DESIGN AND ANALYSIS OF WHEEL RIM

Dr. A.C. Umamaheshwar Rao[1*], K L N Murthy[2], Nandigama Purna Sai Pavan Kalyan[3], Salla Anish Kumar[4], CH. Sai Siddharth[5]

[1]*Professor, Sreyas Institute of Engineering and Technology/ Mechanical Eng. Department, Hyderabad, India.*

[2]*Asst. Professor, Sreyas Institute of Engineering and Technology/ Mechanical Eng. Department, Hyderabad, India*

[3]*Student, Sreyas Institute of Engineering and Technology/ Mechanical Eng. Department, Hyderabad, India.*

[4]*Student, Sreyas Institute of Engineering and Technology/ Mechanical Eng. Department, Hyderabad, India.*

[5]*Student, Sreyas Institute of Engineering and Technology/ Mechanical Eng. Department, Hyderabad, India.*

[1]*umamaheswar4@gmail.com,* [2]*murthy.kln@sreyas.ac.in* [3] *saipk0928@gmail.com,* [4]*sallaanishkumar@gmail.com,* [5]*sid.ch510@gmail.com*

ABSTRACT

The wheel rim of the automobile is an extremely sensitive component as it bears several loads of different intensities. While designing the wheel, its weight needs to be put into consideration as it produces a drag on the vehicle performance. Hence, the wheel rims need to be light enough to improve performance without compromising the integrity of the wheel's safety. The wheel rim performance was evaluated using different testing conditions which can ensure the vehicle's safety. In this work, the method of testing and the loading conditions of the different testing methods are discussed to know the actual stresses and deformation in the wheel rim in real-time applications. The testing methods include radial fatigue test and impact test on the wheel are made of Two different composite materials namely peak-aged aluminium alloy AL 356 T6 and JIG 3113 Standard ferrous alloy and compared the results of these above-mentioned alloy materials.

Keywords**:** Wheel rim, Radial Fatigue Test, Impact Test, Deformation, Peak-aged aluminium alloy Al 356 T6, JIG 3113 steel.

1. Introduction:

The wheel rim is the basic structure in the vehicle dynamic and safety system hence, the wheel rim must withstand the Peak loading conditions. Wheel rims can be classified into several types based on their requirement of performance, characteristics, and aesthetic look. The basic specifications of wheel rim consist of the thickness of rim, spokes/arms/wires, and tires, PCD, height, offset distance, bead width, humps, drop center, etc. The manufacturing process and heat treatment process involved in manufacturing the wheel rim plays a crucial role in the performance of the rim. The manufacturing processes used to fabricate the wheel rims of material aluminium alloy are casting, forging whereas the manufacturing processes used for fabricating the steel alloy wheel rim are machining and casting. Several tests like impact and radial fatigue tests were conducted to know whether the material meets the requirement for application in vehicles. The most accepted procedure for automobile wheel testing is radial endurance test or radial fatigue test. The use of finite element method to simulate various conditions with any number of constraints can predict the strength, any irregularities on surface, fatigue life more instantly and effectively saving lot of time and resources than the use of conventional trial and error method in the development of the wheel rim. The 90-degree impact test is considered as the standard test for evaluating the strength of light weight alloy wheel rims used for compact hatch back cars but to know the fatigue life of the wheel rim the impact test alone is not considered to be enough; this paper proposes a combination of test which are used to evaluate both impact and fatigue strength of the wheel rim[1-4].

1.1. Types of Wheels

The wheel must be strong enough to fulfil its functions effectively, balanced both statically and dynamically, and light enough to transport. Reduce the amount of unsprung weight. The pressure might be delivered inside or externally. There are many different types of wheels available in today's world however, steel and wire spokes are commonly utilized for these purposes all over the place. Wheels made of steel are more durable than wire and aluminium alloy wheels, but they are heavier. This adds to the vehicle's unsprung weight. For this reason, alloy wheels are chosen to lessen the unsprung mass of the wheel hub assembly, design various types of wheels and describe it into three types based on the dimensions

1.2. Wide Drop Centre Wheel Rim (WDC):

The drop centre is a recessed section of the wheel rim that allows the tyre to be installed and mounted to the rim. The barrel is a thinner section of the wheel rim that also contains tall beads that allow the tyre to sit on the wheel rim base, and the section of the drop centre is different for each wheel rim. The wide drop centre wheel rim is widely used in passenger car applications to increase the width of the rim, a minor increase in well, and a lower flange height.

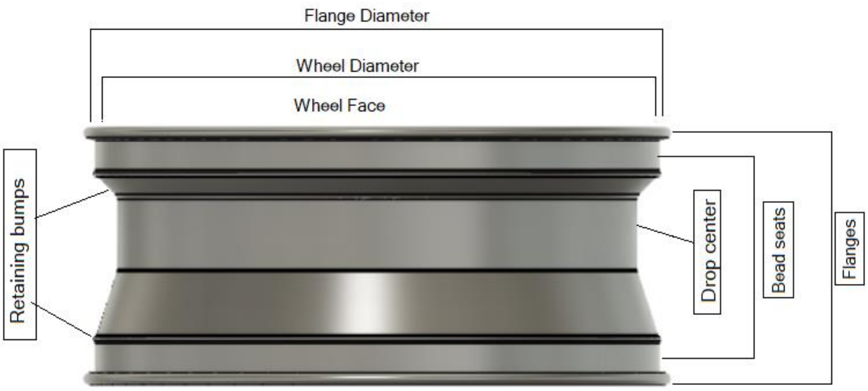


Figure 1(a) nomenclature of wheel rim.

