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DESIGN AND ANALYSIS OF WHEEL RIM WITH MAGNESIUM ALLOYS (ZK60A) BY USING SOLIDWORKS AND FINITE ELEMENT METHOD

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ABSTRACT

A wheel rim is a vital part of any automobile, which has to withstand to a high stress. The stress on rim may cause to bending and torsional loads. The design and manufacturing process of rim is important from point of view of long life, high stress withstanding capacity, need of reduction in weight and the material used. There is huge competition amongst the manufacturers due to these factors due to cost, performance, and weight. Due to this industries are always searching for components with lighter weight, low cost, and high strength, to increase performance. The lighter weight of the rim and wheels improves the handling, grip and results in reduction of overall mass of vehicle which again helps in less consumption of fuel. Nowadays cars have been using steel alloy for its wheel rim. On moving with advancements the magnesium alloy can be used for the wheel rim .In this part structural analysis of wheel rim with magnesium alloy is done and compared the results with steel alloy. As magnesium alloy (ZK60A) matches the target of lighter wheel and having many benefits compared to other metals, it can compete with exists.

KEYWORDS: Wheel rim, Aluminum alloy, Magnesium alloy, Material reduction, Solid works and Ansys.

INTRODUCTION

In this paper authors have tried to compare about rims of various materials. The selection of material used for rim is important as rim design plays a vital role in the performance of vehicle. The magnesium wheels were popular to use for racing vehicles during 1960s. Mag wheels were very rare and used for sports cars. These are similar to die-cast wheels made from any material. These composite wheels using alloys of aluminum to plastic find applications in bicycles, wheel chairs and skate boards. Magnesium has many problems to use, it is vulnerable to pitting, deterioration, cracking and it is also flammable, hence would start to break down in just a few months. Magnesium is used for flares and early flash lamps. Magnesium in bulk is hard to ignite but, once lit, is very hard to extinguish, being able to burn under water or in carbon dioxide, which are common extinguishing materials. Tires that caught fire could soon ignite the magnesium, creating difficulties for fire responders. Magnesium wheels required constant maintenance to keep polished. Alloys of magnesium were later developed to help alleviate some of the problems. Weight of the wheel plays a vital role in performance of vehicle.

Generally it is accepted worldwide that, for predicting performance benefits from sprung vs. un-sprung weight reduction is a factor of approximately 4:1. Hence the weight reduced from the vehicle improves its performance. For example, forged magnesium, large diameter wheels (20"-22") increase the weight advantage over aluminum by eliminating, on average, 70-75 lbs. un-sprung mass, which would provide the same acceleration time and braking distance benefit as eliminating 250-300 pounds from the vehicle engine, chassis or passenger compartment. Due to these lighter wheels, forged wheels are at least 20% lighter, sustaining equal loads with better characteristics, which is always easier on the car and its suspension. Light weight of wheel reduces the consumption of fuel.

WHEEL RIM DESCRIPTION

The rim of a wheel is the outer circular design of the metal on which the inside edge of the tire is mounted on vehicles such as automobiles. For example, in a four wheeler the rim is a hoop attached to the outer ends of the spokes-arm of the wheel that holds the tire and tube. A standard automotive steel wheel rim is made from a rectangular sheet metal. The metal plate is bent to produce a cylindrical sleeve with the two free edges of the sleeve welded together. At least one cylindrical flow spinning operation is carried out to obtain a given thickness profile of the sleeve in particular comprising in the zone intended to constitute the outer seat an angle of inclination relative to the axial direction. The sleeve is then shaped to obtain the rims on each side with a radially inner cylindrical wall in the zone of the outer seat and with a radially outer frusto-conical wall inclined at an angle corresponding to the standard inclination of the rim seats. The rim is then calibrated.

