ISSN 2395-1621

# Fea analysis of alloy wheel rim for corner fatigue test with optimization of weight and shape

[#1]Tejas P. Bhakte,[#2]T. R. Shinde, [#3]C. J. Bhosale

[1]bhaktetejas7@gmail.com
[2]cjbhosale@auraalloywheels.in
[3]trshinde.sae@sinhgad.edu

[1]P.G. Student, Department of Mechanical Engineering,SAOE,SPPU, Kondhwa, Pune, India
[2]General Manager, Precision Auto Industries Pvt. Ltd. Unit-II,
[3]Assistant Professor, Department of Mechanical Engineering,SAOE,SPPU, Kondhwa, Pune, India

**ABSTRACT**

**Alloy wheels are automobile wheels which are made from an alloy of aluminium or magnesium metals. Alloy wheels differ from steel wheels because of lighter in weight for the same strength. It also provides better heat conduction and improved aesthetic appearance. The necessity of car wheel rim provides a firm base on which to fit the tyre. Its dimensions, shape should be suitable to accommodate the particular tyre required for the vehicle. In this project a tyre of car wheel rim belonging to the alloy wheel category is considered. The wheel rim is modeled by using modeling software CATIA V5R19. After modeling this CATIA modal is imported to ANSYS for analysis work. The FE analysis shows that the stress generated in the optimized alloy wheel rim is well below the actual yield stress of the aluminium alloy. The Fatigue life estimation by FEA, under corner fatigue load condition, is carried out to analyse the stress distribution and resulted displacement in the alloy wheel rim. S-N curve of the alloy wheel rim represents that the endurance limit is well below the yield stress of the material and safe for the application. The FE analysis indicated that even after a fatigue cycle of 106, the damage on the wheel is found 0%.**

**Keywords—** **Alloy Wheel Rim, Corner Fatigue Test, Static Structural Analysis.**

ARTICLE INFO

**Article History**

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

**Published online :**

**22nd November 2015**

## I. INTRODUCTION

The invention of wheels has been like a gift to mankind. It is said that the Mesopotamians invented the wheels in 3500 BC. Initially it was used to make pottery then it was used as an important means of transportation. The Mesopotamians first used the wheel for transportation for their chariots in 3200 BC. After the industrial revolutions, the wheels became important elements that shaped today have advanced automobile industries. Today, there are many kinds of wheels available in the market, and each of them has a very specific purposes. Thus wheels are very important in day today life at each and every movement and the safety of the vehicle is to be considered as utmost important criteria in a vehicle and is standardized and certified. The first innovative idea to improve a wheel came by wrapping an iron band around the wooden wheels used on carts and wagons. And then, the pneumatic tyre was invented, and in some form or another, has continued to take us to the roads today. The improvements engineered for tyres, as well as for rims has continued through the years, with the inventions and enhancements of nylon, cord, rubber, and other materials tried out for different types of tyres. The actual rim or wheel has been experimented with and altered in design and material as the world discovered steel, iron, and aluminium, and variations of these metals, and also different types of plastics. Though for the record, plastics are not yet considered suitable for structure of a rim, but mostly for cosmetic purpose, to cover the rim and improve the appearance. The most popular choice of wheels today, is the alloy wheel or the aluminium rim. Not only because they are so much prettier than steel rims, though they really are. However, the real reason that alloy is so much more popular, is because it is so much lighter, and structurally stronger. Steel wheels and hubcaps are heavy, and when riding in a car that has them, you feel every bump in the road. Aluminium wheels make for a much smoother ride; actually, it can feel like gliding over the road. That is why most luxury automobiles have them now. Race cars use alloy wheels because they are lighter weight, cause less tyre stress, and have much better balance; all of which tends to be beneficial for increased speed.

