UNIABUJA Journal of Engineering and Technology
https://ujet.uniabuja.edu.ng/
ISSN: 2714-3236 (Online); 2714-3228 (Print)
Volume 3, Issue 2, 2026; 291-304

Design Modification, Manufacture, and Performance Evaluation of an Automobile Brake Pad Test Rig

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Abstract
This study focuses on the design, modification, and performance evaluation of a low-cost brake pad test rig developed to address the challenge of limited access to testing facilities in developing regions. The objective was to create a locally fabricated, cost-effective system capable of evaluating key braking parameters, such as wear rate, stopping efficiency, and temperature rise, under controlled conditions. The modified rig was constructed using readily available materials, including a 1.5 HP electric motor, a Toyota Starlet 5-speed gearbox, a flywheel to simulate vehicle inertia, and a hydraulic braking system. Two brake pad samples (semi-metallic and organic composite) were tested at various speeds (196.6–851.7 RPM) and loads (10–50 kg) to examine their wear performance and thermal behavior.Results indicated that increased speed and load significantly impacted wear, stopping time, and disc temperature. Sample 1 consistently showed lower wear, reduced temperature rise, and shorter stopping times, demonstrating better thermal stability and braking efficiency. The modified test rig effectively replicated real-world braking conditions, offering a reliable and affordable platform for brake pad testing in developing regions. The study underscores the potential of this test rig for enhancing braking system research, material development, and safety evaluations in resource-limited environments.

***Keywords**: Brake pad test rig, Wear rate, Disc temperature, Stopping time.*

1.0 Introduction

This study focuses on the development of a modified, cost-effective brake pad test rig designed to address the limited availability and high cost of testing equipment in developing countries, particularly Nigeria. Braking systems are critical to vehicle safety, converting kinetic energy into heat through friction. Their performance depends heavily on the materials used and the conditions in which they operate. Reliable testing is essential to evaluate key factors such as wear, temperature rise, and braking efficiency.

In Nigeria, many brake pads still contain asbestos, which poses serious health risks. This highlights the urgent need for safer, locally developed alternatives. However, limited access to proper testing facilities has slowed progress in material development and validation. To bridge this gap, the study aimed to design, fabricate, and evaluate a modified brake pad test rig using locally sourced materials offering an affordable and practical solution for performance testing.

The project involved modifying an existing rig, assembling the system, and testing two commercial brake pad samples under varying weights, speeds, and braking pressures. The research also supports Nigeria's local content development goals by encouraging indigenous innovation and reducing reliance on imported equipment. While challenges such as limited generalizability and resource constraints exist, the study provides a valuable framework for advancing brake pad testing and materials research in developing regions.

The modifications to the existing brake pad test rig focused on enhancing its performance and adaptability. The structural frame of the rig was reinforced using 50×50×4 mm mild steel angle iron, providing increased rigidity and resistance to vibrations during operation. A key modification was the integration of a 5-speed manual gearbox sourced from a Toyota Starlet, replacing the original speed configuration. This gearbox allows for variable speed control, enabling the simulation of different driving conditions.

A mild steel flywheel (SAE 1010) with a radius of 143 mm and mass of 8 kg was added to simulate the rotational inertia of a vehicle, further improving the rig's ability to replicate real-world braking scenarios. Additionally, the original loading mechanism was upgraded to a calibrated lever-and-weight system, capable of applying adjustable loads from 10 kg to 50 kg, ensuring repeatability and consistency across tests. The braking assembly was also modified to include a hydraulic caliper for precise force application, and a non-contact infrared thermometer was incorporated to enhance temperature monitoring accuracy. These modifications collectively improve the rig's structural integrity, operational flexibility, and the precision of performance measurements.

Received: 04-02-2026 / Accepted: 05-03-2026 / Published: 27-06-2026

https://doi.org/10.70118/ujet.2026.0302.25

2.0 Materials and Methods

2.1 Materials

To assess the performance of commonly used automotive brake pads under controlled laboratory conditions, a modified brake pad test rig was developed. The rig was primarily constructed from mild steel and comprised a structural frame, power transmission system, braking assembly, loading mechanism, and measurement instruments.

The structural frame was built using 50 × 50 × 4 mm mild steel angle iron, ensuring adequate stiffness and resistance to vibration. A 1.5 HP, three-phase electric motor operating at a maximum speed of 1460 rpm served as the prime mover. Power was transmitted through a 25 mm diameter mild steel shaft supported on radial ball bearings and coupled to the motor via a keyed mild steel coupling. Table 1 below shows the Test Rig components, specifications and dimensions used.

Table 1.1 Test Rig Components

Component	Material/Specification	Dimensions/Model
Frame	Mild steel (50×50×4 mm angle iron)	Length: 1000 mm, Height: 800 mm, Width: 1000 mm
Motor	3-phase electric motor (1.5 HP)	1460 RPM, power: 1.5 HP
Coupling	Mild steel with keyed connection	Outer diameter: 40 mm, Bore diameter: 25 mm, Length: 50 mm
Shaft	Mild steel	Diameter: 25 mm, Length: 350 mm
Flywheel	Mild steel (SAE 1010)	Outer radius: 143 mm, Thickness: 25 mm, Mass: 8 kg
Brake Disc	Mild steel	Diameter: 150 mm, Thickness: 15 mm
Bearings	Radial ball bearing, steel	Bore diameter: 25 mm, Outer diameter: 52 mm, Width: 15 mm

To simulate vehicle rotational inertia, solid mild steel flywheel (SAE 1010) with a radius of 143 mm was mounted on the shaft, providing a calculated moment of inertia of approximately 0.081 kg·m². A mild steel brake disc (150 mm diameter, 15 mm thickness) was also mounted on the shaft and engaged by a hydraulic brake caliper.

Two brake pad samples were tested: a semi-metallic pad and an organic composite pad, each measuring 140 × 75 × 15 mm. These materials were chosen due to their widespread use in passenger vehicles in Nigeria. For speed variation, a 5-speed manual gearbox (Toyota Starlet model) was integrated between the motor and the shaft, enabling discrete low-to-high speed simulations. Braking loads were applied using a calibrated lever-and-weight mechanism capable of exerting forces between 10 kg and 50 kg.

2.2 Instrumentation

Key operating parameters were monitored using standard laboratory instruments. Disc temperature was measured with a non-contact infrared thermocouple (Omega OS-400) covering a range of −50 °C to 200 °C. Rotational speed was recorded using a digital infrared tachometer (Stanhope DT2234B). Braking pressure was tracked via a hydraulic pressure gauge (WIKA111.10) installed in the brake line. Brake pad wear was determined by mass loss using a digital weighing scale, while stopping time was measured with a digital stopwatch.

