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Research Article

Analysis and Topological Optimization of Motorcycle Front Wheel

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Abstract

This article is based on modification of front wheel of motorcycle. The modification process is based on material and topology modification and validation using finite element analysis. The results obtained from modified analysis are compared with the original one. The main aim is to reduce the mass of the components without much compromise in other factors. For analysis and study, a well reputed general class 150 cc motorcycle was selected.

Keywords: *Front wheel, geometry, boundary conditions, analysis*

1. Introduction

IC engine powered vehicles have a long history and are still dominant in its segment. These engines use fossil fuels mainly petroleum oils and gases as fuels having higher calorific values. Gasoline, diesel oils and natural gases are widely used on regular basis. These are being used continuously since a long time ago and continue to be explored. Although the development of new sources is in progress, there surely is a need to retard the demand of non-renewable energy sources. The process of burning gasoline to power cars and trucks contributes to air pollution by releasing a variety of emissions into the atmosphere. Emissions that are released directly into the atmosphere from the tailpipes of cars and trucks are the primary source of vehicular pollution. But motor vehicles also pollute the air during the processes of manufacturing, refueling, and from the emissions associated with oil refining and distribution of the fuel they burn. India was the sixth largest motor vehicle/car manufacturer in the world in 2013. India is the second largest motorcycle (6.54 m produced in 2007-08) and the fourth largest commercial vehicle manufacturer in the world. This shows that motorcycles are major contributors to the overall vehicles. They share a large part of total daily fuel consumption of our country. An average human weighs about 65-75 kg. The combined weight of motorcycle and rider would be near about 200-220 kg. Hence we can say that about 70 % of fuel is consumed by the motorcycle itself. Obviously this cannot be eliminated nor can be drastically reduced but a slight reduction in one two-wheeler will cause a significant impact upon overall fuel consumed by the same model all over the country

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2. Nomenclature

R_N Normal reaction on front wheel
m_t Total mass
a_b Maximum braking deceleration
M_b Braking moment
r_b Bolt pitch radius
I_f Inertia of wheel
G_c Gyroscopic couple on front wheel
F_b Braking force
ω Maximum rotational velocity of wheel
ω_p Precision velocity
P_{Tm} Maximum tyre air pressure
L_{10} Bearing life
C Dynamic load capacity
P Equivalent bearing load

3. Front wheel

Wheel is 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 huge impact on wheel stability, handling and other characteristics (BGN Satyaprasad, 2013). Wheels are clearly safety related components and hence fatigue performance and the state of stress in the rim under various loading conditions are prime concerns. Further, wheels continue to receive a considerable amount of attention as part of industry efforts to reduce weight through material substitution and down gauging. Although wheels are loaded in a complex manner and are highly stressed in the course of their rolling duty, light weight is one of the prime requirements, hence cast and forged aluminium alloys are essential in the design.

CAD modeling of the wheels was done using CATIA V5 software. A reverse engineering approach was used to model the wheels. The current wheel is being manufactured by casting. The original weight was 3.61 kg whereas the cad model weight showed 3.3553 kg. Hence the accuracy of the model is 93.1%. This may not be totally justified as there is coating of some protective material such as paint.

4. Material modification

Original material used was Al Alloy 201.0-T43 Insulated. The material used in the modified wheel is Al 7075, same as above used in manufacturing of the swing arm. It is used to increase the overall strength of the rim keeping an eye on the weight of material. Aluminium is used instead of steel because it can withstand a lot of forces compared to the steel rims with the advantage being lower density compared to the steel rims. Following is the comparison of the previous material and the new material. Though the density of both the materials is same, al 7075 has higher strength which can be used as a scope for weight reduction by geometry modification.

Table 1 Material comparison (Sanup K Panda *et al*, 2012)

Sr. No	Property	al alloy 201.0-t43	al 7075
1	Elastic Modulus (GPa)	71	72
2	Poisson's ratio	0.33	0.33
3	Mass Density (kg/m^3)	2800	2800
4	Tensile Strength (MPa)	273	423
5	Yield Strength (MPa)	225	510

5. Geometry modifications

The original geometry was tested for stress distribution. The calculations then were used in modifying the rim for proper stress distribution with limiting the mass of the component. More scope was found for material reduction in the rim and hub portion. Hence the thickness of rim was reduced by 1 mm and slots and holes were applied in the hub portion. (Sushant Bawne, 2015) Also the spoke geometry was modified for uniform stress distribution. Following image shows the cad model of modified wheel. The weight of the modified model came out to be 2.8087 kg which is about 0.5 kg less than original one.

