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Design and Analysis of an Automotive Wheel Rim with the Selection of Optimal Material using Weighted-Properties Method

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Abstract **Wheel Rims form a vital part of automobile vehicles. This project mainly deals with the design and analysis of a wheel rim and further improvement within the design by choosing an optimal material from a given number of materials. The design of the rim is created in a suitable CAD software while, a CAE software is used for analyzing the rims for critical conditions. Loading conditions like tyre pressure, radial load and bending load are simulated during the finite element analysis of the component. ETRTO manual and AIS 073 (Part 2), these standards are referred during the design and analysis stage. Optimal selection of the material is done using the Weighted-Properties Method. This methodology is based on concurrent qualitative selection of materials method (CQSM) that takes into consideration the importance of materials properties in the early stages of conceptual design. Various materials alternatives which are considered in this study are LM25 Aluminum Alloy in T6 condition, Magnesium Alloy (Mg_6Al_3Mn), Titanium Alloy (Ti_6Al_4V), Aluminum Alloy (A356.2) , Carbon Fiber and steel. The analysis led to the conclusion that Steel (hot rolled low carbon steel) is the most appropriate material for the design of wheel rims.**

Keywords —Cornering Fatigue Test, Digital Logic Method, Hyperworks, Material Selection, Motorcycle Wheel Rim, Radial Fatigue Test, Steel Wheels, Weighted-properties Method.

I. INTRODUCTION

The rim is the "outer edge of a wheel, holding the tyre". Its main functions are to rotate over the axle of an automobile, to use power from engine in order to take automobile into motion, provide support for braking system over its body, dissipate heat generated in the body of wheel rim to surrounding environment, support whole body weight as well as withstand against impact load due to pot holes and road irregularities.

A wheel rim is the most highly stressed component in an automobile that is subjected to various types of loads. There is an increasing industrial demand for components that are lighter and cheaper to produce, while at the same time maintaining fatigue strength and other functional requirements. The testing of any component for failures during the design stage has become possible with the use of various FEA software packages. The presented work involves design and analysis of a motorcycle wheel rim using suitable softwares. The CAD Model of the motorcycle wheel rim is designed in CATIA. This model is used for CAE . Cornering Fatigue Test (CFT) and Radial Fatigue Test (RFT) are the two testing conditions simulated on the wheel rim model. FEA is done using HYPERMESH – OPTISTRUCT. Similarly one of the most important factor during to design stage of any component is the selection of the stock material to be used for the manufacturing of the component. This selection is mainly categorized by the various properties of a given material. The properties, which directly influence the choice of material, can be summarized under the following categories:

1. Mechanical Properties: e.g. stiffness, strength, ductility, hardness, toughness, etc.

2. Physical Properties: e.g. density, electrical conductivity, thermal conductivity, etc.

3. Chemical Properties: e.g. corrosion resistance in various environments.

4. Manufacturing Properties: e.g. formability, machinability, ease of joining, etc.

The functional requirements of a product are directly determined by the mechanical, physical, chemical properties. However, for the product to be technically manufacturable, the material must have the right

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manufacturing properties. For example, a forged component requires a material with sufficient flowability without cracking during forging, a cast component requires a material that flows readily in the molten state and fills the mould and on solidification does not produce undesirable pores and cracks. Apart from these Properties various factors like final weight of component, cost and availability of raw material should also be studied thoroughly. If the above mentioned points are carefully examined for each and every material under consideration it would eventually lead to selection of the most feasible material i.e. the optimal material for a particular component. In this study the material optimization process is carried out with the combination of two material selection techniques namely, Digital Logic Method and Weighted-Properties Method. So the main aim of this study is to design a wheel rim along with the selection of optimal material for the rim such that the overall life and performance of the rim increases with not much increase in the cost and weight of the rim.

II. Literature Review

For the design purpose the ETRTO[1] standard manual is referred while, for the analysis purposes i.e. in order to determine the loading values for RFT and CFT the AIS 073 (Part 2)[2] standard is referred. In 2005, Kinstler [3] studied all the SAE standards and explained evolution of rim testing year by year. This study gives information about the Radial Fatigue Test and Cornering Fatigue Test and evolution of their setup. In RFT, straight ahead driving condition with accelerated load is simulated and the life of tyre and wheel rim is determined. To evaluate cornering, initially a fixture was developed. By using this fixture, straight ahead testing of wheel rim, with tyre on it, at a camber angle was done. J. Stearns et al [4] in 2005 studied the distribution of tyre pressure and radial loads exerted on the wheel rim due to the weight of the vehicle. As the radial load is exerted on the bead seat of the rim similar loading was applied on the model. The maximum von mises stress equal to 15.8 MPa and maximum displacement of 0.223 mm was developed. It was observed that the tyre pressure does not have direct influence the state of stress. The maximum stress was developed at the edge of disk attachment and the maximum displacement was observed at the bead seat. The stresses were higher in the rim than the disk and the critical points of design are bead seat and well area. Karan Valetava [5] carried out the fatigue and static analysis of a wheel rim using two different materials, which were Aluminium alloy (A356.2) and carbon fiber. He concluded that the rims made from carbon fiber would prove more beneficial than those made from aluminium alloy (A356.2). Nisha.M.Krishnan [6] performed a comparative analysis between rims manufactured using Magnesium Alloy (Mg_6Al_3Mn) and Titanium Alloy (Ti_6Al_4V). After her analysis she concluded that the stress, displacement and weight incurred for the Magnesium alloy were pretty much less than that for the titanium alloy. Paropate et al [7] modelled a wheel rim and performed analysis on the same using four different materials. The materials were Aluminium, Magnesium, Carbon Fiber and Thermoplastic Resin. According to their conclusion they stated that Thermoplastic resin is the most optimal material for wheel rims but they can't be used due to their high manufacturing costs. Yadav et al. [8] optimized a car rim using optistruct solver. The material they considered for their study was an aluminium alloy. Ravi Kumar [9] et al performed the topology optimization of a wheel rim for satisfying the impact test. Topology Optimization was carried out by changing the thickness of the rim of the Wheel until the value of the plastic strain is less than 4.0%. The two different materials which were considered during their research were aluminium alloy and steel. Maleque et al. [10] suggested a Material Selection Method for designing of automotive Brake Disk. They made use of Cost per Unit Property and Digital Logic Method for selecting the most optimal alternative. According to their study the optimal material of brake discs turned out to be AMC 2. Kadhim et al [11] proposed a new method of material selection during conceptual design stage. They made use of the weighted-properties method but along with that instead of using the traditional digital logic method they put forth a modified version of digital logic method. They concluded that the modified digital logic method gave more accurate results as it eliminated the problem caused due to least important criterion. Similarly Talur et al [12] used the weighted-properties method to find the optimal material for manufacturing o Savonius Vertical Axis Wind Turbine Rotor Blade. They concluded that polycarbonate sheets emereged as the most appropriate alternative with the performance value of 74.18%.

