K. J. SOMAIYA COLLEGE OF ENGINEERING

Design, Analysis and Manufacturing of Carbon Fibre Rims

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Team ETA

Table of Contents

ABSTRACT

Motivated by the persistently pursued weight reductions in a vehicle projected for a fuel efficiency competition, this project deals with designing new and lighter rims for the vehicle. The aim of the project is to design the rims with a carbon-fibre reinforced polymer, a lightweight composite material. A profound study on this kind of material is also presented, since it could be useful for lighten, subsequently, other parts of the vehicle. The project is based on a review of literature to acquire a theoretical framework. The design process and its validation is supported by finite element analyses.

The preliminary design starts with a closed V profile, which appears to be a viable and adequate option for the application. The rim is divided into two parts, the contour and sidewall. By modeling and simulating the rim, the profile of each part is optimized and Information about the stress´s state is acquired. Therefore the layered structure for the different parts is defined by taking the optimum proportions of the fibre's orientations into account. The parts are then simulated making use of a layered element which in the end validates the design.

The reserve factors found are 1.26 for the contour and around 1.5 for the sidewalls, which indicates the good adjustment of the design between safety and performance. On the other hand, estimation for the weight reduction is calculated, which achieves values around 35% on the better cases. With further work on the manufacturing process the design can in the end offer a reasonable saving of weight.

CHAPTER - 1
INTRODUCTION

This introduction offers a brief contextualization on the topic as well as the aims and limitations of the present project. The disposition of the project is also explained.

1.1 Background

With the world involved in an advancing global warming, we have started to be concerned about the environment and how we could take care of it since just few decades ago. Nowadays the strategy has changed into reduce consumptions and pollution. The governments and institutions are now setting aims of decrease the emissions during the next decades (the EU has committed to cutting its emissions to 20% below 1990 levels). Accordingly, lately the research and industry faces with reduce consumptions and develop new and green energy sources.

The automotive sector has been dragged to innovate in this way as well, in order to reduce emissions and increase the fuel efficiency (road transport alone contributes about one-fifth of the EU's total emissions of carbon dioxide ($CO2$)). This is done by improving old technologies and developing new ones. One of these growing new technologies is in the field of materials engineering. Coming from aerospace and aeronautic industries, now the composite materials are being introduced to the automotive sector.

Composite materials have the potential of reducing the vehicle weight substantially while maintaining great mechanical properties and this, of course, has a direct effect on fuel consumption. One of the remarkable composite materials with a large future in this sector is the group of carbon fibre reinforced polymers (CFRP).

1.2 Purpose

The purpose of this project is to develop a rim for an efficiency competition vehicle. More specifically, it will be for the vehicle from the team of the K. J. Somaiya College of Engineering called Team ETA which participates in the Shell Eco-marathon®. In this competition, participants design and build their vehicles to achieve the highest possible fuel efficiency. One of the things that the Team ETA wants to do, to further improve the vehicle, is to reduce the weight of the current rims. The current aluminum rims are bicycle rims adapted, therefore they thought about building these ones with a lighter material as could be a composite material. This, then, is the purpose of the present project.

1.3 Aims

The aim of the project is to develop a rim made of carbon fibre reinforced polymer (CFRP). The rim has to withstand safely the stresses imposed by the characteristics and operating conditions of the Team ETA's vehicle, and also be as light as possible. The project also seeks to give an overview of the carbon fibre reinforced polymers, presenting its traits and properties to finally size the laminate for the rim. The design aims match with the parts already selected or designed by the Team ETA.

1.4 Boundaries

The project has aims to complete but also frontiers so that the purposes will not be lost. These ones are:

- The tire for the wheel is already selected so it will be out of the study.
- The shaft that connects the wheel with the vehicle's body is already dimensioned and it is one of the limits of the design as well as the break system.
- Any business plan for commercialization is also out of this project.

CHAPTER - 2
LITERATURE REVIEW

The first bicycle wheels followed the traditions of carriage building: a wooden hub, a fixed steel axle (the bearings were located in the fork ends), wooden spokes and a shrink fitted iron tire. A typical modern wheel has a metal hub, wire tension spokes and a metal rim which holds a pneumatic rubber tire. Now this year we are going to make Carbon Fibre Rims Wheel. This is first in India by any Student team for Prototype vehicle for Team ETA, K J Somaiya College of Engineering. Here are some basic descriptions about previous wheel.

2.1 Hub

A hub is the center part of a bicycle wheel. It consists of an axle, bearings and a hub shell. The hub shell typically has two machined metal flanges to which spokes can be attached. Hub shells can be one-piece with press-in cartridge or free bearings or, in the case of older designs; the flanges may be affixed to a separate hub shell.

2.2 Spokes

The rim is connected to the hub by several spokes under tension. Original bicycle wheels used wooden spokes that could be loaded only in compression, modern bicycle wheels almost exclusively use spokes that can only be loaded in tension. There are a few companies making wheels with spokes that are used in both compression and tension.

One end of each spoke is threaded for a specialized nut, called a nipple, which is used to connect the spoke to the rim and adjust the tension in the spoke. This is normally at the rim end. The hub end normally has a 90 degree bend to pass through the spoke hole in the hub, and a head so it does not slip through the hole.

2.3 Rim

The rim is commonly a metal extrusion that is butted into itself to form a hoop, though may also be a structure of carbon fibre composite, and was historically made of wood. Some wheels use both an aerodynamic carbon hoop bonded to an aluminum rim on which to mount conventional bicycle tires.

Metallic bicycle rims are now normally made of aluminum alloy, although until the 1980s most bicycle rims - with the exception of those used on racing bicycles - were made of steel and thermoplastic.

The cross-section of a rim can have a wide range of geometry, each optimized for particular performance goals. Aerodynamics, mass and inertia, stiffness, durability, tubeless tire compatibility, brake compatibility, and cost are all considerations. If the part of the cross-section of the rim is hollow where the spokes attached, as in the Sprint rim pictured, it is described as box-section or double-wall to distinguish it from single-wall rims such as the Westwood rim pictured. The double wall can make the rim stiffer. Triple-wall rims have additional reinforcement inside the box-section.

Aluminum rims are often reinforced with either single eyelets or double eyelets to distribute the stress of the spoke. A single eyelet reinforces the spoke hole much like a hollow rivet. A double eyelet is a cup that is riveted into both walls of a double-walled rim.

2.4 Composite Material

Overall performance of Aluminium rim is satisfactory. But the major two drawbacks of this are poor aesthetics as well as poor weight to stiffness ratio. So to eliminate this two major drawbacks, this year we are going to make Carbon fibre rims. Now we will see some basics of carbon fibre and carbon fibre rims.

A composite material is formed for two or more different materials or phases, the matrix and the reinforcements. The matrix is the weak part that contents the reinforcements and 3transmits the loads. The reinforcements are usually strong fibres which support the main part of the load.

The characteristics of a composite material depend on the combination of reinforcement and matrix. Different combinations of matrix and reinforcement derive on a material with more stiffness, or more strength, or more thermal resistance, etc. Therefore this versatility is an advantage that the composite materials have. Another great convenience is that they are usually lighter than the common engineering materials (like metals) while maintaining high mechanical properties. So when working with composite materials, it is not only about design one product or piece, it is also about choose the right compound matrix–reinforcement to achieve the right material.

One of the more promising composite materials is the fibre reinforced polymer composite, widely used on the aerospace and aeronautic industries and it is starting to be important on automotive industry. In particular the carbon fibre reinforced polymer (CFRP) presents an excellent combination of low density, high modulus of elasticity, high fatigue resistance and thermal stability. This project will therefore focus on the carbon fibre reinforced polymers (CFRP) since it is considered the optimum material for the application studied.