## II. INTRODUCTION TO OPTIMIZATION

Finite element-based optimization techniques were first developed by UCLA Professor, Lucien Schmit in the1960s (Schmit 1960). Schmit recognized the potential of combining optimization techniques with finite element analysis (FEA) for structural design. Today, three types of finite element based optimization approaches are available within commercial FEA software's: parameter optimization, shape optimization, and topology optimization. Parameter optimization uses physical properties as design variables. This approach strives to find the optimum value of these properties in the constitutive elements of the structure. Typically, cross-sectional parameters are used as design variables. These parameters include thickness, area, and moment of inertia, among others. Shape optimization involves determining the optimal profile or boundary of the structure. Two of the most common approaches for shape optimization are: the basis vector and the grid perturbation approach. The basis vector approach requires the definition of different trial designs called the basis vectors. The design variables are the weighting parameters that define the participation of each basis vector in the design process. On the other hand, the grid perturbation approach requires the definition of perturbation vectors. These vectors perturb or deform the boundary of the design domain. The design variables are the values that determine the amount of the perturbation during the optimization process. The work in this paper makes use of the grid perturbation approach. Topology optimization is being used more frequently in recent studies to find preliminary, and sometimes completely innovative, structural configurations that meet specific conditions (i.e., objective function and constraints).Simulate to Innovate Topology optimization involves the optimal distribution of material within a design domain. Initially, the design domain is comprised of a large number of (finite) elements. The topology optimization process selectively removes unnecessary elements from the domain. Novell optimum structures are usually obtained using this technique. The design variables in topology optimization depend on the type of material model used in the finite element analysis. The nature of these design variables characterizes distinct methods. Two of the most commonly referenced topology optimization methods are the homogenization approach and the density approach. The alloy road wheel is selected for the purpose of optimization for it has huge scope for mass reduction and it falling under the category of unsprung mass.

## III. OBJECTIVE AND DESIGN CALCULATIONS

The objective of this project is to test the alloy wheel according to the specifications given by the industrial standards for styling and achieve optimum designed model. Corner fatigue test can be performed. Stresses developed should be within limit as per industrial standards.

Specifications of Model Wheel Rim
Tyre size suitability = P195/70 R14
Wheel size = 14 inches
Flange shape = J
Rim width = 5.5 inches
Wheel type = disc wheel
Offset = 35mm

Corner fatigue test (Bending endurance test): The bending moment to be imparted in the test shall be in accordance to the following formula:

$M = ((\mu * R) + d) * F * S$

Where,
M = Bending moment in 'Nm'
$\mu$ = Friction Coefficient between the tyre and the road surface (no units)
R = Radius of the tyre applicable to the wheel in 'm'
d = Offset of the wheel in 'm'
F = Maximum load acting on the tyre in 'N'
S = Coefficient specified according to the standards.
According to the industrial standards:
$\mu = 0.7$ d =35 mm = 0.035 m F = 475 kg = 475 * 9.81 =4659.75N S = 1.5
Bending moment

$M = ((\mu * R) + d) * F * S$
$= ((0.7 * 0.178) + 0.035) * 4659.75 * 1.5$
$= 1115.54$ Nm

TABLE I
COMBINATION OF COEFFICIENT WITH SPECIFIED NUMBER OF REVOLUTIONS

| Division of wheel | Light alloy wheel | |
|---|---|---|
| | **Coefficient S** | **Specified number of revolutions $10^4$** |
| Wheels under 100 mm in offset | 1.8 | _($^3$) |
| | 1.5 | 10 |
| | 1.35 | 25 |
| | 1.33 | _($^3$) |
| | 1.26 | _($^3$) |
| | 1.1 | _($^3$) |

_ ($^3$) =$10^3$ specified number of revolutions

A. Corner Fatigue Test

Wheels are subjected to high stress during cornering. Static analysis is performed on the wheel to analyse its characteristics while cornering. Bending moment is applied keeping the outboard rim flange region constrained, to simulate the real time conditions. The stresses in critical zones are noted. The wheel is checked to pass the min. no.

