Structural Analysis of Alloy Wheels

George Hawkins
M.Tech Automobile Engineering
Amity School of Engineering and Technology
Amity University Noida, UP
georgehawkinsp@gmail.com

Dr. Vikas Kumar
Professor, Amity School of Engineering and Technology
Amity University Noida, UP
viksmied@gmail.com

Abstract. The wheel of a car plays a pivotal role to endure the weight applied on it. Usually spokes behave as the supports between the hub and the rim. These spokes must have adequate stiffness and strength to dodge the failure of the wheel. In current days these wheels are comprised of, magnesium alloy, steel and aluminum alloy. To decrease the weight of the wheel, numerous wheel designs are executed and applied for automobiles. As regard to the study of the vehicle stability, it is adequate to perform the structural analysis of the wheels so as to know the equivalent modal considerations.

In this work, a Cad model of a typical alloy wheel was designed in SOLIDWORKS software and dynamic analysis is performed on this model. The Stress analysis and Fatigue analysis was done on the chosen design. By observing the results we can see whether the design of wheel and the material is feasible or not under applied load conditions. A comparative study is performed by using results of the analysis of the wheel using different materials. The materials used are: Magnesium Alloy, Stainless Steel and Aluminum Alloy and Titanium Alloy in the end best suitable material for the wheel is determined.
1. Introduction

In its basic form, a wheel is a rounded block of a tough and strong material at whose center has been bored a circular hole through which is positioned an axle bearing about which the wheel rotates when a moment is applied by gravity or torque to the wheel about its axis. During the early times wheel material used to be stone or wood. Nowadays wheels are made of metal, most of which are alloys of Aluminum and Magnesium.

The objective may be summarized as follows:

- To develop a model of a wheel using SOLIDWORKS software.
- To develop dynamic analysis of the developed model of the wheel using ANSYS software

Major forces acting on the wheel:

- The thrust of the car in the forward direction.
- The drag acting in the backward direction
- Reactive forces of the road surface in the upward direction.
- Weight of the car acting downwards.

Functions of wheel:

- To provide a suitable platform to place the tyre.
- To absorb all the forces acting on it without failure.
- To provide a proper balance to the entire automobile.

1.1 Factors that are to be considered for proper functioning of wheel

- The wheel should have high strength and high hardness to withstand the drag and inertia forces. They should have minimum weight to minimize the overall weight of the car.
- The material of the wheel should not heat up as it will be experiencing high temperatures easily.
- Material of the wheel must possess less ductility qualities, so that the wheel does not deform on loading.
- Material of the wheel should be easily malleable.
2.0 Design

![Diagram of wheel nomenclature](image)

**Figure 1.** Nomenclature of wheel

2.1 Offset
The space from the centerline of the wheel to the face of the mounting surface of the wheel that contacts the hub.

2.2 Negative offset
Shows the mounting pad is behind the centerline of the rim. This is often found on typical rear-wheel-drive cars and on upturned rims.

2.3 Positive offset
States about the wheel that have the mounting pad in front (or outboard) of the centerline of the circumference. Most often found on front-drive uses.

2.4 Centerline
The exact center of the rim width. The width is measured between where the tires rest.

2.5 Design considerations for wheel
- In designing a wheel for I.C. engine, the following points should be taken into consideration
- It should be strong enough to carry the weight of the car.
- It should be able to withstand the drag and acceleration forces experienced by the vehicle.
3.0 Materials for wheel

- The most commonly used materials for wheels are, magnesium alloy, aluminum alloy, stainless steel etc. Wide varieties of materials are available in the market which can be used for the wheel rim.

- Generally used wheel rim materials are Al alloy, Mg alloy, Steel C 1008, Forged Steel.

- Each material has some advantages over the other.

- If original equipment manufacturers require excellent aesthetic shape with very good heat dissipation without compromise with its associated costs then light weight material such as Al and Mg alloys can be used for wheel rims.

- For heavy duty vehicles wheel rims Steel C 1008 and forged steel are best materials.

