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Development of Carbon Fibre Wheel Rims for Formula Student Racing Car

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Abstract

In order to improve the vehicle performance and improve fuel efficiency, the mass of the vehicle must be reduced. An effective way to do this is to construct the wheels out of a woven carbon fiber composite. In doing so, not only is the overall weight of the vehicle reduced, but rotation inertia and unsprung mass are reduced as well. Several designs were evaluated and one was selected for refinement. The final refined design reduced the weight of the wheel by nearly 50%. The project incorporated the design of wheel rims using CREO and SolidWorks, analysis of rims for safety via ANSYS composite pre-post and simulation software and finally in-house manufacturing of wheel rims with the method called Vacuum bagging technique. The wheel was then fabricated and future plans were made to validate and test the wheel.

Keywords— *Sprung Mass, Unsprung Mass, Epoxy Resin, Vacuum Bagging, Tooling*

I. INTRODUCTION

The performance of the car is of utmost importance when the design and analysis of the different components of the car comes into picture. Every year the team strives to design and re-model a car that is a better version of the preceding year. Bringing down the weight of the car to as low as possible is the ultimate goal, which further enhances the performance and elevates the speed of the car. Various ways are adopted to establish a substantial weight reduction of the sprung mass, which obviously leads to reduction in the overall weight of the vehicle but the ratio of sprung to unsprung mass grows apart. This leads to increase in the response time of the suspension system. In order to circumvent that, the unsprung mass of the vehicle should also be minimized. The usage of carbon fibre rims as a substitute to conventional aluminium rims lead to considerable reduction in weight. Research into lightweight components, materials and the related processes, has therefore become one of the main challenges in the automotive industry and has led to the substitution of standard steel with alternative materials in many components and systems. This can also be used for electric vehicles to increase battery efficiency and the distance covered by the car. This technique is not widely used because of the cost of carbon fibre sheets but manufacturing cost is constant. Popular companies such as BMW and MERCEDES have adopted this technique to reduce the weight of their vehicles.

II. AIM

The aim of this thesis is to manufacture a composite wheel rim using carbon fibre in order to lessen the unsprung mass of the car. To upraise the performance of the car and accomplishing higher speeds is the goal towards which each team member works. Creating a better version of the car includes

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reducing the weight, increasing the suspension response time, achieving greater control and acceleration, bringing the sprung to unsprung mass ratio closer to the original, reducing the vehicle's rotational inertia and hence improving the transient response time in both acceleration and braking.

III. Thesis Scope

This project will be utilized in a number of FSAE cars; through which students will be able to design, analyse and manufacture Carbon Fiber rims, used in automobile industry, which are much lighter than the conventional Steel or Aluminium rims. The use of the carbon fibre rims will assist in achieving greater control and better performance of the car. The wheel and tyre assembly contribute a significant portion of the vehicle's rotational inertia as the radius of gyration is much larger than that of the brake discs, hubs and drive train components. Reducing the vehicles rotational inertia will improve the transient response time in both braking and acceleration. There are a limited number of composite wheel products on the market for road cars, race cars and motorbikes in varying sizes. However due to the emerging nature of this technology manufacturers are not willing to provide information on their construction techniques. Also, buying the rim is hardly feasible for the teams which are self-sponsored. The final product can be developed in three phases:

1) *Phase 1:* This phase is about designing the rims according to the specifications of the car. The rim has to be designed as such that there would be feasibility in manufacturing the final product. Alongwith the specifications of the car the dimensions of the tyre should also be taken into consideration. CREO, SolidWorks and Catia might come in handy at the time of designing the rims. The final design is selected after the analysis of the rims such that the FOS obtained must be acceptable. This phase will also consist of the measuring of wheel loads and translating them into the wheel load cases using the ACME Racing design load cases document. The existing rim deflection will be measured through static loading that is illustrative of in-service loads. These deflections will be used as a yardstick that the composite rims have to accomplish when loaded in the equivalent means.
2) *Phase 2:* The rim is to be designed to meet the minimum stiffness and strength requirements using the known critical rim magnitudes and properties. The materials will then be transformed to observe the effect on stiffness, cost and weight on the rim to provide the best conciliation amid the three.
3) *Phase 3:* This phase entails the design and development of molds from which the ultimate part is to be made and the consequent manufacture of the prototype composite rim. This manufacturing phase will involve liaison with the school workshop and also the composites lab to use each department's facilities and engineering familiarity.

