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Modeling and Structural Analysis of Alloy Wheel Using COSMOS

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ABSTRACT

Wheel spokes are the supports consisting of a radial member of a wheel joining the hub to the rim with Carbon Fiber, Magnesium Alloy, Titanium Alloy and Aluminum Alloy. The two main types of motorcycle rims are solid wheels, in which case the rim and spokes are all cast as one unit, usually in Aluminum or magnesium alloys and the other spoke wheels, where the motorcycle rims are laced with spokes which require high spoke tension, since the load is carried by fewer spokes. If a spoke does break, the wheel generally becomes instantly un-ridable also the hub may break. Presently, for high cc bikes Magnesium wheels are used, due to its low heat resistance and micronisation of crystal grains, replacing it with Aluminum alloy. This Simulation work attempts to model the wheel of a two wheeler racing by using the Pro/Engineer Software, and conducting the tests: Static and Fatigue analysis using the Cosmos (Solid Simulation Work) software by reducing the number of spokes from 5 to 4 for the existing model. Based on simulation work, a better material for alloy wheels may be analyzed from the results obtained and validated.

Key words: Alloy Wheel, COSMOS, Static and Fatigue analysis

INTRODUCTION

A wheel is a circular device that is capable of rotating on its axis, facilitating movement or transportation while supporting a load (mass), or performing labour in machines. Safety and economy are particularly of major concerns when designing a mechanical structure so that the people could use them safely and economically. Style, weight, manufacturability and performance are the four major technical issues related to the design of a new wheel and/or its optimization mainly for Aluminum wheels according to governmental regulations and industry standards [1-3]. In the real service conditions, the determination of mechanical behaviour of the wheel is important, but the testing and inspection of the wheels during their development process is time consuming and costly. For economic reasons, it is important to reduce the time spent during the development and testing phase of a new wheel. Finite element analysis (FEA) was carried out by simulating the test conditions to analyze the stress distribution and fatigue life of alloy wheels. The analytical results using FEA to predict the wheel fatigue life agreed well with the experimental results [4]. A mathematical model was developed to predict the residual stress distribution of an A356 alloy wheel, taking into account the residual stress evolution during the T6 quench process and redistribution of residual stress due to the material removal at the machining stage. The fatigue life of an A356 wheel was predicted by integrating the residual stress into the in-service loading and wheel casting defects (pores). The residual stress showed a moderate influence on the fatigue life of the wheel, which was more sensitive to casting pore size and service stress due to applied loads [6]. By improved Smith formula, finite element analysis of stress values as the basic parameters for wheel fatigue life prediction [5]. ABAQUS software to build the static load finite element model of Aluminum wheels for simulating the rotary fatigue test [7]. The equivalent stress amplitude was calculated based on the nominal stress method by considering the effects of mean load, size, fatigue notch, surface finish and scatter factors. The fatigue life of Aluminum wheels was predicted by using the equivalent stress amplitude and Aluminum alloy wheel S-N curve. The results from the Aluminum wheel rotary fatigue bench test showed that the baseline wheel failed the test and its crack initiation was around the hub bolt hole area that agreed with the simulation. Using the method proposed in this paper, the wheel life cycle was improved to over 1.0×10^5 and satisfied the design requirement. A mathematical model was developed to predict the residual stress distribution of an A356 alloy rim, taking into account the residual stress evolution during the T6 quench process [9]. Static and fatigue analysis of Aluminum alloy wheel A356 by finite element idealization modal using the 10 node tetrahedron solid element in static condition and the wheel was designed using CATIA [8], total deformation, alternative stress and shear stress is simulated by using FEA software.

This paper starts by modelling of the alloy wheel in a two-wheeler racing bike using the Pro/Engineer Software for five different materials viz. LM 25, LM25TB7, LM 25TE, LM25TF and AM60A and conducting the tests: Static and Fatigue analysis using the Cosmos software by reducing the number of spokes from 5 to 4 for the existing model. Based on simulation work, a better material for alloy wheels may be analyzed from the results obtained and validated.

MODELING IN PRO-E

Pro/ENGINEER Wildfire is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design while ensuring compliance with industry and company standards. Figure 1 shows the sketch of alloy wheel.

Cosmos Works

Cosmos works is useful software for design analysis in mechanical engineering. COSMOS Works is a design analysis automation application fully integrated with Solid Works. This software uses the Finite Element Method (FEM) to simulate the working conditions of your designs and predict their behaviour. FEM requires the solution of large systems of equations. Powered by fast solvers, COSMOS Works makes it possible for designers to quickly check the integrity of their designs and search for the optimum solution. A product development cycle typically includes the following steps:

- Build your model in the Solid Works CAD system.
- Prototype the design.
- Test the prototype in the field.
- Evaluate the results of the field tests.
- Modify the design based on the field test results.

