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Comparative CAD/CAE-based Structural and Dynamic Analysis of Aluminum Alloy Wheel Rim

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Abstract— ***This research focuses on the design and performance evaluation of a wheel rim for the Kia Carnival Prestige using computer-aided design and engineering tools. The central objective was to compare two aluminum alloys, Al-7075 and Al-7068, and determine which material delivers better performance under realistic loading conditions. The rim was modelled in SolidWorks according to manufacturer dimensions, and its behaviour was studied through finite element analysis in ANSYS. Both structural and dynamic boundary conditions were applied, with load cases representing vehicle operation under three-passenger and five-passenger configurations. The simulations assessed critical parameters such as stress distribution, total deformation, equivalent strain, and safety factors. The results demonstrated that Al-7068 consistently outperformed Al-7075, showing reduced stress levels, lower deformation, and higher safety margins in both loading conditions. Although the five-passenger case naturally produced greater stress and deformation compared to the three-passenger scenario, Al-7068 maintained stability and remained within safe design limits. The findings confirm that material selection plays a decisive role in the strength, durability, and service life of automotive rims. With its superior strength-to-weight ratio, lighter mass, and ability to sustain higher loads without compromising safety, Al-7068 emerges as the more suitable material for high-speed and heavy-duty vehicle applications. This study highlights the value of combining advanced material science with CAD/CAE-based simulations to optimize automotive components, reduce failure risks, and enhance overall vehicle performance.***

Index Terms— ***Ansys Simulation, Automotive, Wheel Rim, Structural Analysis, CAD.***

I. INTRODUCTION

Wheel rims are critical components in modern automotive design, serving both functional and aesthetic roles. Their primary purpose is to mount tires securely and support vehicle loads, while simultaneously influencing ride comfort, handling characteristics, braking performance, and overall safety [1]–[5]. In addition, rim design significantly affects fuel efficiency and contributes to the visual appeal of a vehicle, thereby bridging engineering requirements with consumer expectations. As vehicles continue to evolve with increasing demands for performance, safety, and sustainability, wheel rim engineering has become a highly interdisciplinary domain, integrating principles from materials science, structural analysis, aerodynamics, and advanced manufacturing [6]–[12].

Material selection plays a central role in rim performance, with common choices including steel, aluminum, magnesium alloys, and, in certain high-performance applications, carbon fiber [13]–[15]. Each material offers a distinct balance of strength, weight, durability, and cost. Steel rims are known for their strength and affordability but are relatively heavy, whereas aluminum alloys provide an optimal strength-to-weight ratio with improved fuel efficiency and handling. Magnesium and titanium rims are lighter and stronger but more expensive, while carbon fiber rims represent the premium end, offering unmatched weight reduction with superior strength, often reserved for sports and luxury vehicles [16]–[21]. Beyond material choice, rim geometry—including spoke design, diameter, and width—directly impacts load distribution, tire compatibility, brake cooling, and vehicle dynamics. Rim dimensions remain a key determinant of performance, with guidelines such as maintaining a rim width of at least 75% of the tire section width ensuring safety and compatibility [22]–[25].

II. METHODOLOGY

A. Design Considerations and Calculation for Wheel Rim

Table 1. Design Considerations

Parameter	Value
Kia Carnival Prestige: kerb weight	2195 kgs
Maximum possible weight of each passenger	105 kgs
Mass of Wheel Rim	8.65 kgs
Mass of the Kia Carnival Prestige without the wheel rim	2160 kgs
Vehicle Speed	150 km/hr
Turning Radius of Vehicle	0.229 m

For 3-members:

$$Total\ body\ weight = 2160 + 3(105) = 2475\ Kg$$

For 5-members:

$$Total\ body\ weight = 2160 + 5(105) = 2685\ Kg$$

$$\text{Angular velocity of vehicle} = \frac{v}{r} = \frac{150}{0.229} \times \frac{5}{18}$$
$$= 181.92\,\frac{rad}{sec}$$

B. Wheel Rim Specifications

Table 2. Wheel Rim Dimensions

Parameter	Value
Rim Main Diameter	458 mm
Width of Rim	178 mm
Shaft Diameter	35 mm
Stud Diameter	12 mm
Thickness of Rim	6 mm
Number of Studs in Rim	4 nos

