Weight Optimization of Alloy Wheel

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Abstract - *Wheels are the main components of the car. The wheels with tires provide the better cushioning effect to the car. Without engine a car may be towed but at the same time a car cannot be towed without wheels. The main requirement of the vehicle or automobile tires are it must be perfect to perform its all the functions. Reverse engineering is a good method to redesign the old component. The wheels have to pass different tests for best performance like static analysis, vibration analysis etc. Design is an important manufacturing activity which provides the quality of the product. The 3-dimensional model of the alloy wheel was designed by using the technology reverse engineering & CATIA V5 software and further it was imported to the ANSYS. The static, fatigue and dynamic analysis were performed. This was constrained in all degree of freedom at the bolt. Similarly based on the weight, the thickness of rim & spokes are varied to attain different models. Also changing the number of spokes wheel model is prepared and analysis is done.*

From the analysis done in the project, it can be concluded that the wheel made of magnesium alloy are better as compared to Al alloy wheels. As the stresses developed in the magnesium wheel are less as well as the S-N curve of Mg wheel is better under load condition.

Key Words: *Alloy Wheel, CATIA, Stress Analysis, ANSYS15.0*

1.INTRODUCTION

Automotive wheels have been developed over the decades from the start of spoke designs of wood and steel, with flat steel discs to finally the metal configurations and modern cast and forged aluminum alloys rims of today's modern automobiles, finally these research yielded fruitful designs after extensive field testing and experience. Since 1970's a number of innovative techniques for testing with trial stretch estimations have been begun.

Alloy wheels were produced in the last sixties to take care of the demand of course fans for styling. It was a sloppy industry during that time. Original Equipment Manufacturers (OEM) soon realized that a major market opportunity was being lost as auto proprietors were heading off to a merchant for fitment with costly custom alloy wheels. Soon the OEM's adopted the change and then the alloy wheel market has been growing day by day. Now the alloy wheels are viewed as the accepted standard for cars around the globe. With the growth sought after, came new and efficient improvements in design, innovation and assembling process to deliver the variety of designs with superior quality.

Automobile wheels ought not fail under service conditions. Their fatigue life and strength are significant. To minimize the costs, the design for limited-life and light-weight is bit by bit being utilized more for all automobile segments. In the genuine wheel improvement, rotating fatigue test is utilized for the detection of the strength and fatigue life of the wheel. The performance of braking of a vehicle depends on the size, weight, ventilation or design, materials of the wheel. The design of the wheel decides the space within the rim and the brake. For large diameter wheel rim there will be more span for air stream in the region of the brakes which results in better heat dissipation.

The weight reduction of wheel is more efficient than the weight minimization of somewhere else in a vehicle because of the rotational moment of inertia effect for the period of motion. As a result, the wheel design ought to be optimized by considering essential characteristics of a light business vehicle for example, NVH, Durability and Weight.[1]

1.1 Methodology

Steps involved in the project are

1. Finding the dimensions of existing wheel by reverse engineering.
2. Creating a 3D model using CATIA.
3. Analyzing the existing wheel (Static, Fatigue and Modal Analysis).
4. Modifying the wheel design with same number of spokes and same material.
5. Analyzing the modified wheel design.
6. Modifying wheel design with change in number of spokes and same material.
7. Analyzing the design.
8. Suitable material selection with required mechanical properties.
9. Modifying the wheel design based on the new material properties.
10. Analyzing the Design.
11. Comparing the results and choosing a suitable wheel design.

2. GENERAL RESEARCH ABOUT PROJECT

2.1 Alloy Wheel

The tyre is set on the rim and is inflated only then it works as wheel and therefore; the assembly of wheel and tyre effects the vehicles performance and function. The tire is produced by the design that suit a standard rim and once it is introduced on the proper rim the tire will accomplish its favored level performance. It is pointless to state that the tyre life will be reduced if assembled on an inappropriate rim. The cylindrical part on which the tire is set up is actually called as rim. The grouping between rim and disc plate is known by the name wheel. When the disc plate is settled inside the cylinder this gathering turns into a wheel.

