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Design and Analysis of Alloy Wheel Disc for Optimal Material and Geometric Parameters

V. Dharani and G. Suresh Kumar

Department of Mechanical Engineering, G. Pulla Reddy Engineering College (Autonomous), Kurnool-518007, AP, India.

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ABSTRACT

In an automobile, the wheel plays important role. Through reverse engineering process, better alloy wheel disc designs are possible by capturing the physical dimensions of the existing wheel. The objective of the present work is to recommend better material and optimal geometric shape for the wheel disc. The wheel disc is modeled in CATIA and imported to ANSYS. Analysis is done for different models. Analysis results suggest that modified model with smaller radial slots with magnesium zk60 material gives better life. The wheel disc 1.153kg lighter than that in the original design. This design is still in safe condition.

Introduction

Wheel plays a major role in the field of automobile industry. Even if the engine starts the car cannot be moved without wheels. The wheel is a rotating load carrying member between the tyre and the hub. Wheel is the assembly of hub, disc, frame and tyre. The wheel absorbs shocks and supports the inner weight of the vehicle. The wheels are of many types like disc wheel, spoked wheel, mag wheel, heavy vehicle wheel. In the present work disc wheel is considered. The disc wheel is welded to the inner periphery of the wheel rim. The rim is of rolled section. The disc functions like a spoke. The disc wheel is simple to design, cheap to manufacture and robust in construction.

An automobile wheel disc

- Must be strong and flexible to absorb road shocks.
- Should be able to transmit propulsion and brake force
- Should be balanced both statically as well as dynamically
- Should be as lighter in weight as possible so that the unstrung weight is least
- Should be possible to remove or mount the wheel disc easily
- Material should not deteriorate fast with weathering and age.

Previously steel material is used for manufacturing of wheel disc.

These kinds of wheels are found commonly on all types of vehicles. After that alloy wheels came into existence. The alloy wheels are lighter in weight with similar strength. It also looks modernized and gives trendy appearance. Presently the manufacturers are using aluminum material for manufacturing wheel disc. Because wheel disc made with aluminum alloy material need not to paint and also need not to attach any wheel covers. Magnesium alloy material is used for manufacturing of race cars. The wrought alloys are developed like Electron 43, 21and 675, ZK60 which may be used in manufacturing of wheel discs. Because these are inherently flame resistant even beyond their melting points.

Design and analysis of wheel rim is attempted by many authors. The authors focused on wheel rim that has undergone more stress with respect to its design and type of material used. Several studies proved that aluminum material is the best choice for designing of alloy wheel disc when compared to the other materials. Other studies tried to optimize the alloy wheel disc by studying the results obtained from static, dynamic and fatigue analysis. N. Satyanarayana et.al. [1], in their studies, estimated the fatigue life of aluminum alloy wheel by conducting the tests under radial fatigue load and compared with that of finite element analysis. The results found that the maximum stress is acting on the rim portion. The damage occurs mainly at cross sectional area of wheel spokes. P. Meghashyam et.al. [2], in their studies proved that forged steel is the better material when compared to that of aluminum material for designing of wheel rim. Their studies mainly concentrated on the performance of the wheel rim by observing the analysis results of stress and their deflections. By designing the wheel disc with Y-shaped spokes the static and dynamic analysis is performed and found that aluminum alloy wheel rim is subjected to more displacement when compared to forged steel. By taking the deflections into account T. Siva Prasad [3] suggested that wheel rim with aluminum material has undergone more deflections than compared to forged steel material. When certain load is applied on the wheels the tension will arise. Those tensions are studied by Amalia Ana Dascal et.al. [4], the area of the wheel is undergoing more tensions when subjected to aerodynamic loading conditions are studied. The modifications are made in the design of damage occurring area of the wheel. By using finite element method and applying different forces and accelerations restrictions problems arising on the affected area is reduced. By using this concept the destruction of the wheel is prevented. Based on the studies of Mechanical Testing Methods concerning the stress analysis for a vehicle wheel rim by Alexanderu Valentin Radulescu et.al, [5] conducting experimental studies and theoretical studies. In the theoretical method the car rim is analyzed with FEM, using loading test. The static stresses at different loading masses are studied to find the zones i.e. areas with high stress concentration and to suggest