IV. Composite Materials Literature Review

A. Material Selection

Due to cost and availability three fibres have been considered for use in the manufacture of the wheels, these fibre families are glass, carbon and aramid fibres. Qualitatively, all three families have high ultimate tensile strength (UTS) (above 3GPa per fibre) however all have greatly varying tensile modulus from as low as 11GPa for some glass to in excess of 400 GPa for carbon. The increase in modulus is offset by the decrease in ductility and as such the reduced resistance to shock loading and the increased tendency to fracture as a result. The carbon family has the highest specific modulus, and the intermediate and high modulus fibres having the highest specific strength. Considering the specific

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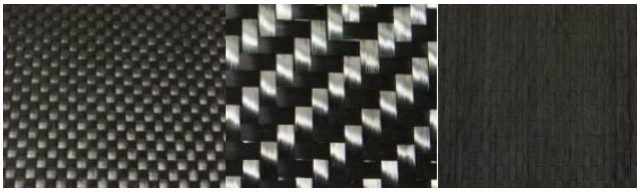
strength and modulus as the primary design factor carbon is the fibre family that has been chosen to use in the design of the composite wheel. Carbon also exhibits far less fatigue than a metal would and therefore does not have the fatigue life implications (Barbero, Introduction to Composite Materials Design, 2011). Handling of dry carbon fabric poses little hazards to the human body; however, post cure operations create hazards such as sanding, grinding and milling as these processes create small particles that can cause irritation to the lungs. Depending on the size of these particles they can become permanently lodged in the lining of the lung and diminish the function of the organ. As such, the appropriate PPE is required when working with composite materials.

B. Fabric selection

A fiber reinforced plastic was selected as the base material for the rim because they are generally considered to have a high specific strength over many metals. There are several different options for the fiber reinforcement material including glass, carbon, and kevlar. A comparison of the tensile modulus can be done, which leads to the conclusion that Carbon has the highest tensile modulus of about 85 Msi when compared to Kevlar 49, Kevlar 29, M-glass, E-glass, S-glass and Polyacrylonitrite. Carbon fiber was eventually chosen over glass and Kevlar, not only for its high specific strength, but because of the significant previous experience in the design and fabrication of carbon fiber components as well as the resources available to produce it.



(a) (b) (c)

Fig. 1 (a)Plain weave (b)Twill weave (c)Unidirectional stitch weave

Another consideration when selecting the material is the weave. The weave of the fabric influences the strength of the fabric in the different directions. Fibres can be biased to provide strength in the required directions. The main directions of the fabric that are most commonly referenced when describing the strength are the wrap and fill, or the 1 and 2 direction. The wrap fibers run along the length of the fabric and is considered the primary, or 0-degree direction. The fill runs parallel with the width of the fabrics and is considered the secondary or 90-degree direction. Generally, carbon fiber is commercially available in three different formats: unidirectional, woven, and braided sleeves. Important considerations in fabric selection are the fabric's drapability, the ease at which a fabric will conform to a surface without wrinkling (Barbero, Introduction to Composite Materials Design, 2011), and the comparative strength of the fabric along the principle axes, the specific fabric orientation is defined by the intended use of the fabric. For this project a woven fabric will be used. Braided sleeve was ruled out due to the specialty item cost of such a large diameter, as well as the difficulty in keeping the weave aligned while pulling the sock over the mold. Unidirectional was also ruled out due to the difficulty of handling the fabric during fabrication. A balance between commercial availability and handling during fabrication was found in a 3k twill. Twill fabric is when one fill yarn is fed over two and then under two warp yarns, appearing to create a constant diagonal of fill yarns and warp yarns alternately. This is a common type of weave and has an improved drapability over a complex curve when compared to a plain weave as the fibres have more freedom of movement. It still exhibits the same properties in two perpendicular directions (Strong, 2008).