Fig-1 : Wheel Assembly

2.1.1 Rim Nomenclature

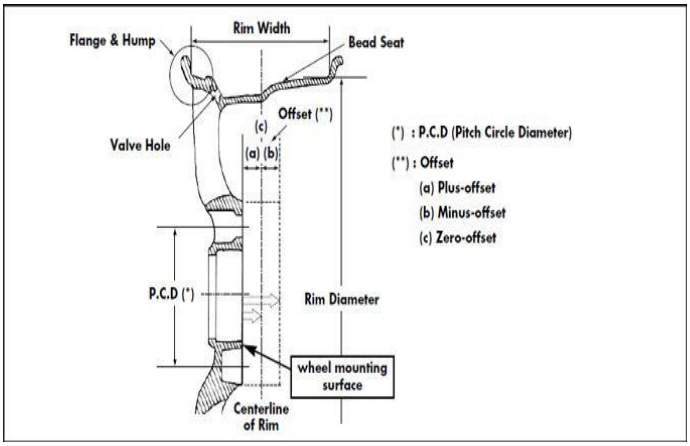

Fig-2 : Rim Nomenclature

1. **Wheel: G**enerally wheel is made out of rim and disc.
2. **Rim:** It is a section where the tire is introduced.
3. **Disc:** This is a part of the rim where it is settled to the hub axel.
4. **Offset:** This is a gap between surface of wheel mounting where it is bolted to hub and centre line of the rim.
5. **Flange:** The flange is a part of rim which holds the both beds of the tire.
6. **Bead Seat:** Bead seat approaches in contact with the bead face and it is a part of rim which holds the tire in a radial direction.
7. **Hump:** It is a bump what was put on the bed seat for the bead to obviate the tire from sliding off the rim while the vehicle is moving.
8. **Well:** This is a part of rim with depth and width to facilitate tire mounting and expulsion from the rim.

2.2 Alloy Wheel Material

2.2.1 Aluminum Alloy (A356)

Aluminum (Al) alloys have six noteworthy components constitute the die cast aluminum alloy system viz. Si(7.20%), Cu(0.02%), Mg(0.29%), Mn(0.01%), Fe(0.18%), Zn(0.01), Ni(0.02), Ti(0.11) and Al(remaining).
Mechanical properties of aluminum A356 alloy

- Density – 2685 kg/m^3
- Yield Strength – 285 MPa
- Elastic Modulus – 71 GPa
- Poisson's Ratio – 0.33

2.2.2 Magnesium Alloy (AZ91)

Magnesium alloys materials are generally utilized for applications in numerous designing fields like in car, aviation and electronic devices. The extensive range of their utilization remains on the reality of their low weight however great mechanical properties, which can be affected in wide range by changes of chemical composition. Chemical composition of Magnesium AZ91 alloy are Al(8.70%), Zi(0.65%), Mn(0.25%), Si(0.006%), Fe(0.003%), Be(0.0008%), Ni(0.0006%), Cu(0.0005%), Mg(remaining).
Mechanical properties of magnesium AZ91 alloy

- Density – 1810 kg/m^3
- Yield Strength – 230 MPa
- Elastic Modulus – 45 GPa
- Poisson's Ratio – 0.35

3. BOUNDARY CONDITIONS (BC) FOR ANALYSIS

The analysis of the wheel is done using the ANSYS software. First a 3D model of the wheel is prepared using CATIA V5 and then it is imported into ANSYS for analysis. The boundary condition is nothing but the working condition of the wheel. The different analysis are done by applying different boundary conditions. The applied boundary conditions for the analysis of the alloy wheel are shown below.