The following chapters will explain the flow of the entire process and how various steps are taken with the help of CAD and CAE softwares. Followed by the explanation of selection of optimal material for the rim model.

III. Design and Testing Standards

Design standards are a set of norms which are accepted all over the world while designing any component which specify various design parameters for designing. The design standards that have been studied are ETRTO, IS 10694, JATMA and ITTAC. As per our requirement, the contour MT 3.5 M/C has been selected from ETRTO Manual. Fig. 1 represents the basic contour of the rim.

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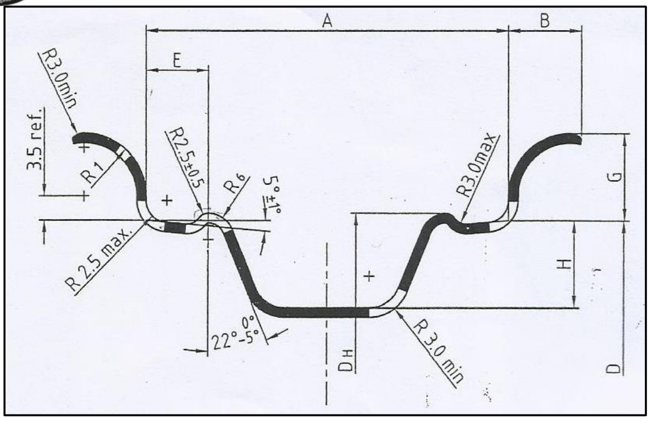

Fig. 1:- Rim contour from ETRTO manual [1]

Similarly, there exist a number of standards for testing of a component. These testing standards specify various testing parameters like applied load, number of cycles for test, total run time of test, etc. Some of the standards used for testing of wheel rims are AIS-073 (Part 1 and 2), IS 9436, SAE J328, ABNT NBR6750, SNI 1896. The comparative study of these standards is stated in Table 2.1. According to the requirement AIS-073 (Part 2) has been selected for the testing purpose.

AIS-073 (Part 2) specifies two types testing methods namely Cornering Fatigue Test (CFT) and Radial Fatigue Test (RFT).

For CFT, the bending moment M (force x moment arm) in

$$M= (R \times \mu + d) F \times S \qquad \ldots\ldots\ldots(1)$$

Where

R = Maximum static loaded radius in meters for which wheel rim is designed;

μ = Assumed coefficient of friction developed between a tyre and road;

d = Inset or outset of the wheel rim in meters;

F = Maximum design load of wheel rim in Newtons (N);

S = Accelerated test factor

For values of μ and S, Table no. 1 has been referred.

Table no. 1:- Test Factors [2]

Test	Accelerated Test Factor
Dynamic Cornering Fatigue Test (μ = 0.7)	S = 1.6
Dynamic Radial Fatigue Test	K = 2.25

For RFT, the radial load F_r in Newtons is determined as follows;

$$F_r = F_v \times K \qquad \ldots\ldots\ldots(2)$$

Where,

F_v = Maximum design load of wheel rim in Newtons (N);

K = Accelerated test factor

For values of K, Table 1 has been referred.

During analysis procedure, loading calculations are done using Equation 1 and 2.

IV. Design

Now, as per the contour selected from the ETRTO Manual [1], the CAD model has been prepared. The CAD Software used for the designing is CATIA. Hence the CAD model of a 5 spoke wheel rim (MT 3.5 X 19) is prepared and the same is shown in the Fig. 2.

Fig. 2:- CAD Model of Wheel Rim

V. Material Properties

For this research we have shortlisted six different materials to be considered for the manufacturing of the wheel rim. The selection of these materials is based on the previous studies performed by a number of authors. The physical and mechanical properties of these materials are specified in Table no. 2. While the chemical composition of these materials and the cost of the raw materials per kg is specified in Table no.3.

Table no. 2:- Material Properties

Material	Youngs Modulus (GPa)	Poissons ratio	Density (gm/cc)	Yeild Strength (MPa)
LM25 aluminum alloy in T6 condition	71	0.3	2.685	185
Magnesium Alloy Mg_6Al_3Mn	45	0.35	1.8	130
Titanium Alloy (Ti_6Al_4V)	112	0.342	4.43	1000
Aluminum Alloy A 356.2	69	0.33	2.7	225
Carbon Fiber	110	0.1	1.6	450
Steel	210	0.3	7.85	250

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Table no. 3:- Chemical Composition and Cost Analysis

Material	Chemical Composition	Cost (Rs/kg)
LM25 Aluminum Alloy in T6 condition	6.5-7.0.0%Si, 0.3-0.4% Mg and rest is Aluminium	155
Magnesium Alloy (Mg_6Al_3Mn)	94% Mg, 5.5% Al, 0.01% Cu, 0.005% Fe, 0.25% Mn, 0.1% Si, 0.22% Zn, 0.002% Ni.	350
Titanium Alloy (Ti_6Al_4V)	90%Ti, 6%Al, 0.2%O, 4%V, 0.25% Fe.	1500
Aluminum Alloy A 356.2	6.5-7.5% Si 0.12% Fe 0.05% Mn 0.3-0.45% Mg 0.50% Zn 0.20% Ti 0.10% Cu 0.15% others Remaining is Aluminum.	260
Carbon Fiber	-	1600
Steel	0.12% C, 0.5% Mn, 0.04% S, 0.04% P and rest is Fe	150

VI. ANALYSIS

The next aim is to simulate the tests which will be performed on the rim after the manufacturing for validation purposes. Also, it would provide a platform for comparing various models of the rim and optimizing them. These simulations will be run in CAE software. The preferred CAE Software is HYPERWORKS.

HYPERMESH Software is used for the meshing purpose. This software is selected because it allows the user to manually mesh any geometry easily as it provides the entire control of the mesh to the user and one could achieve the required quality of the mesh. In our study we have given utmost priority to the meshing procedure because the accuracy of the results depend on the quality of mesh. Hence by keeping the mesh as fine as possible and giving proper connections between different models we would be able to obtain more accurate results. A detailed procedure for the meshing process is as follows:-

1. Import the assembled model of the wheel rim (preferably the .igs file)
2. Delete all the solids, leaving behind only the surfaces of the imported model.
3. At first the outer rim portion is meshed. For this the rim surface is split or trimmed into two halves (check the fill cut checkbox). As a result a sectional surface of the rim wheel is obtained.
4. The above mentioned surface is meshed using 2D AUTOMESH command. While the previously generated mesh is revolved for 360 degrees around the central axis to obtain a fine and ordered 3D MESH of the rim wheel.
5. For meshing the disc, the disc surface is split or trimmed near hollow regions in order to provide washers around the circular patches.
6. Initially meshing of the washers is done using the 2D AUTOMESH command. Once a fine mesh is obtained in the washer patch the remaining area is meshed using the same command (Note:- Even though automesh command is used, manual manipulation of mesh size and number of elements can be carried out easily as the meshing mode is kept as INTERACTIVE).
7. The 2D mesh obtained in the previous step is converted into a 3D mesh using the LINE DRAG command, by selecting the elements to be dragged and the line along which the elements are to be dragged.
8. Once the meshing of the Disc is completed the meshing of the Adaptor Plate is carried out in a similar manner.