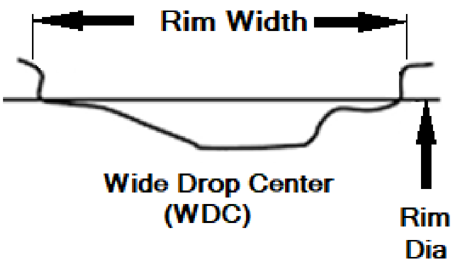


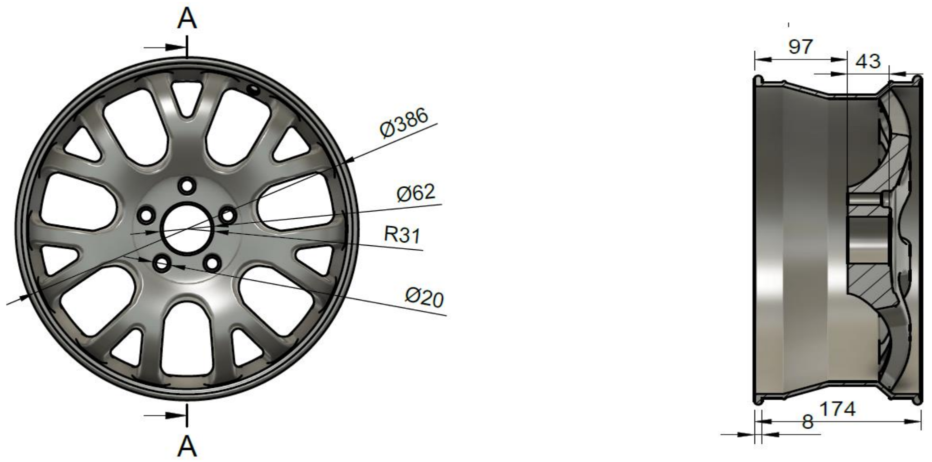
Figure 1 (b) sectional view of wide drop centre wheel rim.

2. Experimentation Procedure

The wheel rim plays an extremely important role in the performance characteristics and the safety of the wheel. While designing the wheel rim one must consider the factor of safety of industrial standards and the rim needs high strength to weight ratio**.** The 15-inch alloy wheel design is developed using CATIA V5 and imported to FUSION 360 simulation environment to study various loading conditions and to determine the stresses and deformation in the wheel rim. This work intended to propose a series of tests that need to be conducted to determine the life of the wheel rim under the application of highly intensive loads[5-9].

2.1. Geometry And Design of Wheel Rim:

The wheel rim is designed as per the industrial standards with 7 spokes, the thickness of rim is adjusted for no air leakages, holes for standard bolt sizes, and all stress concentrating zones & squared edges are replaced with fillets and chamfers. The dimensions and specifications of the wheel are illustrated in figure 2 (a) & 2 (b)



(a) (b)

Figure 2: Dimensions and specifications of the wheel rim (a) Front view (b) Side view

2.2. Materials and Methods:

Over time, the wheel rim has undergone several changes and the material composition played a vital role throughout the evolution of the wheel rim. By using modern manufacturing methods, the wheel rim can be manufactured using different alloy compositions of the material but mostly the materials used are ferrous alloys, aluminium alloys, magnesium alloys, synthetic bonded like Kevlar, and the carbon fibre wheel rims. As most of the compact hatch vehicles use the split rims made of steel alloy SAPH440 and composite solid wheel made aluminium alloy AL356.2 T6, the above materials are considered in the testing procedure[10].

2.2.1. AL356.2 T6:

The AL356.2 T6 is a peak-aged aluminium alloy consisting of a maximum of 0.25% of copper, 0.35% of Manganese, 0.6% of Iron, 0.35% of Zinc, 0.25% of Titanium, and 0.20%- 0.45 % of Magnesium, 6.5%- 7.5% of Silicon, and the remaining balance is the Aluminium[11]. The mechanical properties of the material are listed in Table 1.

2.2.2. SAPH440:

The SAPH440 is JIG 3113 Standard ferrous alloy consisting of ≤ 0.21% of carbon and ≤ 1.5% of manganese it possesses high strength and durability and is ideal for manufacturing the wheel rims[12]. The mechanical properties are listed in Table 1.

Table 1. Mechanical properties of the materials.

PROPERTIES						
Material	Density (G/Cc)	Tensile Strength Ultimate (N/Mm^2)	Tensile Strength Yield (N/Mm^2)	Poisson's Ratio	Shear Strength (N/Mm^2)	Elongation Percentage (In 50 Mm%)
AL356.2T6	2.7	228	166	0.33	103	3.5
SAPH440	7.7	440	250	0.2	200	3.9

2.3. Nature of Loads in Wheel Rim:

For exact approximation of the fatigue life of wheel rim during its application, we can consider various testing methods which are conducted and accepted for both analytically and experimentally. These tests are used to determine the stresses and deformations of the wheel for evaluation of fatigue life.

