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ANALYSIS OF ALLOY WHEEL RIM STYLING STRUCTURE USING ALUMINIUM AND MAGNESIUM ALLOYS

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Abstract - *The wheel rim designed must be durable enough to withstand rough loads, harsh environments and must meet both the styling appearance and engineering functions. The present work gives a brief compilation of research related to analysis of equivalent maximum stresses in passenger car wheel rim by operating various loading conditions like radial, bending and impact loads. The design and analysis of the wheel rim is done based on Design for Manufacturing methodology. A new CAD model of the wheel rim is prepared for the passenger car wheel rim of 17 inch diameter according to TRA standards in CATIA V5. The 3D model of the wheel rim is imported to NX Nastran for analysis and for solving, finite element technique is used. The analysis is done by simulating the model, using Static structural analysis on aluminium and magnesium alloy materials respectively. Finally relative performance characteristics are reported, based on maximum equivalent stresses and the optimal material for usage is selected for the wheel rim, in order to increase the fatigue strength and service life along with optimal fuel consumption for the vehicle.*

Key Words: Alloy Wheel, NX Nastran, Static Structural Analysis, Cornering Fatigue Test, Radial Fatigue Test, Wheel Impact Test, Design for Manufacturing.

1. INTRODUCTION

An automobile is a combination of various parts like engine, transmission, body, suspension system, wheels etc,. Wheels are critical components and are of primary importance for human safety. Wheel is generally composed of rim and tire assembly. Alloy wheels are wheels which are mostly made of aluminium or magnesium alloys. Though other materials like composites, titanium and steel alloys come under this category. The alloy wheel is prominently used due to its lighter in weight, more strength, excellent corrosive resistance, better heat dissipation and stylish appearance. Mostly, the alloy wheels are manufactured by low pressure die casting process.

In general, design of the wheel is done by first modelling the wheel rim and then subjected to various structural analysis. The modelling and analysis is done by using various reliable software which had an ease in solving the component. Finite element methods are mostly used to evaluate the performance of the wheel rim. Based on the studies on material selection of wheel rim, it is observed that the materials that are mostly used are alloys of steel, aluminium, magnesium titanium and composites [1,2,3]. But there is no common solution to say which material is the best for the automobile wheel rim. Though it is due to changes in design structures, manufacturing ease but the main reason is due to volatility in tests. Alloy wheels for use on passenger cars has to pass three tests namely Dynamic Cornering Fatigue Test, Dynamic Radial Fatigue Test and Impact Test before going into the production [4]. The different types of alloy wheels are,

Steel Alloy: It has an excellent feature of high fatigue strength, and can withstand maximum number of cyclic loads. But the main reason for not using this alloy wheel is due to its heavy weight, fuel consumption is more.

Aluminium Alloy: It has features of excellent lightness, thermal conductivity, physical characteristics of casting, low heat, machine processing and re-utilization etc,. This alloy wheel is mostly used due to its main advantages of decreased weight, high precision and design choices of the wheel.

Magnesium Alloy: It has all the features similar to aluminium alloy and additionally, it has superior size stability and impact resistance, but is somewhat costlier than aluminium alloy. However, its use is mainly restricted to racing, which needs the features of weightlessness and high strength.

Titanium alloy: It is an admirable metal for corrosion resistance and the strength is about 2.5 times more compared to aluminium alloy. But the main reason for not using this alloy is due to its inferior machine processing, designing and more costlier.

Composite material: It is different from other alloy wheels, it is developed mainly for low weight. But the main reason for not using this type of wheel is due to its inadequate consistency against heat, best strength and lack of knowledge related to processing and recycling method to be used.

2. MATERIALS AND METHODS

2.1 Aluminium alloy

Aluminium is a chemical element with the symbol 'Al'. Aluminium is the ideal light-weight material as it allows mass saving of up to 50% over competing materials in most applications without compromising safety. [5]. Aluminium alloys are either cast or wrought alloys and can be categorized into a number of groups based on particular materials' characteristics, such as its ability to respond to thermal and mechanical treatment and the primary alloying element added to the aluminium alloy.