A disc is made by stamping a metal plate to support the cylindrical rim structure. It has to have appropriate holes for the center hub and lug nuts. The radial outer surface of the wheel disk has a cylindrical geometry to fit inside the rim. The rim and wheel disk are assembled by fitting together under the outer seat of the rim and the assembly welded together. Wheel rim is the part of automotive where it heavily undergoes both static loads as well as fatigue loads as wheel rim travels different road profile. It develops heavy stresses in rim so we have to find the critical stress point and we have to find for how many number cycle that the wheel rim is going to fail.

TYPES OF WHEEL RIM (MATERIAL)

Steel and light alloy are the main materials used in a wheel however some composite materials including glass-fiber are being used for special wheels as follows:
1. Wire Spoke Wheel
2. Steel Disc Wheel
3. Light Alloy Wheel
3.1 Aluminum Alloy Wheel
3.2 Magnesium Alloy Wheel
3.3 Titanium Alloy Wheel
3.4 Composite Material Wheel

MANUFACTURING METHOD OF WHEEL RIM

The steel disk wheel and the light alloy wheel are the most typical installation. The method of manufacturing the light alloy wheel, which has become popular in recent years, is explained here. The manufacturing method for the light alloy wheel is classified into two. They are cast metal or the forged manufacturing methods.
The aluminum alloy wheel is manufactured both ways, and the casting manufacturing method is used as for the magnesium alloy wheel. There are the following three methods of manufacturing the aluminum alloy wheel.

4.1 ONE PIECE RIM
This is a method of the casting or the forge at the same time by one as for the rim and disc.

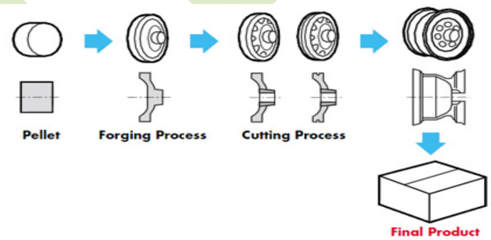

Figure 1: Forging method (one piece rim)

4.2 TWO PIECE RIM
This is the methods which separately manufacture the rim and disc similar to the manufacture of the steel wheel and these components are welded afterwards.

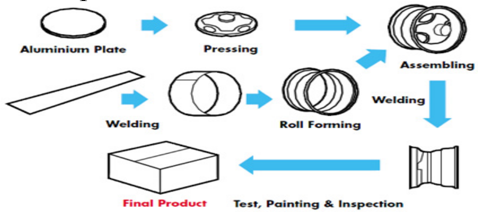

Figure 2: Forging method (two piece rim)

4.3 THREE PIECE RIM

This is a method to manufacture each flange separately, and combining later to the disc by welding.

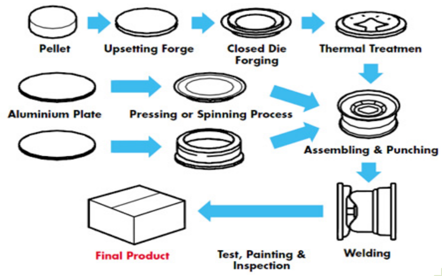

Figure 3: forging method (three piece rim)