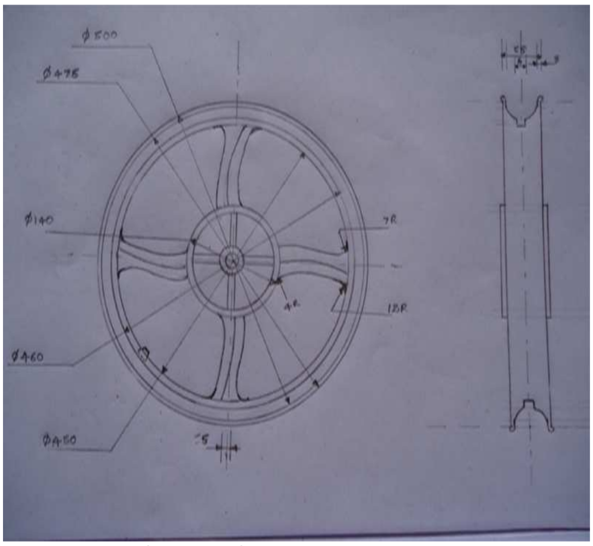


Fig. 1 Specifications of the Alloy Wheel with Dimensions

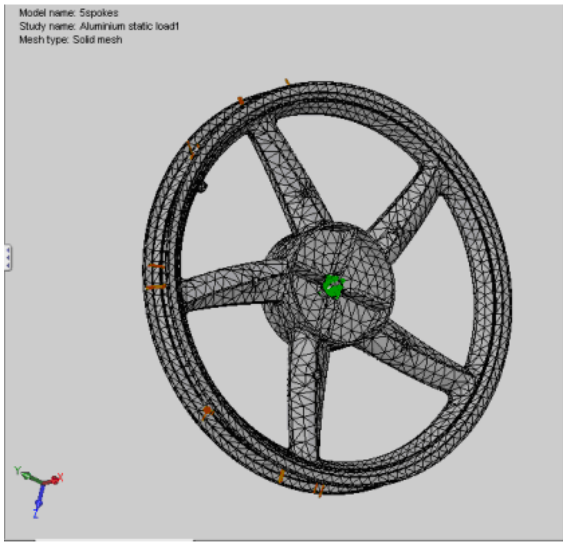


Fig.2 Meshing the Part model

Solid-Works Simulation Type of analysis Static Analysis and Fatigue Analysis

Calculations for Applied Loads

Load 1= weight of Bike (168 kg); Load 2= (168+50) kg; Load 3= (168+100) kg and Load 4= (168+150) kg

Analysis for strength needed

Mass of Bike, Dead Weight of Bike	= 148 Kg
Other Loads	= 20 Kg
Total Gross Weight	= 148 + 20 = 168 Kg = 1648.08 N
Tires and Suspension system reduced by 30% of Loads	
W_{net}	= 1648.08 * 0.7 = 1153.656 N
Reaction Forces On Bike F_T	= 1153.656
Number of Wheels N	= 2
Reaction Force on Each Wheel F_T	=576.828 N
Number of spokes N	= 5
Stress on the each Rim F_T/ Area	= 0.011945 N/mm^2
Area of rim at stressed parts	= 48287.08 mm^2
Stress on the each rim for load1	= 0.011945 N/mm^2

Table- 1 Material Properties

Property	Aluminum Alloy LM 25	Magnesium Alloy AM60A
Yield strength	235 N/mm^2	130 N/mm^2
Elastic modulus	71000 N/mm^2	45000 N/mm^2
Poisson's ratio	0.33	0.35
Mass density	2.685gm/CC	1.8 gm/CC

For Different Loads Stress on Each Rim -

With Load2 on Bike (168+50) Kg

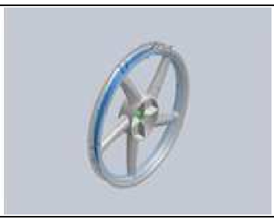
Total Gross Weight = 218 * 9.81 = 2138.58 N
Tires and Suspension system reduced by 30% of Loads
W_{net} = 2138.58 * 0.7 = 1498.006 N
Reaction Forces On Bike F_T = 1498.006
Number of Wheels N = 2
Reaction Force on Each Wheel F_T =748.503 N
Number of spokes N = 5
Stress on the each Rim F_T/ Area = 0.015501 N/mm^2
Area of rim at stressed parts = 48287.08 mm^2
Stress on the each rim for load2 = 0.015501 N/mm^2

