**Automotive Experiences**
Vol. 6 No. 2 (2023) pp. 234-244
p-ISSN: 2615-6202 e-ISSN: 2615-6636

*Research Paper*

# Investigation of Brake Pad Wear Effect due to Temperature Generation Influenced by Brake Stepping Count on Different Road Terrains

**Rusli Majuma**[1], **Mohamad Heerwan Bin Peeie**[1,2], **Kerisvin Ondong**[1], **Othman Abu Hassan**[1]

[1]Fauclty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Malaysia
[2]Automotive Engineering Center, Universiti Malaysia Pahang, 26600 Pekan, Malaysia

mheerwan@ump.edu.my

https://doi.org/10.31603/ae.8869

Published by Automotive Laboratory of Universitas Muhammadiyah Magelang collaboration with Association of Indonesian Vocational Educators (AIVE)

*Article Info*
*Submitted:* 16/03/2023
*Revised:* 18/04/2023
*Accepted:* 23/04/2023
*Online first:* 18/05/2023

**Abstract**

The use of vehicles in Malaysia has become a need and important to commute to the workplace and commercial business transportation. This necessity resulted in an increase in the number of cars on the road that eventually increase the number of accidents that resulted in the loss of life which is also one of the leading killers in Malaysia. Deriving from this phenomenon, car maintenance especially brake systems has become imperative that eventually become the main objective of this research to investigate the effect of different road terrains to brake pad wear. The experimental vehicle is operated in two different road terrains namely hilly and flat roads and each road terrain is set to complete 1000km of investigation traveled distance. Three main investigation parameters are brake pad thickness wear, the temperature generated from rubbing the brake pad with the rotor, and the brake force applied on the brake pedal. A CANedge external onboard diagnostic (OBD) logger is used to collect real-time data on the relevant parameters from the vehicle's ECU for analysis. The result from the experiments found that the average brake pad wear rate during hilly roads is 53% higher than that of flat roads. Likewise, brake pad temperature generation on a hilly road is 34% higher than that on a flat road. However, the brake pedal force applied during braking is 60% higher on flat roads compared to on hilly roads. From the findings, data from the vehicle OBD2 and the brake pad wear can be analyzed to provide an electronic signal for indication of timely maintenance for the brake pad.

**Keywords:** Brake pad thickness; Brake pedal force; Temperature generation; Vehicle monitoring system; Vehicle maintenance

## 1. Introduction

Transportation using automobiles in Malaysia is very common and has become the primary way of commuting from one place to another [1]. The use of vehicles as transport is mostly for commuting to work, going shopping, visiting parents in hometown or places to even in short distances, mainly due to the convenience. In Malaysia, the increase in vehicles has significantly affected our daily activities. According to the Road Safety Report by the World Health Organization (WHO), road accidents in Malaysia contributed to 25 deaths per 100,000 populations [2]. Globally, road accidents have been responsible for massive deaths [3]. In particular, this involves the safety of both passengers on board the vehicle and other road users, including pedestrians [4].

Since the mid-1980s the number of vehicles has significantly increased due to the fact that Malaysia has established its own vehicle manufacturing named PROTON. Since then, the number of vehicles increasing almost exponentially every year, partly due to the establishment of the second national car manufacturer named PERODUA in 1992 on top of existing foreign imported car brands such as Toyota, Honda, Nissan, BMW, and Mercedes, among others. In recent years, Malaysia Automotive Association (MAA), 2021 update, reported the total industry volume in Malaysia has reached 666,667 units (highest in 2015). Due increase in the number of vehicles on the road, has considerably impacted the accident statistics. Based on the several literature and research, it is estimated that the number of vehicles in Malaysia would be continuously increasing on year to year basis and it is also predicted that the number of vehicles accident on the road would also increase in tandem with the increase of population in Malaysia [5].

As reported, road accidents cause massive loss of lives globally, with approximately 1.35 million people dying every year or, on average 3,700 people losing their lives each day on the roads [6]. According to research by Musa *et al*. [7] approximately 18 traffic accidents occur in Peninsular Malaysia that causes, on average, one death in every hour, indicating preventive measures are required. This remains a significant concern that could obstruct human capital development, especially in developing countries such as Malaysia. Moreover, the steady increase in population and vehicles on the roads in Malaysia has significantly influenced traffic accidents. According to the WHO report [8], nations with low and middle earnings are severely affected by the fatalities of road traffic accidents, contributing to approximately 90% of road accident-related deaths globally [7].