4.4 CASTING METHOD

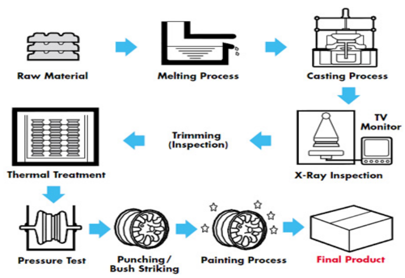

Figure 4: casting method

STUDY ON MATERIAL REDUCTION

As the automotive industry addresses environmental concerns, the problem of fuel consumption and weight reduction has come to the force.
Reducing the weight of automobiles is one of the primary means by which their fuel consumption is lowered. The two basic approaches are in automotive design and in materials selection, and they are closely related. Regarding materials, there has been a trend toward the use of light metals and their alloys in automotive components, particularly automotive bodies. The most commonly used materials are aluminum, magnesium, and their alloys, though some research has also been done on the use of titanium, zinc, and nonmetallic materials.
In order to find the relation between material reduction and mileage we used the data's in the consumer report. It provides curb weight in kilogram and mileage in km/lit. Curb weight is the base weight of the vehicle (i.e.) the weight of the vehicle without any external load.
Fuel economy is, of course, affected by many design factors besides curb weight. Some factors that can be examined are engine HP, transmission characteristics and aerodynamic design. Not all of these can be evaluated quantitatively. However, my study shows that as curb weight increases, fuel economy of the vehicle decreases. The graph of weight versus mileage shows a nice downward trend. There is much less scatter and I can develop a simple linear regression equation (using classical least squares fitting) relating curb weight to mileage.
However, considering the difficulties in testing and the large variations in engine, transmission and aerodynamic characteristics between vehicles, I decided to use a simpler method, and simply connected the extreme points by a straight line. The data point can then be shown to fall between the parallels with the equation $y = mx + c$ where the constants m is

the slope and c is y-intercept. We did an analysis with vehicle weight and fuel economy from the data obtained from the consumer report. Let us consider 10 different suv's from different manufacturers. The raw data is shown in table 1.

Table 1: Curb weight and mileage

Name	Curb weight(kg)	Mileage(km/l)
Santa fe	1920	14.66
Nissan x-trail	1618	15.1
Skoda yeti	1543	17.67
Ford Endeavour	2014	12.22
Xuv 500	1865	15.1
Safari	2040	13.2
Aria	2220	14.5
Scorpio	1850	14

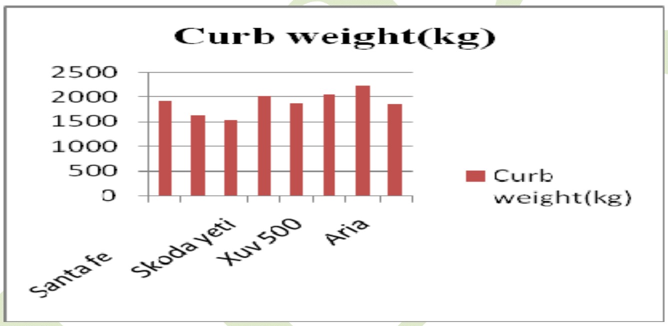

Figure 5: Comparison of Curb Weight in Vehicle

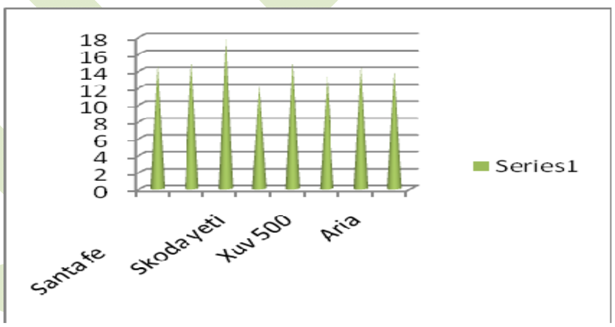

Figure 6: Comparison of Mileage in Vehicle

Here x-curb weight, y-mileage the five points do not fall on a perfect straight line. But, the x-y graph does show a nice downward trend with some scatter..From the graph1 using the straight line equation we can deduce the follow

$$y=mx+c$$

$$y=-0.01123x+25$$

The slope is negative which means fuel economy decreases as curb weight increases.
The reciprocal of the slope has the units of kilogram per km/lit and is equal to 156.25.

In other words, if the vehicle weight decreases by about 89.04 kg (or roughly 90kg), the fuel economy will increase by 1 kmpl.
The intercept c = 25 also has a special significance and represents the highest mpg conceivable if vehicle weight goes x goes to zero. In other words, to develop vehicles with fuel economies significantly greater than 25kmpl.