2.3.1. Impact Test:

The impact test setup is as follows; the wheel rim is fixed by providing constraints at the bolt connections then the derived mass of a triangular prism shaped hammer is placed at 90-degrees over a derived fixed distance from the wheel rim and subjected to initial acceleration and velocity to impact the wheel rim[13-15].

The mass of the hammer is given by

$$M_h = (0.8 \text{ X } W) + 180 \text{ (Kilogram)} \ldots \text{ Eq (1)}$$

where W is the maximum static load that can be subjected to the wheel rim and the impact distance is given by the

$$Di = (0.125 \text{ X } (W + 857)). \ldots \text{ Eq (2)}$$

The wheel rim is does not meet the requirements if the wheel rim deforms more than 6 mm, a visible crack is propagated on the wheel rim, comparatively the first condition is more feasible to considered in this test configuration. The tyre pressure is taken to be 0.241 MPa.

For reducing the time of the experiment and to get faster results the fixed distance between the wheel rim and hammer are reduced to the minimum and the hammer is given an initial velocity as a overcome the lost distance, the initial velocity of the hammer is derived from the velocity equation,

$$v^2 = 2gH \text{ (In M/Sec)} \ldots \text{ Eq (3)}$$

The initial velocity is found to be 1283 mm/sec and the time of simulation is taken as 0.01 seconds.

The impact creates a deformation and stresses in the wheel rim were recorded. The above discussed simulation setup is illustrated in the figure 3. The load applied on the model are formulated and the stress and strain values are evaluated.

Figure 3. simulation setup of impact load on the wheel rim.

2.3.2. Radial Endurance Loads:

The radial endurance test is conducted by giving an initial acceleration to the wheel rim in either clock wise or counter clock wise direction along with the tyre pressure of standard value (0.241 MPa), and the weight of the car is divided by the number of wheels N (where N is equals to 4 for four-wheeler and 2 for two-wheeler vehicles). As the wheel rotates in the specified direction the deformation of the wheel rim takes place due to all external loading, these values have been recorded and noted in the table. The illustration of the simulation setup is shown in the figures 4 (a) &4(b).

The radial loads are a combination of both static and dynamic loads, all the loads have been derived as per the following equations[16, 17]. The static loads are the loads which are always applied on the wheel rim i.e. either the vehicle is in rest position or the vehicle is in motion. The dynamic loads are the loads which are applied on the wheel rim only during the vehicle is in motion.

2.3.3. Static Loads:

2.3.3.1. Internal Tyre Pressure:

The internal tyre pressure is taken as 0.241 MPa as standard tyre pressure.

2.3.3.2.Weight of the Vehicle:

The weight of the vehicle is equally divided on to the number of wheels.

The weight of the vehicle is taken as 2,000 Kg for the model so the load acting on single wheel rim is given by, Fw = 2000/N*g … Eq (4)

Where, N is the number of wheels,

g is the acceleration due to gravity = 9.81 m/sec^2.

2.3.4. Dynamic Loads:

2.3.4.1. Radial Loads:

The radial loads are characterised by the equation below:

Fr = F x k… Eq (5)

Where, Fr = Radial load in Newtons.

F = load applied on the wheel rim in radial direction in Newtons.

F is given by the following equation,

$$F = M \times k \times \omega^2 \ldots \text{ Eq (6)}$$

Where, M is mass of the wheel rim,

K is radius of wheel rim,

ω is the angular acceleration of the wheel rim and it is given by the following equation

$$\omega = \frac{v}{k} \ldots \text{ Eq (7)}$$

Where v is velocity of the vehicle, k is radius of wheel rim.

In this case the velocity of the vehicle is taken to be 45 Kmph.

K = 2.25 as per industrial standards.

The intensities of the load applied on the model are calculated the stress and strain values

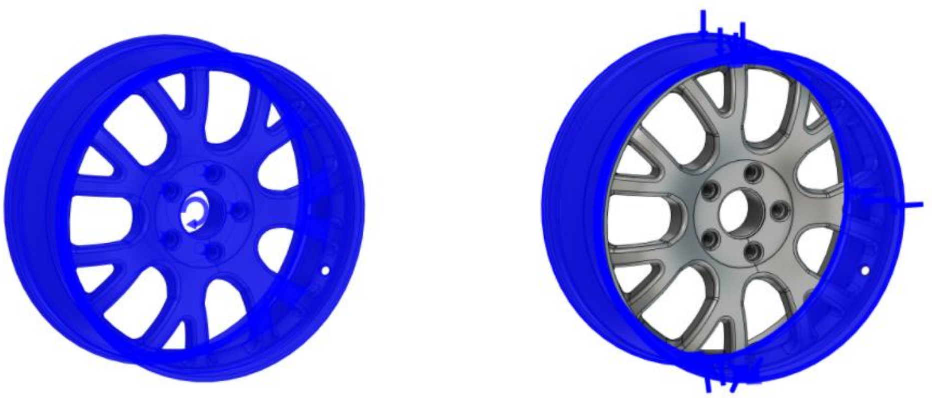
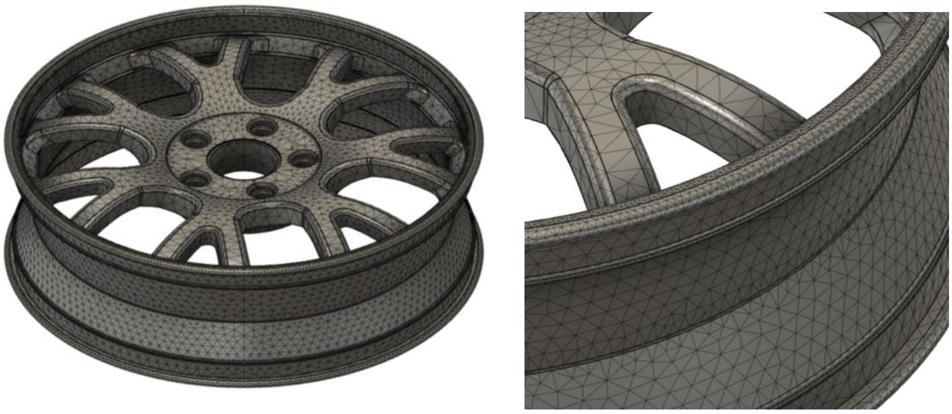