It is worth looking into this in detail to understand the associated problem in the vehicle that possibly contributes to the increase of the road accident apart from the driver skills & experience, road conditions, environmental changes to condition and other causes which are not reported and analyzed by the relevant authority. An investigation by Musa *et al*. [7] on federal road accidents in Malaysia found that the "Out of control" and "Head-on collisions" have out-numbered the other collision type suggesting the brake system components might have maintenance issues where both types of collisions accounted for 82% of collision type. Another investigation by Gavaskar *et al*. [9] on The National Transport Safety Board (NTSB) report found that the poor maintenance practice by the vehicle owner and/or commercial vehicle operators contributed to the failure in brake systems attributed to the lack of understanding and knowledge about the necessity for a well-maintained vehicle. Research by Bohr *et al*. [10] mentioned that by observing and performing regular checks on the brake system and road condition, failures and accidents due to brake failure may not occur. An investigation by Solah *et al.* [11] on PUSPAKOM road worthiness inspection data on a private vehicle for pass or fail has found that the most highlighted items on the fail result are the brake function. Also highlighted that the number of cases increases as the vehicle age increases, and this clearly indicates that the maintenance aspects need to be looked into to ensure the vehicle, especially the brake components, is in good condition and thus performing as expected.

Another investigation by Solah *et. al* [12] on buses accident in Malaysia found that brake and tire failure was common problem factors in the post-crash investigation. Thus, vehicle brake system components monitoring is critical to provide information for timely maintenance to ensure driver and passengers onboard the vehicle is protected when stopping at an occasion such as at a traffic light, approaching other vehicles, and most importantly when stopping for an emergency. To maintain the brake system function performance continuously working best, monitoring the brake component system, such as the brake pad, by inspecting the system component as regularly as possible is crucial [13]. Current practice using a metal pin attached to the brake pad, however, is common. Unfortunately, this could not effectively alert the driver as there could be a lot of other sounds during driving. Thus, this situation has motivated the project to investigate and propose a solution to this monitoring system. Therefore, this research project focuses on the vehicle's vulnerable point, which is the braking system. The main objective of this research is to investigate the effect of different road terrain on brake pad components wear rate which influence the decision for maintenance of the brake pad.

According to a study on driving on a mountainous road in Wyoming by Haq *et al*. [14], the likelihood of crashes caused by brake failure is generally higher, especially as cars get older. Based on the study, trucks are more prone to brake failure since they are heavier than other vehicles in their class. Prolonged application of the brakes under prolonged downhill driving conditions could raise the brake temperature and cause the brake system components to fail. It is obvious that cars travelling across steep terrain operate in harsher conditions, putting additional strain on their mechanical parts [15]. Hence, it is important to understand the effect of hilly road to the brake components maintenance.

From a different perspective study by Jawi *et al*. [16] on vehicle owner attitudes toward maintenance was found to be poor probably due to the influence of lack of general knowledge on automobile maintenance where most owners are inability to perform their own vehicle self-assessment caused heavily relying on workshop mechanics. Therefore, an effective and reliable system with readily available tools in the market is necessary to address this problem. Several studies from the available works of literature have been conducted to look for suitable systems in order to review and propose the best and most applicable for the monitoring of the brake components where in this study the focus is on the brake pad.

In a study conducted by Sivarao *et al*. [17], on a Perdana V6, the brake pad wear limit can be monitored by using a micro-sensor embedded in the brake pad. In this study, the sensor to detect the brake pad thickness has been selected from several available sensors, and choose the best position to install the micro sensor where the study successfully detected the brake pad wear progression. However, during the experiment on the test rig, the wire connection was vulnerable to vibration which implies the issue of reliability to the sensor is become the fundamental problem.

Hatam and A. Khalkhali [18] in their study has proposed the wear prediction of a hydraulic brake pad using an algorithm to simulate the wear based on FE analysis combined with the Archard equation using Python scripting. The experiment was conducted on a Pin-on Disc performed on a standard-size pin known for the brake pad where the rotor and pad contact area and worn mass are obtained to determine the coefficients of friction and wear between steel disc and brake pad. The worn mass of the brake pad is also considered in the experiment where the proposed automotive brake pad wear prediction algorithm is validated by comparison of calculated worn mass to measured values, obtained in a corresponding cylindrical pin-on-disc wear test. In this prediction, it has to conduct several experiments to get the initial data of the brake pad using the Pin-on Disc when using a different type of brake pad material.

In another method for investigation by Praneh *et al*. [19] using vibration signal for prediction of brake system health monitoring utilizing machine-learning & statistical analytic technic, the vibration signal obtained from an experiment using a piezoelectric accelerometer (Dytran make, 10 mV/g sensitivity) where the signal data for good brake system condition and faulty brake conditions are developed as part of the machine learning system input teaching and the data are processed using statistical features that can be extracted and feed into the machine learning algorithm for data classification so that the expected brake system health are demonstrated. This research generally utilizes the latest technology of machine learning and has to collect the data of the vibration and install external measuring tools to capture the required data for the algorithm to work on.

