Design and Analysis of Wheel Rim Using Finite Element Method

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Abstract - *we propose that structural steel stands out as the optimal material choice. This selection leads to a notable reduction in mass, specifically 4.64 kg per wheel, resulting in a total weight of the car's spare wheel at 27.84 kg. This reduction not only contributes to the overall weight reduction of the vehicle but also contributes to decreased production expenses.*

Based on the analysis outcomes, among the six models considered, wheel design 6 emerges as the superior choice. It exhibits a lighter weight of 27.192 kg, minimal deformation (0.00703 mm), a safety factor exceeding 15, and the least equivalent stress (6.13956 MPa). Subsequently, this model undergoes a comprehensive analysis employing specialized tools, which reveals von-Mises stress and total deformation factors across six distinct structural steel wheel designs. Following a meticulous comparison of the results, we will confidently recommend the optimal wheel design.

Key Words: SOLIDWORKS, ANSYS, FEA, Static Analysis, Fatigue Analysis, Wheel Rim

1. INTRODUCTION

The history of the wheel and rim is a fascinating journey that spans thousands of years, shaping the way humans travel, transport goods, and evolve technologically. Here's a brief overview of the history of the wheel and rim:

1. Early Wheel Concepts (Around 3500 BC): The earliest evidence of wheeled vehicles dates back to around 3500 BC in Mesopotamia (modern-day Iraq). These early wheels were solid wooden disks, often attached to carts or chariots. They were initially used for pottery production and later for transportation of goods.
2. Spoked Wheels (2000-1500 BC): Around 2000 BC, spoked wheels were invented, likely in the Caucasus region. Spokes allowed for lighter and more flexible wheels, which improved overall efficiency and reduced the stress on the axle. Spoked wheels spread across civilizations, including ancient China and Europe.
3. Roman Chariots (4th Century BC - 4th Century AD): The Romans made significant advancements in wheel technology, using spoked wheels in their chariots and military vehicles. This innovation improved their transportation and military capabilities.
4. Medieval and Renaissance Innovations (5th-15th Centuries): During the Middle Ages, wheel technology evolved slowly. Improvements were made in terms of axle construction and materials. In the Renaissance period, Leonardo da Vinci's sketches and designs included concepts for gear-driven vehicles with spoked wheels.
5. Industrial Revolution (18th-19th Centuries): The Industrial Revolution brought significant advancements in wheel and rim manufacturing. Iron and steel became common materials for rims and spokes, making wheels more durable and capable of handling heavier loads. The development of railways and steam-powered locomotives also led to the creation of specialized train wheels.
6. Pneumatic Tires (Late 19th Century): In the late 19th century, Scottish inventor John Boyd Dunlop developed the pneumatic tire, which used air-filled rubber to provide a smoother ride and better traction. This innovation marked a significant leap in comfort and performance for wheeled vehicles.
7. Modern Wheel and Rim Technology (20th Century - Present): The 20th century brought further refinements to wheel and rim design, including alloy wheels made from lightweight metals like aluminum and magnesium. These materials enhanced both aesthetics and performance. Tubeless tires, radial tire construction, and advanced tire tread designs also improved safety and handling.
8. Continued Advancements: Today, wheels and rims continue to evolve with advancements in materials, aerodynamics, and manufacturing techniques. The automotive and transportation industries are exploring technologies like carbon-fiber composite wheels for improved efficiency and reduced weight.

The history of the wheel and rim reflects humanity's continuous pursuit of innovation and improved mobility, leading to the diverse and sophisticated wheel designs we see in various vehicles today.

2. **METHODOLOGY** Finite Element Analysis (FEA) is a computational method used to analyze complex structures and systems by dividing them into smaller, more manageable segments called finite elements. These elements are connected at specific points, known as nodes, to represent the overall behavior of the entire system. FEA is The Finite Element Method (FEM) has a wide range of applications across various fields of science and engineering. It is a versatile numerical technique that can be used to solve complex problems involving partial differential equations, and it has proven to be invaluable in simulating and analyzing a diverse set of systems. Here are some notable applications of the Finite Element Method:

3. **Structural Analysis:** FEM is widely used for analyzing the behavior and response of structures under different loads and conditions. It is used in civil engineering for designing buildings, bridges, and other structures, as well as in mechanical engineering for designing components like beams, columns, and frames.

4. **Heat Transfer and Thermal Analysis:** FEM is employed to study temperature distributions, heat transfer rates, and thermal stresses in systems. This is crucial for designing efficient cooling systems, thermal management of electronic devices, and analyzing heat flow in various industrial processes.