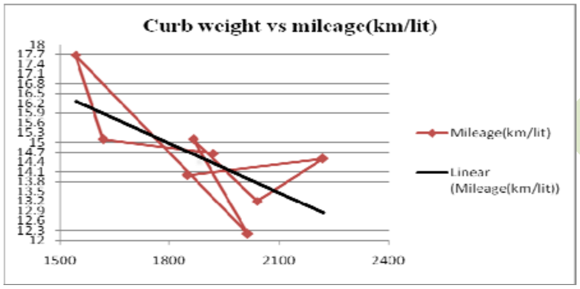

Figure 7: Comparison of Mileage Vs Curb Weight

I also analyzed the data for vehicles produced by a single manufacturer, e.g. Toyota. The data for 6 different vehicles were chosen from this list.

Table 2: Comparison of curb weight and mileage

Name	Curb weight(kg)	Mileage (km/l)
Fortuner	1955	14.66
Innova	1640	14.44
Qualis	1570	14
Prado	1900	11
Prius	1390	20.4
Land cruiser	2720	8

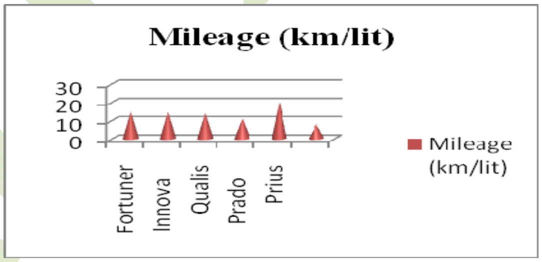

Figure 8: Comparison of Mileage in Vehicle

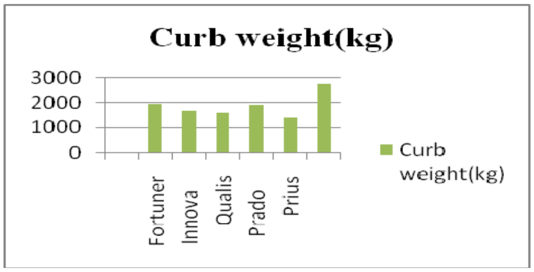

Figure 9: Comparison of Curb weight in Vehicle

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The x-y graph again reveals a nice downward trend with significant scatter. We can deduce the following linear regression equation.

$$y = mx + c$$

$$y = -0.02136x+82$$

The slope h = -0.02136 is higher and implies that for this manufacturer (Toyota), every 46kg reduction in vehicle weight will yield an improvement in fuel economy of 1kmpl. The intercept c = 51.03 is also higher.

The conclusion is that every 100kg reduction in weight will yield a fuel economy improvement of 2.17kmpl and the theoretical highest possible mpg is about 82 mpg, if we focus only on weight reduction.

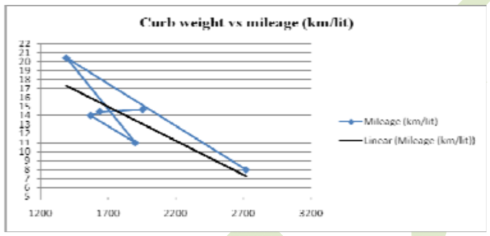

Figure 10: Comparison of Mileage Vs Curb Weight

ROLE OF MAGNESIUM IN MATERIAL REDUCTION

Let us assume that 100kg of steel components are replaced by magnesium, the volume occupied is found by using the formula

Density = mass/volume

For a steel

Density = 7800kg/m^3

Mass = 100kg

Therefore,

Volume= 12.82*10^-3

For magnesium

Density = 1800kg/m^3

Mass = Density x volume

Determined mass value is 23.07kg

From the above we can conclude that 100kg of steel components are

Replaced by of magnesium

Hence, the thumb rule based on the data is 100kg of steel equals nearly 23kg of magnesium.

6.1 UTILITY OF MAGNESIUM ALLOY

Considering its characteristics of low density, its extensive use in vehicles would obtain major reductions of weight and corresponding fuel savings. The data indicate that overall weight saving would lead to fuel saving without drastic change in design. Considering the large number of vehicles around, this weight saving could lead to a significant reduction of carbon dioxide released to the atmosphere, reducing the impact on global warming.

