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Comparative Analysis of Steel Wheel Rim & Alloy Wheel Rim of a Car with Respective Materials

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Abstract: This project conducts a comparative analysis of steel and alloy wheel rims for the Maruti Suzuki Baleno Sigma and Alpha variants. The aim is to assess the performance and suitability of these rim types for the specific vehicle models. Through a systematic examination of design considerations, structural analysis, and overall performance evaluation, the project provides valuable insights into the characteristics and capabilities of Carbon steel and Aluminium alloy wheel rims. CAD modeling, finite element analysis (FEA), and performance assessment techniques are employed to analyze stress distribution, strain levels, and deformation patterns. By understanding the differences and performance attributes of steel and alloy rims, the project assists in enhancing the overall performance and aesthetics of the vehicles.
Keywords: Wheel rims, Carbon steel, Aluminium Alloy, CAD, FEA.

I. INTRODUCTION

The selection of wheel rims for automobiles is a critical decision, as it significantly influences the vehicle's performance, safety, and aesthetics. Two popular options in the market are steel wheel rims and alloy wheel rims. While steel rims have traditionally been used for their durability and cost-effectiveness, alloy rims offer advantages in terms of weight reduction, improved fuel efficiency, and enhanced styling options. This project gives comparative analysis between steel wheel rims and alloy wheel rims.

The study involves a detailed examination of their design considerations, static structural analysis, Dynamic stress analysis , Modal analysis and harmonic response. The focus is on studying and analyzing the steel wheel rim and alloy wheel rim used in the Maruti Suzuki Baleno Sigma and Alpha variants. CAD modeling software, such as Creo Parametric, is utilized to create accurate 3D models of representative steel and alloy wheel rims. Finite Element Analysis (FEA) employed using ANSYS Workbench to simulate the structural behavior of the rims under various loading conditions.

Additionally, harmonic response and vibration analysis is carried out to study the dynamic behavior and potential resonant frequencies of the rims.Furthermore, a study on the fatigue life of both types of rims will be conducted, considering cyclic loading, material properties, and stress distribution. This investigation estimates the expected fatigue life and assesses the durability of the rims under typical operating conditions.

II. MATERIAL SELECTION

Maruti Suzuki (Variants)	Sigma	Alpha
Wheel Rim Type	Steel Wheel Rim	Alloy Wheel Rim
Material	Carbon Steel	Aluminum Alloy
Density	7.85 g/cm³	2.8 g/cm³
Young's Modulus	200 GPa	73.1 GPa
Poisson's Ratio:	0.266	0.33
Yield Stress	250 MPa	505 MPa

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A. Compositions

1) Alloy Wheel Rims

a) Aluminum: Typically 90-95%
b) Magnesium: Typically 2-5%
c) Silicon: Typically 1-3%
d) Other metals: Typically 1-2% (such as copper, nickel, and zinc).

2) Steel Wheel Rims

a) Iron: Typically 97-99%
b) Carbon: Typically 0.2-0.5%
c) Manganese: Typically 0.5-1.2%
d) Other metals: Typically 0.2-0.5% (such as chromium, nickel, and copper)

The alloy compositions play a significant role in determining the material properties and performance characteristics of the wheel rims. Alloy wheel rims, with their aluminum-magnesium-silicon composition, offer lightweight properties, good corrosion resistance, and improved heat dissipation. The addition of other metals helps enhance specific properties such as strength and durability.

Steel wheel rims, primarily composed of iron with carbon, manganese, and other alloying elements, provide high tensile strength, excellent impact resistance, and durability. The carbon content contributes to the hardness and strength of the steel rims. It's important to note that the specific alloy compositions can vary based on the manufacturer and their proprietary formulations.

B. Comparison

1) Steel Wheel Rims

a) Advantages

- *Durability:* Steel wheel rims are known for their strength and durability, making them suitable for heavy-duty applications and rough terrains.
- *Affordability:* Steel wheel rims are generally more affordable compared to alloy rims, making them a cost-effective option for vehicle owners.

b) Disadvantages

- *Weight:* Steel wheel rims are heavier compared to alloy rims, which can affect the overall weight of the vehicle and fuel efficiency.
- *Corrosion:* Steel rims are prone to corrosion, especially in regions with high humidity or salted roads, requiring regular maintenance and protection to prevent rusting.

c) Performance Metrics

- *Tensile Strength:* Steel wheel rims have higher tensile strength, providing excellent load-carrying capacity
- *Impact Resistance:* Steel rims offer superior impact resistance, making them suitable for off-road or rugged driving conditions.
- *Stiffness:* Steel rims have a higher modulus of elasticity, resulting in stiffer overall wheel assemblies.