In a similar investigation approach, Harlapur *et al*. [20] have conducted a machine-learning algorithm by relating the brake pad thickness with the stopping distance. In this investigation, no external sensors and parameters were used as the whole data collection is making use of the vehicle’s onboard sensors for data such as the vehicle’s speed and so on. Since this investigation utilizes a machine learning algorithm, the variation of the vehicle’s stopping distances for various thicknesses of the brake pad is first recorded and then a suitable machine learning algorithm is used to fit this data. This algorithm provides a mathematical relation between the stopping distances and the brake pad thickness. Thus, this mathematical model can be used on the vehicle to calculate the brake pad thickness by monitoring the stopping distance of the vehicle. This study is generally very much similar to this research where the brake pad thickness and vehicle stopping distance is being used to investigate the brake pad health condition as an indicator for the brake pad condition for maintenance. The novelty of this study lay in the data collection which utilized the real-time on-board diagnostic tools to capture the required investigation parameters directly from the vehicle's ECU and using the CANedge2 logging system without external measurement tools to measure the parameters and the experiment is conducted on the actual road for hilly and flat road terrain condition. In addition, in this research, the temperature generated on the brake pad and brake force amount applied on the brake pedal was also included to investigate the relationship between the thickness wear rate associated with temperature and the amount of brake force applied on the brake pedal.

## 2. Methods

The experimental vehicle for this study is a Toyota Avanza based on information that this model is one of the best-selling model in Malaysia and Indonesia [21]. The vehicle is a mini multi-purpose vehicle (MPV) type with 1.5-liter engine capacity with an automatic transmission and the brake system is however not equipped with ABS. The focus of the experiment is on the front brake system which is a disc brake type. The measuring instrument to be used in this experiment indicated in **Figure 1** includes a micrometer, brake pedal force sensor, K-type thermocouple, an On-board diagnostic (OBD2) tool as a data acquisition system called CANedge2 to capture data from the ECU of the vehicle, and Graphtec data logger.

The experimental vehicle is operated in two different road terrains to investigate the effect of wear rate on the brake pad specifically on the front brake to provide a decision guide to do maintenance of the brake components. Two investigation road terrains in this research namely the hilly road covering the Sabah Crocker range and the other road terrain is the flat road covering around Kota Kinabalu city. **Figure 2a** and **Figure 2b** shows the map of hilly road and flat road terrain. Each road terrain is set to complete 1000km of investigation traveled distance to understand the main investigation parameters which are the brake pad thickness wear, the temperature generated on the brake pad rubbing with the rotor, and the brake pedal force. The data collected are analyzed to provide the average data for brake pad thickness wear rate, the average temperature generation as well as for brake force applied to the brake pedal during the experiment.


**Figure 1.** Measuring instruments: (a) Micrometer (0-25mm range); (b) Brake pedal force sensor; (c) K-type thermocouple; (d) CANedge2 logger; (e) Graphtec data logger

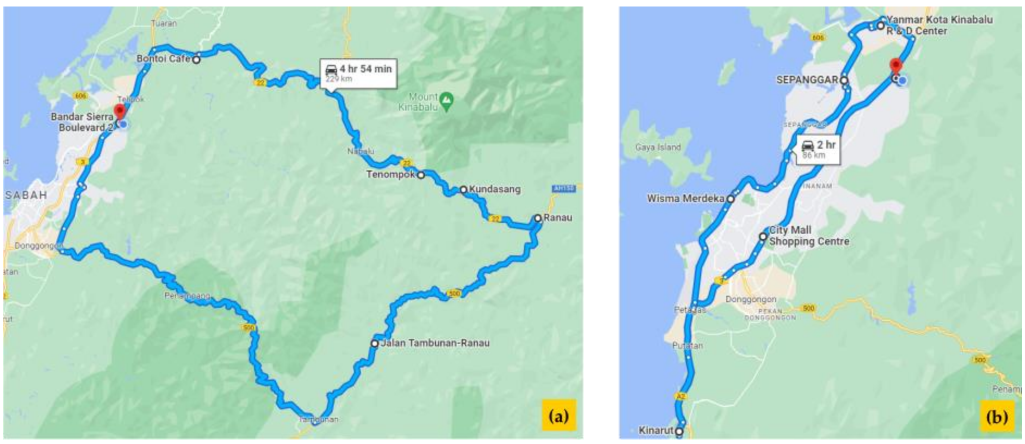


**Figure 2.** (a) Location of hilly road terrain and (b) Flat road terrain

According to Neis [22], any linear measurement of component wear can be performed by any metrological techniques described by ASTM G99 Standard, such as in the case of thickness measurements of a brake pad, micrometer, or vernier caliper are commonly used. In the same research, it was mentioned that international standards for brake pad wear test procedure such as ISO26867, recommends selecting at least 5 points equally spread on the brake pad surface for thickness measurements. Similarly, this approach is being employed in this research experiment with the increase in the number of measurement points to consider the effect of uneven pressure applied in the brake pad.