2.3 Manufacturing Techniques

The fabrication process for the modified brake pad test rig involved several stages. First, 50×50×4 mm mild steel angle iron was used to construct the structural frame of the rig, providing increased rigidity and vibration resistance. The frame components were cut using an electric hacksaw, followed by welding the pieces together to ensure strong, uniform joints. After assembling the frame, the gearbox was mounted onto a fixed plate welded to the frame, and the input shaft of the gearbox was aligned with the motor shaft using a coupling.

The flywheel and brake disc were then installed and securely fixed, ensuring precise torque transfer during braking tests. The modified loading system was also integrated into the rig, with adjustable weights calibrated using a digital scale to apply the required loads. All components were aligned using laser alignment tools to ensure optimal performance and minimal operational friction.

2.3 Design and Operating Principle

The test rig operates by transmitting rotational motion from the electric motor through the gearbox to the shaft, flywheel, and brake disc. The flywheel stores kinetic energy to mimic vehicle motion; while braking force is applied hydraulically through a caliper acting on the disc. Gear selection allows for different rotational

Received: 04-02-2026 / Accepted: 05-03-2026 / Published: 27-06-2026

https://doi.org/10.70118/ujet.2026.0302.25

speeds, simulating varied driving conditions. Heat generation, wear, and stopping behavior are influenced by the applied load, speed, and braking pressure.

2.4 Experimental Procedure

Before testing, all instruments were calibrated, and brake pads were aligned in the caliper to ensure uniform disc contact. Tests were conducted at gear positions representing low, medium, and high speeds. For each speed, braking loads of 10, 20, 30, 40, and 50 kg were applied.

The motor was allowed to reach the desired speed before braking commenced. During each braking event, disc temperature, braking pressure, rotational speed, and stopping time were recorded. Brake pad wear was measured after each cycle. Each condition was repeated ten times to enhance reliability, and the system was cooled to ambient temperature between tests to prevent cumulative thermal effects.

3.0 Results and Discussion

3.1 Wear test results

Figure 1 shows how rotational speed affects brake pad wear when a constant load of 10 kg is applied to two popular brake pad types. At lower speeds (196.6–365.2 RPM), both pads showed almost no wear after ten braking cycles. For Sample 1, noticeable wear only appeared at higher speeds, gradually increasing from 0.05 g at 716.7 RPM to 0.10 g at 851.7 RPM. This suggests strong wear resistance at low to moderate speeds.

In contrast, Sample 2 began to wear earlier and more significantly. Material loss started at 530.6 RPM and rose to 0.20 g at 851.7 RPM roughly double the wear seen in Sample 1 at the same speed.

Overall, the findings confirm that brake pad wear rises with speed, and Sample 1 performs better than Sample 2, especially under high-speed conditions.

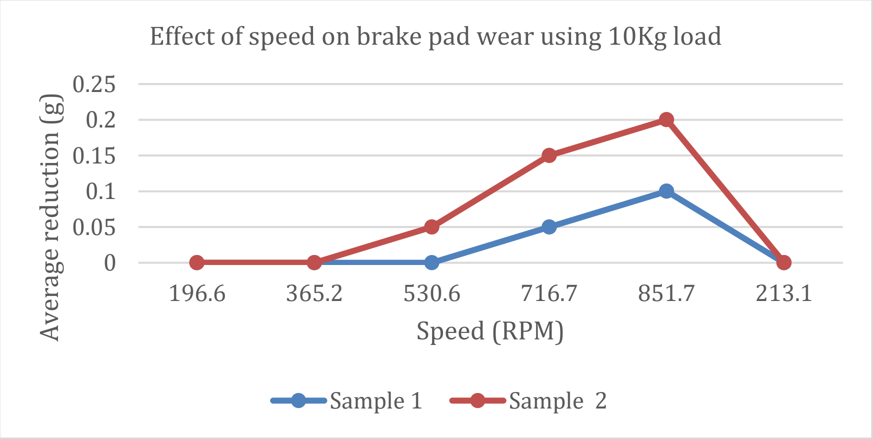

Figure 1: Effect of speed on brake pad wear using 10kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 2 highlights how contact pressure affects brake pad wear at different speeds under a constant 10 kg load for two common brake pad types.

For Sample 1, there was no noticeable wear at low to moderate speeds and pressures (up to about 153 PSI). Wear only became evident at higher pressures, with average material losses of 0.05 g at 195.9 PSI and 0.10 g at 244.9 PSI. This suggests strong resistance to pressure-induced wear under normal operating conditions.

In contrast, Sample 2 showed earlier and more significant wear. Material loss started at 177.7 PSI (0.05 g), increased to 0.15 g at 205.7 PSI, and reached 0.20 g at 250.1 PSI. The steeper wear progression indicates that Sample 2 is more sensitive to contact pressure than Sample 1.

Overall, the results confirm that brake pad wear rises with contact pressure, especially at higher speeds. Sample 1 demonstrates better durability and resistance to pressure-related wear, making it more suitable for demanding braking conditions.

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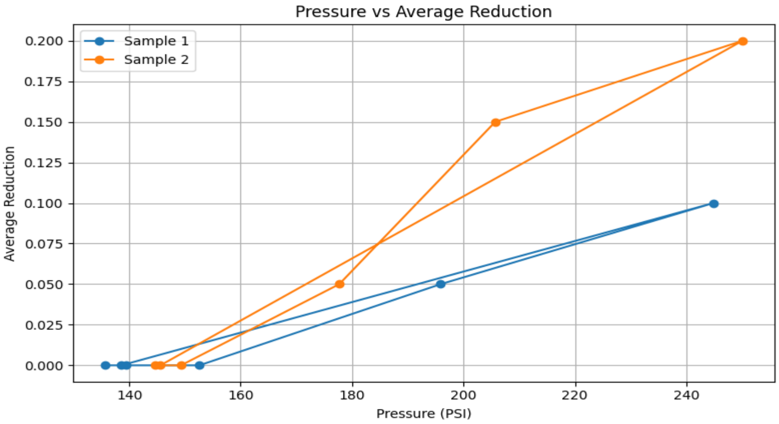

Figure 2: Effect of brake contact pressure on brake pad wear rate at varying speed using 10kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 3 shows how speed affects the average stopping time of the brake disc at different contact pressures under a constant 10 kg load for two brake pad samples.

For both pads, stopping time increased gradually as speed rose, which is expected since higher speeds mean more kinetic energy to dissipate during braking.

Sample 1 delivered shorter and more consistent stopping times, rising only slightly from 1.27 seconds at 196.6 RPM to 1.40 seconds at 851.7 RPM. This indicates stable braking efficiency across the tested speed range.

In comparison, Sample 2 recorded longer stopping times, increasing from 1.33 seconds to 1.48 seconds over the same speed range, suggesting a slower braking response.

Overall, the results confirm that stopping time is directly influenced by speed, with higher speeds leading to longer braking durations. Sample 1 demonstrated better braking efficiency and quicker response, making it more suitable for applications that demand reliable and prompt braking performance.