 

of cycles considering the factor of safety. Following figure 1 shows the corner fatigue test apparatus

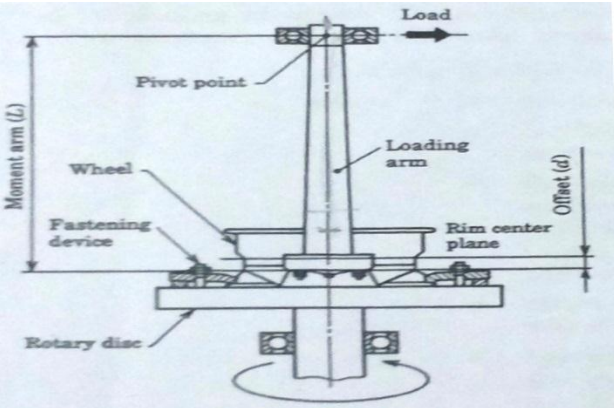


Fig. 1 Corner Fatigue Test Apparatus

## IV. MATERIAL PROPERTIES

Material used Aluminum Alloy A 356.2
Mechanical properties:
Ultimate strength - 228 MPa
Density - 2.7 gm/cm3
Yield strength - 166 MPa
Composition:
Silicon- 6.5-7.5%
Iron- 0.12%
Manganese -0.05%
Magnesium- 0.3-0.45%
Zinc- 0.50%
Titanium -0.20%
Copper- 0.10%
Others- 0.15% Remaining Aluminum.

## V. MODELING OF ALLOY WHEEL RIM

CATIA is used for creation and modifications of the alloy wheel rim model. In CATIA modeling of alloy wheel rim is done as per The European Tyre and Rim Technical Organization (E.T.R.T.O.) and industrial specification.

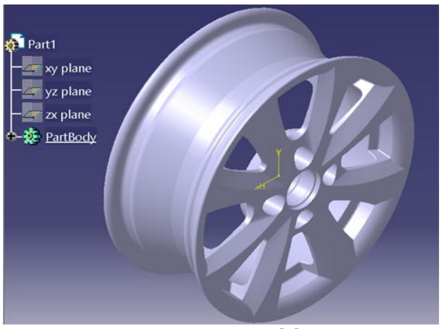


Fig. 2 CAD model

Above figure 2 shows the generated CAD model in CATIA software which is imported to FEA software for structural analysis

## VI. STATIC STRUCTURAL ANALYSIS FOR CORNER FATIGUE TEST

A. Material Properties

Figures must be numbered using Arabic numerals. Figure captions must be in 8 pt Regular font. Captions of a single line (e.g. Fig. 2) must be centered whereas multi-line captions must be justified (e.g. Fig. 1). Captions with figure numbers must be placed after their associated figures, as shown in Fig. 1.

B. Static Structural Analysis on actual wheel

Static analysis is carried out by applying bending load in CAE software. In the case of bending test a lateral load of 1115.54 N is applied at a distance of 1 m from the centre of the hub. Before applying the load the model should be meshed properly. Provide appropriate constrain condition.

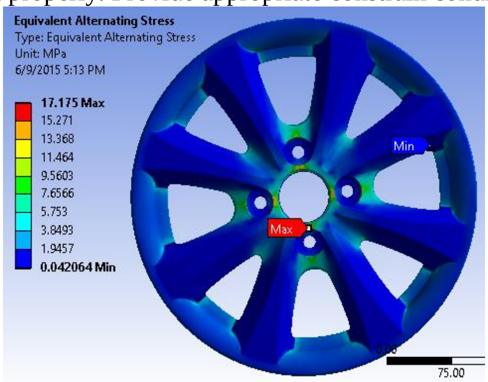


Fig. 3 Equivalent stress

As shown in above Fig. 3 Equivalent stress is found out which is well below safe limit.

