DESIGN AND DEVELOPMENT OF COMPOSITE RIM

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Abstract: Reducing the weight of a racing vehicle can substantially increase its performanceand durability abilities. The un-sprung mass is mostly made up of the tires, wheels, and other components housed within the wheel package.So, the idea of a lighter composite wheel is proposed, with the goal of developing a lightweight and stiff wheel, by optimising the design and using FEA methodology, in this project carbon fibre reinforced plastics(CFRP) is used as an alternative to conventional alloy wheels.

Index terms – Carbon fibre, Rim, Epoxy, Layup.

I. INTRODUCTION:

The wheel (rim) is a critical component in its form and function with respect to vehicle motion in the automotive industry. In the last decade, wheel manufacturers have focused on lightweight wheel designs. This was done by introducing new materials and manufacturing technologies, which are in line with the changing requirements in the automotive industry

II. Significance of wheel mass

As is the case with most components, the mass of the wheels can have a significant effect on the vehicle dynamics and performance of a race car. The simple concept of Newton's second law provides quick proof of this; in general, if a vehicle's mass is reduced it can accelerate more quickly. Going beyond affecting overall vehicle weight, the wheels have additional significance as a rotating and un-sprung mass.

As a rotating mass, the wheels affect the car's longitudinal motion with regards to their rotational acceleration. Longitudinal motion can be described by an equilibrium equation that combines the car's driving forces and resistances in the longitudinal direction, expressed as

$$F_{drive} = F_{\mathrm{R,air}} + F_{\mathrm{R,roll}} + F_{\mathrm{R,grade}} + F_{\mathrm{R,acc}}$$

SYMBOL	RESISTANCE FORCE	DESCRIPTION
$F_{\mathrm{R,air}}$	Aerodynamic resistance	-Resistance due to aerodynamic drag
$F_{\mathrm{R,roll}}$	Rolling/frictional resistance	-Resistance from tyres rolling on surface -Frictional resistance from moving components such as power train, transmission and suspension
$F_{\mathrm{R,grade}}$	Grade resistance	-Resistance due to gravity on inclined road surface
$F_{\mathrm{R,acc}}$	Acceleration resistance	-Resistance from all rotating components due to their rotational inertias

Here, Fdrive is the driving force applied by the car's power train and the terms on the right side represent the resisting forces

III. General theory:

Composite Materials

A material is considered a composite if there are two or more materials that are combined on the macroscopic level to develop a third material. Composite materials are usually designed to exhibit the best qualities of its constituents and/or new qualities altogether. This broad definition means that the list of composite material possibilities is endless, but there are four commonly accepted general types: fibrous, laminated, particulate, or some combination of those three.

Laminated fibre-reinforced plastic (FRP)

For the purposes of this project, FRP laminates are made up of layers, or laminae, of long continuous carbonfibres in a unidirectional or woven arrangement and in a epoxy matrix. In these laminae, the fibres are the principal load-carrying constituent and the matrix provides support, protection and a means of distributing and transferring loads between the fibres. Laminates are simply stacks of laminae bonded together. The orientation and specific material type of the stacked laminae can differ to provide various possibilities of macro mechanical behaviours.

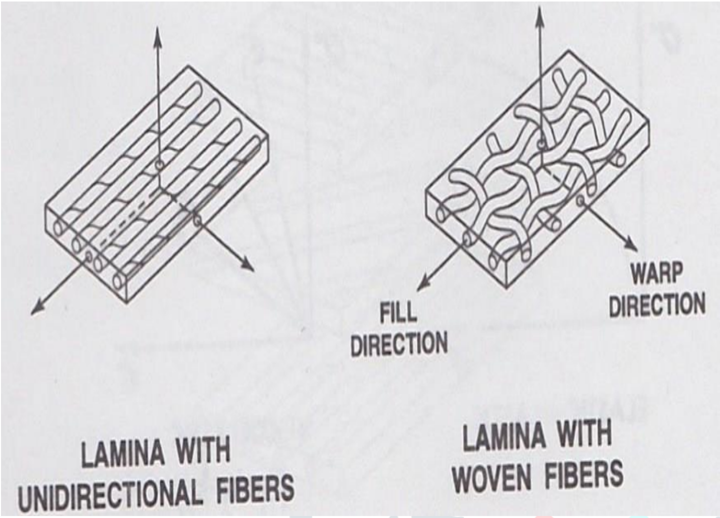


fig 1. Lamina orientations

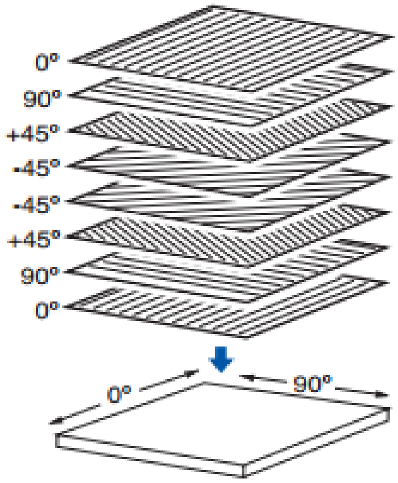


fig 2. Layupsequence

Carbon Fibre Reinforced Plastic (CFRP)

