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MODELING AND STRUCTURAL ANALYSIS OF ALLOY WHEEL USING ANSYS

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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 CATIA Software, and conducting the tests: Static and Fatigue analysis using the ANSYS 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.

KEYWORDS: Alloy Wheel, CATIA, ANSYS, 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, and 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 CATIA software by reducing the number of spokes from 6 to5 and then 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.

CATIA Works

CATIA is useful software for design analysis in mechanical engineering. CATIA 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, CATIA 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:

1. Build your model in the Solid Works CAD system.
2. Prototype the design.
3. Test the prototype in the field.
4. Evaluate the results of the field tests.

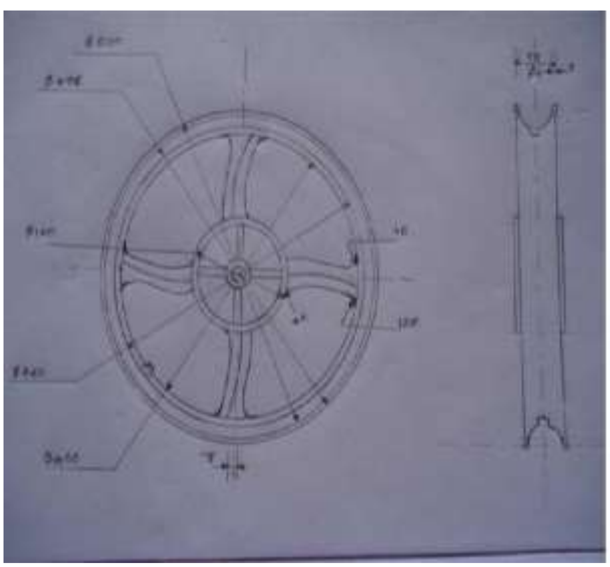

Fig. 1:- Specifications of the Alloy Wheel with Dimensions

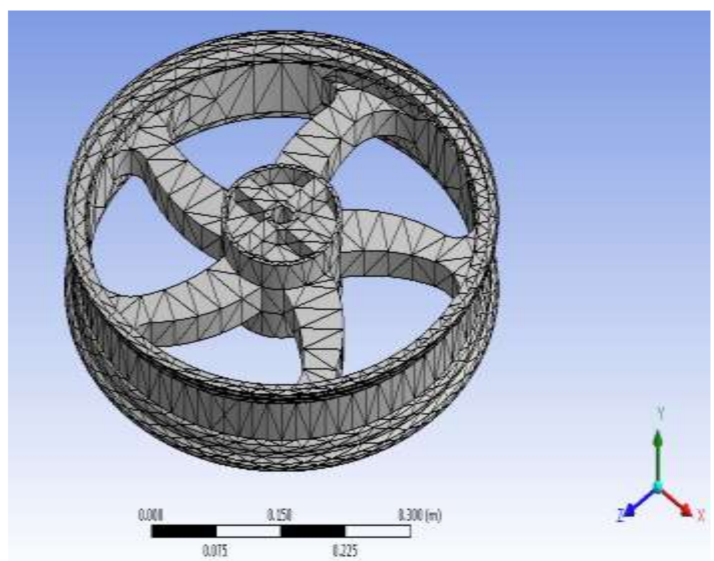

Figure 2:- the importing of Alloy Wheel with meshing

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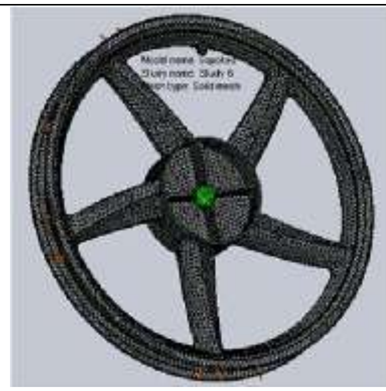
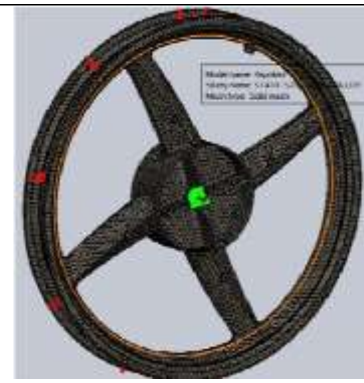
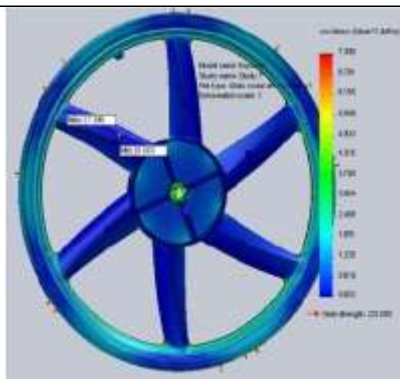
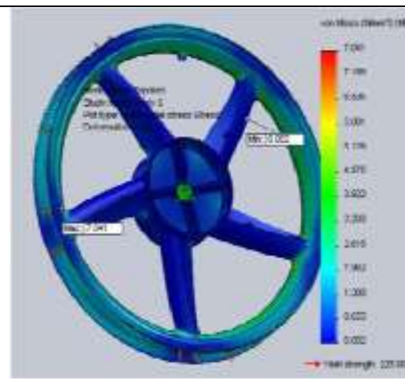
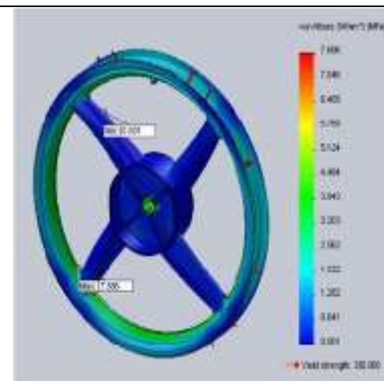
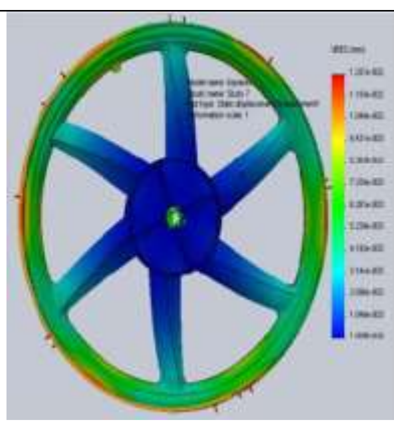
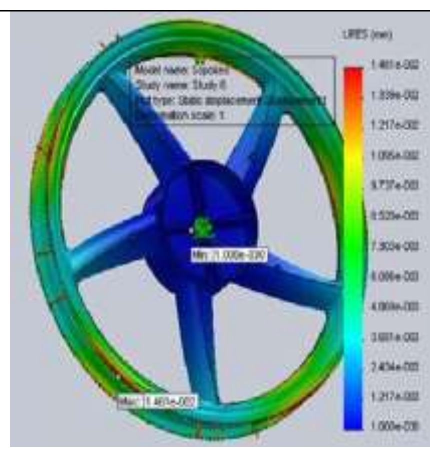
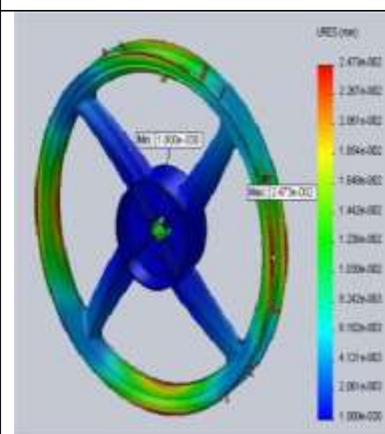
Table- 1 Material Properties

