

Mathematical And Simulation Investigation of Automobile Wheel Rim Material

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Abstract—Wheels are one of the most important components of a car. Two wheels, there are two wheels used. One is an alloy wheel and the other is a spoke wheel. Most alloy materials are used to make wheel rims. The main reason for using alloys is to increase the efficiency of the two wheels by reducing the weight. The current concept is to design and modify sequential wheel rims for cars. Flanges are usually made of forged steel or alloy steel due to its excellent properties in terms of strength and affordability the material gives great strength, but increasing its strength increases the weight of the wheels. Therefore, in this study, an attempt was made to replace the steel material with a mixed matrix composite to maintain or increase strength with reduced weight. The rim of the wheel is designed keeping in mind the various loads it carries, such as forces, traction, torsion, shear, bending and sudden loads. Mathematical modeling is performed using each load analysis. Limited factor analysis is performed using ANSYS software to determine the areas of stress concentration. Content and size are modified using the same software. An experimental test of bending stress and Impact strength is to be performed to verify and verify the feasibility of the result obtained in the simulation.

Index Terms—Wheel Rim, AI Matrix, Material Optimization, Ansys.

I. INTRODUCTION

A wheel is a circular block of solid and durable material in which a circular hole is drilled in the center through which an axle bearing is placed around which the wheel rotates when a moment by gravity or torque is applied to the wheel. its hub, which together make one of six simple machines. When placed vertically under a platform or conveyor body, a wheel that rotates on the horizontal axis allows heavy loads to be moved. Alloy rims are automobile wheels made of aluminium

or magnesium alloy, or sometimes a mixture of the two. The difference between the alloy rim and the ordinary steel frame is due to their lighter weight, which improves the vehicle's trajectory and speed. A rim is the component holding the tire of vehicle. It is the outer circular wheel design where the inner rim of the tire is attached to vehicles such as cars. For example, on a bicycle wheel, the rim is a large hoop attached to the outer ends of the wheel spokes that hold the tire and inner tube together. In cross sectional shape, the rim is having depth and shallow center outer edge which forms a U-bend shape which indeed supports the edge of frame. Since the rim is where the tire is on the wheel and the rim supports the shape of the tire, the dimensions of the rims are a factor in the vehicle's handling characteristics. For example: rims that are too wide relative to the width of a particular car's tire can lead to more vibration and a less comfortable ride because the sidewalls of the tire have insufficient curvature to flex properly on rough driving surfaces. Oversized rims can cause the tire to rub against the body or suspension components when cornering. Rims that are too narrow relative to the width of the tire can lead to poor handling as the tire can twist sideways in fast corners.



Figure 1: Automobile Wheel Rim

1.1. Nomenclatures Of Wheel Rim

The tire works as a wheel only after it is set up on the rim and is inflated therefore: the tire and wheels assembly affects the function and performance of the vehicle. The tire is designed and manufactured to fit the regular rim and when installed on the right rim the tire will work at its desired level. Wheel: Wheels usually have rims and discs to which the tires are attached. Disc: This is the part of the flange where it is attached to the shaft of the hub. Offset: This is the space between the wheel mounting surface where it bolts to the axle and the center of the line. Flange: A flange is a part of a flange that connects two frame beds. Bead Seat: The wooden seat touches the face of the bead and is part of the flange holding the tire in the radial direction. Bead space: The embroidered seat touches the face of the rim and is part of the rim that holds the tire in a radial direction.

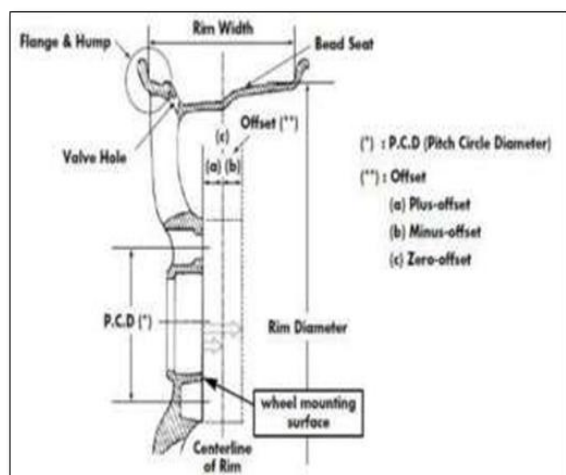


Figure 2: Nomenclatures of Wheel rim.