The carbon fibre can be found in two main types, with high modulus of elasticity (HM) or with high strength (HR). The difference of properties is due to its different routes of production. Carbon fibre is usually continuous, with a diameter around 7 µm. The fibre itself presents a grade of anisotropy since the modulus of elasticity is totally different in the longitudinal direction of the fibre than in the radial one. It can be seen on the Table 2, which lists their main mechanical properties. Note that these can vary due to many causes; this table just provide generalized information to give an order of magnitude.

Property	Symbol	Values for type of carbon fibre		Units
		(HS)	*(HM)*	
Density	ρ	1.750	1.800	kg/m^3
Modulus of elasticity axial	E_l	230.000	390.000	MPa
Modulus of elasticity radial	E_r	15.000	6.000	MPa
Shear modulus	G	50.000	20.000	MPa
Poisson ration	ν	0,3	0,35	-
Tensile strength	σ_{rupt}	3.200	2.500	MPa
Useful Temperature limit	T_{max}	>1.500	>1.500	ºC

By using above property of carbon fibre, we are going to make carbon fibre rims which results in high percentage of weight reduction and also better performance characteristics.

CHAPTER - 3
SUMMARY OF LITERATURE REVIEW

After doing so much research on carbon fibre material, we comes on conclusion that making of carbon fibre rims is very much useful in today's scenario as well as it really helpful in our prototype vehicle of Team ETA in Shell Eco Marathon 2018. It gives drastically weight reduction and gives better aerodynamic consideration.

The vehicle was driven in different condition states. When it was driven in cities, it showed greater fuel economy advantage from weight reduction than highway or steady state. The reduction of vehicle weight resulted to higher acceleration of the vehicle, thus giving less rolling resistance from the tires. The engine is at higher throttle operating points and provides less opportunity for improvement. The potential for fuel economy gain from weight reduction is greater at lower vehicle speeds. At lower speeds, tire losses increases in percentage of total tractive effort.

CHAPTER - 4

METHODOLOGY

The next step was to understand correctly the functions and requirements that the design had to accomplish. This part took care of the joints between the rim and the already designed or selected parts on the vehicle and also of the competition's rules. Furthermore the loads that the rim had to withstand were calculated using the classic physic and mechanic laws. According to the timeline of our competition, we decided to follow the below methodology to make carbon fibre rims.

Design

- Esthetics
- Ergonomics
- Hub Design
- Mould Design

Analysis

- Analysis of Carbon fiber disc unsin ANSYS ACP
- Analysis of Hub in ANSYS 18.0
- Full assembly analysis

Manufacturing

- MDF Pattern
- Aluminium mould using Sand Casting procress
- Machininf of Casted mould for finishing cut on VMC
- Manufacturing of CF Disc from mould
- Hub machining on CNC Lathe
- Assembly of Disc and Hub using Loctite as bonding agent

Testing

- Idle Testing
- On road testing

Now we are going to see the details of each and every step which is followed by above methodology.

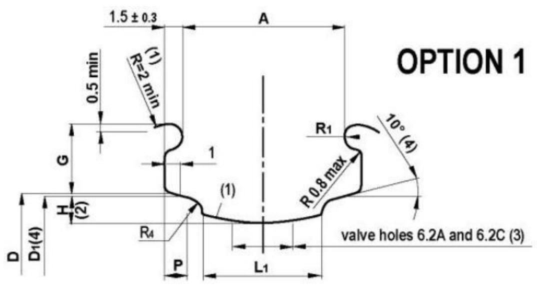
4.1 Design:

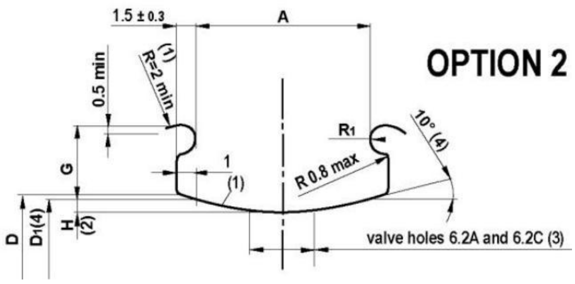
4.1.1 Aesthetics & Ergonomics:

As per the rules and regulation of competition, the ergonomics is decided. Also we use Michelin tyre so we have to design our Carbon fibre rims according to their standard diminution. Below are the table which includes the variety of standard dimension of rim as well as the profile of rims which suits to our tyre.

As we used carbon fibre material, our aesthetics is already above the line. Because carbon fibre itself has a high aesthetics property.

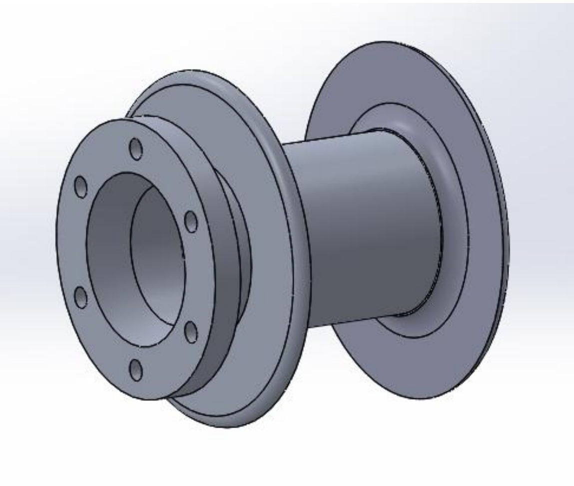
Rim contour	DIMENSIONS (mm)									
	A ±0,5	G ±0,5	H min.	H max	L_1 min.	P min.	R_1 ±0,25	R4 min.	D	D_1 ±0,5
406x19C	19	6	2.2	6	11	3	1.5	1.5	405.6	405.25
406x21C	21	6	2.2	6	11	3	2	2	405.6	405.25
406x23C	23	6.5	3.5	6.5	11	3	1.1	2.5	405.6	405.25
406x25C	25	6.5	3.5	6.5	14	3	1.1	2.5	405.6	405.25