3.1 Solid works Design

![Solid works design of wheel](image)

**Figure 2.** Solid works design of wheel
3.2 Material and their Properties

**Table 1. Properties of Aluminum Alloy**

| Parameters                  | Values               |
|-----------------------------|----------------------|
| Density                     | 32770 kg m$^{-3}$    |
| Coefficient of thermal expansion | 2.3e-005 C$^{-1}$  |
| Poisson's ratio             | 0.33                 |
| Tensile ultimate strength   | 3.1e+008 Pa          |
| Tensile yield strength      | 2.8e+008 Pa          |
| Compressive yield strength  | 2.8e+008 Pa          |
| Specific heat               | 875 J kg$^{-1}$ C$^{-1}$ |

**Table 2. Properties of Magnesium Alloy**

| Parameters                  | Values               |
|-----------------------------|----------------------|
| Density                     | 1800 kg m$^{-3}$     |
| Coefficient of thermal expansion | 2.6e-005 C$^{-1}$  |
| Poisson's ratio             | 0.35                 |
| Bulk modulus                | 5.6e+010 Pa          |
| Specific heat               | 1024 J kg$^{-1}$ C$^{-1}$ |
4.0 Design for analysis

4.1 Dynamic Analysis of Wheel
Dynamic Finite Element Analysis can be done on complex systems with very powerful simulation techniques. This method can be used to test the effect of transient loading and also to reduce noise and vibrations across the body. Carrying out this analysis during the design stage itself will save costs in the material category. During dynamic loading if a failure happens it can be disastrous. FEA testing during design stage will help in avoiding costly errors during the real life usage of the product.

In order to do analysis of the wheel, a cyclic force with max value of 7000N was applied on one side of the wheel. The hub of the wheel and the bores for the bolts were taken as the fixed support. Fatigue analysis and Static analysis was done to the wheel.

The force was applied in the time intervals and it can be shown in tabular form as:

| Steps | Time [s] | Force [n] |
|-------|----------|-----------|
| 1     | 0        | 1400      |
| 2     | 1        | 2800      |
| 3     | 2        | 4200      |
| 4     | 3        | 5600      |
| 5     | 4        | 7000      |

Table 3. Force-time intervals
According to this table the force was applied at one side of the wheel which will be in contact with the road surface and the analysis was done for the wheel designed taking two different materials

The factors on which the analysis was done were:-

- Total Deformation
- Equivalent Stress
- Equivalent Strain

Graphs for all the materials were obtained for total deformation and equivalent stress and accordingly they were compared.

5.0 Results and Discussion

5.1 ANSYS Results

Figure 4. Equivalent Stress for Magnesium Alloy

Figure 5. Total Deformation for Magnesium Alloy
Figure 6. Equivalent Stress for Aluminium Alloy

Figure 7. Total Deformation for Aluminium Alloy
5.2 Graphical representation and tabular results

| Model (A4) > Static Structural (A5) > Solution (A6) > Results |
|-------------------------------------------------------------|
| **Object Name** | **Equivalent Stress** | **Equivalent Elastic Strain** | **Total Deformation** |
| State | Solved |

**Scope**
- Scoping Method: Geometry Selection
- Geometry: All Bodies

**Definition**
- Type: Equivalent (von-Mises) Stress
- By: Time
- Display Time: Last
- Calculate Time History: Yes
- Identifier: No
- Suppressed: No

**Integration Point Results**
- Display Option: Averaged
- Average Across Bodies: No

**Results**

|       | Equivalent Stress | Equivalent Elastic Strain | Total Deformation |
|-------|-------------------|---------------------------|-------------------|
| Minimum | 13717 Pa          | 7.7549e-007 m/m          | 0. m              |
| Maximum | 5.6368e+006 Pa    | 1.2684e-004 m/m          | 1.3326e-005 m     |
| Average | 8.2667e+005 Pa    | 1.999e-005 m/m           | 3.486e-006 m      |

**Minimum Occurs On**
- The good wheel-FreeParts

**Maximum Occurs On**
- The good wheel-FreeParts

**Minimum Value Over Time**

|       | Equivalent Stress | Equivalent Elastic Strain | Total Deformation |
|-------|-------------------|---------------------------|-------------------|
| Minimum | 2743.4 Pa         | 1.655e-007 m/m           | 0. m              |
| Maximum | 13717 Pa          | 7.7549e-007 m/m          | 0. m              |

**Maximum Value Over Time**

|       | Equivalent Stress | Equivalent Elastic Strain | Total Deformation |
|-------|-------------------|---------------------------|-------------------|
| Minimum | 1.1274e+006 Pa    | 2.5168e-005 m/m          | 2.6652e-006 m     |
| Maximum | 5.6368e+006 Pa    | 1.2684e-004 m/m          | 1.3326e-005 m     |