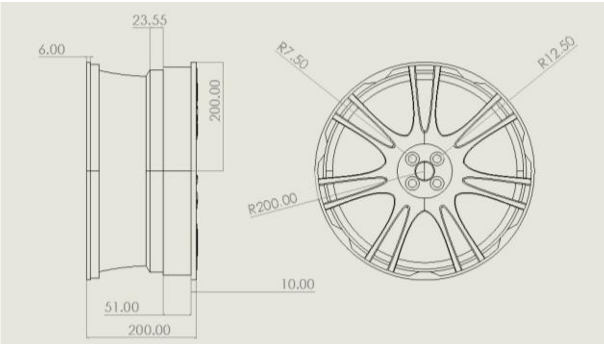

Fig. 1. Sectional View of Rim

The geometric specifications of the wheel rim considered for this study are summarized in Table 2. The rim has a main diameter of 458 mm and a width of 178 mm, which ensures compatibility with the intended tire dimensions and load requirements. The shaft diameter is 35 mm, while the stud diameter is 12 mm, providing sufficient strength for mounting and load transfer. The rim thickness is maintained at 6 mm to balance weight reduction with structural integrity. Four studs are incorporated into the rim design to ensure uniform distribution of loads and secure attachment to the hub assembly. Table 2 presents the detailed dimensions of the wheel rim used for the analysis.

C. Material Selection

Aluminum 6082-T6 is a strong and reliable material that combines good tensile strength with excellent weldability and resistance to corrosion, which makes it a popular choice for structural parts and wheel rims that need to handle high stresses. On the other hand, Aluminum-Lithium alloys take performance a step further. They are lighter, stiffer, and offer an outstanding strength-to-weight ratio along with excellent fatigue resistance. These qualities make them especially well-suited for demanding applications such as aerospace, high-performance cars, and racing wheels, where every gram of weight saved can translate into better efficiency and performance.

Table 3. Material Properties

Property	Aluminum 6082-T6	Aluminum (Al-Li) Alloy
Young's Modulus	70 GPa	80 GPa
Poisson's Ratio	0.33	0.32
Density	2700 kg/m³	2670 kg/m³
Yield Strength	355 MPa	420 MPa

Fig. 2. 3D CAD Model

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D. Analysis Setup

After completing the wheel rim design, the model was exported into ANSYS Workbench by saving it as a step file. The materials were then chosen based on their yield strength, with both aluminum alloys commonly used in the aerospace industry. Using these advanced alloys helps improve the overall strength of the rim compared to standard aluminum alloys, while also reducing weight. This results in a higher strength-to-weight ratio, which is a critical factor in performance applications. For the analysis, four key material properties were required: density, yield strength, Young's modulus, and Poisson's ratio.

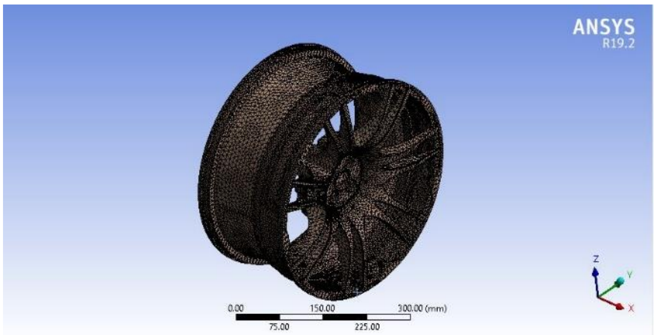

Fig. 3. Mesh for Analysis

The wheel rim described is transformed into small segments through a procedure involving elements and nodes, a process referred to as meshing. Meshing plays a critical role in yielding the results of finite element analysis. The quantity of elements and nodes fluctuates depending on the size of the

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elements. If the size of the elements is diminished, the quantity of elements and nodes will escalate. Conversely, if the element size is enlarged, the quantity of elements and nodes will reduce. An exceptionally small element size yields more precise results that mirror real-world applications. In this study, the element size utilized is only 1mm. This fine mesh is often referred to as "fine meshing".

III. RESULTS AND DISCUSSION

A. Results for 3-Member Loaded System

After meshing, boundary conditions were set, including the vehicle's speed of 150 km/h (converted to 181.92 rad/s), the load of 24271N on three members, and fixing the object at the studs' position. These conditions simulate real-world forces and constraints for analysis. For 3-members, 24300N was applied and then solved.