3.1 BC for Static and Fatigue Analysis

Static analysis is used to calculate the effect of steady loading conditions on a structure. For the car wheel the boundary conditions are as shown in the bellow fig-3. The wheel is fixed at the bolts and the torque of 190 N-m is applied at the centre of the wheel. The car load of 4500 N compressive for static analysis and 0-4500 N alternating compressive for the alternating stress analysis is applied on the rim. In static analysis the Total Deformation and Equivalent (Von-Mises) Stress is calculated.

Fatigue analysis is used to calculate Equivalent Alternating Stress, Number of Cycles to Failure and to Determine the S-N Curve.

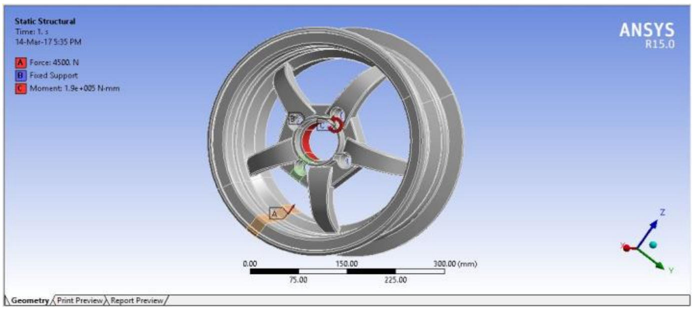

Fig-3 : BC for static & fatigue analysis

3.2 BC for Modal Analysis

Modal analysis is utilized to find the vibrations of a component. For the project purpose the natural frequency of vibration of the wheel is calculated. The Natural Frequency is characterized as the frequency at which the system is vibrating when it is not subjected to a continuous or rehashed external force. According to NVH standards the first natural frequency of all the automotive part should be over 350 Hz. To find the natural frequency of the wheel it is just fixed at the bolts without application of any external force as shown fig-4

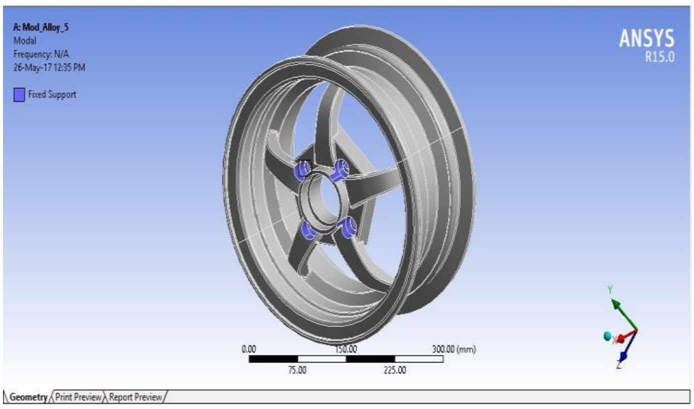

Fig-4 : BC for modal analysis

3.3 Applied Load on Alloy Wheel

Table-1 : Specification of alloy wheel

S. No.	Parameter	Value
1.	Volume	2.53 X 10^6 mm^3
2.	Diameter	283 mm
3.	Weight of the car	1200 Kg
4.	Passengers (5 People)	500 Kg
5.	Extra load	500 Kg
6.	Total	21,582 N
7.	Tires and suspensions reduced by 25%	16,186 N
8.	Weight on individual wheel	4,050 N

For the safety purpose and also to make the calculations easy the load of 4500 N is applied on each wheel.

4. ANALYSIS OF THE WHEEL MODELS

The model of existing alloy wheel is prepared by reverse engineering method. Then based on the weight the thickness of rim & spokes are varied to attain different models. Also changing the number of spokes wheel model is prepared and analysis is done.

4.1 Analysis of Existing Wheel

4.1.1 Weight of the Wheel

The existing wheel material is aluminum A356 alloy. The wheel weighs 7.01 Kg.