**Figure 3** shows the brake pad both the inner brake pad and the outer brake pad of the front brake pad of the vehicle with the measurement point selection. The brake pad is identified to have 16 measurement points each where measurement point selection is based on the method used by Neis [22]. The measurement points are marked with a marker pen to ensure measurements are being done at the same points every time the measurement is being performed. In order to minimize errors from the measurement personnel it was decided to only one person to do the measurement of the brake pad thickness from the beginning until the experiments are completed.

Due to the difficulty in measuring the temperature changes in the brake pad by normal temperature measurement tools on a continuous basis, a suitable method is required to be employed especially due to the brake pad location and operation are not easy to measure without stopping the vehicle. According to Grkić *et al*. [23] the best method to measure the temperature generated on brake pads is by using a thermocouple. The temperature of the heat generated by the rubbing brake pad against the disc brake during the braking process in this experiment is measured using a K-type thermocouple which accurately measures temperature ranging between -200 °C to 1000 °C. This K-type thermocouple is selected based on the suitability of the experiment where the temperature measurements are taken on a continuous basis and real-time monitoring apart from the capability of the thermocouple which is convenient and easy to install. The engine room temperature and environment temperature outside of the vehicle are measured for control and check for any influence from both areas on the brake pad temperature data.

Before the brake pedal force sensor is installed on the brake pedal, it is first calibrated using a known weight for the expected range of force applied to the sensor so that the display is accurately indicated on the display unit. The calibration weight is from 1kg up to 40kg and once the calibration curve has been obtained, the data is then set on the Graphtec Data Logger to display and record the data for analysis purposes after all the experiments are completed.

**Figure 4** shows the setup of the brake pedal force sensor on the brake pedal. When the brake pedal force sensor is stepped by the driver, the brake force applied to the brake pedal is displayed on the display unit which is connected to the Graphtec data logger where the data is displayed and recorded in real-time. The data will be recorded with one-second sampling interval to ensure the data for the brake force are captured


**Figure 3.** Brake pad measurement point selection

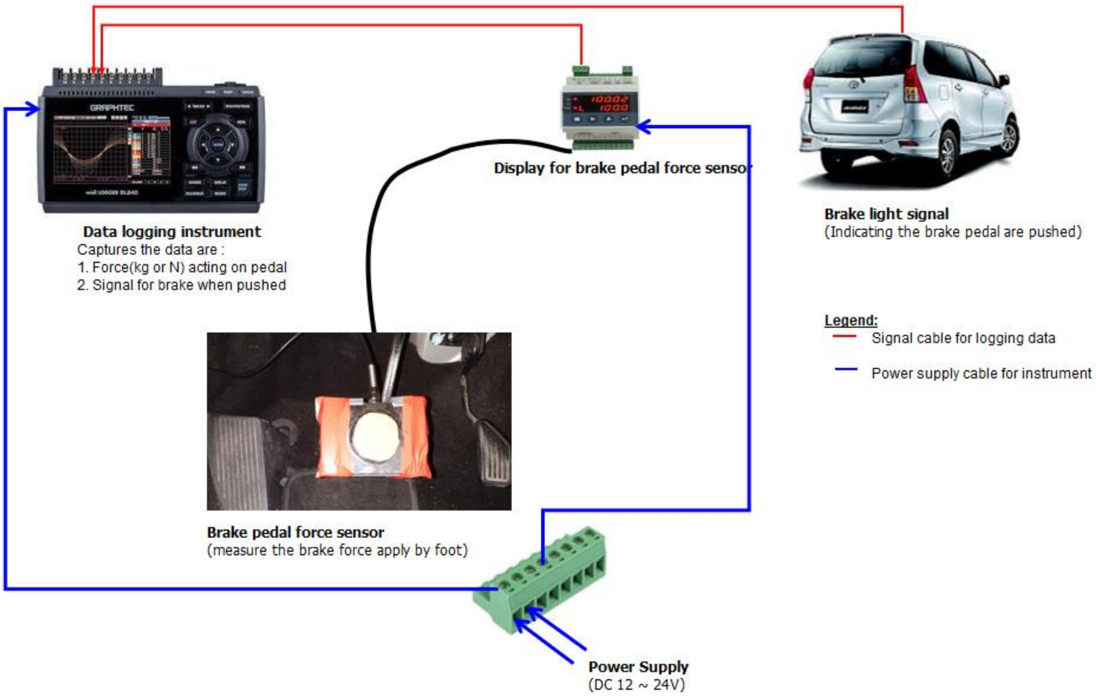


**Figure 4.** Brake pedal force sensor system setup on the experimental vehicle

during the braking action in which it takes at a short interval and needed to be captured and recorded without missing any of the braking force data during the braking action. In this study, CANedge external On-board Diagnostic (OBD2) tool is used to collect real-time data of vehicle speed. This data is reliable because CANedge OBD2 taken the vehicle speed directly from the vehicle's ECU.