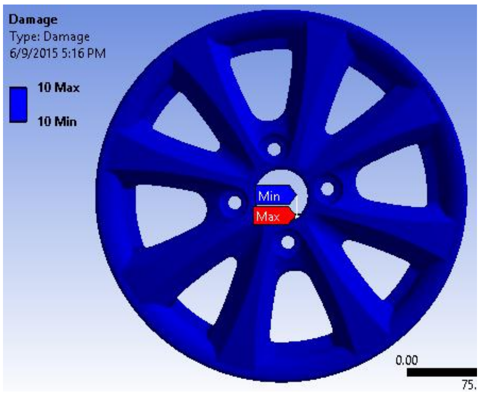


Fig. 4 Damage

As shown in above Fig. 4 analysis results shows Damage on alloy wheel rim. It is seen that there is no damage on wheel rim after application of bending load.

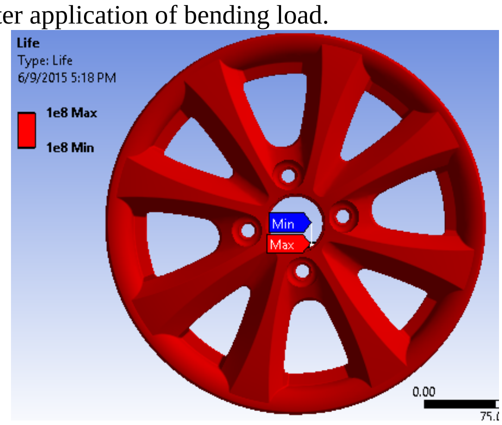


Fig. 5 Estimated Life

Fig. 5 shows estimated life of alloy wheel component is upto 1e8 cycles which is well above 2e5 cycles which is given by industrial standards.

 

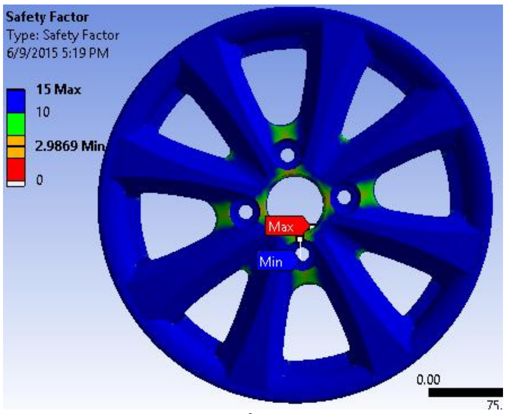


Fig. 6 Safety Factor

Fig. 6 shows factor of safety after CFT analysis in CAE and is having minimum value 2.9869 which is greater than 1 so design safe.

Cornering Fatigue Analysis is performed on wheel. It is observed that the FEA result of the above test shows that the maximum stress being induced in the wheel is much less than the allowable stress of aluminum alloy which is 51.3 MPa for reversed stress theory. Here comes the scope for further optimization of the wheel. Structural optimization is aimed at to minimize the mass of wheel without compromising the strength of wheel.

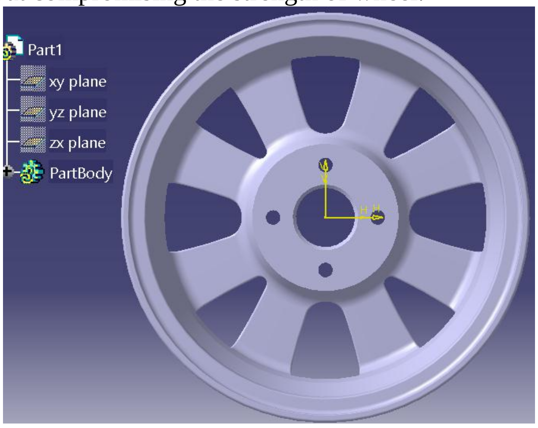


Fig. 7 Actual model

Shape optimization is done by removing the material from rim hub where stresses are minimum above Fig. 7 shows that actual CAD model in CATIA.


Fig. 8 Optimized CAD Model

Above Fig. 8 shows optimized CAD model in CATIA after removing material as shown

C. Analysis result on Optimized wheel

Static structural analysis is performed again on optimized wheel rim model and checks the equivalent stress, damage, life and factor of safety are within limits.