A356-T6 aluminium alloy: The primary alloying element is silicon plus copper and/or magnesium. Alloy A356 has greater elongation, higher strength and considerably higher ductility than alloy 356 because of low iron content in it. This A356 aluminum casting alloy has good cast-ability, this makes it a logical choice for intricate and complex castings.

The advantages of using aluminium alloy A356 are mainly due to its properties of, strength to weight ratio, ductility and durability, hardness, fatigue strength, pressure tightness, corrosion resistance, easy to machine, recycle and re-usability.

2.2 Magnesium alloys

Magnesium is a chemical element with the symbol 'Mg'. Magnesium alloys significantly contribute to greater fuel economy and environmental conservation. Magnesium alloy results in a 22 to 70% weight reduction in compared to alternative materials [6]. The physical properties of the alloys change based on their chemical compositions. Magnesium alloys are defined based on codes in ASTM (American Society for Testing and Materials).

AZ91 Magnesium alloy: The primary alloying elements is of aluminium (9%) and zinc (1%). AZ91 dominates as a production route of magnesium alloy and large number of parts are cast due to its high productivity, high precision and high quality surface. In this AZ91, aluminium improves strength, hardness and ductility, facilitating the alloy's casting process while zinc increases room-temperature strength, fluidity in casting, and corrosion resistance.

The advantages of using AZ91 magnesium alloy are mainly due to its properties of, strength to weight ratio, damping capacity, dimensional stability, electromagnetic shielding, anti-galling, corrosion resistance, recycle and re-usability.

Table-1: Material properties of Al and Mg alloys

S.No	Material Property	A356	AZ91
1	Elastic Modulus (GPa)	72	45
2	Density (kg/m3)	2670	1800
3	Poisson ratio	0.33	0.35
4	Yield Strength (MPa)	186	169
5	Ultimate Tensile Strength(MPa)	262	240

2.3 Methodology: Design for Manufacturing (DFM)

Design for Manufacturing is an engineering practice of designing products in such a way that, they are easy to manufacture, reduce manufacturing costs, potential problems fixed in design phase. In the present work, for deign of wheel rim there are three phases used. The phases in DFM for the wheel rim are listed below.

Design for Form: The shape, size, dimensions or other parameters which characterize the physical look of the item.

- No sharp edges, that is the edges are removed by applying fillet at the corners.
- Wheel rim profile drawn following the standards (TRA, ETRTO, JIS), in the present study the TRA(Tire and Rim Association) standards are being used.
- A minimum of 7° draft angle is to be maintained for casting ease.
- Thickness of spoke should be more than 12mm.

Design for Fit: The parameters and ability which make it appropriate for integration with other components within an assembly including its tolerances.

- Wheel fitment with the tire.
- Providing fitment for brake calliper
- Required hole for mounting flange to fit.
- Provision for wheel balancing (sticking, clip set)
- Spacing's in the wheel rim for wrenches, bolts, nuts etc,.

Design for Function: The operation of the item or the actions it is intended to perform.

- Cornering fatigue test (CFT).
- Radial fatigue test (RFT).
- Wheel Impact test (13°).

Cornering Fatigue Test: The cornering fatigue test is one of the traditional durability tests of prototype verification. The test procedure for cornering fatigue performed in accordance with SAE (Society of Automotive Engineers) standards. The dynamic CFT simulates the loading condition of wheel in normal driving mode, the test machine shall have a driven rotatable device whereby wheel rotates under the influence of stationary bending moment and is subjected to rotating bending moments [7].

Radial Fatigue Test: The radial fatigue test is one of the traditional durability tests of prototype verification. Wheel radial fatigue tests were performed in accordance with SAE (Society of Automotive Engineers) standards. The dynamic RFT is equipped with a driven rotatable drum parallel to the axis of test wheel, this load constantly compresses the wheel radially [8].

Wheel Impact Test: The wheel impact test establishes minimum performance requirements and evaluates axial (lateral) curb impact collision properties of all wheels intended for use on passenger cars. The Impact Loading Machine and the wheel hub mount are designed as per the SAE (Society of Automotive Engineers) specifications. The wheel tire assembly is mounted at an angle of 13^0 to the horizontal plane, so that the striker impacts the outer bead radius at the rim near the air valve hole. [9].

