Design and Analysis of Wheel Rim for Mass Optimization by Using Composite Material

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Abstract— The purpose of the passenger Vehicle wheel rim provides a firm base on which to fit the tire. Its dimensions, shape should be suitable to properly accommodate the particular tire required for the vehicle. In this study we are focusing on the optimization of weight by using FEA method. The wheel rim is designed by using modeling software catiaV5R19 by reverse engineering procedure. In modeling the time spent in producing the 3-D models and the risk involved in design and manufacturing process can be easily minimized. For better design results this CATIA model is imported to ANSYS for analysis work. ANSYS software is the latest used for simulating the different forces acting on the component and also for calculating and viewing the results. A solver mode in ANSYS software calculates the stresses, deflections and their relations without manual interventions, reduces the time compared with the method of mathematical calculations by a human. Also in the weight of component is display by density and size of material. ANSYS static analysis work is carried out by considered four different materials namely aluminum alloy, Mg alloy, mild steel and Composite material. Also their relative performances have been observed respectively. In addition to this rim is subjected to FEA analysis. In this paper by observing the results of both FEA static analysis and testing results obtained by comparing weight of all selected material and find the best material in that all material.

Keywords: ANSYS, Wheel Rim, aluminum alloy, Mg Alloy, Carbon Fibre, and mild steel

I. INTRODUCTION

Automotive wheels have been developed over the periods from early spoke designs of wood and steel, flat steel discs and lastly to the stamped metal configurations and structural steel and aluminum alloys rims of today's modern vehicles. Historically, successful designs reached after years of experience and widespread field testing. In the latest years, the procedures have been enhanced by a variety of experimental and analytical methods used for structural analysis (strain gauge and finite element methods). Within the past 10 years, durability analysis (fatigue life predication) and reliability methods for dealing with the differences inherent in engineering structures has been applied to the automotive wheel. Wheels are clearly safety allied components and hence fatigue performance and the state of stress in the rim under various loading conditions are major concerns. Further, wheels carry on obtaining a considerable amount of attention as a part of industry efforts to reduce weight through material replacement and down gauging. Even though wheels are loaded in a complex manner and are highly stressed in the course assumed multiple choices in respect of material, cross section for rim and arm connecting hub and rim. The newer car is supposed to have lesser weight without compromising the strength. Consequently, there is a scope for optimization of wheel design in respect of geometry of car rim, geometry of arm, material etc. The car rim is subjected to static loading condition. It undergoes Pressure, Tensile, circumferential loading and also impact loading. Consequently, it is justified to have a detailed analysis using the technique like FE for the stresses developed during used. It is proposed to analyze the car rim using FE approach for varied geometry parametric parameter for optimization of its weight. Of their rolling duty, lightweight is one of the major requirements hence cast and forged aluminum alloys are essential in the design. So, the current generation automobile have the alloy wheel. This technology ups gradation has wheeled is the one of the most important components of an automobile. It supports and bears the entire vehicle load. It suffers not only the vertical force but also the irregular forces resulting from the car's ride, braking, cornering, road bumps, and all uneven shocks in the process of moving on road. Due to high speed rotation, its quality has a massive impact on wheel stability, handling and other characteristics. Cornering Fatigue Test and Radial Fatigue Test are performed on any road wheel. It is observed that the FEA result of the above two tests shows that the maximum stress being induced in the wheel is much less than the allowable stress of aluminum alloy. Here comes the scope for further optimization of these wheels. Structural optimization is aimed at to minimize the mass of wheel without compromising the strength of wheel

II. PROBLEM DEFINITION

The failure of rim wheel is due to crack initiated near the hole which further gets propagated. To improve the strength of wheel rim, material optimization and design optimization is necessary for which the best material has to be selected by conducting design of experiments to find parametric design which gives higher strength of wheel rim. So I am doing the analysis of wheel rim with materials are magnesium alloy, Aluminium alloy, Carbon fiber+ Kevlar, mild steel. After testing the material in ansys software its material samples will be tested to check better material to reduce the wheel rim weight and improve the strength

A. Images of failure:

Fig. 1: Crack near the hub hole

Fig. 2: Bend due to impact:

III. AIM AND OBJECTIVE

The failure of the wheel rim can be avoided by changing the design of the wheel rim cross section. The alternate design option provides the strength and stiffness to the wheel rim. To prevent the failure of wheel rim due to crack initiated near the hole which further gets propagated throughout the rim which leads to fatigue failure.