Our objective is to utilize the value of magnesium alloy in wheel rim for improving the effects. From a ride standpoint, the weight of the wheel has much to do with the ability of the suspension to control the tire/wheel motion over bumps. This is the "unsprung weight" issue that seems to come up frequently when talking about vehicle performance.

Unsprung weight is the weight of the vehicle that is not supported by the suspension. This includes the wheel tire, and brake components.

Since the suspension does not support this weight, it is not easily controlled when a bump or impact is incurred. The lighter the unsprung weight, the less affect it has on ride, and the easier it is for the shock and spring to work together to keep the tire in consistent contact with the road surface.

ZK60A is a wrought magnesium base alloy containing zinc and zirconium. Increased strength is obtained by artificial aging from the as-fabricated form. ZK60A-T5 has the best combination of strength and ductility at room-temperature of the wrought magnesium alloys.

6.2 CHEMICAL COMPOSITION

Zinc	4.8-6.2%
Zirconium	0.65%min
Magnesium	balance

6.3 PHYSICAL PROPERTIES

Table 3: Properties and values of ZK60A

Property	Value in metric units
Density	1.83*10e3
Modulus of elasticity	45pa
Thermal expansion	26.0*10e-6
Specific heat capacity	1000 j/(kg*k)
Thermal conductivity	120w/(m*k)
Electric resistivity	6.08*10-8 ohm*m
Tensile strength(F)	340 Mpa
Yield strength(F)	260 Mpa
Elongation(F)	11 %
Shear strength(F)	185 Mpa
Hardness(F)	75 HB (500)
Tensile strength(T5)	365 Mpa
Yield strength(T5)	305 Mpa
Elongation(T5)	11%
Shear strength(T5)	180 Mpa
Hardness(T5)	88 HP (500)
Annealing temperature	290C
Liquidus temperature	635C
Solidus temperature	520C

6.4 MACHINING

ZK60A, like all magnesium alloy forgings, machines faster than any other metal. Providing the geometry of the part allows, the limiting factor is the power and speed of the machine rather than the quality of the tool material. The power required per cubic centimeter of metal removed varies from 9 to 14 watts per minute depending on the operation.

6.5 SURFACE TREATMENT

All the normal chromating, anodizing, plating, and finishing treatments are readily applicable.

6.6 CORROSION RESISTANCE

ASTM B117 salt spray test
Corrosion rate 0.6 mg/ cm2 /day 50 mpy

6.7 APPLICATIONS

Forging in ZK60A find application in high strength parts for use primarily where the service temperature is below 150°C. ZK60A forgings can be used where pressure tightness or Machinability are required. Those parts are dimensionally stable during and after machining is also an important design consideration.
Forgings in ZK60A find application in high strength parts for satellites, helicopter gearboxes and rotor hubs, bicycle frames, road wheels, missile frames and interstate fairings, brake housings and landing gear struts.

MODELING OF WHEEL RIM

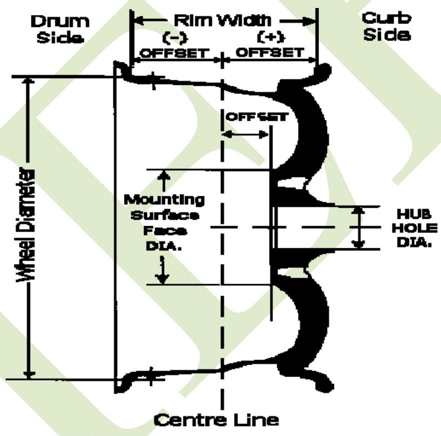

Figure 12: Wheel Rim Nomenclature

7.1 2D MODEL OF THE WHEEL RIM

Initially the 2D drawing of wheel rim is done by using SOLID WORKS according to dimensions specified in the Table 4.