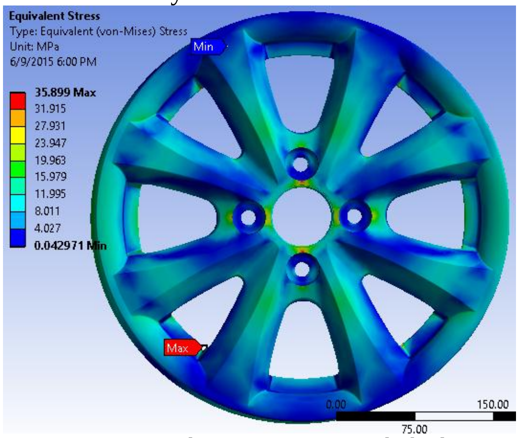


Fig. 9 Equivalent stress on optimized wheel

As shown in above Fig. 9 Equivalent stress is found out which is well below safe limit.

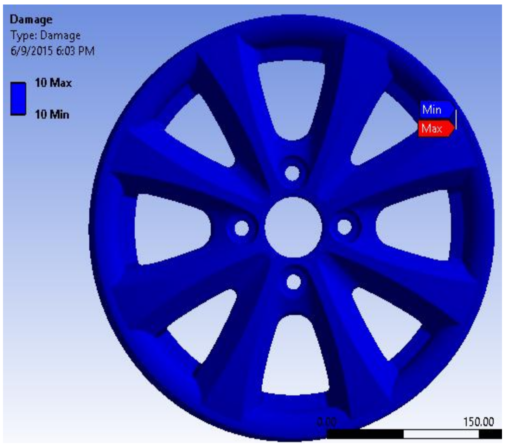


Fig. 10 Damage on optimized wheel

As shown in Fig. 10 analysis results shows Damage on alloy wheel rim. It is seen that there is no damage on wheel rim after application of bending load.

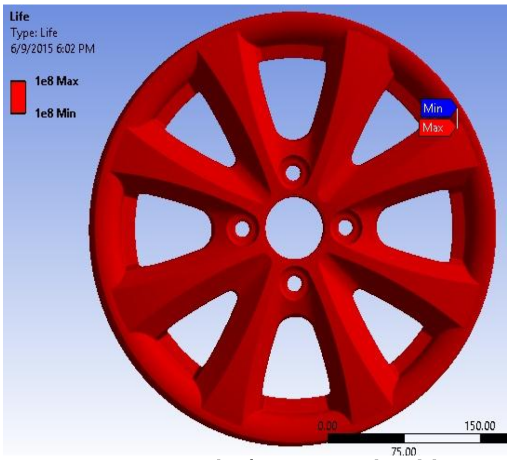


Fig. 11 Estimated Life on optimized model

Fig. 11 shows estimated life of alloy wheel component is up to 1e8 cycles which is well above 2e5 cycles which is given by industrial standards

 

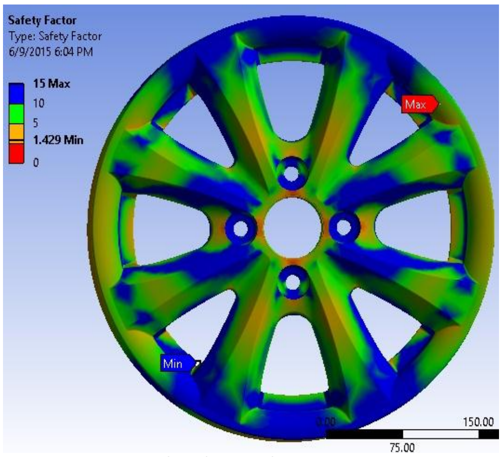


Fig. 12 safety factor of optimized model

Fig. 6 shows factor of safety after CFT analysis in CAE and is having minimum value 2.9869 which is greater than 1 so design safe.