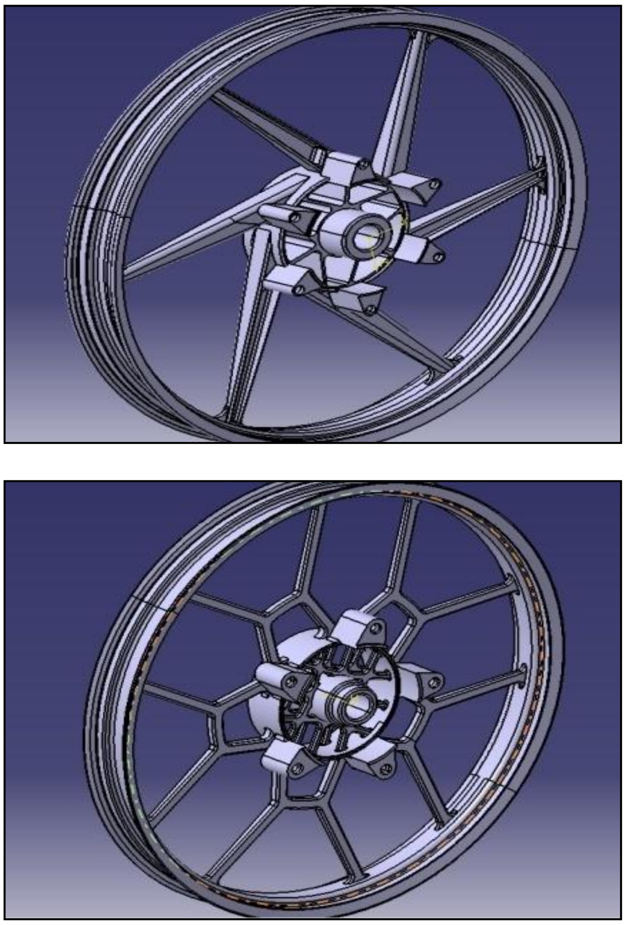


Fig. 1 CAD models

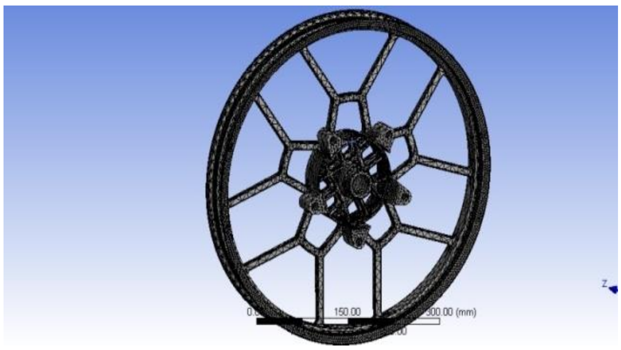


Fig. 2 Meshed model of modified front wheel

6. Analysis

FEA analysis is performed on both original and modified front wheel model. Auto meshing (K Venkateswara, 2014) was used and was done using ANSYS workbench 15.0 software. Default element size of 4 mm was used and refinement was applied in critical areas. The number of nodes generated was 201763 while the number of elements generated was 106643.

6.1 Front Wheel under Speed and Pressure

This is the simplest static condition when the wheel is running at normal or highest designated speed. Maximum rated tyre pressure along with normal reactions is applied (Madhu K S, 2014).

Loads and boundary conditions- The motorcycle weight of 143 kg along with average occupants' weight of 150 kg was considered. Bearing load was applied to the centre axle where bearings will be mounted. Out of the total load, 40% was distributed to the front wheel. Hence reaction at front wheel R_N = 293 × 0.4 ×9.81 = 1149.7 N. Considering a maximum speed of 120 kmph *i.e.*33.33 m/s, the rotational speed for wheels is calculated as 148.35 rad/s *i.e.* ω = 148.35 rad/s. The maximum rotational speed of 150 rad/s was applied for analysis purpose. Thus vertical reaction was applied as 1150 N approximately. Also the maximum permissible tyre pressure of 28 psi was used for the analysis *i.e.* P_{Tmax} = 28 psi. For the original wheel model, the bearings used were deep groove ball bearings with designation 6301LLUC3. Assuming a standard bearing life of 50 million revolutions *i.e* L_{10} = 50mR. For this bearing, Dynamic load capacity C = 9750 N (V B Bhandari, 2014).