The mesh of the design consists of 2D elements quad and tria(mixed) extruded over the geometry forming 3D elements. The average element size is 4 mm. The FREEZE contact is specified between the rim and the disc and also between the spokes and the hub. The property considered for the elements is 3D PSOLID. During the analysis procedure the simulations are carried out on the rim model using all the six different material alternatives as per discussed in table no. 2.

The tests which are simulated using the software are:-

A. Cornering Fatigue Test

Using the equation (1) and using the values from table (1) the value of bending moment to be applied is calculated as follows,

$$M = (R \times 0.7+0) \times F \times 1.6. \qquad \ldots\ldots(3)$$

As per the design R = 0.3429 m.

and assuming load equal to 400 kg on each wheel the force,

$$F = 400 \times 9.81=3924N. \qquad \ldots\ldots(4)$$

Substituting the values of R and F in the Equation (3)

$M = 1507Nm.$

The test simulation is done as per the description given in AIS-073 (Part 2). To simulate the exact test conditions, along with the wheel rim moment arm is also modelled. The moment arm is modelled using the rigid (RBE2) elements. The length of the moment arm is taken as 1000mm while a force of 1507 N is applied at the end of the moment arm. This would simulate the required loading condition and would create a combined effect of a moment of 1507N-m on the rim. Once the Force is applied the next step is to apply constraints. As per the observations made from the actual setup of the test the rim was constrained circumferentially on one side using clamps. Similar condition is simulated in the software by restricting all the

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degrees of freedom of the circumferential points. The loading conditions i.e. the load collectors are being shown in the Fig. 3.

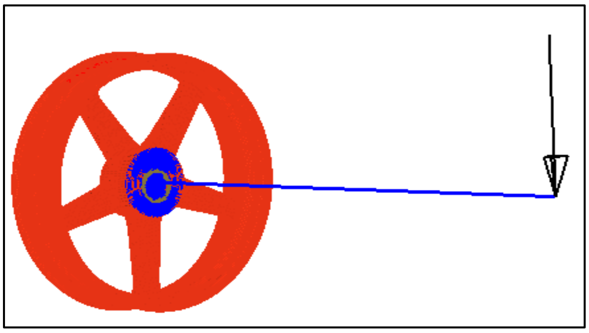

Fig. 3:- CFT CAE Model

After defining the load collectors the load step is created and the model is solved using OPTISTRUCT solver. We know that the stress values are independent of the component material and they depend mainly on the geometry of the component. Due to this reason even if we change the material during the analysis procedure the stress value will more or less remain the same. The Stress result for CFT obtained for the component is given in Fig. 4.

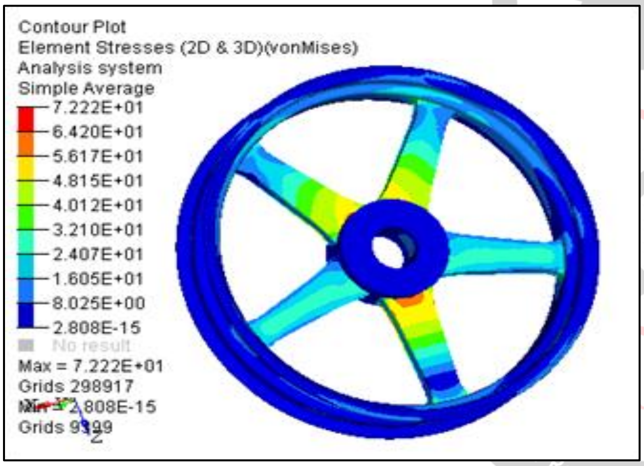

Fig. 4:- Stress result for CFT Loading Condition

While the displacement results will vary with the change in material during the analysis. Hence the Displacement results obtained for each material during the CFT simulation are given in the figures from Fig. 5 to Fig. 10.

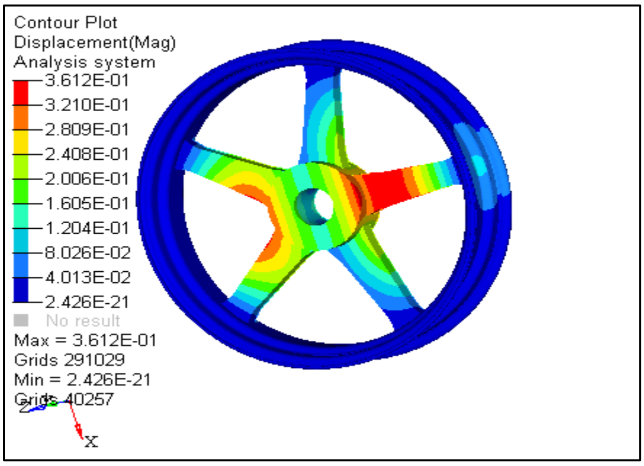

Fig. 5:- Displacement result for LM25 Aluminum Alloy in T6 condition

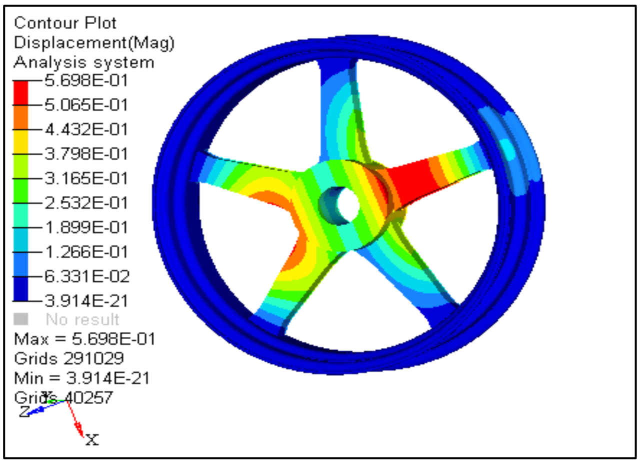

Fig. 6:- Displacement result for Magnesium Alloy (Mg_6Al_3Mn)

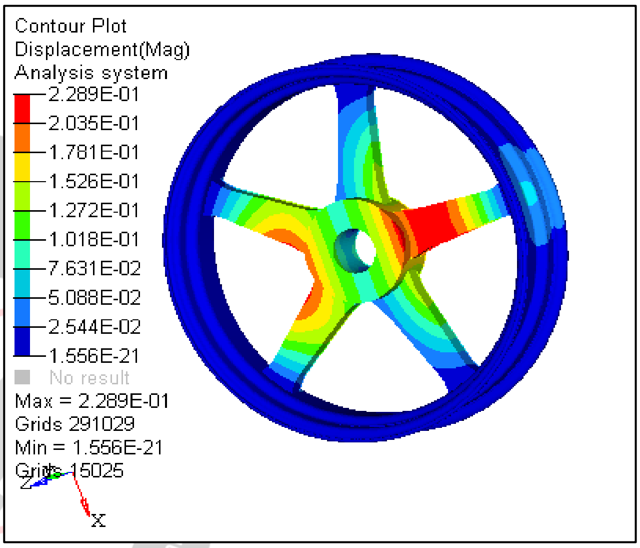

Fig. 7:- Displacement result for Titanium Alloy (Ti_6Al_4V)