5. **Fluid Dynamics:** FEM is used in computational fluid dynamics (CFD) to simulate fluid flow, analyze pressure distributions, and study the behavior of liquids and gases in pipes, channels, and other flow domains.

6. **Electromagnetic:** In electromagnetic analysis, FEM is used to model and predict the behavior of electromagnetic fields, such as in antennas, motors, transformers, and electronic devices.

7. **Acoustics and Vibrations:** FEM is employed to analyze the propagation of sound waves and vibrations in structures, vehicles, and other systems. This is crucial for noise reduction and improving the durability and comfort of products.

8. **Geomechanics and Geotechnical Engineering:** FEM is used to study the behavior of soils and rocks under different loading conditions. It's important for analyzing foundation stability, slope stability, and excavation processes.

9. **Aerospace and Automotive Engineering:** FEM is extensively used in the design and analysis of aircraft, spacecraft, and vehicles. It helps optimize structures for weight, strength, and aerodynamics.

10. **Biomechanics:** FEM is applied in biomedical engineering to analyze the mechanical behavior of biological tissues, bones, joints, and implants. It aids in designing prosthetics, orthotics, and medical devices.

11. **Material Science:** FEM is used to study the mechanical properties of materials and predict their behavior under different conditions. This is crucial for designing new materials and understanding material failure mechanisms.

12. **Manufacturing Processes:** FEM is employed to simulate various manufacturing processes such as welding, machining, and forming to optimize process parameters and predict potential defects.

13. **Nuclear Engineering:** FEM is used to model and analyze the behavior of nuclear reactors, including heat transfer, structural integrity, and safety assessments.

14. **Environmental Engineering:** FEM can be used to simulate and analyze environmental processes such as groundwater flow, pollution dispersion, and the behavior of contaminants in the environment.

15. These are just a few examples of the many applications of the Finite Element Method. Its ability to handle complex and nonlinear problems makes it an essential tool in engineering and scientific research.

    Widely employed in engineering, physics, and other fields to simulate and understand how structures or systems respond to various conditions, forces, and loads.

Here's a simplified overview of the FEA process:

1. Model Creation: The first step involves creating a digital representation of the physical object or system you want to analyze. This digital model is often created using specialized software and is composed of geometric shapes and dimensions.

2. Mesh Generation: The model is divided into a mesh of finite elements. These elements are usually triangles or quadrilaterals in two

dimensions and tetrahedra or hexahedra in three dimensions. The more elements you have, the more accurate the analysis, but it also increases computational complexity.

3. Boundary Conditions: Boundary conditions are defined to simulate the real-world environment in which the structure operates. These conditions include fixed points (constraints) and applied loads or forces.

4. Material Properties: Material properties, such as elasticity, density, and thermal conductivity, are assigned to the finite elements to mimic the behavior of the real material.

5. Solving the Equations: FEA involves solving a set of mathematical equations derived from the physical principles governing the behavior of the system. These equations relate the forces, displacements, and material properties of the finite elements.

6. Analysis: The software calculates the displacements, stresses, strains, and other relevant variables within each finite element. These results provide insights into how the structure responds to the applied loads and boundary conditions.

7. Interpretation of Results: Engineers and analysts interpret the results to assess the performance, safety, and reliability of the system. This may involve identifying areas of high stress, deformation, or potential failure points.

8. Optimization and Iteration: Based on the results, design modifications can be made to improve the system's performance. The FEA process can be iterated to refine the design until the desired outcomes are achieved.

FEA is a powerful tool that allows engineers and researchers to gain insights into the behavior of complex systems without having to rely solely on physical testing. It is used in a wide range of applications, including structural analysis, thermal analysis, fluid dynamics, electromagnetic, and more.