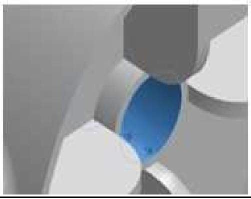
With Load3 on Bike (168+100) Kg

Total Gross Weight = 268 * 9.81 = 2629.08 N
Tires and Suspension system reduced by 30% of Loads
W_{net} = 2629.08 * 0.7 = 1840.356 N
Reaction Forces On Bike F_T = 1840.356 N
Number of Wheels N = 2
Reaction Force on Each Wheel F_T = 920.178 N
Number of spokes N = 5
Stress on the each Rim F_T/ Area = 0.019050 N/mm^2
Area of rim at stressed parts = 48287.08 mm^2
Stress on the each rim for load3 = 0.019050 N/mm^2
Similarly Load4 Stresses induced on each Rim is
Stress on the rim for load4 = 0.022611 N/mm^2
Figure 2 shows the importing of Alloy Wheel with meshing

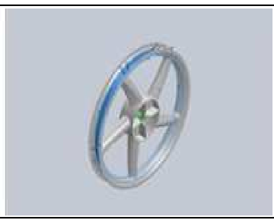
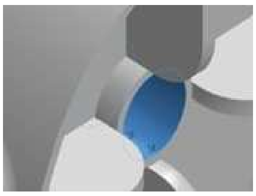
RESULTS

Static and Fatigue analysis for 5-spokes Aluminum alloy wheel

Material Properties		
Model Reference	Properties	Components
	Name: Aluminum Alloy Wheel	Solid Body1 (Imported 1) (5 Spokes)
	Model Type: Liner Elastic Isotropic	
	Default Failure: Max Von Mises Stress	
	Yield Strength: 2.35e+008 N/m^2	
	Tensile Strength: 3e+007 N/m^2	
	Elastic Modules: 7.1e+010 N/m^2	
	Poisson's Ratio: 0.33	
	Mass Density: 2.685e-006 Kg/m^3	
	Shear Stress: 3.189e+008 N/m^2	
Load and Fixtures		
Load Image	Load Name	Load Details
	Pressure 1	Entities: 3Face(s) Type: Normal to selected face Value: 0.011945 Units: N/m^2(MPa)

Fixtures Image	Fixtures Name	Fixtures Details
	Fixed 1	Entities: 1Face(s) Type: Fixed Geometry
Mesh report	Total Nodes: 41528	Total Elements: 21498

Static and Fatigue analysis for 4-spokes Magnesium alloy wheel

Material Properties		
Model Reference	Properties	Components
	Name: Magnesium Alloy Wheel	Solid Body1 (Imported 1) (4 Spokes)
	Model Type: Liner Elastic Isotropic	
	Default Failure: Max Von Mises Stress	
	Yield Strength: 1.3e+008 N/m^2	
	Tensile Strength: 3e+007 N/m^2	
	Elastic Modules: 4.5e+010 N/m^2	
	Poisson's Ratio: 0.35	
	Mass Density: 1.85e-006 Kg/m^3	
	Shear Stress: 3.189e+008 N/m^2	
Load and Fixtures		
Load Image	Load Name	Load Details
	Pressure 1	Entities: 3Face(s) Type: Normal to selected face Value: 0.011945 Units: N/m^2(MPa)
Fixtures Image	Fixtures Name	Fixtures Details
	Fixed 1	Entities: 1Face(s) Type: Fixed Geometry
Mesh report	Total Nodes: 39450	Total Elements: 20063

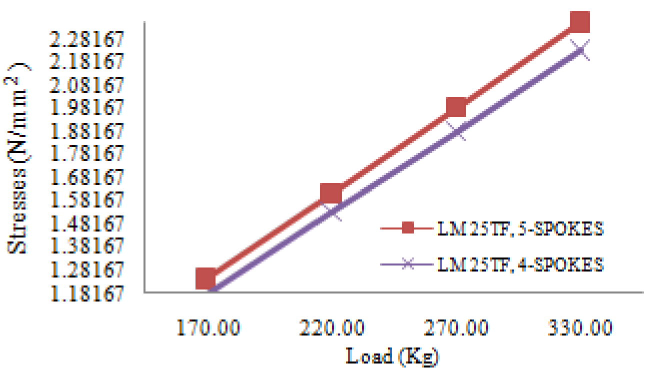


Fig. 3 Stress Comparison between 5-Spokes and 4-Spokes alloy wheel of Aluminum Alloy (LM 25TF)