2) Alloy Wheel Rims

a) Advantages

- *Lightweight:* Alloy wheel rims are significantly lighter than steel rims, improving the vehicle's overall performance, handling, and fuel efficiency.
- *Aesthetics:* Alloy rims offer a wide range of stylish designs and finishes, enhancing the appearance of the vehicle.
- *Corrosion Resistance:* Alloy rims are more resistant to corrosion compared to steel rims, requiring less maintenance and providing longer-lasting aesthetics.

b) Disadvantages

- *Cost:* Alloy wheel rims tend to be more expensive than steel rims due to the higher cost of materials and manufacturing processes.
- *Vulnerability to Damage:* Alloy rims are more susceptible to damage from impacts and potholes compared to steel rims.

c) Performance Metrics

- *Weight Reduction:* Alloy rims contribute to reducing the unsprung weight of the vehicle, leading to improved handling and suspension response.
- *Heat Dissipation:* Alloy rims offer better heat dissipation compared to steel rims, reducing the risk of brake fade during prolonged braking.

III. DESIGN AND MODELING

A. CREO

Creo is a family of Computer-aided design (CAD) apps supporting product design for discrete manufacturers and is developed by PTC. The suite consists of apps, each delivering a distinct set of capabilities for a user role within product development. Creo runs on Microsoft Windows and provides apps for 3D CAD parametric feature solid modeling, 3D direct modeling, 2D orthographic views, Finite Element Analysis and simulation, schematic design, technical illustrations, and viewing and visualization. Creo can also be paired with Mastercam (Machining based software) to machine any designed model in a minimal timeframe

.

B. ANSYS

For doing analysis of the model created in CREO PARAMETRIC, we used the finite element solver ANSYS 19.1. ANSYS is a general purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behavior of these elements and solve them all creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabular or graphical forms.

This type of analysis is typically used for design and optimization of a system that is too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations. ANSYS is the standard FEA teaching tool within mechanical engineering.