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Tele:

E-mail addresses: valuvadharani@gmail.com

the best design. Here they used the steel material. The stress distribution in the area of central disc was found. In the experimental tests the wheel rim is tested until the first crack for each load mass is obtained. The stresses are responsible for the fatigue breaks of the rim. The authors attempted to reduce costs, eliminating the stresses and increased the long life of the rim. The authors Satya Prasad and Anil Kumar [6] of HYUNDAI, Motor Engineering concentrated most on development of product with low lost, high quality and performance.

In this Hypermesh and Optistruct is used for modeling and analysis. At first the existing alloy wheel with 8 spokes and 6.73kg mass is taken. By conducting the cornering fatigue test, Radial fatigue test, dynamic stiffness test and impact test were performed. After some changes are done in designing of existing wheel the aluminum material is reduced to some extent. The dynamic stiffness of rim, safety factor and obtained as the results. Finally they reduced a mass of 350gm per wheel i.e., 5% of total weight is achieved by them. The advantage of this optimization is decrease in total weight of car and decrease in cost of production. Anusha Srikanta and Veeraraju [7] developed a parametric model for designing four wheeler alloy wheel. For modeling Sedan vehicle wheel is considered. For analysis of alloy wheel the materials considered were aluminum, cast alloy steel, magnesium alloy and ZAMAK. COSMOS software was used for design and analysis. Four different spoke shapes were analyzed such as straight, inclined, Y-shape and honey-comb for four different materials. By the analysis they found stress, strain, and displacement for different materials with four different spoke shapes. After simulation they concluded that honey-comb model is the best geometric shape compared to the other models. Zamak is the best material when compared with other materials because of its higher tensile and yield strength. Praveen and Gopichand [8] developed a parametric model for designing four wheeler alloy wheel. For designing Mercedes Benz c250 vehicle wheel is considered. For analysis of alloy wheels the materials considered were aluminum, magnesium and zamak. Creo 2.0 was used for the modeling of alloy wheel and the simulation was done by using ANSYS. In this the spoke shapes such as straight, inclined, Y-type and H- type cross members for different materials were analyzed. In this Y- type cross member showed best results when compared to the other geometric spoke shapes. Zamak material is giving the best results in this paper. Result shows that zamak material along with Y- shaped spoke shape is better.

Objective: The objective of the present study is to recommend the optimal material and geometric parameters for designing of alloy wheel disc.

Methodology

The present work mainly focused on reducing the weight of the wheel disc. Honda city alloy wheel is considered for design and analysis purpose. By capturing the physical dimensions of the original wheel disc another wheel disc is designed with some modifications in the geometric spoke shapes. The materials aluminum 6061, magnesium ZK60, aluminum 201 is considered.

Load Calculations

In this work Honda city vehicle wheel disc is considered.

Weight of the Car, wc = 1090 kg's

Weight of 5 passengers + Weight of the luggage, wp = 500 kg's

Total weight of the Car, WT = wc+ wp = 1590 kg's

Area of the wheel disc, A = 272511.58 mm2

Pressure, P = WT /A = 1590 X 9.81/272511.58 = 0.0572 N/mm2

Material Properties:

Aluminum 6061

Yield strength : 3.49e+008 N/ m2

Tensile strength : 3.59e+008 N/m2

Mass density : 2800 kg/

Elastic modulus : 7.1e+010 N/m2

Poisson's ratio : 0.33

Thermal expansion coefficient: 3.5e-005 /Kelvin

By using the dimensions of alloy wheel disc of Honda city vehicle the modeling is done in CATIAV5 software. The dimensions of Honda city alloy wheel disc.

