the design should be optimized for the applied material. Therefore, a component design for an aluminum component must be different from a design for a steel part. Thus, the optimized design for fiber carbon component is not necessarily similar with the design for the steel component. However, composites could be customised. For instance, the aerospace industry has developed a fiber composite component called Black Aluminum with the aluminum optimized design [16]. Thus, the composite could be made in a way which acts like steel.

Regarding to the fact that the weight of carbon fiber BIW has been estimated to about 148 kg, the cost of raw material with the average amount will be 2442\$. Similarly, the weight of steel BIW has been estimated to be about 370 kg and the value of raw material has estimated 1.03 \$/kg. So, the cost of raw material for steel BIW will be 381.1 \$. Therefore, the cost of raw material for carbon fiber BIW is about 6.3 times more than steel BIW.

In addition, the minimum and maximum costs for each material have been calculated regarding to the range of values. In this case, the minimum cost for steel BIW will be 284.9 \$ while this cost will be 1628 \$ for a carbon fiber BIW. Also, the maximum cost for steel with consideration of 1.3 \$/kg will be 481 \$. Though, the calculation has estimated 3256 \$ for carbon fiber BIW because of the fact that the maximum value is 22 \$/kg.

The result of calculations is presented in Table III:

Table III: Pre manufacturing cost

	Weight (kg)	Average value (\$/kg)	Total cost for raw material(\$)	Maximum and minimum (\$/kg)	Range of cost for raw material (\$)
Steel BIW	370	1.03	381.1	0.77 – 1.3	284.9 - 481
Carbon fiber BIW	148	16.5	2442	11 - 22	1628 - 3256

Manufacturing

In this part, different aspects of manufacturing a BIW have been studied. Body fabrication and assembling costs are the amounts which should be considered for this part of the assessment.

Also, each of the car components would have their own special method for production. However, fiber carbon components are usually produced with molding methods and coated with graphite layer so that this study has assumed the amounts for these two operations [17].

The truth is that molding methods are usually applied for producing carbon fiber components so that the cost of fabrication will be reduced in comparison to steel [17]. There are several molding methods for producing a component. However, the most suitable method for manufacturing fiber carbon car components is Vacuum Bagging or Compression Molding. In this method, the mold will be placed in a horizontal position and a clear gel applied on it. Then, the molded material will fill the mold and a bag placed and sealed on it. In the next step, the air will be sucked out which forces the bag against the mold. Thus, the material will fill every crevice of the mold. After that, the component will be left to cure before trimming and finishing. Finally, the component will be coated with a colored resin on the visible side of the component. This final process could be applied either by hand or by a spray gun [18].

In comparison with steel, carbon fiber needs no pressing operations so that the cost of designing jig and fixtures and pressing operations will be omitted. Thus, the only fabrication cost for producing a carbon fiber car component is for molding and coating. This cost will also include the cost of designing and producing the molds for each component which will be differing due to the type of the mold. In comparison with steel, the manufacturing cycle time for a fiber carbon part will be reduced because of the fact that some operations will be omitted.

Fiber carbon components for BIW are usually designed in a way which uses less assembling job. For example, two components are collided and designed as a continual part in order to consume less work for assembling.

According to previous discussions, manufacturing costs of steel BIW and fiber carbon BIW has been evaluated [19]. The result has presented in Table IV:

Table IV: Manufacturing cost

Manufacturing	Steel BIW (\$)	Fiber carbon BIW (\$)
Labor cost	259	240
Equipment cost	423	110
Tooling cost	325	172
Other cost	395	208
Total operations	593	264
Total	1995	994

Thus, it can be realized that the cost of manufacturing steel BIW is about 2 times higher than fiber carbon BIW.