For the development of a composite rim described in this thesis, the choice was made to use carbon-epoxy fibre reinforced plastic, or CFRP. Carbon fibres are widely used in the aerospace and automotive racing industries, mostly due to their characteristic high specific strength and chemical resistance. Manufacturers are able to produce carbon fibre material with a wide range of stiffness and strength values, more so than for other fibre materials. Having a high stiffness-to-weight ratio makes carbon fibre material a great choice for racing wheels. The major limiting factor is the material’s cost. So, the use of carbon fibre is only economically practical in instances where weight savings provide a large payoff and it “is used as an enabling material rather than a substitution material”

IV. <u>Methodology:</u>

Material Selection

When it comes to an automotive wheel, there are a number of material options that can be used to create a product that serves the basic function. Currently, the most conventional materials used for wheel production are metals like steel or aluminium, and generally these materials work just fine for most road cars and production vehicles where optimizing handling and high-speed driving performance may not be the most important goal, unlike the case for race cars. However, when weight reduction is a significant factor for race cars, it seems that the lightest metallic options have plateaued in terms of reaching minimum weight while still providing necessary strength and stiffness. It is for this reason that composite materials are considered as an alternative throughout this report. Particularly, CFRP is chosen for development of the new racing wheel due to its high stiffness-to-weight ratio.

Choosing the specific CFRP

There are many types of CFRP that are commercially available. For this project, the specific materials available are those that are currently in the possession of the CPDC.

Carbon fibre T700 in the form of spools were used for unidirectional winding along with epoxy resin 1555 and hardener 5200. The hardener was first heated up to 40°C to reduce its viscosity and provide a better mixture of the hardener consequently.

The macro/micromechanics and density of the material, which are defined in the engineering data.

V. Calculation:

Bending test

The bending moment to be imparted in the test shall be in accordance to the following formula:

M = ((μ×R) + d) × F ×S

M = Bending moment in 'Nm'

μ = Friction Coefficient between the tyre and the road surface (no units)

R = Radius of the tyre applicable to the wheel in 'm'

d = Offset of the wheel in 'm' =40 mm =0.04 m

F = Maximum load acting on the tyre in 'N'

S = Coefficient specified according to the standards.

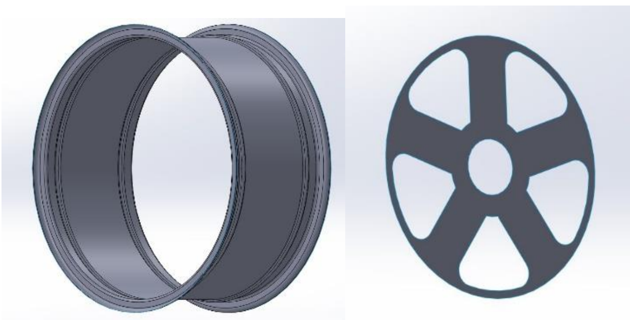
Tyre specification Radial 205/65 R15

- 205 is the section width in millimetres
- 65 is the Aspect ratio in percentage
- R is the construction type i.e., Radial
- 15 is the rim diameter in inches
- Aspects ratio = section height / section width
- Section height = Section width * Aspect ratio
  = 205 * 0.65 = 133.25 mm = **0.133 m**
- Rim diameter = 15 inches = 15* 2.54 = 38.1cm
- Rim radius = 19.05 cm = 0.19 m
- Tyre radius = Rim Radius + Section height
  = 0.19 + 0.133 = 0.323 m
- According to the industrial standards μ = 0.7
- F = 1400 lbs = 1400 * 0.453 = 634.2 kg = 634.2 * 9.81 = 6221.5 N S = 1.5
- Bending moment M = ((μ*R) + d) * F * S
  = ((0.7 * 0.323) + 0.04) * 6221.5 * 1.5

