MULTIDISCIPLINARY SCIENCE JOURNAL

RESEARCH ARTICLE
Published Online: July 18, 2023
https://doi.org/10.31893/multiscience.2024013

Investigation of alloy materials on a sports bike wheel rim designs using finite element analysis

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Abstract Investigators are dedicating more work to the creation of lightweight vehicles as a result of the rising emphasis placed by the automotive industry on energy efficiency and environmental responsibility. While developing a wheel, it is important to keep both technology and safety considerations in mind simultaneously. Alloy materials are commonly used in the design of sports bike wheel rims due to their lightweight, strength, and durability. The ultimate goal of this study is to lay the groundwork for coming up with new designs for wheels and spokes that can be used on sports bike. In this work, it would be possible to compare how alloys of magnesium and titanium respond to stress and strain compared to structural steel materials. Using an equivalent stress and deformation investigation, two modern designs of wheel spokes for the sports bikes and three materials were compared. This study makes some insightful projections about the reliability of the structural design and provides useful references for the manufacture of alloy wheels. According to the stress analysis, the Ti alloy produces a stress concentration that is about 0.5% lower than on Model A and around 1% lower value for stainless steel on the Model B wheel rim design. Mg alloy has a deflection of about 77% and 53% more than stainless steel and titanium alloy, respectively, in the construction of the model A and B wheel rim.

Keywords: structural analysis, magnesium alloy, titanium alloy, structural steel, wheel rim design

1. Introduction

The alloy wheel rim design for a sports bike is optimized for performance, with a focus on reducing weight, improving handling, and enhancing aerodynamics. The rim size, width, spoke design, rim profile, and material are all carefully considered to achieve the desired performance characteristics. Wheels contribute significantly to a vehicle's overall resistance to force, making them an essential component. Spokes are often utilised whenever there is a need for the wheel to be held together between the hub and the rim. It is absolutely necessary for these spokes to have the necessary stiffness and strength in order to prevent the wheel from cracking. Magnesium alloy, steel, and aluminium alloy are examples of typical contemporary materials used in the building of wheels (Gadwala and Babu G 2022). There is a huge number of design options available for wheels used on automobiles, and the majority of these options are intended to make the wheel lighter. It is sufficient to simply do a structural study of the wheels in order to determine equivalent modal concerns while conducting research on the stability of a vehicle. Important goals in static analysis include displacement and internal stress measurement. Then, using convergent meshing sizes and other factors like the stress and displacement ratio, the values of the displacements and stresses were calculated. The fact that different mesh sizes provide different results for the simulation shows that mesh size does, in fact, affect the outcomes of the simulation (Agarwal et al 2021).

Wheel rims, sometimes known as spherical wheels, are a type of circular component that can rotate along an axis, making it possible for them to carry and propel their loads. The vehicle's rim wheels play a vital role in the vehicle's steadiness and manoeuvrability (Rahul and Jaya Prakash 2020). Having sturdy rim wheels is one way to improve the safety of a vehicle, but they have a negative impact on performance because of their weight and resistance to motion. It is crucial to undertake rim wheel testing in compliance with present rules as there are still many wheels on the market that do not meet the standards. Rim wheels can crack or break in different ways due to strain. As a result, certain quality requirements are tested for on a regular basis to guarantee satisfaction (Bhattacharyya et al 2008).

While there was no discernible difference in fatigue between on-axis and off-axis loading during the same lifetime, testing did reveal evident differential damage mechanisms in several stress dimensions. More study is necessary to determine

 Received: March 20, 2023 | Accepted: June 17, 2023

the exact rules that off-axis fatigue in wheel steels follows to create microscopic damage. When it comes to the conception and evaluation of the myriad components that go into the construction of the vehicle, performance is of the utmost significance (Zhu et al 2020). The weight of the vehicle needs to be reduced as much as possible in order for it to be able to accelerate to higher speeds and keep going at such speeds for longer. This study provides an in-depth analysis of the implications of switching from alloy wheels to composite ones, as well as a description of the design process involved in making the switch. In this setting, engineers are working on improving the design of two-wheeled vehicles' wheels for both current and future models in order to mitigate the negative effects of the alloy construction of the former. The weight of the cyclist, along with the cyclical motion of riding on varied routes, can harm the wheel in several ways. Failure normally takes place when the stress value of the material is reduced below its ultimate stress value and below its fatigue life (Murugu Nachippan et al 2021; Padmanabhan et al 2023).