II. LITERATURE SURVEY

T. Siva Prasad et.al. [1] Explains the A Review on Modelling and Analysis of Car Wheel Rim Using CATIA & ANSYS. In this project, a tire rim belonging to the class of disc wheels is being considered. An amount of 21.3 kPa is applied along the circumference of the aluminum alloy and forged steel rims, and the rim-bolt circle is installed. The aluminum alloy rim is subjected to more displacement compared to forged steel. The aluminum alloy rim is subjected to more displacement compared to forged steel.

Sandip Bhattacharyya et.al. [2] Describes the Failure analysis of cracking in wheel rims – material and manufacturing aspects. The paper discusses about one

of the failure types in wheel rims, where the wheel rim thins down locally and cracks at the weld. high yield ratio are prone to localized necking and cracking at the weak HAZ. On the contrary, a material with lower strength and favorable yield ratio can accommodate a weak HAZ by diffused necking characteristics as the material has a favorable microstructure and can bear the forming stresses.

Aman Pandya et.al. [3] Explains the Design Modification and Analysis of Automobile wheel Rim Using Finite Element Analysis. The purpose of the car wheel rim provides a firm base on which to fit the tire. The motorcycle riders are subjected to extreme vibrations due to the vibrations of its engine, improper structural design of the motorcycle and the bad road conditions. So in this project the attempt has been made to reduce the vibrations of vehicle by providing springs instead of the spokes at the wheel.

The framework or the outcomes of literature is the summarised structure of Literature Survey. In this section all the abstracts and point are mentioned and explained in the order of the paper survey done. The summary is the outline of research data collected and analysed, which further will be in application with the organisation of dissertation. The different loading conditions are described from the paper which are utilized for mathematical modelling of the component. A wheel rim is subjected to sudden impact, radial, circumferential and centrifugal kind of loading of which the description and background is been described. The survey is specially been designed to verify the materials that are been used for manufacturing of Wheel rim. The scope has been concluded that the materials that are used for components are generally casted iron with low strength or ANSI Steel grades. Hence we have the scope of modifying the materials with different composites and alloys. Hence forth, the material A17068 and 7075 are being selected for optimization. Moreover, the aim of literature is to define the failure analysis in various aspects of loading conditions. The various loading conditions and reactions for design are determined. In this survey, all the forces acting in the wheel rim body has been described which where helpful for the dissertation. The methodology for FEA and experimental investigation is also useful from the survey.

III. PROBLEM STATEMENT

Modify and analyse the Wheel Rim of an automobile, and compare the results through simulation and experimental investigation. Rims are usually forged steel that is heavier. Therefore, this study sought to replace and find the best alternative material. Works on

various load systems, such as snap load, bend load and shear load. Therefore, considering the analysis of the entire pregnancy, the tip must be changed. On the other hand, the weight of the flange should be reduced and the technology of material optimization will be used for this purpose.