1) Geometry of Wheels

a) Steel

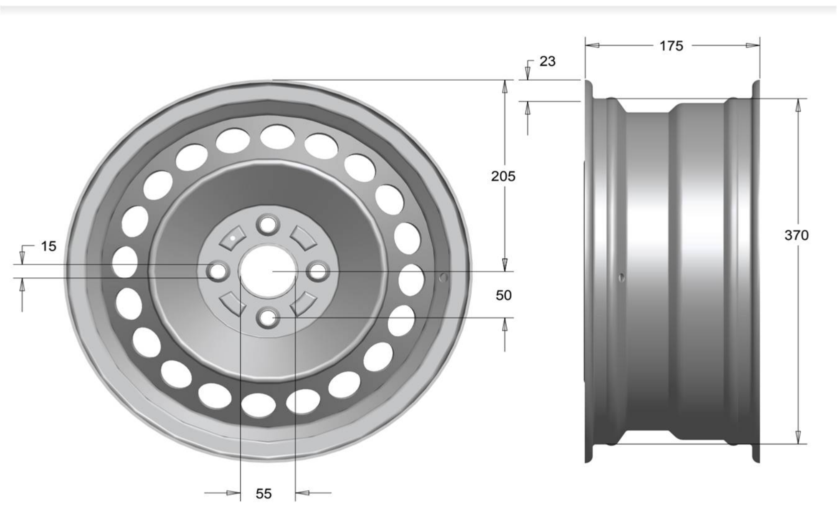

Fig. 3.1.1 steel wheel geometry

2) Material

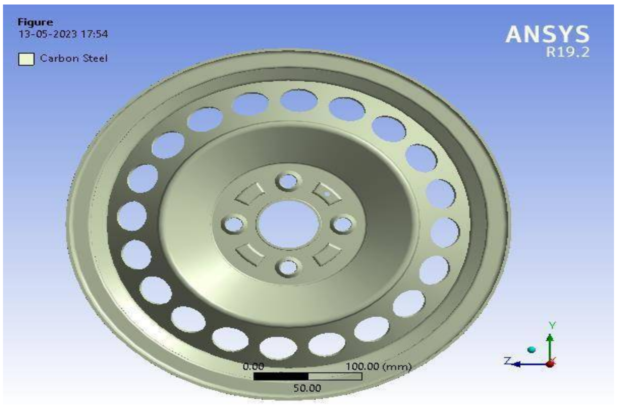

Fig. 3.3. Carbon steel

a) Meshing

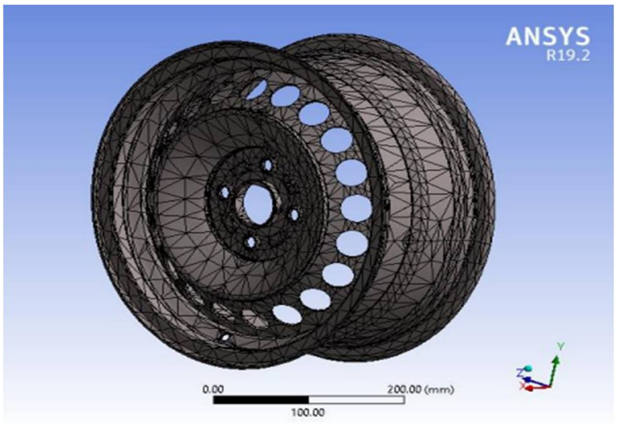

Fig. 3.4. Meshing in steel rim

Nodes: 40684
Elements : 21420

b) Alloy

Fig. 3.2. Alloy wheel geometry

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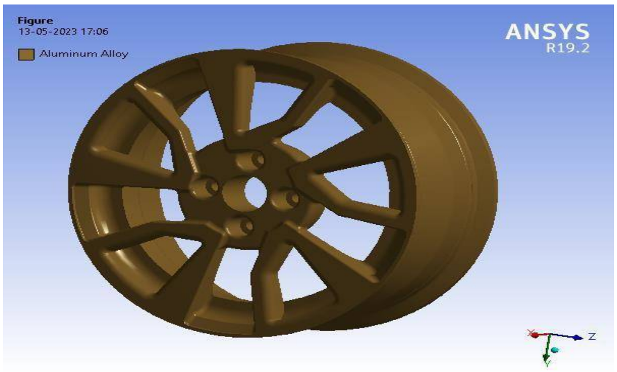


Fig. 3.3. Aluminum Alloy

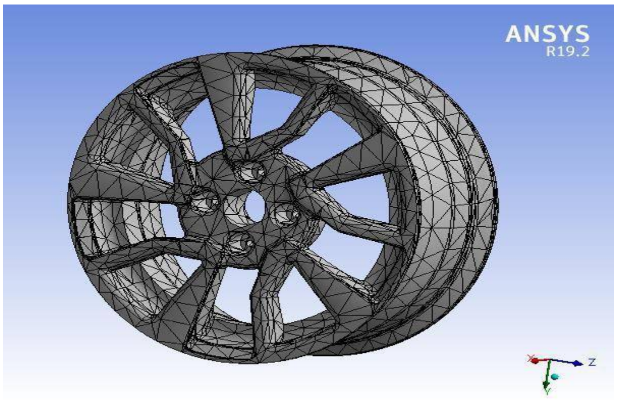


Fig 3.6. Meshing in Aluminium wheel rim

Nodes: 27307
Elements: 15135

IV. ANALYSIS

A. Static structural Analysis

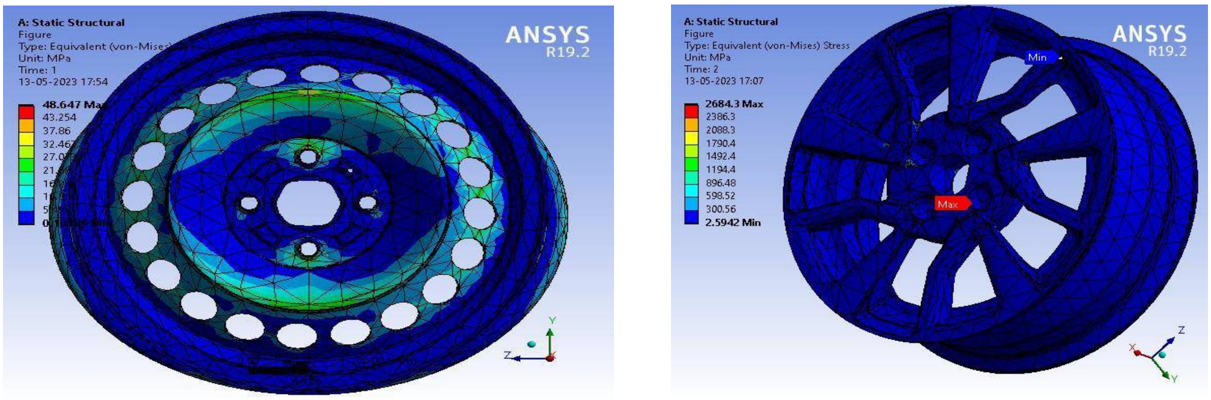


Fig. 4.1.1. Equivalent stress (Von-mises stress)