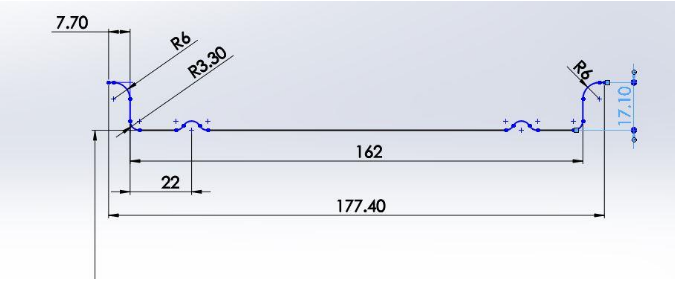
= 2483.3Nm

VI. DESIGN:

- A surface model of the rim was created using solid works surface modelling.Surface model allows for the definition of the rim thickness, through material design in the FEA software platform. The material design was done by setting the material properties, stacking sequence and orientation of the plies. The rim mainly consists of two parts the rim flange and the wheel plate.
- The Dimensions of the rim were taken by subjection of a reverse engineering idea on the wheel rim of a maruthi Suzuki Swift desire car of 2010 model following are the corresponding tyre ratings 205/65 R15 with a maximum load capacity of 870 kg (1477 lbs) at 300 kpa(44psi).
- The design of the composite rim was divided into two different components namely rim and wheel plate appropriate moulds were designed to meet the required specifications in accordance with the available tyre dimensions.



Rim Wheel Plate



Rim Profile

- The transition between the components is to be reinforced for better dissipation of the forces. therefore, the understanding of this geometry and stress plots was essential before moving into the FEA (ANSYS) phase

VII. ANALYSIS:

Finite element analysis (FEA):

FEA carried out on the composite road wheel is dealt in this section. The analysis of metallic components and composite components are quite different. The analysis of polymer matrix composite (PMC) requires complex technique of modelling and formulation. The FEA for composite can be used to evaluate the strength as well as for understanding the defects like de-bonding and de-lamination. The software used is Ansys Composite Pre-Post(ACP). A lamina consists of fibre and matrix. The lamina properties depend on the fibre orientation.

- The process flow is outlined in the project schematic. Static Structural is interfaced with ACP in order to clearly define composite properties. The functional blocks of the project schematic are outlined below

ANSYS COMPOSITE PREPOST:

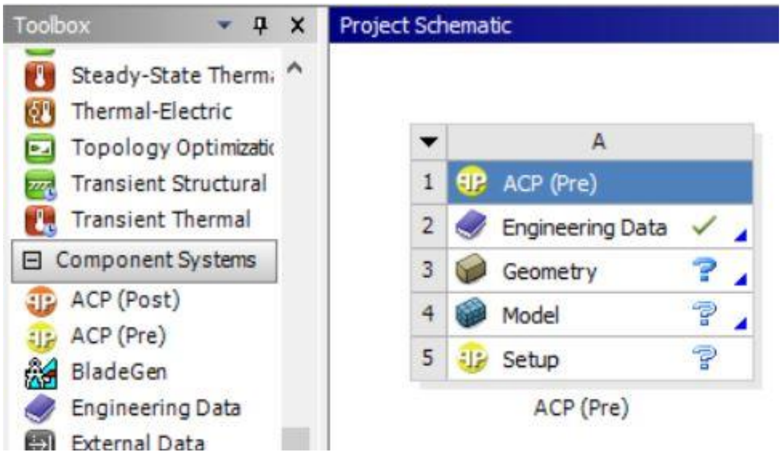
Engineering layered composites involves complex definitions that include numerous layers, materials, thicknesses and orientations. The engineering challenge is to predict how well the finished product will perform under real-world working conditions. This involves considering stresses and deformations as well as a range of failure criteria. ANSYS Composite PrePost provides all necessary functionalities for the analysis of layered composite structures.

KEY FEATURES:

- Support for material layer information in assemblies
- A wealth of tools for defining stacking and orientation of composite layers
- Draping and Flat Wrap
- Output of ply books
- Post processing environment specifically designed for composites
    - A wide choice of state-of-the-art failure criteria models
- 3D Shell elements for thin composites
- 3D Solid elements for thick composites

PROCESS OF OPERATION:

- ACP is incorporated in the WB architecture of the ansys software. One can simply drag the subsystem into the standalone system.