IV. METHODOLOGY

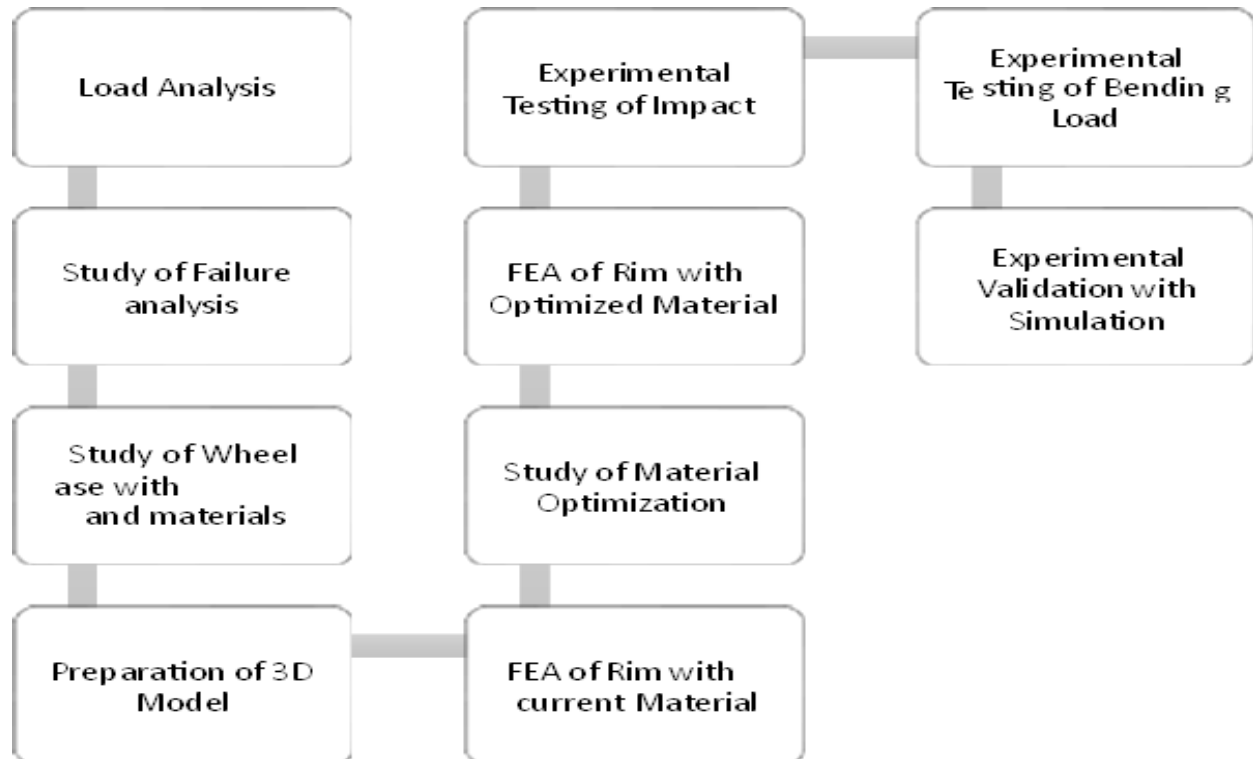


Figure 3 Proposed Methodology

V. MATHEMATICAL MODELLING

5.1. General Specifications of Wheel Rim

The flange used in the case study was used on Hyundai Santro. It is a city car which is produced by the South Korean company called Hyundai between the years 1998 and 2014. The Initial model and base generation of car was launched in the year 1998 and in early 1999. It was also sold in Europe under the Atos Prime name and in South Korea and Indonesia under the Kia Festo name. It was also known as Santro Zip in India from 1998 to 2006.



Figure 4 Specifications of Hyundai Santro

The material used for the flange is C-1008 steel, deeply called AISI 1008 carbon steel. AISI 1008 carbon steel has excellent welding ability, which includes drop, butt, spot and smelt, brazing ability.

Steels that mainly contain carbon as an alloying component are called carbon steels. It contains about 1.2% manganese and 0.4% silicon. Nickel, aluminium, chromium, copper and molybdenum are also present in small amounts in carbon steel. Cold rolled steel 1008 is the standard type of carbon steel. This alloy is commonly used in commercial grade cold rolled steel sheets. It is an cost effective common purpose steel grade with medium strength and hardness. As a standard grade, this steel has many applications.



Figure 5: Actual Wheel Rim for Case Study

Table 1: Specifications of Hyundai Santro

Parameter	Value
Max Power	68.05 bhp @ 5500 rpm
Max Torque	99.04Nm @4500 rpm
Overall Length (mm)	3650 mm
Overall Width (mm)	1650 mm
Overall Height (mm)	1560 mm
Seating Capacity	05
Kerb Weight (Kgs)	895 Kg
Gross Vehicle Weight (GVW)	1175 Kg
Body Option	Hatchback
Mileage (Petrol Fuel)	14.25 Kmpl

Table 2: Material Properties of AISI Steel

Parameter	Value
Tensile Strength (MPa)	358
Yield Strength (MPa)	240
Modulus of Elasticity (GPa)	200
Bulk Modulus (GPa)	158
Shear Modulus (GPa)	77
Poisson's Ratio	0.29
Density (Kg/m ³)	7872

Table 3: Chemical Composition of AISI 1008

Material	Mn	C	S	P	Fe
Contribution	0.8	0.1	0.05	0.04	Bal

5.2. Radial Load

The radial load is equivalent to the constant load applied to both the tire and the tire in the normal direction of the road surface. For the radial load, the tensile strength of the rim has a profound effect on the durability, or fatigue life, of a caster. According to the Gross weight of the vehicle,

$W = 1345 \text{ Kg}$, hence the total Static Load, $F = 1345 * 9.81 = 13194 \text{ N}$.

There are total Four rims, hence the total static load acting on each rim can be given as, $F = 13194/4$ $F_s = 3298 \text{ N}$. [For each rim]

Hence the radial load acting on the rim can be given as, $FR = FS \times K$

K = an acceleration factor is a value that can be used to speed up the convergence and reduce the number of required alteration = 2.25

$FR = 3298 \times 2.25 = 7420 \text{ N}$.