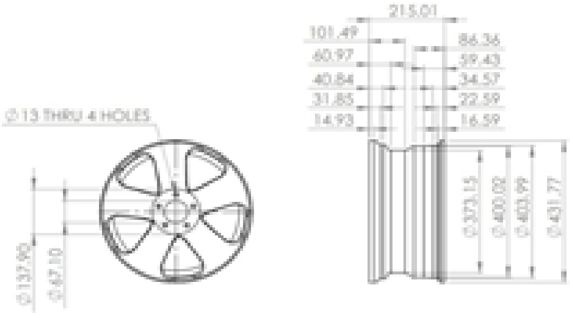

Figure 1. Dimensions of alloy wheel disc

Modeled screen shots in CATIA

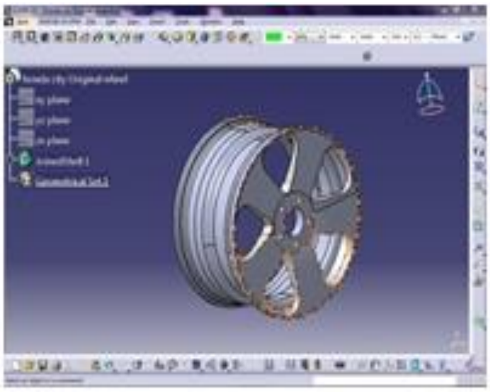

Figure 2. Original alloy wheel disc

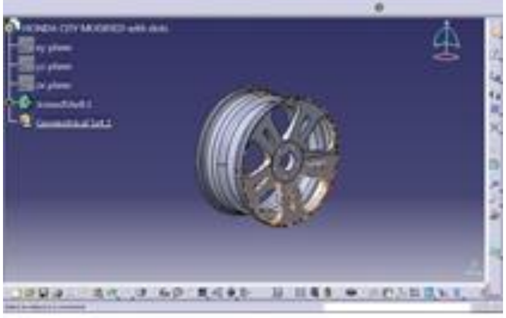

Figure 3. Wheel disc with smaller radial slots

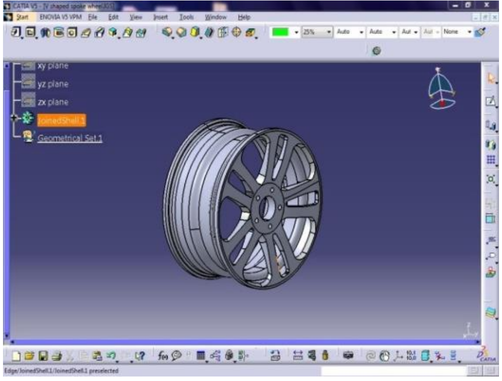

Figure 4. Wheel disc with larger radial slots

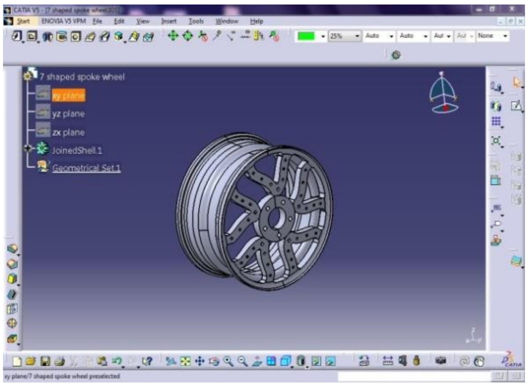

Figure 5. Wheel disc with V- shaped spokes

Result Analysis and Discussions

The modeled wheel disc in CATIA V5 is imported to ANSYS for analyzing the results.

Static Analysis of original model of wheel disc

For Aluminum 6061: Element Type- Solid 20node 186, Material Properties: Poisson's ratio- 0.33, Young's Modulus-71000N/mm^2, Density- 0.000002700kg/ mm^3, Yield strength- 349N/ mm^2

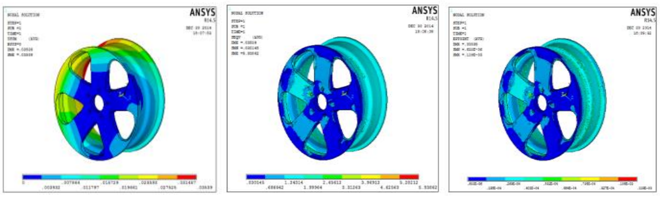

Figure 6. Displacement, Von-mises stress , Strain

For Magnesium alloy ZK60: Element type- Solid 20 node 186, Material properties: Poisson's Ratio- 0.35, Young's Modulus- 45000 N/mm^2, Density- 0.0000017 kg/ mm^3. Yield strength- 382 N/ mm^2