1) To improve material optimization.
2) To improve design optimization is necessary for which best material has to be selected by conducting design of experiments.

IV. DESIGN METHODOLOGY

Methodology used in the analysis and design of the wheel rim

A. Research Paper

For This Project We were focusing on finding research papers for finding the research gap and the idea to find new concept with focus of project development regarding design and manufacturing. The research papers were gave us the domains and works which were already completed and provided lots of information and research data regarding design and analysis of wheel rim for weight optimization by using composite material.

B. Collection of Data

From research papers and resources we were collect the data for actual design of bumper and to overcome the bugs and challenges. We were come to know about many material used for wheel rim. The all collected data was used for getting proper path for development

C. CATIA design for Arrangement

For our project the next step to design of actual wheel rim with dimension and approximate calculations of different forces acting on wheel rim. For Catia modeling we have taken the help of selection of the research papers and car catalogue we created the 3D model of our project that is wheel rim design in CATIA v5 software.

D. Analysis

For our project we are doing analysis on Ansys Workbench 16. With modal analysis and static structural analysis workbench for solving procedure.

E. Testing

In this step we did the testing of wheel rim material plates with different forces acting on it. This will give us data regarding different parameter which help us to improve the design of wheel rim and for selection of better material.

F. Result comparison, Conclusion and report writing

In this last step we are comparing the result of theoretical and practical method and finding the better material by minimum weight, high strength and low deflection. By using this result we are concluded the best material.

V. LITERATURE SURVEY

Karthi et al studied the design of motor cycle alloy wheel using the PRO-E and Analyzed with the ANSYS. Analysis a tool used for the evaluation of systems and structures. It is needed to analyze complex structures, whereas very simple ones. There are three processes involved which are reprocessing, analysis and visualization. The chosen material was an Aluminum alloy, magnesium alloy, titanium alloy. The aluminum alloy is well to the conventional steel wheels in strength and durability. It has excellent wear resistance, anticorrosion properties and longer service life as estimated by the stress frequency distribution. The analysis is done with the extreme load can be applied on rim. The rear wheel and front wheel have their maximum load that can be sustained. It was found that the stress of the analysis is still in the range of the yield strength of Aluminum alloy. The Displacement is at the low value. This design is still in the safe condition.

Choudhury & Dipesh Rohan discussed about vehicle mass effect. Mass can be categorized as sprung-mass and unsprung-mass. A lower value of unsprung mass leads faster response time. There will be steady vertical load acting through the tyres and therefore a consistent level of friction acts between the car and road. Acceleration, braking and cornering performance of the vehicle is better. This paper goals to develop a composite wheel rim to be used with a lightweight aluminum center to reduce the unsprung mass of the vehicle and thus decrease the suspension response time for a better control of the vehicle. This will work towards bringing the sprung to unsprung mass ratio closer to the original value, and therefore allow for further reduction of the unsprung mass as well as sprung mass

H. N. Kale et al, studied about Wheel rim design. Rim is a central part of wheel above which a rubber tyre is mounted. In wheel assembly tyre fixed on the rim in between the left and right board flange over the bead seat area. Wheel convert axle torque into the rotational motion that rotating tyre comes in contact with road surface and rotational motion gets converted into the linear motion of a vehicle, that means the wheel assembly is very important part of any automobile without it vehicle cannot displace from one position to another. Well build road surfaces are not available everywhere in the world. On the road there are so many up and downs as well as pot holes which are responsible for impact load on the wheel and rim directly. Wheel is exposed to the loads of passenger, goods in addition with self-weight of vehicle itself, such load act as an alternating load and responsible for induction of irregular stresses into the rim and resulted fatigue failure of rim. Distinctly from above load wheel rims come in contact with environmental conditions which adversely affects on the rim. This paper presents

reasonable study of various types of wheel rim materials in comparison to wide varieties of aspects. Right material for right design acts as an important role in the life of any mechanical components. Relative study will help any designer while selecting materials for wheel rims of any type of ground vehicles. Deformation of lightweight alloy wheel is additional than the steel and forged steel, which means forged steel, can be used for light as well heavy duty vehicles such as trucks, tractors, trolley, scooter, bikes etc. Heat dissipation and corrosion resistance of Mg and Al alloy is well as compared to Steel C1008 and forged steel. All materials presented in table-1 are strong yet durability is also dependent on the manufacturing method employed for rim, dimensional design of rim.