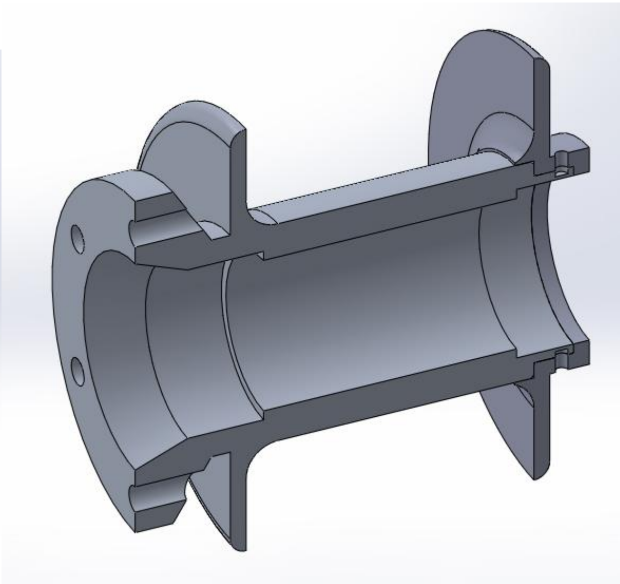


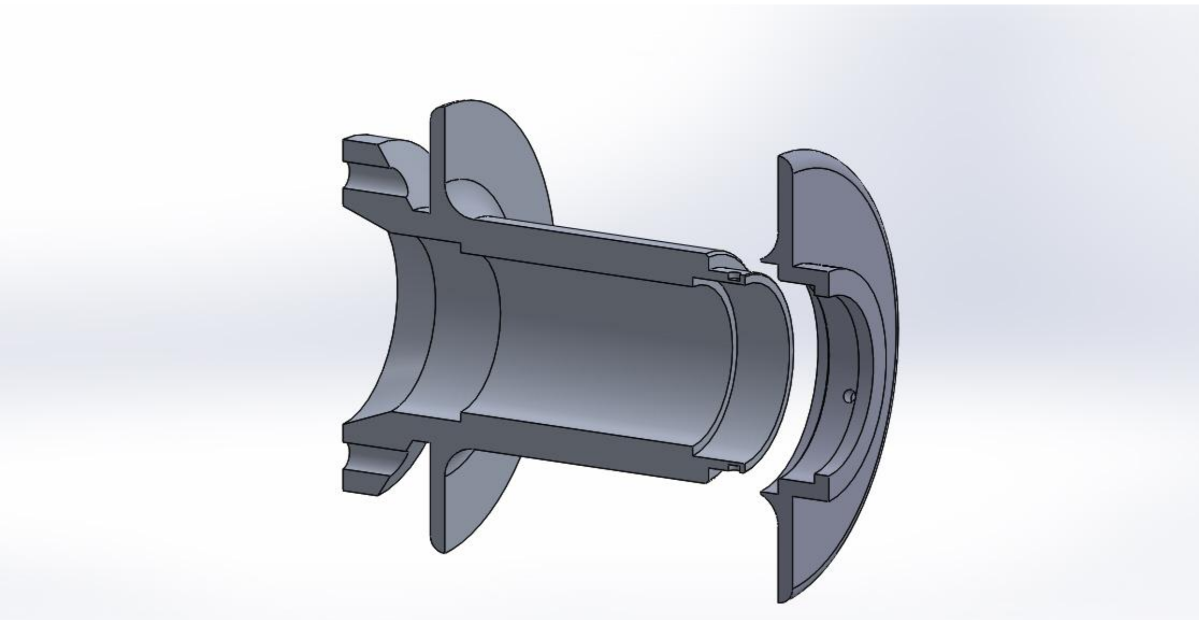


4.1.2 Hub Design:

A hub is the centre part of a bicycle wheel. It consists of an axle, bearings and a hub shell. The hub shell typically has two machined metal flanges to which Carbon fibre disc can be attached. Hub shells can be one-piece with press-in cartridge or free bearings or, in the case of older designs; the flanges may be affixed to a separate hub shell. The design of hub for this year is as shown in figure



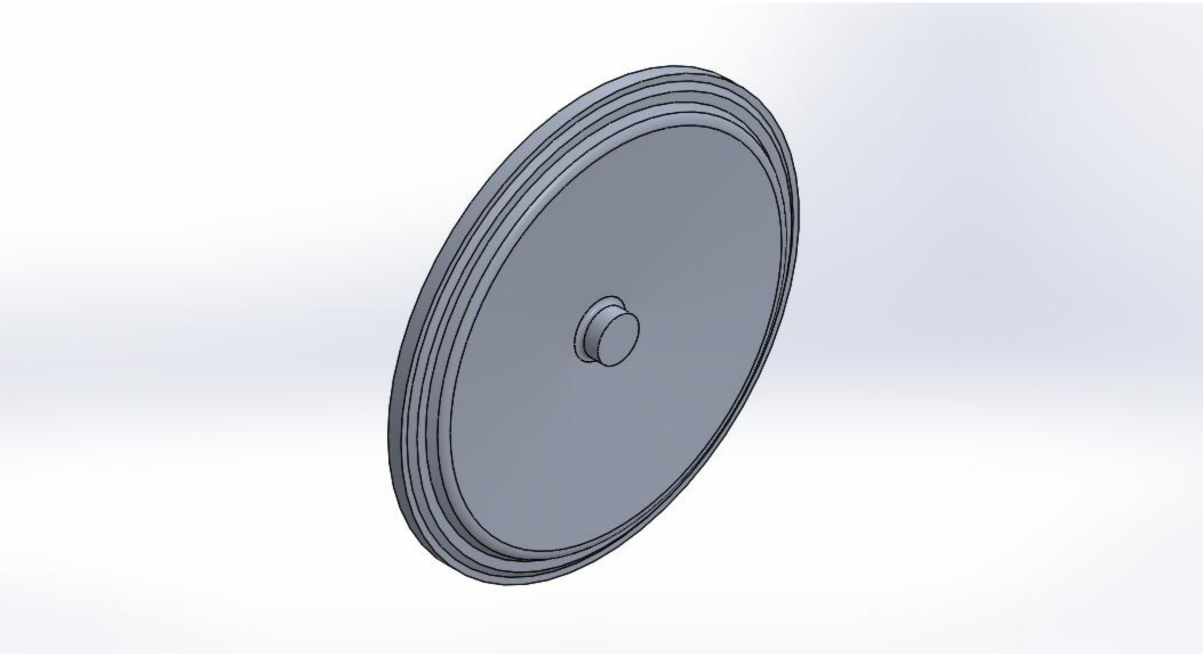


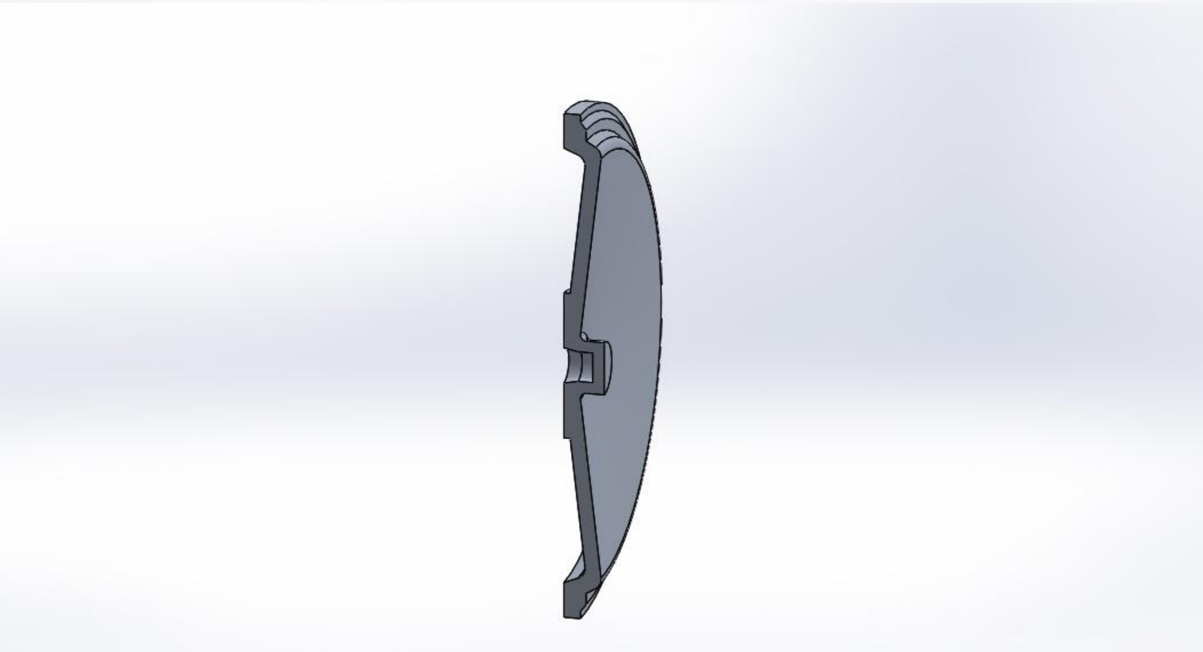


4.1.3 Mould Design:

As mould is very important part to manufacture carbon fibre rims. If mould is not proper in shape than finally the output, i.e. disc is not gets properly moulded. So in order to eliminate any error during the carbon fibre layup process, we decided to make our mould from Aluminium material.