C. Matrix selection

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The use of epoxy as a matrix has been chosen for this project. It is easy to work with, reasonably inexpensive and is the most common form of carbon reinforced preimpregnated fabric (prepreg) (Rosato, 1997), making it easier to obtain than some of the other resins available. Furthermore, epoxy resin systems emit limited quantities of styrene's compared to other resins and as such is less of a risk to the health of the manufacturer and other people working in the area (Huntsman, 2004). Epoxy resins can have an operational service temperature of up to 180 degrees C. They have high physical and adhesion properties and as they are the main resin used in the composite industry, make their acquisition for a low cost project more realistic than a rarer material. In its cured form, epoxy is considered to be a relatively safe material; it is not known to cause any allergic reactions. It is not carcinogenic and even in its dust form it is officially considered to be little more than a nuisance. However, prior to mixing the two parts of the epoxy are moderately toxic and can be corrosive. The two components have low vapour pressures so there is little risk to the user unless the chemicals are directly spilt onto them.

D. Core Materials

The use of a light weight core material can reduce the weight of a product by providing an increase in the height of the cross section of the layup. This increases the moment of area of the product and consequently increases the stiffness and reduces the stress. When the core is lighter than the material it replaces, it decreases the weight of the component and increases the specific stiffness and specific strength of the composite particularly in bending (Dorworth, Gardiner, & Mellema, 2009). When a core is used it is referred to as a sandwich panel construction. Cores can be made of any light weight material that will bond to a composite skin. A core can be a material as simple as balsa wood or as complex as XCOR® a carbon fibre reinforced foam developed for use in aircraft manufacture. Common cores also include paper, Kevlar® and aluminium honeycomb panels and also a mat known as LANTOR SORIc SF/XF. This initial conceptual design can be sized appropriately for the design loads and then analysed and further improved using greater FOS.

V. Design and Analysis

A. Design and Analysis Method

In order to design the rims according to the specifications of the car, the designing softwares such as CREO and SolidWorks were used. SolidWorks is definitely a seamless software for developing complex structures with accuracy. CREO being a comprehensible software, was used initially but some operations were very easily obtainable on SolidWorks. After designing a number of iterations, a final design was selected considering the feasible factor of safety alongwith minimum weight.

ANSYS Composite PRE/POST® (ACP) is an add-in to ANSYS Workbench and is integrated with the standard analysis features. The entire workflow for composite structure can be completed from design to final information production as a result. The ANSYS® product PRE/POST® (ANSYS® ACP) is a composite pre The ANSYS® product PRE/POST® (ANSYS® ACP) is a composite pre and post processor that has an intelligent user interface and still uses the ANSYS® solver, the script can also be saved before execution in order to be modified by the user for increased flexibility. This would be the ideal package to design and analyse the composite rim. Basis for analysis and evaluation is geometry of rim. Boundary properties and composite definitions are applied for model in ACP (Pre) mode. After processing, ACP (Post) mode used for evaluating design and composite material properties (Stress and load results in individual layers, evaluation of load capacity, failure criteria etc.)

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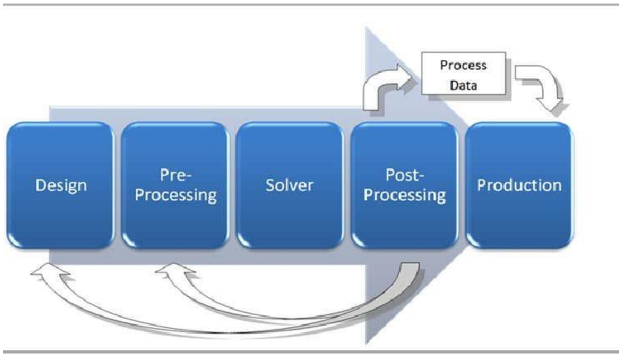

Fig. 2 Design process in ACP module, which has 5 steps

However due to the complicated nature of the shape that the fabric will be placed over, the fibres will not be in the same orientation that the FEA package assumes them to be. As such the calculated results will not be accurate and cannot be relied upon. In light of this the rim calculations will be conducted by hand and the final product tested to prove its strength. Conceptually, the forces imparted on the rim can be visualised as there are very clearly defined contact areas, this has driven the initial layup considerations of the rim. The drive/braking torsion loads are fed into the rim from the wheel centre and carried around the entire structure before being fed into the tyre through friction acting between the beads and the rim. These loads are best transferred through the use of a +/- 45-degree fabric so that they are balanced in both acceleration and braking.