S. Ganesh &Dr. P. Periyasaamy research on Aluminium Alloy wheels of automobiles. Wheels which are manufactured from an alloy of aluminum, magnesium metals or sometimes a mixture of both Alloy wheels vary from normal steel wheels because of their lighter weight which improves the steering and the speed of the car. Alloy wheels will decrease the unstrung weight of a vehicle compared to one fitted with standard steel wheels. The benefit of decreased unsprung weight is more precise steering as well as a nominal reduction in fuel consumption. Alloy is an excellent conductor of heat, refining heat dissipation from the brakes, reducing the risk of brake failure under demanding driving conditions. At latest design four wheeler wheels are made of Aluminum Alloys. In this project a parametric model is designed for Alloy wheel used with four wheeler by collecting data from reverse engineering process from current model. Design is valued by analyzing the model by altering the design of rim styles to be strong and balanced. Its material should not deteriorate with weathering and corrosion.

P. Meghashyam et al has motive study about car rim wtth Catia & Ansys Tool. The car wheel rim provides a firm base on which to fit the tire. Its dimensions, shape required as appropriate to effectively accommodate the particular tire required for the vehicle. In this study a tire of car wheel rim fitting to the disc wheel category is considered. Design in important industrial activity which affects the quality of the product. The wheel rim is designed by using modeling software catiav 5 r18. In modeling the time spent in creating the complex 3-D models and the risk involved in design and manufacturing process can be easily minimized. So, the modeling of the wheel rim is completed by using CATIA. Later this CATIA model is imported to ANSYS for analysis work. ANSYS software is the newest used for simulating the different forces, pressure acting on the component, and also for calculating and viewing the results. A solver mode in ANSYS software calculates the stresses, deflections, bending moments and their relations without manual interventions, reduces the time compared with the method of mathematical calculations by a human. ANSYS static analysis work is conceded out by deliberating two different materials namely aluminium and forged steel and their virtual performances have been observed respectively. In addition to this rim is exposed to vibration analysis (modal analysis), a portion of dynamic analysis is carried out its performance is observed. In this paper by detecting the results of both static and modal analyses obtained forged steel is recommended as best material.

VI. CALCULATIONS OF LOAD AT WHEELS

Average Vehicle Weight considered in Indian SUV vehicle segment = 2225 Kg.

Loading conditions for the wheel rim: Below are forces acting on the wheel rim while driving the vehicle.

- The Vehicle at the instant of braking: The braking force transferred to wheel rim is calculated as below,

Bump Force calculated below:-

For bumping force value first we required to calculate below values.

1) Brake Pedal Force
   The Brake applied on the pedal is assumed to be 300 N (30.6 Ksp)
2) Pedal ratio of every 4 wheeler is 6:1
3) Fmax = Force X Pedal Ratio
   = 300 X 6
   = 1800 N

Hence, $P = Fmax / \Pi / 4 \times d^2$

∴ P = Hydrostatic Pressure d = dia of master cylinder

$Fmax = P \times \Pi / 4 \times D^2$ by Pascal Law Fmax = Force acting on each cylinder D = Dia of piston cylinder in caliper

By Solving,

$Fmax = fmax \times (D/d)^2$

$= 1800 \times (0.3 / 0.19)^2$

= 4487.5346 N

4) Now we calculate the torque acting on the disc,

T = Fmax X u X Re X no. of Piston per caliper

= 4487.6346 X 0.3 X 0.097 X 3

T = 391.7671

Where, u = Coefficient of friction between the brake pad and disc with thus = 0.3

Re = Radius of disc.