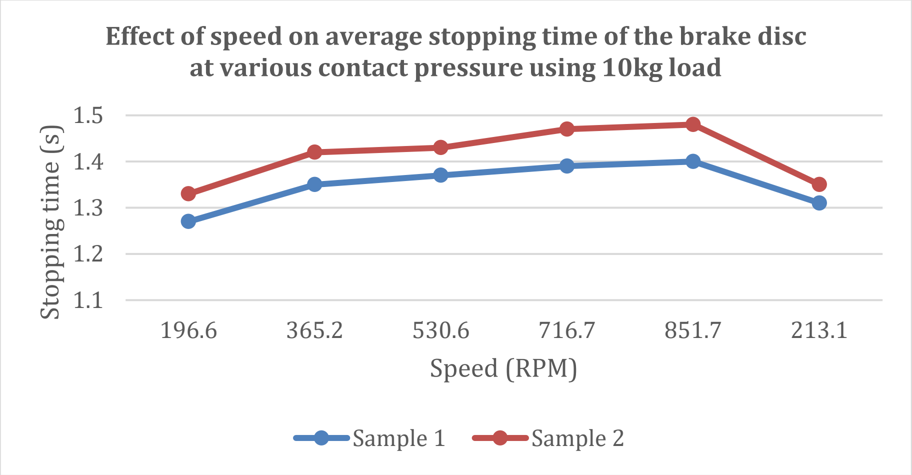

Figure 3: Effect of speed on average stopping time of the brake disc at various contact pressure using 10kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 4 shows how speed affects brake pad wear under a 20 kg load for two common brake pad types. For both pads, wear increased as speed rose, confirming that higher rotational speeds accelerate material loss when the load is heavier.

Sample 1 showed no measurable wear up to 531.1 RPM, demonstrating strong resistance at low to moderate speeds. Wear became noticeable at higher speeds, with an average loss of 0.05 g at 716.7 RPM and rising to 0.15 g at 851.7 RPM.

In contrast, Sample 2 began wearing earlier and more significantly, starting at 531.1 RPM with a loss of 0.10 g and climbing steadily to 0.25 g at 851.7 RPM.

Overall, the trend reveals that brake pad wear is strongly influenced by speed and becomes more severe under higher loads. Sample 1 offers better durability and is more suitable for high-speed, high-load braking conditions.

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https://doi.org/10.70118/ujet.2026.0302.25

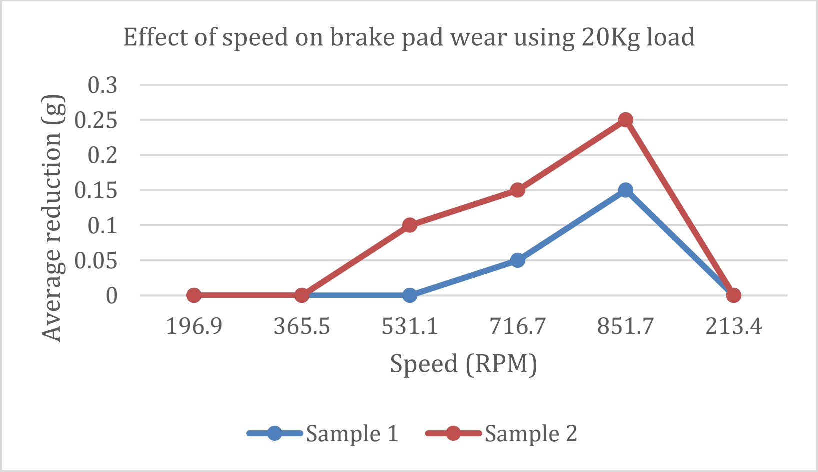

Figure 4: Effect of speed on brake pad wear using 20kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 5 shows how speed and contact pressure together affect brake pad wear under a 20 kg load for two common brake pad types. For both pads, wear increased as contact pressure and speed rose, confirming that harsher operating conditions accelerate material degradation.

Sample 1 displayed strong resistance at low speeds and moderate pressures, with no noticeable wear up to about 170 PSI. Wear only became evident at higher pressures and speeds, starting with an average loss of 0.05 g at 211.6 PSI and rising to 0.15 g at 267.7 PSI.

In contrast, Sample 2 began wearing earlier and more significantly, with material loss starting at 174.5 PSI (0.10 g) and climbing steadily to 0.25 g at 275.5 PSI.

Overall, the results show that brake pad wear accelerates sharply with higher contact pressures, especially at elevated speeds. Sample 1 demonstrates better durability and is more suitable for heavy-load, high-speed braking, while Sample 2 offers lower wear resistance under the same conditions.

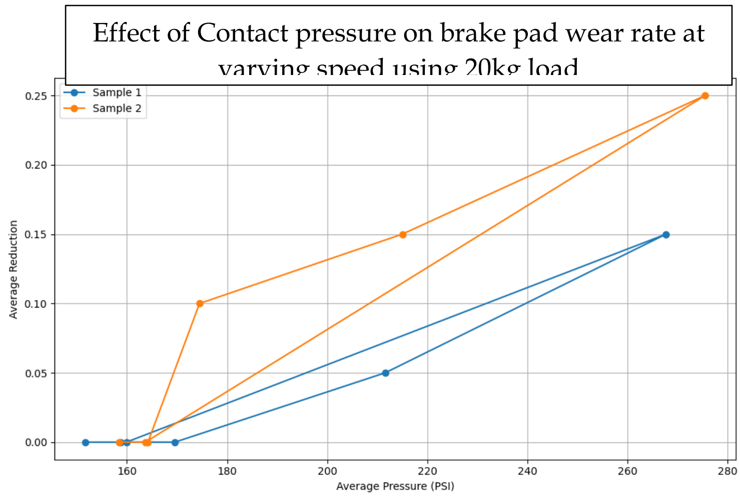

Figure 5: Effect of brake contact pressure on brake pad wear rate at varying speed using 20kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 6 illustrates how speed and contact pressure affect the average stopping time of a brake disc under a 30 kg load for two brake pad samples. For both pads, stopping time increased steadily as speed and pressure rose, which is expected since more severe braking conditions require greater energy dissipation.

Sample 1 delivered shorter and more consistent stopping times across all test conditions. It increased gradually from 1.24 seconds at low speed and pressure to 1.50 seconds at the highest levels, showing reliable braking performance even under demanding conditions.

In comparison, Sample 2 consistently recorded longer stopping times, rising from 1.41 seconds at low speed to 1.59 seconds at the highest operating condition, indicating reduced braking efficiency.

Overall, the results confirm that higher speeds and pressures lead to longer stopping times. Sample 1 demonstrates superior braking efficiency, consistency, and reliability under heavy-load, high-speed conditions compared to Sample 2.