Eqn. 1 Hence the total Radial Load acting on the rim is 7420 N



Figure 6: Phenomena of Radial Load

5.3. Bending Load

The bending of the load is the stiffness of the component. This assumes the casing is deep enough below the mud line to be secured rigidly. For the structural envelope, bending is a primary design consideration. The internal reaction loads in the cross section of the structural member can be resolved into resultant force and resultant torque. The tilting moment of a section by a structural member can be defined as the sum of the moments around this section of all external forces acting on one side of the section. The wheel is subject to an equivalent load in relation to the gross vehicle weight (FS)

$M = [(\mu \times R) + d] \times FS \times S$ Eqn. 2

M = Bending moment in N-mm

μ = Friction Coefficient between the tire and the road

surface (no units) = $0.7 R$ = Radius of the tire applicable to the wheel = 204.2 mm

d = Offset of the wheel in mm = 35mm

FS = Maximum load acting on the rim = 3298

S = Coefficient specified according to the standards = 2.87 $M = [(0.7 \times 204.2) + 35] \times 3298 \times 2.87$

$M = 1.677 \times 10^6 \text{ N.mm}$

The maximum Bending Moment on the rim is analysed as $1.677 \times 10^6 \text{ N.mm}$.

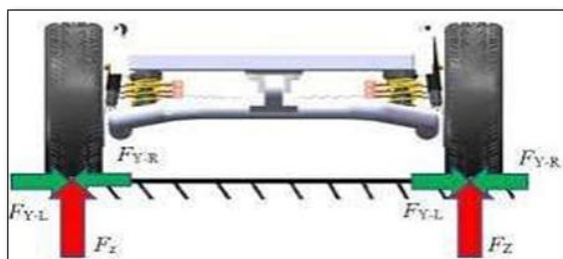


Figure 7: Phenomena of Bending Moment

5.4. Rotational Velocity Of Wheel Rim

The net velocity of any point on a wheel is the vector sum of the speed of travel, which has a constant direction, and the speed of rotation, which rotates around the point at which the wheel rotates. The Speed of the vehicle may vary from 0 kmph to 110 Kmph (standard maximum speed of the santro car). Hence referring to the Automobile Research association of India Standards (ARAI) the vehicle is been tested for the cumulative speed of 66 Kmph.

Speed of the vehicle, $N = 66 \text{ kmph}$ Velocity of the Vehicle,

$V = 66 \times [1000/3600] \text{ m/s } V = 18.33 \text{ m/s}$

The angular speed of the rim can be given as, $\omega = V/r$ Eqn. 3

r = radius of rim = 0.203m $\omega = 90.29 \text{ rad/sec}$

The total rotational velocity of the rim can be analysed as 90.29 rad/sec .

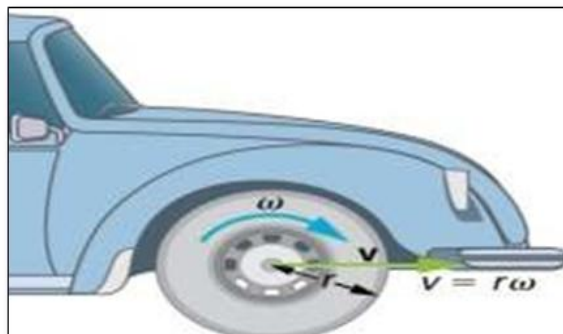


Figure 8: Rotational Velocity of Wheel Rim

5.5. Twisting Moment Of Wheel Rim

If you add a wheel to the end of the vertical rod and turn it at the same low angle, it will rotate more and more slowly. The greater the moment of gravity of the wheel, the more the pendulum will turn backwards and forwards. Therefore, the torque in the wheel rim is generated at the speed of the engine.

N = Speed of Vehicle = 66 Kmph $V = 18.33 \text{ m/s}$

$V = [\pi \times d \times N]/60 \text{ Eqn. 4}$

$N = [V \times 60] / [\pi \times d]$

$N = [18.33 \times 60] / [\pi \times 0.406] N = 862.25 \text{ RPM}$

The engine power as per the company standard specification of Hyundai is stated as, $P = 68.05 \text{ bhp}$ or 4853 KW

$P = [2 \times \pi \times N \times T]/60 \text{ Eqn. 5}$

$T = [P \times 60] / [2 \times \pi \times N]$

$T = 53746 \text{ N.m}$ or $53746 \times 10^3 \text{ N.mm}$

Hence the wheel rim is subjected to maximum twisting moment of 53746 N.m for the average speed of 18.33 m/s or 66 kmph .