Figure 4 (a) & 4 (b). simulation setup of radial endurance loads on the wheel rim.

In the figure 4(a) the wheel is subjected to the initial angular acceleration and a load in the direction of gravity. In the figure 4(b) the wheel rim is subjected to the internal tyre pressure on the barrel surface of the wheel rim.

3. Meshing of Wheel Rim:

The wheel rim is meshed using fine tetrahedra structured elements and Base mesh: 255047nodes, 142204 elements with a Face Angle min: 4.25, max: 167 degrees. The meshed wheel rim is shown in the figure 5(a) & 5 (b).



(a) **(b)**

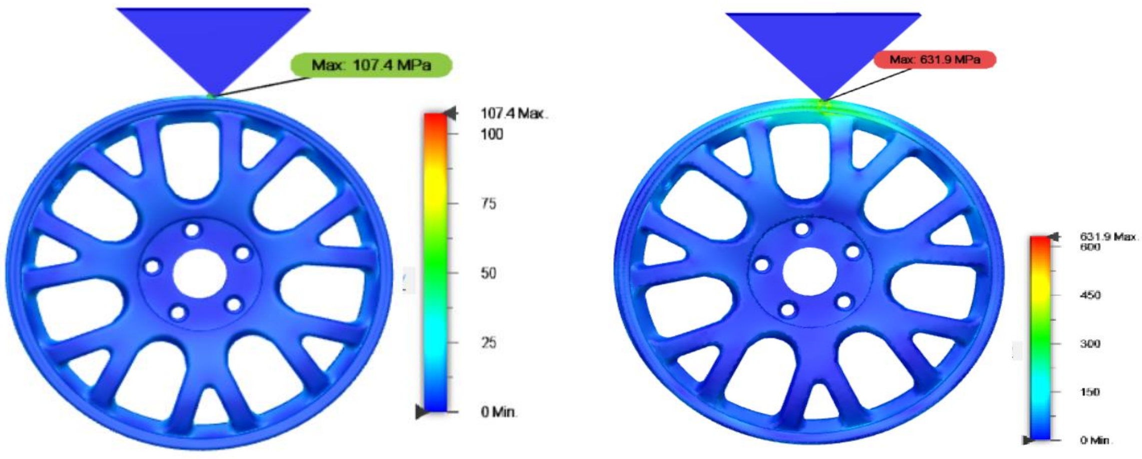
Figure 5(a) Meshing of wheel & 5 (b). Enlarged view of meshing

4. Results and Discussions:

4.1. Impact Test

4.1.1. AL 356.2 T6

In this setup the hammer penetrates the wheel rim which indicates the failure of the wheel rim, the depth of penetration differs from material as the resistance to penetration and failure is based on the density of the material, but as the density increases the weight of the wheel rim is also increased which in turn reduces the fuel economy and comfort. As the dynamic range of the hammer is limited to time for exact referencing of the state, the steps are considered the hammer is subjected to initial acceleration and velocity from a fixed distance from the wheel rim as shown in the figure 6, as the hammer penetration starts at the step 13 the maximum von mises stress recorded is 107.4 MPa and the wheel rim shows the formation and propagation of the cracks which causes the failure of the wheel rim, at the end of the simulation the step 26 records the von mises stresses at 631.9 MPa , the value recorded at the step 26 is much greater than the ultimate tensile strength of the material which confirms the failure of the wheel rim.



STEP 13 STEP 26

Figure 6. the simulation results at step 1 (a) step 13 (b) step 26 (c).