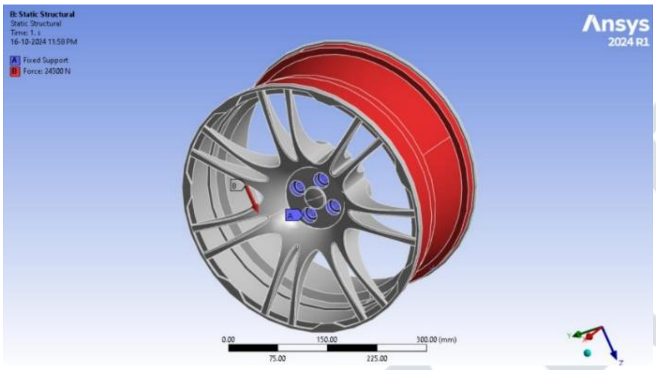

Fig. 4. Boundary conditions for 3-member system

1) For Al-6082:

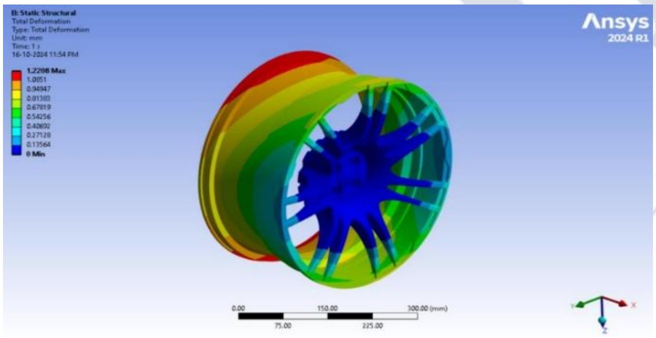

Fig. 5. Deformation contour for 3-member Al-6082

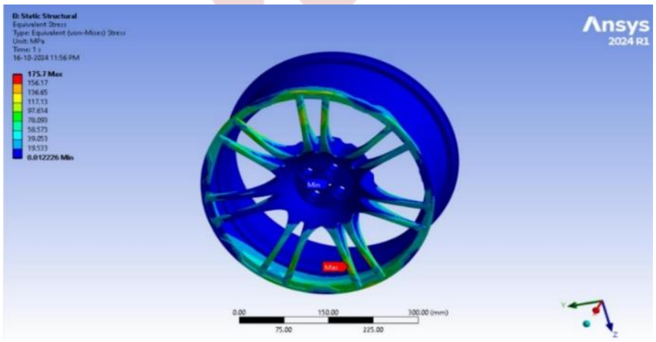

Fig. 6. Stress contour for 3-member Al-6082

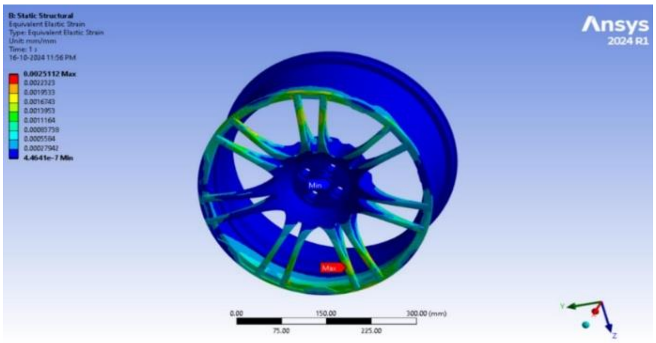

Fig. 7. Strain contour for 3-member Al-6082

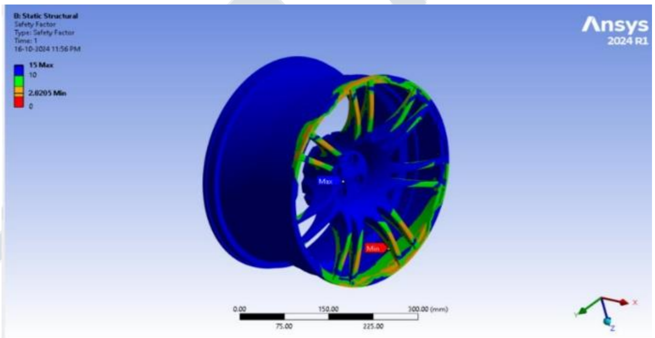

Fig. 8. FOS contour for 3-member Al-6082

The structural analysis of the Kia Carnival Prestige rim made of Al-6082 under a three-member applied load of 24,300 N was carried out to evaluate its deformation, stress, strain, and safety factor. The maximum deformation obtained was 1.2208 mm with a minimum of 0 mm, indicating limited displacement under the applied load. The