Use (Fuel economy)

A 10% weight reduction will result in 5 % fuel efficiency so that fiber carbon composites will have the fuel efficiency of 30% in comparison with steel. If the car runs 174140 miles during its life span, steel made car will consume 8707 gallons. Though, a fiber carbon car will consume 6697.69 gallons which means that 2009.3 gallons will be saved in comparison with a steel car. Also, all the costs have been converted to present value with the interest rate of 3%.

For converting the cost to present value, the following formula has been used [22]:

$$C_t = C(1 + i)^{-t} = \frac{C}{(1 + i)^t}$$

In this formula, “C” is the amount of money (\$) in future year, “i” is the interest rate, and “t” is the number of year. Due to the average of fuel cost (2.3\$/gal), fiber carbon car will saves about 4621.39 \$ during the usage level. The result has presented in Table V:

Table V: use costs for both BIWs (considering the average value for gas)

year	Steel BIW gas consumption (g)	Cost of gas for steel BIW(\$)	Present value (\$)	Carbon fiber BIW gas consumption(g)	Cost of gas for carbon fiber BIW(\$)	Present value (\$)
Year 1	761	1750.3	1669.32	585.38	1346.38	1307.17
Year 2	712.5	1638.75	1544.68	548.07	1260.57	1188.21
Year 3	712.5	1638.75	1499.69	548.07	1260.57	1153.60
Year 4	712.5	1638.75	1456.01	548.07	1260.57	1120
Year 5	712.5	1638.75	1413.60	548.07	1260.57	1087.38
Year 6	628	1444.4	1209.66	483.07	1111.07	930.5
Year 7	628	1444.4	1174.43	483.07	1111.07	903.4
Year 8	628	1444.4	1140.22	483.07	1111.07	877.09
Year 9	628	1444.4	1107.01	483.07	1111.07	851.54
Year 10	628	1444.4	1074.77	483.07	1111.07	826.74
Year 11	489	1124.7	812.05	376.15	865.15	625
Year 12	489	1124.7	788.40	376.15	865.15	606.8
Year 13	489	1124.7	765.44	376.15	865.15	589.13
Year 14	489	1124.7	743.14	376.15	865.15	571.07
Total cost for 14 years	8707	20026.1	16398.42	6697.69	15404.68	12637.63

For having a precise analysis, the lower and higher value of gas has been considered as well. For this reason, the fuel cost has been calculated for steel BIW and the result is presented in Table VI:

Table VI: Fuel cost (use cost) for steel BIW

year	Steel BIW gas consumption (g)	Cost of gas for steel BIW(\$)	Present value (\$)	Minimum cost (\$)	Present value for Min cost(\$)	Maximum cost(\$)	Present value for Max (\$)
Year 1	761	1750.3	1669.32	1400.24	1359.46	2100.36	2039.18
Year 2	712.5	1638.75	1544.68	1311	1235.74	1966.5	1853.61
Year 3	712.5	1638.75	1499.69	1311	1199.75	1966.5	1799.63
Year 4	712.5	1638.75	1456.01	1311	1164.81	1966.5	1747.21
Year 5	712.5	1638.75	1413.60	1311	1130.88	1966.5	1696.32
Year 6	628	1444.4	1209.66	1155.52	967.73	1733.28	1451.59
Year 7	628	1444.4	1174.43	1155.52	939.54	1733.28	1409.32
Year 8	628	1444.4	1140.22	1155.52	912.18	1733.28	1368.27
Year 9	628	1444.4	1107.01	1155.52	885.61	1733.28	1328.41
Year 10	628	1444.4	1074.77	1155.52	859.82	1733.28	1289.72
Year 11	489	1124.7	812.05	899.76	650.01	1349.64	975.01
Year 12	489	1124.7	788.40	899.76	631.07	1349.64	946.61
Year 13	489	1124.7	765.44	899.76	612.69	1349.64	919.04
Year 14	489	1124.7	743.14	899.76	594.85	1349.64	892.27
Total cost for 14 years	8707	20026.1	16398.42	16020.88	13144.14	24031.32	19716.19