S. No	PROPERTY	Al Alloy 201.0-T43 Insulated Mold Casting (SS)	Mg Alloy ZK60*
1	Elastic Modulus(GPa)	71	45
2	Poisson's Ration	0.33	0.35
3	Mass Density (kg/m3)	2800	1700
4	Tensile Strength (MPa)	273	425
5	Yield Strength (MPa)	225	382
6	Thermal Expansion Coefficient(/K)	1.90E-05	1.90E-05
7	Thermal Conductivity W/(m. K)	121	160
8	Specific Heat J/(kg.K)	963	1000

Table- 2 Mesh Information and details are represented

TYPE OF WHEEL MODEL	With 6 Spokes	With 5 Spokes	With 4 Spokes
Element Size	6 mm	6 mm	6 mm
Tolerance	0.3 mm	0.3 mm	0.3 mm
Mesh Quality	High	High	High
Total Nodes	138283	129933	121024
Total Elements	77485	72121	66289
Maximum Aspect Ratio	27.471	27.339	27.337
% of elements with Aspect Ratio < 3	76.2	74.2	72.8
% of elements with Aspect Ratio > 10	0.246	0.326	0.291
% of distorted elements(Jacobian)	0	0	0
Time to complete mesh*(hh;mm;ss):	00:02:00	00:01:59	00:01:56

TABLE 3 : SIMULATION RESULT DETAILS

	With 6 Spokes **Al alloy**	**With 5 Spokes Al alloy**	**With 4 Spokes Mg alloy**
MESHED MODELS	 Fig 1	 Fig 8	 Fig 15
STRESS ANALYSIS	 Fig 2	 Fig9	 Fig 16
DISPLACEMENT ANALYSIS	 Fig 3	 Fig 10	 Fig 17