3. RESULTS AND DISCUSSION

3.1 Design of Wheel Rim

The CAD model of the wheel rim is prepared for the passenger car wheel. For a passenger car wheel rim, 17 inch diameter rim, 7.5 inch rim width, J type of flange and the rim of 5^0 drop centre rim contours are taken as specified in the TRA. Iterations are made for the spoke profile by roughly drawing the spoke pattern and changing the number of spokes. By taking rim diameter and rim width the offset, centre bore and bolt pattern can be chosen based on DFM in CATIA V5.

Table-2: Specifications of Wheel Rim

S.No	Wheel Specification	Value
1	Rim Diameter	17 inch
2	Rim Width	7.5 inch
3	Offset	45 mm
4	Pitch Circle Diameter	120 (16*6) mm
5	Centre Bore Diameter	60 mm
6	No. of Spokes	6

The different steps that followed for a new wheel rim design are as follows,

1. Drawing rim profile
2. Drawing spoke profile
3. Drawing lug nut hole
4. Drawing mounting flange hole
5. Edge Filling
6. Review the Wheel Rim design

During this design of styling concept of the wheel rim, a great importance is given while drawing the chamfer edges, draft angles and fillet radius to minimize stresses due to fatigue loading for satisfying the design for form, in addition the lug nut holes, mounting flange holes are drawn for satisfying the design for fit. The final view of the wheel rim design in CATIA V5 is shown in fig-1. Finally the design is saved in IGES file format.

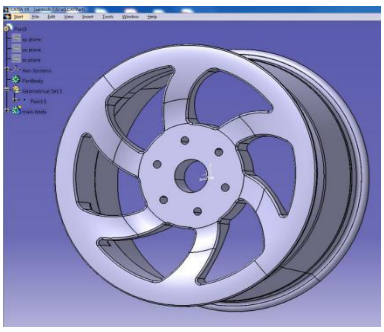

Figure-1: Final 3 D view of wheel Rim

3.2 Analysis of Wheel Rim

Analysis of the wheel rim is done by, simulating the designed wheel rim based on static structural analysis using finite element analysis technique to validate the results in NX Nastran software.

The analysis of the wheel rim is done following the these steps mentioned below,

1) **Pre-processing:** It is the initial stage of simulation which include checking the geometry, assigning material, meshing the model and applying boundary conditions.

2) **Processing:** It is simply the solution finding stage, here the different structural analysis (CFT, RFT, Wheel Impact test) are performed by applying the different loads on the model.

3) **Post-processing:** This is the final stage of simulation where the results are obtained for the model. Based on the results critical stress points are noted down and finally validate the model.

Simulation for Cornering Fatigue Test

The 3D model of the wheel rim along with a shaft is imported to NX Nastran, and for solving FEM is used. The Wheel rim and shaft assembly is made properly with the materials selected for wheel rim as Aluminium alloy/ Magnesium alloy and for shaft as Structural steel.

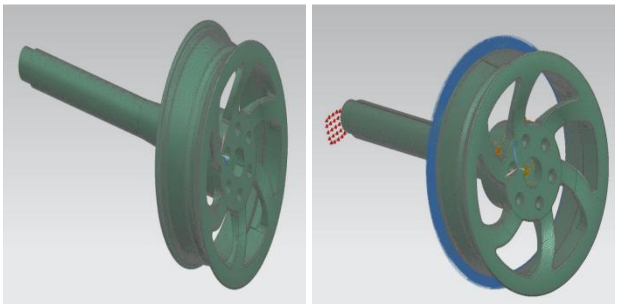

Figure-2 : a) CFT meshed model, b) CFT meshed model with loading & boundary conditions

The model is meshed by using a tetrahedral mesh of type CTETRA 10, as shown in fig-2(a). By making use of mesh command the size of the mesh is controlled. The inner flange surface is constrained in all six degrees of freedom. A vertical load of 3882 N on the free end of the shaft is applied, as shown in fig-2(b). Finally for each component, assigned material specifications, boundary conditions, load applied, 3D mesh geometry are checked properly according to the cornering fatigue test simulation procedure, and run the analysis.

Simulation for Radial Fatigue Test

The 3D model of the wheel rim along with a tire and slab is imported to NX Nastran, and for solving FEM is used. The Wheel rim, tire and slab assembly is made properly with the materials selected for wheel rim as Aluminium alloy/

Magnesium alloy, slab as structural steel, and for tire as polyethylene.