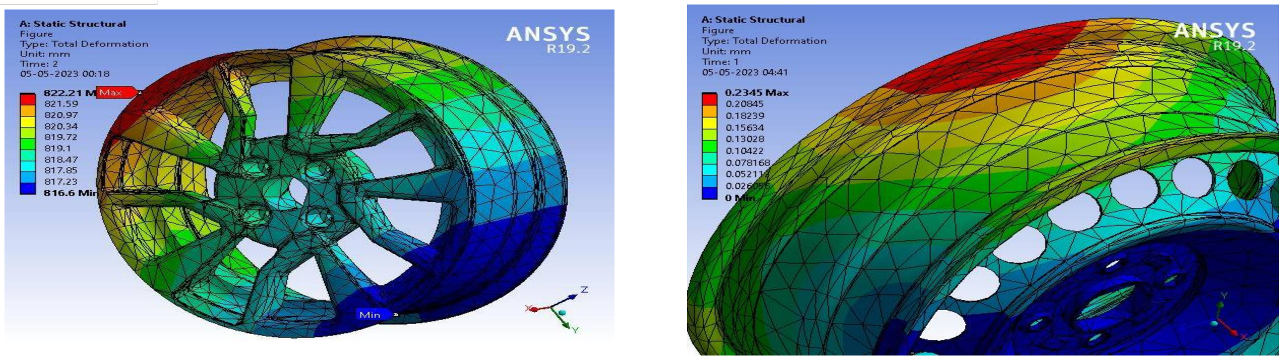


Fig. 4.1.2. Total deformation

B. Modal Analysis

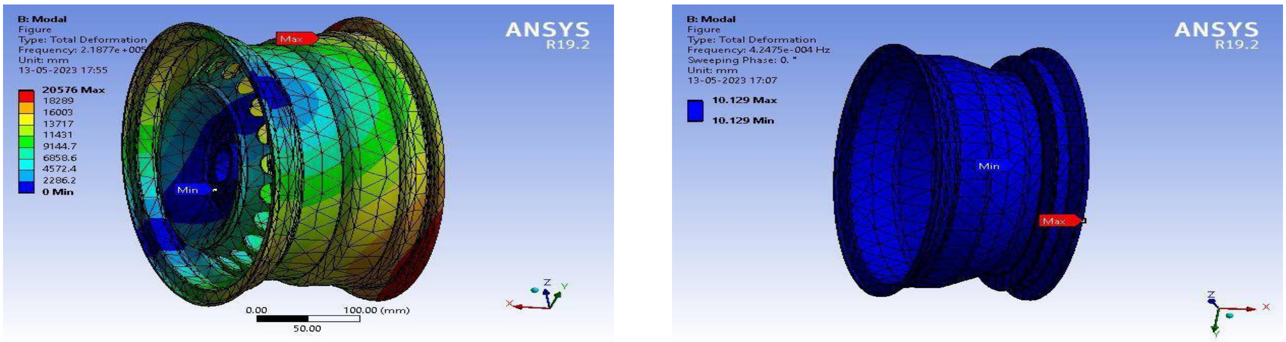


Fig. 4.2.1. Total deformation

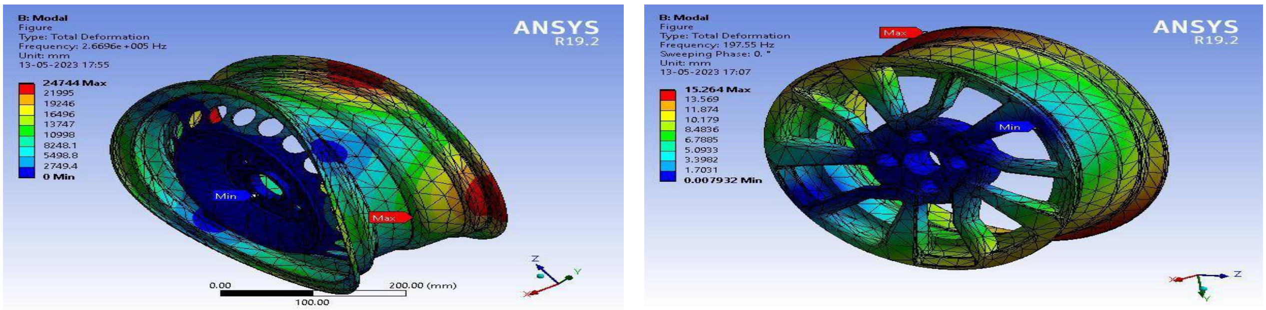