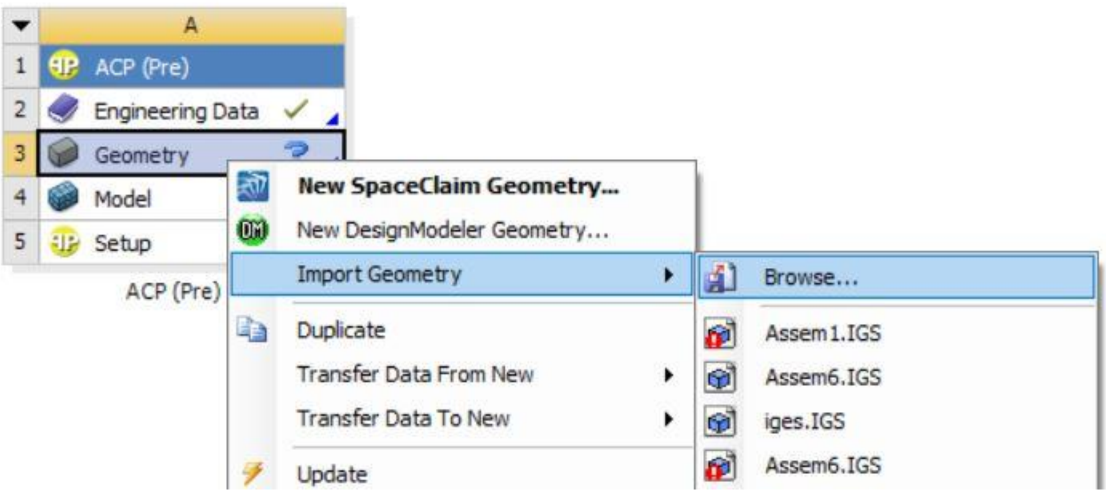
Ansys WB architecture and standalone systems.

- Once the acp module is started the material selection can be performed in the engineering data.

Properties of Outline Row 6: Epoxy Carbon Woven (230 GPa) Prepreg

	A	B	C
1	Property	Value	Unit
2	Density	1.42E-09	mm^-3 t
3	Orthotropic Secant Coefficient of Thermal Expansion		
8	Orthotropic Elasticity		
9	Young's Modulus X direction	61340	MPa
10	Young's Modulus Y direction	61340	MPa
11	Young's Modulus Z direction	6900	MPa
12	Poisson's Ratio XY	0.04	
13	Poisson's Ratio YZ	0.3	
14	Poisson's Ratio XZ	0.3	
15	Shear Modulus XY	19500	MPa
16	Shear Modulus YZ	2700	MPa
17	Shear Modulus XZ	2700	MPa
18	Orthotropic Stress Limits		
19	Tensile X direction	805	MPa
20	Tensile Y direction	805	MPa
21	Tensile Z direction	50	MPa
22	Compressive X direction	-509	MPa
23	Compressive Y direction	-509	MPa
24	Compressive Z direction	-170	MPa
25	Shear XY	125	MPa
26	Shear YZ	65	MPa
27	Shear XZ	65	MPa
28	Orthotropic Strain Limits		
29	Tensile X direction	0.0126	
30	Tensile Y direction	0.0126	
31	Tensile Z direction	0.008	

- An IGES format of the surface model is required into this subsystem as it provides a base for the layup stacking sequence
- The geometry is imported into the module further operations are performed into the model.

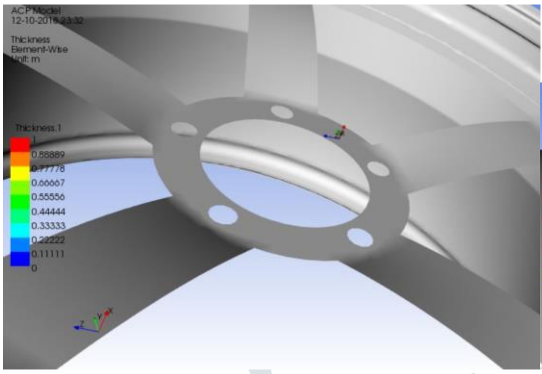


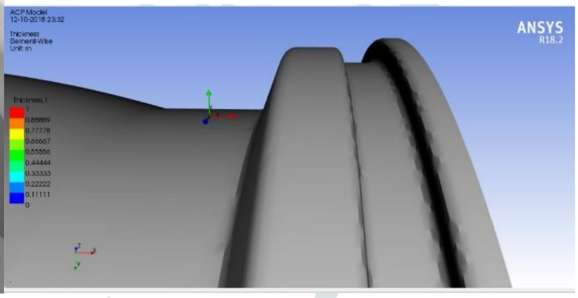
Importing geometry in IGES format.

- There is a process involved which allows the user to create desired amount of layers in the stackup corresponding to respective coordinate systems, which are nothing but the number of different components involved in the geometry which can be specifically named in the option on named selecions this process is known as segmentation.