The equivalent bearing load is given by the formula

$$P = \frac{C}{(L_{10})^{0.3}} \quad (1)$$

Using this formula, the equivalent bearing load is calculated to be 3015 N in radial direction. Frictionless support is applied at the centre and the wheel is constrained to move in the axial direction. The equivalent stress was found to be 19.916 MPa. The stress in original wheel was 18.262 MPa. These values are quite low than allowable stress.

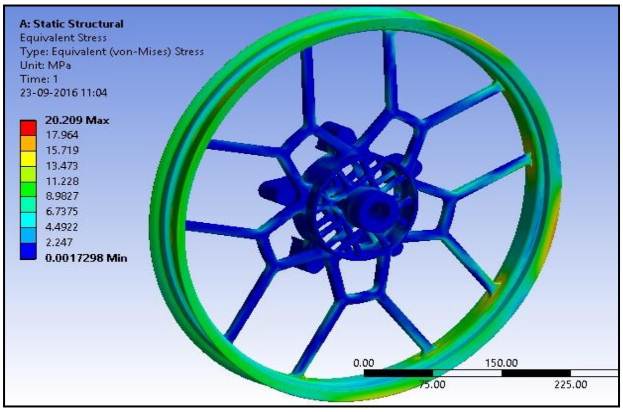


Fig. 3 Equivalent stress in Front wheel under speed and pressure

6.2 Braking Condition

Due to immediate braking, high shear stresses are generated at the rim spoke interface. Condition worsens if only front brake is applied at high speed. The overall momentum gets transformed into a moment at the portion where front disk is mounted on the hub.

Loads and boundary conditions: The maximum deceleration of the motorcycle was estimated to be -7.6636 m/s² in speed range from 60 miles per second to absolute zero. (This deceleration is calculated only for front braking). This acceleration and weight accounts for the force acting on the disk. This force gets transformed into moment along the bolt pitch circle on the hub.

Force $F_b = m_t \times a_b$ = 2245.5 N.
Moment $M_b = F_b \times r_{bp}$ = 2245.5 × 82.65mm = 185.6 Nm

Bearing load and support was applied as mentioned earlier. In order to find shearing stress in spokes, the outer rim is fixed.

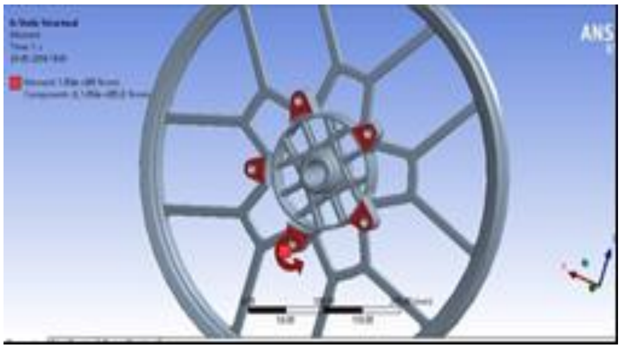


Fig. 4 Application of moment

The figure shows application of moment on the front wheel. The maximum equivalent stress generated will be 33.546 MPa in the spoke region. The maximum deformation was found to be 0.0557mm. Comparatively, these values for original wheel were 28.36 MPa and 0.0239 mm. Thus original factor of safety was 7.86 while the modified factor of safety is 12.6. High factor of safety is necessary in braking condition.