To make Al mould we first design the exact wooden pattern and after that we perform sad casting process for making aluminium mould. The design of mould is as shown in figure.





4.2 Analysis:

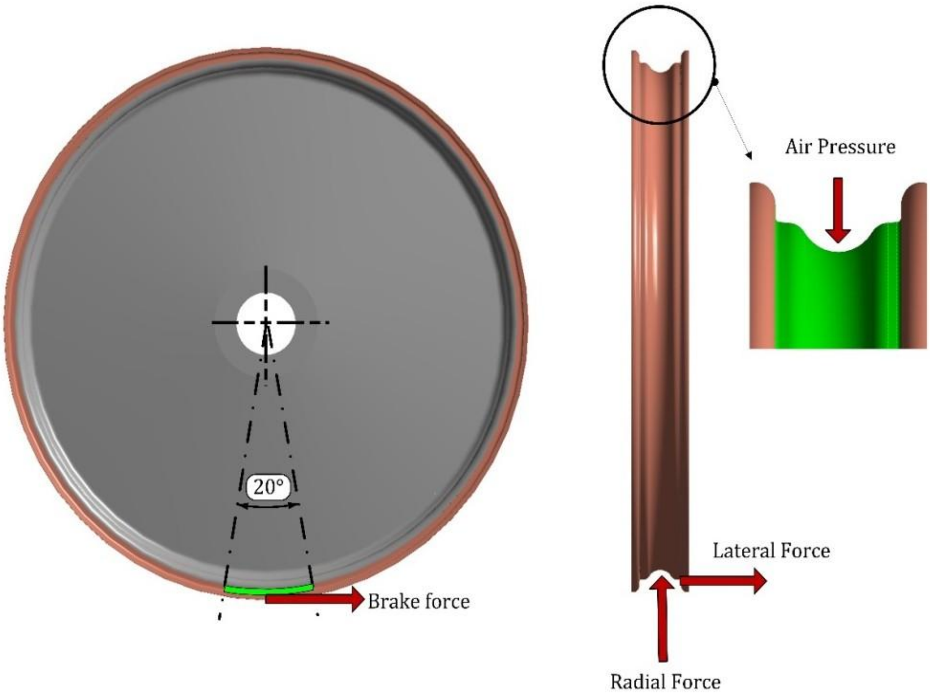
To perform the analysis operation firstly we need to conform the loading condition and amount of load which is acted on wheel. These are some basic features of our prototype vehicle. On the basis of this we calculate amount of force.

- Mass of vehicle (Including Driver) = 110 kg
- C.G. from front axle = 2.5 m
- Wheel base = 1.7 m
- Velocity at turn = 30 km/hr
- C. G. From ground = 0.2 m
- Turn Radius = 7.5 m
- Track width = 0.55 m
- Wheel diameter = 0.5 m

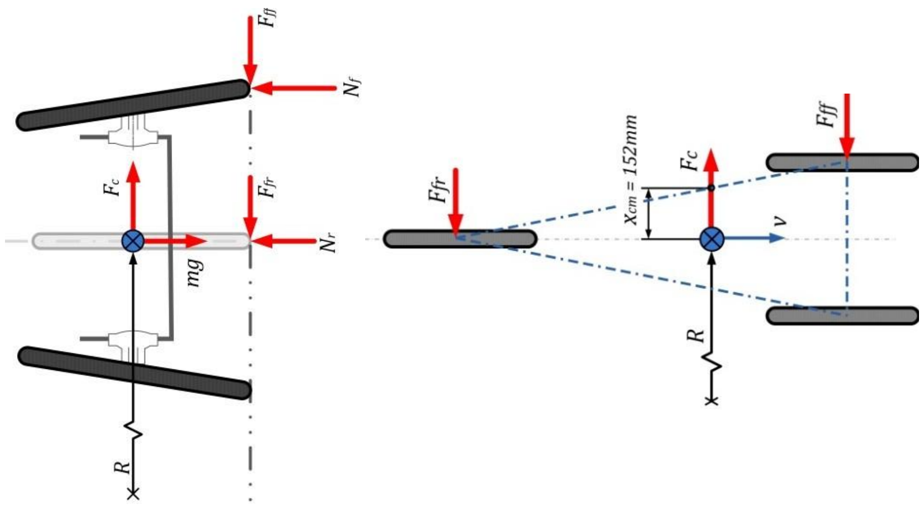
There are four main types of loads acting on the rim:

- Torque on the shaft axis: Caused mainly for the braking situations (prevailing over the torque caused on the acceleration situation).
- Radial forces: They can be caused for different situations, like the vehicle weight itself, the driver ingress in the vehicle, and the irregularities of the road.
- Lateral forces: They occurs mainly on the cornering situations, induce normal and lateral load components on the rim.
- Pressure: The special tires are inflated at high pressures that are applied on the outer surface of the rim's contour.

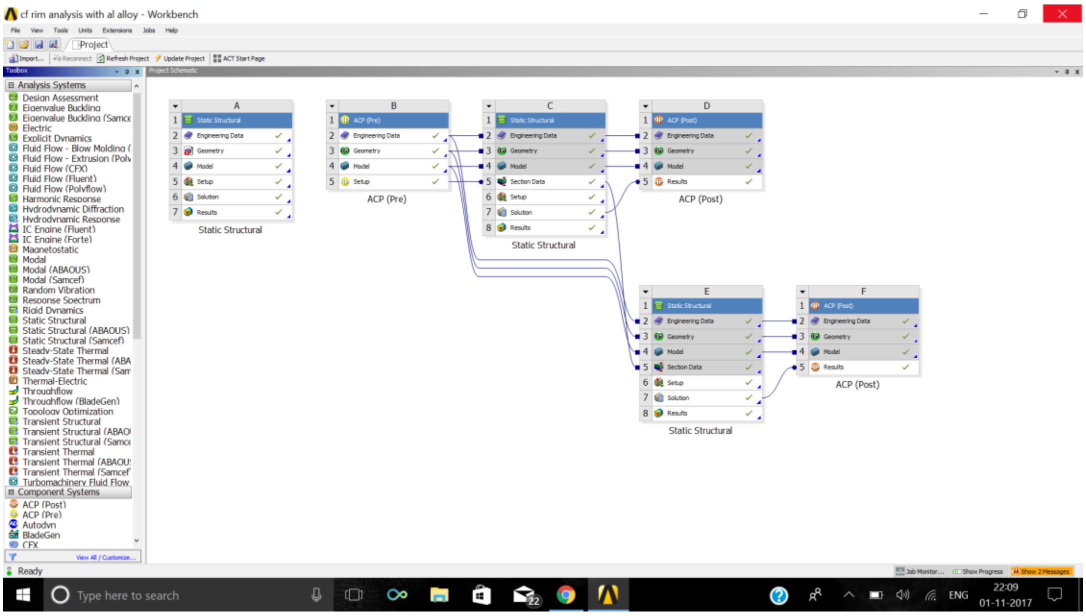
In order to find the values for each of these loads, an analytic study for the different cases was done. Previously, the main vehicles characteristics were looked for. The weight of the vehicle plus the driver was estimated in 110 kg, with the distribution of 35 kg on each of the front wheels and 40 kg on the rear wheel (on a flat ground).



