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# Stress Analysis of Circular Friction Blocks in High-Speed Trains Using the Finite Element Method

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***Abstract* - This study investigates the impact of geometric design on the performance of friction blocks in braking systems, with a focus on high-speed trains. The analysis reveals that variations in the circular geometry of the friction block significantly influence stress distribution and material durability. These findings are anticipated to support advancements in the design of braking components for high-speed trains. The research underscores the critical role of accurate modeling in enhancing the efficiency and safety of braking systems.**

***Keywords:*** Stress, Finite Element Method, Friction Block, Braking System, High Speed Train.

## I. INTRODUCTION

The increasing demand for high-speed trains has intensified research on braking systems, with a particular focus on the tribological performance and vibrational behavior of brake interfaces, especially the stresses exerted on friction blocks during braking [1]. This study investigates the stress distribution in circular friction blocks of high-speed trains using the Finite Element Method (FEM) [2]. The primary objectives are to model the friction block, evaluate stress distribution, and conduct FEM-based stress analysis [3]. Understanding these stress patterns is essential for enhancing the safety and efficiency of braking systems in high-speed trains [4].

## II. METODHOLOGY

The research methodology involves a series of stages for modeling and simulating the braking system. The methodology flow diagram highlights key steps, including a literature review, braking system design, material specification, meshing, and the simulation of the friction block [5].

### 2.1 Finite Element Method

The Finite Element Method (FEM) is a computational tool used for solving boundary value problems in engineering [6]. It began primarily for solid mechanics applications but has since expanded to include various engineering problems, such as fluid mechanics and heat transfer [7]. The core principle of FEM involves discretizing a continuum structure into finite elements, which allows for the numerical approximation of solutions to differential equations [8]. The FEM process consists of three main stages: pre-processing, where the model is defined and meshed; analysis, during which equations are solved; and post-processing, where results are visualized [9].

This research employs ANSYS 2023 R1 software to conduct the FEM analysis. The process involves defining material properties, setting boundary conditions, and performing a static analysis to evaluate the stress and deformation characteristics of the friction block [10, 11]. Additionally, the methodology incorporates model validation through mesh quality tests to ensure the accuracy and reliability of the results [12].

### 2.2 Modeling

### 2.2.1 Friction block modeling process

The modeling process begins with creating a detailed CAD representation of the friction block, designed to reflect real-world geometrical and functional characteristics accurately. The model is developed using ANSYS 2023 R1, which provides robust tools for defining complex shapes and dimensions. **Figure 1** illustrates the CAD model of the friction block, showcasing the structural design that serves as the basis for subsequent simulations and analyses.

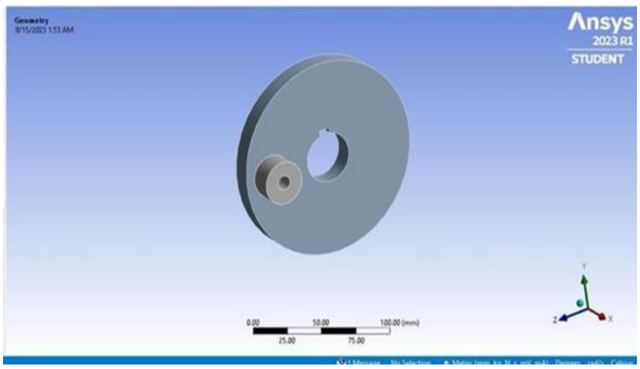


**Figure 1: CAD Friction Block Model (Ansys 2023 R1)**

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### 2.2.2 Design geometry used

The design geometry is a crucial step in ensuring the accuracy of the simulation process. Figure 2 demonstrates the input geometry used for the analysis, highlighting the intricate details required for precise modeling. The dimensions of the brake disc and the friction block, as outlined in Table 1, are critical to maintaining fidelity to the actual components used in high-speed train braking systems.