Received: 04-02-2026 / Accepted: 05-03-2026 / Published: 27-06-2026

https://doi.org/10.70118/ujet.2026.0302.25

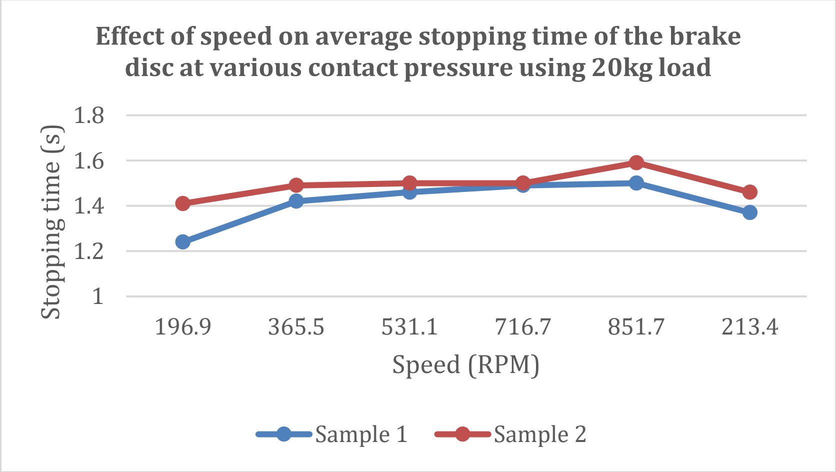

Figure 6: Effect of speed on average stopping time of the brake disc at various contact pressure using 30kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 7 shows how increasing speed affects brake pad wear under a 30 kg load for two common brake pad types. For both pads, wear rises with speed, confirming that higher operating speeds accelerate material loss under heavy loads.

Sample 1 demonstrated strong resistance at lower speeds, with no measurable wear at 197.3 RPM and 366.0 RPM. Wear became noticeable only at higher speeds, increasing gradually from 0.05 g at 531.4 RPM to 0.20 g at 851.8 RPM. This trend suggests Sample 1 maintains good durability at low to moderate speeds, with gradual degradation at higher speeds.

In contrast, Sample 2 showed earlier onset and greater wear across all speeds. Measurable wear appeared as early as 366.0 RPM, and material loss climbed steadily to 0.275 g at the highest speed—consistently exceeding Sample 1. The widening gap between the two pads at higher speeds highlights Sample 2's greater sensitivity to speed-induced wear.

Overall, the results confirm that brake pad wear increases significantly with speed under a 30 kg load. Sample 1 offers superior wear resistance and durability, making it better suited for high-speed, high-load braking applications, while Sample 2 shows faster degradation and a shorter service life under the same conditions.

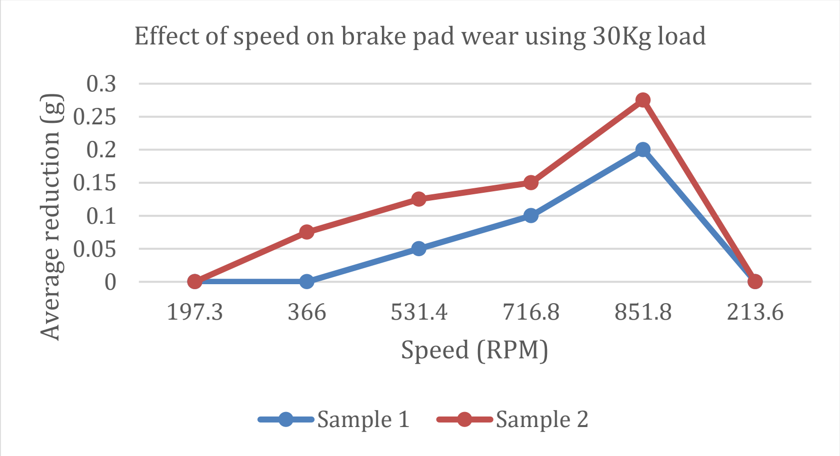

Figure 7: Effect of speed on brake pad wear using 30kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 8 illustrates how brake contact pressure affects pad wear at different speeds under a 30 kg load for two common brake pad types. The results show that wear increases as contact pressure rises, especially when combined with higher speeds.

Sample 1 displayed strong resistance at lower pressures, with no measurable wear at 138.9 PSI and 192.4 PSI. Wear became noticeable only at higher pressures, increasing gradually from 0.05 g at 250.2 PSI to 0.20 g at 270.2 PSI. This indicates that Sample 1 performs reliably under moderate conditions, with gradual wear as pressure and speed increase.

Received: 04-02-2026 / Accepted: 05-03-2026 / Published: 27-06-2026
https://doi.org/10.70118/ujet.2026.0302.25

In contrast, Sample 2 showed earlier onset and greater wear. Material loss appeared at 254.2 PSI and rose sharply to 0.275 g at the highest pressure tested. Across all pressure levels, Sample 2 consistently recorded higher wear than Sample 1, with the gap widening at elevated pressures.

Overall, the findings confirm that higher contact pressure significantly accelerates brake pad wear under a 30 kg load. Sample 1 offers better resistance to pressure-induced wear and is more suitable for high-speed, high-pressure braking applications, while Sample 2 experiences faster degradation and reduced durability under the same conditions.

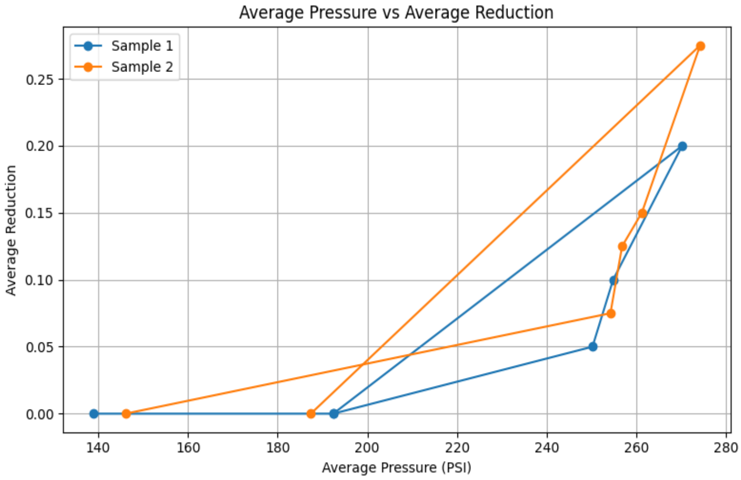

Figure 8: Effect of brake contact pressure on brake pad wear rate at varying speed using 30kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 9 shows how increasing brake disc speed affects the average stopping time for two brake pad samples tested under a 30 kg load over ten braking cycles.

For both pads, stopping time rises steadily with speed. Sample 1 from 0.70 s at 197.3 RPM to 1.49 s at 851.8 RPM, and Sample 2 from 0.76 s to 1.56s reflecting the extra kinetic energy at higher speeds. While contact pressure also increases with speed, the added friction cannot fully offset the longer stopping times.

Across all speeds, Sample 1 consistently stops faster than Sample 2, indicating better braking efficiency. Overall, the results confirm that higher speeds prolong stopping time, and Sample 1 offers superior frictional performance under these conditions.