**Table 4.** Results for Magnesium Alloy
Figure 8. Equivalent Stress for Magnesium Alloy

Figure 9. Total Deformation for Magnesium Alloy
Table 5. Results for Aluminium Alloy

| Objective Name | Total Deformation | Equivalent Stress |
|----------------|-------------------|-------------------|
| State          |                   | Solved            |
| Scope          |                   |                   |
| Scoping Method | Geometry Selection|                   |
| Geometry       | All Bodies        |                   |
| Definition     |                   |                   |
| Type           | Total Deformation | Equivalent (von-Mises) Stress |
| By             |                   | Time              |
| Display Time   |                   | Last              |
| Calculate Time History | Yes   |                   |
| Identifier     |                   |                   |
| Suppressed     |                   | No                |
| Results        |                   |                   |
| Minimum        | 0. m              | 25757 Pa          |
| Maximum        | 1.1366e-005 m     | 2.1709e+007 Pa    |
| Average        | 3.1714e-006 m     | 1.6876e+006 Pa    |
| Minimum Occurs On | The good wheel-FreeParts | |
| Maximum Occurs On | The good wheel-FreeParts | |
| Minimum Value Over Time | | |
| Minimum        | 0. m              | 5151.4 Pa         |
| Maximum        | 0. m              | 25757 Pa          |
| Maximum Value Over Time | | |
| Minimum        | 2.2732e-006 m     | 4.3417e+006 Pa    |
| Maximum        | 1.1366e-005 m     | 2.1709e+007 Pa    |
These were the graphs obtained from the analysis done for the two different materials for the “equivalent stress”, “equivalent strain” and “total deformation” on the model of the wheel and the difference between them can be observed from the graphs itself.
| Material         | Minimum equivalent stress [pa] | Maximum equivalent stress [pa] | Minimum total deformation [m] | Maximum total deformation [m] |
|------------------|--------------------------------|--------------------------------|-------------------------------|-------------------------------|
| Aluminum alloy   | 25757                          | 2.1709e+007                    | 0                             | 1.1366e-005                  |
| Magnesium alloy  | 13717                          | 5.6368e+006                    | 0                             | 1.3326e-005                  |

Table 6. Results

6.0 Conclusion

The suitable material out of the two can be decided on the basis of their results i.e. “equivalent stress”, “equivalent strain” and “total deformation”. From the results table it can be seen that the maximum total deformation is more for Magnesium Alloy than Aluminum Alloy by a very minute amount. It can also be seen that the Maximum Equivalent Stress is more for Aluminum Alloy as well. From this information, we can conclude that Magnesium Alloys are more suitable for manufacture of the alloy wheel.
7.0 References

1. E Esmailzadeh, G.R.Vossoughi and A. Goodarzi, 2011 “Dynamic Modeling and Analysis of a Four Motorized Wheels Electric Vehicle”

2. H. N. Kale , Dr. C. L. Dhamejani, Prof. D. S. Galhe, 2008, “A review on materials used for wheel rims”

3. Mehmet Firat, Recep Kozan, Murat Ozsoy, O. Hamdi Mete, 2009 “Numerical modeling and simulation of wheel radial fatigue tests.” Engineering Failure Analysis.

4. Sunil N. Yadav, N. S. Hanamapure, 2013 "Analyze the Effect of Camber Angle on Fatigue Life of Wheel Rim of Passenger Car by Using Radial Fatigue Testing", International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 2, Issue 5

5. P. Ramamurthy Raju, B. Satyanarayana, K. Ramji, K. Suresh Babu, 2007 "Evaluation of fatigue life of aluminum alloys wheels under radial loads”, Engineering Failure Analysis 14

6. Y.H Kim, T.K. Ryou, H.J. Choi, 2002 "An analysis of the forging processes for 6061 aluminum-alloy wheels", Journal of material processing technology

7. N. Satyanarayana, 2012 "fatigue analysis of aluminum alloy wheel under radial load", International journal of mechanical and industrial engineering (IJMIE).

8. U. Kocabicak, M. Firat, 2000 "Numerical Analysis Wheel Cornering Fatigue Tests", Engineering Failure Analysis.

9. Vivek Asnani, Damon Delap, Colin Creager, 2009 "The development of wheels for lunar roving vehicle", Journal of terramechanics.

10. Ravi Lidoriya, Sanjay, Chaithary and Anil Kumar Mhohapatra, 2013 "Design and Analysis of Aluminum Alloy Wheel using PEEK Material", International Journal of Mechanical Engineering and Research.