Table 4: Dimensions of Material

S. No	Diameter	Dimensions (mm)
1	Outer	450
2	Hub hole	150
3	Bolt hole	20
4	Rim width	254

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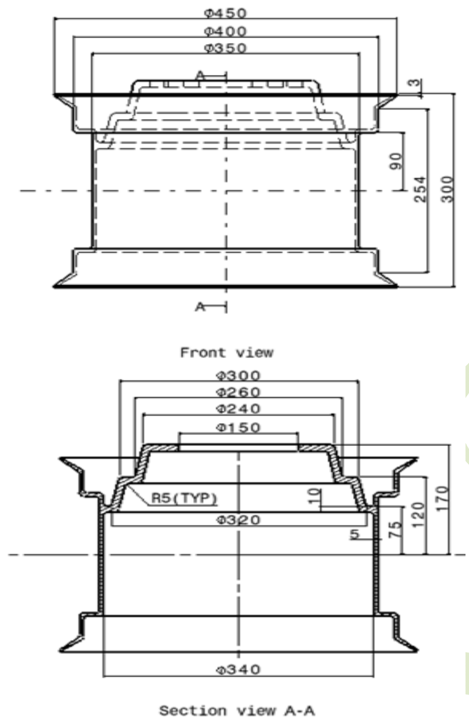


Figure 13: 2D Dimensions of Wheel

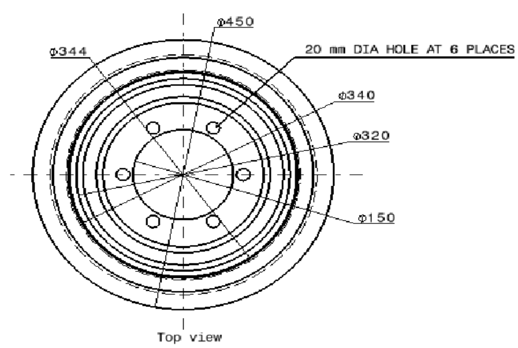


Figure 14: 2D drawing of wheel rim

Figure 15: 3D Model of Wheel Rim

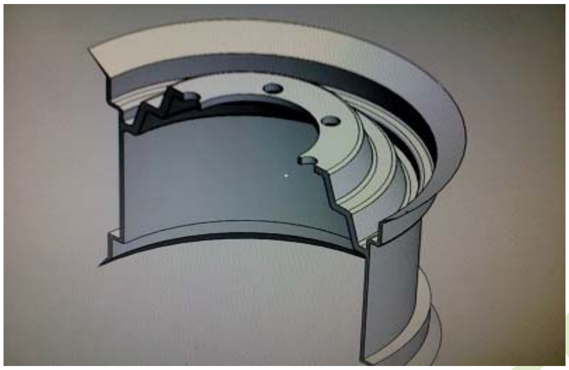


Figure 16: Cut sectional View

FINITE ELEMENT ANALYSIS

8.1 DESCRIPTION OF ELEMENT USED IN STATIC ANALYSIS IN ANSYS

The procedure for a model analysis consists of four main steps:

1. Build the model.
2. Apply loads and obtain the solution.
3. Expand the modes.
4. Review the results.

a. Importing the Model:

The finite element meshed model (.hm file format) of wheel rim is imported from Hyper Mesh Software to **ANSYS** Software.

- Centrifugal force, $F=mr\omega^2$ N
- ω =2*(22/7)*N/60 rad/s
- M=4 kg
- For N=600 rpm
- ω =62.8 rps

By substituting, we get centrifugal force=3.54 kN which acts at each node of the circumference of the rim

For mg alloy

- Centrifugal force, $F=mr\omega^2$ N
- ω =2*(22/7)*N/60 rad/s
- M=1 kg
- For N=600 rpm
- ω =62.8 rps

By substituting, we get centrifugal force=0.819kN which acts at each node of the circumference of the rim.

b. Boundary conditions and Loading:

To get compressive and tensile stress, a load of 21.3kN is applied on the bolt holes of the wheel rim.

- Displacements
  a. Translation in x, y, z directions is zero.
  b. Rotation in x, y, z direction is zero.
- Angular velocity in X direction is zero,
  Y direction is 62.8 rps,
  Z direction is zero.

