INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING
WWW.IJRAME.COM
ISSN (ONLINE): 2321-3051

Vol.13 Issue 4,
April 2025
Pg:- 01 – 13

DESIGN, ANALYSIS AND OPTIMIZATION OF THE WHEEL RIM

Rajesh Khatiwada[1], Sandip Giri[2], Raju Khadka[3], Chiranjeevi Mahat[4]

[1]Rajesh Khatiwada, khatiwada.rajesh1998@gmail.com
[2]Sandip Giri, girisandeep02@gmail.com
[3]Raju Khadka, rajkhadka478@gmail.com
[4]Assitant Professor ChiranjeeviMahat, chiranjeevi.mahat@ku.edu.np
Author Correspondence: Department of Mechanical Engineering, Kathmandu University, Dhulikhel, Nepal

Abstract

This project presents a comprehensive study on the design, analysis, and weight optimization of a wheel rim using SolidWorks and ANSYS. The primary focus is to assess key performance parameters such as stress distribution, displacement, and fatigue life to ensure reliability under various loading conditions. Different materials, including steel alloy, aluminum alloy, magnesium alloy, and forged steel, were evaluated for their suitability in manufacturing lightweight, durable wheel rims. Through detailed simulations, the study identified the most efficient material for balancing strength, weight, and cost. The findings reveal that steel alloy offers the best combination of performance in terms of stress distribution, deformation, and weight, making it the most suitable material for modern wheel rim applications. The optimization process further explores the potential of reducing weight while maintaining structural integrity, with promising results for improving fuel efficiency and vehicle performance.

***Keywords**:* Wheel Rim, Stress Analysis, SolidWorks, ANSYS, Steel Alloy, Weight Optimization

1. Introduction

The wheel rim is one of the most essential components in any vehicle, acting as a bridge between the hub and the tire. It must support vehicle loads, maintain tire positioning, and endure various forces during dynamic driving conditions. A well-designed rim improves performance, handling, and safety. With growing demand for better fuel efficiency and vehicle dynamics, automotive industries are continuously seeking ways to reduce the unsprung weight of vehicles, and optimizing the wheel rim plays a crucial role in this endeavour.
Advancements in computer-aided design (CAD) and finite element analysis (FEA) have allowed engineers to model, analyze, and refine components with high precision. These tools help identify stress points, deformation under load, and fatigue behaviour, which are critical in evaluating the performance of rims under realistic conditions. Furthermore, the selection of lightweight and durable materials is vital to meet design requirements without compromising safety.
In recent years, materials such as magnesium alloy, aluminum alloy, and carbon fiber have been considered due to their lightweight nature and adequate strength characteristics. However, trade-offs among cost, manufacturability, and performance demand a detailed comparative study to select the most appropriate material.
This paper focuses on the design and structural optimization of a wheel rim using SolidWorks and ANSYS. The work involves modelling a typical passenger vehicle rim, analyzing its behaviour under applied loads, and

comparing the performance of three different materials. The aim is to determine the optimal material and design configuration for improved durability and reduced weight.