Similarly, the costs for carbon fiber BIW have been evaluated during the usage (Table VII):

Table VII: Fuel cost (use cost) for carbon fiber BIW

year	Carbon fiber BIW gas consumption(g)	Cost of gas for carbon fiber BIW(\$)	Present value (\$)	Minimum cost (\$)	Present value for min(\$)	Maximum cost(\$)	Present value for max(\$)
Year 1	585.38	1346.38	1307.17	1077.09	1045.72	1615.64	1568.58
Year 2	548.07	1260.57	1188.21	1008.44	950.55	1512.67	1425.84
Year 3	548.07	1260.57	1153.60	1008.44	922.87	1512.67	1384.31
Year 4	548.07	1260.57	1120	1008.44	895.99	1512.67	1343.99
Year 5	548.07	1260.57	1087.38	1008.44	869.89	1512.67	1304.84
Year 6	483.07	1111.07	930.5	888.84	744.39	1333.27	1116.59
Year 7	483.07	1111.07	903.4	888.84	722.71	1333.27	1084.07
Year 8	483.07	1111.07	877.09	888.84	701.66	1333.27	1052.50
Year 9	483.07	1111.07	851.54	888.84	681.22	1333.27	1021.84
Year 10	483.07	1111.07	826.74	888.84	661.38	1333.27	992.08
Year 11	376.15	865.15	625	692.11	499.99	1038.17	750
Year 12	376.15	865.15	606.8	692.11	485.43	1038.17	728.15
Year 13	376.15	865.15	589.13	692.11	471.29	1038.17	706.94
Year 14	376.15	865.15	571.07	692.11	457.57	1038.17	686.35
Total cost for 14 years	6697.69	15404.68	12637.63	12323.49	10110.66	18485.35	15166.08

Consequently, the fuel consumption of the carbon fiber car is lower than the steel car. Firstly, the results are seems to be not remarkable. However, if a mass production of 100,000 cars per year considered, the fuel saving during the use will be 200,931,000 gallons which costs about 462,141,300 \$. This factor has also affected the air pollution which is related to environmental issues.

The result from the chart without considering the present value is presented in Figure 1:



Figure 1: Use cost for carbon fiber BIW Vs steel BIW

The minimum, maximum, and present value of each BIW has presented in Figure 2.