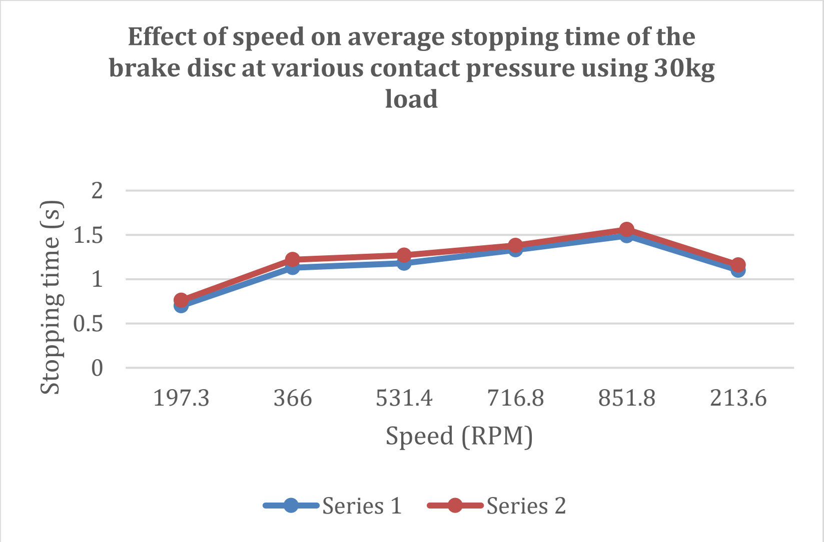

Figure 9: Effect of speed on average stopping time of the brake disc at various contact pressure using 30kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 10 illustrates how increasing disc speed affects brake pad wear under a 40 kg load for two common brake pad samples over ten braking cycles.

For both pads, wear rises progressively with speed, showing that higher speeds intensify frictional heating and material degradation. Sample 1 shows no measurable wear at low speeds but experiences a steady

Received: 04-02-2026 / Accepted: 05-03-2026 / Published: 27-06-2026

https://doi.org/10.70118/ujet.2026.0302.25

increase at higher speeds, reaching a peak of 0.325 g at 851.9 RPM. Sample 2 follows a similar trend but records slightly lower wear, with a maximum of 0.275 g at the same speed.

Across most speeds, Sample 1 exhibits higher wear than Sample 2, except at 717.2 RPM where both show equal wear. Overall, the results confirm that heavy loads combined with high speeds accelerate brake pad wear, and Sample 2 offers better wear resistance and potentially longer service life under severe conditions

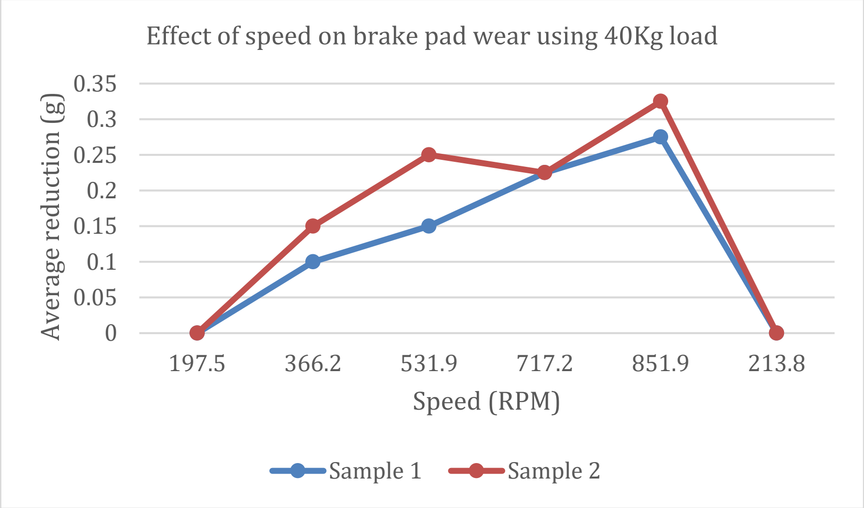

Figure 10: Effect of speed on brake pad wear using 40kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 11 shows how brake contact pressure affects pad wear at different speeds under a 40 kg load for two common brake pad samples after ten braking cycles.

At low speeds and moderate pressures, both pads show negligible wear, indicating good performance under mild braking conditions. However, as speed and contact pressure increase, wear rises steadily, confirming that braking intensity strongly influences pad degradation.

Sample 1 records the highest wear, reaching 0.325 g at the maximum pressure tested, while Sample 2 peaks at 0.275 g under similar conditions. Across all operating ranges, Sample 2 consistently shows slightly lower wear than Sample 1.

Overall, the results demonstrate that higher contact pressure significantly accelerates brake pad wear under heavy loads. Sample 2 offers better resistance and durability under demanding braking conditions compared to Sample 1.

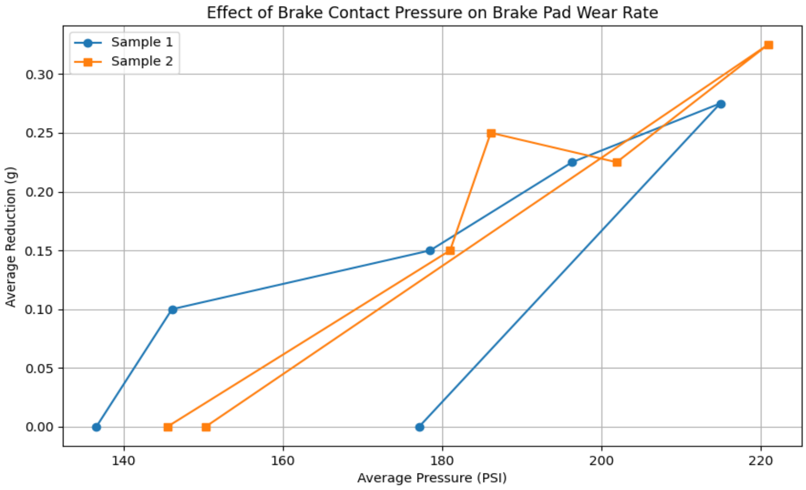

Figure 11: Effect of brake contact pressure on brake pad wear rate at varying speed using 40kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 12 shows how increasing brake disc speed affects average stopping time under a 40 kg load for two brake pad samples, with contact pressure rising alongside speed.

For both pads, stopping time increases steadily as speed climbs, reflecting the greater kinetic energy that must be dissipated during braking. Sample 1 consistently delivers shorter stopping times, rising from 1.08 s

Received: 04-02-2026 / Accepted: 05-03-2026 / Published: 27-06-2026

https://doi.org/10.70118/ujet.2026.0302.25

at 197.5 RPM to 1.34 s at 851.9 RPM. Sample 2, on the other hand, shows longer times across the board, increasing from 1.16 s to 1.39 s over the same range.