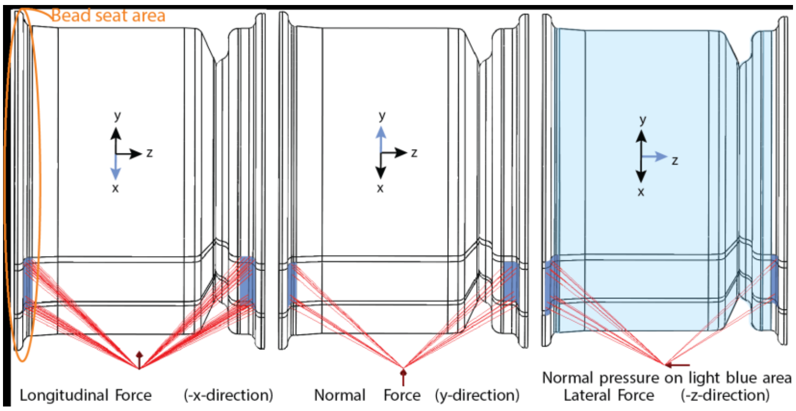

Fig. 3 Three different force components (blue faces) and one pressure (light blue faces) applied on the rim

The vertical loads are taken on the bead surfaces as a bearing load, in addition to the initial preload on the rim surface, as this takes the form of a hoop stress it is best supported through the use of a unidirectional tape forming a cylinder under these loaded areas. Finally, the lateral loads will be in compression and tension, through the surface of the rim in the axially biased fibres. This initial conceptual design can be sized appropriately for the design loads and then analysed and further improved.

B. Manufacturing Methods

There are numerous methods for fabricating composite components. These all require the use of some sort of mold to determine the shape and ensure dimensional accuracy of the finished component. High-performance parts using single molds are often made with the vacuum-bagged technique.

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As the profile of the rim has the symmetric shape and it can be formed on a simple one-piece mold. Hence the vacuum bagging technique is selected for the manufacturing of the rims. The mold is made up of glass-fiber material as its low cost, availability, mouldability is high compared to high-cost aluminum molds. The glass fiber mold is made with the help of a wood pattern for better dimensional accuracy and low thermal conductivity which is required for the manufacturing of mold. To apply the resin to the fabric in a vacuum mold, the wet layup is used which is a manual method where the two-part resin is mixed and applied before being laid in the mold and placed in the bag.

Then the bag is sealed over the wet laid-up laminate and onto the mold. The air under the bag is extracted by the vacuum pump and up to one atmosphere of pressure can be applied to the laminate. This compression under the vacuum helps remove air voids, and excess gas going off during curing.

VI. CONCLUSIONS

The Carbon fiber designed wheel rim demonstrates significant weight reduction with comparison to the conventional aluminum wheel rims which leads to the achievement of the report's objective to lessen the unsprung mass of the vehicle. Subsequently, it led to the optimization of the ratio between the vehicle sprung and unsprung which improved the control characteristics and handling of the vehicle and therefore, the vehicle gives better performance on the race track. Lighter the unsprung mass, faster will be the response time, allowing better acceleration, braking, and cornering physiognomies.

The wheel rims are designed without overlooking the structural strength, reliability of the manufactured component. Also, the rims have high efficacy because of the selected manufacturing technique, i.e., Vacuum bagging. The tooling cost required for manufacturing is relatively low due to the usage of wood patterns and glass fiber mould. The wood is replaced with the aluminum pattern, which also leads to less tooling cost with required dimensional accuracy. Glass fiber mould which has high manufacturability and availability in the local market contributed to the feasibility in manufacturing.

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