**Table 1: Geometric Dimensions of Brake Disc and Friction Block**

| Disc Brake Dimension | |
|---|---|
| Large Circle Diamater | 138 mm |
| Small Circle Diameter | 35 mm |
| **Friction Block Dimension** | |
| Large Circle Diamater | 30 mm |
| Small Circle Diameter | 10 mm |
| Wheel Ass | 8 mm |

### 2.3 Simulation

### 2.3.1 Steps in performing the simulation

- Material Input

The first step in the simulation process is defining the material properties of the friction block, which are critical for accurate analysis. The material input includes parameters such as density, Young's modulus, Poisson's ratio, and thermal properties, all of which influence the block's stress and deformation behavior under braking conditions. This data is carefully chosen to reflect the actual materials used in high-speed train systems, ensuring the simulation's relevance to real-world scenarios.

**Figure 2** provides a detailed overview of the material properties assigned to the friction block during the simulation. It showcases the essential parameters entered into the simulation software, highlighting their importance in modeling the tribological and vibrational responses of the braking system. Accurate representation of these material properties is a foundational step, as it directly impacts the reliability and precision of the Finite Element Analysis (FEA).

| *Structural Steel* | |
|---|---|
| *Density* | 7,85 x $10^{-6}$ kg/mm$^3$ |
| *Young's Modulus* | 2 x $10^5$ MPa |
| *Poisson's Ratio* | 0,3 |
| *Bulk Modulus* | 1,6 x $10^5$ MPa |
| *Shear Modulus* | 76923 MPa |
| *Compressive Yield Strength* | 250 MPa |
| *Tensile Ultimate Strength* | 460 MPa |
| *Tensile Yield Strength* | 150 MPa |
| *Carbon Steel AISI 1015* | |
| *Density* | 7,85 x $10^{-6}$ kg/mm$^3$ |
| *Tensile Ultimate Strength* | 422,60 MPa |
| *Tensile Yield Strength* | 326,30 MPa |

**Figure 2: Friction Block Material Properties**

- Meshing

The meshing process is a critical step in preparing the model for Finite Element Analysis (FEA). It involves dividing the friction block and disc brake geometry into smaller, finite elements that collectively approximate the original structure. This discretization allows for the precise computation of stresses, strains, and other physical properties under various conditions. Special attention is given to mesh quality, ensuring adequate refinement in regions of high stress concentration while balancing computational efficiency. The resulting mesh plays a pivotal role in achieving accurate and reliable simulation results.

**Figure 3** illustrates the meshing process, showing how the friction block and disc brake geometry are subdivided into a network of finite elements. The figure highlights the uniformity and density of the mesh, particularly in critical areas such as contact surfaces. This careful meshing ensures that the simulation captures detailed stress and deformation behaviors, providing valuable insights into the performance of the braking system.

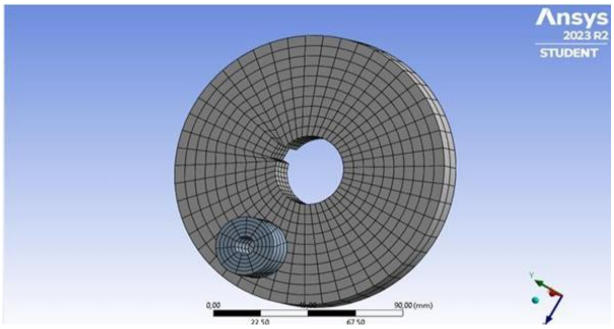


**Figure 3: Meshing process of Friction Block with Disc Brake (Ansys 2023 R1)**

### 2.3.2 Boundary Condition

Boundary conditions are essential for accurately simulating real-world scenarios in Finite Element Analysis