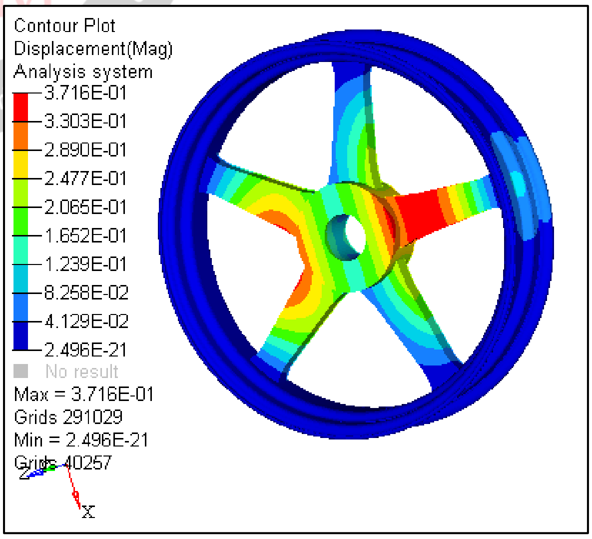

Fig. 8:- Displacement result for Aluminum Alloy A 356.2

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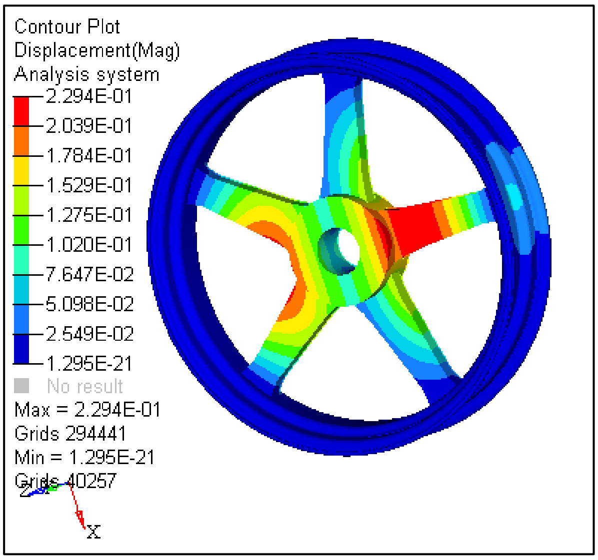

Fig. 9:- Displacement result for Carbon Fiber

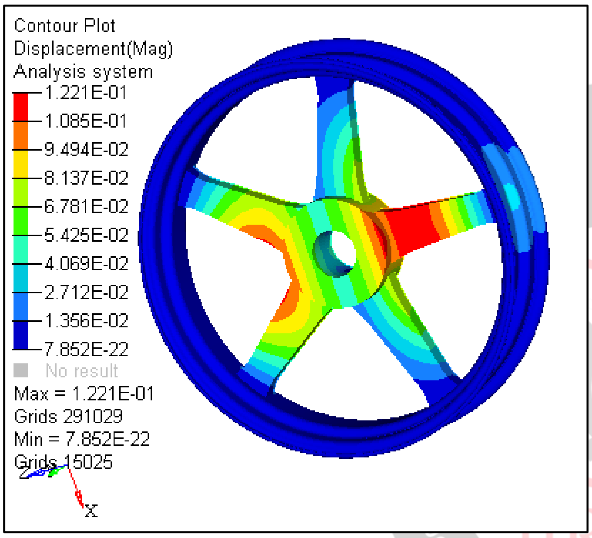

Fig. 10:- Displacement result for Steel

B. Radial Fatigue Test

This test is mainly used to determine the conjoint influence of tyre inflation pressure and radial load on stress and concomitant displacement distribution of the wheel rim. The radial load mentioned above is the vertical reaction force exerted on the two tyres in order to balance the entire weight of the vehicle. Each of these forces act normally on the tyre and tends to compress the wheel rim in the vertical direction. As the vehicle is motion this radial force becomes cyclic in nature. Due to this reason the wheel fatigue strength should be evaluated very carefully in order to maintain the structural integrity of the wheel. As prescribed by AIS-073 (Part 2), the wheel rim should maintain its structural integrity, without developing any cracks or experiencing excessive plastic deformation, for more than 4×10^6 cycles, under the radial load (F_r), which is given by equation (2). In this equation the value of accelerated test factor (K) is taken from Table 1 as, K=2.25 , while the value of Maximum design load of wheel rim (F_v) is taken as, F_v=3924N(400kg). Now substituting the above values in equation we get the value of radial load as, F_r = 2.25 × 3924 = 8829N.

In this study the loading condition is applied by referring the research presented by J. Stearns .et al. [8]. It is observed that in an actual wheel, the radial load is applied to the wheel at the bead seat where the tyre actually rests on the rim. The actual distribution of stresses is shown in Fig. 11.

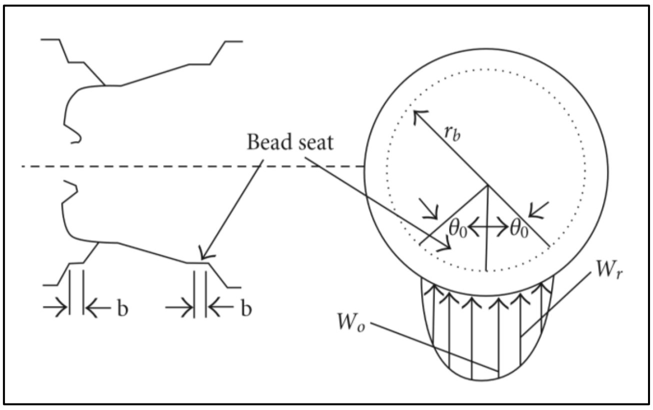

Fig. 11:- Actual RFT Loading Condition

For this analysis the radial load is applied as variable pressure distribution. This pressure distribution, along the circumferential direction, is assumed to follow a cosine function distribution. This pressure distribution is applied in the software using the equation option and a user defined cylindrical co-ordinate system. This equation is calculated as follows:-

The distributed pressure W_r is given by the expression

$$W_r = W_0 \cdot cos[(\pi/2)\cdot(\theta/\theta_0)] \quad \ldots\ldots(5)$$

Where,

Wr is the Distributed Pressure in (N/m^2)

W_0 is the Total Radial Pressure on the rim (N/m^2)

θ is the circumferential angle in radians

$\theta_0 = 35^\circ = 0.6108$ radians

The Total Radial Pressure is calculated using the following equation,

$$F_r = 2b\int_{-\theta_0}^{\theta_0} W_r \, . \, r_b \, d\theta = (8.b.r_b.\theta_0.W_0)/\pi \quad \ldots\ldots(6)$$

Where,

Fr is the Radial Load in N

b = Width of bead seat = 15 mm

r_b = Radius of bead seat = 240 mm

$\theta_0 = 35^\circ = 0.6108$ radians

W_0 is the Total Radial Pressure on the rim (N/m^2)

The equations 5 and 6 are used to obtain the equation of the pressure distribution function, which is as follows,

$$W_r = 1.5766.cos(2.5717)$$

Along with the Radial Load, uniform pressure is also applied on the model in order to simulate the tyre pressure exerted on the rim. The tyre pressure is taken as 206.843KPa (30psi). After applying both these loads, the constraints are applied on the model. For this purpose, all the nodes of the hub hole are constrained i.e. all their degrees of freedom are set to zero. Fig.11 shows the model

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which has been created for the simulation of Radial Fatigue Test. Once the model is ready it is solved using OPTISTRUCT solver to obtain the required stress and displacement values. As discussed earlier during the CFT process, the stress results for RFT will also remain constant with the change of materials. The stress result for RFT obtained for the rim model is shown in Fig. 12.