Segmentation:

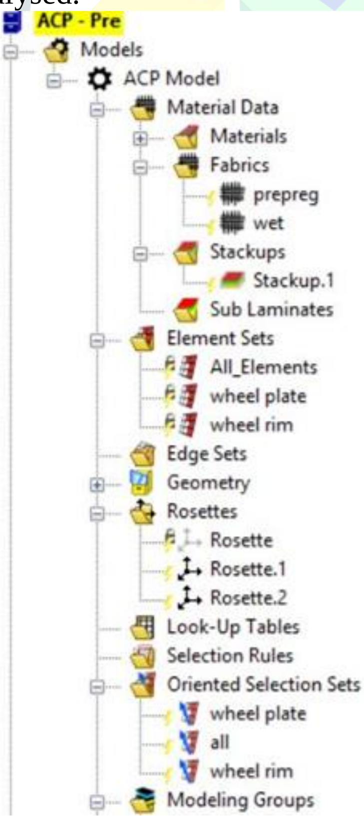
The rim was segmented into components that make up the rim. Material flows from segment to segment to form the entire rim. These components are unique and have their own stacking sequence and ply orientation. Each component has a coordinate system, which was used in the stacking sequences.





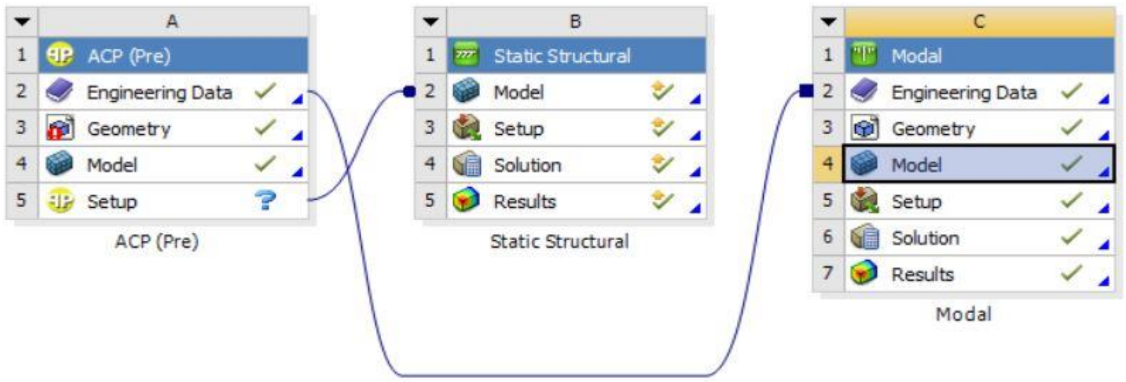
Co-ordinate system 1 Co-ordinate system 2

Two different coordination systems are used for the rim and the wheel plate. This feature allows us to create different thickness at the critical areas. The orientation and placement of the plies is dependent on the components co-ordinate system. once the coordinate systems are defined the fibres are created along with the element sets and the rosettes and modelling groups are made. A stack up of laminates is created with various orientations and can be separately analysed.



Process tree in ACP

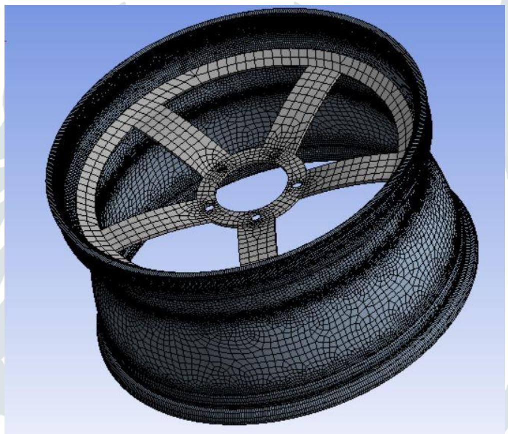
After careful selection of the material, fabric , orientations sets ,element sets and rosetts the complete ACP model is dragged into the static structural model for the application of forces depending on various load scenarios.The process flow is outlined in the project schematic. Static Structural is interfaced with ACP (Ansys Composite Pre-Post) in order to clearly define composite properties. The functional blocks of the project schematic are outlined below.



VIII. MESHING:

After the composite modelling the ACP was interfaced with the static structural sub system of Ansys 18.2 and the meshing was performed using tetrahedral element.The assumptions made regarding the tetrahedral element are:

- Zero thickness elements are prohibited
- No slippage is assumed between the element layers
- Six DOF



Mesh using tetrahedral elements.

The constraints were taken on the holes provided for bolting purpose and the loads were applied

The loading cases include the inflation pressure load and the weight on the vehicle divided into four tyres and the results include deformation and equivalent von-mises stresses. A modal analysis was also performed on the rim

Loading cases:

Bending moment:

In the case of bending test, a vertical load of 2755.16 N is applied at a distance of 1 m from the centre of the hub. Before applying the load, the model should be meshed property. There are six degrees of freedom of which there are three translations and three rotations. The type of constraints depends upon the type of model. In our case we have arrested all the six degrees of freedom. In case of wheel outer rim is constrained for all six degrees of freedom. The outer rim is selected by means of a selection set. The load is applied to the node in Y direction (downward direction) after the constraints are specified for the model. Before running the analysis, the model should be feed with sufficient data such as material property, real constants and element group.