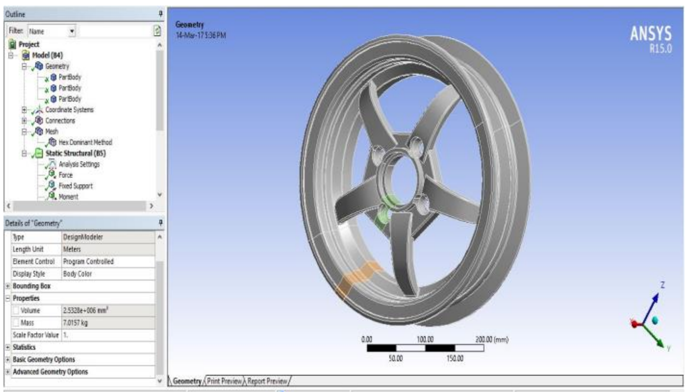

Fig-5 : Weight of existing wheel

4.1.2 Static Analysis

Maximum Deformation- The Maximum deformation observed in the existing alloy wheel is 0.1591 mm.

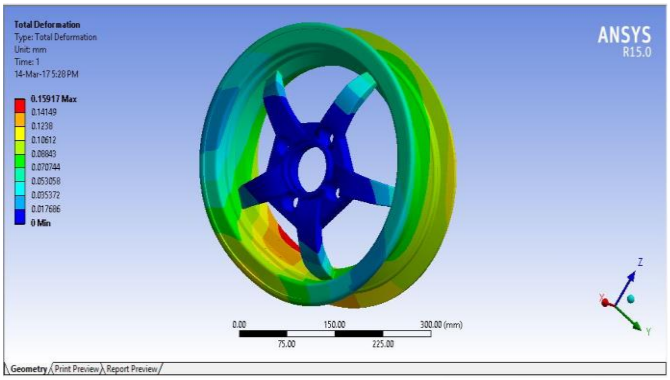

Fig-6 : Deformation in existing wheel

Equivalent (von-mises) stress- The induced stress in the wheel is 114.79 MPa

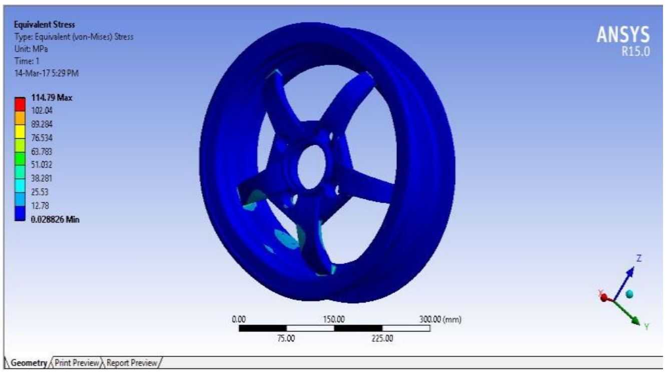

Fig-7 : Equivalent stress in existing wheel

4.1.3 Fatigue Analysis

Equivalent alternating stress- The observed equivalent alternating stress is 57.393 MPa.

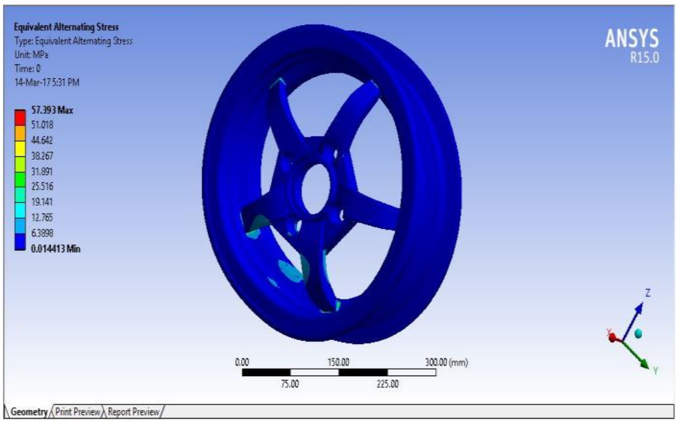

Fig-8 : Equivalent alternating stress in existing wheel

Life cycle- The life cycle the wheel can survive without failure is 1X10^8 cycles.