2. Literature Review

A study by Meghashyam focused on the structural design and stress analysis of a car wheel rim using advanced modeling and simulation tools. A disc-type steel rim was first modeled in CATIA and then analyzed using ANSYS under real-world boundary conditions. The main observations included deformation under static loading, equivalent stress, and total strain energy, leading to material selection for improved performance. Forged steel was found to perform better than aluminum in terms of durability, with lower total deformation and stress under identical loading conditions. This study provided insights into the comparative advantage of traditional materials in structural stability [1].Karthi presented a design and structural analysis of a motorcycle alloy wheel rim using PRO-E for CAD modeling and ANSYS for finite element analysis. The study evaluated the performance of aluminum alloy, magnesium alloy, and titanium alloy under various loading scenarios. The results showed that aluminum alloy exhibited high strength, better wear resistance, and dimensional stability. Stress and displacement remained well within safe limits, indicating the suitability of aluminum alloy for motorcycle wheels. This analysis emphasized the significance of selecting the right alloy based on both mechanical performance and weight [2]. Jape carried out a weight optimization study on an aluminum alloy wheel rim, focusing on reducing the mass while ensuring mechanical integrity. A CAD model was developed, and finite element analysis was conducted to measure von Mises stress and fatigue life. The results showed that optimized designs could achieve a weight reduction of up to 50% compared to conventional rims without compromising on safety. The stress levels remained within permissible ranges, and fatigue analysis indicated a satisfactory lifespan under dynamic loads. This study demonstrated the potential of structural optimization for material and cost efficiency in automotive components[3]. In another study, Karthik introduced a hybrid metal composite design for wheel rims aimed at improving ride comfort by enhancing the damping capacity of the rim. The rim was designed in SolidWorks and analyzed in ANSYS, considering materials like aluminum combined with a composite layer. The study specifically analyzed the effects of vertical loading, damping behavior, and stiffness by incorporating a frictional damping layer between two different materials. Results suggested that hybrid structures provided better damping without significantly increasing the weight, thus improving ride quality and vibration resistance. The research presented a new avenue for combining materials in wheel rim design[4]. Babu developed a disc-type wheel rim model using CATIA V5R20 and performed static and fatigue analysis in ANSYS, investigating materials such as aluminum alloy, kevlar49, and carbon fiber. The study compared the mechanical response of each material in terms of equivalent stress, strain, and weight under the same boundary conditions. While aluminum alloy showed balanced performance, carbon fiber offered the lowest weight but raised concerns about cost and fatigue behavior. The study concluded that lightweight composites could be suitable in niche applications but required further testing for large-scale automotive use [5]. Salukhe examined the structural integrity of wheel rims using Creo for design and ANSYS for simulation. The rim design followed aesthetic and manufacturability considerations commonly used in commercial applications. Simulations focused on the deformation and equivalent stress behavior under increased static loading to mimic real-life driving conditions. Among the various materials tested, aluminum alloy offered a good trade-off between strength and weight. The research highlighted the critical role of design features such as rib thickness, fillet radius, and cross-sectional area in managing stress concentration and load-bearing efficiency [6].

IJRAME

INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING
WWW.IJRAME.COM
ISSN (ONLINE): 2321-3051

Vol.13 Issue 4,
April 2025
Pg:- 01 – 13

Table 1 Comparison between rim materials [7]

Factor considered/materials	**aluminium**	**Magnesium alloys**	**Steel C1008**(sheet metal wheel)	**Carbon fiber**	**Forged steel**
Weight	Light	Medium	Heavier than Al and Mg	Light	Heavier than Al and Mg
Appearance	Pleasant	Pleasant	Bright	Somewhat dull	……….
Cost of rim	Costlier	Costlier	Cheap	Costlier	Expensive
Material cost	Costlier	Costlier	Cheap	Costlier	Cheap
Deformation under load	Too much deformation	Less compared to Al	Less as compared to Al and Mg	………..	Less deformation than other materials
Corrosion resistance	Excellent	Excellent	Poor but improved by adding alloys.	excellent	….........
Cast ability	Casted easily	Casted easily	Difficult to cast	……….	………..
Maintenance/Repair of rim	Easy to repair	Cant repaired	………..	……….	………..
Effect on unsprung mass	Reduce	Reduce	More than Al and Mg	……….	More than Al, Mg and steel C1008
Heat dissipation	Better	Best	Good	………..	Good
Durability	As equal to forged rim	Durable	………..	………..	Durable
Mechanical properties	Poor than steel	Poor than steel	As good as forged steel	………..	Better than forged wheels
No. of piece in a rim	If casted single piece &Sheet metal multi piece	Generally casted hence single piece	Generally two piece	………..	Single piece
Ground contact	Regain Easily	Regain Easily	Good ground contact for light weight rims	Better ground contact	Poor ground contact
Flammability	Not Flammable	Flammable	Not Flammable	Flammable	Not Flammable

3. Methodology

3.1 Design Calculations

While working on the project, we made some assumptions that would make the theoretical analysis work more manageable.