The wheel itself is the primary suspension device, dampening both static and dynamic forces as the car moves. While trying to save costs and excess weight, wheel manufacturers typically target the rim. Alloy wheels are used by practically every manufacturer nowadays because of their small weight, which reduces unsprang weight and improves fuel use. While wheels may cost more than tyres initially, they are a worthwhile investment for high-end and performance automobiles (Hawkins and Kumar 2020; Gadwala and Babu G 2022). Wheel rims must be defect-free in order for a vehicle to operate well due to the static and dynamic stress and vibrations they endure when in use. Wheel rim deformation and subsequent structural failure can occur under real-world service circumstances due to flaws such as intrinsic cracks and fissures. As a result, it is essential, though not always practicable, to check for flaws in a wheel rim before putting it through its paces in actual use (Jiang et al 2018; Jiang et al 2021). It has been noted that, while efforts have been made to estimate and predict fatigue life and suitability of alloy for wheel disc, no efforts have been made to optimise and design alloy wheels for mass. The inquiry therefore attempted to analyse the alloy wheel from a solid disc shape to an improved design, resulting in the usage of less required mass of material with an enhanced design. Minimizing component weight has been a major focus as of late, and the resultant reduction in vehicle weight has been impressive. It has been detected that the weight of a component can be reduced by designing it in such a way that the applied load is maintained while the component retains its usable shape. Three different types of wheels with spokes were tested for durability. The wheel rim is made of aluminium alloy, a lightweight metal that is also an excellent heat conductor (Sharma et al 2021). The alloy wheels were examined for the factor of safety, which provides evidence that the vehicle can be driven safely. In the stress analysis, the magnesium alloy produces more deflection and a stress concentration on both design, whereas design I produces less deflection and a stress concentration over the design II (Karthick et al 2023).

In this work, the investigation was on the structural soundness of current wheels and compute the stresses within them by use of finite element modelling and solution techniques. The accounted for the impact of the stress value range we acquired from Finite Element Analysis (FEA) to derive more precise estimates of the pressure needed to cause the wheel to expand (Padmanabhan et al 2010; Joel et al 2021; Somayaji et al 2022). The purpose of the research is to find, with the use of finite element analysis ways in which the existing wheels-over design might be made easier to implement. In order to take into account the peculiarities of the material, the specifications of the bike will need to be updated when the stress study has been completed and a model has been created. Substantial study was also carried out to establish which of the myriad of possible rim materials offered the greatest results when it came to fabricating a sturdy wheel rim. This article details the findings of a finite element analysis of a newly developed wheel and spoke for the sports bike. Stress and strain responses in magnesium alloy (mg), structural steel (ss), and titanium alloy (Ti) may all be compared with one another. Comparing the two designs and three materials with regards to comparable stress and deformation yielded some interesting findings. In this study, two separate models of alloy wheel spokes were examined for structural stress and maximum deflection in response to three material properties.

2. Materials and Methods:

The material used to make the alloy rim is also an important factor. For sports bikes, lightweight materials such as aluminum or magnesium are commonly used. These materials provide strength while minimizing weight, which is essential for sports bike performance. Carbon and iron are the main components of steel, and while they can be found in large quantities, they are almost never found together in their pure forms. Iron, needed to create steel, is extracted from iron ore, which naturally includes abundant iron oxides. Steel has several desirable physical characteristics, including strength, light weight, durability, malleability, and resistance to corrosion. Steel is incredibly powerful yet being quite lightweight. Steel has the lowest strength-to-weight ratio of any major construction material. Considering steel's qualities during the planning and building stages of a project is crucial to making sure that the finished structure will be strong enough to carry out its intended function. Common steel characteristics include tensile strength, hardness, notch toughness, and fatigue stress (Agarwal et al 2021). Some of the many desirable characteristics of Mg alloys include high mechanical strength, non-toxicity, remarkable damping capabilities, outstanding casting fluidity, low heat capacity, and negative electrochemical potentials (Sharma et al 2021). Titanium alloys have a high tensile strength even at high temperatures, are lightweight, resist corrosion well, and can sustain high temperatures without deforming. You can count on its durability, shine, and immunity to corrosion. While insoluble in water, pure titanium dissolves in strong acids. When heated in air, this metal creates a passive yet protective oxide covering that prevents corrosion, while at ambient temperature, it does not tarnish (Hawkins and Kumar 2020).