## 3. Results and Discussion

The data collected from the study on the different road terrain, the temperature generated from the rubbing brake pad with the rotor disc, and brake pedal force applied during braking are analyzed to understand the effect of the brake pad thickness wearing phenomenon that leads to the maintenance decision of the brake components. Figure 5 shows the brake pad wear rate during 1000km of the hilly road and flat road. The results consist of the inner and outer parts of both the front left and rear right brake pads. From the experimental result, after completing the 1000 km travel distance, it was found that the rate of thickness reduction for the front left inner and outer pad on the hilly road is 0.55% and 0.61% respectively, which means the total thickness reduction for both front left pad is 1.16%. For the front right pad, it can be seen that the rate of thickness reduction for the inner and outer pad is 0.88% and 0.89% respectively, which means the total thickness reduction for the right brake pad is 1.77%. The right brake pad reduction is greater than the left pad because of the travel direction from the origin toward the left side. When the vehicle turns to the left-hand side, the load will be transferred from the left to the right tire. This caused more force required to stop or decrease the rotational speed of the right-hand side wheel. As a result, more wear on the right pad as indicated by the wear rate in Figure 5a.

Compared to the flat road surface, the thickness reduction rate for the front left inner and outer pad is 0.28% and 0.38%, respectively, while for the front right inner and outer pad, 0.27% and 0.40%, respectively. The total thickness reduction of the front left and right brake pads can be summarized into 0.66% and 0.67%, respectively. During the flat road experiment, the wear rate is about the same between the left and right tire due to the traveling direction within Kota Kinabalu city not being fixed to one direction only. Furthermore, it was more random in the direction selection as there was more option for route and direction even though most of the time, followed the selected path. Consequently, the load distribution from left to right or right to left will be the same, and the effect on the pad's wear is almost the same.

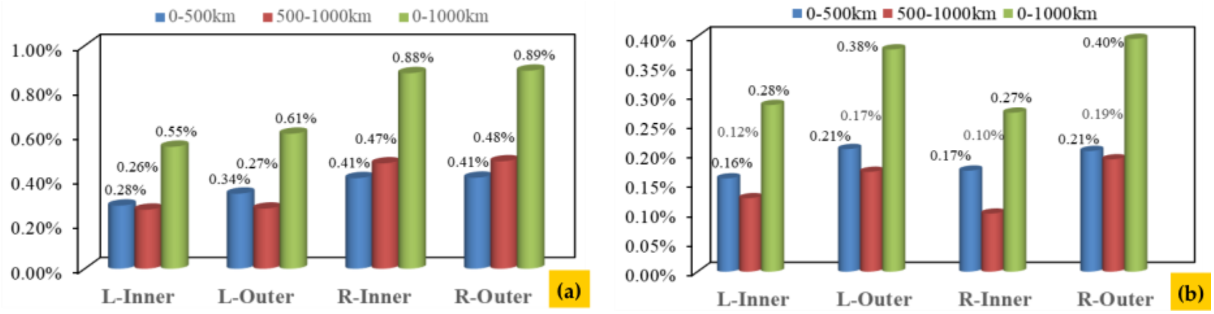


**Figure 5.** Brake pad wear rate during 1000km of the hilly road (a) and flat road (b)

The temperature analysis consists of outside temperature, engine temperature, and brake pad temperature, as depicted in **Figure 6a** and **Figure 6b**. Based on **Figure 6a** and **Figure 6b**, the outside temperature on the hilly and flat roads is almost the same, which means that the outside temperature can be neglected in the analysis of the brake pad. For engine room temperature, both hilly and flat road shows the maximum temperature is approximately 100 °C for hilly roads and 80 °C for flat road. The maximum temperature on the hilly road is higher than flat road due to the more torque required during ascending. Higher torque also means more braking force when braking on a hilly road, which leads to more temperature generated on the brake pad.

The heat generated on the rubbing brake pad and rotor during hilly road terrain was found to be at an average of 71.5 °C, compared to an average of 47.2 °C during flat road terrain. Higher temperatures are recorded mostly during descending and ascending the hill area where the braking action is applied to slow down the vehicle speed to ensure it is in control and generally following the speed limit. The result of the experiment is generally consistent with the information from Bryant's study [24], where the wear rate of the brake pad will increase when the temperature of the brake pad is increased, which is the effect of high temperature during the braking operation is not good for the brake pad especially when the brake pad is made from material with a low resistance to temperature.