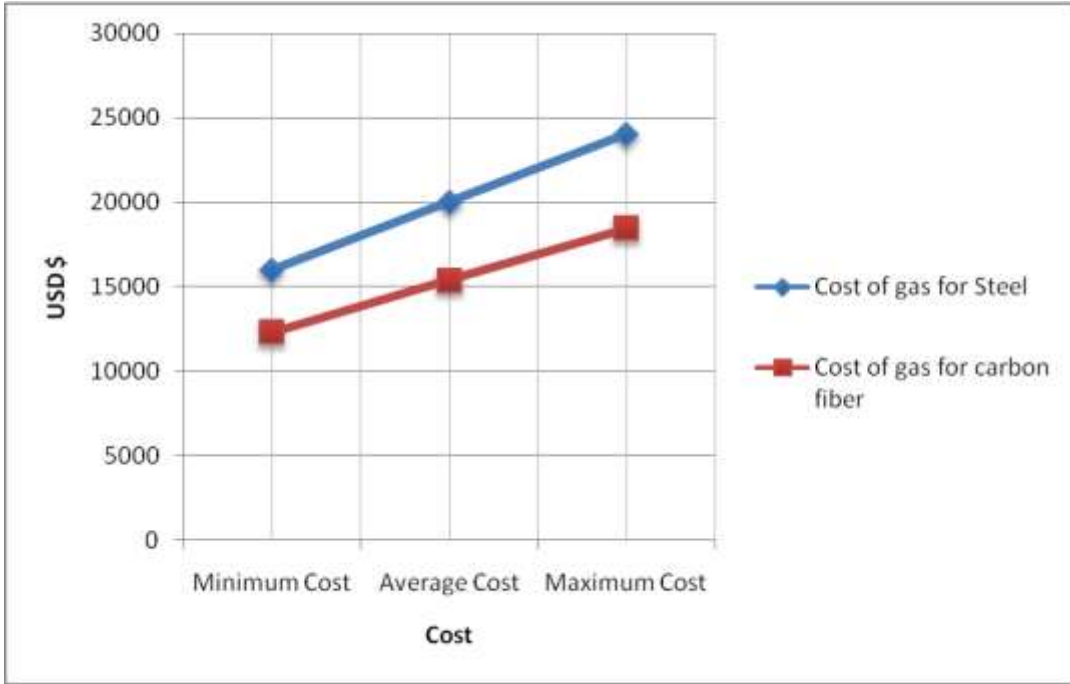


Figure 2: Differences between costs of steel BIW and carbon fiber BIW

Post Use

Post use cost is related to recycling issues and it is estimated to 7\$ for steel BIW [19]. This cost is estimated to 29\$ for carbon fiber BIW which shows that recycling fiber carbon is more expensive than recycling steel. In other words, post use cost for fiber carbon is 4 times higher than steel. These amounts have been converted to present value and shown in Table VIII:

Table VIII: post use cost

	Steel BIW Post use cost (\$)	Fiber carbon BIW Post use cost (\$)
Future value (after 14 years)	7	29
Current value	4.63	19.17

Results

Total Life Cycle Cost

In previous discussions, the cost for each step has been evaluated for both steel BIW and carbon fiber BIW. Hence, the total life cycle cost for each of them is presented in Table IX:

Table IX: Total life cycle cost

	Min for Steel BIW	Average Steel BIW	Max for steel BIW	Min for Carbon Fiber BIW	Average Carbon fiber BIW	Max for carbon fiber BIW
Pre manufacturing	284.9	381.1	481	1628	2442	3256
Manufacturing	1995	1995	1995	994	994	994
Use	13144.14	16398.42	19716.19	10110.66	12637.63	15166.08
Post use	4.63	4.63	4.63	19.17	19.17	19.17
Total life cycle cost	15428.7	18779.2	22196.8	12751.8	16092.8	19435.3

The total life cycle cost of steel BIW is 18779.15 \$ while this amount is 16092.8 \$ for carbon fiber BIW. This has also means that life cycle cost of carbon fiber BIW is only 16% lower than the steel one.

Thus, the life cycle cost analysis for these two cars has shown that the use of carbon fiber composites is reasonable for manufacturing. The result is shown in the Figure 3:

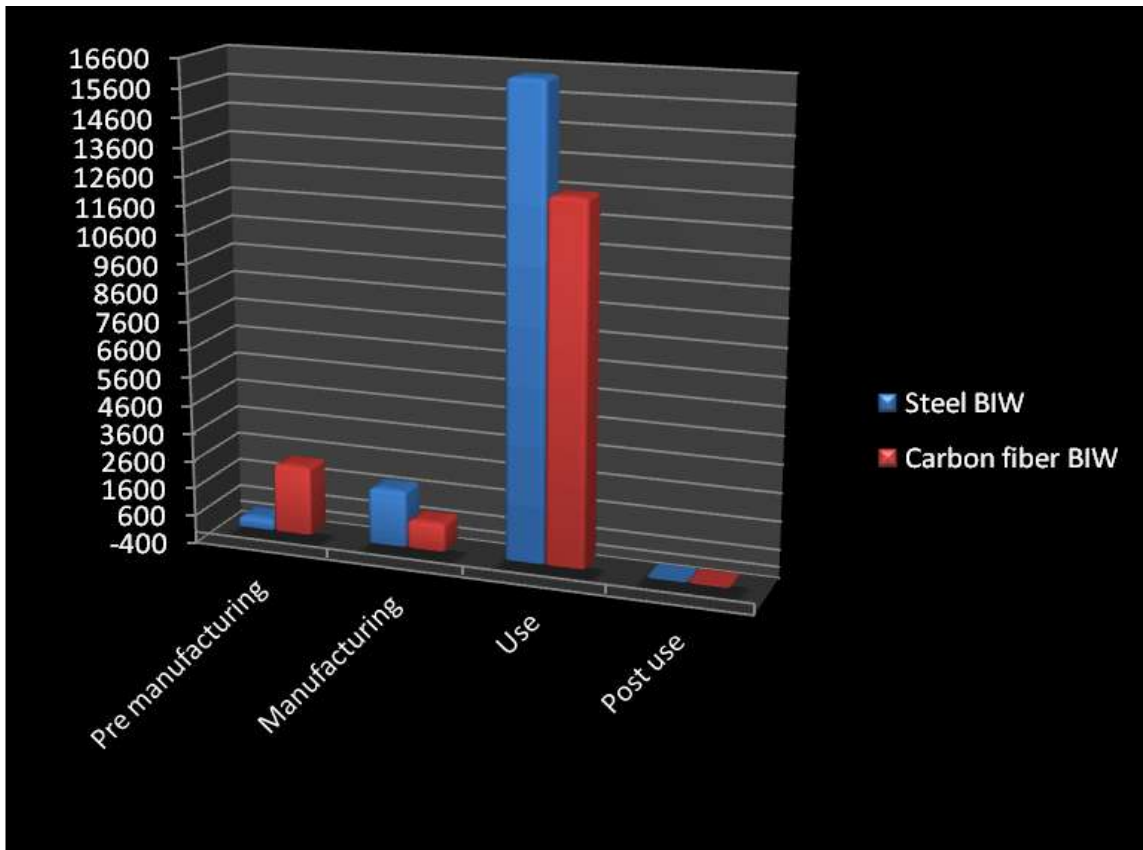


Figure 3: Total life cycle cost (in present value)

One of the major variance between two BIWs is in the pre manufacturing. Therefore, the cost of raw material for carbon fiber is the problem for the car manufacturers to use it as the primary material. This cost is 6.3 times higher for carbon fiber BIW in comparison with steel.

Nevertheless, carbon fiber BIW is cheaper in manufacturing and use parts. Also, the major difference between two studied BIWs is in manufacturing part while the cost for carbon fiber is half of the cost for steel BIW.

As the post use section is not that high, it needs to be considered as an important effecting factor for life cycle cost.

These facts are shown in figure 4 and figure 5:

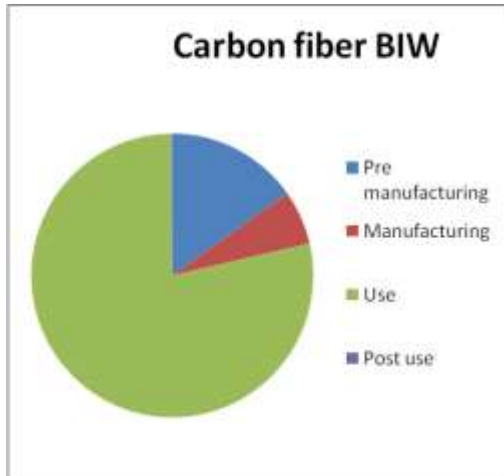


Figure 5: cost deviation for steel BIW

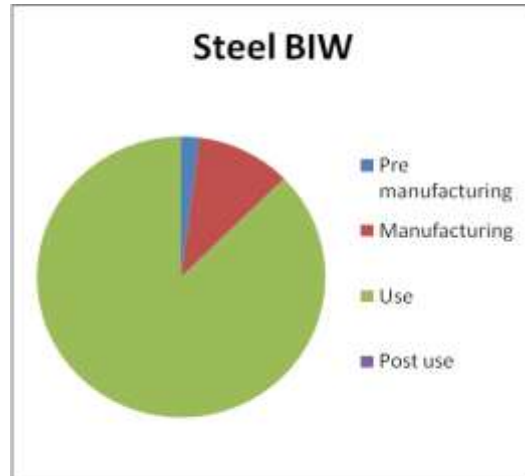


Figure 4: Cost deviation for carbon fiber BIW

Discussion and Recommendation

Conclusion

According to the life cycle cost analysis, using fiber carbon as the primary material in BIW has reasonable cost so that car industries could accept and develop this kind of material for mass production. However, reviewing the results showed that one problem for mass production of fiber carbon cars is the price of raw material.

The cost of manufacturing for steel is higher than fiber carbon so that it could help the car manufacturer to reduce the costs in this part. Moreover, the weight reduction will result in lower fuel consumption for carbon fiber cars without reducing safety, stability, durability, and other performances.

If a mass production of 100,000 cars per year is considered, the fuel saving during the life span will be 200,931,000 gallons. Considering the current fuel price of 2.3 \$/gal, the total saving cost for 100,000 vehicles will be 462,141,300 \$. Thus, the saved cost might not seem considerable for only one car but it has a wide effect on a larger scale.

Despite of what the customer thinks about lower performance, carbon fiber cars are meeting higher standards for safety as well as lower maintenance cost with almost the same performance. Also, different performance factors could be improved even more than before because of the fact that composites can be customized for different uses.

Future Work

Regarding to the fact that composites can be customized, the properties of the material for each part of the car could be different. For example, the properties for the hood could be different from the roof so that different composite could be used. In other words, the processes in pre manufacturing should be different for producing the suitable fiber carbon material. This can be achieved by using more or less fibers in the reinforcement part in order to change the properties and the cost of the raw material. With this strategy, cost of pre manufacturing will be reduced so that the final product might be compatible with steel [20].

Fiber carbon cars are more expensive in pre manufacturing so that it might lead the producer to use a combination of materials in BIW making. In other words, some parts might cost too much when they are produced by fiber carbon. Nevertheless, those parts could be made by steel and apply fiber carbon for other parts. Consequently, the combination of both of these materials will lead the cost to be more reasonable.

Considering manufacturing cost, some steel parts might need expensive operations which lead the total manufacturing cost to a higher level. This occasion could be found in complex designs especially in luxury cars. In this situation, using carbon fiber composites will reduce the manufacturing cost as well as reduce the total life cycle cost. By this strategy, the total weight of the car will be reduced and the fuel consumption will be more economic.

In spite of all the mentioned items, if car industries use carbon fiber for BIW production the material cost will be reduced in mass production. Hence, cheaper carbon fiber will lead the car industry to produce low weight cars with reasonable life cycle cost.