A one percent vehicle mass reduction improves fuel economy by 0.7%. Reducing engine moving parts rather than body weight should improve fuel efficiency significantly. Titanium alloy has 60% the density of steel and 50% the elastic elasticity. Replacing steel components with titanium would reduce weight by forty percentage. Titanium's low modulus makes it a good spring material, however stiffness-constrained applications may need component redesign. Titanium outperforms steel and aluminium alloys in strength, hardness, and fatigue. Table 1 displays the material properties of wheel rim (Hawkins and Kumar 2020). Magnesium and titanium alloy wheels are high-performance wheels that are commonly used in high-performance cars, racing cars, and motorcycles. Both magnesium and titanium alloys have a high strength-to-weight ratio, which makes them ideal for applications where weight reduction is important (Jiang et al 2021; Liu et al 2023).

Table 1 Materials Properties of wheel rim.

Wheel Materials	Density (g/m³)	Young's Modulus (GPa)	Poisson's Ratio
SS	7.86	2.1e+6	0.30
Mg – Alloy	1.82	450000	0.35
Ti – Alloy	4.45	1.2e+6	0.36

Magnesium alloy wheels are made from a combination of magnesium, aluminum, and other elements. They are known for their lightweight, high strength, and excellent heat dissipation properties, which make them a popular choice for racing cars. However, magnesium alloy wheels can be brittle and prone to cracking if they are exposed to extreme stress or impact, which can be a safety concern. Titanium alloy wheels are made from a combination of titanium, aluminum, and other elements. They are also lightweight and have excellent strength and durability properties, which make them a popular choice for high-performance cars and motorcycles. Titanium alloy wheels are also more resilient to stress and impact compared to magnesium alloy wheels, making them a safer choice for high-speed applications. Overall, both magnesium and titanium alloy wheels offer superior performance benefits over traditional steel or aluminum wheels. However, they also come with higher costs and require specialized manufacturing processes, which can make them less accessible for the average consumer.

3. Wheel Rim Design and Modelling:

The size and shape of the wheel rim are important factors that determine the overall performance of the bike. For sports bikes, the wheel rims are usually larger in diameter and narrower in width, which reduces weight and improves handling. The width of the rim determines the amount of tire that can be mounted onto it. A wider rim provides better grip and stability, but also adds weight. For a sports bike, a narrower rim is usually preferred, which allows for a lighter weight and better acceleration. The profile of the rim can vary depending on the intended use of the sports bike. A higher profile rim can provide better handling and stability at high speeds, while a lower profile rim can improve acceleration and manoeuvrability. In this examination, the wheel from the sports bike was taken into consideration and used as a source of information. Wheel design at 17 inch rim with 108 mm width, as model of KTM bikes and design with two unique design of spokes. Figure 1 depicts a three-dimensional view of the Model A Wheel design, whereas Figure 2 depicts a similar perspective of the Model B Wheel design.

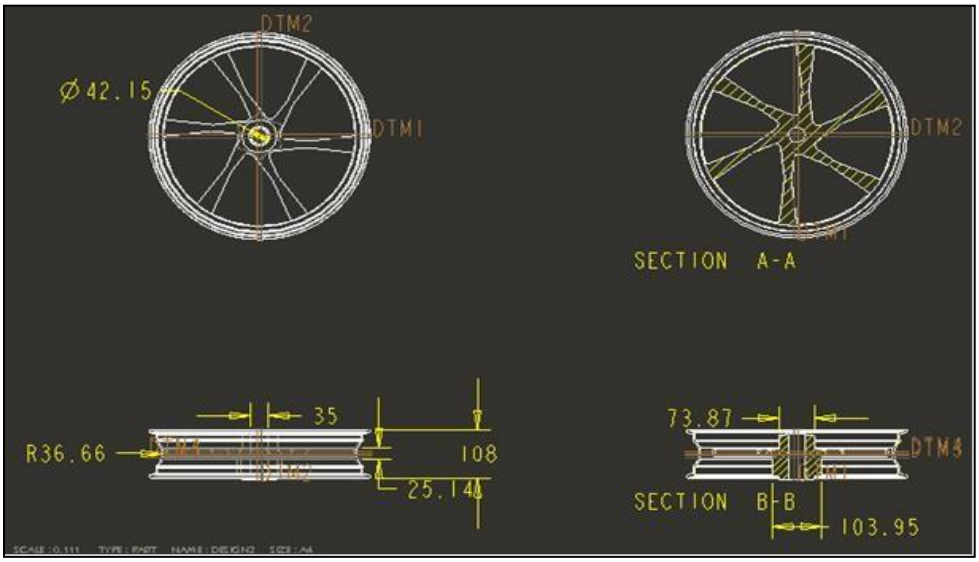


Figure 1 Dimensional view of Model A Wheel rim design.

