

Performance Evaluation of Motorcycle Racing Cast Wheels Under Dynamic Load Using Finite Element Method with Aluminum Material

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Article Information	ABSTRACT
Article History Received : December 16, 2024 Revised : December 27, 2024 Published : January 06, 2025	The racing cast wheel made of aluminum 6061-T6 is a critical component in motor vehicles, particularly in supporting performance, safety, and aesthetics. This study aims to analyze the mechanical performance of the wheel through Finite Element Analysis (FEA) simulation. The FEA simulation was conducted using Ansys 18.1 software with a load of 1500 N, covering both static and dynamic loading conditions. The material tested is Aluminum Alloy 6061-T6, with material properties derived from tensile testing. The simulation results indicate that maximum stress occurs in critical areas, such as bolt holes and the intersection of spokes with the wheel rim, with a maximum stress value of 46.027 MPa. This stress level remains below the material's yield strength (276 MPa), demonstrating that the design is safe from plastic deformation. The total deformation observed is 0.053 mm, which is negligible and does not affect the wheel's functionality. A safety factor exceeding 2.5 confirms that the wheel can withstand more extreme loads. Based on these findings, design optimizations such as adding fillets and surface treatments are recommended to enhance the wheel's reliability. This research provides valuable insights for the development of stronger, lighter, and more durable wheels, particularly suited to the diverse road conditions found in Indonesia.
Keywords: <i>Cast wheel; Aluminum 6061-T6; Finite Element Analysis; Von mises stress.</i>	

INTRODUCTION

In the automotive industry, vehicle performance and safety heavily rely on supporting components such as wheels. Wheels not only serve as supports for tires but also play a crucial role in enhancing vehicle stability, comfort, and aesthetics. One commonly used type of wheel for motorcycles is the cast wheel, manufactured through a casting process using aluminum alloy (Al-alloy) as the primary material.

According to (Putra et al., 2023), aluminum alloy offers a unique combination of strength and lightweight properties, making it a preferred material in automotive applications. Aluminum 6061-T6, as one of the Al-alloys, has advantages such as a maximum tensile strength of up to 310 MPa and a yield strength of 276 MPa, which supports its ability to withstand dynamic loads in vehicles. Previously, research by (Kustono et al., 2018) showed that the lightweight nature of this material contributes to vehicle energy efficiency by reducing fuel consumption by up to 15%, especially in two-wheeled vehicles operating in dense traffic, such as in Indonesia

However, despite its advantages, cast wheels also have limitations. Research by (Putra et al., 2021) and (Kiani Khouzani et al., 2018) indicates that the fatigue strength of Al-alloy materials

is lower than that of steel. As a result, stress concentration areas on the wheel, such as around the spoke holes or spokes, become vulnerable to cracks. Failures such as cracked rims, bent rims, and broken rims are commonly reported, especially when the wheels are used under extreme conditions such as pothole-ridden roads or excessive loads (Putra et al., 2024) (Kustono et al., 2018). This is also in line with the findings of (Weerasinghe et al., 2020), who stated that the fatigue strength of aluminum alloy is lower than that of steel, making this material more susceptible to harsh road conditions.

On the other hand, the geometric design of cast wheels presents additional challenges. Although the solid spoke design provides stability, it tends to be more rigid compared to spoked wheels, making it less effective in absorbing shocks. Analyses by (Putra, Andoko, et al., 2020) and (Putra, Pradani, & Saepuddin, 2022) highlight the importance of optimizing geometry and surface treatments to enhance resistance to corrosion and cracking. Furthermore, based on the study by (Seguin et al., 2018), design optimization through finite element simulation can reduce the risk of stress concentration by up to 40%, especially on wheels subjected to high dynamic loads. Additionally, research by (Petrov & Tongov, 2020) recommends surface treatments such as anodizing to enhance corrosion resistance and extend the service life of aluminum-based automotive components.

In the automotive industry, material selection is a critical aspect to support vehicle performance while meeting energy efficiency requirements. One widely used material is aluminum alloy, particularly the 6061-T6 type, which is renowned for its superior mechanical and physical properties for structural applications.

Aluminum 6061-T6 offers numerous advantages that make it highly suitable for automotive components, including cast wheels. One key benefit is its low density, approximately 2.7 g/cm^3 , which is significantly lighter than steel (7.8 g/cm^3). According to (Putra, Pradani, & Momani, 2022) and (Putra & Pradani, 2020), this lightweight property helps reduce the vehicle's overall mass, thereby improving fuel efficiency and vehicle performance. Aluminum 6061-T6 has a maximum tensile strength of up to 310 MPa and a yield strength of 276 MPa. These properties enable the material to withstand high loads without permanent deformation, making it ideal for components subjected to dynamic stresses, such as wheels (Putra, Rohman, et al., 2020) (Petrov & Tongov, 2020).