3. MODELING AND ANALYSIS

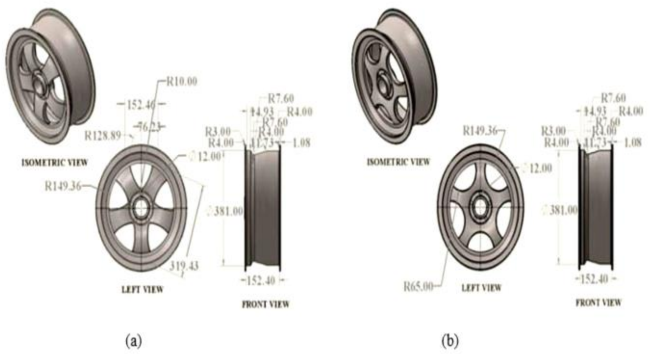
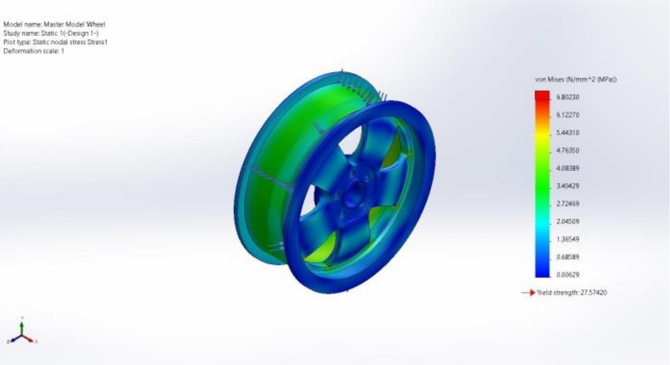
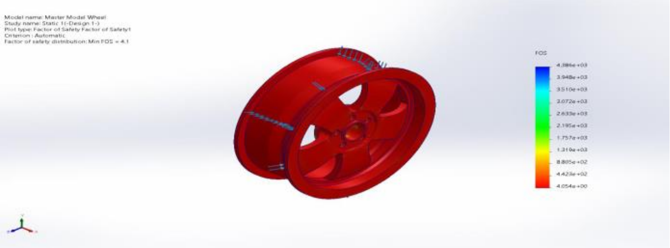


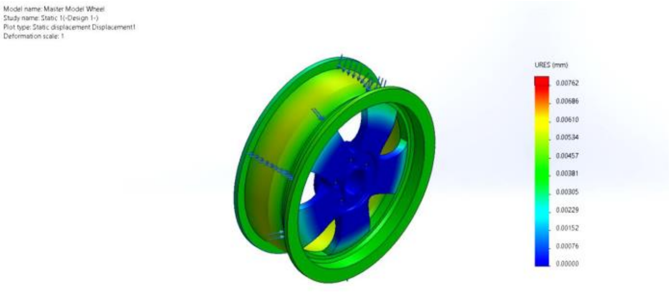
Figure 4.1(a) Wheel Design 1 and (b) Wheel Design 2



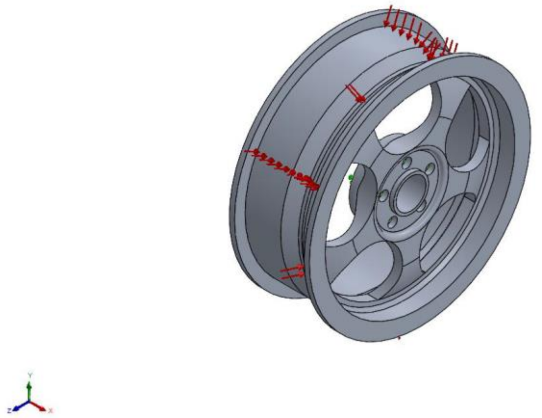
Master Model Wheel-Static 1-Stress-Stress1 Name



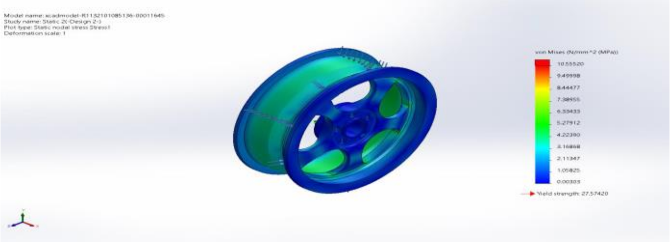
Master Model Wheel-Static 1-Factor of Safety-Factor of Safety1 Structural Steel