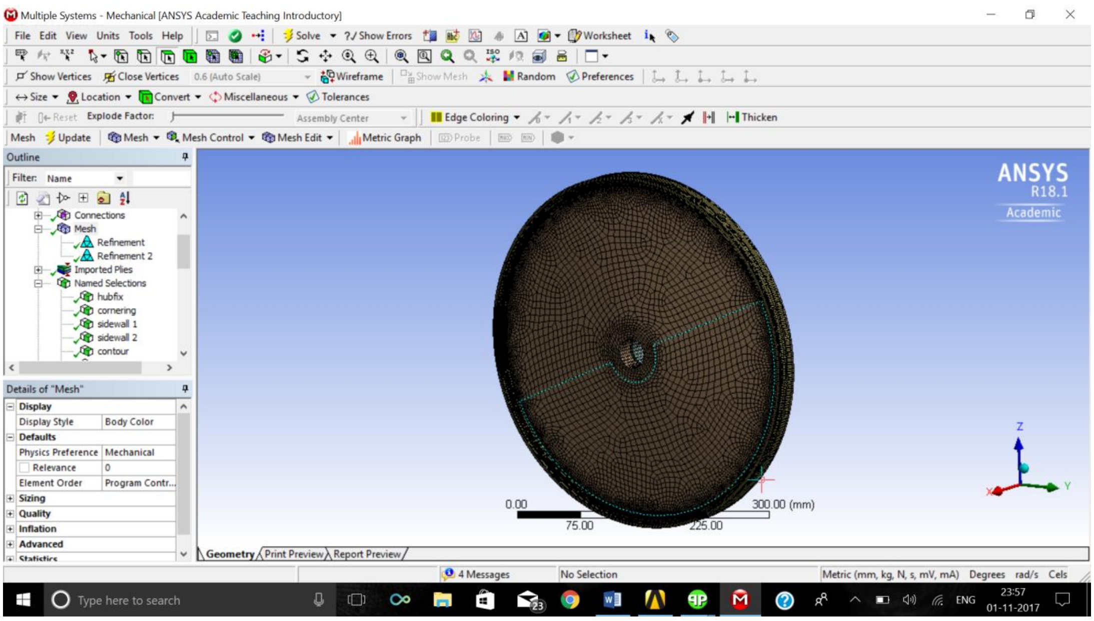
Type of load	Value with safety factor	Units
Radial Force	400	N
Lateral Force	750	N
Brake Force	350	N
Air pressure	5.5	Bar
Torque	40	N-m



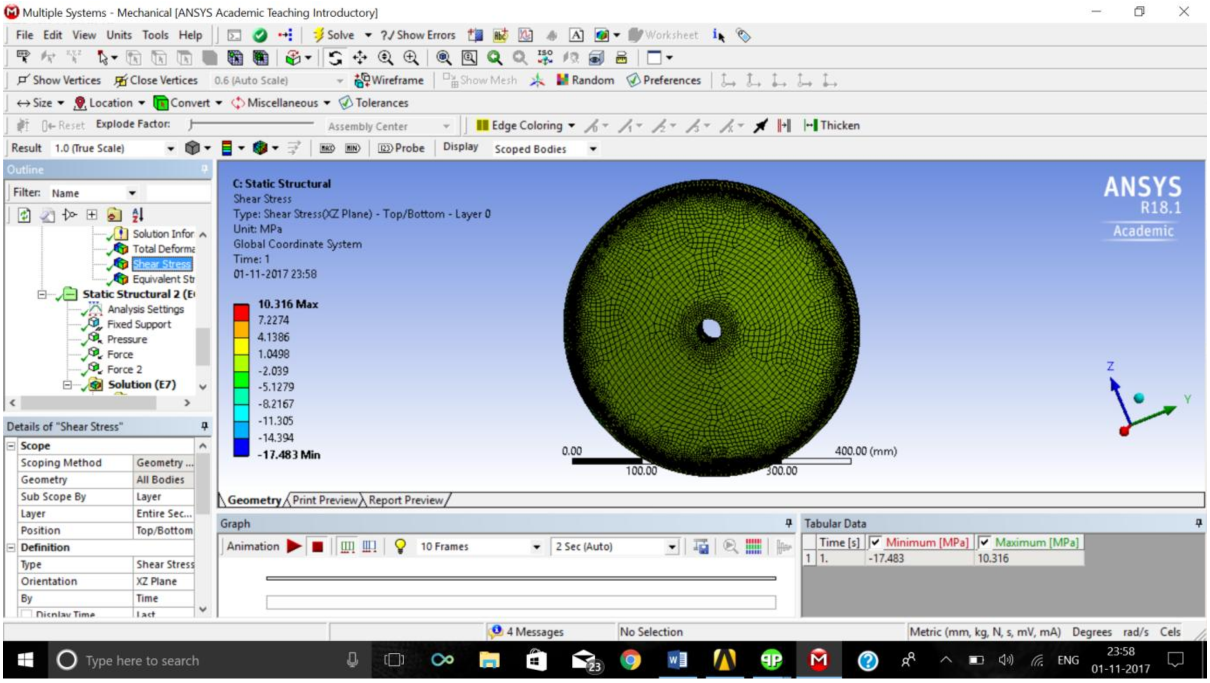
The finite element method (FEM) is a numerical procedure for obtaining solutions to the Differential equations that describe, or approximately describe a wide variety of physical problems like solid mechanics, electromagnetism, fluid dynamics, heat transfer inter alia. After completing our design phase we used to do analysis of Carbon fibre disc in ANSYS ACP 18.0 and aluminium hub in ANSYS 18.0. These are some pictures which explain the result of analysis.