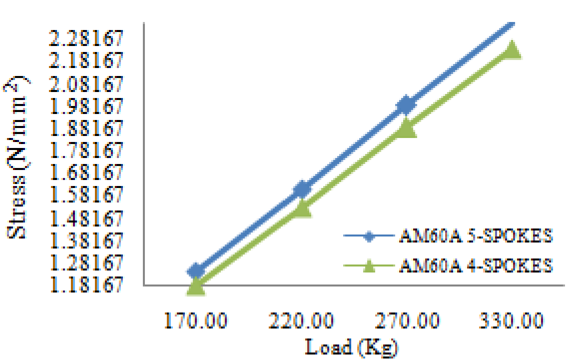


Fig. 4 Stress Comparison between 5-Spokes and 4-Spokes alloy wheel of Magnesium material (AM 60A)

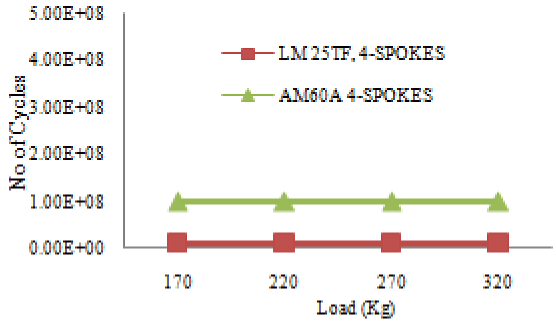


Fig. 5 Illustrates the Fatigue Life Cycle of 4-Spokes alloy wheel of Magnesium and Aluminum material

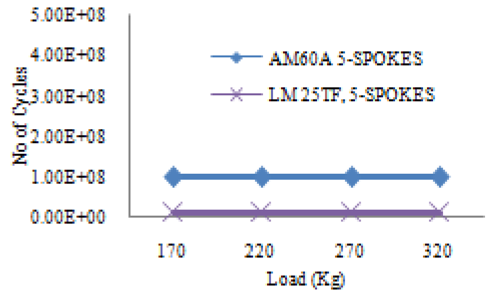


Fig. 6 Illustrates the Fatigue Life Cycle of 5-Spokes alloy wheel of Magnesium and Aluminum material

Figure 3 indicates Stresses induced in the 4-Spokes alloy wheel is less as compared with the Stress induced in the 5-Spokes alloy wheel, for Aluminium Alloy (LM 25TF- U.K Standards) by 0.05%. Figure 4 indicates, Stresses induced in the 4-Spokes alloy wheel as less as compared with the Stress induced in the 5-Spokes alloy wheel, for Magnesium Alloy (AM 60A – ASTM Standards) by 0.05%. Figures 5 and 6 shows that, Fatigue life cycle of Magnesium alloy wheel is more as compared with the Fatigue life cycle of Aluminium alloy wheel. Due to High Strength of Mg-Alloy, Fatigue life is more compared with all Al-Alloys.

Validation

The Stresses induced in the 5-Spokes Aluminium Alloy wheel (LM 25TF) 2.34163MPa is less as compared with the Stresses induced in the 5-Spokes Magnesium alloy (AM60A), Al-alloys (LM 25, LM 25TB7, LM25TE) wheels as shown in table 2. The Stresses induced in the 4-Spokes Aluminium Alloy wheel (LM 25TF) 2.22029 MPa is less as compared with the Stresses induced in the 4-Spokes Magnesium alloy (AM60A), Al-alloys (LM 25, LM 25TB7, LM25TE) wheels as shown in table 3. Due to High Strength and Hardness of Mg-Alloy, Fatigue life is more compared with all Al-Alloys as shown in table 4.
The Stresses induced in the 4-Spokes Aluminium Alloy wheel (LM 25TF) 2.21029 MPa is less as compared with the Stresses induced in the 4-Spokes Aluminium Alloy (LM25TF) wheels by changing fillet radius from 8mm to 9mm as shown in table 5.