Fig. 4.2.2. Total deformation

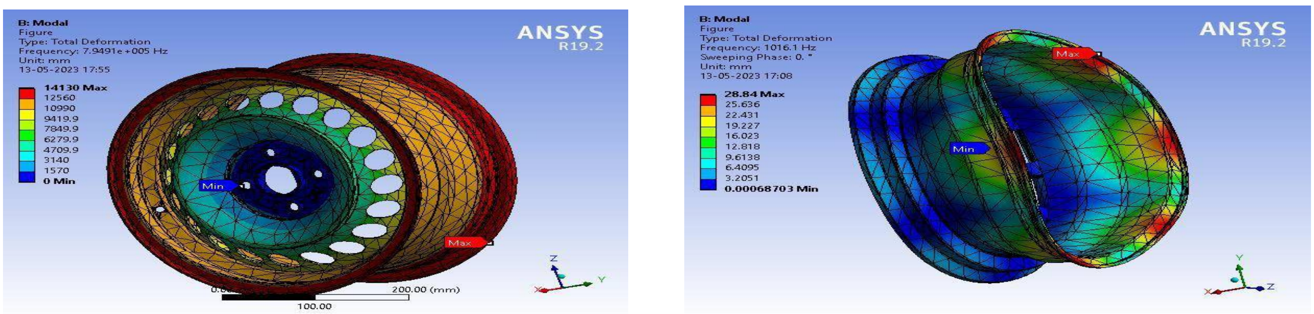


Fig. 4.2.4. Total deformation 4

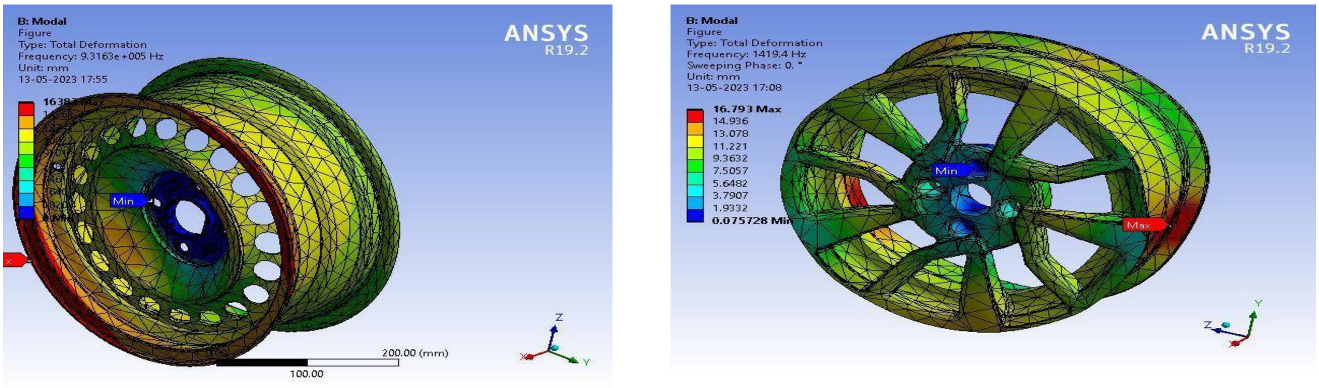
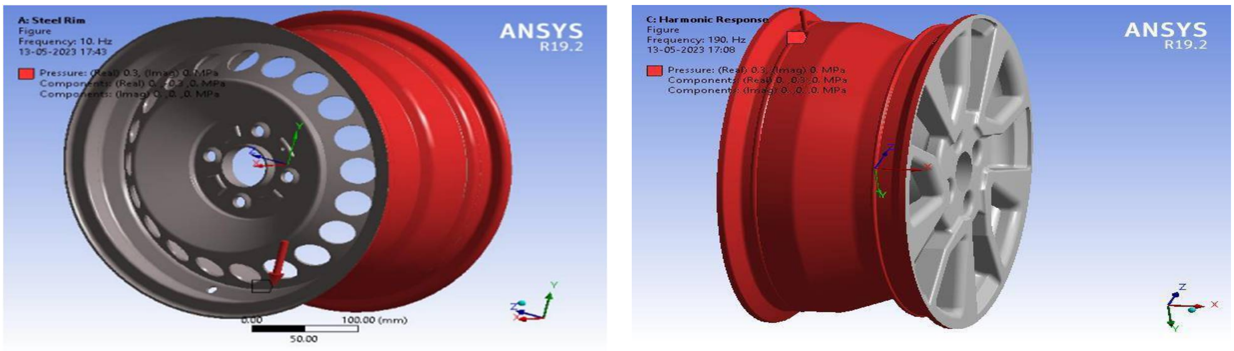