Analysis under Tires Air Pressure:

However, 35 psi is the regular inflation pressure setting.

35 Psi = 35x0.4535x9.81/ $(25.4)^2$ = 0.241 Mpa

Analysis under Radial Load

Normal passenger car's weight is approximately = 1500kg

Seating capacity of the car = 5 persons

Approximate weight of each person = 80Kg

Overages added = 100Kg.

The total weight on wheels =2000Kg.

Which is distributed over 4 tires, therefore 500 Kg per tire.

But we assumed for worst case condition considering Braking, Cornering etc. as 700kg of mass Therefore the Maximum vertical load is F= 700x9.81=6867 N

The radial load is calculated by the expression

$$F_r = k.\ F$$

Where F is the highest load carried by the wheel,

k= 2.2 with conformance from SAE, also called an acceleration test factor.

In our analysis,

We considered F=6867N,

Therefore F_r =15107. 4N

= 15.1KN

Angular Velocity (ω):

$\omega = Velocity\ of\ vehicles\ (V)/Radius\ of\ tires\ (r)$

Where,

V = Maximum speed of vehicles i.e. 120 km/hr = 33.33 m/s

r = tires radius = 0.1326

$= \frac{33.33}{0.3126}$

= 106.6 rad/sec

≈ 100 rad/sec

Wheel Rim specification used in the project is:

184-J392 23 5 70

Where 184 = Width of Rim in mm

J = Shape of Flange

392 = Diameter of Rim in mm

23 = positive offset

5 = bolt hole

70 = bolt pitch circle diameter

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April 2025
Pg:- 01 – 13

Table 2 Design parameters of the Wheel Rim

SN	Parameters	Value
1	Rim diameter	392 mm
2	Rim width	184 mm
3	Positive offset	23.1 mm
4	Bolt pitch circle diameter	70 mm
5	Rim thickness	6 mm
6	Bore Diameter (Centre hole)	31.07 mm
7	Bolt hole diameter	15 mm
9	Flange Shape	J
10	No. of bolt holes	5
11	No. of spokes	5

3.2 Design

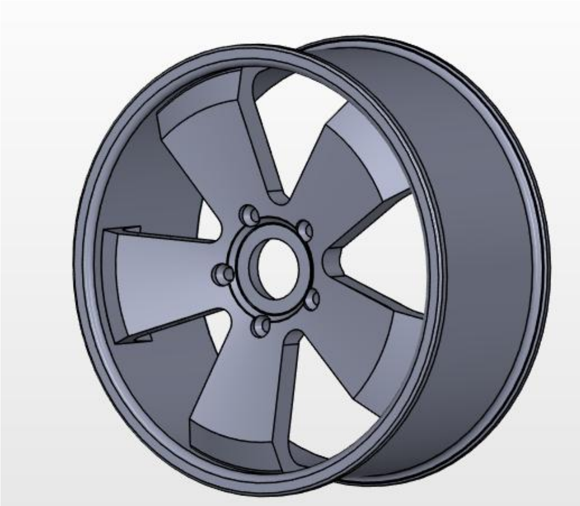

Figure 1 Initial design of wheel rim

3.3 Simulation
Materials selected:

1. Steel Alloy
2. Aluminum Alloy
3. Magnesium Alloy
4. Forged Steel

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WWW.IJRAME.COM
ISSN (ONLINE): 2321-3051

Vol.13 Issue 4, April 2025
Pg:- 01 – 13

Table 3 Materials properties for ANSYS input

Materials	Young's Modulus N / mm^2	Poisson Ratio	Yield stress N / mm^2	Density Kg / m^3
Steel Alloy	$2.34 * 10^5$	0.3	240	7800
Aluminum Alloy	$72 * 10^3$	0.32	160	2800
Magnesium Alloy	$45 * 10^3$	0.281	180	1800
Forged Steel	$21 * 10^4$	0.287	220	7600