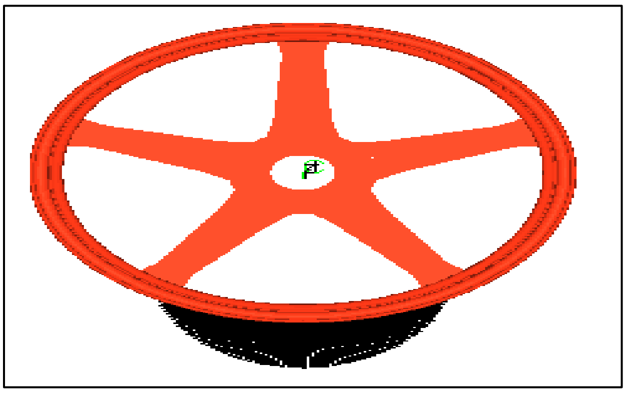

Fig. 12:- RFT CAE Model

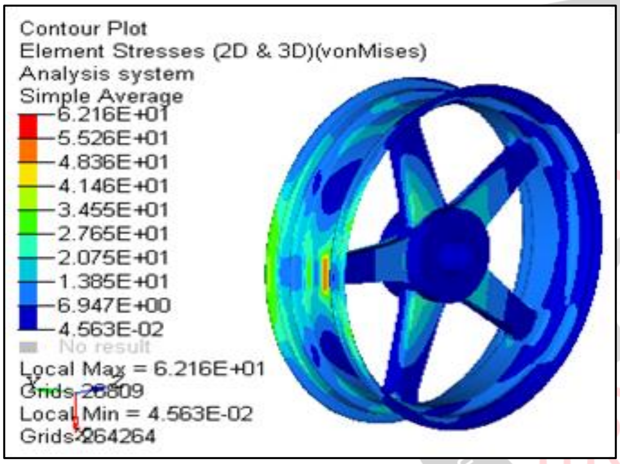

Fig. 13:- Stress result for RFT Loading Condition

Similarly as we know that the displacement results will vary with the change in material during the analysis. Hence the Displacement results obtained for each material during the RFT simulation are given in the figures from Fig. 13 to Fig. 18.

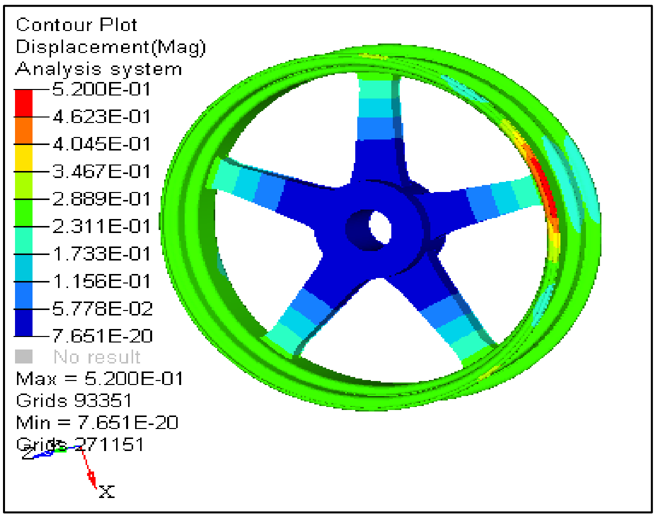

Fig. 14:- Displacement result for LM25 Aluminum Alloy in T6 condition

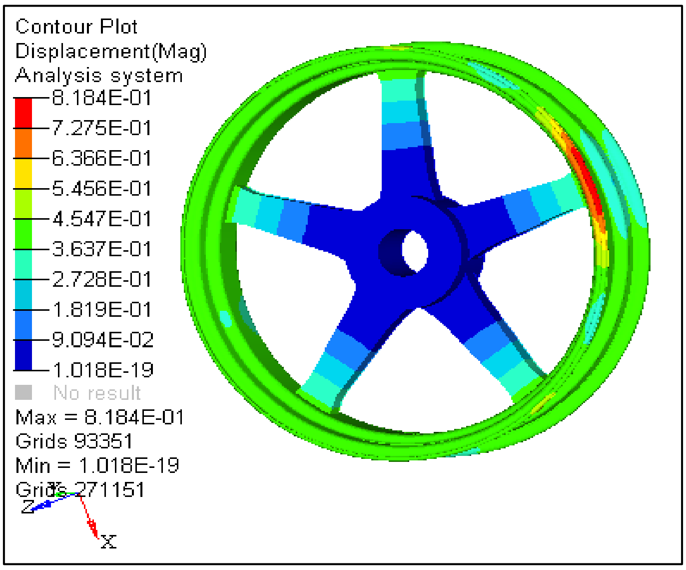

Fig. 15:- Displacement result for Magnesium Alloy (Mg_6Al_3Mn)

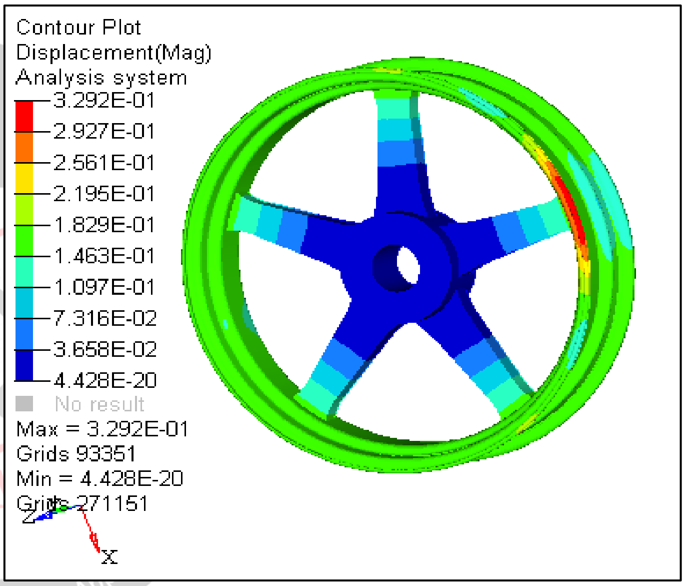

Fig. 16:- Displacement result for Titanium Alloy (Ti_6Al_4V)