Fig.4.2.5. Total deformation 5

C. *Harmonic Response*



V. RESULTS

A. *Alloy wheel Static Structural results*

Type	Total Deformation	Equivalent (von-Mises) Stress	Maximum Principal Stress	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Shear Stress
			Results			
Minimum	816.6 mm	2.5942 MPa	-2169.6 MPa	5.1788e-005 mm/mm	7.5013e-006 mm/mm	-155.34 MPa
Maximum	822.21 mm	2684.3 MPa	5061.7 MPa	6.1532e-002 mm/mm	4.9137e-002 mm/mm	159.23 MPa
Average	818.98 mm	90.586 MPa	82.011 MPa	1.4457e-003 mm/mm	1.1895e-003 mm/mm	-9.8214e-002 MPa

Minimum Value Over Time						
Minimum	0.26737 mm	4.1186e-002 MPa	-2169.6 MPa	6.738e-007 mm/mm	-1.185e-006 mm/mm	-155.34 MPa
Maximum	816.6 mm	2.5942 MPa	-42.105 MPa	5.1788e-005 mm/mm	7.5013e-006 mm/mm	-4.0706 MPa
Maximum Value Over Time						
Minimum	2.799 mm	55.984 MPa	94.604 MPa	1.1655e-003 mm/mm	9.667e-004 mm/mm	7.9015 MPa
Maximum	822.21 mm	2684.3 MPa	5061.7 MPa	6.1532e-002 mm/mm	4.9137e-002 mm/mm	159.23 MPa

B. Alloy Wheel Modal Analysis Result

Total deformation										
Object No.	1	2	3	4	5	6	7	8	9	10
Results										
Minimum	10.129 mm	1.4017 mm	7.932 e-003 mm	1.5311 e-003 mm	1.3784e-002 mm	4.0214e -003 mm	3.9962e -003 mm	6.870 3e-004 mm	0.2257 mm	7.5728 e-002 mm
Maximum	10.129 mm	13.299 mm	15.264 mm	23.474 mm	15.299 mm	23.777 mm	29.573 mm	28.84 mm	20.078 mm	16.793 mm
Average	10.129 mm	9.4634 mm	5.9321 mm	5.4006 mm	5.8811 mm	5.4133 mm	4.8129 mm	4.8193 mm	10.044 mm	9.2254 mm
Information										
Damped Frequency	4.24 75e-004 Hz	0.64156 Hz	197.55 Hz	331.7 Hz	440.83 Hz	588. Hz	810.99 Hz	1016.1 Hz	1331.5 Hz	1419.4 Hz

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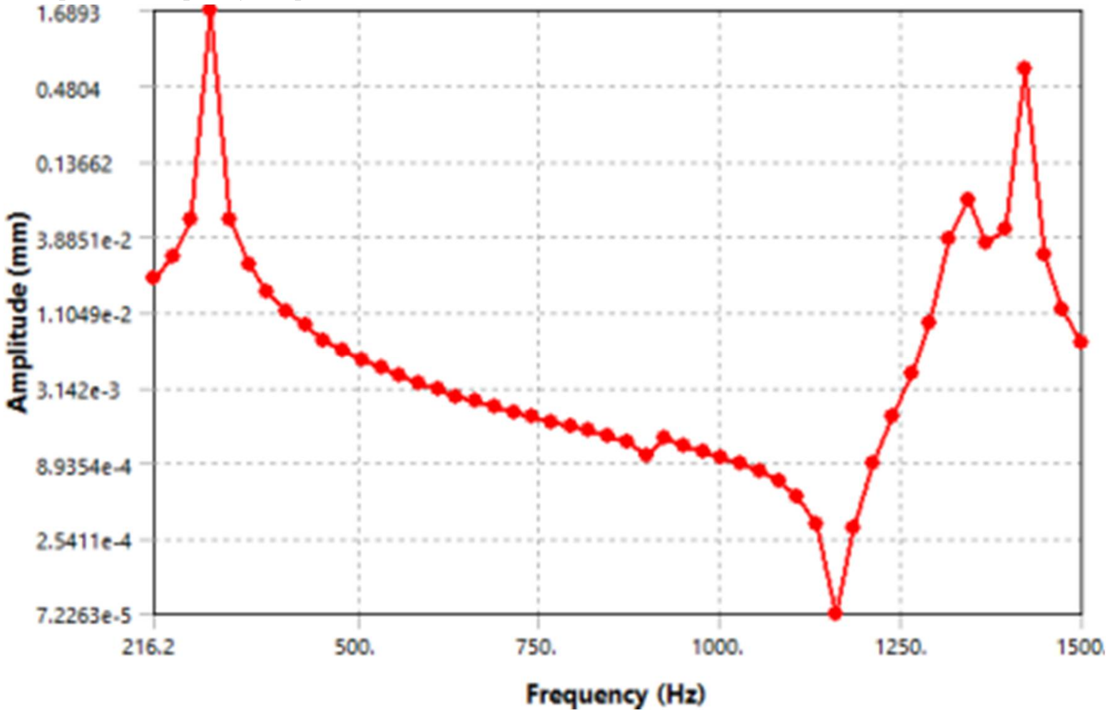
C. Harmonic Response / Frequency Response