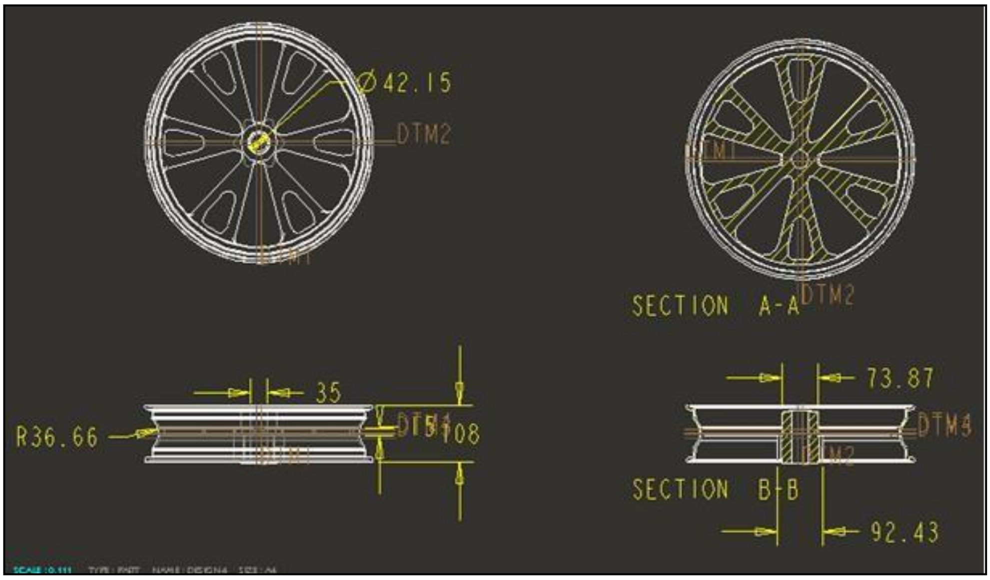


Figure 2 Dimensional view of Model B Wheel rim design.

This set of directions can result in at least three different situations depending on how they are followed. The added weight of the vehicle and the weight of the driver, bringing the total mass of the vehicle up to 140 kg. A factor of safety of five was taken into consideration, the value of the static load was found to be 1.55 MPa after being measured. The wheel was locked at the cylinderical support and sideways displacement, and a load of 1.55 MPa was applied to the circumference of the barrel as shown in Figure 3. The load and constraints of the Wheel Model A and Wheel Model B designs are shown in Figure 3.

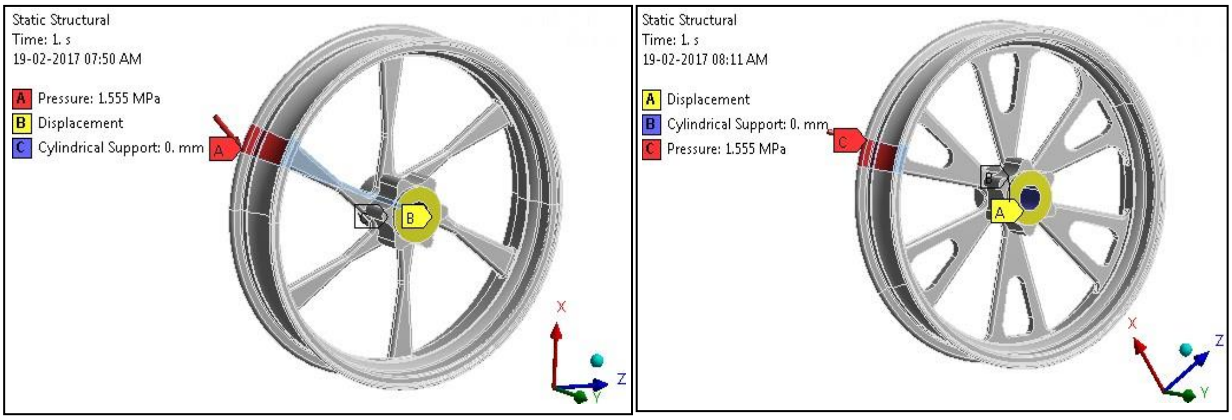


Figure 3 Load and Constraint of Model A and B wheel rim design.