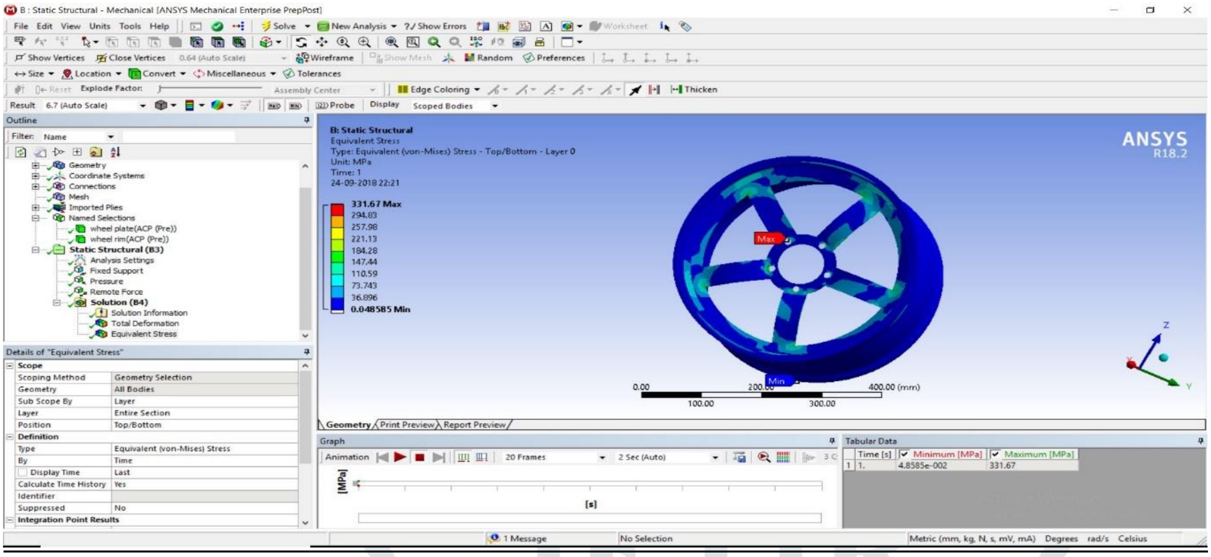
Under material property, the property such as density, Poisson's ratio, Young's modulus should be given as data for material, which have been selected for the model

Inflation pressure:

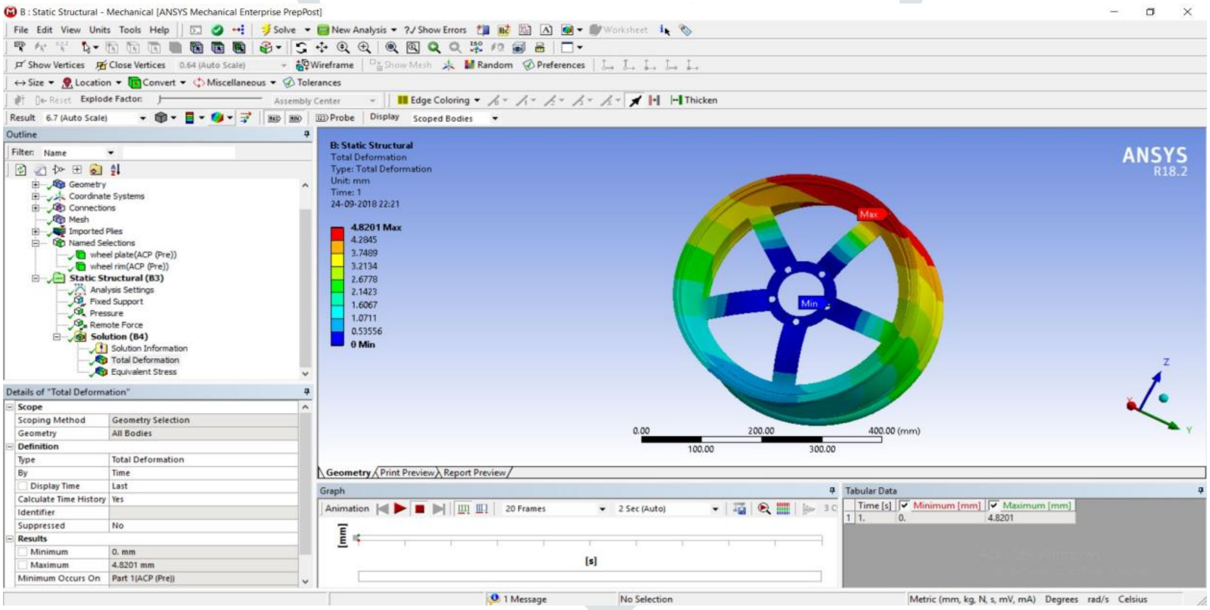
In case of pressure loading, the pressure of 40 PSI is applied through the circumference of the wheel. Before applying the load, the model should be constrained properly. The type of constrain depends upon the type of model. In our case we have constrained all the six degrees of freedom. In the case of pressure loading, bolts are constrained for all six degrees of freedom. The bolt is selected by means of a selection set.