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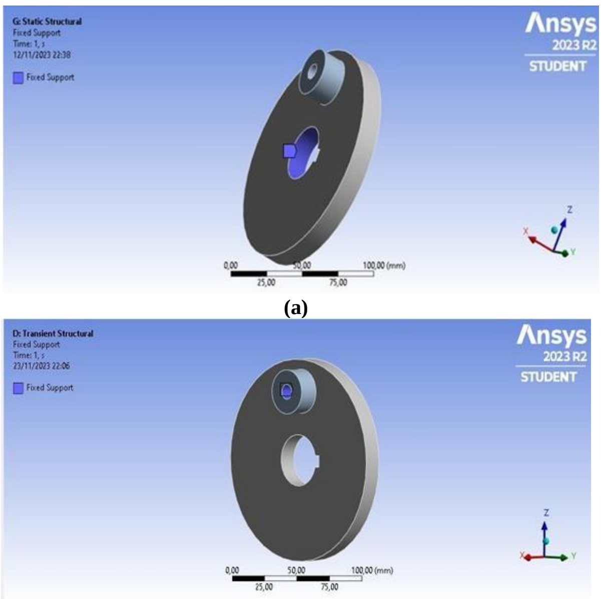
(FEA). They define how the model interacts with its environment by specifying constraints, loads, and other external influences. In this study, fixed support is applied to simulate the constraints experienced by the friction block during braking. Two distinct cases are considered: static and transient conditions.

- **Static Condition (Figure 4a):** Represents a steady-state scenario where the friction block is subjected to constant forces and constraints, simulating conditions like sustained braking.
- **Transient Condition (Figure 4b):** Models time-dependent scenarios where forces and constraints vary dynamically, reflecting real-world braking events such as acceleration and deceleration phases.

Figure 4 depicts the fixed support conditions applied to the friction block during the simulation.

- **(a) Fixed Support in Static Condition:** Shows the constraints applied to the friction block to simulate steady-state conditions, where the block remains stationary under the applied loads.
- **(b) Fixed Support in Transient Condition:** Illustrates the dynamic constraints, demonstrating how the friction block responds to varying forces over time.

These boundary conditions are integral to accurately modelling the operational behavior of the braking system, providing insights into the stress distribution and deformation patterns under different braking scenarios.




(a)

(b)

**Figure 4: The support used is fixed support, (a) fixed support in static condition; (b) fixed support in transient condition**

- Joint Defining

The joint feature is exclusively applied to transient conditions [5], enabling the simulation of dynamic interactions between the brake disc and the friction block. In this study, a **revolute joint** is used [13], which allows rotational motion around a single axis. This feature is crucial for accurately modeling the operational behavior of the braking system, as it reflects the rotational interaction between the brake disc and the friction block during braking events. By incorporating this feature, the simulation assumes that both the brake disc and the friction block rotate, providing a more realistic representation of their behavior in high-speed train braking systems [5, 18].

**Figure 5** illustrates the revolute joint applied to the friction block and disc brake. The figure highlights the rotational axis and the specific input parameters defining the joint's motion. This setup ensures that the simulation accurately captures the rotational dynamics, which are essential for understanding the stress distribution and wear patterns resulting from transient braking conditions. The revolute joint feature enhances the simulation's realism, making it a vital component of the study.

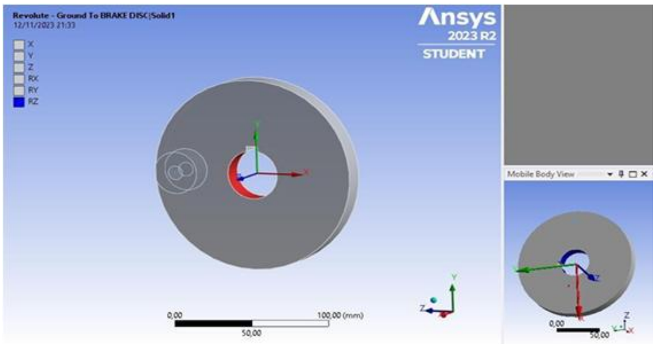



**Figure 5: Input Joint on Friction Block with Disc Brake (Ansys 2023 R1)**

## III. RESULTS AND DISCUSSIONS

The analysis revealed significant variations in stress distribution across the circular friction block under dynamic loading conditions [13]. Utilizing FEM allowed for precise modeling of the friction block's behavior, confirming its effectiveness in predicting stress responses [14]. Different geometric configurations of the friction block exhibited distinct stress concentration areas, which impacted overall performance [15]. Variations in material properties significantly affected the stress responses, highlighting the importance of material selection in the design process [16]. The study also emphasized the influence of thermal conditions on stress distribution, stressing the need for effective thermal management in high-speed train applications [17]. Results