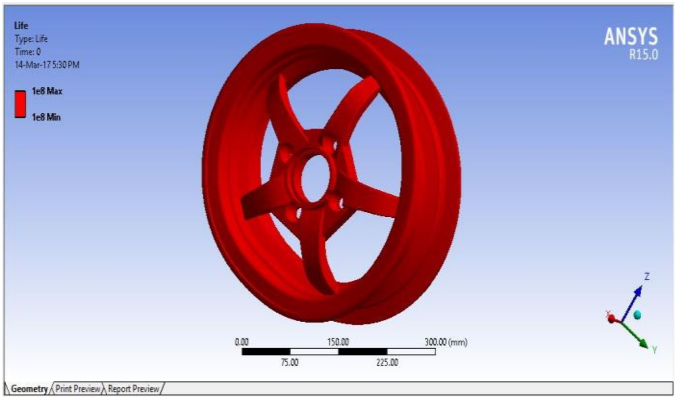

Fig-9 : Life cycles of existing wheel

S-N Curve- The Stress v/s No. of Cycles to failure graph of existing wheel is shown in the fig-10

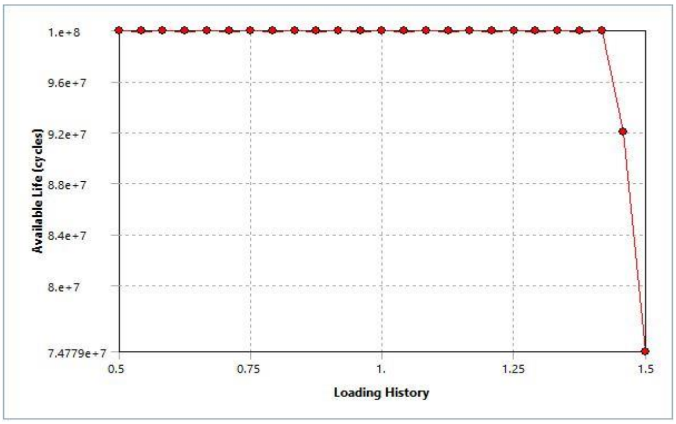

Fig-10 : S-N curve of existing wheel

4.1.4 Modal Analysis

The first six Mode Shapes of the existing wheel is shown below (Figure 6.10). The first mode shape is 461.61 Hz.

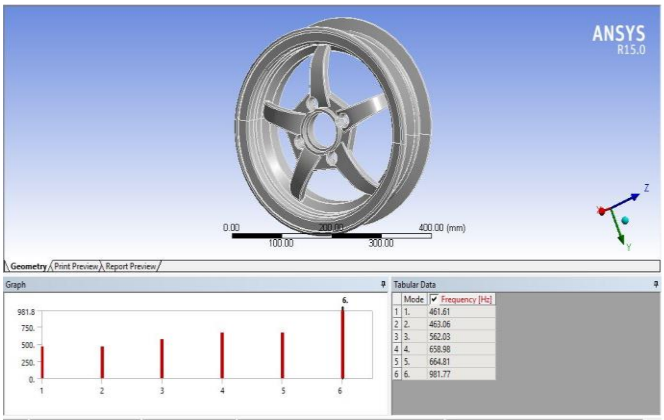

Fig-11 : Mode shapes of existing wheel

4.2 Analysis of Magnesium Alloy Wheel

For this analysis the Magnesium AZ91 alloy is taken as the wheel material. The 3D model is prepared by keeping the same number of spokes and varying the thickness of rim and changing the cross section area of spokes of the existing wheel without changing any parameters which are necessary to fit the wheel to the vehicle like diameter of the wheel, PCD of the bolt or bore diameter.