After input of those materials properties in the ANSYS workbench for the materials, input of the meshing is started. Tetrahedron meshing is input for the meshing of the initial wheel rim design. After that boundary condition are set. As for the setting of the boundary conditions, fixed point is selected. Wheel rim axle shaft center is selected as a fixed location for the wheel rim. After that, force exerting point is selected to be 15108 N in the project. Wheel rim outer diameter is selected as the force exerted location and finally for the pressure inflation point to be 0.241 Mpa, same location is selected at radial axis. After that necessary output factors like equivalent stress, deformation, strain energy etc. are selected and analysis is ran for the single materials at first. Room temperature of 22^{o}C is selected with 18 as the factor of safety for the simulation. After complete simulation, results are obtained for that and similar types of simulation are ran for the remaining materials as well to obtain results.

4. Results, Analysis and Optimization

4.1 Results

From the conducted simulation of the wheel rim, various and different types of output parameters are obtained for each of the selected materials i.e. steel alloy, aluminum alloy, magnesium alloy and forged steel. Deformation, working von-misses stress, strain energy etc. of the each materials is obtained through the help of input parameters like density, yield stress, young's modulus etc. after obtaining the results; analysis of the results is instigated.

For Steel Alloy:

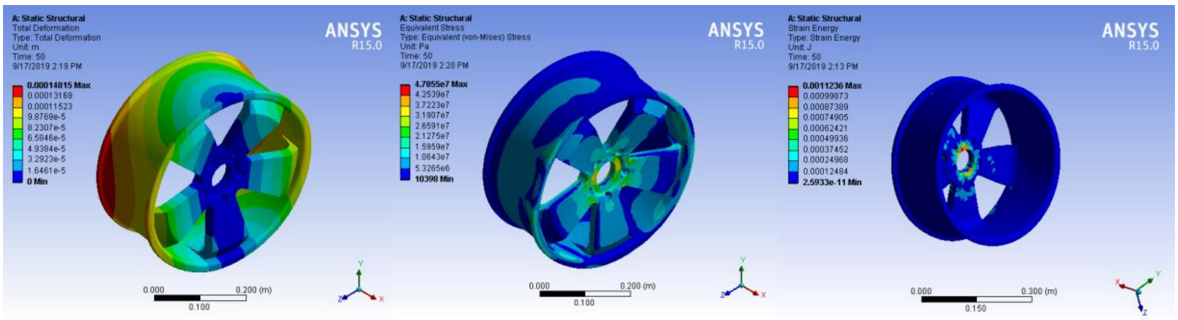

Figure 2 (a) Total Deformation, (b) Equivalent Stress and (c) Strain Energy for Steel Alloy

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ISSN (ONLINE): 2321-3051

Vol.13 Issue 4,
April 2025
Pg:- 01 – 13

For Aluminum Alloy:

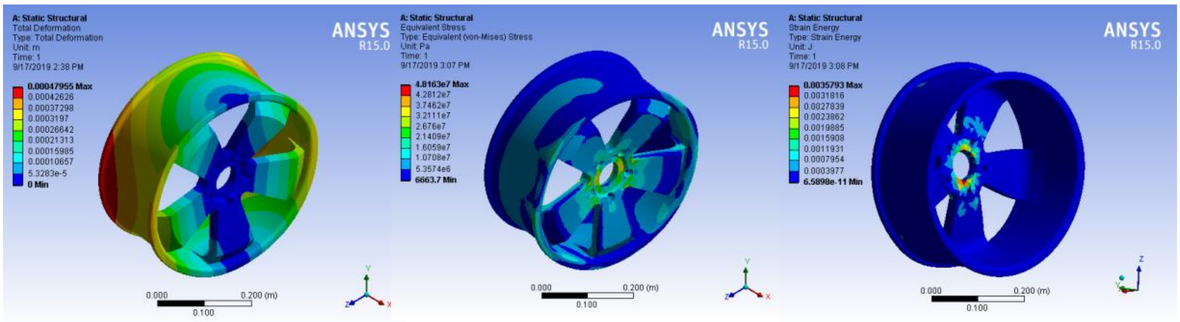

Figure 3 (a) Total Deformation, (b) Equivalent Stress and (c) Strain Energy for Aluminum Alloy