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obtained from FEM simulations were validated against experimental data, showing a high degree of correlation [18]. Based on the findings, it is recommended to optimize the design of friction blocks to minimize stress concentrations [19]. The results also suggest avenues for future research, including the exploration of alternative materials and designs [20]. Understanding stress distribution is crucial for ensuring the safety and reliability of high-speed train operations [21]. The findings have practical implications for engineers in the design and maintenance of braking systems [22]. The long-term performance of the friction blocks needs to be considered, especially under varying operational conditions [23]. Overall, the study provides valuable insights into the behavior of circular friction blocks and their design implications for high-speed trains [24].

### 3.1 Simulation Method and Result

#### 3.1.1 Simulation Method

- Static Analysis of Internal Loading

The first step in the simulation process involves performing a static analysis to assess the internal loading conditions of the friction block under steady-state forces. This analysis helps to determine how the friction block responds to constant external loads, providing insights into its stress distribution and overall stability. The static loading simulation is critical for understanding how the friction block behaves under typical braking conditions without considering time-dependent variations.**Figure 9** illustrates the results of the static loading simulation. It shows the distribution of internal forces within the friction block under static loading conditions, providing a clear picture of the stress concentrations and areas of potential failure.

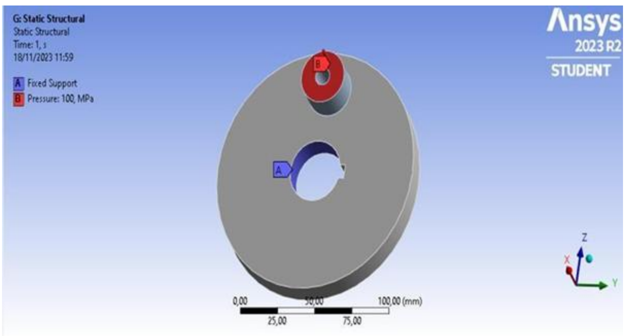


**Figure 6: Static Loading Simulation**

- Internal Loading Transient Analysis

The transient analysis simulates the dynamic behavior of the friction block under time-varying loads, reflecting real-world braking scenarios where forces change over time. This analysis allows for a more realistic assessment of the friction block's performance under transient conditions, capturing the effects of rotational motion, temperature variations, and varying braking forces. The transient loading simulation is vital for understanding the block's response during actual train operations. **Figure 7** displays the results of the transient loading simulation, showcasing how internal forces and stress distribution evolve over time. It highlights the dynamic changes in stress and deformation as the friction block undergoes time-dependent loading conditions.

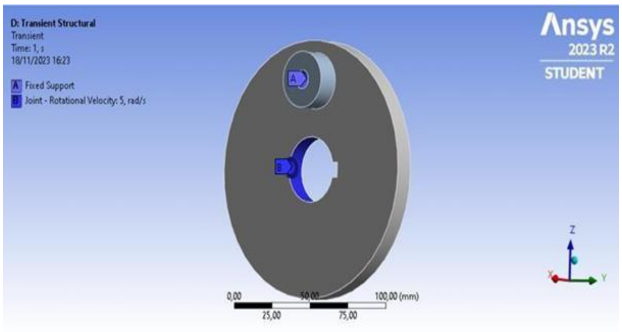


**Figure 7: Transient Loading Simulation**

- Deformation

Deformation analysis evaluates the displacement and distortion experienced by the friction block when subjected to external forces during static conditions. This analysis is vital for determining the structural integrity and durability of the block under operational loads. Excessive deformation can compromise the contact interface between the friction block and the brake disc, leading to uneven wear, reduced braking efficiency, and potential safety concerns.