## VII. RESULTS & DISCUSSIONS

On trying on these two cases with varying dimensions, one model is finally reached at with a total of 3% (200gm) mass reduction without compromising its performance. The wheel on subjection to Cornering Fatigue Test, is observed to pass through all the requirements. In Cornering fatigue test, the alloy wheel is observed to have a safety factor of greater than 1which is a very safe value, the minimum requirement for safety factor in case of CFT and RFT being 1.0.

TABLE 2
ANALYSIS RESULTS

| Item | Base | Optimized | Target |
|---|---|---|---|
| Mass(Kg) | 7.748 | 7.548 | Minimum |
| Equivalent stress(MPa) | 17.135 | 35.899 | <51.3 |
| Damage | 0% | 0% | 0% |
| Life | 1e8 | 1e8 | >2e5 |
| Safety factor | 2.98 | 1.429 | >1 |

## VIII. CONCLUSION

There is a mass reduction of 200gm per wheel is achieved which mounts to 1kg per car considering the spare wheel. This mass reduction results in two benefits. Decrease in total weight of the car and decrease in cost of production. Optimization techniques help largely in reducing the mass of solid components which results in overall body weight reduction and thus lesser cost. Lesser weight in turn gives better performance and better fuel efficiency. These result in many indirect benefits to mankind which includes conservation of natural resources to some extent, reduction in air pollution etc.

## IX. SCOPE FOR FUTURE WORK

In the above proposed shape optimization of wheel rim for bending loading is only considered, this can be extended to other forces that act on the wheel rim and weight optimization is carried out, this can be extended to transient analysis and by changing the material we can check whether the results are within specified industrial limit or not.

## ACKNOWLEDGEMENT

We thank to general manager C.J. Bhosale aura alloy wheel pvt.Ltd.for their continuoussupport and cooperation throughout thestudy.

## REFRENCES

[1] T. Siva Prasad,T. Krishnaiah, J. Md. Iliyas, M.Jayapal Reddy, “A Review on Modeling and Analysis of Car Wheel Rim using CATIA & ANSYS”, International Journal of Innovative Science and Modern Engineering (IJISME) May 2014, Volume-2, Issue-6, ISSN: 2319-6386.

[2] Sourav Das, (CAE Analyst), “Design and Weight Optimization of Aluminium Alloy Wheel”, International Journal of Scientific and Research Publications, June 2014, Volume 4, Issue 6, ISSN 2250-3153.

[3] S.Ganesh, Dr.P.Periyasamy, “Design and Analysis of Spiral Wheel Rim for Four Wheeler”, The International Journal Of Engineering And Science (IJES), 2014, Volume 3, Issue 4, Pages, 29-37.

[4] P. Meghashyam1, S. Girivardhan Naidu and N. Sayed Baba, “Design and Analysis of Wheel Rim using CATIA & ANSYS”, International Journal of Application or Innovation in Engineering & Management (IJAIEM) August 2013, Volume 2, Issue 8,

[5] Ravi Lidoriya, SanjayChaudhary and Anil Kumar Mohopatra, “Design and Analysis of Aluminum AlloyWheel using PEEK Material”, International Journal of Mechanical Engineering and Research. (2013), Volume3, Number5, ISSN No. 2249-0019, pp. 503-516

[6] P. RamamurtyRaju , B. Satyanarayana , K. Ramji, K. Suresh Babu, ”Evaluation of fatigue life of aluminum alloy wheels under radial loads”, November 2006.

[7] XiaofengWanga, XiaogeZhang,”Simulation of dynamic cornering fatigue test of a steel passenger car wheel”, International Journal of Fatigue 32 (2010),

[8] Mark Easton a, Wei Qian Song b, Trevor Abbott, “A comparison of the deformation of magnesium alloys with aluminium and steel in tension, bending and buckling, Materials and Design”, (2006), 935–946,

[9] Kubilay Yay and I. Murat Ereke, ”Fatigue Strength of a Rim Model with FEM Using a New Approximation Technique”, Copyright 2001 SAE International

 