4. Results and Discussion

Wheel rim analysis is a process of evaluating the structural integrity and performance of the rim of a wheel, which is the outer circular portion of the wheel on which the tire is mounted. The analysis is typically conducted using computer-aided engineering software to simulate various operating conditions and loads on the wheel rim. The analysis considers a range of factors, including the material properties of the rim, the shape and dimensions of the rim, the loads applied to the rim during normal use, and the stresses and strains that result from those loads. The goal of the analysis is to ensure that the wheel rim is strong enough to withstand the expected loads and stresses without failing or deforming excessively. All of the rim wheel simulations were run using a mesh consisting of a standard mechanical tetrahedron with 10 nodes. Depending on the geometry and composition of the chassis, various mesh parameters had to be provided to the various rim wheels. While choosing a mesh shape, the tetrahedron was chosen because of its higher curve informing capabilities with nodes (Figure 4). To accurately compute structural analysis and determine the stress value for current wheels, this study use the Finite Element model and solution methodologies. After that, in order to improve upon the earlier estimates for wheel expansion pressure, we gave consideration to the impact of the stress value range that we discovered using analysis. This research attempts to estimate, via the use of the FEA methodology, how much weight can be cut from the existing design of wheels by analysing how much space may be saved (Shinde et al 2022; Somayaji et al 2022).

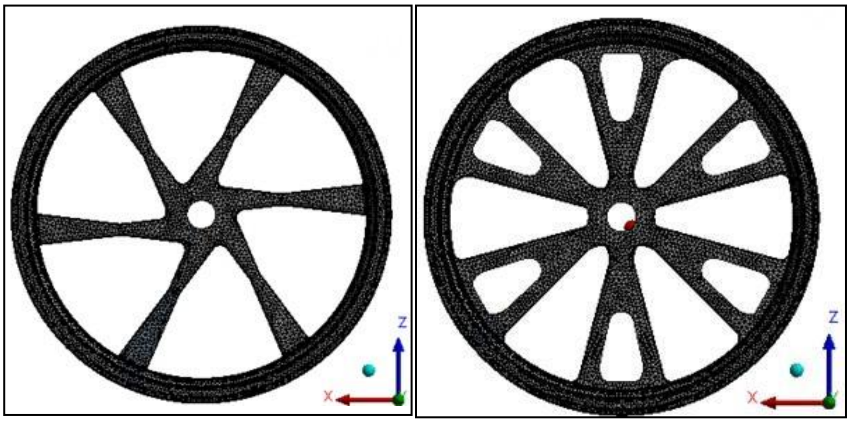
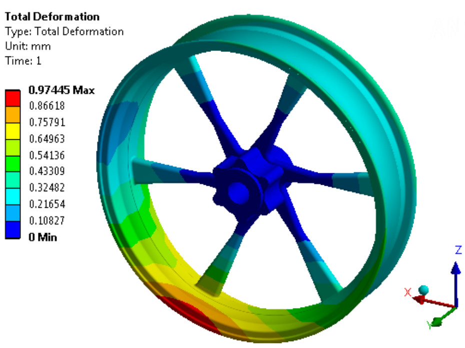


Figure 4 Model A and B meshed wheel rim design.

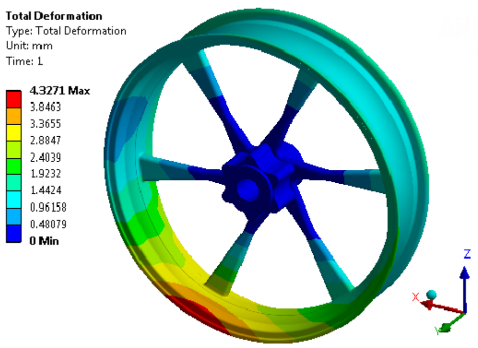
4.1 Total Deformation of Model A and B wheel rim design:

Total deformation on an alloy wheel rim design of a sports bike refers to the amount of distortion or change in shape that the rim undergoes when subjected to various forces and loads during riding. It is elucidated that the total deformation, defined as the square root of the sum of squared stretching deformation and squared shearing deformation, is an invariant independent of the coordinate system used. The deformation can be caused by a variety of factors, including the rider's weight, road conditions, and the bike's speed. The deformation data is analyzed to ensure that the rim is capable of withstanding the loads and stresses it will encounter during normal use without causing failure or compromising the rider's safety. This analysis may involve simulations, testing, and other methods to evaluate the rim's strength and durability under various conditions.