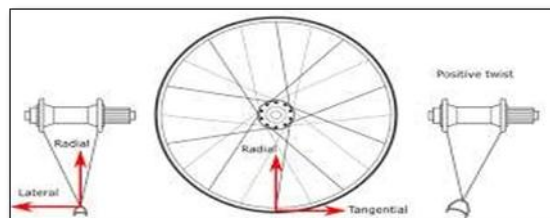


Figure 9: Twisting Phenomena of Wheel Rim

5.6. Centrifugal force

The centrifugal force is the apparent external force that acts when rotating the mass. For example, consider the ball at the end of the string you are spinning or the external movement you feel as you turn the curve in the car. In the inertia frame of reference, there is no external acceleration because the system does not rotate. It is the actual force which is felt by the object which is rotating or moving in the curved path which is acting away from the center of rotation. It is an imaginary force, specific to a particle traveling in a circular path and has the same amplitude and dimensions in which the particles are held in a circular path intersecting each other, as the two flow in opposite directions. As this force is due to the mass of the rotating body which acts in upward direction,

Hence the mass of the wheel rim, $m = 4.6 \text{ Kg}$

the speed of rim in rad/sec, $\omega = 90.29 \text{ rad/sec}$ the radius of rim, $r = 0.203 \text{ m}$

Hence the centrifugal force is given as, $FC = m \times r \times$

ω^2

Eqn. 6

$$F_C = 4.6 \times 0.203 \times 90.292 = 5957 \text{ N.}$$

Hence we get centrifugal force= 5957 N which acts at each node of the circumference of the rim.

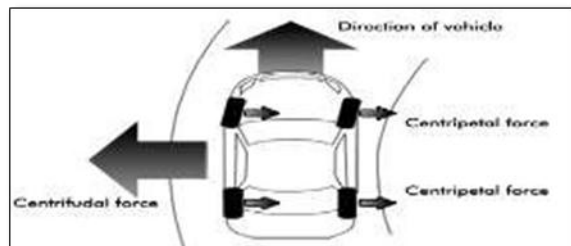


Figure 10 Centrifugal Force on wheel rim

Table 4: Loading Constraints for FEA

Section of Loading	Notation	Design Loading	Ultimate Loading with FOS = 1.5
Radial Load	P1	7250 N	10875 N
Bending Moment on Shaft	P2	1.677×10^6 N.mm	2.51×10^6 N.mm
Rotational Velocity	P3	90.29 rad/sec	135 rad/sec
Twisting Moment	P4	54.74×10^6 N.mm	80.61×10^6 N.mm
Centrifugal Force	P5	5957 N	8935.5
Air pressure of Tire	P6	0.25 MPa	0.375 MPa.

VI. MATERIAL OPTIMIZATION

The materials that are used Wheel Rim is AISI 1008 and processed material of Structural Steel. The material possesses considerable strength which is useful for design and manufacturing the part. But the implementation of these materials increases the unnecessary cost of the assembly as it is been famous for its heavy weight. Hence in order to obtain the same strength with considerable reduction in cost, it is necessary to optimize the material. A limit is the constraint is something that prevents something from happening. The stresses created after the initial analysis of the AISI steel flange, are the adaptive limits that are applied to optimize the arm material to select the optimal replacement material. This pressure is in the form of strength, weight, stress, strain, etc.

1. The design constraints for strength of material is been defined between the stress values ranging from 52 MPa to 460 MPa.
2. The design constraints for strain rate of material is been defined between the values ranging from

5.7. Tire Pressure

Car tire pressure measures the amount of air in your pneumatic tire and ensures that the tire wears evenly and maintains a proper grip on the road surface. This is commonly expressed in PSI, or pounds per square inch. Most passenger cars recommend 32 to 35 psi in tires when they are cold.

The general tire pressure of car automobile is maximum considered as 35 Psi $P = 35$ Psi.

Hence in terms of SI system of units, the Pressure of the tire air is termed as 0.25 MPa which is acting on the surface wedge area of the rim.

0.002.

3. The design constraints for total deformation of the material is been defined between the values ranging from 1.0165 mm.
4. The important criteria of weight reduction are vital characteristics of the Suspension arm Wheel rim which will further effect the reduction in cost and manufacturing time. The overall weight of the rim is defined as 3.6 Kg. Hence the functional weight constraint of optimization for modification of wheel rim should be limited to or under 3.6 Kg.
5. The constraint of optimization for fatigue life is determined as 1790 Cycles.
6. The constraint of optimization for damage at regular interval is determined as 5.85 cycles.
7. The safety factor of the wheel rim is 0.1872 constant.
8. Biaxiality indication is the generation of the stress parameters which are occurred at every section of the rim which is 0.99.
9. The fatigue sensitivity is maximum of 15602 loading and will fail eventually at the loading

constraint of 1.5. Hence the constraint of optimization for fatigue sensitivity is 15602.