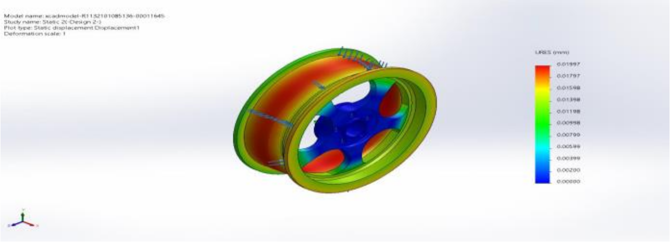
Total Deformation



Wheel Design 2 Aluminium alloy



VON: von Mises Stress



Resultant Displacement

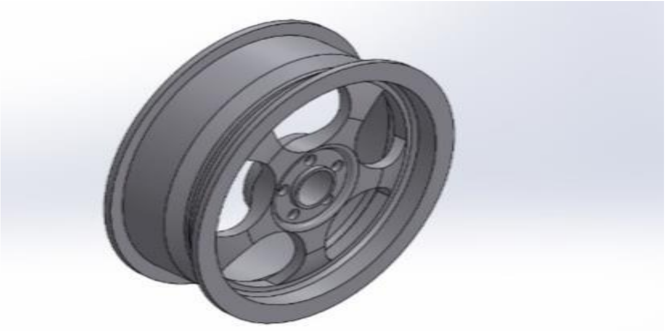


Figure (a) Wheel Design 1 (b) meshed model

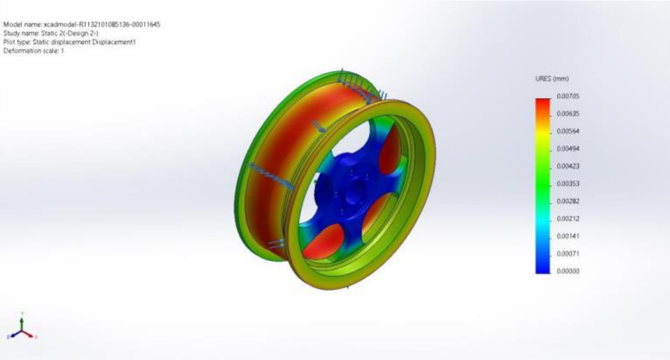


Figure (c) Total Deformation (Design 2)

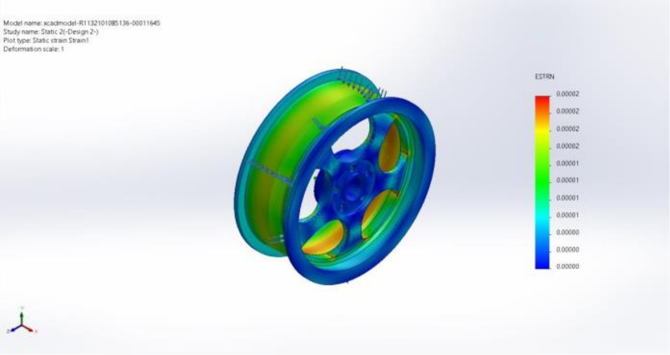


Figure (c) Equivalent Strain (Design 2)

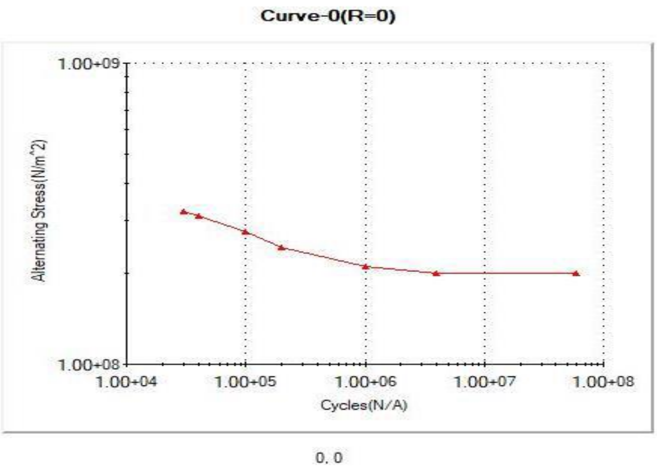
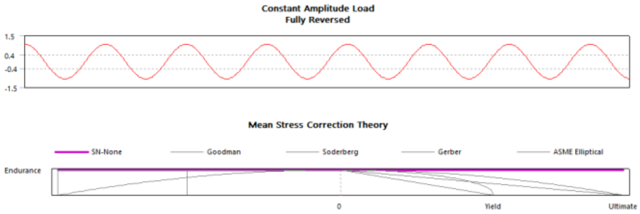