4.2.1 Weight of the Wheel

The wheel material is Magnesium AZ91 alloy. The wheel weighs 5.13 Kg.

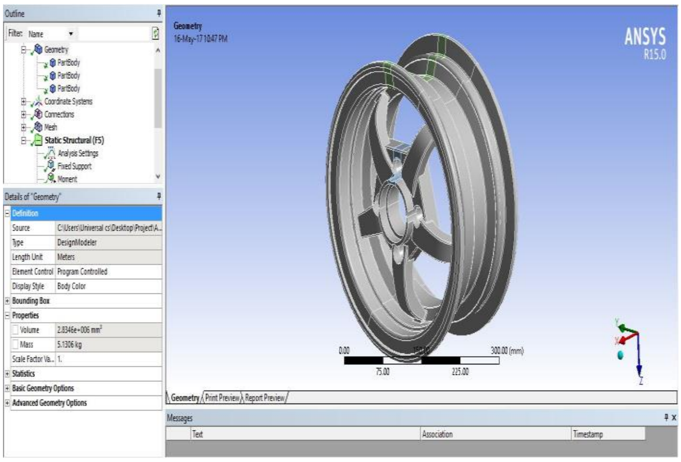

Fig-12 : Weight of magnesium alloy wheel

4.2.2 Static Analysis

Maximum deformation- The maximum deformation is found out to be 0.2128 mm

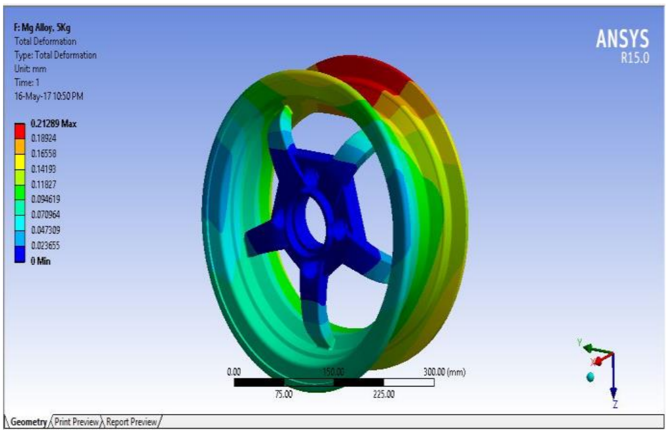

Fig-13 : Deformation in magnesium alloy wheel

Equivalent (von-mises) stress- The stress that will be induced in the wheel is 105.12 MPa

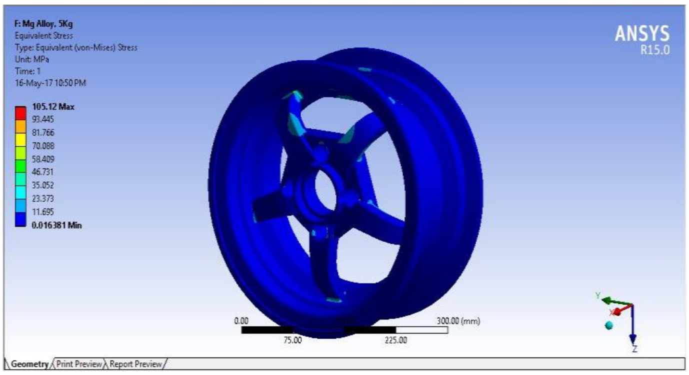

Fig-14 : Equivalent stress in magnesium alloy wheel

4.2.3 Fatigue Analysis

Equivalent alternating stress- The equivalent alternating stress that will be observed is 52.562 MPa