6.1. Approach of Optimization using Material Al7068: Aluminum alloy 7068 is alloy of the aluminum-magnesium-silicon family which is one of the most common alloys in its series (along with alloys 7075, 7082 and 7063), although it is not significantly featured in the ASTM (North American) standards. It is usually formed by extrusion and rolling, but as a working alloy it is not used in castings. It can also be forged and plated, but this is not a common practice of this alloy. The work cannot be hardened, but heat is usually handled to create a high- strength quenching process but with less flexibility. Aluminum Alloy 7068 has medium strength with good corrosion resistance. Also known as structural alloy. In plate form, aluminum alloy 7068 is the most widely used aluminum alloy in the process.

Table 5: Chemical Composition of Al-7068

Material	Zn	Cr	Cu	Fe	Others
Contribution	7.3	0.05	0.2	0.15	0.15
Material	Mg	Mn	Si	Ti	Al
Contribution	3	0.2	0.12	0.1	Bal.

Table 6: Properties of Al-7068 Material

Parameter	Value
Shear Strength	365 MPa
Ultimate Tensile Strength	710 MPa
Yield Strength	683 MPa
Young's Modulus	71.7 GPa
Shear Modulus	27 GPa
Poisson Ratio	0.33
Density	2850 Kg/m ³
Electrical Resistivity	3.99e-6 Ω -m

In this section, the feasibility of Al7068 is analysed using Ansys simulation software for finite element methods. The loading conditions and shape topology of the component is kept same as that of AISI Steel but the material is been replaced by Al7068. The different material properties which are uploaded in Ansys Version. The loading conditions are kept same which are explained above. The behaviour of material under stress strain and deformation is been described below.

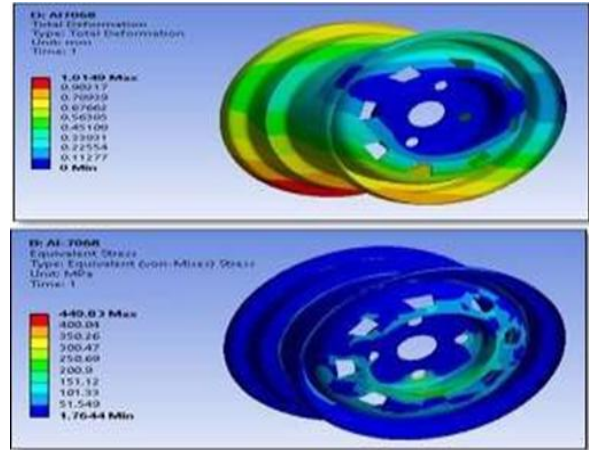


Figure 11: Total Deformation Produced in Wheel Rim for Al7068-T6

The deformation produced in the wheel rim for the material AL7068, the same loading conditions were applied, the value of deformation 1.04 mm and the stress was determined as 449 MPa.