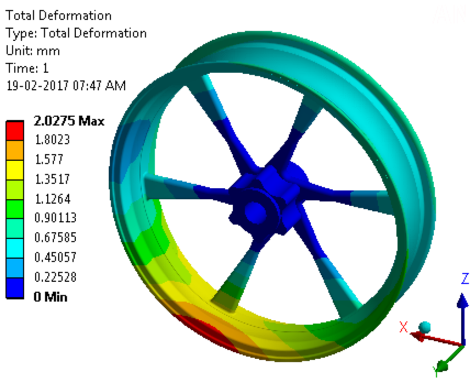
As a consequence of this investigation into the deformation, which is depicted in Figures 5 and 6, the magnesium alloy deflects more than the other materials by roughly 77% and 53% with regard to the various designs of the Model A wheel rims, respectively (Table 2). In a manner that is analogous, the Model B wheel rim demonstrates that magnesium alloy deflects more than stainless steel and titanium by around 77.5% and 53% respectively. According to these findings, the design of the wheel rim used for the Model A wheel creates a greater amount of deflection in the magnesium-titanium-steel alloy than the design used for the Model B wheel does.



(a) Structural Steel

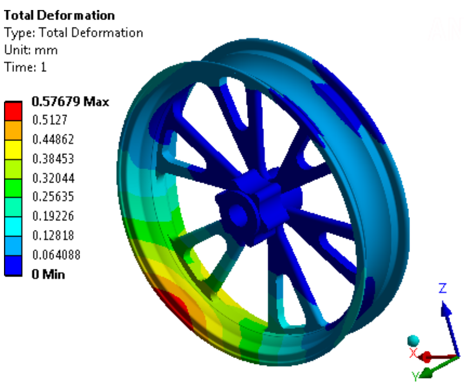


(b) Magnesium alloy

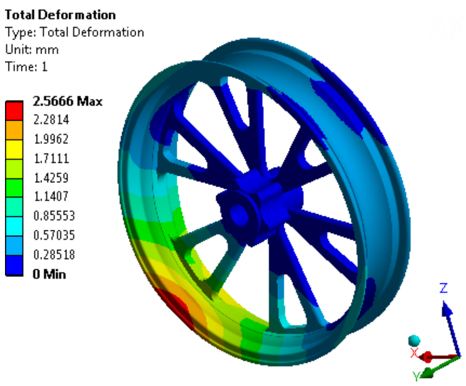


(c) Titanium alloy

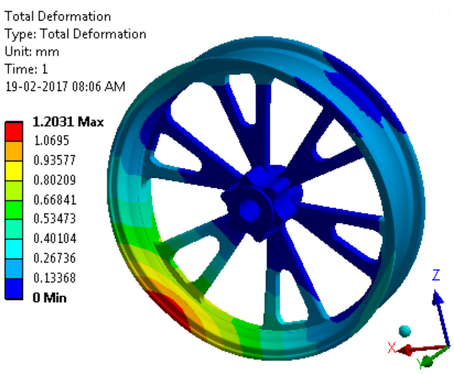
Figure 5 Total Deformation of Model A wheel rim design.



(a) Structural Steel



(b) Magnesium alloy



(c)Titanium alloy

Figure 6 Total Deformation of Model B wheel rim design.

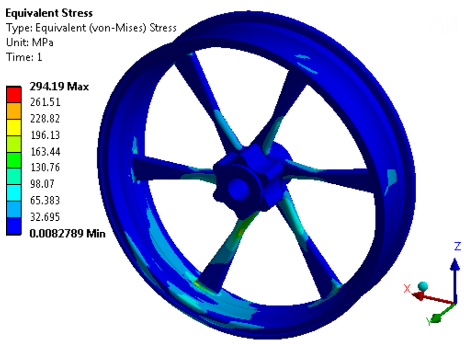
Table 2 Total Deformation of Model A and B wheel rim design.

Deformation (mm)	SS	Mg alloy	Ti alloy
Model A Wheel Rim Design	0.97445	4.3271	2.0275
Model B Wheel Rim Design	0.57679	2.5666	1.2031

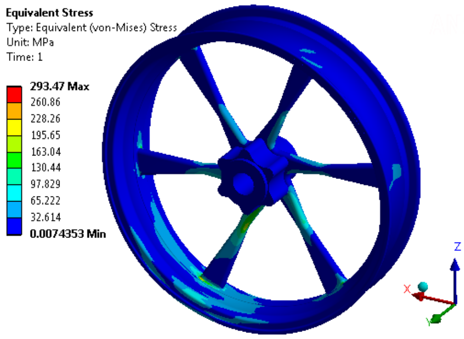
4.2 Equivalent Stress of Model A and B wheel rim design:

Equivalent stress is widely used to represent a material's status for ductile material. Equivalent stress is a scalar quantity that represents the magnitude of stress at a point. The equivalent stress is always positive and is useful for comparing stress states under combined loading situations. Equivalent stress is a measure of the maximum stress experienced by a material due to various loading conditions, taking into account all types of stresses acting on it, such as tensile, compressive, and shear stresses. In the context of a titanium wheel rim design of a sports bike, equivalent stress can be used to determine whether the wheel rim can withstand the stresses it is subjected to during operation. The equivalent stress on alloy wheel rim design of a sports bike is a critical factor in determining its strength and durability. By analyzing the stresses experienced by the wheel rim using FEA or analytical calculations, engineers can ensure that the design meets the necessary safety standards and can withstand the demands of high-performance sports bike operation.

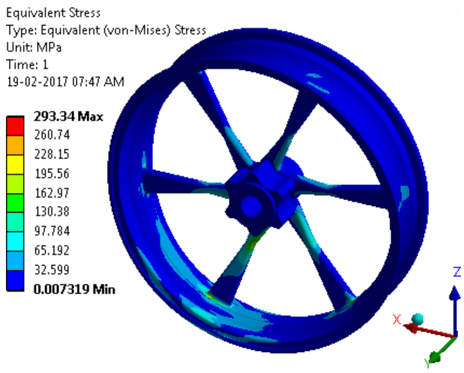
According to the findings of the stress experiment, which are depicted in Figure 7 and 8, the Ti alloy creates a reduced stress concentration on the Model A wheel rim design by roughly 0.5%. Also, compared to magnesium and titanium alloy, the use of stainless steel results in a stress concentration that is roughly one percent lower on the Model B wheel rim design (Table 3). This value displays the radial extent, in the event of a collision with a symmetric barrier, of the stress map. One way to express this dimension is as the distance between two spots on the outer circle and the surface that follows the curve that encloses the central hub. The distance between these two points is equal to the circumference. As soon as the blockage makes full contact with the rim, the stress level spikes to its maximum and stays there for the remainder of the simulation. The simulation begins the moment the barrier makes physical contact with the rim. This is true even if the obstacle merely makes brief contact with the rim. Based on the results of the analysis, the design of the wheel rim may be modified to improve its performance and durability, or different materials may be selected to better suit the expected operating conditions. Ultimately, the goal of the analysis is to ensure that the wheel rim is safe, reliable, and performs well under a range of conditions.



(a) Structural Steel

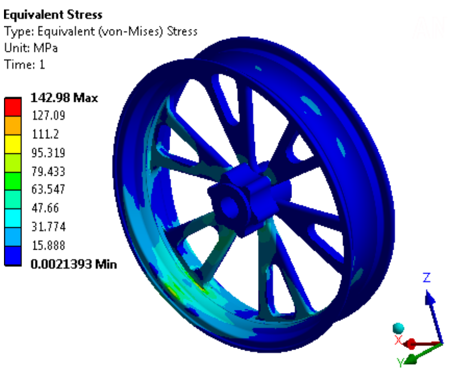


(b) Magnesium alloy

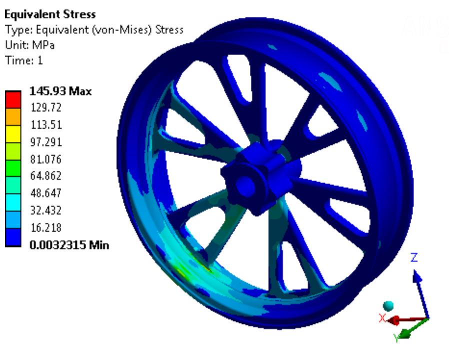


(b) Titanium alloy

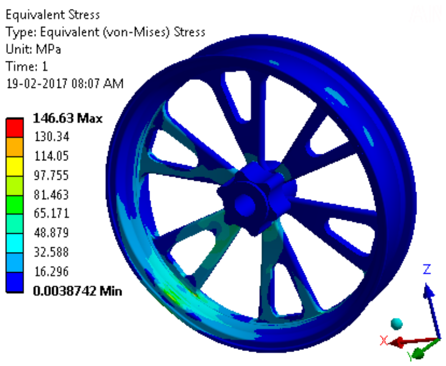
Figure 7 Equivalent Stress of Model A wheel rim design.