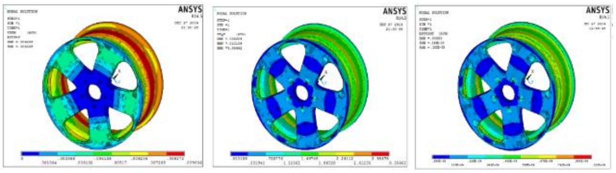

Figure 7. Displacement, Von-mises stress, Strain

For Aluminum 201: Element Type- Solid 20node 186 Material Properties: Poisson's ratio- 0.33, Young's Modulus- 45000N/mm^2, Density- 0.000002800kg/ mm^3, Yield strength- 435N/ mm^2

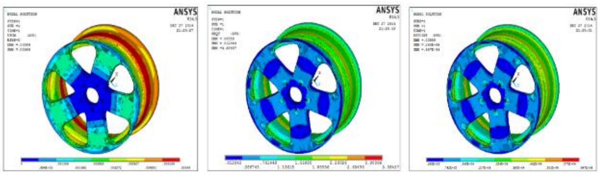

Figure 8. Displacement, Von-mises stress, Strain

Static Analysis of Modified Model with Smaller Radial Slots

For Aluminum 6061: Element Type- Solid 20node 186

Material Properties: Poisson's ratio- 0.33,

Young's Modulus- 71000N/mm^2,

Density- 0.000002700kg/ mm^3, Yield strength- 349N/ mm^2

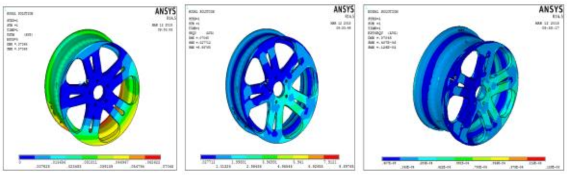

Figure 9. Displacement, Von-mises stress, Strain

For Magnesium alloy ZK60: Element type- Solid 20 node 186, Material properties: Poisson's Ratio- 0.35, Young's Modulus- 45000 N/mm^2, Density- 0.0000017 kg/ mm^3. Yield strength- 382 N/ mm^2

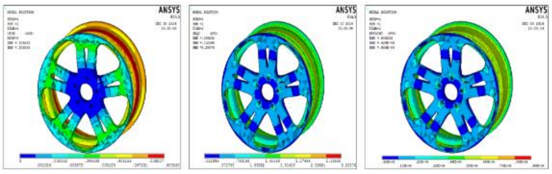

Figure 10. Displacement, Von-mises stress, Strain

For Aluminum 201: Element Type- Solid 20node 186 Material Properties: Poisson's ratio- 0.33, Young's Modulus- 45000N/mm^2, Density- 0.000002800kg/ mm^3, Yield strength- 435N/ mm^2

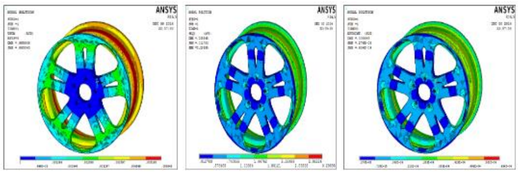

Figure 11. Displacement, Von-mises stress, Strain

Static Analysis of Modified Model with Larger Radial Slots

For Aluminum 6061: Element Type- Solid 20node 186

Material Properties: Poisson's ratio- 0.33,

Young's Modulus- 71000N/mm^2,

Density- 0.000002700kg/ mm^3, Yield strength- 349N/ mm^2

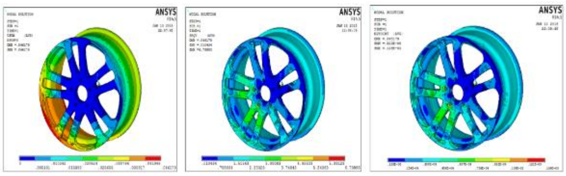

Figure 12. Displacement, Von-mises stress, Strain

For Magnesium alloy ZK60: Element type- Solid 20 node 186, Material properties: Poisson's Ratio- 0.35, Young's Modulus- 45000 N/mm^2, Density- 0.0000017 kg/ mm^3. Yield strength- 382 N/ mm^2