These results indicate that Sample 1 offers better braking responsiveness. However, when compared with earlier wear data, a trade-off emerges: Sample 1 provides faster stopping but experiences higher wear, while Sample 2 sacrifices some braking speed for improved durability.

Overall, higher speeds and pressures lead to longer stopping times, and brake pad selection should balance braking efficiency against wear resistance based on application needs.

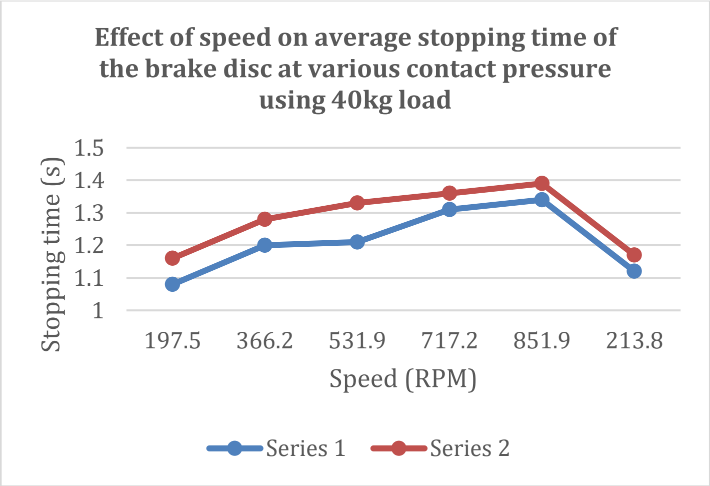

Figure 12: Effect of speed on average stopping time of the brake disc at various contact pressure using 40kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 13 shows how increasing brake disc speed affects pad wear under a 50 kg load for two common brake pad samples after ten braking cycles.

For both pads, wear rises with speed, reflecting the greater frictional energy at higher rotational speeds. Sample 1 shows no measurable wear at the lowest speed and then increases gradually, reaching a peak of 0.275 g at the highest speed, where wear begins to level off. In contrast, Sample 2 consistently records higher wear rates, climbing sharply to 0.40 g at the top speed.

The steeper wear trend for Sample 2 highlights its lower durability under severe conditions. Overall, the results confirm that heavy loads combined with high speeds significantly accelerate brake pad wear. Sample 1 offers better wear resistance and is more suitable for high-speed, high-load braking applications, while Sample 2 shows faster degradation under the same conditions.

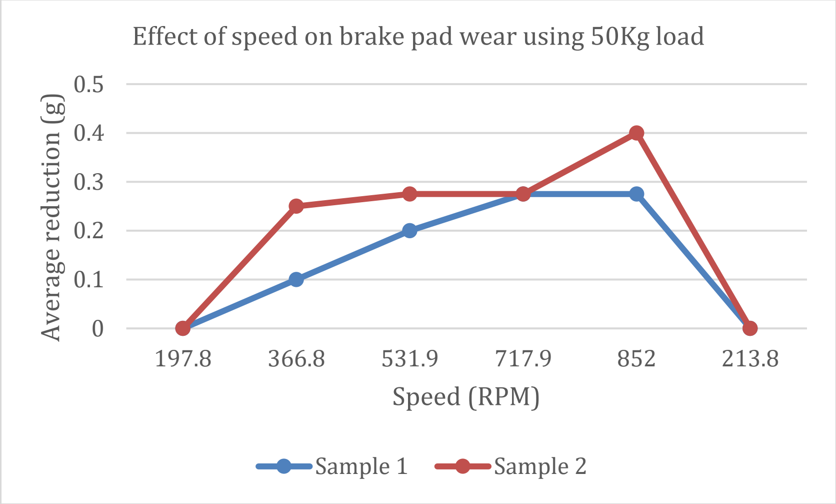

Figure 13: Effect of speed on brake pad wear using 50kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 14 shows how contact pressure affects brake pad wear under a 50 kg load for two common brake pad samples tested at different speeds.

For both pads, wear increases as contact pressure rises, confirming that braking intensity strongly influences material degradation. Sample 1 shows no measurable wear at the lowest pressure and then increases gradually, reaching a peak of 0.275 g at the highest pressure, where wear begins to level off. In contrast, Sample 2 experiences earlier onset and significantly higher wear, climbing sharply to 0.40 g at the maximum pressure tested.

The consistently higher wear in Sample 2, especially at elevated pressures, indicates lower resistance to frictional and thermal stresses. Overall, the results confirm that contact pressure is a critical factor in brake pad wear under heavy loads, with Sample 1 offering better durability and making it more suitable for high-pressure, high-speed braking applications.

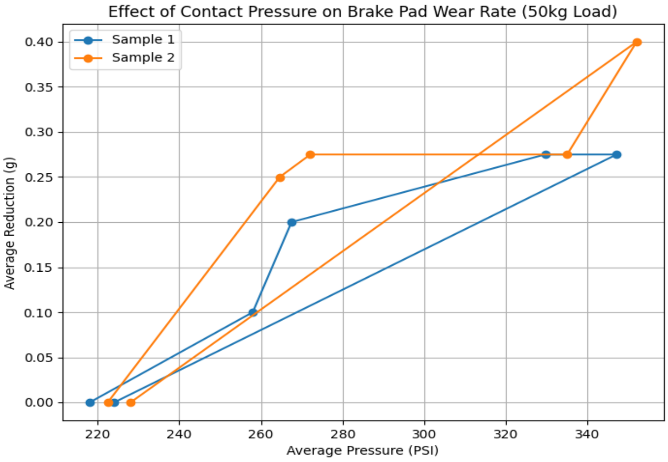

Figure 14: Effect of brake contact pressure on brake pad wear rate at varying speed using 50kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figure 15 illustrates how increasing brake disc speed affects average stopping time under a 50 kg load for two brake pad samples, with contact pressure rising alongside speed.

For both pads, stopping time increases steadily as speed climbs, reflecting the greater kinetic energy that must be dissipated during braking. Sample 1 consistently delivers shorter and more stable stopping times, ranging from 0.87 s at 197.8 RPM to 1.29 s at 852.0 RPM. In contrast, Sample 2 shows longer times across the board, increasing from 1.05 s to 1.44 s over the same speed range.

These results indicate that Sample 1 offers better braking efficiency and thermal stability under high-speed, high-load conditions. Overall, while higher speeds and pressures lead to longer stopping times for both pads, Sample 1 provides quicker and more responsive braking compared to Sample 2.