For Magnesium Alloy

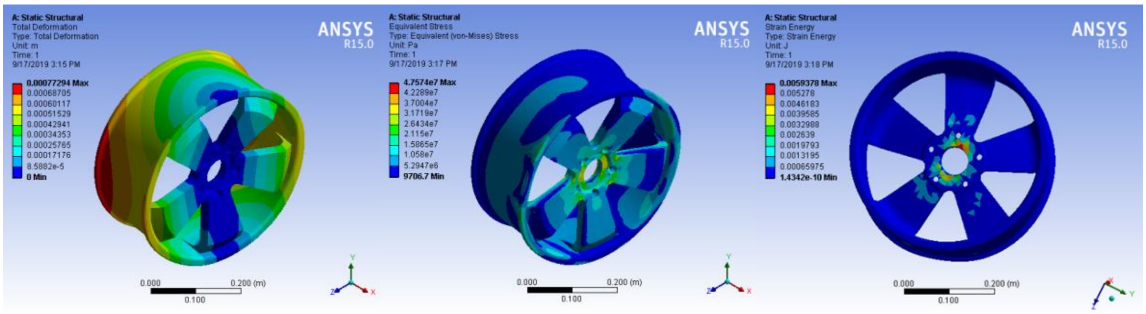

Figure 4 (a) Total Deformation, (b) Equivalent Stress and (c) Strain Energy for Magnesium Alloy

For Forged Steel

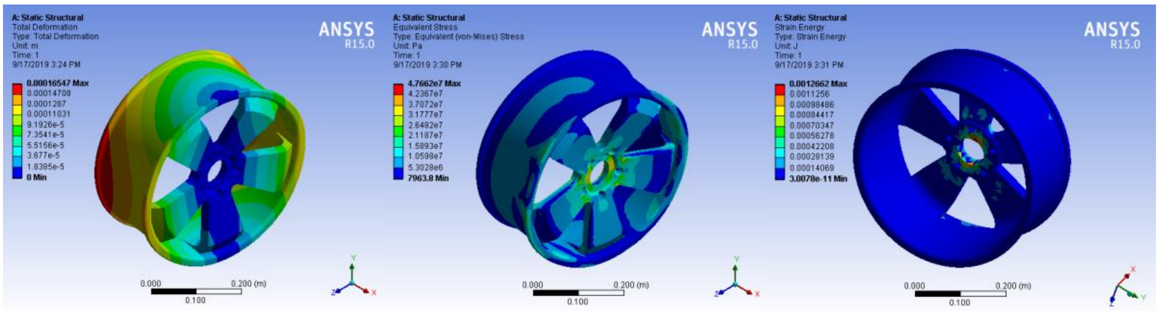

Figure 5 (a) Total Deformation, (b) Equivalent Stress and (c) Strain Energy for Forged Steel

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ISSN (ONLINE): 2321-3051

Vol.13 Issue 4, April 2025
Pg:- 01 – 13

4.2 Analysis

After the collection of the overall results obtained though the conducted simulations; analysis of the obtained results was done. At first, comparison table was created for comparing the outcomes of the four different wheel rim manufacturing materials.