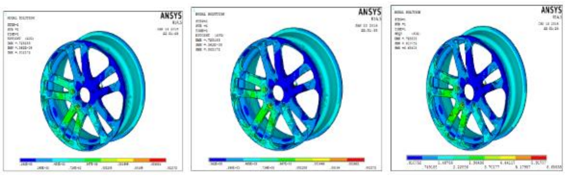

Figure 13. Displacement, Von-mises stress, Strain

For Aluminum 201: Element Type- Solid 20node 186 Material Properties: Poisson's ratio- 0.33, Young's Modulus- 45000N/mm^2, Density- 0.000002800kg/ mm^3, Yield strength- 435N/ mm^2

Aluminum Alloy 201

Table 1. Chemical Composition of the A02010 Aluminum Alloy (Wt.%)

	AL	Cu	Ag	Mg	Mn	Ti	Fe	Si	Other
Min	bal	4	0.4	0.15	0.2	0.15			
Max	bal	5.2	1	0.55	0.5	0.35	0.2	0.1	0.1

Table 2. Material Properties of the A02010 Aluminum Alloy

Property	Values			Units
	T43	T7	T6	
Elastic Modulus	71000	71000	71000	N/mm^2
Poisson's Ratio	0.33	0.33	0.33	N/A
Shear Modulus	23000	23000	23000	N/mm^2
Mass Density	2800	2800	2800	kg/m^3
Tensile Strength	273	345	485	N/mm^2
Yield Strength	225	344	435	N/mm^2
Thermal Expansion Coefficient	1.9e-005	1.9e-005	2.9e-005	/K
Thermal Conductivity	121	121	121	W/(m·K)
Specific Heat	963	963	963	J/(kg·K)
Charpy Impact	3.30 - 21.7	3.30 - 21.7	3.30 - 21.7	J
Charpy Impact, Unnotched	16.3 - 77.0	16.3 - 77.0	16.3 - 77.0	J

Magnesium alloy

Table 3. Chemical Composition of the ZK60 Magnesium Alloy (Wt. %)

Mg	Zn	Zr	Al	Mn	Other elem.
bal	5.49	0.55	0.005	0.025	max 0.3

Table 4. Material Properties of the ZK60 Magnesium Alloy

Property	Value	Units
Elastic Modulus	45000	N/mm^2
Poisson's Ratio	0.35	N/A
Shear Modulus	17000	N/mm^2
Mass Density	1700	kg/ m^3
Tensile Strength	425	N/mm^2
Yield Strength	382	N/mm^2
Thermal Expansion Coefficient	1.9e-005	/K
Thermal Conductivity	160	W/(m·K)
Specific Heat	1000	J/(kg·K)
Charpy Impact	2.70	J
Charpy Impact, Unnotched	1.4-4.1	J

Table 5. Results of Modified wheel disc with smaller radial slots

	AL6061	MgZK60	AL201
Displacement (mm)	0.0093	0.00923	0.00584
Von-misesstress (N/mm^2)	3.37	3.255	3.2859
Strain	$0.102e^{-3}$	$0.996e^{-4}$	$0.634e^{-4}$
Yield stress	349	382	432

Table 6. Mass Properties of alloy wheel disc

Wheel Disc	Mass of Aluminum	Mass of Magnesium
Original wheel disc	23.744kg	15.416kg
Wheel disc with smaller radial slots	23.49	14.263
Wheel disc with larger radial slots	22.96	13.94
Wheel disc with V- shaped spoke	23.52	14.28

Table 7. Results of Modal Analysis

Mode Shape	Frequency (Hz)	Displacement (mm)
Mode shape -1	7.93792	0.860486
Mode shape -2	7.94219	0.86086
Mode shape -3	10.1118	1.03833
Mode shape -4	10.1125	1.03806
Mode shape -5	11.0423	0.538817