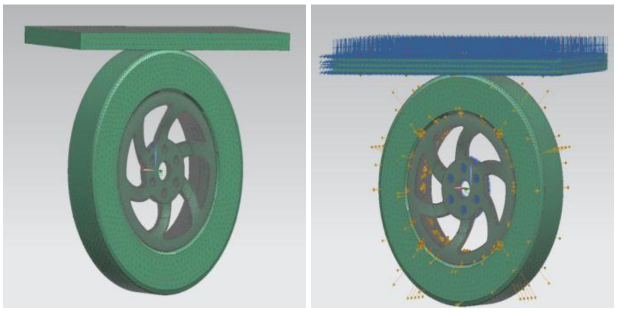

Figure-3 : a) RFT meshed model, b) RFT meshed model with loading & boundary conditions

The model is meshed by using a tetrahedral mesh of type CTETRA 10, as shown in fig-3(a). By making use of mesh command the size of the mesh is controlled. The lug holes and mounting flange surface is constrained in all six degrees of freedom. A radial load of 17805 N on the slab towards the wheel rim and tire is applied, as shown in fig-3(b). Finally for each component, assigned material specifications, boundary conditions, load applied, 3D mesh geometry are checked properly according to radial fatigue test simulation procedure, and run the analysis.

Simulation for Wheel Impact Test

The 3D model of the wheel rim along with a slab is imported to NX Nastran and for solving FEM is used. The Wheel rim and slab assembly is made properly with the materials selected for slab as structural and wheel rim as Aluminium alloy/ Magnesium alloy.

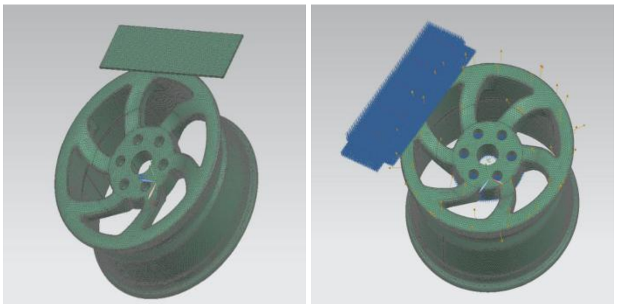

Figure-4 : a) Impact test meshed model, b) Impact test meshed model with loading & boundary conditions

The model is meshed by using a tetrahedral mesh of type CTETRA 10, as shown in fig-2(a). By making use of mesh command the size of the mesh is controlled. The lug holes and mounting flange surface is constrained in all degrees of freedom. An impact load of 6033 N on the slab at an incline of 13° to horizontal direction is applied, as shown in fig-4(b). Finally for each component, assigned material specifications, boundary conditions, load applied, 3D mesh geometry are checked properly according to the wheel impact test procedure, and run the analysis.

3.3 Test results under Cornering Fatigue Test

For the cornering bending load of 3882 N is applied on the free end of the shaft, the maximum equivalent stress value obtained for aluminium alloy of grade A356-T6 is 94.20 N/mm^2, as shown in fig-5(a) and magnesium alloy of grade AZ91 is 114.60 N/mm^2, as shown in fig-5(b). The maximum stress value is obtained at the hub and spoke joining area on the front face of the wheel.

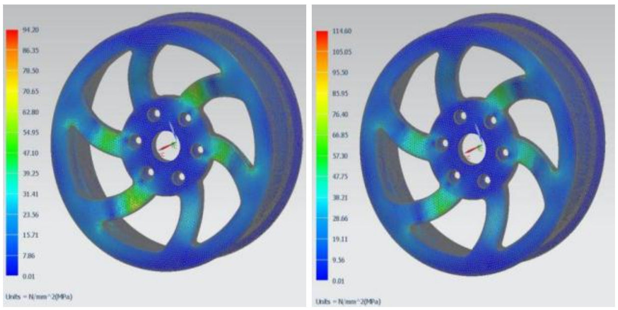

Figure-5 : a) Al wheel rim results under CFT, b) Mg wheel rim results under CFT

3.4 Test results under Radial Fatigue Test

For the radial load of 17805N applied on the slab towards the wheel rim and tire, the maximum equivalent stress value obtained for aluminium alloy of grade A356-T6 is 73.00 N/mm^2, as shown in fig-6(a) and magnesium alloy of grade AZ91 is 92.80 N/mm^2, as shown in fig-6(b). The maximum stress value is obtained at the ends of the spoke connecting to mounting face.