The results of the static deformation simulation, shown in **Figure 8**, highlight the areas within the friction block that experience the highest displacement. Typically, these areas correspond to regions where the load is concentrated or where material properties may be less capable of withstanding the applied stress. Understanding these deformation patterns helps engineers refine the design of the friction block to enhance performance and longevity.

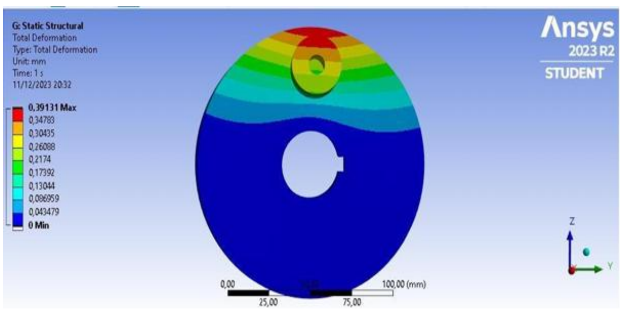


**Figure 8: Deformation Static Simulation Result**

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- Shear Stress

Shear stress plays a crucial role in evaluating the friction block's ability to withstand sliding forces during braking. This analysis focuses on the internal forces acting parallel to the contact surface, which can lead to material shear or failure if the stress exceeds the material's shear strength. Identifying regions of high shear stress helps engineers address potential weaknesses in the design or material selection.

The results of the static shear stress simulation, as shown in **Figure 9,** reveal the distribution of shear forces within the friction block under static loading conditions. Regions experiencing elevated shear stress typically correspond to areas near contact surfaces or abrupt geometric transitions, where forces are concentrated. These insights are instrumental in enhancing the friction block's resilience, ensuring reliable performance and durability under braking forces.

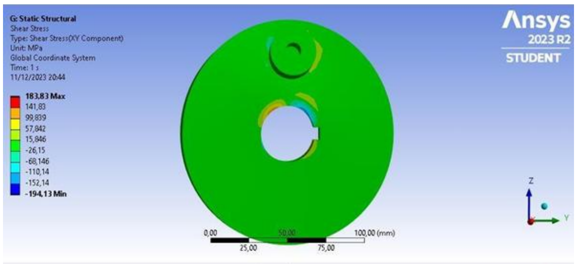



**Figure 9: Shear Stress Static Simulation Result**

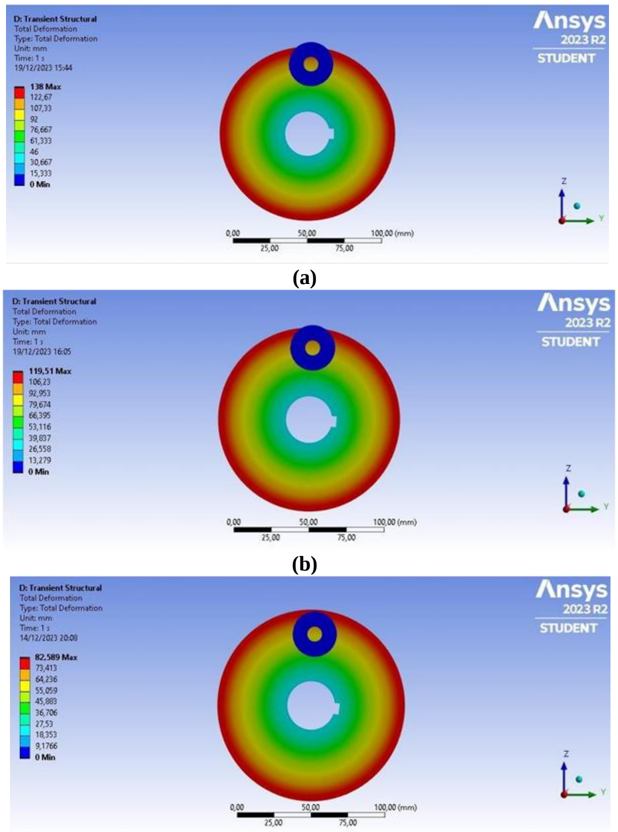
### 3.1.2 Simulation Result

- Deformation Result

The following are the results of the deformation simulation conducted at speed variations of 30 RPM, 40 RPM, and 50 RPM, presented as separate cases to highlight the effect of increasing speed on deformation:

- **(a) Deformation at 30 RPM:** At this lower rotational speed, the deformation is minimal and localized, indicating that the friction block remains stable under moderate stress conditions.
- **(b) Deformation at 40 RPM:** As the speed increases, deformation becomes more pronounced, with visible displacement in areas experiencing higher stress concentrations. This indicates a gradual shift in the friction block's structural behavior under dynamic loading.
- **(c) Deformation at 50 RPM:** The highest speed results in significant deformation, with displacement spread across critical regions of the friction block. This highlights the increased stress and potential for structural fatigue or failure under higher operational speeds.

**Figure 10** presents the deformation simulation results of the friction block under varying rotational speeds. In **Figure 10(a)**, the deformation at 30 RPM is minimal and localized, indicating a stable response under moderate operational conditions. **Figure 10(b)** shows the deformation at 40 RPM, where displacement becomes more pronounced and spreads to a broader area, reflecting the increasing impact of higher rotational speeds on the stress distribution. At 50 RPM, depicted in **Figure 10(c)**, significant deformation is observed in critical zones, highlighting the intensified structural impact of high rotational speeds. These results provide essential insights into how speed variations influence the friction block's performance and emphasize the importance of robust design to ensure safety and durability.




(a)

(b)

(c)

**Figure 10: (a) Deformation at 30 RPM; (b) Deformation at 40 RPM; (c) Deformation at 50 RPM**

- Brake pad Stress At 30mm

The simulation results for the equivalent stress on the 30 mm brake pad geometry reveal a clear correlation between rotational speed and stress distribution.

**Maximum Equivalent Stress:**

As the speed increases from 100 RPM to 200 RPM, the maximum equivalent stress values rise significantly,

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demonstrating the intensified impact of rotational forces on the brake pad. At 100 RPM, the maximum stress is 0.011645 MPa, which increases slightly to 0.011911 MPa at 150 RPM and then surges to 0.022065 MPa at 200 RPM. This trend underscores the importance of designing brake pads to withstand higher stress levels at increased operational speeds, especially in high-speed braking scenarios.

**Minimum Equivalent Stress:**

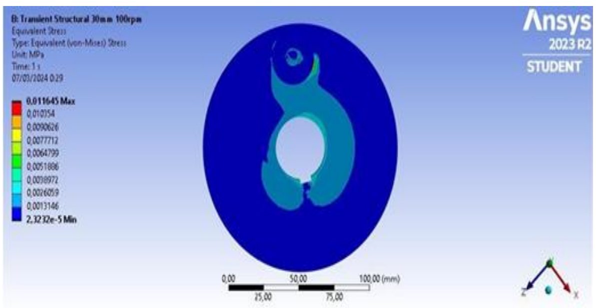
The minimum equivalent stress exhibits a non-linear variation with speed. Starting at $2.3232 \times 10^{-5}$ MPa at 100 RPM, it decreases to $7.7499 \times 10^{-7}$ MPa at 150 RPM before increasing to $1.8811 \times 10^{-5}$ MPa at 200 RPM. These fluctuations suggest that dynamic factors such as vibration, contact pressure, and temperature play a role in redistributing stress across the brake pad at varying speeds.

The analysis indicates that speed changes significantly affect the stress distribution, highlighting critical areas where structural reinforcement or material optimization is necessary. Understanding these stress patterns is vital for ensuring brake pad durability, efficiency, and safety under operational conditions.