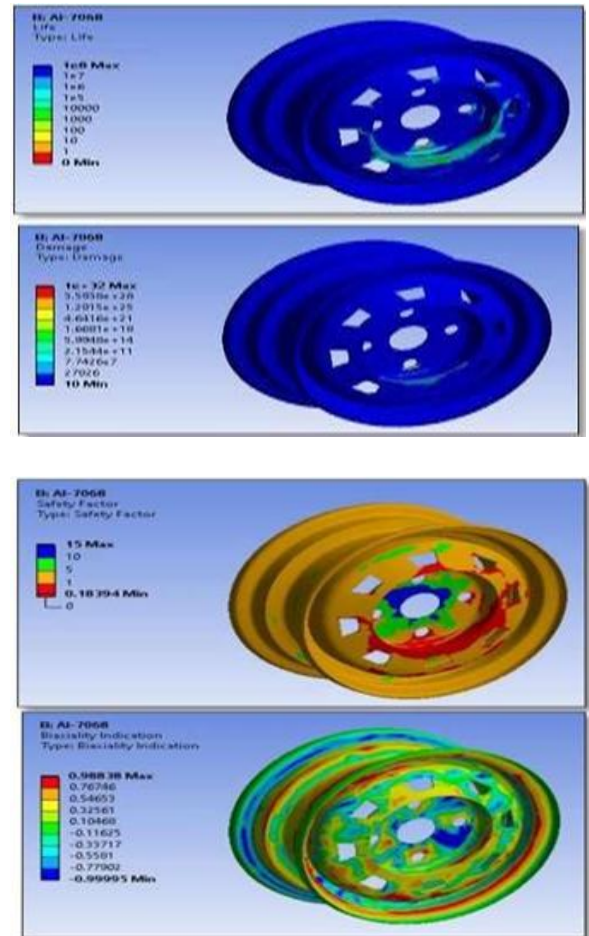


Figure 12: Fatigue Analysis of the Wheel Rim for Al7068-T6

1. The above Figures 5.4 shows the fatigue behaviour of wheel rim using Al-7068 Aluminium Matrix composite under the same loading as that of Steel.
2. With respect to the fatigue analysis, the Fatigue life of Al7068 rim is determined to be 1x108 Cycles.
3. The damage coefficient is determined as 0.00036 whereas the Biaxiality indication is determined to be 0.98.
4. The safety factor obtained for Wheel rim of Al 7068 is found to be 0.183.
5. The Biaxiality indexing of is determined as 0.988.

6.2. Approach of Optimization using Material Al7075: Al 7075 is an aluminum-based alloy that is often used in the aerospace industry. It is the second most common aluminum alloy in the 7000 series after the Aluminum 75 Lodi 7075. The corrosion resistance of these metals is particularly poor. To combat this, it is often coated with pure aluminum. If 2014's unpainted aluminum components come in contact, they should be painted as a measure to protect against rust.

Table 7: Chemical Composition of Al7075-T6

Material	Al	Cr	Cu	Fe	Mg
Contribution	87.1	0.28	1.2	0.5	2.9
Material	Mn	Si	Ti	Zn	Others
Contribution	0.3	0.4	0.2	6.1	0.15

Aluminum alloys have the characteristics of strong corrosion resistance and high electrical conductivity. The strength of these alloys increases at subzero temperatures and the strength is lost when these alloys are exposed to high temperatures.

Table 8: Material Properties of Al7075-T6

Parameter	Value
Ultimate Tensile Strength	572 MPa.
Yield Strength	503 Mpa.
Shear Strength	331 Mpa
Young's Modulus	72 Gpa.
Shear Modulus	27 GPa
Poisson Ratio	0.33
Density	2810 Kg/m ³

Property	Value	Unit
Material Field Variables	Table	
Density	2810	kg m ⁻³
Isotropic Secant Coefficient of Thermal Expansion		
Isotropic Elasticity		
Derive from	Young's Modulu...	
Young's Modulus	72	GPa
Poisson's Ratio	0.33	
Bulk Modulus	7.0588E+10	Pa
Shear Modulus	2.7068E+10	Pa
S-N Curve	Tabular	
Tensile Yield Strength	503	MPa
Compressive Yield Strength	2.8E+08	Pa
Tensile Ultimate Strength	572	MPa
Compressive Ultimate Strength	0	Pa

Figure 13: Material Properties Updated in Ansys Setting for Al7075-T6

Aluminium alloy 7075 is used in High stress applications like Trusses, Bridges, and Cranes, Transport applications, Ore skips, Beer barrels and Milk churn. In this section, the feasibility of Al7075 is

analysed using Ansys simulation software for finite element methods. The loading conditions and shape topology of the component is kept same as that of AISI Steel but the material is been replaced by Al7075.

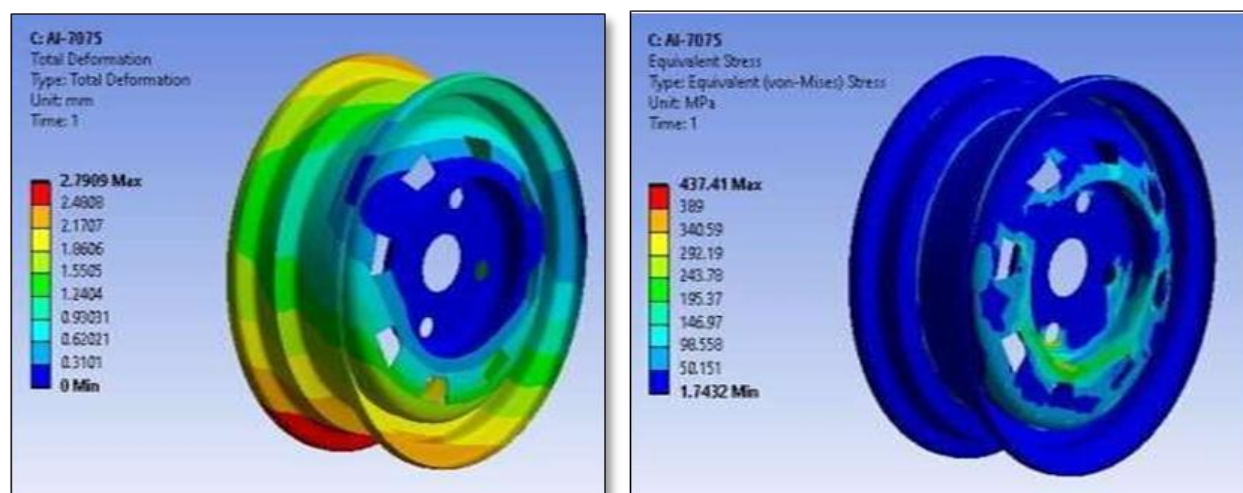


Figure 14: Buckling Behaviour of Wheel rim Made of Al-7075 Material.