Table 4 Analysis of simulated outcomes based on factors and materials

Materials / Factors	Steel Alloy		Aluminum Alloy		Magnesium Alloy		Forged Steel	
Mass (Kg)	36.51		13.107		8.4257		35.575	
Volume (m^3)	$4.680 * 10^{-3}$		$4.680 * 10^{-3}$		$4.680 * 10^{-3}$		$4.680 * 10^{-3}$	
	Min	Max	Min	Max	Min	Max	Min	Max
Total Deformation (m)	0	$1.48 * 10^{-4}$	0	$4.795 * 10^{-4}$	0	$7.729 * 10^{-4}$	0	$1.654 * 10^{-4}$
Von-misses Stress (Pa)	$10.3 * 10^{3}$	$4.78 * 10^{7}$	6663.7	$4.816 * 10^{7}$	9706.7	$4.75 * 10^{7}$	7963.8	$4.766 * 10^{7}$
Strain Energy (J)	$2.593 * 10^{-11}$	$1.12 * 10^{-3}$	$6.58 * 10^{-11}$	$3.579 * 10^{-3}$	$1.434 * 10^{-10}$	$5.93 * 10^{-3}$	$3.007 * 10^{-11}$	$1.2662 * 10^{-3}$

After completing the preparation of the comparison tables, comparing between the obtained outcomes of different factors for the different materials was started. Mass of the materials was compared and analyzed between the materials. Analysis of the volumes occupied by the design was done. Total deformation of the wheel rim was analyzed for the different materials and categorized them on theirs working level and performances basis. As for the Von-misses stress, analysis and categorization between them was conducted during the analysis. Categorized table was:

Table 5 Comparison between factors and materials performances condition

Conditions / Factors	Best	Better	Good	Worst
Total Mass	Magnesium Alloy	Aluminum Alloy	Forged Steel	Steel Alloy
Total Deformation	Steel Alloy	Forged Steel	Aluminum Alloy	Magnesium Alloy
Von-misses Stress	Magnesium Alloy	Forged Steel	Steel Alloy	Aluminum Alloy

From the conducted categorization, materials properties for the selected factors for the choosing of the best materials was made crystal clear. From the table, it was seen that Magnesium alloy had the low weight mass for the same volume materials of the wheel rim when compared to others materials. It was then followed by the

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Pg:- 01 – 13

aluminum alloy in mass and then by forged steel and last comes the Steel alloy due to its high mass. When they were categorized and analyzed for the total deformation, theirs was occurrences of the less deformation on the steel alloy followed by the forged steel, then aluminum and lastly the magnesium alloy but magnesium alloy comes top when they were divided among the low von-misses stress followed by forged steel and steel alloy and last comes the aluminum alloy. From the obtained outcomes and analysis, it can be said that magnesium alloy was the best materials for the wheel manufacturing looking its best performances on two factors i.e. total mass and von-misses stress but magnesium alloy was the obsolete materials for the wheel manufacturing and it also has very low ductility as well as highest total deformation among all materials. So it couldn't be concluded as best wheel rim manufacturing materials. So taking the account of the total deformation as the influential factors for the optimization, steel alloy was selected as the best materials among all fours even though it had high total mass. As for the optimization of the best materials, the main focuses would be on the weight optimization to reduce the high wheel rim mass to the low wheel rim mass for the steel alloy.

4.3 Optimization

After selecting the Steel Alloy as a working materials for the design optimization of the wheel rim, optimization work wasdone. At first, calculation would be conducted to find out the factors and locations for the optimization of wheel rim. Since, total deformation was mainly taken as a vital and most influential factors for the current optimization so from the previously obtained total deformation plot, it was known that there was minimum and very negligible occurrences of the deformation at the center of the wheel rim and section around the bolt joints. So those location was the best for conducting the weight optimization of the wheel rim. So, previous prepared 3D design of the wheel rim was taken and then design optimization was started. Hit and trail methods was utilized during the design optimization of the steel alloy wheel rim. Seeing the low deformation around the center area of the wheel rim; mainly on the bolt and shaft location, optimization was started. At first, thickness of the wheel rim center was optimized. ANSYS simulation was conducted for the decrement in three thickness i.e. 1.5 mm, 3 mm and 5 mm respectively out of 20 mm thickness.