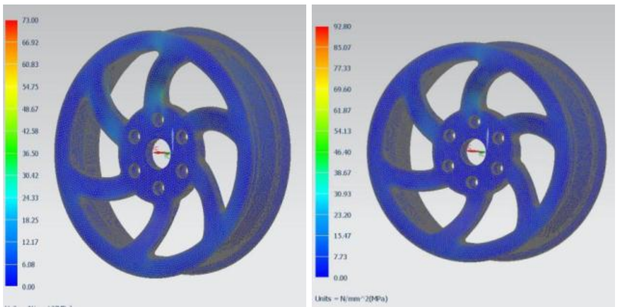

Figure-6 : a) Al wheel rim results under RFT, b) Mg wheel rim results under RFT

3.5 Test results under Wheel Impact Test

For the impact load of 6033N applied on the slab at an incline of 13° to horizontal direction, the maximum equivalent stress value obtained for aluminium alloy is 1009.02 N/mm^2 and magnesium alloy is 1106.00 N/mm^2 respectively. The maximum stress value is obtained at the flange part on the front surface of the wheel rim. The maximum stress obtained under wheel impact test is not considered, as we don't consider the hit area of the wheel rim, as this is a sudden load applied. The maximum stress obtained nearby bolt hole on the front surface of the wheel rim is 504.53 N/mm^2 for aluminium alloy of grade A356-T6, as shown in fig-7(a) and 553.02 N/mm^2 for magnesium of grade AZ91 alloy, as shown in fig-7(b) respectively.

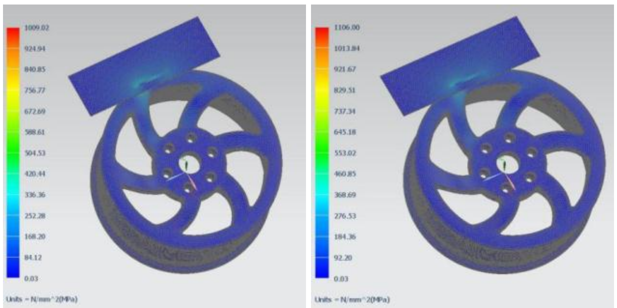

Figure-7 : a) Al wheel rim results under Impact test, b) Mg wheel rim results under Impact test

4. CONCLUSIONS

The following are the conclusions for the results obtained for the present work,

1) The maximum equivalent stresses obtained in cornering fatigue test are 94.1 MPa for aluminium alloy and 114.61 MPa for magnesium alloy. The maximum stress obtained for aluminium alloy is within the limits, but for magnesium alloy it exceeds the yield strength (with safety limits) of the material, during simulation under cornering fatigue test.

2) The maximum equivalent stresses obtained in radial fatigue test are 73 MPa for aluminium alloy and 92.91 MPa for magnesium alloy. The maximum stresses obtained for both the materials, during simulation under radial fatigue test are within the limits.

3) The maximum stresses obtained nearby bolt hole on the front surface of wheel rim, in wheel impact test are 504.53 MPa for aluminium alloy and 553.02 MPa for magnesium alloy. For wheel impact test the maximum stress indicate that both the materials can withstand impact loads, not exceeding 560 MPa which is standardized by the wheel manufacturers.

The maximum stress obtained for Aluminum alloy is lower compared to Magnesium alloy in the above three functionality test performed viz,. Cornering Fatigue Test, Radial Fatigue Test and Wheel Impact tests.

This indicate that aluminium alloy is more durable, improve the fatigue strength and service life along with optimal fuel consumption of wheel rim (based on CFT, RFT results) and can better absorb shock loads (based on Wheel impact test results), in addition to these using aluminium alloy is better corrosion resistant and less flammable when compared to magnesium alloys. Hence, selecting the Aluminium alloy of grade A356-T6 is more efficient than selecting the Magnesium alloy of grade AZ91, for an alloy wheel rim of 17 inches in diameter for passenger car.

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