Modelling & Static Analysis of Automotive Wheel Rim using different materials

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Abstract. In this paper, we compare equivalent stress, Total deformation and equivalent elastic strain in 19-inch wheel rim of MG Gloster by Finite element method. The need of Wheel Rim is to get the stable base on which the tyre mounted. It should acquire the tyre as per the size, dimension, and shape required for the vehicle. Modelling of the rim was done by using 3-D modelling software SOLIDWORKS 2019, whereas the static structural analysis was done by using ANSYS R2 2020. ANSYS WORKBENCH R2 2020 is the software used for regular testing and simulation of materials used for the wheel rim to get the required calculations and result. ANSYS WORKBENCH R2 2020 performed the structural analysis by the material used are structural steel, carbon fiber (Low Grade), Kevlar 29, E-Glass, S-Glass, basalt, Al 6061 T6 and High Strength Low Alloy steel, their relative performances have observed respectively. The analysis is carried out for tyre inflation pressure, rotational velocity and moment condition. This analysis carried out to find the best material out of the listed materials for the wheel rim that gives optimum results for making an effective rim structure.

Keywords: Wheel rim, Static Analysis, ANSYS R2 2020, FEM, 3D Design.

1. Introduction

The terms "wheel" and "rim" are generally considered as the words which nearly have the same meaning but it isn’t so. Rim is the metal part where tyre is mounted. Proper fitting of the tyre to the rim is needed to be ensured [1]-[2]. Wheels are required to be strong and light enough so that it can support the vehicle and all the forces that act on the wheel [3]. Maximum Pressure inside the tyre and the rim is 0.241 MPa and this pressure mostly occurs while refilling the air [4]-[5]. Wheels have various applications in such as bikes, cars, aerospace etc. [6]. Wheel rim is considered to be the most important part of the assembly in the vehicle, that’s the reason why it’s made with practicality so that one can get best out of it [7]. Major factors that can cause damage to the rim are rust, excessive radial load, cracks and dents etc. [8]-[9]. These all can cause huge damages such as instability, excessive vibrations, loss of air present in
tyres and many times can cause structural failure [10]. So, focusing on these issues we have some more promising and long-lasting solution without compromising to safety [11]. This analysis will help to predict the best material for the rim out of the listed materials without compromising the performance and safety. The Automotive wheel is one of the indispensable parts of the vehicle frame at a different offset of wheel [12]. The offset of the wheel rim is the distance between the hub surface to the center of the wheel, as illustrated in figure 1.

Figure 1. Wide drop center of the hump wheel [13]

1.1. Materials Selected
Different types of materials have been selected and used for a 3D model of the rim.

List of materials used for the analysis are:

1. Al 6061 T6
2. Structural Steel
3. Kevlar 29
4. S-Glass
5. E-Glass
6. Basalt Fiber
7. Carbon Fiber
8. HSLA Steel

Table 1. Properties of Materials

| S.No | Materials      | Density (kg/m³) | Young's Modulus (GPa) | Poisson's Ratio |
|------|---------------|----------------|----------------------|----------------|
| 1    | Al 6061 T6    | 2703           | 69                   | 0.33           |
| 2    | Structural Steel | 7850          | 200                  | 0.3            |
| 3    | Kevlar 29     | 1440           | 70.5                 | 0.37           |
| 4    | S-Glass       | 2500           | 90                   | 0.22           |
| 5    | E-Glass       | 2600           | 73                   | 0.22           |
| 6    | Basalt Fiber  | 2630           | 89                   | 0.2            |
| 7    | Carbon Fiber  | 1800           | 290                  | 0.2            |
| 8    | HSLA Steel    | 7800           | 190                  | 0.28           |

Properties of selected materials for the analysis of rim as shown in Table 1.

1.2. Modeling of Rim
Rim was designed by using 3D modeling software solid works, 2019 version [14]- [15].

Table 2. Dimension of the Rim

| S.No. | Specifications       | Value(mm) |
|-------|----------------------|-----------|
| 1     | Rim Width            | 256       |
| 2     | Rim Diameter         | 482       |
| 3     | Offset               | 20        |
| 4     | No. of Spokes        | 8         |
| 5     | Rim Thickness        | 5         |
| 6     | Bolt Diameter        | 24        |
| 7     | No. of Bolt Holes    | 5         |
| 8     | Central Hole Diameter| 60        |
| 9     | Diameter of Stud Hole| 163       |

Various steps used to create the 3D model of rim modelling. As figure 2. indicates the flange part of the rim which is a design by using revolve command whereas figure 3. illustrate the flange part with the hub designed by using extrude command and Figure 4. gives the complete design of the rim and its cuts by using extrude cut command.

Figure 2.(Step1)          Figure 3.(Step2)          Figure 4.(Step3)

The paper aims to analyze different properties in different materials selected for the rim.
2. Finite Element Analysis of Rim:

2.1. Boundary Conditions

- Fixed support is given to the five stud holes because the wheel fixed upon axle through bolts on stud holes.
- By considering the diameter of the rim as 482 mm, the rotational velocity of the rim considered as 4000 rpm. This is the maximum rpm at which the M.G Gloster runs.
- The taken value of moment for the rim is 5.0969e+5 Nmm as stated in AIS- 073 (part 2).
- There is the presence of 0.241 MPa, which acts normally on the circumferential tread and flange position of the rim. This pressure usually occurs at the time of refilling of air.
- Frictionless support applied to the central hub part of the rim [16].