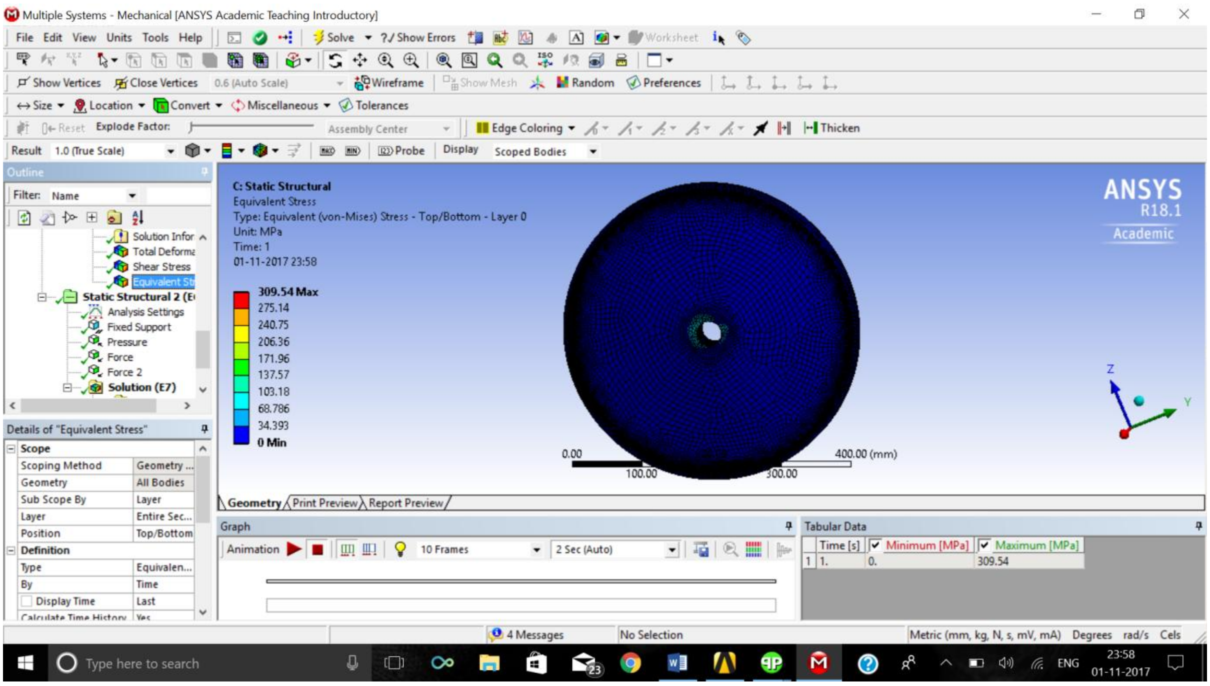
4.2.1 Mesh View



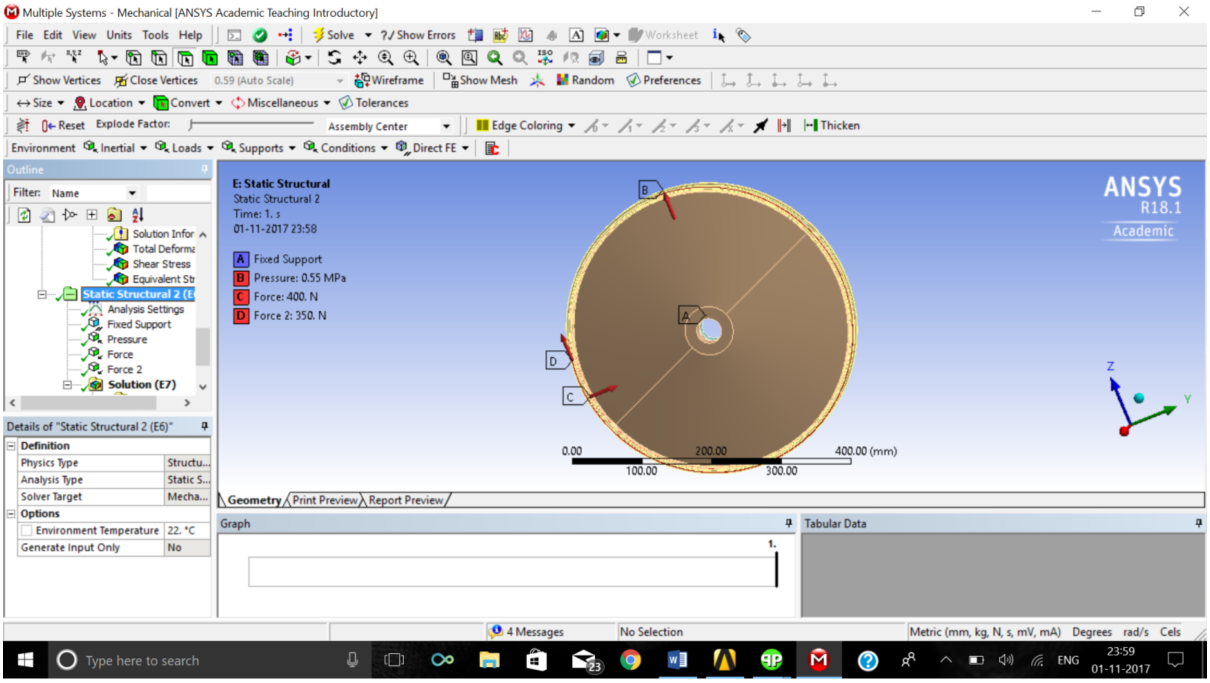
4.2.2 Total Shear Stress



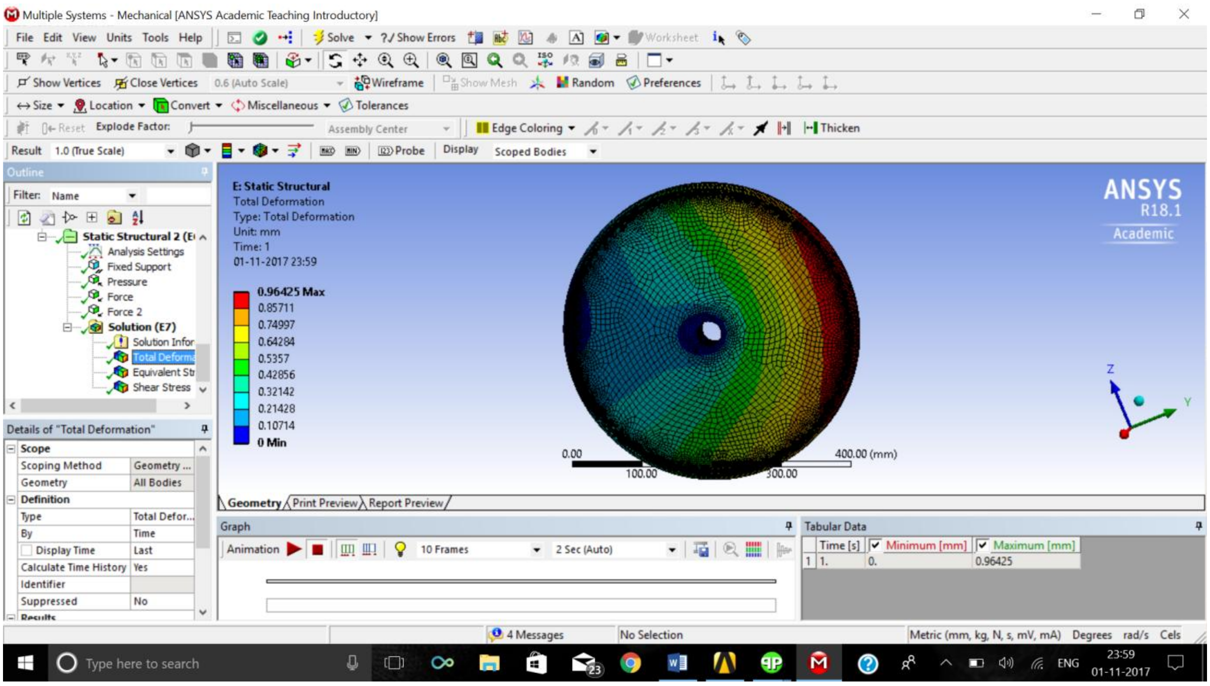
4.2.3 Total Deformation



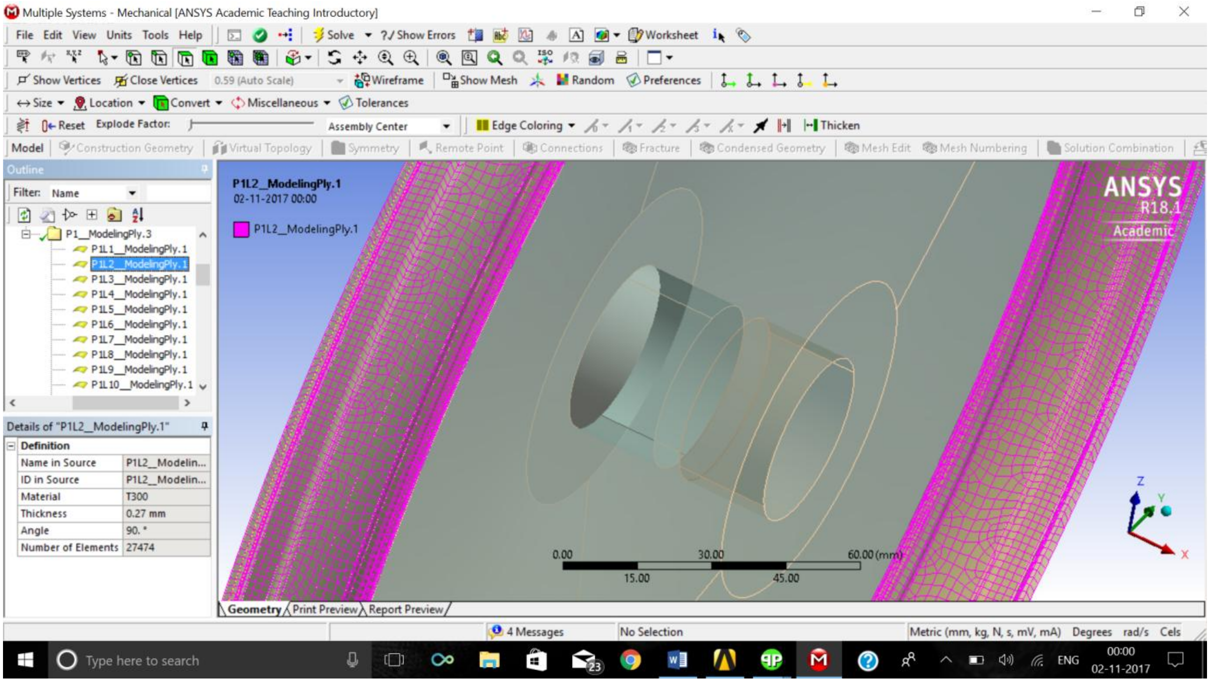
4.2.4 Applying loading condition



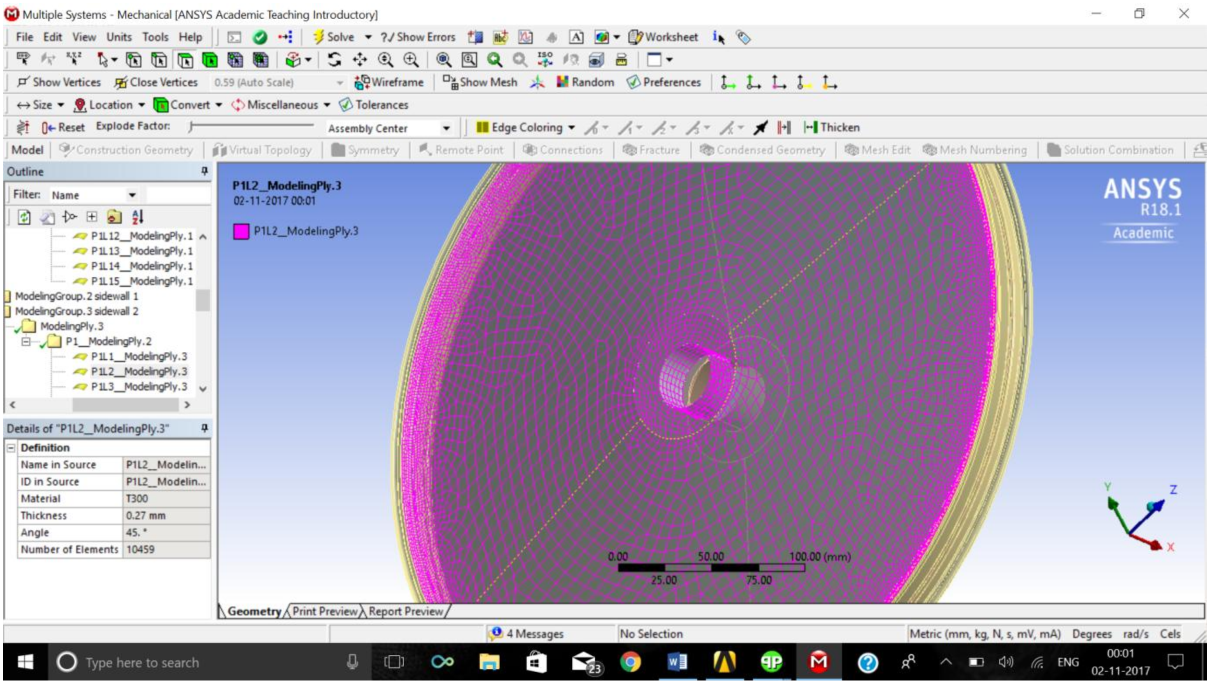
4.2.5 Total Deformation



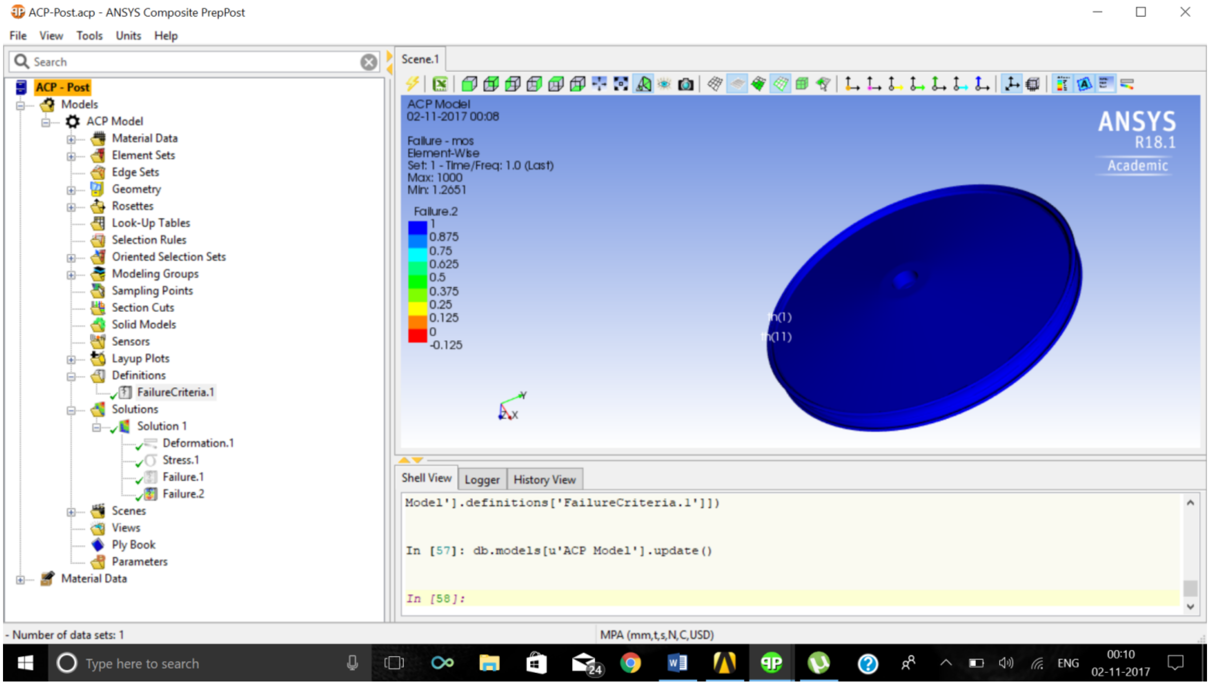
4.2.6 Applying air pressure

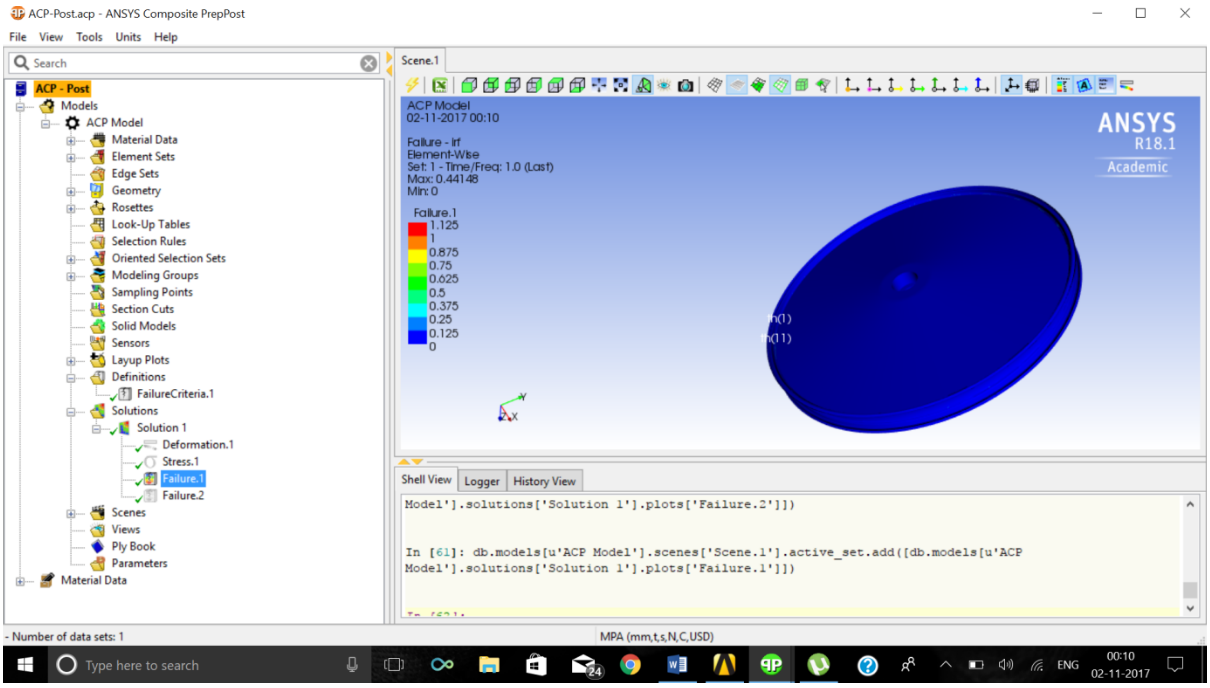


4.2.7 Meshing of Disc



4.2.8 Ansys Composite Processor (ACP)





4.3 Manufacturing:

In this phase we convert out design into actual product and after this stage, we are going to test that component. Below steps shows gradual making of Carbon Fibre Rims.

4.3.1 MDF Pattern

In order to make the Aluminum mould via sand casting process, firstly we have to prepare wooden pattern made up from MDF material. This design of pattern includes all the casting allowances like shrinkage, machining allowance etc. We have completed this stage and these are some pictures of MDF pattern. This is done on 3 axis CNC router machine.

4.3.2 Aluminum mould using Sand Casting process

After making the wooden pattern, we use this pattern to make aluminum casted mould. The picture shows the aluminum mould. The process used to make aluminum mould is Sand casting procress.

4.3.4 Machining of Casted mould for finishing cut on VMC

After the process of casting, the surface of casted mould is rough and irregular. So in order ot get good surface finish, we will perform machining operation on aluminum mould. And after machining we will perform buffing operation in order to get mirror finish on mould.

<u>(We cannot able to put image, because we are currently working on this stage)</u>

4.3.5 Manufacturing of CF Disc from mould

After perfect mould making process, we shift our focus towards manufacturing of carbon fibre disc. According to analysis, we decided to stack the carbon fibre as follows

<table>
<tr><th colspan="3">Rim Area</th><th colspan="3">Disc Area</th></tr>
<tr><th>Layer No.</th><th>GSM</th><th>Orientation</th><th>Layer No.</th><th>GSM</th><th>Orientation</th></tr>
<tr><td>1</td><td>250</td><td>0</td><td>1</td><td>250</td><td>0</td></tr>
<tr><td>2</td><td>250</td><td>45</td><td>2</td><td>250</td><td>45</td></tr>
<tr><td>3</td><td>250</td><td>90</td><td>3</td><td>250</td><td>90</td></tr>