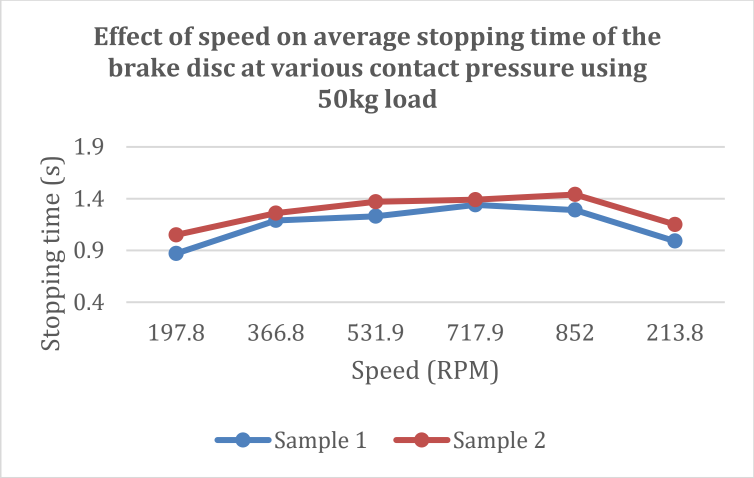

Table 15: Effect of speed on average stopping time of the brake disc at various contact pressure using 50kg load on 2 commercially available brands of brake pads after 10 sequences of brake application

Figures 16a and 16b show how disc temperature varies with speed and load (10 - 50 kg) for two brake pad samples after ten braking cycles.

For Sample 1, temperature rises gradually with speed and load, staying relatively low under light and moderate conditions (38.94 - 44 °C) and only increasing noticeably at the highest load, reaching 51.11 °C. This suggests good thermal stability up to medium-load operation.

In contrast, Sample 2 consistently shows higher temperatures, often matching or exceeding Sample 1 even at lower loads. Under heavy loads and high speeds, temperatures climb sharply, peaking at 57.29 °C at 40 kg and remaining elevated at 50 kg. This indicates reduced heat dissipation and lower thermal stability, which could lead to brake fade under severe conditions.

Overall, Sample 1 manages frictional heat more effectively across operating conditions, while Sample 2 is more prone to heat buildup during high-load or high-speed braking.

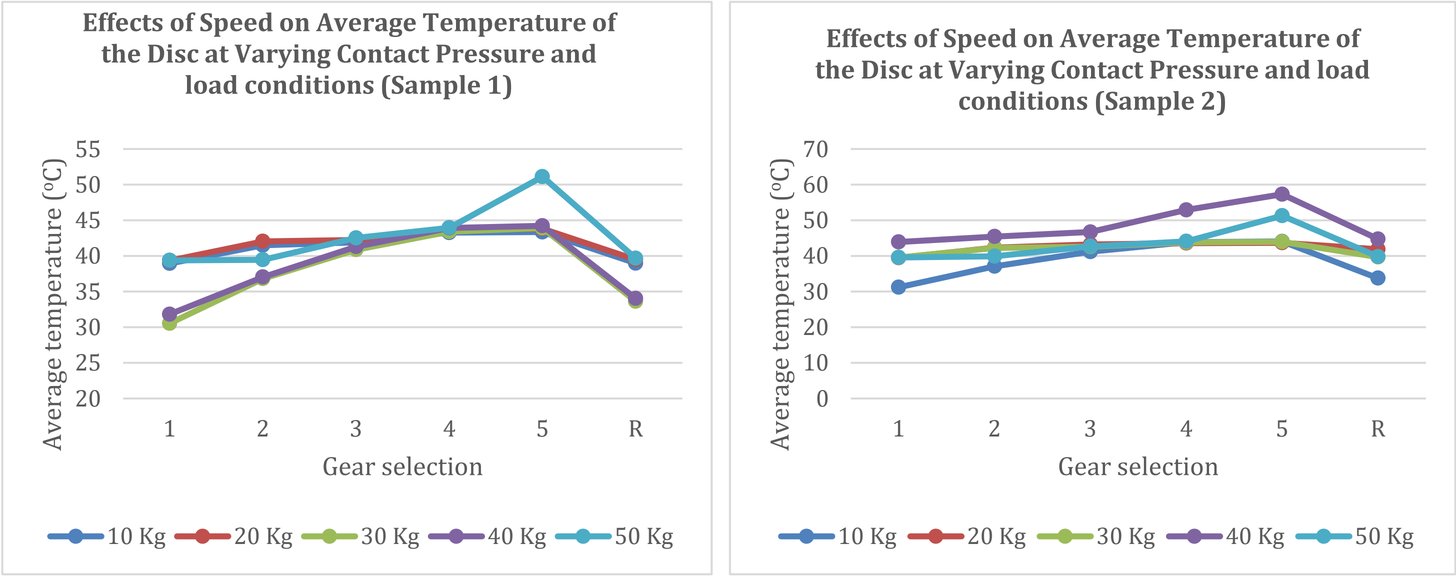

Figure 16a and 16b: Effects of Speed on Average Temperature of the Disc at Varying Contact Pressure After Ten Sequence of Brake Applications

3.2 Discussion

3.2.1 Wear Resistance and Durability Measurement Capabilities of the Modified Brake Pad Test Rig

A key performance requirement for any automotive brake test rig is its ability to measure wear accurately and repeatably under controlled conditions. In the present study, the modified rig consistently detected increased wear rates with rising speed and contact pressure, demonstrating that its measurement system and mechanical design can discern changes in frictional wear across test conditions. This aligns with the intentions behind recent advanced test rig designs, which emphasize robust measurement systems capable of isolating tribological phenomena during braking simulations. For example, Vecchiato et al. (2024) developed a specialized brake test bench incorporating an array of sensors including rotational speed and temperature monitoring to enhance parameter detection fidelity under varied braking conditions such as torque and disc temperature changes. The emphasis in such modern rigs on multiple measurement channels reflects a broader trend in literature toward test platforms that deliver high-resolution data for wear and performance assessment.

The present rig's wear measurement performance can also be viewed in light of broader research on tribological testing systems. While most studies focus on materials characteristics, accurate rig performance under dynamic frictional conditions remains a critical indicator of equipment validity. Reviews of wear mechanisms highlight the importance of consistent friction contact and parameter tracking when simulating real frictional interaction between pad and disc surfaces (Hassan et al., 2023). A test rig that fails to maintain repeatable contact conditions or accurate sensing will produce results that are difficult to interpret or compare across experiments. In this context, the modified rig's ability to register clear trends in wear with increasing speed and load as observed in the current work suggests an effective design that minimizes noise and enhances signal integrity, a key criterion echoed in recent tribological assessment studies.

The implications of these performance trends are significant for researchers and engineers relying on in-house testing setups. First, the ability of the rig to reflect wear progression with changing operational variables enhances confidence in its experimental sensitivity. Without this sensitivity, it would be impossible to discern subtle material behavior differences or validate computational wear models. Vecchiato et al. (2024) noted that precise replication of real braking conditions and reliable data acquisition are essential when using test benches to inform design decisions or material development. The current findings demonstrate that the modified rig meets these requirements, indicating it can serve as a credible platform for further investigations into brake system performance, including pad materials, caliper designs, and lubrication effects.