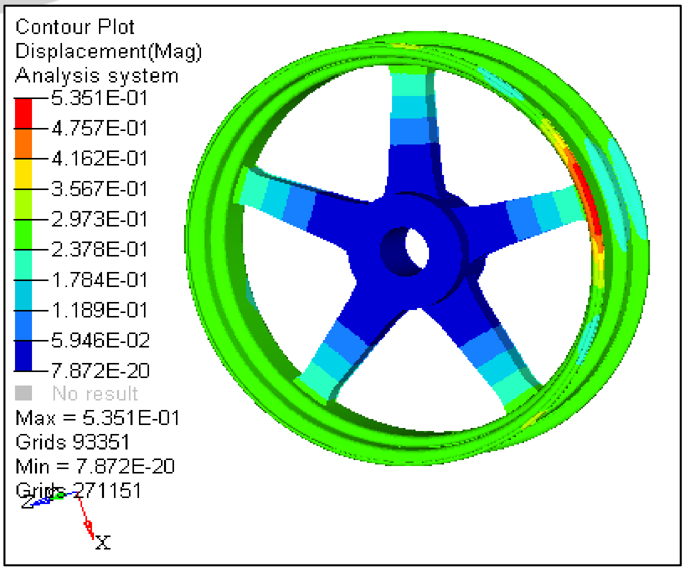

Fig. 17:- Displacement result for Aluminum Alloy A 356.2

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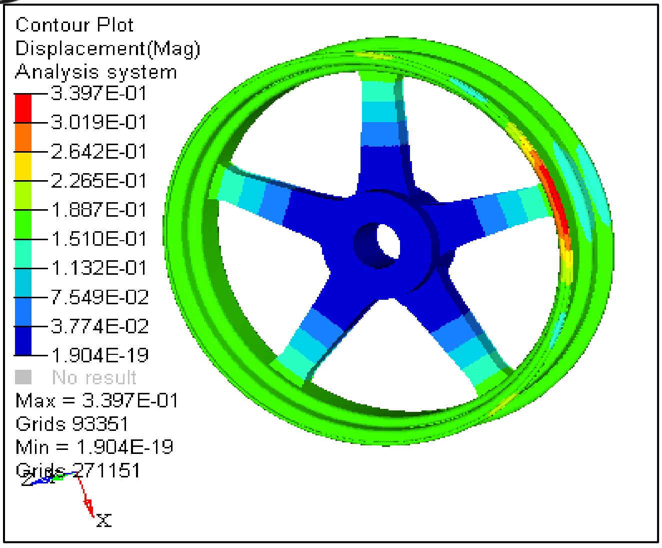

Fig. 18:- Displacement result for Carbon Fiber

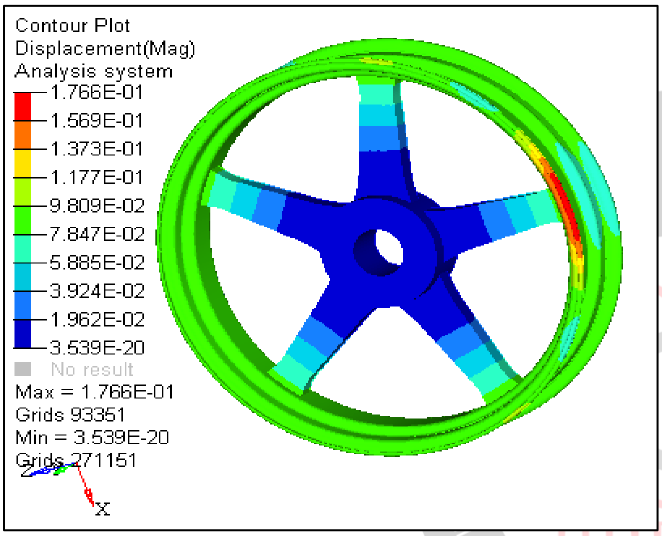

Fig. 19:- Displacement result for Steel

VII. WEIGHTED-PROPERTIES METHOD

In the following chapter instead of mentioning the entire material name everywhere only a specific number would be used to denote or address a particular material. This would save the space requirement and would make the entire procedure less complicated. Table no. 4 gives the details regarding the materials and their material numbers.

Table no. 4 :- Material Number index

Material	Material Number
LM25 aluminum alloy in T6 condition	1
Magnesium Alloy (Mg_6Al_3Mn)	2
Titanium Alloy (Ti_6Al_4V)	3
Aluminum Alloy A 356.2	4
Carbon Fiber	5
Steel	6

In the previous stage we have successfully obtained the stress and displacement results for both CFT and RFT loading conditions using all the material alternatives which were at our disposal. Now in this stage we will select the best or optimal material from all the given alternatives. This stage involves critical evaluation of all the available in order to select an optimal solution such that not only the strength and life of the component increases but also the future cost of material and manufacturing and the finished weight of the component decreases. Due to this reason selection of materials during the conceptual design step plays a vital role in the manufacturing of any component. In this study we have used Weighted-Properties Method with the help of Digital Logic Method in order to select an optimal material for our wheel rim model. Hence we are using a combination of Weighted-Properties Method and Digital Logic Method which collectively forms a part of a broader methodology known as concurrent qualitative selection of materials method (CQSM).

In the weighted-properties method each material requirement, or property, is assigned a certain weight, depending on its importance to the performance of the part in service. A weighted-property value is obtained by multiplying the numerical value of the property by the weighting factor (α). The individual weighted-property values of each material are then summed to give a comparative materials performance index (ϒ). Materials with the higher performance index (ϒ) are considered more suitable for the application.

The very first step in the material selection process is to select the various properties of the materials to be considered for the evaluation process. The materials and their respective properties which are considered in this project are shown in Table no. 5.

Table no. 5 :- Properties under Consideration

Mat. No.	Youngs Modulus (GPa)	Tensile yeild stress (MPa)	RFT Displacement (mm)	Material Cost (Rs/kg)	Weight (kg)
1	71	185	0.52	155	7.5
2	45	130	0.818	350	5
3	112	1000	0.329	1500	12
4	69	225	0.535	260	7
5	110	450	0.34	1600	4
6	210	250	0.177	150	21

The number of individual properties which are considered for comparison are denoted by (n). in our case n=5. The values of Young's Modulus, Yield Strength and Cost of each and every material is taken from table no. and table no. . As discussed earlier the stress results obtained during the analysis stage is almost the same for each and every material. Hence the materials cannot be differentiated

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on the basis of of their stress values. But the Safety Factor obtained using different materials is different, And as the Safety Factor is directly proportional to the Yield Strength of the material, it has been considered as a property for comparing purposes during the material selection Process. Also as the displacement values obtained for RFT are higher than the values obtained for CFT, only these values are considered in the selection process. Finally the Finished Weight values of the component for different materials is obtained from the designing software itself by giving the varying desnsity of each material as input.