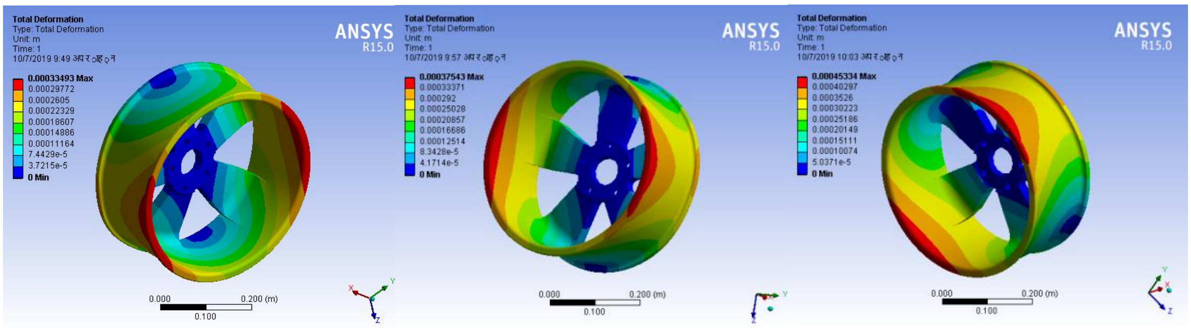

Figure 6 Total deformation of the thickness decrement (a) by 1.5 mm (b) by 3 mm (c) by 5mm

Table 6 Mass and deformation comparison between initial design and optimized design

Decrement	Mass (kg)	Total Deformation (m) (* 10^{-4})
Initial Design	36.511	1.4815
Decreased by 1.5 mm	36.396	3.3493
Decreased by 3 mm	36.277	3.7543

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ISSN (ONLINE): 2321-3051
Vol.13 Issue 4, April 2025
Pg:- 01 – 13

From the obtained outcomes of the conducted simulation and values tabulated above shows the gradual decrement in the mass which is main focus for the optimization but there is also gradual increment in the total deformation values of the steel alloy wheel rim. Even though there is weight reduction but increment in the deformation is main factors for the optimization so increasing total deformation signifies that risk increases even though there is decrement in the masses so conducted simulation cannot be utilized as the optimization of the steel alloy wheel rim. So new optimized design should be designed again. During the initial design static analysis,there is low deformation in the spokes of the wheel rim. As for the new optimized design, it is created with the 5 holes in every spokes of 15.77 mm and simulation is conducted in the ANSYS.

For the holes in every spokes:

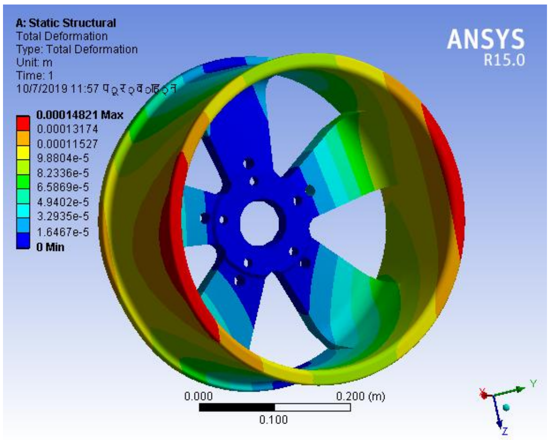

Figure 7 Total Deformation of the final optimized design

Table 7 Mass/deformation comparison between initial design and final optimized design

Changes in design	Mass (kg)	Total Deformation (m) (* 10^{-4})
Initial Design	36.511	1.4815
Holes in every spokes	36.314	1.4821

Increment in the total deformation:

$$= \frac{1.4821 - 1.4815}{1.4815} * 100\%$$

= 0.040%

Total Mass reduction:

$$= \frac{36.511 - 36.314}{36.511} * 100\%$$

=0.5395%

Even though there is slight increment in the total deformation of the optimized design of steel alloy wheel rim when compared initial design but it is negligible compared to the weight reduction of the optimized design

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WWW.IJRAME.COM
ISSN (ONLINE): 2321-3051

Vol.13 Issue 4,
April 2025
Pg:- 01 – 13

when compared with the initial design since main motto of the optimization is weight optimization of the wheel rim. There is reduction of 197 gram weight of the optimized wheel rim compared with the initial wheel rim design. So finally, optimized wheel rim design is obtained for the project.