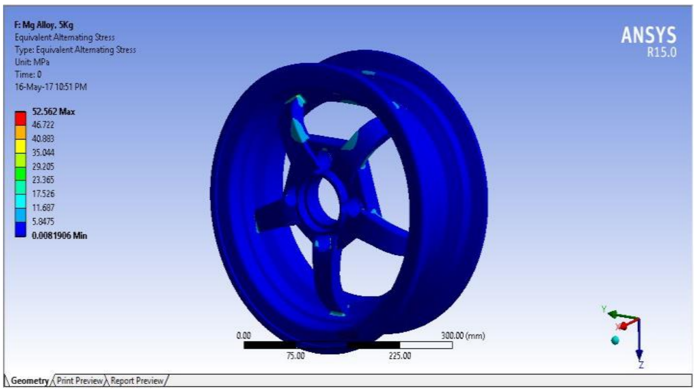

Fig-15 : Equivalent alternating stress in magnesium alloy wheel

Life cycle- The life cycle the wheel can survive without failure is $3X10^8$ cycles

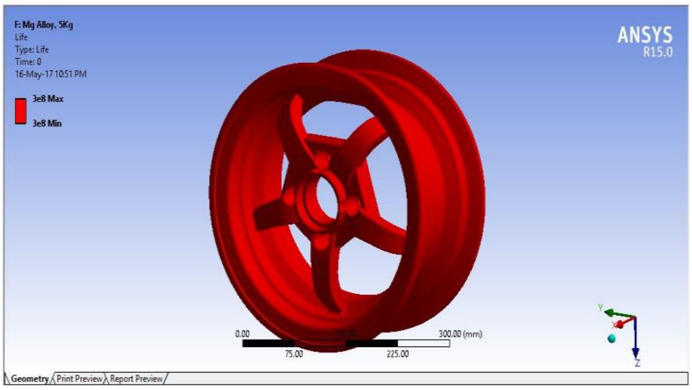

Fig-16 : Life cycles of magnesium alloy wheel

S-N Curve- The Stress v/s No. of Cycles to Failure graph for Magnesium Alloy wheel is shown in the fig-17.

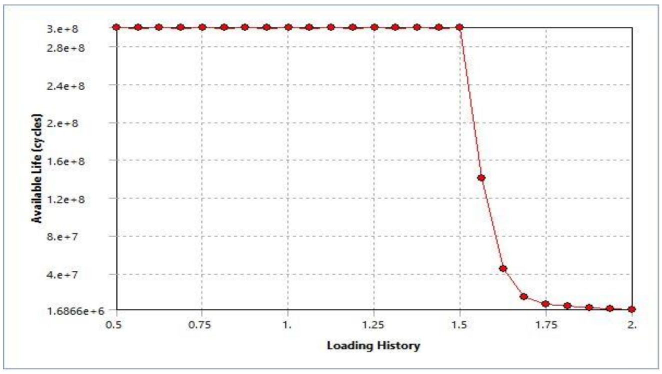

Fig-17 : S-N Curve of magnesium alloy wheel

4.2.4 Modal Analysis

The first six Mode Shapes of the existing wheel is shown in fig-18. The first mode shape is 446.1 Hz

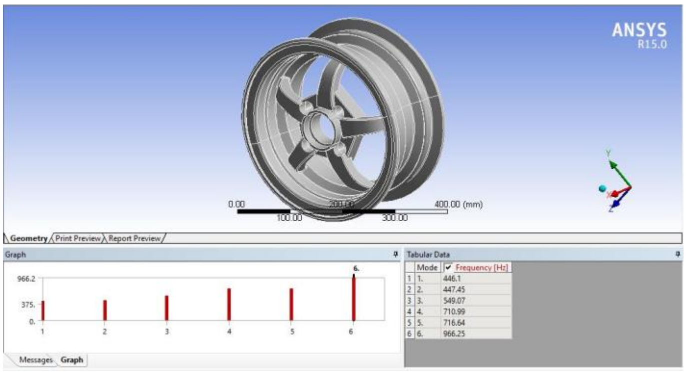

Fig-18 : Mode shapes of magnesium alloy wheel

5. Comparison of Results

In this report four wheel designs have been analyzed as above. With the intention to reduce the weight of the wheel. The comparison of the results for different analysis given below.