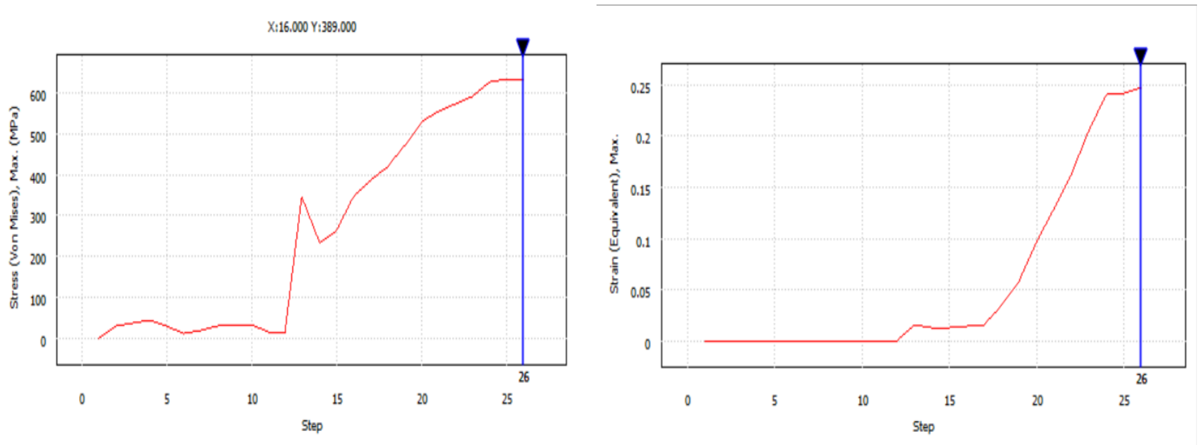
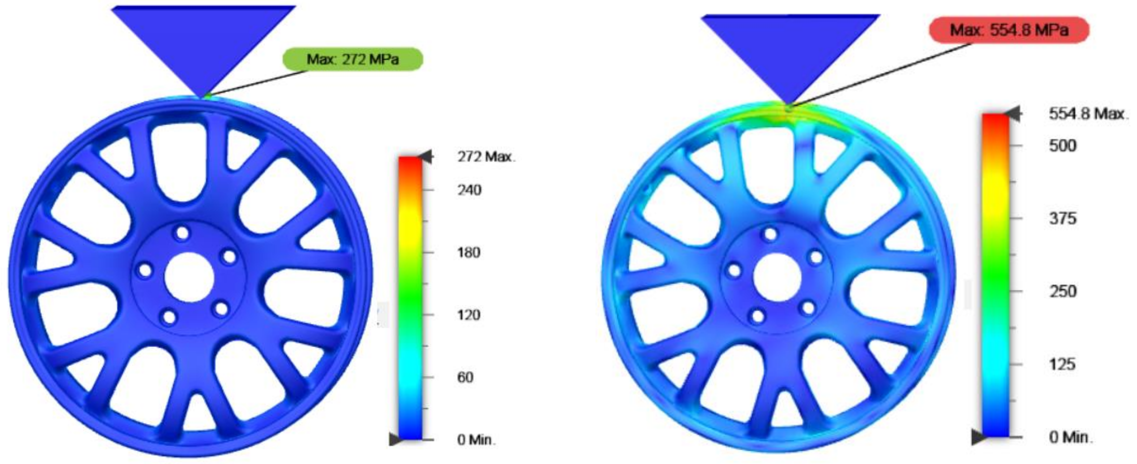


Figure 7 graphical representation of simulation results of Von mises stresses (a), equivalent strain(b).

The graphical representation of Von mises stresses for impact test on Al356.2 T6 in figure 7 (a) shows us that the materials exhibit a sudden spike decrease in the strength after the hammer gets into contact with the wheel and then a gradual increase in the strength of the wheel rim as the depth of penetration increases. The figure 7 (b) shows us the equivalent strain of the wheel rim where the value of the strain remains “0” until step 13 which allows us to determine the exact step where the hammer starts to penetrate the wheel rim and the maximum value of strain is 0.1779 mm which is accepted as the value of strain must not exceed the value of 0.3mm for safer application as per industrial standards.

4.1.2. SAPH 440

The simulation setup for the SAPH440 is exactly same as the Al356.2 T6, the initial conditions of the setup are exactly same so the moment of the hammer is similar to that of previous setup, as the material properties such as the density and strength of the steel alloy is much larger than the aluminium composite the maximum value of von mises stress recorded during the impact test is 554.8 MPa from the figure 9 (b) which is significantly less than the maximum value of AL356.2 T6.



STEP 13 STEP 26

Figure 8 simulations results of SAPH440 at STEP 1(a) STEP 13 (b) STEP 26 (c).