In the automotive environment, components are often exposed to water, salt, and other chemicals that can cause corrosion. Aluminum 6061-T6 exhibits excellent corrosion resistance, especially after anodizing, making it a reliable choice for use in various weather conditions. This alloy also has good machinability, enabling manufacturing processes such as cutting, casting, and forming to be performed with high precision. This capability allows manufacturers to produce components with complex designs and tight tolerances, such as racing wheels, particularly for manufacturers in Indonesia. Aluminum 6061-T6 can be welded using various techniques, although post-welding heat treatment is required to maintain its mechanical properties. This capability is crucial for automotive repair and manufacturing (Putra et al., 2024) (Seguin et al., 2018). The material has an elastic modulus of 69 GPa, providing a balance between stiffness and the ability to absorb impact energy, which is essential for components like wheels that frequently encounter shocks.

The use of aluminum 6061-T6 in the automotive industry extends beyond wheels. This material is also employed in chassis and vehicle frame components, suspension parts such as control arms, exhaust systems, and body panels in lightweight vehicles. However, despite its numerous advantages, aluminum 6061-T6 has limitations, such as lower fatigue strength compared to steel and susceptibility to cracking in stress concentration areas. This underscores the importance of design development and simulation analysis to optimize its application in cast wheels. Given its superior properties, this study aims to analyze the performance of aluminum 6061-T6 in automotive applications, particularly in racing cast wheels, to provide technical recommendations for improving durability and reliability. To achieve this, the research focuses on

performance analysis of cast wheels made of aluminum 6061-T6 through load simulations and material testing (Weerasinghe et al., 2020) (Doshi et al., 2017).

This study aims to evaluate the advantages and disadvantages of Al-alloy materials in automotive applications, identify the factors contributing to the failure of cast wheels, and provide technical recommendations, such as design optimization and material modification, to enhance the durability and lifespan of the wheels. With this approach, the research is expected to make a significant contribution to the development of more reliable and efficient cast wheels.

RESEARCH METHODS

This study was conducted to analyze the performance of racing cast wheels made from aluminum 6061-T6 through material testing, design evaluation, loading analysis, and simulation. The following are the research methodology steps undertaken: , manuals or technical manuals in research activities that are too detailed should not be included.

Tensile Test Analysis

The tensile test is conducted to determine the mechanical properties of the material, such as Ultimate Tensile Strength (UTS), Yield Strength (σ_y), Young's Modulus (E), and maximum elongation (ϵ_{max}).

Theoretical principles applied in the testing process involve deriving equations from:

$$\sigma = \frac{F}{A} \quad (1)$$

$$\epsilon = \frac{\Delta L}{L_0} \quad (2)$$

The results of the tensile test indicate that Aluminum 6061-T6 exhibits the following mechanical properties, as presented in Table 1. The results of this tensile test also serve as the baseline reference for inputting initial data on material properties in ANSYS 18.1 software.

Table 1. Mechanical Properties of Aluminum 6061-T6

Properties	Value
Tensile strength	310 MPa
Yield strength	240 MPa
Elongation	10%
Young Modulus	68.9 GPa
Density	2.70 g/cm ³
Poisson's ratio	0.33

Design Process

The design is carried out to ensure that the wheel can withstand both static and dynamic loads. The wheel geometry is designed using CAD software such as SolidWorks, considering load distribution, aesthetics, and a wheel diameter of 17 inches. The 3D model of the wheel is created based on the specifications of sport motorcycles in Indonesia. Preliminary analysis is performed to ensure even mass distribution and minimize stress concentration in critical areas such as bolt holes and spokes. Aluminum 6061-T6 is used as the material property for the design simulation. The results of the geometric design process are shown in Figure 1.



Figure 1. Wheel geometry design

Material Loading

Material loading includes both static and dynamic analyses. The maximum load is calculated based on the weight of the vehicle and the rider, along with the dynamic load caused by vertical acceleration on uneven roads. The load calculation can be applied using the following theorem.

The calculation of static load can be derived using the following static loading formula:

$$F_{static} = m \cdot g \quad (3)$$

Meanwhile, the dynamic load can be derived using the following dynamic loading formula:

$$F_{dynamic} = m \cdot (g + a) \quad (4)$$

The loading process considers several components, as outlined in Table 2 below.