5.1 Comparison of Weight of The Wheel

Table-1 : Weights of the wheels

S.N.	Wheel model	Weight in Kg
1.	Existing Al alloy wheel	7.01
2	Modified Al alloy wheel with five spokes	6.48
3	Modified Al alloy wheel with four spokes	6.57
4	Magnesium alloy wheel	5.13

As said earlier the main intention of the project is to reduce the weight and the above table clearly states that Mg alloy wheel is comparatively very light weight.

5.2 Comparison of Static Analysis Results

The static analysis is done to study the stresses and deformation induced in the part. The stress induced should be within the yield strength of the material for the performance of the part without failure. The list of deformation and stresses developed in the wheels are listed below.

Table-2 : Static analysis results

S.N.	Wheel model	Deformation (mm)	Equivalent stress (MPa)
1.	Existing Al alloy wheel	0.15	114.79
2	Modified Al alloy wheel with five spokes	0.20	125.57
3	Modified Al alloy wheel with four spokes	0.21	141.85
4	Magnesium alloy wheel	0.21	105.12

The stresses induced in the Mg alloy wheels are less than the existing wheel although the deformation is more but because of the light weight of Mg wheel it will be a better choice.

5.3 Comparison of Fatigue Analysis Results

In fatigue analysis equivalent alternating stress and S-N curves of the wheels are compared for the selection. The cycles for fatigue analysis is taken from zero to load, as there will not be any tension in the wheel. As we have seen above from all the S-N curves of wheels, all wheels work over 10^5 cycles of life without failure for the working condition.

Table-3 : Fatigue analysis results

S.N.	Wheel model	Equivalent alternating stress (MPa)
1.	Existing Al alloy wheel	57.39
2	Modified Al alloy wheel with five spokes	62.78

3	Modified Al alloy wheel with four spokes	70.92
4	Magnesium alloy wheel	52.56

Here as well the stresses are less in Mg alloy wheel. Also as we have seen above S-N curve of Mg alloy wheel (Fig-17) is better than the S-N curve of existing Al alloy wheel (Fig-10).

5.4 Comparison of Modal Analysis Results

Table-4: Modal analysis results

S.N.	Wheel model	Natural Frequency (Hz) (First Mode Shape)
1.	Existing Al alloy wheel	461.61
2	Modified Al alloy wheel with five spokes	402.52
3	Modified Al alloy wheel with four spokes	409.93
4	Magnesium alloy wheel	446.10

As we have seen earlier the experimental and values obtained from the ANSYS analysis are very close with negligible error, so the other analysis results can be considered as actual values.

All of the three designs of the wheel can be accepted because all the designs have fundamental frequency greater than 350 Hz which is interior noise limit according to NVH standards. The natural frequency of the Mg alloy wheel is closer to the natural frequency of the existing wheel.

6. Conclusion

From the analysis done in the project, it can be concluded that the wheel made of magnesium alloy are better as compared to Al alloy wheels. As the stresses developed in the magnesium wheel are less as well as the S-N curve of Mg wheel is better under load condition. Although the deformation seen in magnesium wheel is slightly higher than that of Al wheel it can be neglected. Also the cost of production of Mg alloy wheel will be comparatively more than that of aluminum alloy wheel. But the weight reduction obtained by using magnesium alloy instead of Al alloy is almost 2 Kg per wheel. Which will reduce almost 8 Kg in a vehicle, which will provide better results as the weight reduction in the wheel is more effective than weight reduction in anywhere in the vehicle due to rotational moment of inertia effect during motion. Hence the Magnesium Alloy Wheel can be used as a replacement for Aluminum Alloy Wheel for better performance.

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