Table- 2 Stress Analysis Values for 5-Spokes Mg-alloy and Al-alloys (LM 25, LM 25TB7, LM 25TE, LM 25TF)

5-Spokes	Aluminum Alloys				Magnesium alloy (AM60A)
	LM 25	LM 25TB7	LM 25TE	LM 25TF	
LOAD1	1.23366	1.23324	1.23282	1.23250	1.24426
LOAD2	1.60394	1.60349	1.60290	1.60234	1.61467
LOAD3	1.97349	1.97290	1.97236	1.97177	1.98441
LOAD4	2.34366	2.34296	2.34238	2.34163	2.35595

Table- 3 Stress analysis values for 4-Spokes Mg-alloy and Al-alloys (LM 25, LM 25TB7, LM 25TE, LM 25TF)

4-Spokes	Aluminum Alloys				Magnesium alloy (AM60A)
	LM 25	LM 25TB7	LM 25TE	LM 25TF	
LOAD1	1.16996	1.16961	1.16923	1.16881	1.18167
LOAD2	1.52037	1.51989	1.51938	1.51887	1.53389
LOAD3	1.87069	1.87016	1.86966	1.86912	1.88506
LOAD4	2.22184	2.22134	2.22802	2.22029	2.23756

Table- 4 Fatigue Life values for 5-Spokes and 4-Spokes Mg-alloy and Al-alloys (LM 25, LM 25TB7, LM 25TE, LM 25TF)

5-Spokes and 4-Spokes	Magnesium Alloy (AM60A)	Aluminum Alloys			
		LM 25	LM 25TB7	LM 25TE	LM 25TF
LOAD1	1.0E8	1.2E7	5.0E6	5.0E6	1.0E7
LOAD2	1.0E8	1.2E7	5.0E6	5.0E6	1.0E7
LOAD3	1.0E8	1.2E7	5.0E6	5.0E6	1.0E7
LOAD4	1.0E8	1.2E7	5.0E6	5.0E6	1.0E7

Table- 5 Stress analysis values for 4-Spokes Al-alloy (LM 25 TF) with different Fillet radii

4-Spokes	Aluminum Alloy (LM 25TF) with Fillet 8 mm	Aluminum Alloy (LM 25TF) with Fillet 9mm
LOAD1	1.16881	1.16252
LOAD2	1.51887	1.51193
LOAD3	1.86912	1.86125
LOAD4	2.22029	2.21029

Aluminum Alloy (LM25) is utilized for the validation of this thesis from Deepak (2012). Due to different Heat Treatment conditions, Aluminum Alloys obtained are LM 25TB7, LM 25TE and LM 25TF. Analysis is done on the three different Al-alloys and also on an existing material of the Magnesium alloy (AM 60A).

The stresses obtained in the three different alloys are less as compared with the LM25, because if a material is heated to high temperature followed by quenching in hot water or rapid cooling, first larger grains will break into small grains and secondly hardness and Strength increases, due to Ionic bond between the molecules. But the Stresses obtained in the Magnesium Alloy (AM 60A) is more as compare with all the three Aluminum Alloys, because an HCP structure exists in magnesium which makes magnesium more brittle because of their few active slip systems. Also magnesium is highly active in presence of Oxygen forming magnesium oxide and an improvement is needed in heat dissipation and micronization of Crystal grains of magnesium. Due to all these, the stresses obtained in Mg-alloy are more as compared with all Al-Alloys.

CONCLUSION

An Al-Alloy Wheel was modeled using Pro-E of two Spokes i.e., 4 and 5 with fillet radii (8mm and 9mm). These models were analyzed using COSMOS for five different materials, LM 25, LM25TB7, LM 25TE, LM25TF and AM60A.

From the results obtained it may be concluded that

- The analysis results showed that the maximum stress area was located at Spoke-Rim contact. Stresses induced in 4-Spokes Aluminum Alloy (LM 25TF) are less as compared with Magnesium Alloy (AM 60A) and all the three Aluminum Alloys of 4 and 5 Spokes.
- Fatigue life cycle is estimated based on the Equivalent Stresses induced on Al-alloys and Mg-alloy materials. Fatigue life cycle for the Mg-alloy is more as compared with all Al-alloys materials.
- Re-model of alloy wheel, from 5-Spokes to 4-Spokes, along with small change in Fillet radius from 8 mm to 9 mm, at Rim-Spoke contact. The Stresses induced in Aluminum alloy (LM 25TF) are further reduced as compared to all the three Al-alloys.

Thus, it is clear that by adding the material at fillet edges the stress concentration will be reduced which in turn increases the fatigue life of the material and material reduction can be done by reducing number of Spokes.

Even though, the Fatigue Life of Magnesium alloy is more, by considering all the properties of Aluminum alloy like easy availability, recyclable, good heat dissipation rate. Aluminum Alloy (LM 25TF) is the better material for alloy wheels.

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