![Figure 5. Applied Boundary Conditions](image1.png)

A denotes Moment, B denotes Pressure, C denotes Rotational Velocity, D denotes Frictionless support and E denotes Fixed Support applied on the rim respectively.

3.1. Analysing Testing Result of Al 6061 T6

3.1.1. Total Deformation

The Max. And Min. Total Deformation in Al 6061 T6 is 0.2684 mm and 0 mm respectively shown in Figure 6. The Minimum deformation is 0 mm because there is no deformation occur at the hub part of the rim.

![Figure 6. Total Deformation in Al 6061 T6](image2.png)
3.1.2. Stress Distribution

The Max. and Min. Stress Distribution in Al 6061 T6 is 63.7 MPa and 0.3898 MPa respectively shown in Figure 7.

![Figure 7. Stress Distribution in Al 6061 T6](image)

3.1.3. Strain Distribution

The Max. and Min. Strain Distribution in Al 6061 T6 is 0.00096883 and 0.0000076477 respectively shown in Figure 8.

![Figure 8. Strain Distribution in Al 6061 T6](image)

3.2. Analysing Testing Result of Structural Steel

3.2.1. Total Deformation

The Max. and Min. Total Deformation in Structural Steel is 0.18644 mm and 0 mm respectively shown in Figure 9. The Minimum deformation is 0 mm because there is no deformation occur at the hub part of the rim.

![Figure 9. Total Deformation in Structural Steel](image)
3.2.2. Stress Distribution
The Max. and Min. Stress Distribution in Structural Steel is 183.73 MPa and 1.8481 MPa respectively shown in Figure 10.

![Stress Distribution in Structural Steel](image)

Figure 10. Stress Distribution in Structural Steel

3.2.3. Strain Distribution
The Max. and Min. Strain Distribution in Structural Steel is 0.0010678 and 0.000012423 respectively shown in Figure 11.

![Strain Distribution in Structural Steel](image)

Figure 11. Strain Distribution in Structural Steel

3.3. Analysing Testing Result of Kevlar 29
3.3.1. Total Deformation
The Max. and Min. Total Deformation in Kevlar 29 is 0.19844 mm and 0 mm respectively shown in Figure 12. The Minimum deformation is 0 mm because there is no deformation occur at the hub part of the rim.

![Total Deformation of Kevlar 29](image)
3.3.2. Stress Distribution
The Max. and Min. Stress Distribution in Kevlar 29 is 36.704 MPa and 0.26231 MPa respectively shown in Figure 13.

3.3.3. Strain Distribution
The Max. and Min. Strain distribution in Kevlar 29 is 0.00054321 and 0.000005542 respectively shown in Figure 14.
3.4. Analysing Testing Result of S-Glass

3.4.1. Total Deformation

The Max. and Min. Total Deformation in S-Glass is 0.18974 mm and 0 mm respectively shown in Figure 15. The Minimum deformation is 0 mm because there is no deformation occur at the hub part of the rim.

![Figure 15. Total Deformation in S-Glass](image)

3.4.2. Stress distribution

The Max. And Min. Stress distribution in S-Glass is 59.887 MPa and 0.3646 MPa respectively shown in Figure 16.

![Figure 16. Stress distribution in S-Glass](image)

3.4.3. Strain Distribution

The Max. and Min. Strain distribution in S-Glass is 0.00069941 and 0.000005478 respectively shown in Figure 17.

![Figure 17. Strain Distribution in S-Glass](image)
3.5. Analysing Testing Result of E-Glass

3.5.1. Total Deformation

The Max. and Min. Total Deformation in E-Glass is 0.23872 mm and 0 mm respectively shown in Figure 18. The Minimum deformation is 0 mm because there is no deformation occur at the hub part of the rim.

![Figure 18. Total Deformation in E-Glass](image18)

3.5.2. Stress Distribution

The Max. and Min. Stress Distribution in E-Glass is 62.053 MPa and 0.37676 MPa respectively shown in Figure 19.

![Figure 19. Stress Distribution in E-Glass](image19)

3.5.3. Strain Distribution

The Max. And Min. Strain Distribution in E-Glass is 0.0008937 and 0.0000069443 respectively shown in Figure 20.
3.6. Analysing Testing Result of Basalt Fiber

3.6.1. Total Deformation

The Max. And Min. Total Deformation in Basalt Fiber is 0.19542 mm and 0 mm respectively shown in Figure 21. The Minimum deformation is 0 mm because there is no deformation occur at the hub part of the rim.

3.6.2. Stress Distribution

The Max. And Min. Stress Distribution in Basalt Fiber is 62.804 MPa and 0.37819 MPa respectively shown in Figure 22.
3.6.3. Strain Distribution

The Max. And Min. Strain Distribution in Basalt Fiber is 0.00074223 and 0.0000057032 respectively shown in Figure 23.