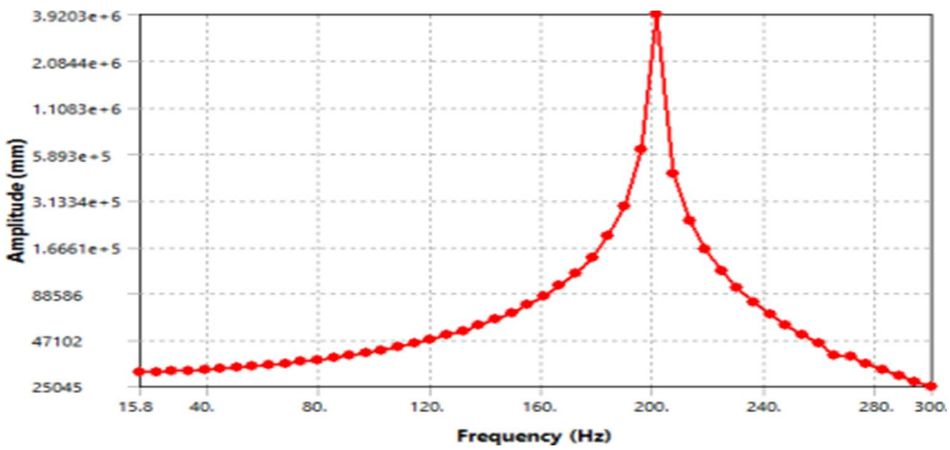
D. Steel Rim Static Structural Analysis Results

Type	Total Deformation	Equivalent (von-Mises) Stress	Maximum Principal Stress	Equivalent Elastic Strain	Maximum Principal Elastic Strain
Results					
Minimum	0. mm	0.10549 MPa	-21.641 MPa	2.2229e-006 mm/mm	-6.6948e-006 mm/mm
Maximum	0.2345 mm	48.647 MPa	66.728 MPa	3.3365e-004 mm/mm	2.8385e-004 mm/mm
Average	5.5055e-002 mm	5.4395 MPa	2.9567 MPa	3.4552e-005 mm/mm	1.8827e-005 mm/mm
Minimum Occurs On	Sold_Steel_Rim_3-FreeParts				
Maximum Occurs On	Sold_Steel_Rim_3-FreeParts				

E. Steel Rim Modal Analysis Results

Object No.	1	2	3	4	5	6	7	8	9	10
Results										
Minimum	0. mm									
Maximum	20576 mm	20621 mm	24744 mm	24891 mm	12856 mm	25706 mm	25670 mm	14130 mm	16474 mm	16383 mm
Average	8183.2 mm	8338.3 mm	7080.6 mm	7458.2 mm	9311.4 mm	6812.6 mm	6724.3 mm	8861.2 mm	9557.2 mm	9527.6 mm
Information										
Frequency	2.1877 e+005 Hz	2.1937 e+005 Hz	2.6696e+005 Hz	2.7252 e+005 Hz	5.0782e +005 Hz	7.7079e+005 Hz	7.7164e+005 Hz	7.9491e +005 Hz	9.287e +005 Hz	9.3163e+005 Hz

F. Harmonic Response / Frequency Response



VI. CONCLUSIONS

A comprehensive parametric modeling using Creo was conducted on both carbon steel and aluminum alloy wheel rims, followed by various analyses performed in ANSYS. A force of 625N was applied to assess the stress and strain values.