<tr><td>4</td><td>250</td><td>-45</td><td>4 (Core Material)</td><td>NA</td><td>0</td></tr>
<tr><td>5</td><td>250</td><td>0</td><td>5</td><td>250</td><td>-45</td></tr>
<tr><td>6</td><td>250</td><td>45</td><td>6</td><td>250</td><td>90</td></tr>
<tr><td>7</td><td>250</td><td>90</td><td>7</td><td>250</td><td>-45</td></tr>
<tr><td>8</td><td>250</td><td>-45</td><td>8</td><td>250</td><td>0</td></tr>
<tr><td>9</td><td>250</td><td>0</td><td colspan="3" rowspan="5">Total thickness of Rim area is 3 mm and disc is approximately 2.25 mm.</td></tr>
<tr><td>10</td><td>250</td><td>45</td></tr>
<tr><td>11</td><td>250</td><td>90</td></tr>
<tr><td>12</td><td>250</td><td>-45</td></tr>
<tr><td>13</td><td>250</td><td>0</td></tr>
</table>

4.3.6 Hub machining on CNC Lathe

Hub is main part of wheel of any vehicle. In order to match our carbon fibre disc with hub, we design new hub which is lighter in weight as compare to previous hub.

To manufacture hub we already purchase the aluminum round bar of 80 mm diameter and 1000 mm in length. We will do machining on CNC Lathe.

4.3.7 Assembly of Disc and Hub using Loctite as bonding agent

After the manufacturing of both Hub and Disc, we will assemble both components together by means of Loctite. Loctite is the best option available to stick aluminum with any composite material part.

4.4 Testing

After the manufacturing phase gets completed, we shift our focus on testing of our wheel. We will do two types of testing on wheel. One is Idle testing and other is on road testing.

Idle testing is done when the wheel is not connected to the vehicle. Is is also called off load testing. In Idle testing, we will apply load to wheel is all the direction and rotate at required speed.

In case of on road testing the weight of driver as well as breaking force is acting on wheel. So in order to check weather our wheel is sustain that high breaking force or not, we do on road testing. It is also called as on Load testing, where actually all the loads are acting on Carbon fibre wheel.

CHAPTER - 5
EXPECTED CONCLUSION

Description	Expected (A18)	Previous (Triton)	Conclusion
Bearing	Hybrid ceramic bearing	Steel Bearing	Very minor Frictional loss
Hub	Simple is construction	Complicate in construction	Easy to manufacture
Hub weight	140 grams	330 grams	42% weight reduction