Max velocity of vehicle = 156 kmph Mass of Vehicle = 2225 kg

Newton's law of motion,

F= m x ag = 9.31 m/s

Here,

= 2225 X 9.81

= 21827.25 Kg.m

S^2

F = 21827.25 N

∴ Force applied on each wheel

= F / 4

= 21827.25 / 4

F = 5456.8125 N Units

Bump force calculated with reference of paper no. 11 mentioned in reference list.

VII. MATERIAL PROPERTIES

To optimize weight of the wheel rim and ensure its durability three new different materials considered.

Al alloy is existing material. And Carbon fibre, Mg alloy, Mild steel are new materials.

	Al Alloy	Carbon fiber	Mg alloy	Mild steel
Young's Modulus	7.1e+4 Mpa	70 e3Mpa	4.6 e5 Mpa	140 e3 Mpa
Poisson's Ratio	0.33	0.10	0.35	0.290
Density	2770 kg/m3	1600 Kg/m3	1800 kg/m3	7850 kg/m3
Ultimate tensile strength	310Mpa	1200Mpa	230Mpa	440 Mpa
Yield Strength	280Mpa	945Mpa	130 Mpa	250 Mpa

Table 1: Material Properties

VIII. FINITE ELEMENT ANALYSIS AND CATIA DESIGN

CATIA &ANSYS Workbench Simulation11.0 (also known as ANSYS Workbench Meshing 11.0) is used in this research work.

A. Building and Importing CAD model in ANSYS

The baseline Wheel rim model is prepared in CATIA using Sketcher and Part Design workbench. The model prepared in CATIA is as shown in the below figure.

Fig. 3: Al Wheel rim CAD model in CATIA

1) Meshing

Baseline Wheel rim is meshed with meshed with solid 187 elements for better accuracy and results.
Number of nodes = 201888
Number of elements = 1114332
Mesh element size - 8 mm
Element Type = Higher order Solid 187 elements

Fig. 4: Mesh model of Al wheel rim

2) Boundary Conditions

The pressure generated from the action of bumping pressure is applied at the region where top of the wheel rim Section are touching to wheel rim. Following boundary conditions are applied on the wheel rim

Total downward direction pressure-9806.6 mm/s² as a worst loading scenario. Bump force 5456.81N is considered as impact force during bump analysis in FEA.

Boundary conditions for baseline wheel rim model

3) Analysis of Al alloy Wheel Rim

1st analysis Al alloy tube pressure:

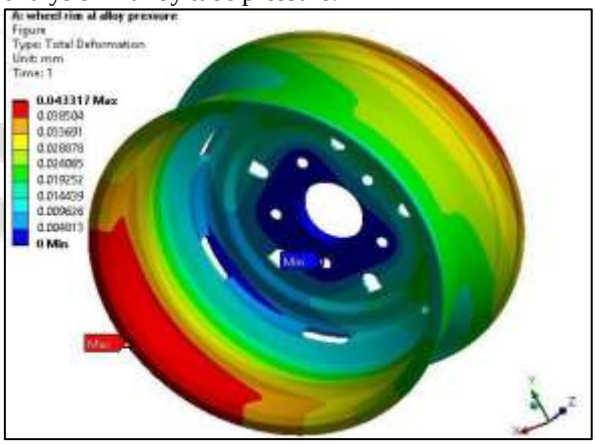


Fig. 5: Total deformation contour plot for baseline Al Wheel rim

The maximum displacement shown by the baseline wheel rim design is 0.043317 mm.

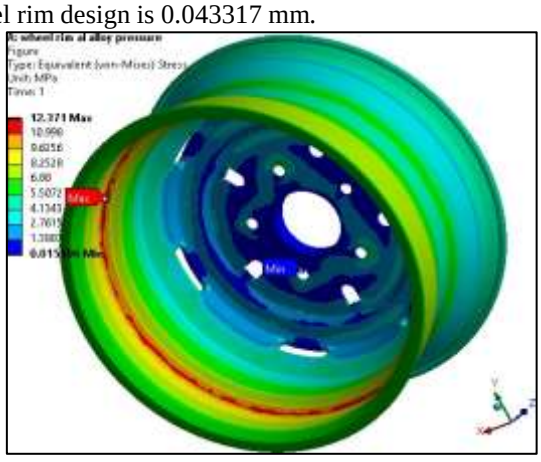


Fig. 6: Von-Mises stress contour plot for baseline Al wheel rim by tyre tube pressure

4) 2nd Analysis Tube pressure + bump

Fig. 7: Wheel rim al alloy pressure + bump gravity force downward direction

The maximum equivalent stress observed in the baseline wheel rim is 12.371 MPa.