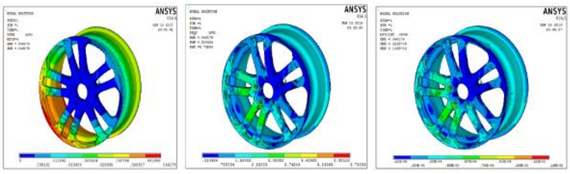

Figure 14. Displacement, Von-mises stress, Strain

Static Analysis of Modified Model with V-Shaped Spokes

For Aluminum 6061: Element Type- Solid 20node 186

Material Properties: Poisson's ratio- 0.33,

Young's Modulus- 71000N/mm^2,

Density- 0.000002700kg/ mm^3, Yield strength- 349N/ mm^2

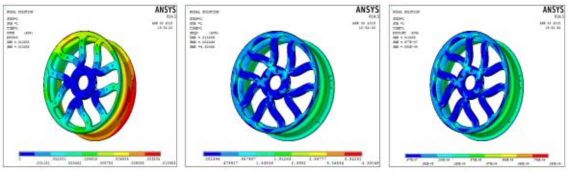

Figure 15. Displacement, Von-mises stress, Strain

For Magnesium alloy ZK60: Element type- Solid 20 node 186, Material properties: Poisson's Ratio- 0.35,

Young's Modulus- 45000 N/mm^2, Density- 0.0000017 kg/ mm^3. Yield strength- 382 N/ mm^2

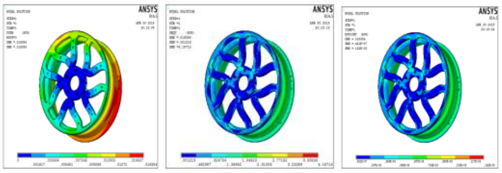

Figure 16. Displacement, Von-mises stress, Strain

For Aluminum 201: Element Type- Solid 20node 186

Material Properties: Poisson's ratio- 0.33, Young's Modulus- 45000N/mm^2, Density- 0.000002800kg/ mm^3, Yield strength- 435N/ mm^2

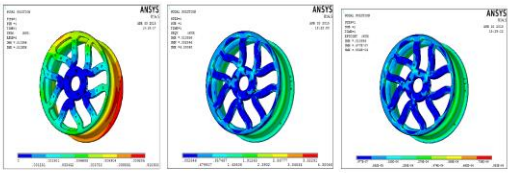

Figure 17. Displacement, Von-mises stress, Strain

By observing these results the displacement and von-mises stresses of modified model with smaller radial slots are less than the others. Modal analysis is done for the best geometric spoke shape i.e. modified model with smaller radial slots and the best material magnesium ZK60 alloy.

Modal Analysis of Modified Model with Smaller Radial Slots

For Magnesium alloy ZK60: Element type- Solid 20 node 186, Material properties: Poisson's Ratio- 0.35,

Young's Modulus- 45000 N/mm^2, Density- 0.0000017 kg/ mm^3. Yield strength- 382 N/ mm^2

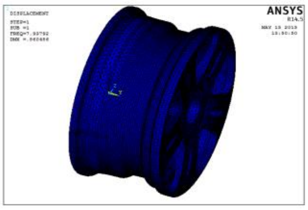

Figure 18. Mode shape-1

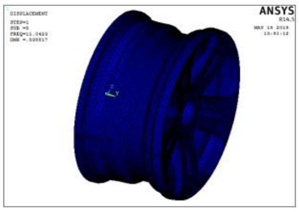

Figure 19. Mode shape- 5

The objective of reducing the weight of wheel disc has been achieved. The current modified design is 1.153 kg lighter than the original design

Saving in material = Existing weight – Proposed weight
= 15.416 – 14.263 = 1.153kg

Considering the cost of magnesium zk60 alloy of INR 550/- per kg resulted in saving of 2200/- approximately for Honda city vehicle by using proper wheel disc design and selecting the material.

Future Scope

1. To enrich the present work this can be extended to transient dynamic analysis.
2. The optimization of spoke thickness can be done that is out of the present work in order to minimize the use of material.

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