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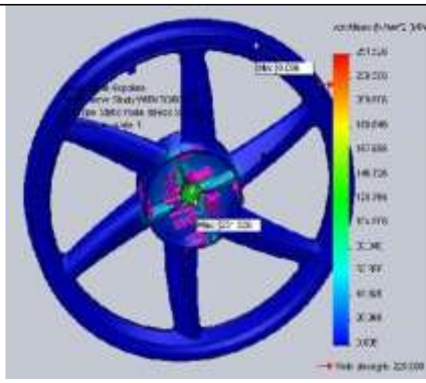
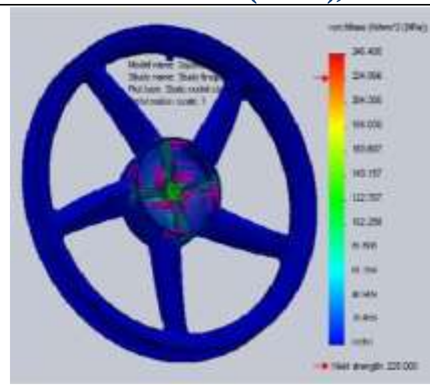
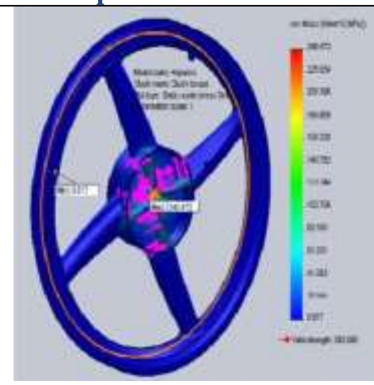
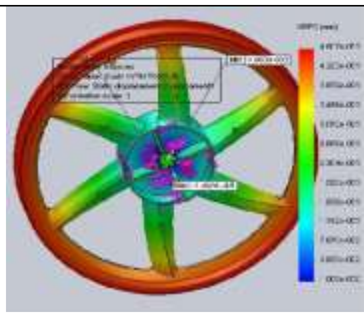
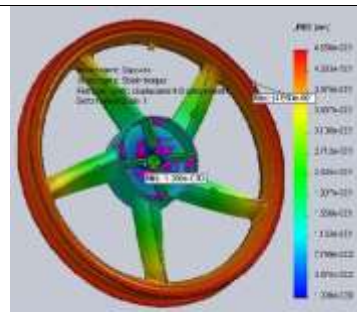
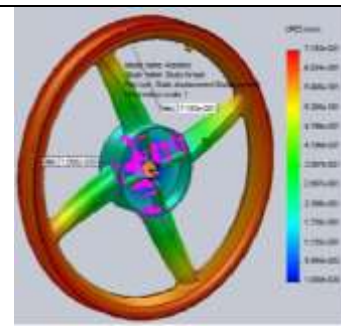
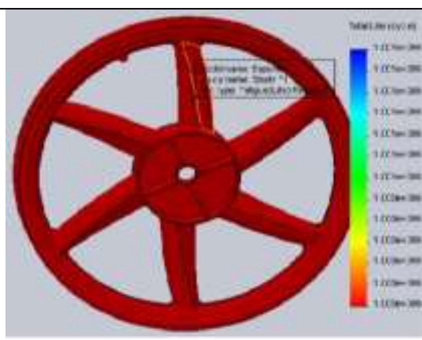
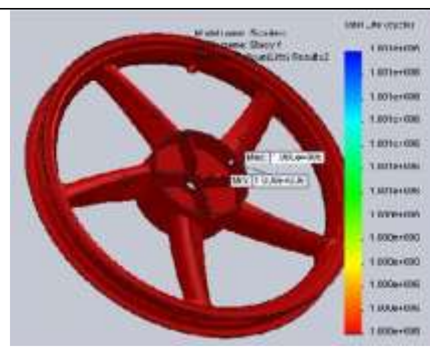
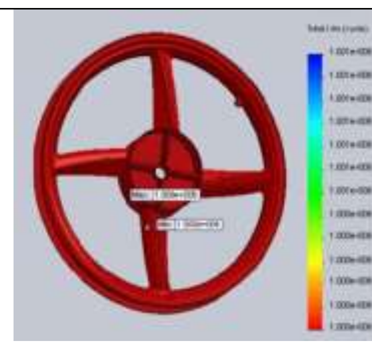
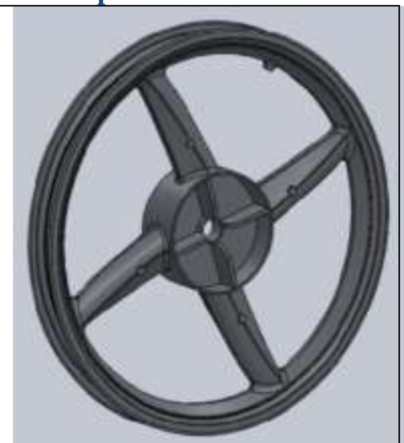
STRESS ANALYSIS FOR BREAKING TORQUE	 Fig 4	 Fig 11	 Fig 18
DISPLACEMENT ANALYSIS FOR BREAKING TORQUE	 Fig 5	 Fig 12	 Fig 19
FATIGUE LIFE ANALYSIS	 Fig 6	 Fig 13	 Fig 20

ISOMETRIC VIEWS OF MODELS			
	 Fig 7	 Fig 14	 Fig 21

For Different Loads Stress on Each Rim –

Applied Loads

Load 0 = weight of Bike (143 vehicle +20extra kg)
Load 1 = (163+65) kg
Load 2 = (163+65X2) kg
Load 3 = (163+65X3) kg
Load 4 = (163+65X4) kg
Load 5 = (163+65X5) kg
Load 6 = (163+65X6) kg

Analysis for strength needed:

Mass of Bike, Dead Weight of Bike =143kg
Other Loads = 20 Kg
Total Gross Weight =143 + 20 = 163 Kg
= 163X 9.81 N
Tires and Suspension system reduced by 30% of Loads
W_{net} = 163 X 9.81 X 0.7 N = 1119.32N
Reaction Forces On Bike=N_r = 1119.32N
Number of Wheels: 2
But by considering total Reaction Force on only one wheel F_T =1119.32N
Rim surface area which is having 6 spokes: A_6 = 48299.69 mm^2
(This can be obtained from selecting faces on rim by using measuring tool in solid works)
Stress on the each Rim = $\frac{N}{A}$ = 0.02321 N/mm^2
So pressure on the each rim for load 0 = 0.02321 N/mm^2
It is similarly for different Loads Stress on Each Rim with Loads
Pressure by Load 1 = 0.0324 N/mm^2
Pressure by Load 2 = 0.0417 N/mm^2
Pressure by Load 3 = 0.0509 N/mm^2
Pressure by Load 4 = 0.0601 N/mm^2
Pressure by Load 5 = 0.0694 N/mm^2
Pressure by Load 6 = 0.0786 N/mm^2

Applying Pressures:

Apply 0.011945MPa pressure simulations normal to the faces as shown in the figure
Again it is similarly for rims with spokes 5 & 4. The simulation results are as shown in figures.

Applying Braking Torque:

In general Acceleration of the street motorcycle: $a = (v_f - v_i) / t$

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v_f- *final velocity= max of 60miles in 3.5sec*
v_i- *initial velocity = 0 miles,*
=>a - acceleration= 7.6636m/s²

Brake force is required to estimate the load on the wheel hub. Now Total force acting on the vehicle:
Mass of the vehicle including rider and other five more persons M=163+65X6

$$F_{total} = M \times a = 4237.9 \text{ N}$$

Torque on the hub:
T = F_r X R in N.m
(here F_r is the force on the each wheel=0.5F_{total} & R is radius of the rim = 0.25m)
T = 2119X0.25 = 529 N.m

RESULTS AND DISCUSSION

Stress analysis values for 6, 5-Spokes Al-alloy and 4 spoke Mg-alloy in the following table.

	LOADING		Stresses In the Alloy Wheel in MPa		
S.NO	Description	load (N)	With 6 Spoke Al Alloy	with 5 Spokes Al Alloy	With 4 Spokes Mg Alloy
1	Motorcycle Load	1119.321	2.182	2.312	2.269
2	with 1 Man	1565.676	3.044	3.323	3.169
3	with 3 Men	2012.031	3.925	4.154	4.078
4	with 4 Men	2458.386	5.054	5.075	4.978
5	with 5 Men	2904.741	5.655	6.002	5.877
6	with 6 Men	3351.096	6.532	6.924	6.788
7	with 7 Men	3797.451	7.398	7.841	7.686

The Stresses induced in the 4-Spokes Mg Alloy wheel 7.686 MPa is less as compared with the Stresses induced in the 5-Spokes Al alloy (AM60A), and also nearer to Al-alloys with 6 spokes. So in the 4 spoke model can substitute to the 6 or 5 spoke wheels safely.

Table-4 Weight (N) reduction in the model

No. of spokes	Mg	Al	% of weight saving
6 spokes	24.3911	40.1294	60.78
5 spokes	21.8042	35.8761	60.77
4 spokes	19.1728	31.608	60.66

Table-5 Max. Von-Mises Stress due to braking torque in the wheel (by considering drum braking):

in 6 spoke Al-alloy wheel	251.526 > yield stress
in 5 spoke Al-alloy wheel	250.148> yield stress
in 4 spoke Al-alloy wheel	246.472< yield stress (safe stresses)

CONCLUSION

The objective was to reduce the weight of the alloy wheel has been achieved. The current design is 60% lighter than the original design. What more can be done to reduce the weight. In this work the overall dimensions are controlled by reducing number of spokes to the alloy wheel with same functioning stability and less weight. The stress and displacements in 4 spoke alloy wheel are lesser than six and five spokes alloy wheels. And also having higher FOS in the four spoke model design.

SCOPE FOR FUTURE WORK:

1) Further to do optimization of material thickness to reduce the material consumption.
2) Further to improve life of component by using advanced fatigue strain life approach.

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