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References

- [1] K.mazumdar, Sanjay. (2002). *Composite manufacturing: Material, product, and process engineering*. Retrieved 12 May 2009, from <http://www.npd-solutions.com/dtc.html>
- [2] Crow, Kenneth. (2000). *Achieving target cost, design-to-cost objective*. Retrieved 10 May 2009, from <http://www.npd-solutions.com/dtc.html>
- [3] *Non-recurring cost*. (n.d). Retrieved 10 May 2009, from <http://www.businessdictionary.com/definition/non-recurring-cost.html>
- [4] *Recurring cost*. (n.d). Retrieved 10 May 2009, from <http://www.businessdictionary.com/definition/recurring-cost.html>
- [5] *Life cycle cost*. (n.d). Retrieved 10 May 2009, from <http://www.businessdictionary.com/definition/life-cycle-cost.html>
- [6] *Life cycle cost estimation*. (n.d). Retrieved 9 May 2009, from <http://www.directives.doe.gov/pdfs/doe/doetext/neword/430/q4301-1chp23.pdf>
- [7] Fuller, Sieglinde. (2008). *Life cycle cost analysis*. Retrieved 9 May 2009, from National Institute of Standards and Technology (NIST), National institute building sciences website: <http://www.wbdg.org/resources/lcca.php>
- [8] *Composites Industry Overview*. (n.d). Retrieved 12 May 2009, from American composite manufacturing association (ACMA), American composite manufacturing association (ACMA) website: <http://www.acmanet.org/professionals/index.cfm>
- [9] *Cars being lighter with composite parts*, (n.d). Retrieved 12 May 2009, from Chemeurope, Chemeurope website: <http://www.chemeurope.com/news/e/21737/?PHPSESSID=7c0d13b5fe35b0360130a032fcea732d>
- [10] *What are carbon fiber car parts?* (2008) Retrieved 12 May 2009, from concept rides, concept rides website: <http://www.conceptrides.com/blog/aftermarket-car-parts/what-are-carbon-fiber-car-parts>
- [11] *Automotive light weight car body parts*. (n.d.) Retrieved 14 May 2009, from Gurit, Gurit website: http://www.gurit.com/sector_introduction.asp?section=000100010009&itemTitle=Automotive
- [12] Cramer, David R. Taggart, David F. (2002). *Design and Manufacture of an Affordable Advanced-Composite Automotive Body Structure*, Retrieved 13 May 2009, from Hypercar inc, Hyper car website: http://rmi.org/images/PDFs/Transportation/T02-10_DsnManuAdvComp.pdf
- [13] Ungureanu, S. Das2, & I.S. Jawahir. (2007). *Life cycle cost analysis: Aluminum Vs steel in passenger cars*, University of Kentucky. Retrieved 10 May 2009, from: http://www.secat.net/docs/resources/Aluminum_vs_Steel_in_Passenger_Cars07.pdf

- [14] *Body in white*. (29 April 2009). Retrieved 13 May 2009, from http://en.wikipedia.org/wiki/Body_in_White
- [15] *Body in white*. (n.d). Retrieved 13 May 2009, from Babylon free dictionary, Babylon website <http://dictionary.babylon.com/Body%20in%20White>
- [16] Mason, Karen. (2004). *Compression molding press technology adapts to meet new composite material processing requirements*. Retrieved 15 May 2009, from composite world, composite world website: <http://www.compositesworld.com/articles/compression-molding-press-technology-adapts-to-meet-new-composite-material-processing-requirements.aspx>
- [17] *Fiberglass Fabricators Upgrades Open Mold Processing Equipment*. (n.d.). Retrieved 17 May 2009, from University of Minnesota, University of Minnesota website: <http://www.mntap.umn.edu/fiber/61-FibFab.htm>
- [18] *What are the different methods of composite manufacture in the automotive industry?* (2007). Retrieved 17 May 2009, from <http://uk.answers.yahoo.com/question/index?qid=20071121075603AAb1kGr>
- [19] Mascarin, Anthony E., & Dieffenbach, Jeffrey R.. (n.d). *costing the Ultralite in Volume Production: Can Advanced Composite Bodies-in-White Be Affordable?* Retrieved 18 May 2009, from The Hyper car Center, Rocky Mountain Institute website: http://www.rmi.org/images/PDFs/Transportation/T95-35_CostTheUltralite.pdf
- [20] Carbon fiber. (1996). Retrieved 20 May 2009, from department of polymer science, University of southern Mississippi website: <http://pslc.ws/macrog/carfib.htm>
- [21] Kirchain R, & Field F. R.(n.d) *Creating a process-based cost model*, Massachusetts Institute of Technology. Retrieved 19 May 2009 from website: <http://ocw.mit.edu/NR/rdonlyres/Materials-Science-and-Engineering/3-044Spring-2005/963C323F-364B-499E-BCA5-22C378094C3B/0/slides10.pdf>
- [22] Present Value, (7 June 2009). Retrieved 22 May 2009, from http://en.wikipedia.org/wiki/Present_value