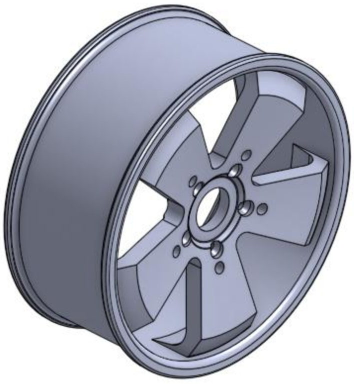

Figure 8 Optimized and final design of the wheel rim

4. Conclusion

This project successfully investigated the design, analysis, and weight optimization of a wheel rim using SolidWorks and ANSYS. An extensive literature review provided foundational understanding on wheel rim functionality, materials, and manufacturing processes. A standard passenger vehicle rim was modeled in SolidWorks, and four different materials—aluminum alloy, magnesium alloy, forged steel, and steel alloy—were evaluated under static structural conditions in ANSYS. Among these, steel alloy exhibited the most favorable performance based on stress distribution and total deformation.

To improve efficiency, a weight optimization approach was carried out by modifying the geometry of the steel rim. Specifically, holes of 15.77 mm diameter were introduced in each of the five spokes. The simulation results confirmed that this optimized design achieved a weight reduction of 197 grams (0.54%) with only a minimal increase in deformation, making it suitable for real-world applications while maintaining structural integrity.

The study provided several key insights: a comparative material analysis for wheel rim design, identification of the optimal material, and successful execution of a lightweight design. However, it is worth noting that the analysis was limited to static conditions. Future research could incorporate dynamic analysis and fatigue testing to simulate actual driving scenarios more accurately. Furthermore, integrating hybrid materials or exploring additive manufacturing techniques may unlock additional possibilities for performance enhancement and sustainability in automotive component design.

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Pg:- 01 – 13

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Pg:- 01 – 13

A Brief Author Biography

Rajesh Khatiwada Received his Bachelor of Engineering (B.E.) in Mechanical Engineering from Kathmandu University in 2019. During his undergraduate studies, he was actively involved in multiple design and fabrication projects, with a strong focus on mechanical systems optimization. He later pursued a Post Graduate Certificate in Applied Manufacturing Management from Lambton College, Canada, where he expanded his knowledge in industrial practices, lean manufacturing, and production systems. His academic interests lie in mechanical design, manufacturing optimization, and the integration of modern tools in engineering problem-solving.

SandipGiri Earned his Bachelor of Engineering in Mechanical Engineering from Kathmandu University in 2019. As a dedicated student, he gained valuable experience in design and analysis software, and contributed to multiple group projects throughout his studies. His role in the final-year project focused on applying engineering principles to optimize structural components for automotive applications. Sandip maintains an interest in mechanical design and material optimization.

RajuKhadka Graduated with a Bachelor of Engineering in Mechanical Engineering from Kathmandu University in 2019. With a strong academic interest in mechanical systems and applied mechanics, he actively participated in collaborative research and design projects. For his final-year project, he worked alongside his peers on the design and optimization of a wheel rim, focusing on structural integrity and weight reduction. His academic background reflects a solid grounding in core mechanical engineering principles.

Chiranjeevi Mahat Professor Chiranjeevi Mahat is an Assistant Professor at the Department of Mechanical Engineering, Kathmandu University, Nepal. With extensive experience in mechanical system design and applied research, Professor Mahat has guided numerous undergraduate and graduate research projects. His supervision and insightful guidance were instrumental in shaping the development and successful completion of this study.