Table 2. Loading process

Item	Value
Vehicle and rider mass	200 kg
Weight distribution	Front tyre 30%-40% total weight

The assumptions for static loading are as follows:

- Total weight of the vehicle and rider (W_{total}): $(200 \text{ kg}) \cdot (9.81) = 1,962 \text{ N}$
- Weight distribution to the front wheel 40%

$$F_{static} = (1962) \cdot (0.4) = 784.8 \text{ N}$$

The assumptions for dynamic loading are as follows: Dynamic loading occurs when the vehicle travels over uneven roads or during sudden braking. This load includes forces resulting from vertical acceleration and horizontal deceleration.

- Dynamic load component of vertical acceleration:

This load occurs as a result of the front wheel encountering shocks from the road.

$$F_{vertical} = m \cdot a_{vertical}$$

Where $a_{vertical}$ is the acceleration due to shocks, typically reaching 3–5 g on rough roads.

$$\text{With } a_{vertical} = 3 \text{ g} = (3) \cdot (9.81) = 29.43 \text{ m/s}^2$$

$$F_{vertical} = (200) \cdot (29.43) = 5,886 \text{ N}$$

- Dynamic load component of horizontal acceleration:

This load occurs during sudden braking or acceleration.

$$F_{horizontal} = m \cdot a_{horizontal}$$

$$\text{Assumption of sudden braking with } a_{horizontal} = 0.8g = (0.8) \cdot (9.81) = 7.848 \text{ m/s}^2$$

$$F_{horizontal} = (200) \cdot (7.848) = 1569.6 \text{ N}$$

$$F_{dynamic} = f_{vertical} + f_{horizontal}$$

$$F_{dynamic} = 5886 + 1569.6 = 7455.6 \text{ N}$$

To simplify the loading calculation, the total load is rounded to 7500 N. Dynamic loads are significantly greater than static loads because dynamic loads tend to occur when the object is in motion. The dynamic load will later serve as a reference for inputting load parameters in the simulation process.

Finite Element Method Simulation

Finite Element Analysis (FEA) is used to predict the structural response to loading. The analysis is conducted using ANSYS 18.1 software. The simulation process begins by importing the 3D design that has been created into the simulation software, as well as inputting the mechanical data into the software based on the results of the tensile testing. The next process is meshing, also known as model discretization, which is performed to ensure the accuracy of the results. Static and dynamic loads are applied according to the calculations done in the loading section, with fixed support conditions.

The simulation results aim to analyze von Mises stress, which indicates the stress distribution within the structure. Furthermore, deformation analysis is used to evaluate total deformation by measuring the shape changes due to loading. Finally, a safety factor analysis is performed to ensure the wheel's safe usage. The approach used for the safety factor analysis is as follows.

$$\sigma_{VM} = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}} \quad (5)$$

RESULTS AND DISCUSSION

The simulation was conducted to evaluate the performance of racing cast wheels made of aluminum 6061-T6 under static and dynamic loading conditions using the Finite Element Analysis (FEA) method. The key results from the simulation are as follows:

Von Mises Stress

The range of von Mises stress obtained from the simulation process is between 7,601.8 Pa and 46.027 MPa. The critical areas with the highest stress occur around the bolt holes and the junction of the spokes with the wheel rim. The simulation also reveals that the maximum stress is still below the yield strength of the material (276 MPa), indicating that the wheel design is safe from plastic deformation under these loading conditions. The geometry around the bolt holes causes stress concentration due to sharp corners and sudden changes in geometry geometri (Andoko et al., 2020) (Hojati & Baktash, 2021) (Infante et al., 2017). Sharp corners impede the uniform distribution of loads, leading to stress concentration at those points. In a similar study by (Ramadhani et al., 2020), aluminum 6061-T6 wheels for passenger vehicles were tested using a similar method, resulting in a maximum stress range of 42 MPa to 48 MPa under dynamic loading conditions, which is also below the material's yield strength. This comparison shows the material's performance consistency and validates the design for automotive applications. Additionally, according to the SAE J328 industry standard (Society of Automotive Engineers), the minimum lateral load testing for light vehicle wheels requires components to withstand stress without cracking or significant deformation under design loads. The simulation results in this study show that the maximum stress of 46.027 MPa still meets these standards, ensuring that the design complies with safety requirements.