The yield strength of the material is 280 MPa. According to the results, the von-Mises stress 280 MPa is less but nearer to the yield strength of the material. The sudden or impact braking action can cause the failure of the wheel rim at weakest cross sectional area of the wheel rim. The Field failure of the disc is caused due to sudden and dynamic load acting on the bumper. The same location of the failure is detected in finite element analysis study which is shown in the Figure.

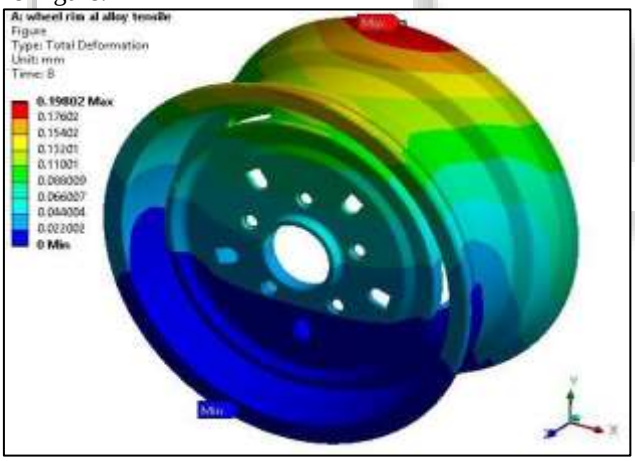


Fig. 8: Total deformation of al alloy rim by tensile loading

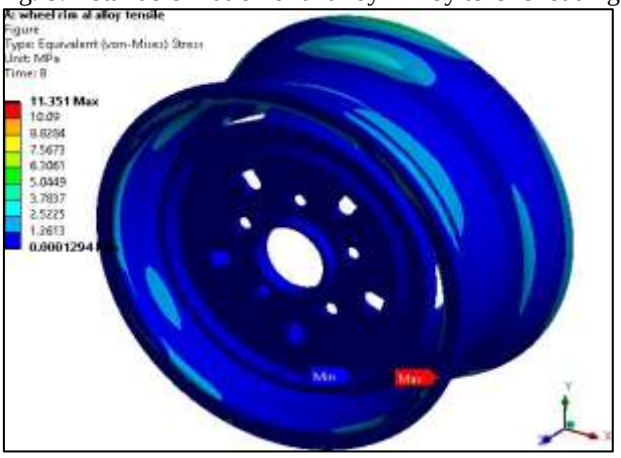


Fig. 9: Equivalent von mises stress of al alloy rim by tensile loading

5) Analysis of Wheel rim with Carbon Fiber material:

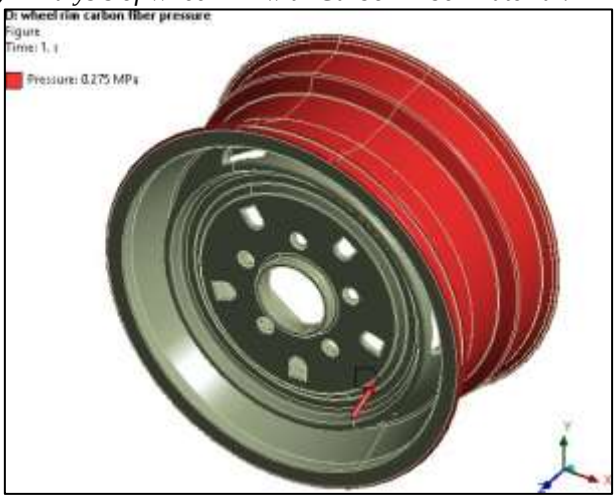


Fig. 10: Tyre tube pressure on rim surface

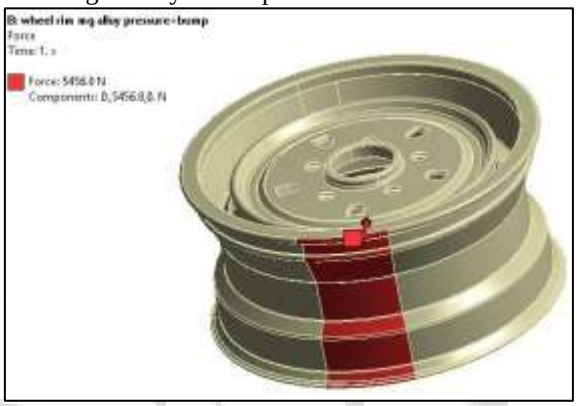


Fig. 11: Bump force 5456.8 N applied at carbon fibre rim

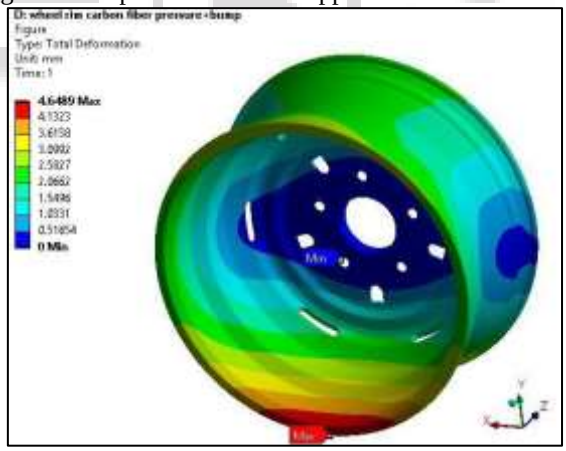


Fig. 12: Total deformation on carbon fiber rim by bump

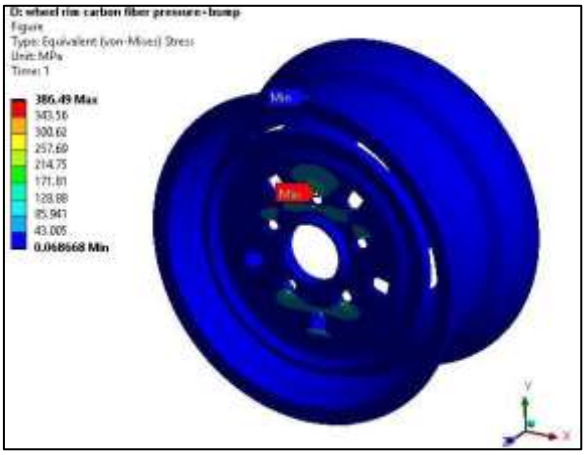


Fig. 13: Von Mises stresses on carbon fiber rim by bump

6) Analysis of wheel rim Magnesium alloy material:

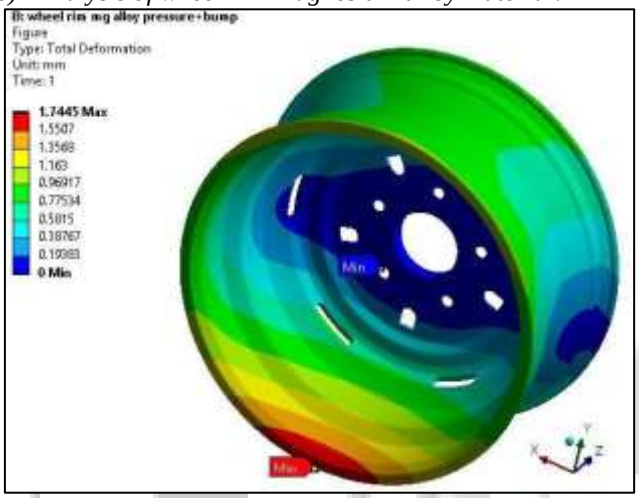


Fig. 14: Total deformation on Mg alloy rim by bump

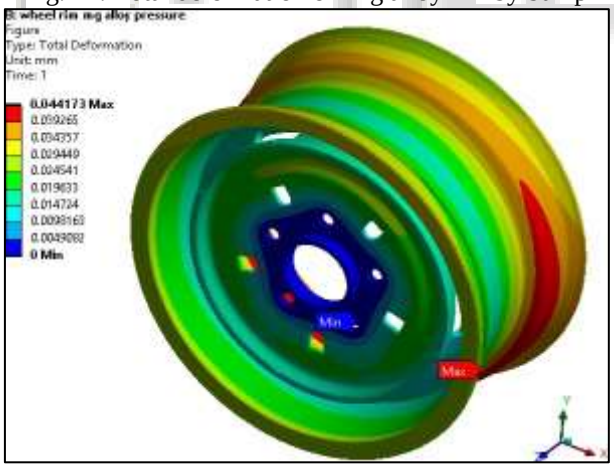


Fig. 15: Total deformation on Mg alloy rim by tyre tube pressure

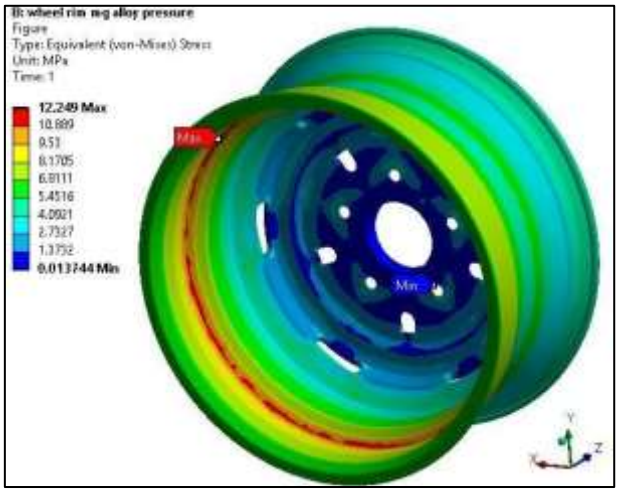


Fig. 16: Von Mises stresses on Mg alloy rim by tyre tube pressure

7) Analysis of wheel rim with Steel material:

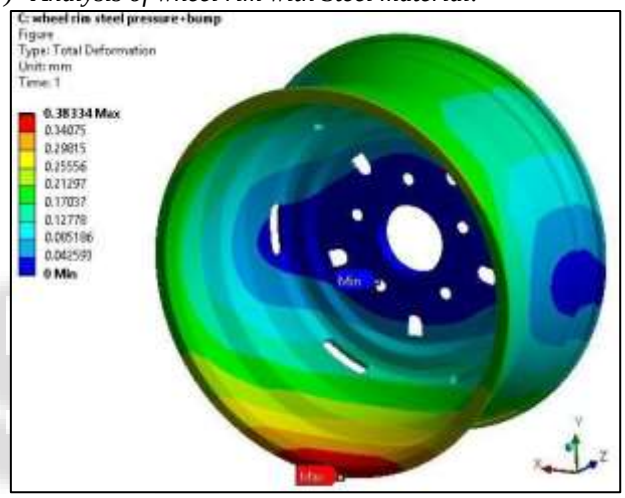


Fig. 17: Total deformation on steel rim by bump

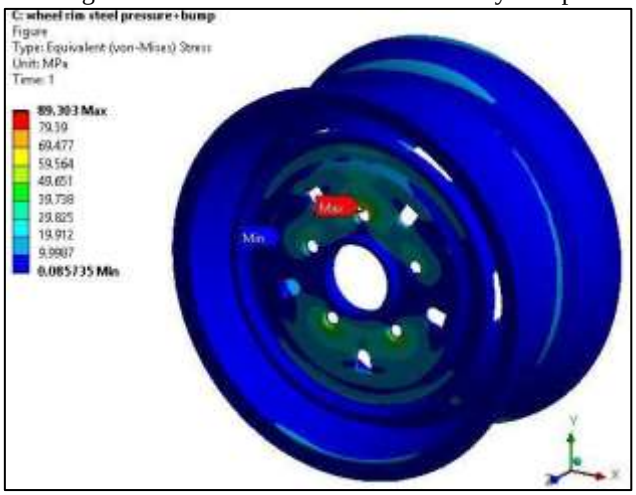


Fig. 18: Von Mises stresses on steel rim by bump

IX. RESULTS AND DISCUSSION

Results summarized after Design, FEA and Testing of respective material samples.