equivalent von Mises stress distribution showed a maximum value of 175.7 MPa and a minimum of 0.012226 MPa, which is well below the yield strength of Al-6082, confirming that the rim remains in the elastic range. The equivalent elastic strain values ranged between 0.0025112 and 4.4641×10^{-7}, consistent with stress levels and material behavior. The factor of safety varied from a minimum of 2.0205 to a maximum of 15, which is above the design standard requirement of 1.5, demonstrating that the rim can safely withstand the applied load without risk of permanent deformation.

2) For Al-Li alloy:

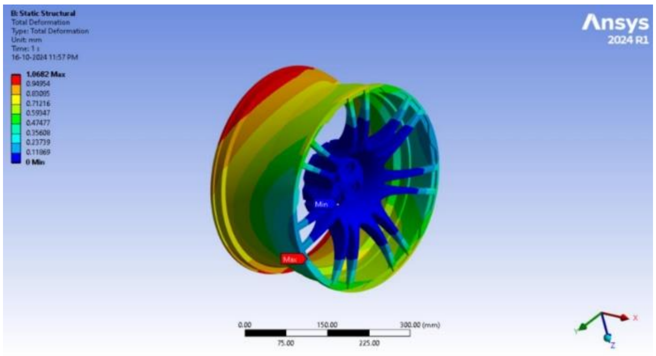

Fig. 9. Deformation contour for 3-member Al-Li alloy

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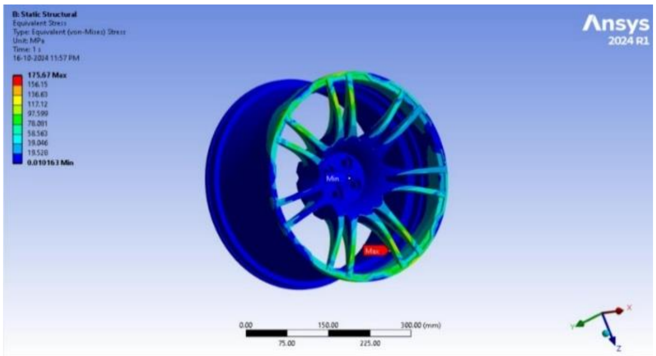