As for the trend of braking force applied to the brake pedal as in **Figure 7a** and **Figure 7b**, it was found that the average braking force is 12N and 18N for hilly roads and flat roads respectively approximately 33% difference between the road terrain. This result is opposite to the brake pad thickness wear rate result where the hilly road has a higher wear rate but less brake force applied while lesser brake pad thickness wear rate during flat road but higher average brake force applied. This perhaps could be due to the influence of the total duration of braking time and the average vehicle speed in completing the 1000 km traveling distance is higher during hilly roads compared to the flat roads as indicated in **Table 1**. In a study by Mahadika [25], requires higher brake pedal force to stop the vehicle at a higher vehicle speed compared to a lower vehicle speed. This is inconsistent with the result of the brake force trend for the hilly road terrain experiment where the lower average brake force of around 12N was applied during hilly road terrain for a higher average vehicle speed of around 39.8 km/h while during flat road terrain experiment the brake force

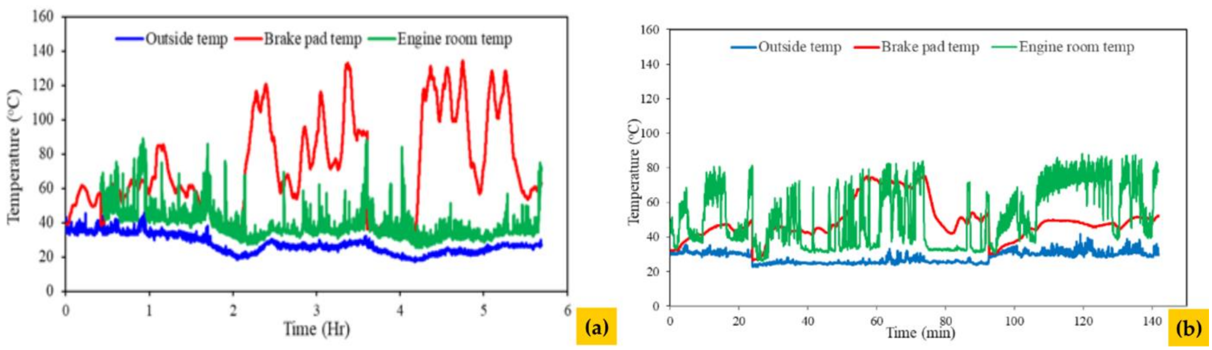


**Figure 6.** Brake pad temperature generated during hilly road (a) and flat road (b)

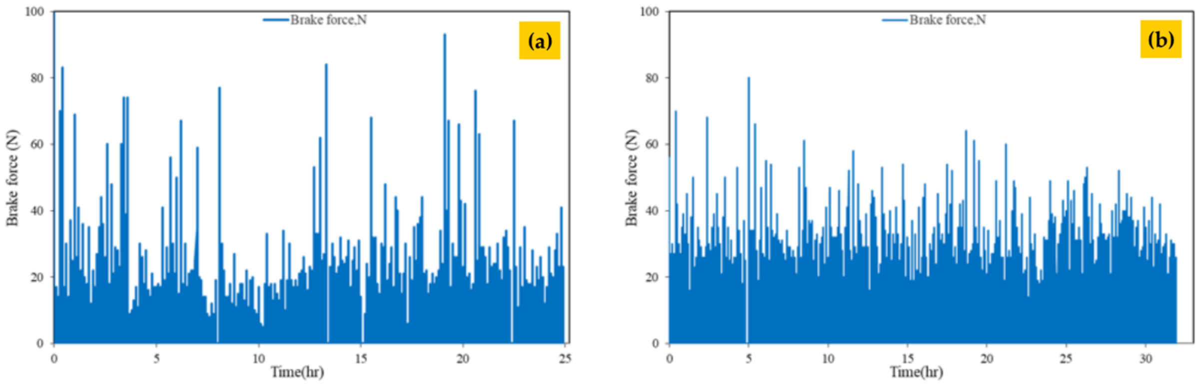


**Figure 7.** Brake pedal force applied during hilly road (a) and flat road (b)

**Table 1.** Summary of braking force, vehicle speed and other information

| Parameter | Unit | Hilly road | Flat Road |
|---|---|---|---|
| No of braking count | Count | 14523 | 2256 |
| Total time for braking | Hour | 4.1 | 0.6 |
| Total travel time for 1000 km | Hour | 23 | 25 |
| Average braking force | Newton | 12 | 18 |
| Average vehicle speed | km/h | 39.8 | 29.9 |

is about 18N for average vehicle speed of around 29.9 km/h which is lower speed compared to hilly average speed. This inconsistent result is due to driving on a flat city road requiring more force to stop the vehicle at the traffic light and junctions. Furthermore, sudden braking is also more frequent on the city road and the experiment for flat road surfaces is conducted at the Kota Kinabalu City Central. During driving on a hilly road, the driver also tends to drive the vehicle carefully and will apply the lower force on the brake pedal to slow down the vehicle speed during descending the hill to ensure a safe downhill.