explains the different material properties which are uploaded in Ansys Version. The properties are explained in section 13 and same are uploaded in Ansys. The loading conditions are kept same which are explained in section 5. The behaviour of material under stress strain and deformation is been described below.

The deformation produced in the wheel rim for the material AL7075, the same loading conditions were applied, the value of deformation 2.19 mm, which is more than the material of Al7068 and AISI Steel. The stress was determined as 437 MPa.

1. The above Figures 15 shows the fatigue behaviour of wheel rim using Al-7075 Aluminium Matrix composite under the same loading as that of Steel.
2. With respect to the fatigue analysis, the Fatigue life of Al7075 rim is determined to be 1×10^8 Cycles.
3. The damage coefficient is determined as 0.00038 whereas the Biaxiality indication is determined to be 0.98.
4. The safety factor obtained for Wheel rim of Al 7075 is found to be 0.183.
5. The Biaxiality indexing of is determined as 0.988.

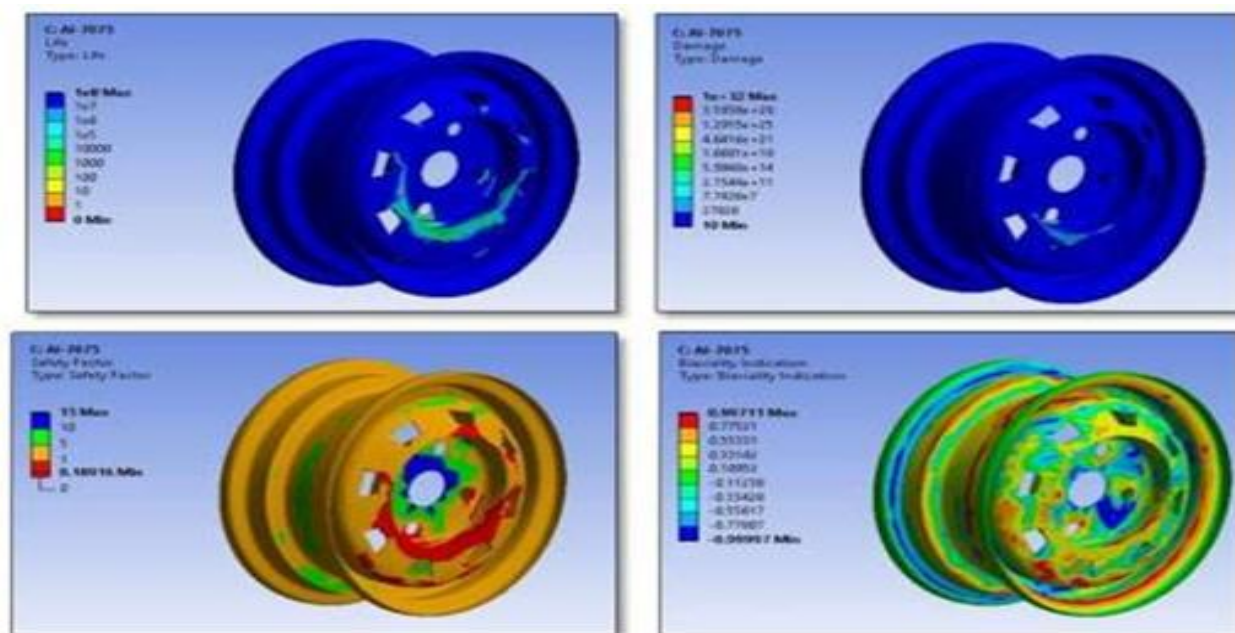


Figure 15: Fatigue Behaviour of the Wheel Rim for Al7075-T6

VII. CONCLUSION

Form the above research we got to know about the problems in the wheels rim made from the AISI steel 1008. Failure in the various regions of the wheel rim that may be by buckling, bending, twisting etc. So there was a need for the material optimization which can replace by the Aluminum Alloy 7068 and 7075 for the longer life of the wheel rim and sustain better conditions.

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