IX. RESULTS:

- The loads were applied in the static structural after the meshing.



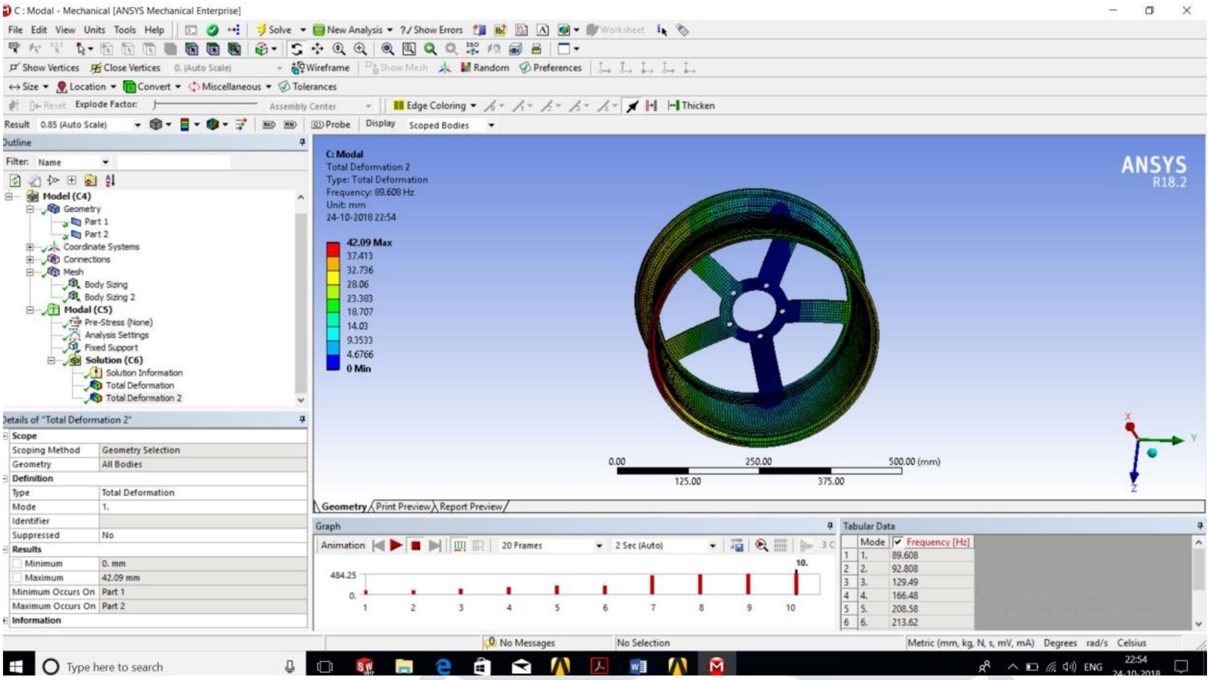
Equivalent stress: 337.67 Mpa.



Total deformation: 4.489 mm

MODAL ANALYSIS

- Frequency: 86.608 hz.
- Deformation: 42.09 mm



Mode	Frequency
1	89.608
2	92.808
3	129.49
4	166.48
5	208.58
6	213.62
7	451.12
8	463.8
9	475.94
10	484.25