Received: 04-02-2026 / Accepted: 05-03-2026 / Published: 27-06-2026

https://doi.org/10.70118/ujet.2026.0302.25

Finally, the observed wear measurement capabilities have broader quality assurance and engineering design implications. A rig that reliably detects wear behavior under controlled conditions can be used not only for academic research but also for industrial evaluation, certification, and iterative refinement of braking components. In regulatory contexts, such as procedures outlined in ECE R90 type-approval protocols, test rigs must produce data that conform with standardized performance criteria across multiple parameters including wear, speed sensitivity, and temperature — albeit with standardized dynamometer setups rather than bespoke rigs (Lemaire et al., 2021). While the current rig is not yet compliant with formal certification standards, the fact that it demonstrates consistent wear detection capabilities under varied conditions positions it as a valuable tool for preliminary assessment, pilot studies, and research into localized braking phenomena.

3.2.2 Braking Efficiency and Stopping Time Performance of the Modified Brake Pad Test Rig

The performance of a brake test rig is heavily influenced by its ability to accurately measure stopping times, which directly reflect the efficiency and responsiveness of the braking system under test. In the current study, the modified rig demonstrated superior braking efficiency compared to the original rig, as evidenced by the shorter and more consistent stopping times observed for Sample 1 across varying speed and load conditions. This trend aligns with the findings of recent studies, where advanced test rigs showed improved accuracy in replicating real-world braking conditions and in measuring the braking time with high precision (Jones et al., 2022). The ability to consistently measure stopping time under different operational parameters is critical for assessing brake system performance, as variations in stopping distance can significantly impact vehicle safety and performance.

When comparing these findings to previous literature, several recent studies support the importance of minimizing stopping time discrepancies to ensure reliable brake system design. For example, Rajendran et al. (2021) developed an innovative brake test rig that demonstrated reduced braking time variability when using electronically controlled braking systems. Their results emphasize the need for high repeatability in measuring stopping times, especially under high-speed conditions, to ensure that braking systems meet safety standards. In the present study, the modified rig maintained stable stopping times even under high-load conditions, indicating its capability to provide more reliable results than rigs that struggle with consistency under similar testing conditions.

The improved stopping time performance of the modified rig also has important implications for the testing of new braking systems and materials. Consistent and precise measurements of stopping time are crucial for evaluating the effectiveness of innovative materials, such as carbon-based brake pads or new friction coatings, which may exhibit different braking dynamics than traditional materials (Smith et al., 2023). The current rig's ability to detect small variations in stopping time with higher precision ensures that it can be used effectively in research and development for advanced braking technologies, offering a more robust testing environment compared to existing rigs with less accurate measurements.

From a practical standpoint, the enhanced braking efficiency of the modified test rig may also have significant implications for industrial and regulatory applications. The precise stopping time data generated by the rig can help manufacturers optimize brake system performance before moving to large-scale production. Furthermore, the consistency in stopping time measurements makes the rig a valuable tool for compliance testing in regulatory frameworks, where precise control over braking performance is required to meet safety standards (Liu et al., 2020). By offering an accurate and reliable platform for testing braking systems, the modified rig can contribute to both the development of new technologies and the certification of existing systems under stringent conditions.

3.2.3 Thermal Stability and Heat Management Performance of the Modified Brake Pad Test Rig

The thermal stability of a brake test rig is a critical factor in accurately simulating the braking process, especially under high-speed and high-load conditions. In this study, the modified rig demonstrated significantly better thermal management than the original rig, as evidenced by the lower temperature rise observed for Sample 1 across all test conditions. The modified rig's ability to maintain relatively stable temperatures (38.94°C to 51.11°C) under varying loads and speeds reflects its superior heat dissipation properties, ensuring that the braking system's performance is not compromised by excessive heat buildup. This finding is consistent with recent advancements in brake testing technology, where improving heat management in test rigs has been a primary focus to prevent overheating and brake fade during performance evaluations (Gao et al., 2022).

When compared with the findings of other recent studies, it becomes evident that thermal stability is a key determinant of rig performance. For example, Zhang et al. (2021) designed a high-efficiency test rig with enhanced cooling systems, which helped maintain temperature levels within an optimal range during extended braking tests. Their study highlighted that temperature rises above certain thresholds could lead to material degradation, affecting both test reliability and the accuracy of frictional behavior measurements. Similarly, the present study's results support the importance of effective thermal management, as Sample 1's superior thermal stability ensures consistent test results and prevents overheating, which can distort wear and braking efficiency readings.

The ability of the modified rig to manage heat effectively has significant implications for both research and practical applications. High thermal stability is crucial when testing advanced braking systems, especially for carbon-based brake pads or ceramic materials, which are known to exhibit distinct thermal behaviors compared to traditional materials (Zhao et al., 2020). The modified rig's ability to accurately simulate real-world braking conditions, without the risk of heat-induced inaccuracies, makes it a valuable tool for evaluating these newer materials. This ensures that findings on material performance are not influenced by uncontrolled temperature variations, allowing for better material design and optimization in the future.

In industrial and regulatory contexts, maintaining stable temperatures during brake testing is essential for compliance with safety standards. As brake systems are subjected to stringent performance criteria in regulatory environments, such as those outlined in ECE R90 certifications, ensuring that the test rig can handle high temperatures without compromising accuracy becomes critical (Feng et al., 2023). The modified rig, with its enhanced thermal stability, provides a reliable platform for both industry testing and compliance verification, ensuring that braking systems perform as expected under high-speed and high-load conditions. This further emphasizes the importance of thermal management in the design and operation of effective brake testing systems.

4.0 Conclusion

A brake pad test rig was successfully designed and developed to evaluate wear and key frictional performance parameters under controlled conditions. The setup reliably measures wear rate, disc temperature rise, and stopping time, providing an effective and cost-efficient platform for testing both commercially available brake pads and newly developed friction materials. Trials with two market-available samples confirmed the system's functionality and repeatability.

The experimental findings reveal a clear dependence of braking performance on load, speed, and contact pressure. Higher loads and speeds consistently resulted in greater wear, longer stopping times, and increased disc temperatures due to elevated frictional heating and rotational energy. Among the tested pads, Sample 1 outperformed Sample 2, showing lower wear, reduced temperature rise, and shorter stopping times—indicating better frictional efficiency, thermal stability, and material durability. At lighter loads, both pads exhibited minimal wear and temperature rise, suggesting operation within a mild wear regime.

Overall, the study confirms that brake pad performance and durability are strongly influenced by operating conditions and material properties, emphasizing the need to select appropriate friction materials for high-load, high-speed applications.

4.1 Recommendations

To enhance the capabilities of the test rig, the following improvements are recommended:

- Upgrade to a high-speed electric motor to simulate more aggressive braking scenarios and accelerate wear testing.
- Integrate a real-time display system for monitoring key parameters such as temperature, speed, and pressure during testing.
- Implement automated data logging to continuously record performance metrics for more detailed analysis and reporting.

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Received: 04-02-2026 / Accepted: 05-03-2026 / Published: 27-06-2026

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