The static and dynamic loads on the wheel are primarily focused on the central hub and distributed across the wheel spokes. The spokes and the wheel rim serve as the main pathways for stress distribution. In cast wheels, the solid spoke geometry results in more concentrated stress compared to spoked wheels, which are more flexible (Amalia, 2015) (Turan et al., 2017). In this context, a study by (Gondhali et al., 2019) found that wheel designs based on solid spokes are more susceptible to stress concentration in certain areas compared to designs based on spoke wheels, which have a more evenly distributed stress. With a modulus of elasticity of 69 GPa and a yield strength of 276 MPa, aluminum material effectively absorbs high stresses before reaching its plastic limit. The implications of this study also suggest that design optimization, such as the use of fillets in the bolt hole areas or modifications to the spoke geometry, can further improve stress distribution to reduce stress concentration, as recommended by (Seguin et al., 2018). This study emphasizes the importance of a combination of optimal geometric design and material selection in accordance with industry standards to ensure the reliability and safety of the wheel components.

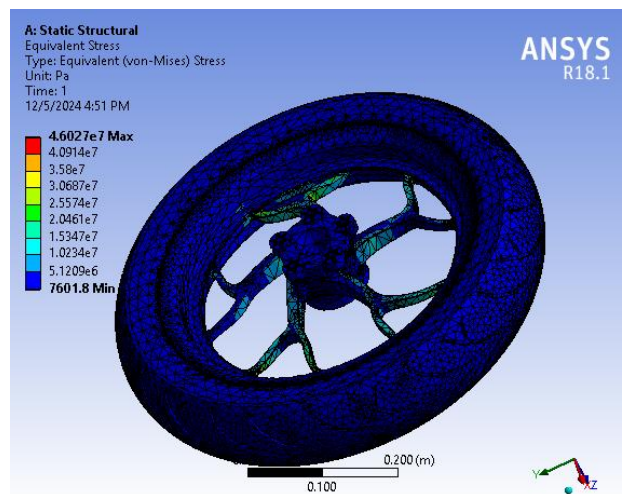


Figure 2. *Von mises stress results*

Total Deformation

The range of deformation observed in the simulation is between 0 and 0.053 mm. The analysis of total deformation in the wheel indicates minimal deformation, which does not significantly impact the wheel's functionality. Aluminum 6061-T6, with a modulus of elasticity of 69 GPa, demonstrates sufficient rigidity while still being capable of absorbing energy from loads without experiencing significant deformation. The spoke design of the wheel has a relatively uniform mass distribution, which helps minimize deformation (Andoko & Puspitasari, 2016). Dynamic loads from uneven roads are well-absorbed by the wheel structure. The maximum load of 7500 N is distributed across the entire surface of the spokes and the wheel rim, resulting in very small deformation values.

In a similar study by (Ramadhani et al., 2020), on wheels made of aluminum 6061-T6 with a similar design, the measured deformation ranged from 0.02 to 0.06 mm after applying a dynamic load of 8000 N. This deformation range is consistent with the findings of this research, which confirms that aluminum 6061-T6 has the ability to maintain its shape under heavy loads without causing significant deformation, in line with design requirements for automotive components. According to the SAE J328 industry standard, which governs wheel performance, the maximum allowable deformation for light vehicle wheels under loading conditions is no more than 0.1 mm to ensure component function and safety. The results of this study, with a maximum deformation of 0.053 mm, demonstrate that the aluminum 6061-T6 cast wheel meets or even exceeds this standard, indicating an efficient design in maintaining its structural performance under extreme loading conditions.

Furthermore, in the study by (Huang et al., 2017), they also noted that a solid spoke design with uniform mass distribution on the wheel can reduce local deformation, which aligns with the findings of this research. The thicker spoke structure on racing wheels helps distribute the load more evenly, contributing to lower deformation. Thus, the simulation results show that the aluminum 6061-T6 wheel is capable of withstanding loads with minimal deformation, meeting safety standards, providing good performance under dynamic loading conditions, and offering potential for broader automotive applications.

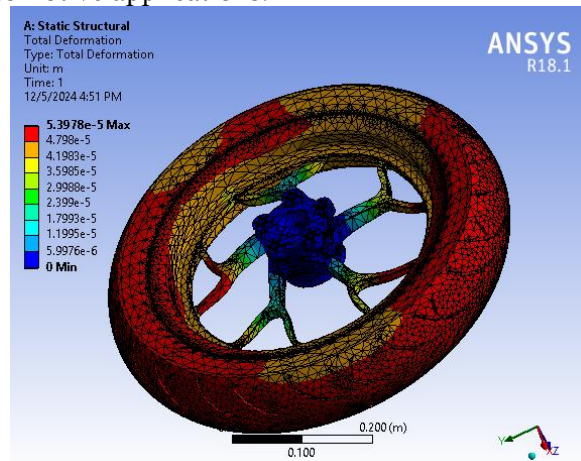


Figure 3. Total deformation results

Shear Stress Maximum

The shear stress analysis results range from 4.273 Pa to 23.458 MPa. The maximum shear stress is significantly below the material's strength, indicating that the wheel has good resistance to shear forces.