In addition, from **Table 1**, it can be seen that the wear rate of the brake pads is also affected by the number of steps on the brake pedal as indicated by the number of braking counts and the total time taken for the braking action. However, the test results are only applicable and valid for the types of brakes and brake pads specifically used in this research. Meanwhile, research in the development of brake systems [26] and brake pad materials is also growing rapidly at this time, mainly due to issues related to reducing asbestos content [27]–[30] and the development of local materials for brake pads [31]–[34]. Therefore, further research on different brake system technologies and a wider range of brake pad materials can be carried out to complete the reference on the topic of brake pad wear.

## 4. Conclusion

In the first part of the experiment for driving the experimental vehicle on hilly road terrain and flat road terrain to complete a 1000 km distance, the three parameters of concern were evaluated to investigate the effect of each parameter on the extent of brake pad wear level progression. The three parameters are the brake pad thickness, the temperature generated on the rubbing brake pad with the rotor, and the third parameter is the trend of brake force applied on the brake pedal. The study found that the brake pad wear rate on the hilly road is 53% higher compared to flat road terrain. For the heat generated from the rubbing action between the brake pad and the rotor disc where in the experiment, the temperature generated on the brake pad during the hilly road terrain is 34% higher average temperature compared to the flat city road terrain during the total of 1000km traveled distance. Regarding the brake force trend applied to the brake pedal, it was found that the average brake force applied to the brake pedal during the hilly road is 33% lower compared to the brake force applied during the hilly flat city road.

Based on the result from the experiment, the OBD2 system is capable of being further developed to provide real-time information to monitor the brake pad wear by utilizing the data from the OBD2 to be collected and analyzed to indicate to the driver in the form of blinking light on the meter cluster for replacement of the brake pad when the recommended thickness is reached. This will greatly assist in a timely replacement of the brake pad without exposing the driver to a braking system failure, thus providing a solution to many accident cases due to brake failure.

## Acknowledgements

The authors would like to thank Universiti Malaysia Pahang (UMP) for prividing a research grant RDU192219 and experimental instrument. Special thanks to Yanmar Kota Kinabalu R&D center for allowing to use the company vehicle for this research.

## Author's Declaration

### Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript

### Funding

This research is fully supported by Universiti Malaysia Pahang (UMP) through research grant RDU192219.

### Availability of data and materials

All data are available from the authors.

### Competing interests

The authors declare no competing interest.

### Additional information

No additional information from the authors.

## References

[1] Y. Ngadiman, A. Aziati, A. Bon, M. Ahmad, R. Z. RM Rasi, and M. Hock, "Identification of Public Awareness in Preventive Maintenance for Personal Automobile," in *ndustrial Engineering, Management Science and Applications 2015*, 2015, pp. 1073–1090. doi: 1https://doi.org/0.1007/978-3-662-47200-2_111.

[2] Z. Eusofe and H. Evdorides, "Assessment of road safety management at institutional level in Malaysia: A case study," *IATSS Research*, vol. 41, no. 4, pp. 172–181, 2017, doi: https://doi.org/10.1016/j.iatssr.2017.03.002.

[3] I. M. Zulhilmi, P. M. Heerwan, S. M. Asyraf, I. M. Sollehudin, and I. M. Ishak, "Experimental study on the effect of emergency braking without anti-lock braking system to vehicle dynamics behaviour," *International Journal of Automotive and Mechanical Engineering*, vol. 17, no. 2, pp. 7832–7841, Apr. 2020, doi: https://doi.org/10.15282/ijame.17.2.2020.02.0583.

[4] S. I. Mohammed, "An Overview of Traffic Accident Investigation Using Different Techniques," *Automotive Experiences*, vol. 6, no. 1, pp. 68–79, 2023, doi: https://doi.org/10.31603/ae.7913.

[5] M. G. Masuri, A. Dahlan, A. Danis, and K. A. M. Isa, "Public Participation in Shaping Better Road Users in Malaysia," *Procedia - Social and Behavioral Sciences*, vol. 168, pp. 341–348, 2015, doi: https://doi.org/10.1016/j.sbspro.2014.10.239.

[6] S. K. Ahmed *et al.*, "Road traffic accidental injuries and deaths: A neglected global health issue.," *Health science reports*, vol. 6, no. 5, p. e1240, May 2023, doi: https://doi.org/10.1002/hsr2.1240.

[7] M. F. Musa, S. A. Hassan, and N. Mashros, "The impact of roadway conditions towards accident severity on federal roads in Malaysia," *PLoS ONE*, vol. 15, no. 7 July, Jul. 2020, doi: https://doi.org/10.1371/journal.pone.0235564.