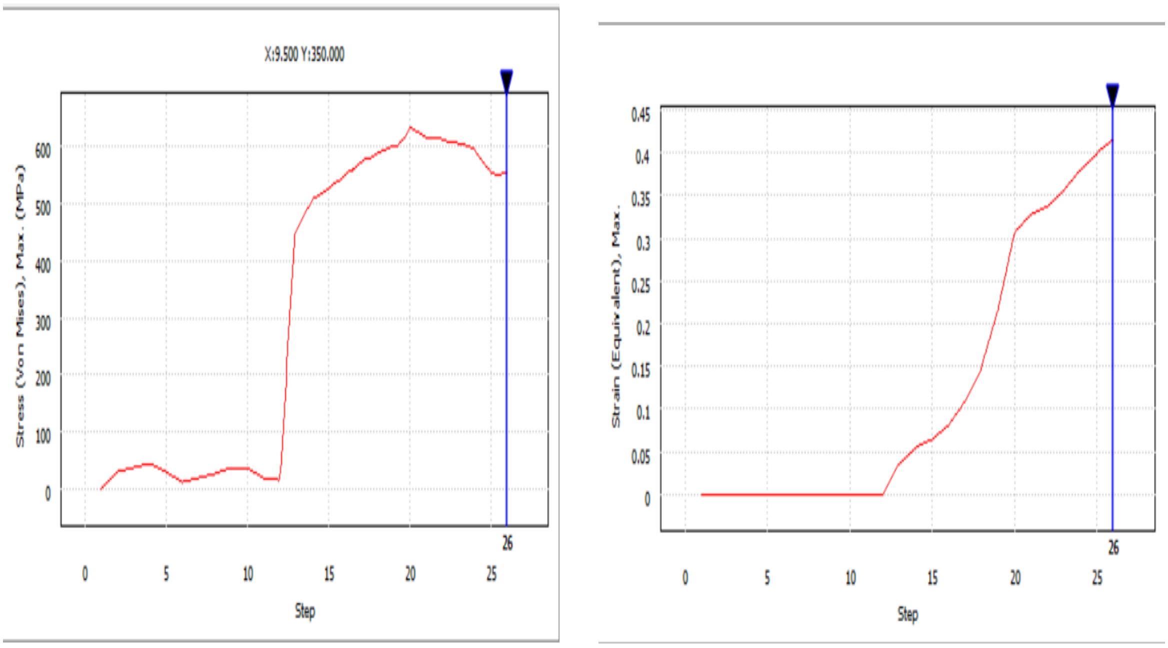


Figure 9 graphical representation of simulation results of Von mises stresses on SAPH440 (a), equivalent strain on SAPH440(b).

The above figure 9 (a) indicates that the resistance towards impact loads of SAPH440 is more than that of the AL356.2 T6, as the graph has no sudden changes as the density of the material is much higher but the figure 9 (b) shows that the breaking point of the wheel is same but the penetration of the hammer is less than the pervious case. The values of the results are compared in the table 2 which confirms that both the materials are under the acceptable range as the acceptable value of strain must be under 0.3 mm but the strain value of the SAPH440 is lower than AL356.2 T6.

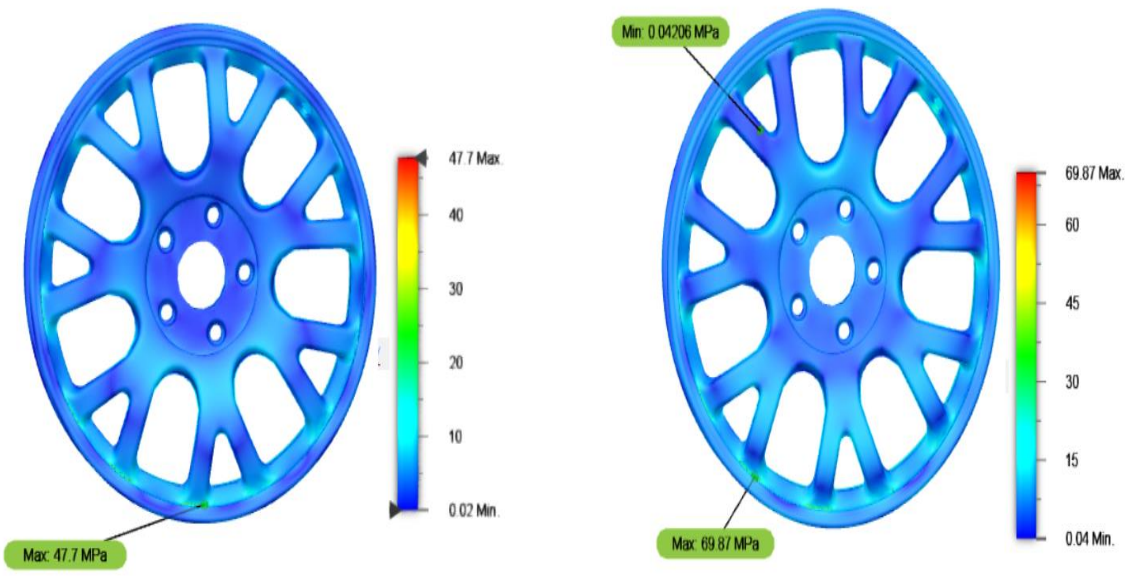
Table 2: Illustrating Analysed Results on Impact Loads.

Name	AL356.T6		SAPH440	
	Minimum	Maximum	Minimum	Maximum
Von Mises Stresses (MPa)	0	632.1	0	633.1
Total Displacement (In mm)	0	3.021	0	3.039
Displacement In Z Direction (In mm)	-3.021	0.1779	-3.039	0.1444
Strain (Equivalent)	0	0.2469	0	0.414

4.2. Radial Endurance Test Comparison.

4.2.1. AL 356.2 T6

In this testing conditions the fixed constraint has been applied to the bolts and the wheel rim subjected to angular velocity of 300 rad/sec and angular acceleration 100 rad/sec^2, the normal load acting on the wheel rim is entire mass of the vehicle divided by the number of tyres in this case the weight of vehicle is taken to be 2000 kilograms and the number of wheels is taken as 4 then the load subjected is 500 kilograms per wheel, for conversion into newtons we multiplied by 9.81 m/sec^2 and the final value of the normal load is 4905 Newtons and the internal tyre pressure as per standards 0.241 MPa is applied on the cylindrical surface section of the wheel rim.