A. Digital Logic Method

When a number of material properties are specified and the relative priority of each property is not clear, determinations of the weighting factors, (α), is largely based on intuitions, which eventually reduces the reliability of selection. The digital logic approach can be used as a systematic tool to determine (α). In this procedure evaluations are arranged such that only two properties are considered at a time. Every possible combination of properties or goals is compared and no details of choice are required, only a yes or no decision for each evaluation. To determine the relative importance of each property or goal a table is constructed, the properties or goals are listed in the left-hand column, and comparisons are made in the columns to the right, as shown in Table no. 6. In comparing two properties or goals, the more important goal is given numerical one (1) and the less important is given zero (0). The total number of possible decisions N = n (n - 1)/2, where n is the number of properties or goals under consideration. In our case as n=5, therefore the value of N=10. (α), for each goal is obtained by dividing the number of positive decisions for each goal by the total number of possible decisions (N). The values of Positive decisions and weighting factors for each property is calculated individually and is shown the Table no. 7. Always the summation of the individual weighting factors is equal to1.

Table no. 6:- Determination of Relative Importance of Properties Using Digital Logic Method

Property (n)	Positive Decisions	Weighting Factors (α)
Youngs Modulus (GPa)	1	0.1
Yeild Strength (MPa)	2	0.2
RFT Displacement (mm)	2	0.2
Material Cost (Rs/kg)	2	0.2
Weight (kg)	3	0.3

Table no. 7:- Weighting Factors (α)

Property (n)	Positive Decisions	Weighting Factors (α)
Youngs Modulus (GPa)	1	0.1
Yeild Strength (MPa)	2	0.2
RFT Displacement (mm)	2	0.2
Material Cost (Rs/kg)	2	0.2
Weight (kg)	3	0.3

B. Performance Index

In its simple form, the weighted-properties method has the drawback of having to combine unlike units, which could yield irrational or misleading results. This is particularly true when different mechanical, physical, and chemical properties with widely different numerical values are combined. The property with higher numerical value will have more influence than the one guaranteed by its weighting factor. This drawback is overcome by introducing scaling factors. Each property is so scaled that its highest numerical value does not exceed 100. When evaluating a list of candidate materials, one property is considered at a time. The best value in the list is rated as 100 and the others are scaled proportionally. Introducing a scaling factor facilitates the conversion of normal material property values to scaled dimensionless values. For our present application, materials with higher yield strength and young's modulus are more desirable and their respective highest value is rated as 100. Their scaled values are calculated using the equation (3).

$$Scaled\ Property\ (\beta) = \frac{Numerical\ value\ of\ property\ X\ 100}{Maximum\ value\ in\ the\ list} \qquad \text{……….(3)}$$

Since Displacement, material cost and weight are desirable for the automotive Wheel Rim, therefore, their lowest value is considered as 100 and scaled values are calculated using equation ().

$$Scaled\ Property\ (\beta) = \frac{Minimum\ value\ in\ the\ list\ X\ 100}{Numerical\ value\ of\ property} \qquad \text{……….(4)}$$

Using the Data from Table no. 5 and the equations (3) and (4), scaled property (β) is found out for all the properties of each and every material under consideration. These values are represented in Table no. 8.

Table no. 8:- Scaled Property (*β*)

Mat no.	Youngs Modulus (GPa)	Tensile yeild stress (MPa)	RFT Displacement (mm)	Material Cost (Rs/kg)	Weight (kg)
1	3.4	3.7	6.8	19.4	15.9
2	2.15	2.6	4.3	8.6	24

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3	5.3	20	10.8	2	9.9
4	3.3	4.5	6.6	11.6	17.1
5	5.2	9	10.4	1.8	30
6	10	5	20	20	5.7

Using the values of scaled properties for each and every element, the material performance index can be calculated using equation (5)

$$\text{Material Performance Index } (\gamma) = \sum_{i=1}^{n} \beta i \alpha i \quad \ldots\ldots(5)$$

Where, β is the scaled property,
α is the weighting factor and
i is summed over all the n relevant properties.

Using the Scaled Property values from Table no. 8 and equation (5), the individual performance index for each and every property is calculated and represented in Table no. 9. Similarly the summation of these individual performance index gives the value of material performance index (γ) for every material which is properly tabulated in Table no. 10.

Table no. 9:- Individual Performance Indices

Mat no.	Youngs Modulus (GPa)	Tensile yeild stress (MPa)	RFT Displacement (mm)	Material Cost (Rs/kg)	Weight (kg)
1	3.4	3.7	6.8	19.4	15.9
2	2.15	2.6	4.3	8.6	24
3	5.3	20	10.8	2	9.9
4	3.3	4.5	6.6	11.6	17.1
5	5.2	9	10.4	1.8	30
6	10	5	20	20	5.7

Table no. 10:- Material Performance Index (γ)

Material	Material Number	Material Performance Index (γ) (%)
LM25 aluminum alloy in T6 condition	1	49.2
Magnesium Alloy (Mg6Al3Mn)	2	41.65
Titanium Alloy (Ti6Al4V)	3	48
Aluminum Alloy A 356.2	4	43.1
Carbon Fiber	5	29.4
Steel	6	60.7

VIII. RESULTS AND DISCUSSION

After performing CAE on the wheel rim, the stress and displacement results were obtained for both the loading conditions namely, CFT and RFT. These results were obtained by considering all the six different materials taken into account for evaluation. Fig no. 19 and Fig no. 20 give a Graphical analysis of the Displacement values and safety factor respectively, obtained for the various materials which are to be studied. From the obtained results it can be seen that the stress values obtained are well below the yield strengths of the materials due to which a considerable amount of safety factor is achieved. Maximum value of safety factor was shown by Titanium Alloy (Ti6Al4V) during the RFT simulation with the value equal to 16. Also it is observed that the displacement values obtained for both CFT and RFT are well under the permissible levels. Maximum displacement was shown by Magnesium Alloy (Mg6Al3Mn), while steel gave the least displacement values, which is desirable.