X. Manufacturing

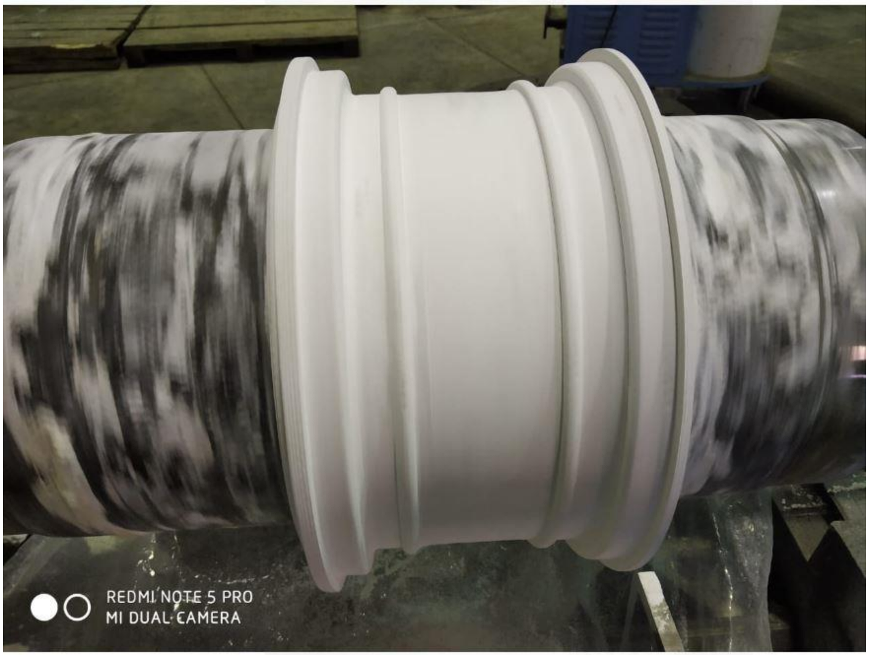
- This chapter discusses the methods and processes practiced for the manufacturing of the composite rim developed within this thesis.

Moulds:

- A mixture of plaster of Paris, Fevicol and water was used to create a mould for the rim and the machined manually on a lathe machine according to the required dimensions.
- A 300 diameter Mandrel was used and the POP paste was applied with a rough diameter up to 400 diameters the mandrel was installed on to a lathe and machined therefore creating the appropriate profile for the layup. The figures below show the mould preparation for the rim.

Before machining.

Rim mould machining



Rim profile after careful machining.

XI. Composite Manufacturing Process

- There are several steps involved in the manufacturing of a laminated composite structure, and those taken for the manufacture of the CFRP 5-spoke rim

Lamina preparation

- Because there are two main pieces namely the outer rim and wheel plate that are riveted together, the layup occurs in two basic steps. To describe briefly, however, the unidirectional CNC helical winding provides the necessary radial strength for the rim. But due to discontinuity along the axial direction the shear strength was unable to achieve, for this purpose a woven fabric was alternately introduced during the layup.
- With a thickness of 0.5 mm 10 layers were used to create a rim thickness of 5 mm.
- Before the application of any type of fabric on the mould a release film was used to cover it for better removal of mould.
- In the manufacturing of the wheel plate a polyutherene foam was used as a core material onto which the layup was performed. The foam was machined on a lathe and the complex profiles were manually machined

Before and after images of the foam

Once the foam was machined into the required shape a hand layup was performed the layup was done entirely with a woven fabric for better adhesion purpose carbon fibre spool was used to wind up near the critical areas. Finally, both the parts were heated in an oven for about 6 hours at a temperature of 180°c and for 4 hours at 160°c.

XII. Bonding process:

- Aluminium rivets were used to mechanically bond both the parts between the spokes for this purpose appropriate holes were drilled around the circumference of the rim.

- Apart from this a room temperature resin with a ratio of 50:40 grams of resin and hardener were mixed respectively at room temperature and was used to make a strong conjunction at the interface.

Prototype:

After layup

While the FEA simulations provide promising results for the expected performance of the 5-spoke composite wheels, it is recommended that physical testing of a prototype be conducted for validation. There are several standardized testing procedures that automotive wheel manufacturers must subject their designs to in order to receive certification for safe use on public roads, however these tests require high-end equipment and facilities

XIII. Installation of the tyre:

As the conventional lever based installation was vulnerable for the finishing of the an automatic tyre installation machine was used as this way the effort is more on the tyre compared to the rim.

Automatic tyre installation machine.

A hole was drilled in the rim such that the tube valve emerges at an outward angle for better inflation purpose this was done at the time of bonding.

Installation of the tyre

XIV. CONCLUSION:

The 5-spoke rim exceeds the goal of maintaining the stiffness of a commercial aluminium option while significantly reducing the weight and maintaining structural integrity. As designed for the specific load cases studied herein, the 5-spoke rim provides almost 19% higher stiffness than the aluminium wheel and at 2.5 KG, the manufactured prototype is 60% lighter. The weight loss in the wheels alone can benefit the cars acceleration and handling by reducing rotational, unsprung mass. This will lead to a more agile and responsive race car, especially if additional vehicle weight loss strategies are employed.

XV. References

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