STEP 13 STEP 26

Figure 10 Simulation results of AL356.2 T6 at STEP (13), STEP 26 (c)

The results obtained after the simulation are below the yield point limits of the material AL 356.2 T6 as the step 13 records the value of 47.7 MPa and the Step 26 records the maximum von mises stress value of 69.87 MPa as shown in the figure 10, confirms that the material subjected to these loads only deforms elastically and there is no plastic deformation occurred in the model of wheel rim. the Figure 11 confirms that through out the whole simulation the maximum value of the von mises stresses are well under 80 MPa which is below the elastic point of the material, so there is no plastic strain in the wheel rim which states that the wheel rim is safe during the operation and the design is acceptable.

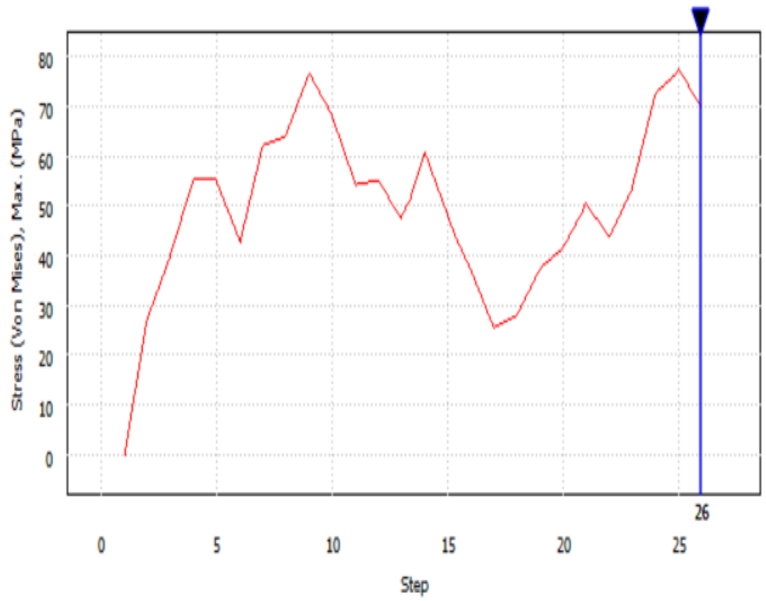
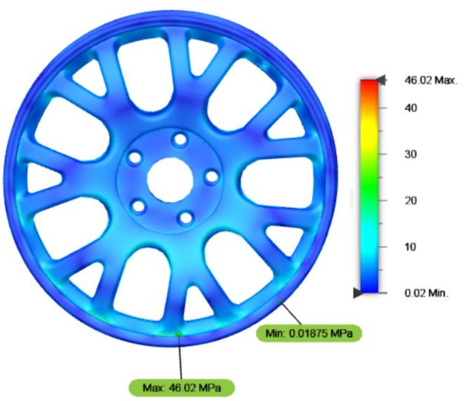
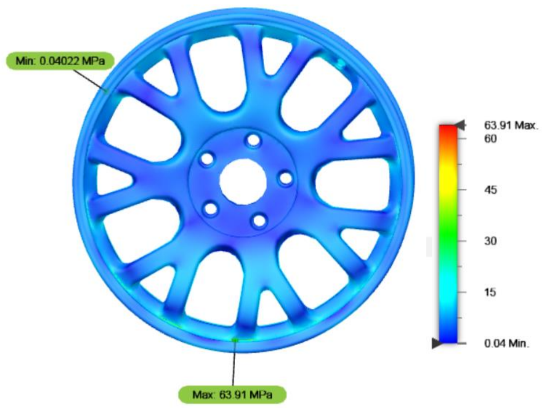


Figure 11 Graphical representation of results of von mises stresses of Al356.2 T6

4.2.2. SAPH440.



STEP 13



STEP 26

Figure 12 simulation results of SAPH440 under radial loads at step 13 (a), step 26 (b).

The figure 12 shows us the results obtained for simulation of SAPH440 wheel rim under radial endurance loads and the maximum value of von mises stresses recorded at step 26 is 63.91 MPa at the outer rim surface and the minimum value of the same is recorded as 0.040222 MPa at the cylindrical surface of the wheel model, during this test is 71.6 MPA is the maximum value of the von mises stresses as recorded in the Figure 13 graph and we can confirm that all the values of stress are well under the elastic limit of the material and by comparison with the AL356.2T6 material, the SAPH440 exhibit lower von mises stress value.

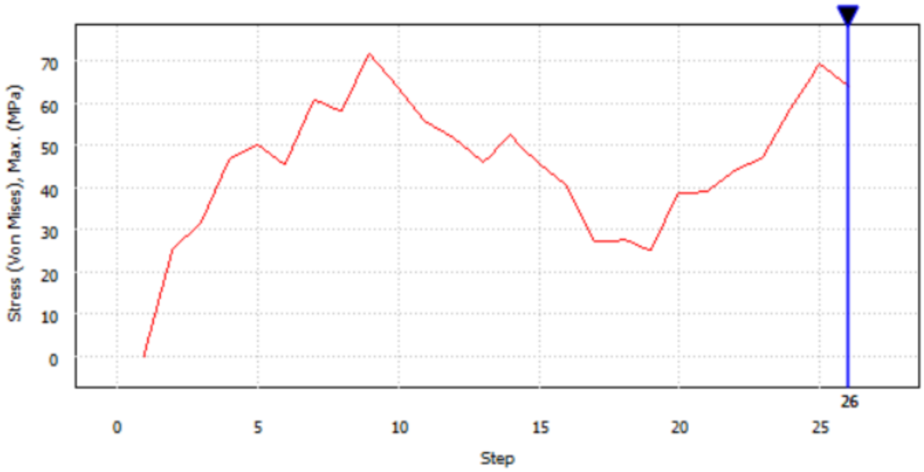


Figure 13 Graphical representation of simulation results the SAPH440 wheel rim under radial endurance loads.