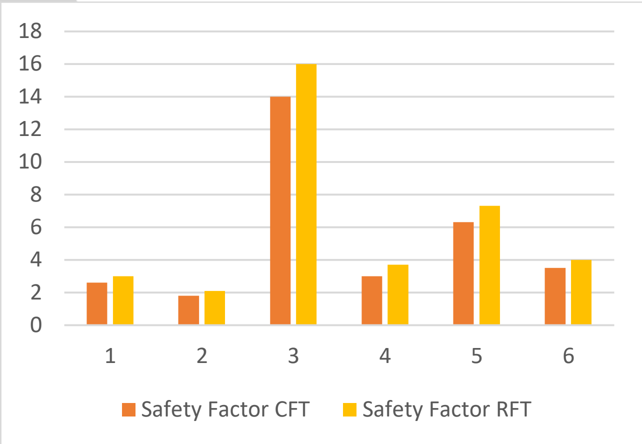

Fig. 20:- Safety factor chart

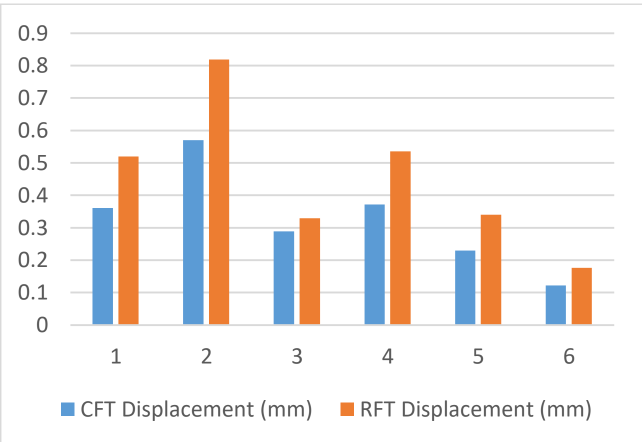

Fig. 21:- Displacement chart

Similarly the cost and weight analysis of the materials is done and a comparative analysis of the same is depicted via Fig no. 21 and Fig. no. 22. It is observed that the cost of steel is the lowest while that of carbon fiber is the highest..

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The weight analysis which is performed by considering the density of each and every material suggested that Carbon Fiber is the lightest material, while steel is the heaviest one. Considering the application of wheel rim, weight of the final component is very vital. Hence optimum weight of the component is a priority. But in spite of the low weight of carbon fibers, the high cost of carbon fiber, it's costly and tedious manufacturing process makes it undesirable for our application. Also in the further analysis it is made clear that the Performance index of Carbon Fiber is the lowest which makes it least expected to be selected for our application.

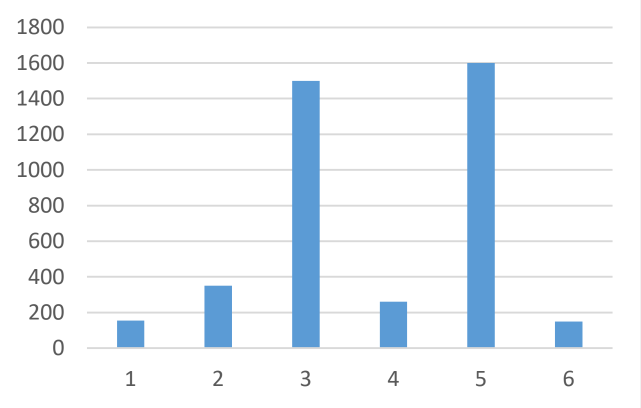

Fig. 22:- Material chart

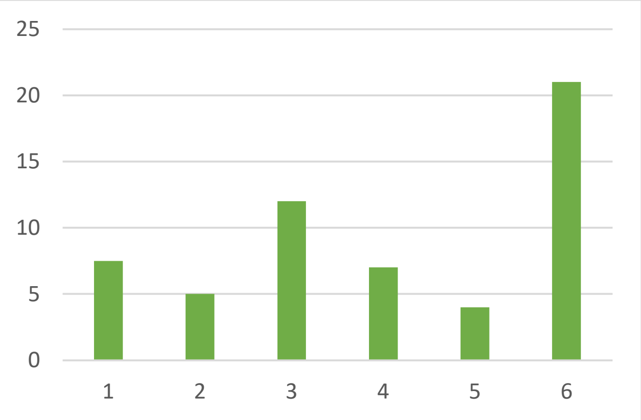

Fig. 23:- Final Component Weight chart

For more accurate estimation of the solution for our problem a Concurrent Qualitative Selection of Material (CQSM) methodology is adopted. In this methodology first a number of properties are shortlisted to be considered for the comparison of the materials. This is followed by application of Weighted-Properties Method, which with the help of Digital Logic Method helps in conducting a critical examination of the available materials in order to select the optimal one. After performing the Weighted-Properties method the Material Performance index for each material is calculated and same is represented in a graphical form in Fig. no. 23. From the fig. . it can be noted that steel holds the highest Performance Index(γ) of 60.7 %. Also LM25 Aluminum Alloy and Titanium Alloy (Ti_6Al_4V) are just behind steel with performance indices of 49.2% and 48% respectively.

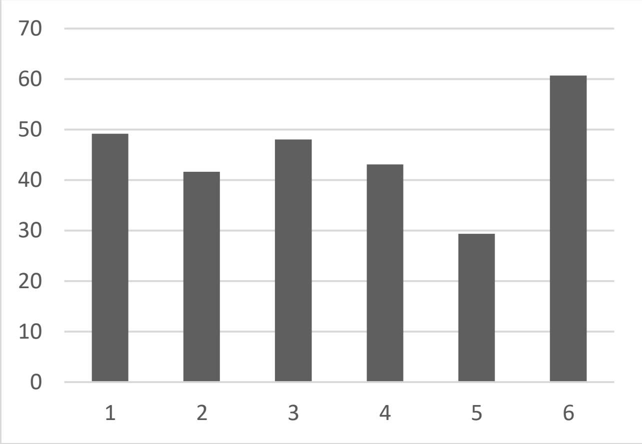

Fig. 24:- Performance index ϒ

IX. Conclusion

The design of an automobile rim wheel has been successfully prepared. After the model is designed, CAE analysis procedures are performed on it. These procedures mainly include the simulation of Radial Fatigue Test (RFT) and (CFT). The Stress and displacement results obtained for the above mentioned tests are used validation of the rim before it has been completely manufactured. As mentioned above we have considered six different materials for analysis purposes. Hence the analysis results for all these materials are successfully obtained and thoroughly studied. The maximum displacements were observed for Magnesium Alloy (Mg6Al3Mn) with the values equal to 0.5698mm 0.8189mm for CFT and RFT respectively. While the minimum Displacement was observed for Carbon Fibre which was equal to 0.1221mm and 0.1771mm for CFT and RFT procedures respectively. The maximum stress results were observed to be 72.22MPa and 62.61MPa for CFT and RFT simulations respectively. After the CAE stage is done the next step is to choose a suitable material from the given number of options. For this purpose firstly, the data obtained from CAE stage and other data regarding the properties of the materials is gathered. For example:- Young's Modulus, Yield Strength, Cost, Finished component weight etc. Using this collected data and with the help of Weighted-Properties Method (WPM) the critical evaluation of all the six materials is done in order to predict the optimal material for the wheel rim model. WPM is used to calculate the Material Performance Index (γ), while it is observed that steel has the highest Material Performance Index (γ), which is equal to 60.7%.

On the other side Carbon Fiber exhibits minimum value of Material Performance Index (γ), which is equal to 29.4%. Hence by going through the various analysis results and comparative charts prepared for the various materials, which help us to study every material on the basis of a variety of properties, we conclude that Steel is the most optimal or desirable material to be used as a stock material for automobile wheel rim applications. After Steel the material which is highly recommendable is LM25

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Aluminium Alloy, while Carbon Fiber is the least feasible material for the required application. Hence it can be concluded that the optimal material for the rim model is Steel.

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