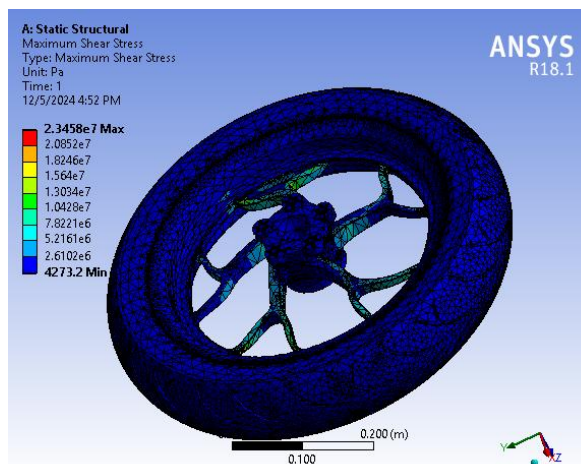


Figure 4. Shear stress results

When the wheel rotates and bears the load, shear forces occur along the surface of the spokes and bolt holes, which experience pressure from different directions. The contact surface area at the bolt holes is smaller compared to other areas, leading to higher localized shear stress (Winchester et al., 2023). Aluminum 6061-T6 exhibits good resistance to shear forces due to its mechanical properties, which provide a favorable combination of stiffness and elasticity. In the study by (Armendáriz et al., 2014), which analyzed shear strength in automotive components made from aluminum 6061-T6, it was found that the measured maximum shear stress ranged around 20 MPa, which is consistent with the findings of this research. This indicates that aluminum 6061-T6 wheels have good resistance to shear forces, even under relatively heavy loading conditions. In the SAE J328 industry standard, which regulates wheel performance, there are no specific limitations regarding shear stress; however, the standard focuses on the wheel's resistance to static and dynamic loads that could lead to material failure. A wheel that can maintain

shear stress below the material's strength, as found in this study, meets or even exceeds expectations regarding resistance to shear forces.

A study by (Singh et al., 2018) also confirmed that aluminum 6061-T6 has good resistance to shear forces in structural components such as wheels, with the measured maximum shear stress around 25 MPa. This finding supports the results of this study, which show that aluminum 6061-T6 racing cast wheels can withstand shear forces without significant structural damage. Therefore, the shear stress analysis results indicate that aluminum 6061-T6 wheels have excellent resistance to shear forces, which aligns with industry standards and similar studies, ensuring their reliability in automotive applications under heavy and dynamic loading conditions.

Normal Stress

The normal stress analysis results range from -33.7 MPa to 45.90 MPa. The static load from the vehicle's weight and the dynamic load from shocks exert perpendicular pressure on the spoke surfaces, resulting in normal stress. Non-uniform geometric areas, such as the central hub and spoke intersections, lead to variations in normal stress.

In the study by (Karteek et al., 2021), which analyzed the distribution of normal stress in aluminum wheels, a similar stress range was found, between -40 MPa and 50 MPa, at specific points such as the intersection of the spokes and the hub center. This study emphasizes the importance of geometry and structural design to distribute stress more evenly in order to prevent damage caused by stress concentration. According to the SAE J328 industry standard for wheel durability, this standard suggests that wheel designs must be able to withstand the normal stresses that may arise from both static and dynamic loads, with the primary focus on ensuring that the stresses do not exceed the material's yield strength. In this case, the normal stresses observed in this study, which are below the yield strength of aluminum 6061-T6 (276 MPa), indicate that the wheel meets the durability criteria for normal stresses as outlined in the industry standards.

The findings of this study are also supported by (Zhang et al., 2014), who found that wheel designs with stress concentrations in areas of uneven geometry (such as the hub center and the junction of the spokes) need to be improved using design optimization techniques to distribute the load more evenly and reduce the normal stresses that could lead to structural failure. Therefore, the results of the normal stress analysis in this study align with previous research and industry standards, emphasizing the importance of considering geometry design to enhance the reliability of wheels in automotive applications.