(a) Structural Steel



(b) Magnesium alloy



(c) Titanium alloy

Figure 8 Equivalent Stress of Model B wheel rim design.

Table 3 Equivalent Stress of Model A and B Wheel rim design.

Equivalent stress (MPa)		SS	Mg alloy	Ti alloy
Model A Wheel Rim Design	Max	294.19	293.47	293.34
	Min	0.00828	0.00743	0.00732
Model B Wheel Rim Design	Max	142.98	145.93	146.63
	Min	0.00214	0.00323	0.00387

4.3. Statistical Analysis of Wheel Rim Design

Response optimization is a statistical technique used to find the best combination of input variables to optimize a response variable of interest. In other words, it is a method of finding the optimal values of one or more independent variables that will maximize or minimize a dependent variable. Response optimization is commonly used in experimental design and is a key component of quality improvement and process optimization. By using response optimization techniques, researchers can identify the key factors that affect a particular response and determine the best settings for those factors.

The ultimate goal of response optimisation is to improve the performance of a product by finding the best combination of input variables that will lead to the desired result. In this analysis, Model A and Model B wheel designs and magnesium and titanium alloy materials were taken as input variables (Table 4). Total deformation and equivalent stress were analysed for the minimum occurrence on the wheel rim design. The optimal response the response optimization was tabulated in Tabel 5 and response plot was displayed at Figure 9. The optimum response resulting from Model B with titanium alloy will have a minimum stress of 146.63 MPa and a total deformation of about 1.203 mm (Table 5). Among the possible responses, the composite desirability of 0.998812 was selected as the best response.

Table 4 Input for Response Optimization.

Response	Goal	Lower	Target	Upper	Weight
Stress	Minimum	100	145.930	293.470	0.5
Deformation	Minimum	1.00	1.203	4.327	0.5

Table 5 Optimal response from Response Optimization.

Solution	Model	Material	Stress Fit	Deformation Fit	Composite Desirability
1	B	Ti	146.63	1.203	0.998812
2	B	Mg	145.93	2.567	0.866364
3	A	Ti	293.34	2.028	0.159575

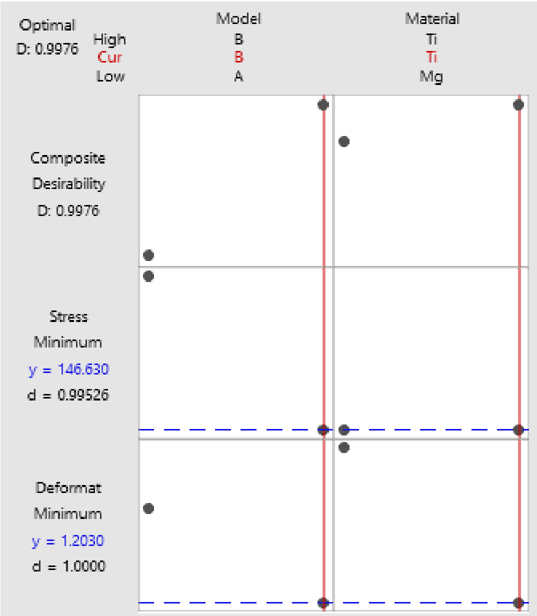


Figure 9 Optimal response plot for Wheel Rim design.

5. Conclusion

As the automotive sector becomes more conscious of the need to reduce its carbon footprint, more resources are being devoted to the study and development of lightweight sports bikes' wheel rim. Nowadays, almost all wheel manufacturers opt for lightweight alloys for wheel rims due to the benefits they provide in terms of reduced unsprang weight and increased fuel efficiency. As wheel rims are subjected to high static and dynamic stress and vibrations when the vehicle is in operation, they must be free of defects. The purpose of this research is to explore how new design approaches may improve the development of automotive wheels and spokes. By comparing the responses of structural steel, magnesium alloy, and titanium alloy to stress and strain, it may be possible to acquire a better knowledge of the features of these materials. The basic goal of static analysis is to ascertain the stress and deflection that arise from an applied force. According to the stress analysis, the Ti alloy produces a stress concentration that is about 0.5% lower than on Model A and around 1% lower value for SS on the Model B wheel rim design. Mg alloy has a deflection of about 77% and 53% more than stainless steel and titanium alloy, respectively, in the construction of the model A and B wheel rim.

Ethical considerations

Not applicable.

Conflict of Interest

The authors declare that they have no conflict of interest.

Funding

This research did not receive any financial support.

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