Fig. 10. Stress contour for 3-member Al-Li alloy

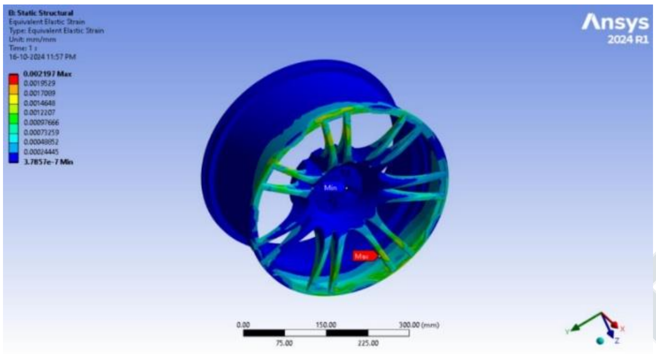

Fig. 11. Strain contour for 3-member Al-Li alloy

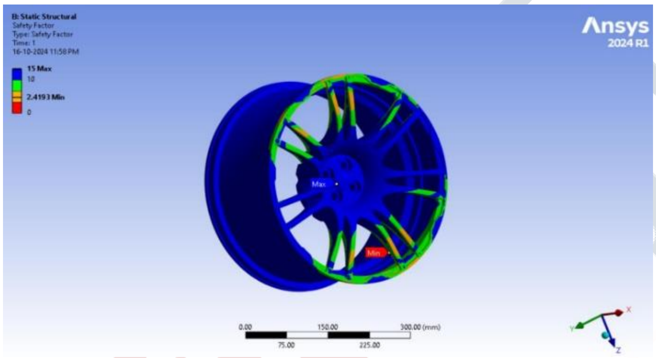

Fig. 12. FOS contour for 3-member Al-Li alloy

The structural analysis of the Kia Carnival Prestige rim made of Al-Li alloy under a three-member applied load of 24,300 N was conducted to determine its deformation, stress, strain, and safety factor. The maximum deformation was found to be 1.0682 mm, while the minimum remained 0 mm, indicating limited displacement under loading. The equivalent von Mises stress distribution revealed a maximum stress of 175.67 MPa and a minimum of 0.010 MPa, which is below the yield strength of Al-Li alloy, confirming purely elastic behavior of the rim. The equivalent elastic strain values ranged from 0.002197 to 3.7857×10^{-7}, consistent with the stress distribution and material properties. The factor of safety ranged between 2.4193 and 15, exceeding the minimum design standard requirement of 1.5, thereby demonstrating that the rim safely withstands the applied load without approaching permanent deformation.

Table 4. Obtained results for 3-member condition

3-members	Al-6082	Al-Li
Deformation (mm)	1.2208	1.0682
Stress (Mpa)	175.7	175.67
Strain	0.002112	0.002197
Safety Factor	2.0205	2.4193

B. Results for 5-Member Loaded System

Fixed support was applied at the studs, and a rotational velocity of 182 rad/sec was assigned. For the case of five members, a load of 26,400 N was considered. The boundary conditions and loading were applied, and the required values were subsequently obtained through the simulation.

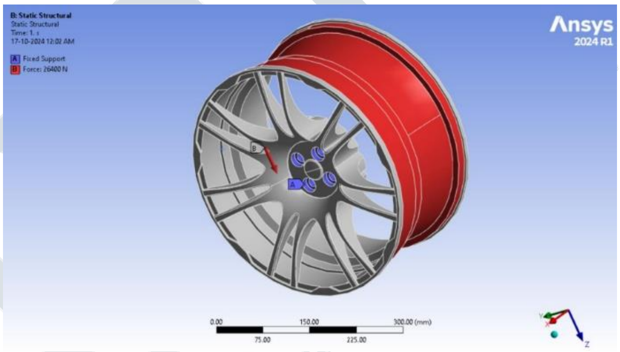

Fig. 13. Boundary conditions for 5-member system

1) For Al-6082:

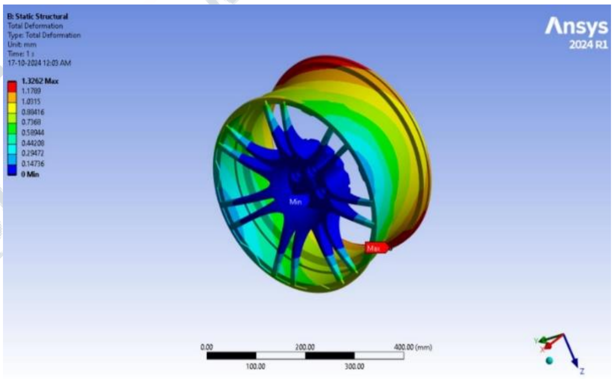

Fig. 14. Deformation contour for 5-member Al-6082

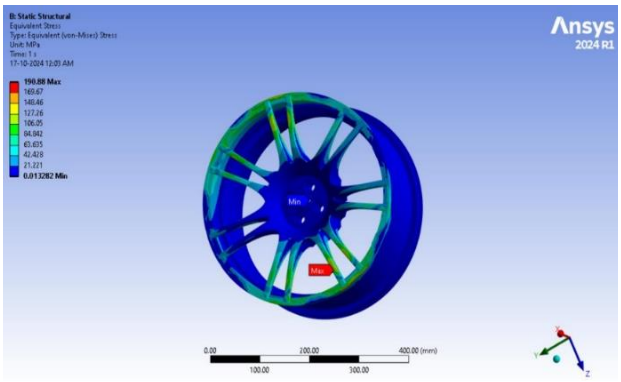

Fig. 15. Stress contour for 5-member Al-6082

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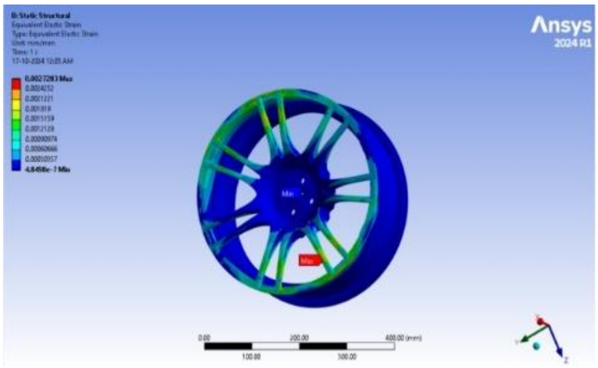

Fig. 16. Strain contour for 5-member Al-6082

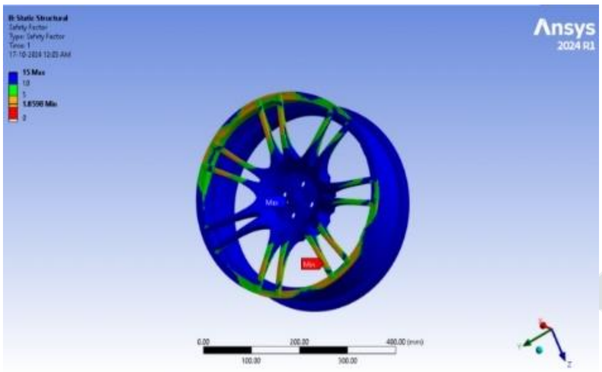

Fig. 17. FOS contour for 5-member Al-6082

The deformation, stress, strain, and safety factor of the Kia Carnival Prestige rim made of Al-6082 alloy were analyzed under a five-member applied load of 26,400 N. The maximum deformation was obtained as 1.3262 mm, while the minimum was 0 mm, indicating limited displacement under the applied conditions. The equivalent von Mises stress distribution showed a maximum stress of 190.88 MPa and a minimum of 0.013282 MPa, which is below the yield strength of Al-6082, confirming that the rim remained within the elastic range. The equivalent strain values ranged between 0.0027283 and 4.8498×10^{-7}, consistent with the stress response of the material. The factor of safety was found to vary between 1.8598 and 15, which is greater than the minimum design requirement of 1.5, thereby validating that the rim safely withstood the applied load without risk of permanent deformation.

2) For Al-Li alloy:

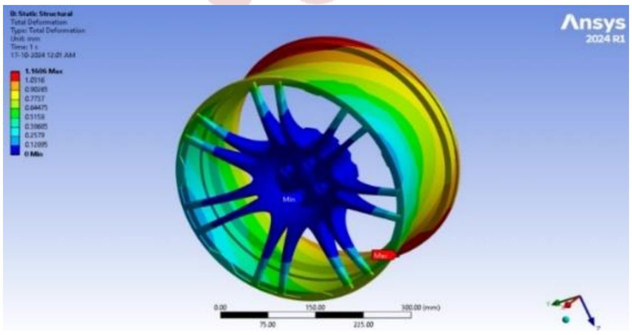

Fig. 18. Deformation contour for 5-member Al-Li alloy

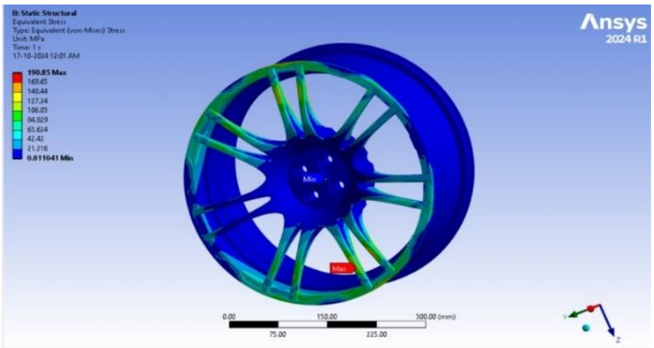

Fig. 19. Stress contour for 5-member Al-Li alloy

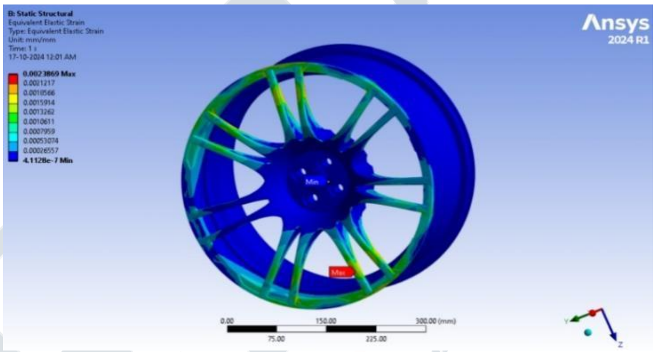

Fig. 20. Strain contour for 5-member Al-Li alloy

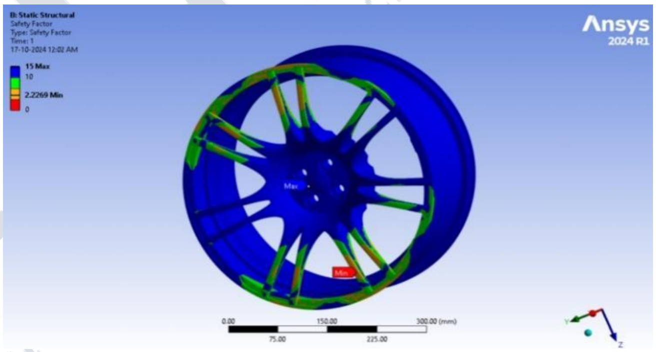

Fig. 21. FOS contour for 5-member Al-Li alloy

The deformation, stress, strain, and safety factor of the Kia Carnival Prestige rim made of Al-Li alloy were evaluated under a five-member applied load of 26,400 N. The maximum deformation was found to be 1.1606 mm, while the minimum was 0 mm, indicating minimal displacement of the rim. The equivalent von Mises stress analysis revealed a maximum value of 190.85 MPa and a minimum of 0.011041 MPa, which is below the yield strength of the Al-Li alloy, confirming that the rim remained within the elastic range. The equivalent strain values were observed between 0.0023869 and 4.1128×10^{-7}, consistent with the stress distribution and material response. The safety factor ranged from 2.2269 to 15, which is above the design standard requirement of 1.5, thereby ensuring that the rim can safely withstand the applied loading conditions without the risk of permanent deformation.

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Table 5. Obtained results for 5-member condition

5-members	Al-6082	Al-Li
Deformation (mm)	1.3262	1.1606
Stress (Mpa)	190.88	190.85
Strain	0.0027283	0.0023869
Safety factor	1.8598	2.2269

IV. CONCLUSION

This paper focuses on the modelling and analysis of Kia Carnival Prestige vehicle wheel rims using CAD/CAE tools. The study involved developing the rim model with SolidWorks and conducting structural and dynamic analyses under various boundary conditions, including minimum and maximum load scenarios. Two materials, Al-6082 and Al-Li, were evaluated for their suitability to withstand high speeds and maximum loads. The analysis results indicated that Al-Li outperforms Al-6082 in several aspects, including higher strength-to-weight ratio, better natural frequency range, and greater resistance to vibrations. Additionally, Al-Li exhibits higher safety factors and lower stress values, contributing to improved vehicle performance and fuel efficiency due to reduced weight. Overall, Al-Li was identified as the more optimal material for wheel rims, especially in performance-critical applications, owing to its superior deformation resistance, safety margins, and durability.

The cost estimation for designing a prototype wheel rim for a Kia Carnival Prestige in India involves several key components. Software costs can be minimized through educational or research licenses, potentially under INR 20,000 annually. Material costs for high-quality aluminum alloys like Al-7075 or Al-7068 are estimated between INR 20,000 and 40,000 for approximately 10 kg of material. Manufacturing costs, primarily CNC machining, could range from INR 30,000 to 60,000 depending on complexity. Additional expenses include finishing processes such as polishing or coating, which may add INR 5,000 to 10,000, and costs for specialized tools if needed. Testing and analysis, including physical validation, could cost between INR 10,000 and 30,000, especially if third-party services are involved. Overall, the total estimated cost for developing a prototype in India ranges from approximately INR 65,000 to 160,000, influenced by resource access, project scope, and unforeseen challenges.

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