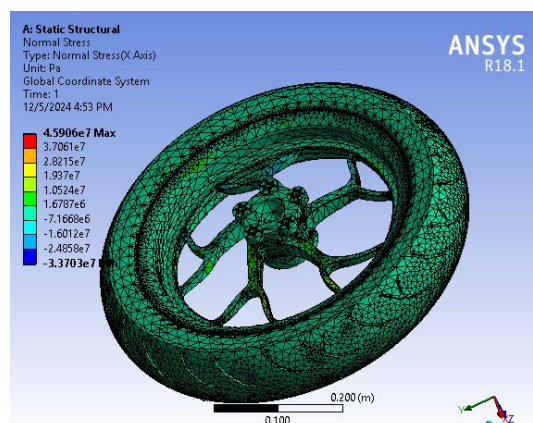


Figure 5. Normal stress results

Safety Factor

The safety factor analysis results vary, with a minimum value above 2.5. This value indicates that the wheel has a sufficiently high safety margin to withstand the applied loads. The wheel geometry effectively distributes the load, keeping maximum stress low (Chen et al., 2018). With a yield strength of 276 MPa, the generated stress remains well below this limit, resulting in a high safety factor (Chen et al., 2018). The maximum dynamic load of 7500 N has been conservatively estimated, ensuring the safety factor remains high.

The study by (Xu et al., 2017), which evaluated the safety factor of cast wheel rims, also demonstrated that a well-designed geometry can result in a safety factor greater than 2.5, with a more uniform stress distribution across the component. This research emphasizes the importance of material selection and geometry design to achieve an optimal safety factor in automotive applications, similar to the findings in this study.

As an industry reference, the SAE J328 standard for wheel durability recommends a minimum safety factor of 2.0 for wheels used in automotive applications, to ensure that components can withstand the dynamic and static loads encountered during use. In this case, the higher safety factor value found in this study (greater than 2.5) indicates that the wheel not only meets but exceeds the industry standards set for durability and component reliability. Thus, the results of this study align with previous research and meet the safety factor criteria outlined by industry standards, showing that the wheel design has a high level of reliability in withstanding the applied loads, including the maximum dynamic load.

CONCLUSION

Based on the simulation analysis and discussion, it can be concluded that Aluminum 6061-T6 demonstrates superior mechanical properties for cast wheel applications. With a yield strength of 276 MPa and a maximum tensile strength of 310 MPa, this material can withstand both static and dynamic loads without experiencing plastic deformation. This capability is supported by its modulus of elasticity of 69 GPa, which allows the material to effectively absorb impact energy. The simulation results indicate that maximum stress occurs in stress concentration areas, such as bolt holes and the junction of the spokes with the wheel rim. However, the generated stress remains below the material's strength, ensuring the current design is sufficiently safe. Adding fillets or reinforcements to these areas can further reduce the risk of cracking. The total deformation is very small, around 0.053 mm, and does not affect the mechanical function of the wheel. The maximum shear stress is also below the material's strength limit, showing that the design can withstand the applied shear forces. The high safety factor (above 2.5) indicates that the wheel has sufficient strength reserves to handle more extreme loading conditions, including pothole-ridden roads or severe impacts.

The recommendations from the author are as follows: Optimize the design by minimizing stress concentration areas, particularly around the bolt holes and spoke intersections. Validate the Finite Element Analysis (FEA) results through experimental testing, such as tensile testing, material fatigue testing, or impact testing on the wheel. Evaluate the potential use of composite materials, such as Carbon Fiber Reinforced Polymer (CFRP), for lighter and more durable wheels. Perform more complex dynamic load simulations, such as sudden impact loads caused by extreme road conditions or accidents. Additionally, conduct fatigue life analysis using the S-N Curve method to evaluate the wheel's lifespan under cyclic loading conditions. To strengthen the conclusion, future research could explore alternative materials, such as advanced composites or high-strength metal alloys, for cast wheel applications. Additionally, more advanced simulation techniques, such as integrating multi-physics models that consider temperature effects or real-world material behavior, could improve the accuracy and relevance of predictions for extreme conditions. Further research on wheel design optimization for various types of vehicles and environmental factors would also provide valuable insights.

ACKNOWLEDGEMENTS

With a deep sense of gratitude, the author would like to express sincere thanks to all parties who have provided support, guidance, and contributions in completing this research. Special thanks are extended to:

1. Allah SWT, for His blessings and grace that have always accompanied every step of this research.
2. My beloved family, for their constant prayers, support, and motivation.
3. Fellow researchers and the laboratory team, for their collaboration and discussions that helped the analysis and simulation process proceed smoothly.
4. The institution and supporting parties, for providing the facilities, data, and resources to support this research.