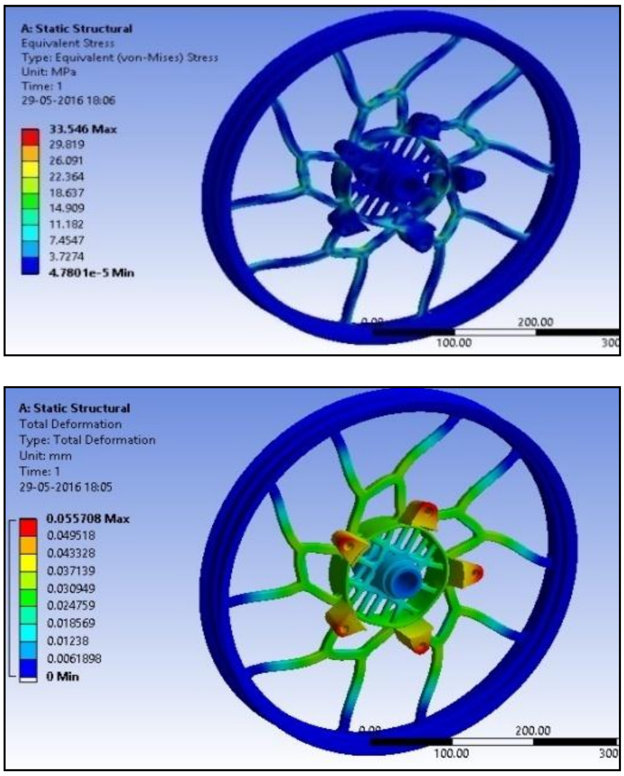


Fig. 5 Von-mises stress and deformation during braking

6.3 Gyroscopic Effect

Whenever the axis of a rotating object, about which it revolves, moves angularly, a couple acts on the object in the lateral plane. This is known as the gyroscopic effect. In case of a two-wheeler, whenever the front wheel axis is displaced while taking a turn, a couple will act on the wheel plane. The magnitude of this couple is proportional to the inertia of wheel about its axis, the angular velocity and the precision velocity.

Loads and boundary conditions: Moment of inertia of wheel about its axis is found to be I_f =0.076019 kg m^2. The maximum angular velocity of the wheel is taken as ω = 150 rad/s maximum. The precision velocity is assumed to be ω_p = 0.5 rad/s maximum. Therefore gyroscopic moment $G_c = I_f\omega\omega_p$= 5.7 Nm. Hence gyroscopic moment is found to be 5.7 Nm. This is an average value and actual value will be variable depending upon the precision velocity, which in turn depends upon the driving nature and skills of the rider. This moment is applied along with tyre pressure; angular velocity and bearing load same as earlier. Comparatively, the inertia for original wheel was 0.099861 kg m^2 and moment was 7.49 Nm. The effect of this couple is to introduce bending stresses in the spokes and rim while the hub remains fixed. The stress and deformation were found to be 0.125 mm and 76.06 MPa respectively.

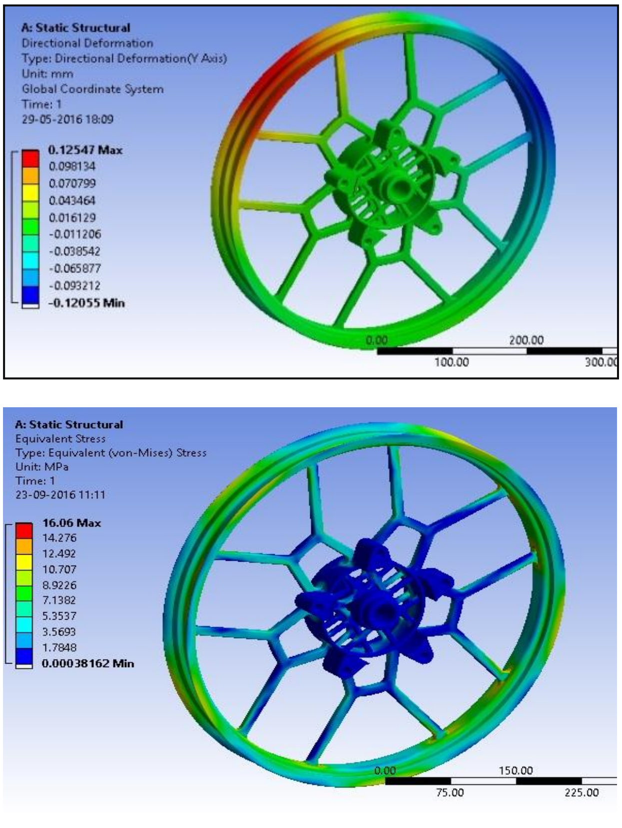


Fig. 6 Deformation and stress due to gyroscopic couple

6.4 Modal Analysis

Modal analysis is performed to find the natural frequency and mode shapes for the wheel model. For safe working, all the mode frequencies should exceed the actual encountered frequency. The maximum speed encountered will not exceed 33.5 m/s. (Jeetendra Kumar *et al,* 2014). The circumference of the wheel being 1.5384m, maximum revolutions for the wheel are limited to 21.78 per second. Therefore we fix a value of 40 Hz as safe frequency. Hence all the mode frequencies should exceed this value for safe and effective working (BGN Satyaprasad *et al*, 2013).