Figure 5.11 S-N curve of Structural Steel Figure Figure

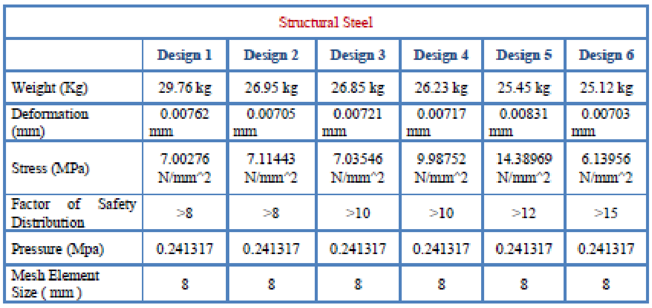


5.12 Loading Type is Fully Reversed and Analysis Type is stress Life (Total Life)

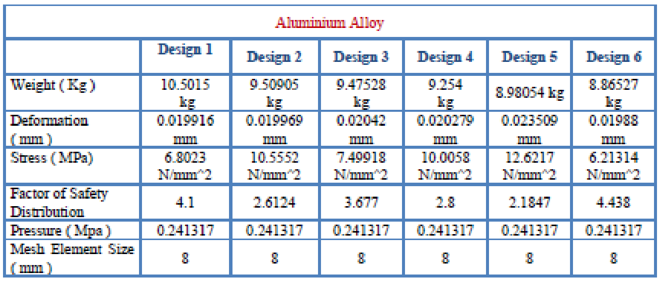
In a fatigue study, it's essential to maintain consistent material properties as those used in static analysis. Nonetheless, it's imperative to define the fatigue strengths of materials, which are represented by S-N curves. These curves encapsulate how a material performs under repetitive loading, illustrated in Figure 5 as a fully reversed alternating stress plotted against the number of cycles on a logarithmic graph. When plotting structural results on this graph, stress ranges are positioned on the vertical axis while the cycle count is on the horizontal axis, often leading to considerable dispersion.

Should the alternating stress surpass the material's endurance limit, the component's longevity is restricted to a finite number of cycles. This finite life encompasses two distinct regions termed low cycle fatigue and high cycle fatigue. Low cycle fatigue transpires at high stress levels and relatively few cycles, where the material behavior is predominantly plastic. Conversely, the high cycle fatigue region features lower stress levels and elastic material behavior. Structures exposed to stress levels beneath a material's endurance limit undergo a substantial number of load cycles without incurring damage.

5. RESULT



Structural Steel						
	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Weight (Kg)	29.76 kg	26.95 kg	26.85 kg	26.23 kg	25.45 kg	25.12 kg
Deformation (mm)	0.00762 mm	0.00705 mm	0.00721 mm	0.00717 mm	0.00831 mm	0.00703 mm
Stress (MPa)	7.00276 N/mm^2	7.11443 N/mm^2	7.03546 N/mm^2	9.98752 N/mm^2	14.38969 N/mm^2	6.13956 N/mm^2
Factor of Safety Distribution	>8	>8	>10	>10	>12	>15
Pressure (Mpa)	0.241317	0.241317	0.241317	0.241317	0.241317	0.241317
Mesh Element Size (mm)	8	8	8	8	8	8



Aluminium Alloy						
	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Weight (Kg)	10.5015 kg	9.50905 kg	9.47528 kg	9.254 kg	8.98054 kg	8.86527 kg
Deformation (mm)	0.019916 mm	0.019969 mm	0.02042 mm	0.020279 mm	0.023509 mm	0.01988 mm
Stress (MPa)	6.8023 N/mm^2	10.5552 N/mm^2	7.49918 N/mm^2	10.0058 N/mm^2	12.6217 N/mm^2	6.21314 N/mm^2
Factor of Safety Distribution	4.1	2.6124	3.677	2.8	2.1847	4.438
Pressure (Mpa)	0.241317	0.241317	0.241317	0.241317	0.241317	0.241317
Mesh Element Size (mm)	8	8	8	8	8	8

6. CONCLUSION:

Through our investigation, we've discerned that the design of the wheel rim wields substantial influence over the overall performance of the wheel. This, in turn, leads to enhanced handling and a more enjoyable ride due to reduced weight and an elevated safety factor. The reduction in weight contributes to improved braking performance and fuel efficiency, amplifying the benefits for the vehicle.

A methodology centered around the wheels was employed to forecast nominal stress and fatigue life. Within the nominal stress approach, predictions about the wheels' fatigue life relied upon the S-N curve and the equivalent stress amplitude of the wheel material.

1. The wheel's mass has been effectively trimmed from 29.76 kilograms to 25.12 kilograms, all the while maintaining its physical attributes and functionality.

2. This weight reduction corresponds to a decrease of 4.64 kilograms per wheel, culminating in a total car spare wheel weight of 27.84 kilograms. This weight reduction carries advantages such as an overall reduction in vehicle weight and a consequential reduction in production expenses.

3. The lighter weight contributes to heightened performance and improved fuel economy. These findings extend to a range of indirect benefits, including decreased air pollution due to reduced fuel consumption, the conservation of natural resources through diminished crude oil usage, and more.

4. While the data collection adhered to the same material and boundary conditions, the diverse wheel designs significantly influence their lifespan and safety factor.

Based on analytical statistics, it is evident that among the six models, wheel design 6 emerges as the optimal choice. It boasts a lighter weight of 27.192 kilograms, minimal deformation (0.00703 mm), the highest safety factor (>15), and a diminished equivalent stress (6.13956 MPa).

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