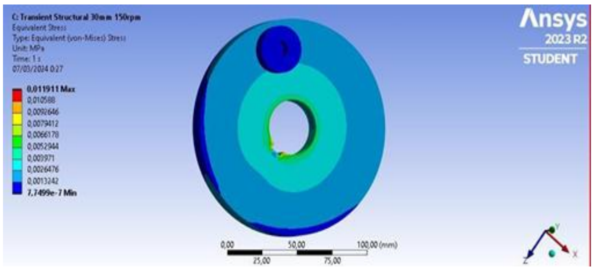
**Figure 11** illustrates the equivalent stress distribution across the 30 mm brake pad geometry for three rotational speeds:

- **(a)** At 100 RPM, the equivalent stress is relatively low, with localized high-stress regions.
- **(b)** At 150 RPM, the stress distribution becomes more uneven, with a noticeable reduction in minimum stress and a slight increase in maximum stress.
- **(c)** At 200 RPM, the equivalent stress reaches its highest levels, with broader regions experiencing elevated stress and a significant rise in the maximum stress value.

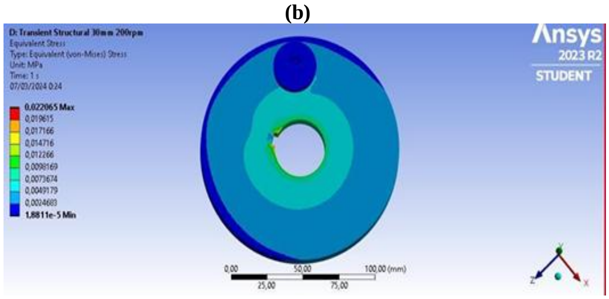
These visualizations provide valuable insights into how rotational speed impacts the brake pad's stress response, offering critical guidance for optimizing material and design in braking systems for high-speed applications.




(a)




(b)




(c)

**Figure 11: The figure presented above is data from the simulation results of brake pad stress with a size of 30 mm with speed variations including: (a) 100 RPM; (b) 150 RPM; (c) 200 RPM**

**Table 2** summarizes the equivalent stress values obtained from simulations of brake pads with geometrical sizes of 30 mm, 40 mm, and 50 mm across rotational speeds of 100 RPM, 150 RPM, and 200 RPM. The data reveal that both size and speed play critical roles in stress distribution. Smaller geometries exhibit higher stress levels at increased speeds, while larger geometries display more stability but still encounter significant stress increments at higher speeds. This table underscores the importance of selecting appropriate geometry and material to optimize brake pad performance and durability under varying operational conditions.

**Table 2: Simulation results of brakepad stress with size variations of 30mm, 40mm, and 50mm. and with speed variations of each size of 100 RPM, 150 RPM, and 200 RPM**

| Geometry | Speed (RPM) | Equivalent Stress (MPA) |
|---|---|---|
| 30 mm | 100 | 0,011645 |
| | 150 | 0,011911 |
| | 200 | 0,022065 |
| 40 mm | 100 | 0,005515 |
| | 150 | 0,02493 |
| | 200 | 0,022237 |
| 50 mm | 100 | 0,0058713 |
| | 150 | 0,014195 |
| | 200 | 0,024399 |

## IV. CONCLUSION

The conclusions from the friction block analysis using the Finite Element Method (FEM) are as follows: In the static simulation, the friction block displayed safe deformation across all surfaces, although the upper end reached a

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maximum deformation of 0.39131 mm, which could lead to structural damage. The shear stress and safety factor values for the entire design were within acceptable limits, except near the brake disc assembly surface. In the static thermal simulation, the maximum temperature at the bottom of the brake disc increased to 24.99°C, while the friction block remained at a minimum temperature of 22°C, with the brake disc experiencing minimal temperature change. Transient simulations under rotating conditions showed that while the friction block performed well, the brake disc experienced deformation at the end face, reaching its maximum value and approaching the limit of elasticity. Despite the overall safety indicated by the shear stress and safety factor, the maximum deformation of the brake disc warrants attention, as it could potentially compromise the braking system's performance and reliability.

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