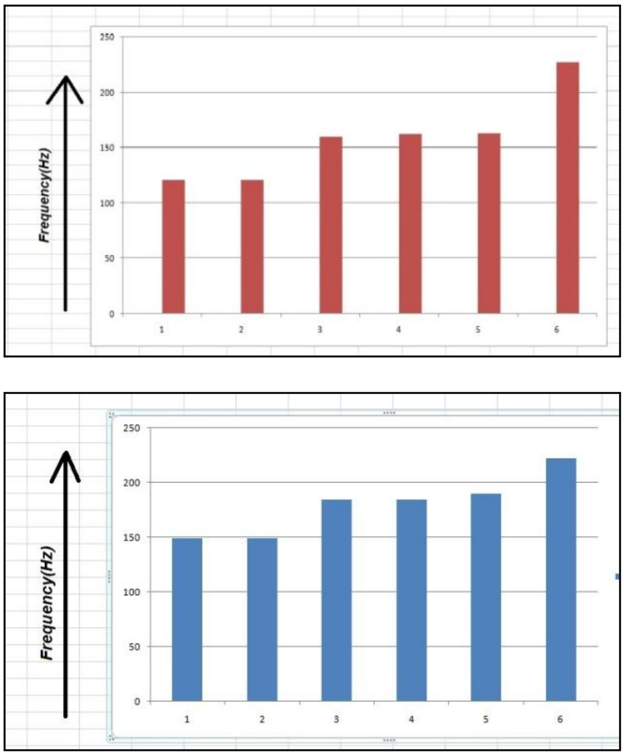


Fig. 7 Mode frequencies for modified (left) and original wheel

6.5 Radial Fatigue Test

Aluminum wheels should not fail during service. Their strength and fatigue life are critical. In order to reduce costs, design for light-weight and limited-life is increasingly being used for all vehicle components. In the actual product development, the rotary fatigue test is used to detect the strength and fatigue life of the wheel (J Janardhan *et al*, 2014). Therefore, a reliable design and test procedure is required to guarantee the service strength under operational conditions and full functioning of the wheel. Loads generated during the assembly may cause significant levels of stress in components. Under test conditions, these high levels of stress alter the mean stress level which in turn, alters the fatigue life and critical stress area of the components as well.

Fatigue strength of Al 7075 (Liangmo Wang *et al,* 2011) For analysis, high cycle fatigue criterion was used for wheel. The objective is to design the wheel for infinite life. The fatigue data of Al 7075 was obtained from. Following graph shows the material SN curve. Simulation of radial fatigue test: A vertical force of 1300 N was added considering weight and overages. A rotational velocity of 150 rad/s was applied. Pressure and bearing load were applied as mentioned earlier. Bearing frictionless support was applied to hub.

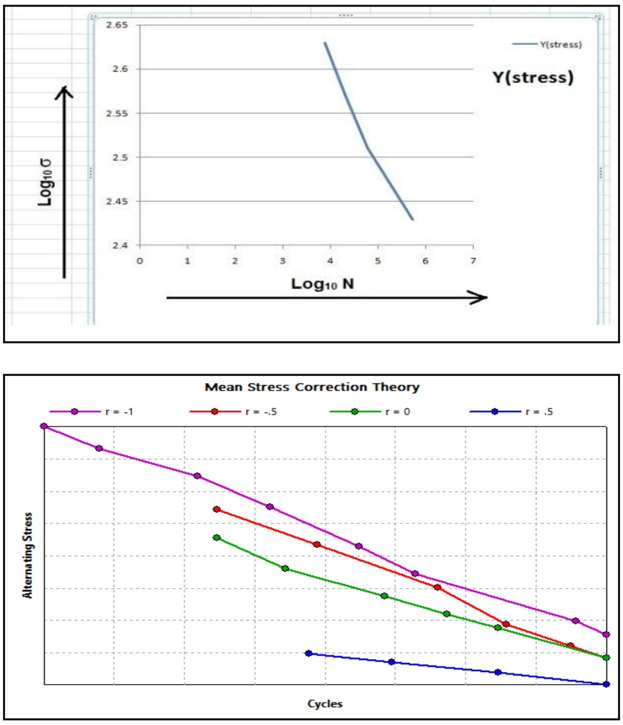
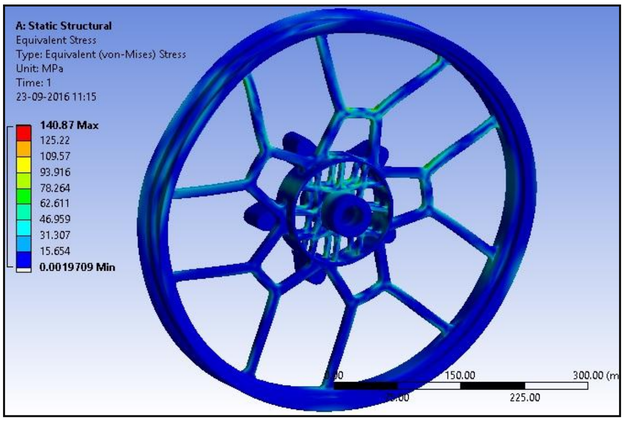