It is hoped that this research can provide broad benefits and contribute significantly to the field of science, particularly in the automotive industry. The author also acknowledges that this research still has limitations. Therefore, constructive feedback and suggestions are greatly appreciated for future development.

REFERENCES

- Amalia, F. (2015). *Karakterisasi Struktur Mikro Komposit Al-ZrSiO₄ dengan Scanning Electron Microscopy (SEM) dan X-Ray Diffraction (XRD)*. April, 200–203.
- Andoko, A., Wulandari, R., Gapsari, F., Putra, A. D., Kurniawan, P., Pradica, D. R., Jeady, R. P., & Prasetya, R. (2020). SIMULATION OF TIME AND MOTION ACTIVITY EFFECT ON HIP JOINT IMPLANTS. *JOURNAL OF SOUTHWEST JIAOTONG UNIVERSITY*, Vol. 55 No.
- Andoko, & Puspitasari, P. (2016). Finite element analysis of surface tension on piston due to pressure variation. *AIP Conference Proceedings*, 1778. <https://doi.org/10.1063/1.4965798>
- Armendáriz, I., López, J., Olarrea, J., Oliver, M., & Climent, H. (2014). Case study: Analysis of the response of an aircraft structure caused by a propeller blade loss. *Engineering Failure Analysis*, 37, 12–28. <https://doi.org/10.1016/j.engfailanal.2013.11.011>
- Chen, J., Wei, Y., Zhan, X., Li, Y., Ou, W., & Zhang, T. (2018). Melt flow and thermal transfer during magnetically supported laser beam welding of thick aluminum alloy plates. *Journal of Materials Processing Technology*, 254, 325–337. <https://doi.org/10.1016/j.jmatprotec.2017.11.046>
- Doshi, K., Roy, T., & Parihar, Y. S. (2017). Reliability based inspection planning using fracture mechanics based fatigue evaluations for ship structural details. *Marine Structures*, 54, 1–22. <https://doi.org/10.1016/j.marstruc.2017.03.003>
- Gondhali, S. L., Dhale, A. D., & Pagare, S. (2019). Static Structural Analysis of Car Rim by Finite Element Method. In H. Vasudevan, V. K. N. Kottur, & A. A. Raina (Eds.), *Proceedings of International Conference on Intelligent Manufacturing and Automation* (pp. 181–193). Springer Singapore.
- Hojati, M., & Baktash, A. (2021). Design and fabrication of a new hybrid stepper motor with significant improvements in torque density. *Engineering Science and Technology, an International Journal*, xxxx. <https://doi.org/10.1016/j.jestch.2021.01.016>
- Huang, R., Zhang, X., Keong, W., Kumar, A. S., & Liu, K. (2017). Ultra-precision machining of grayscale pixelated micro images on metal surface. *Precision Engineering*, October, 0–1. <https://doi.org/10.1016/j.precisioneng.2017.12.009>
- Infante, V., Fernandes, L., Freitas, M., & Baptista, R. (2017). Failure analysis of a nose landing gear fork. In *Engineering Failure Analysis* (Vol. 82, pp. 554–565). <https://doi.org/10.1016/j.engfailanal.2017.04.020>
- Karteek, N., Rao, P. K. V., Ravi Prakash Babu, K., & Mojeshwara Rao, D. (2021). Structural Analysis of Motorcycle Alloy Wheel. *E3S Web of Conferences*, 309, 1–9. <https://doi.org/10.1051/e3sconf/202130901158>
- Kiani Khouzani, M., Bahrami, A., & Eslami, A. (2018). Metallurgical aspects of failure in a broken femoral HIP prosthesis. *Engineering Failure Analysis*, 90(November 2017), 168–178. <https://doi.org/10.1016/j.engfailanal.2018.03.018>
- Kustono, D., Wulandari, R., Andoko, Puspitasari, P., Kurniawan, G. A., & Putra, A. D. (2018). Simulation of knee implants made of Ti6Al4V material during walking. *MATEC Web of Conferences*, 204, 1–6. <https://doi.org/10.1051/matecconf/201820407015>