Disc material	Carbon Fibre	Aluminium spokes	Great aesthetics and aerodynamics
Rim construction	Integral part of disc	Different from spokes	Easy to manufacture
Tyre	neoprene rubber tyre	Michelin tyre	Low rolling resistance

CHAPTER - 6
FUTURE SCOPE

Nowadays people demanding for product of low weight and good in strength. This project is aims toward that demand only. The project has provided theoretical baggage in relation with structural parts made of composite materials, particularly with carbon fibre reinforced polymers. In other parts of the Team ETA's vehicle a weight reduction can also be achieved using composites, a good option would be the chassis of the vehicle. Before that some more experience is needed and the manufacturing of the rims could be an appropriate start. In relation with the rims designed in this project, few points should be reviewed before the fabrication of these. On one hand the manufacturing process must be studied further. The type of epoxy used and the curing conditions have to be known. The tooling needed for the manufacturing process has to be custom for the rim, which is basically the moulds and some tools for the assembly process. If the budget and the time allow it, building a first prototype for the rim would be a good option. It would provide experience on the manufacturing process and also a verification of the design, as well the real weight reduction. On the other hand the hub's design needs to fit into the whole design. The current aluminum hub could be optimized to reduce its weight or otherwise the design of the hub made of carbon fibre reinforced polymer could be studied since it can provide a better overall weight reduction for the rims. For this last option, the present project can provide useful information.

CHAPTER - 7
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ACKNOWLEDGEMENT

This report is the result of my bachelor project that was carried out in the K. J. Somaiya College of Engineering, in Mumbai, during the Academic year 2017-18.

I would like to thank the people of the Team ETA who helped me in any way, especially Sandeep Chopade sir and Luckman sir.

I would like to extend my appreciations to my supervisor, Vijay Khaparde sir and my examiner A. K. Gangrade sir, for their guidance during the project.

Finally, I would also like to thank my family and especially my parents and my lord.