3.7. Analysing Testing Result of Carbon Fiber

3.7.1. Total Deformation

The Max. And Min. Total Deformation in Carbon Fiber is 0.68523 mm and 0 mm respectively shown in Figure 24. The Minimum deformation is 0 mm because there is no deformation occur at the hub part of the rim.
3.7.2. Stress Distribution
The Max. And Min. Stress Distribution in Carbon Fiber is 97.378 MPa and 0.28227 MPa respectively shown in Figure 25.

3.7.3. Strain Distribution
The Max. And Min. Strain Distribution in Carbon Fiber is 0.0024296 and 0.000021423 respectively shown in Figure 26.
3.8. Analysing Testing Result of HSLA Steel

3.8.1. Total Deformation

The Max. And Min. Total Deformation in HSLA Steel is 0.19371 mm and 0 mm respectively shown in Figure 27. The Minimum deformation is 0 mm because there is no deformation occur at the hub part of the rim.

![Figure 27. Total Deformation in HSLA Steel](image)

3.8.2. Stress Distribution

The Max. And Min. Stress Distribution in HSLA Steel is 181.96 MPa and 1.2159 MPa respectively shown in Figure 28.

![Figure 28. Stress Distribution in HSLA Steel](image)

3.8.3. Strain Distribution

The Max. And Min. Strain Distribution in HSLA Steel is 0.0011085 and 0.00000815 respectively shown in Figure 29.

![Figure 29. Strain Distribution in HSLA Steel](image)
4. Result Table:

Table 3. Results obtain from different materials

| S.No | Materials    | Total Deformation (mm) | Equivalent Stress(MPa) | Equivalent Strain |
|------|--------------|------------------------|------------------------|-------------------|
|      |              | Max.       | Min.    | Max.       | Min.    | Max.       | Min.    |
| 1    | Al 6061 T6  | 0.2684     | 0       | 63.7       | 0.3898  | 0.0009688  | 0.000007647 |
| 2    | Structural Steel | 0.18644  | 0       | 183.73     | 1.8481  | 0.0010678  | 0.000012423 |
| 3    | Kevlar 29   | 0.19844    | 0       | 36.704     | 0.26231 | 0.0005432  | 0.000005542 |
| 4    | S-Glass     | 0.18974    | 0       | 59.887     | 0.3646  | 0.0006994  | 0.000005478 |
| 5    | E-Glass     | 0.23872    | 0       | 62.053     | 0.37676 | 0.0008937  | 0.000006944 |
| 6    | Basalt Fiber| 0.19542    | 0       | 62.804     | 0.37819 | 0.0007422  | 0.000005703 |
| 7    | Carbon Fiber| 0.68523    | 0       | 97.378     | 0.28227 | 0.0024296  | 0.000021423 |
| 8    | HSLA Steel  | 0.19371    | 0       | 181.96     | 1.2159  | 0.0011085  | 0.00000815  |

The Analysis report of maximum total deformation, maximum equivalent stress and maximum equivalent strain is presented below in bar graphs:

4.1. Maximum Total Deformation:

Maximum Total Deformation is shown in carbon fiber i.e. 0.68523 mm and it is shown at the upper flange part of the rim.
4.2. Maximum Equivalent Stress

Maximum Equivalent Stress is shown in Structural Steel i.e. 183.73 MPa and it is shown at the hub part of the rim.

4.3. Maximum Equivalent Strain

Maximum Equivalent Stress is shown in Carbon Fiber (Low Grade) i.e. 0.0024296 and it is shown in the upper flange part of the rim.
5. Conclusion

Conclusion derived from the work performed above are-

I. Wheel rim is acts as a primary suspension which directly absorbs shock & vibrations produced by uneven road conditions.

II. The main aim of analyzing wheel rim on different materials is to find out the most feasible material within the set boundary condition.

III. After analyzing Al-6061 T6, Structural steel, Kevlar 29, S Glass, E- Glass, Basalt Fiber, Carbon Fiber, HSLA steel, it has been observed that maximum value of total deformation observed in carbon fiber 0.68523 mm, equivalent stress -stain value 97.378 MPa, 0.0024296, which make it a least preferable material for wheel rim. The reason behind it's less suitability as a rim material is that we have used low grade carbon fiber for analyzing wheel rim. For future work, the different grades of carbon fiber can be analyze to get better results under same boundary conditions. Whereas structural steel, basalt, Kevlar 29, S- glass are the most feasible material option for wheel rim.

IV. After comparing the result obtained within the set boundary condition, Kevlar 29 appears to be the most feasible option for wheel rim design as its maximum- minimum values of Total Deformation (0.19844,0) mm, Equivalent Stress (36.704, 0.26231) MPa and equivalent strain (0.0005432, 0.000005542) respectively.

V. Apart from structural steel, materials like s- glass, e-glass, Kevlar 29, HSLA steel, carbon fiber and all others mentioned above are less susceptible for corrosion.

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