Sr. No.	Description	Mass (kg)	Deflection (mm)	Von- Mises stress (MPa)	FOS	Yield strength of material
1	Aluminium alloy Tube pressure Tube Pressure + Bump	12.2 12.26	0.04331 1.1056	12.371 93.793	25.05 3.30	280Mpa
2	Carbon Fiber Tube pressure Tube	6.596	0.20334	27.495	34.55	945Mpa

	Pressure + Bump	6.596	0.46489	386.49	2.45	
3	Magnesium alloy Tube pressure Tube Pressure + Bump	7.968 7.968	0.04417 1.7445	12.249 97.041	10.61 1.3396	130 Mpa
4	Mild steel Tube pressure Tube Pressure + Bump	34.75 34.75	0.38334 0.01911	89.303 12.542	2.799 19.93	250 Mpa

Table 2: FEA results for various samples

Results for compressive, tensile and impact strength of Aluminium alloy, Magnesium alloy, Stainless Steel & Carbon fibre composites in Praj Lab, Kothrud Pune represented in following table.

Sr No.	Defl-ectio	Load at Various Deflection (N)			
		Comp-osite	Mg	SS	Al
1	0.15	555.6	1136.8	984.9	940.80
2	0.30	1989.4	3322.2	3400.6	2195.2
3	0.45	4449.2	6027.0	6365.1	3777.9
4	0.60	7173.6	8859.2	9476.6	5566.4
5	0.75	10230.1	11686.5	12940.9	7389.2
6	0.90	13916.0	14709.8	16640.4	9192.4
7	1.05	17742.9	17836.o	20570.2	8879.8
8	1.20	21746.2	20981.8	24764.6	7918.4
9	1.40	26783.4	25666.2	26420.8	----

Table 3: Compressive strength of various samples
(As per ASTM D – 695-2002)

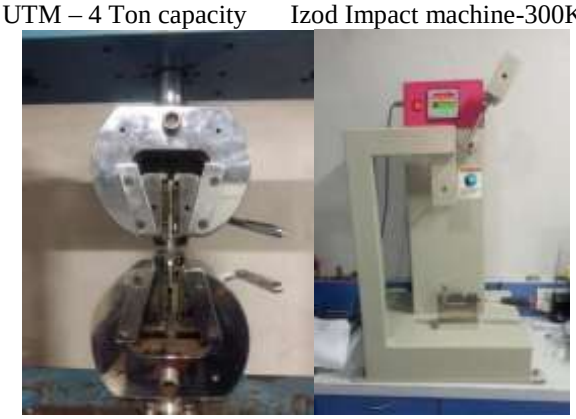
Sr. No.	Sample Identification	Tensile Strength Mpa
1	Carbon Fibre	349.34
2	MS sample	697.28
3	SS Sample	790.62
4	Al Sample	267.48

Table 4: Tensile strength of various samples
(As per ASTM D 638 - 2003)

Sr.No.	Sample Identification	Impact Value (J)	Izod Impact Strength
1	Composite Sample	17.20	252.29 Kj/m2

Table 5: Impact strength of Carbon fibre sample
(As per ASTM D 256 - 2003)

UTM – 4 Ton capacity Izod Impact machine-300Kj



Tensile and compression testing is carried out by using UTM machine and Impact testing is carried out by using Izod Impact test machine at Praj Lab, Kothrud, Pune

X. Conclusion

It is observed from the results that, Maximum stresses are developed in the various type material and its tube pressure, tube pressure + Bump and precisely matches with the test sample failure. A comparison of maximum total deformation and equivalent stress values of the wheel rim are calculated. By comparing the ansys results and material sample test results with respect to the value of factor of safety of various materials and their weight comparison. It is resulted that Carbon Fiber is better material. And it can be used for modified wheel rim design.

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