In the below table 3 compares the material characteristics under the radial loads and it proves that even though the AL356.2 T6 wheel rim is much less dense but exhibits the similar mechanical properties and offers approximately similar resistance towards the radial loads and does not under plastic deformation, so it concludes that the both the materials are safer in application and can be applied in the field of application.

Table 3: Illustrating material characteristics under the radial loads

NAME	AL356.T6		SAPH440	
	Minimum	Maximum	Minimum	Maximum
Von Mises Stresses (MPa)	0	77.4	0	71.6
Total Displacement (In mm)	0	17.72	0	17.51
Displacement In Z Direction (In mm)	-16.78	16.81	-16.98	16.8
Strain (EQUIVALENT)	0	0.001019	0	3.49E-04

5. Conclusion:

1. The materials AL 356.2 T6 has better performance characteristics than SAPH440 but the mentioned materials have very close difference between the mechanical characteristics.
2. The material SAPH440 has better resistance to radial loads and impact loads than AL356.2 T6.
3. The lesser density AL356.2 T6 material has much more endurance for the plastic strain under the impact loads.
4. We can recommend the use of AL 356.2 T6 to reduce the unsprung mass of the vehicle for better performance and SAPH440 for heavy load bearing vehicles such as commercial trucks, etc.
5. Under general working conditions alloys rims consist if enough strength to withstand the loads but just to make sure the passenger's safety we must conduct these tests.

REFERENCES:

1. Stearns, J., et al., *Analysis of stress and strain distribution in a vehicle wheel: finite element analysis versus the experimental method.* The Journal of Strain Analysis for Engineering Design, 2005. **40**(6): p. 513-523.
2. Liu, J.P., B.Y. Ye, and G. Li. *Application of Finite Element Analysis in Automotive Wheel Design*. in *Key Engineering Materials*. 2011. Trans Tech Publ.
3. Beigzadeh, S. and J. Marzbanrad, *Automotive Wheel Optimization to Enhance the Fatigue Life.* Automotive Science and Engineering, 2018. **8**(3): p. 2739-2758.
4. Das, S., *Design and weight optimization of aluminum alloy wheel.* International Journal of Scientific and Research Publications, 2014. **4**(6): p. 1-12.
5. Mahadik, S.S., *Design and ANSYS analysis of components of wheel assembly of SAE car.* Int. J. Curr. Eng. Technol, 2018. **8**(02): p. 407-438.
6. Kara, A., et al., *Design and weight optimization of aluminum alloy wheels.* Pamukkale University Journal of Engineering Sciences, 2017. **23**(8): p. 957-962.
7. Theja, M.S. and M.V. Krishna, *Structural and fatigue analysis of two wheeler lighter weight alloy wheel.* IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE) e-ISSN, 2013: p. 2278-1684.
8. Sudhakar Mishra, D.L., *Structural and Material Analysis of an Automobile Wheel Rim using ANSYS.* 2019.
9. Bhavikatti, S., *Finite element analysis*. 2005: New Age International.
10. Budinski, K.G. and M.K. Budinski, *Engineering materials*. 1999: Pearson Education India.
11. Subrahmanyam, A., G. Naresh, and V. Venkatesu, *Microstructure and mechanical properties of rice husk ash reinforced aluminium alloy (A356. 2) metal matrix composite.* IOSR J. Eng.(IOSRJEN), 2018. **8**: p. 36-42.
12. Li, M.-L., D.-S. Bi, and J.-K. Hao. *Automotive sheet metal SAPH440 and Q235 formability of comparative study*. in *2015 International Conference on Material Science and Applications (icmsa-15)*. 2014. Atlantis Press.

13. Gao, Q., et al., *90-degree impact bench test and simulation analysis of automotive steel wheel.* Engineering Failure Analysis, 2019. **105**: p. 143-155.
14. Zainuddin, H., et al., *Correlation between vertical wheel impact energy with lateral wheel impact energy: A finite element analysis approach.* International Journal of Automotive & Mechanical Engineering, 2016. **13**(3).
15. Zheng, Z.-G., G.-W. Cai, and S.-Q. Pan. *Fatigue life prediction of automotive steel wheel using damage mechanics*. in *2010 International Conference On Computer Design and Applications*. 2010. IEEE.
16. Wang, L., et al., *Fatigue life analysis of aluminum wheels by simulation of rotary fatigue test.* Strojniški vestnik-Journal of Mechanical Engineering, 2011. **57**(1): p. 31-39.
17. Han, S., et al., *Structural design and numerical simulation of AM60B magnesium alloy automobile wheel based on UG.* 2010.