- Petrov, P., & Tongov, M. (2020). Study of the cathode emissivity in generators for electron beam systems. *Optik*, 209(May 2019), 164358. <https://doi.org/10.1016/j.ijleo.2020.164358>
- Putra, A. D., Andoko, Wulandari, R., & Kurniawan, G. A. (2020). Simulation of hip joint implants using finite element method with time and load variations. *Key Engineering Materials*, 851 KEM, 111–121. <https://doi.org/10.4028/www.scientific.net/KEM.851.111>
- Putra, A. D., & Pradani, Y. F. (2020). SIMULASI BATANG PENGHUBUNG PISTON DENGAN VARIASI MATERIAL Al Alloy DAN Ti Alloy MENGGUNAKAN METODE ELEMEN HINGGA. *Jurnal Teknologi Terapan: G-Tech*, 4(1), 279–285. <https://doi.org/10.33379/gtech.v4i1.545>
- Putra, A. D., Pradani, Y. F., & Momani, M. O. Al. (2022). Analisis material polimer ramah lingkungan berbahan rumput laut e-cottonii sebagai kandidat pengganti kemasan plastik. *Taman Vokasi*, 10(2), 137–148. <https://doi.org/10.30738/jtvok.v10i2.13274>
- Putra, A. D., Pradani, Y. F., & Saepuddin, A. (2022). *MEKANIKA TEKNIK 1 (STATIKA STRUKTUR)* (Vol. 1).
- Putra, A. D., Rohman, M., & Sulaiman, M. (2021). Simulasi Pengaruh Waktu dan Gerak Terhadap Desain Implan Sendi Pinggul. *Jurnal Pendidikan Teknik Mesin Undiksha*, 9(1), 23–31. <https://doi.org/10.23887/jptm.v9i1.28885>
- Putra, A. D., Rohman, M., & Wahab, A. (2020). Analisis Desain Excavator Bucket Menggunakan Metode Elemen Hingga dengan Material Baja. 16, 4–7.
- Putra, A. D., Tjiptady, B. C., Tsamroh, D. I., Pradani, Y. F., & Hani, D. (2024). Analisis Shaft Piston Rod Shock Absorber dengan Material Baja Karbon Menggunakan Finite Element Method. 15(2), 11–18.
- Putra, A. D., Tsamroh, D. I., Pradania, Y. F., Meditama, R. F., & Muffliha, A. (2023). Effect of Cathode Distance, Anode and Electroplating Time on Aluminum Alloy Corrosion Rate. *Transmisi*, 19(1), 49–55. <https://doi.org/10.26905/jtmt.v19i1.9650>
- Ramadhani, F., Hussain, M. A., Mokhlis, H., & Azil Illias, H. (2020). Optimal heat recovery using photovoltaic thermal and thermoelectric generator for solid oxide fuel cell-based polygeneration system: Techno-economic and environmental assessments. *Applied Thermal Engineering*, 181(September), 116015. <https://doi.org/10.1016/j.applthermaleng.2020.116015>
- Seguin, C., Blaqui re, G., Loundou, A., Michelet, P., & Markarian, T. (2018). Unmanned aerial vehicles (drones) to prevent drowning ☆. *Resuscitation*, 127(January), 63–67. <https://doi.org/10.1016/j.resuscitation.2018.04.005>
- Singh, R. R., Kumar, B. A., Shruthi, D., Panda, R., & Raj, C. T. (2018). Review and experimental illustrations of electronic load controller used in standalone Micro-Hydro generating plants. *Engineering Science and Technology, an International Journal*, 21(5), 886–900. <https://doi.org/10.1016/j.jestch.2018.07.006>
- Turan, D., Karabayrak, B., Baskut, S., & Dalkilic, S. (2017). Failure analysis of landing gears strut bearings. *Engineering Failure Analysis*, 82, 525–532. <https://doi.org/10.1016/j.engfailanal.2017.04.002>
- Weerasinghe, D., Mohotti, D., & Anderson, J. (2020). Incorporation of shear thickening fluid effects into computational modelling of woven fabrics subjected to impact loading: A review. *International Journal of Protective Structures*, 11(3), 340–378. <https://doi.org/10.1177/2041419619889071>
- Winchester, T., Kustra, E., Cormier, I., & Cherniaev, A. (2023). Ballistic performance of integral body armor with closed-cell aluminum foam: A numerical study. *Forces in Mechanics*, 11(February), 100187. <https://doi.org/10.1016/j.finmec.2023.100187>
- Xu, Y., Chen, X., Wang, Y., & Yuan, Z. (2017). Stabbing resistance of body armour panels impregnated with shear thickening fluid. *Composite Structures*, 163, 465–473. <https://doi.org/10.1016/j.compstruct.2016.12.056>
- Zhang, Y., Li, Y., Su, D., & Jin, L. (2014). Advanced flight control system failure states airworthiness requirements and verification. *Procedia Engineering*, 80, 431–436. <https://doi.org/10.1016/j.proeng.2014.09.101>