1) The deformation levels differed for each wheel rim at varying frequencies, with the alloy wheel rim exhibiting higher stability compared to the steel wheel rim.
2) To further evaluate the structural behavior, a vibrational analysis was carried out. The harmonic response analysis indicated a maximum amplitude of 1.6893, suggesting a stable model.
3) These findings indicate that the aluminum wheel rim outperforms the steel wheel rim in terms of heat dissipation, braking performance, and fatigue life.
4) The results strongly suggest that the aluminum alloy wheel rim is more suitable for the intended application due to its superior stability under vibrational loads, enhanced heat dissipation capabilities, improved braking performance, and extended fatigue life. These factors contribute to its overall superiority over the carbon steel wheel rim

Further research can be conducted to develop advance aluminum alloys with enhanced mechanical properties,this coil dinvolve exploring novel alloy compositions or incorporating reinforced elements to optimize the material performance.

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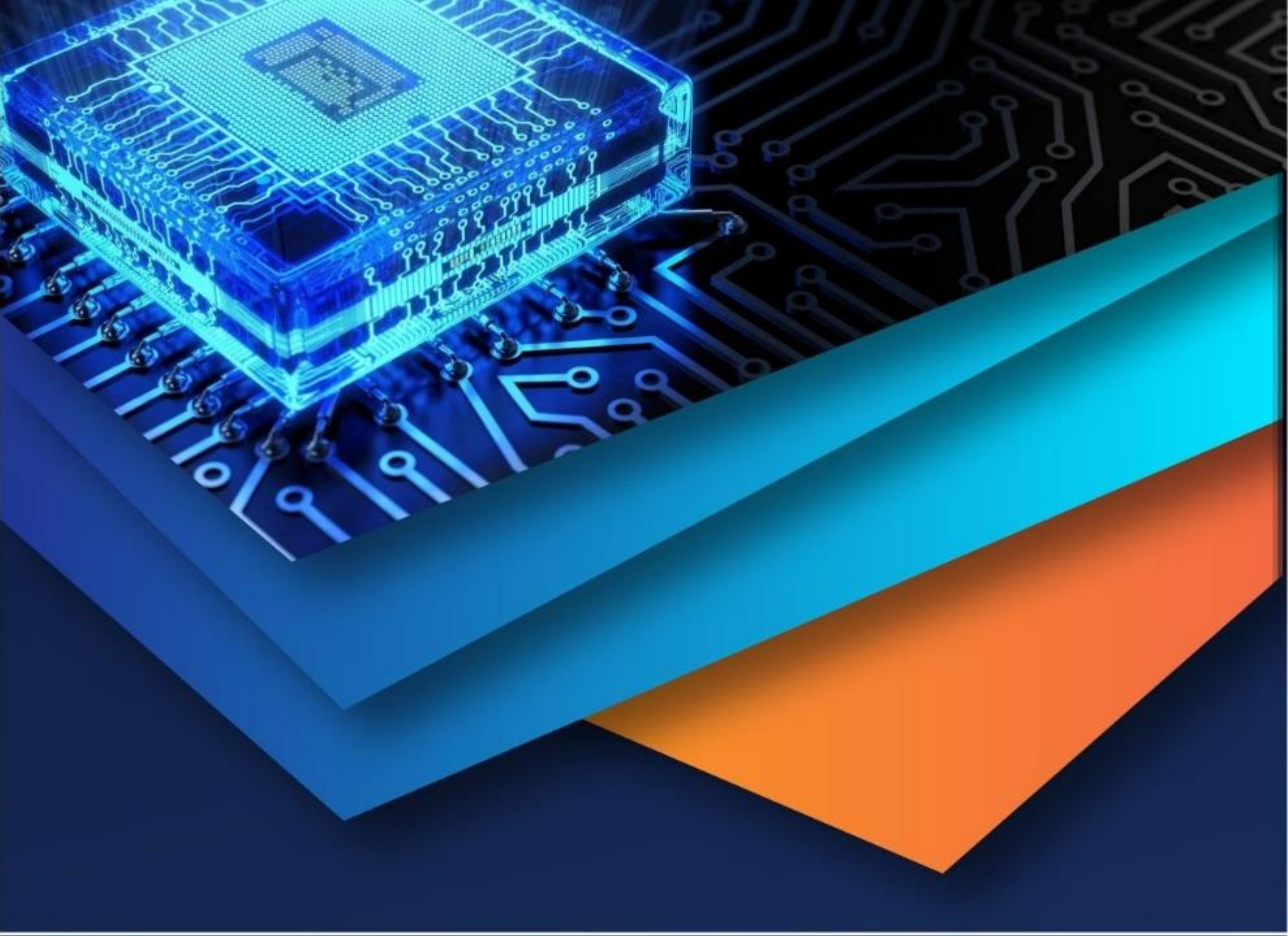

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