- These conditions are applied on the six holes provided on the rim.

In the same way, Centrifugal force is also applied in the loading condition on the holes. Analyzed picture of the wheel rim with the steel alloy and magnesium alloy is listed in APPENDIX 1 and APPENDIX 2.

RESULTS AND DISCUSSIONS

9.1 MATERIAL PROPERTIES

- **Steel alloy:**

Young's modulus (E) =$2.34*10^5$ N/mm^2

Yield stress (σ_{yield}) =240 N/mm^2

Density ρ =7800kg/m^3

- **Magnesium alloy:**

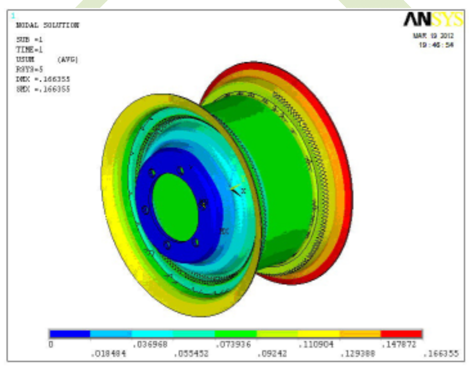
Young's modulus (E) =45000N/mm^2

Yield stress (σ_{yield}) =130 N/mm^2

Density ρ =1800kg/m^3

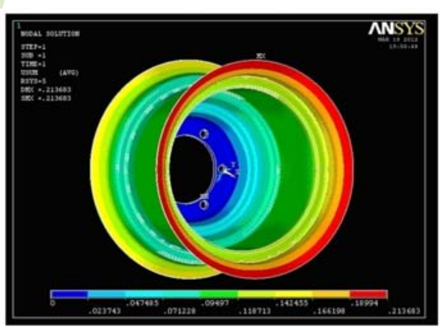
9.2 APPENDIX I (DISPLACEMENT)

9.2.1 Steel alloy



Displacement=0.166 mm

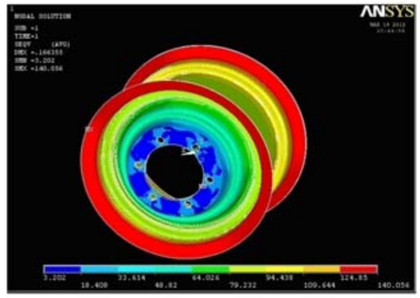
9.2.2 Magnesium (mg) alloy.



Displacement=0.21mm

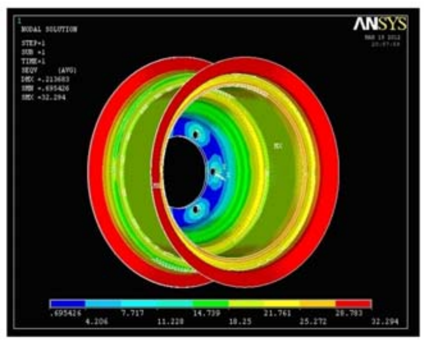
9.3 APPENDIX II (VONMISES STRESS)

9.3.1 (Steel alloy)



Max vonmises stress=140.056 Mpa
Min vonmises stress=3.202 Mpa

9.3.2 Magnesium (mg) alloy



Max vonmises stress=32.294 Mpa
Min vonmises stress=0.6954 Mpa

9.4 RESULTS OBTAINED FROM SOFTWARE:

Steel alloy:-

Displacement = 0.166mm

Von misses stress (σ_V) =140.056 N/mm^2

Magnesium alloy:-

Displacement = 0.21mm

Von misses stress (σ_V) =32.204 N/mm^2

CONCLUSION

1. Stress developed in the steel alloy is 140.056Mpa which is below the yield stress of the material.
2. Stress developed in the magnesium alloy is 32.294Mpa which is below the yield stress of the material.
3. Comparatively stress developed in the magnesium alloy is lower than the stress developed in steel alloy. By using magnesium alloy the unsprung mass of the vehicle is reduced which improves the vehicle performance.

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