Fig. 8 Al 7075 SN curve and component SN curve

The minimum safety factor was found to be 13.311 and minimum life was found to be 1.182e5 cycles. The maximum design life came out as 1e9 cycles indicating the infinite life design of the component. Following graph depicts the stress life relation for the component.

6.6 Impact Testing

Impact testing is necessary to ensure safe working of the wheel (Madhu K S et al, 2014). For this reason an impact force of 6000 N was applied radially and 2000 N laterally. The factor of safety of 3 was found in the radial impact test while that in lateral impact test was 1.73.



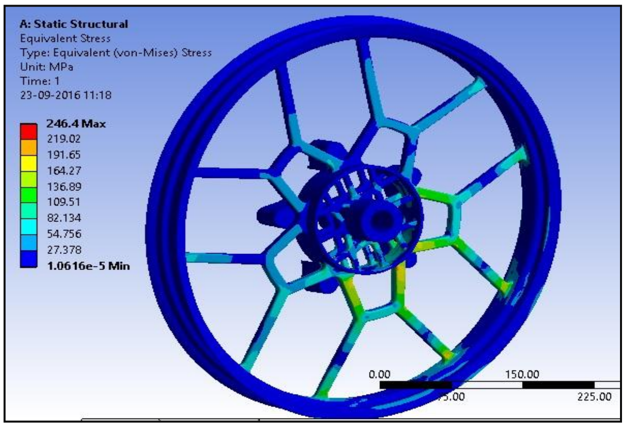


Fig. 9 Equivalent stresses in radial and lateral impact tests

Conclusions

For modified front wheel, the weight was found to be 2.54 kg whereas the original front wheel weighed 3.36 kg. The stresses induced are found to be within limits. This shows that the above proposed design could be a good option as far as weight is concerned. Further study may be needed to investigate the manufacturing feasibility, although high pressure die casting seems suitable. Hence the overall weight reduction achieved was 24.45%.

References

Sushant K. Bawne (2015), Optimization of Car Rim, *Int. Journal of Engineering Research and Applications,* 5, pp.1-8.

Jeetendra Kumar Chakrawarti (2014), Static and Modal Analysis of Rotating Wheel Rim Using Ansys, *International Journal of Engineering Science Invention* 3, pp.18-33.

Liangmo Wang (2011), Fatigue Life Analysis of Aluminium Wheels by Simulationof Rotary Fatigue Test, *Strojniški vestnik - Journal of Mechanical Engineering,* 57, pp.31-39.

BGN Satya Prasad (2013), Topology Optimization of Alloy Wheel, *Altair technology conference,* pp. 1-6.

J. Janardhan (2014), Radial Fatigue Analysis of An Alloy Wheel, *Int. Journal of Engineering Research and Applications,* 4, pp.253-258.

Sivakrishna V (2014), Impact Analysis of Aluminium Alloy Wheel, *International Journal & Magazine of Engineering, Technology, Management and Research,* 1, pp.608-618

Madhu K S (2014), Structural Analysis and Optimization of Two Wheeler Alloy Wheel by Using FEA Approach, *International Journal of Ignited Minds,*1 ,pp.35-40.

K. Venkateswara Rao (2014), Analysis of Wheel Rim Using Finite Element Method, *International Journal of Engineering Research & Technology,* 3, pp.1259-1263.

Sanup Kumar Panda (2012), Fatigue life estimation of Pre-corroded 7075 aluminium alloy, National institute of technology, Rourkela.

V.B.Bhandari,(2010), Design of Machine elements, *McGraw Hill*