[8] WHO, "Global Status Report on Road Safety 2018," *World Health Organization*, 2018, [Online]. Available: https://www.who.int/publications/i/item/9789241565684

[9] S. S. Gavaskar, P. K. Devan, and T. G. Loganathan, "Failure analysis of brake system in light commercial vehicles using SQC tools," *International Journal of Engineering Research & Technology*, vol. 3, no. 11, pp. 513–518, 2014, doi: https://doi.org/10.17577/IJERTV3IS110444.

[10] E. N. Bohr, C. P. Ukpaka, and B. Nkoi, "Reliability Analysis of an Automobile Brake System to Enhance Performance," *International Journal of Production Engineering*, vol. 4, no. 2, pp. 47–56, 2020, doi: https://doi.org/10.37628/ijpe.v4i2.746.

[11] M. S. Solah *et al.*, "Private Vehicle Roadworthiness in Malaysia from the Vehicle Inspection Perspective," *Journal of the*

*Society of Automotive Engineers Malaysia*, vol. 1, no. 3, pp. 262–271, 2017, doi: https://doi.org/10.56381/jsaem.v1i3.67.

[12] M. S. Solah, A. H. Ariffin, M. H. M. Isa, and S. V. Wong, "In-depth crash investigation on bus accidents in Malaysia," *Journal of Society for Transportation and Traffic Studies*, vol. 3, no. 1, pp. 22–31, 2013.

[13] A. Manghai, R. Jegadeeshwaran, G. Sakthivel, R. Sivakumar, and S. Kumar, "Condition monitoring of hydraulic brake system using rough set theory and FUZZY rough nearest neighbor learning algorithms," in *2019 IEEE International Symposium on Smart Electronic Systems (iSES)(Formerly iNiS)*, 2019, pp. 229–232. doi: https://doi.org/10.1109/iSES47678.2019.00058

[14] M. T. Haq, V. M. K. Ampadu, and K. Ksaibati, "An investigation of brake failure related crashes and injury severity on mountainous roadways in Wyoming," *Journal of Safety Research*, vol. 84, pp. 7–17, 2022, doi: https://doi.org/10.1016/j.jsr.2022.10.003.

[15] S. Grimaldi, "An innovative approach to maintenance for a bus fleet," Politecnico di Torino, 2022.

[16] Z. M. Jawi, F. Lamin, A. R. A. Manap, K. A. A. Kasim, F. Abas, and W. S. Voon, "Review of the national automotive policy on car maintenance issues: Malaysia's automotive ecosystem explained," *MIROS Review Report, Kuala Lumpur*, 2012.

[17] S. Subramonian, M. S. Amarnath, A. Rizal, and Kamely, "An Investigation Toward Development Of Economical Brake Lining Wear Alert System," *International Journal of Engineering & Technology*, vol. 9, no. 9, pp. 251–259, 2009.

[18] A. Hatam and A. Khalkhali, "Simulation and sensitivity analysis of wear on the automotive brake pad," *Simulation Modelling Practice and Theory*, vol. 84, pp. 106–123, May 2018, doi: https://doi.org/10.1016/j.simpat.2018.01.009.

[19] H. Pranesh, K. Suresh, S. S. Manian, R. Jegadeeshwaran, G. Sakthivel, and T. M. Alamelu Manghi, "Vibration-based brake health prediction using statistical features - A machine learning framework," in *Materials Today: Proceedings*, 2021, vol. 46, pp. 1167–1173. doi: https://doi.org/10.1016/j.matpr.2021.02.060.

[20] C. C. Harlapur, P. Kadiyala, and S. Ramakrishna, "Brake pad wear detection using machine learning," *International Journal of Advance Research, Ideas and Innovations in Technology*, vol. 5, pp. 498–501, 2019.

[21] B. R. Gumilar, U. Sumarwan, and B. Sartono, "Analysis of factors affecting car purchasing decision," *Inovasi*, vol. 16, no. 1, pp. 60–71, 2020, doi: https://doi.org/10.30872/jinv.v16i1.7289.

[22] P. D. Neis, N. F. Ferreira, and F. P. da Silva, "Comparison between methods for measuring wear in brake friction materials," *Wear*, vol. 319, no. 1–2, pp. 191–199, 2014, doi: https://doi.org/10.1016/j.wear.2014.08.004.

[23] A. Grkić, D. Mikluc, S. Muždeka, Ž. Arsenić, and Č. Duboka, "A model for the estimation of brake interface temperature," *Strojniski Vestnik/Journal of Mechanical Engineering*, vol. 61, no. 6, pp. 392–398, 2015, doi: https://doi.org/10.5545/sv-jme.2014.2364.

[24] D. Bryant and A. Day, *Thermal effects in friction brakes*, Second Edi. 2022. doi: https://doi.org/10.1016/b978-0-12-822005-4.00003-2.

[25] K. Anam, I. Prasetyo, H. P. Mahadika, and S. Suprapto, "Perbandingan Kinerja Rem ABS dan Rem Biasa Terhadap Jarak Pengereman dan Waktu pada Mobil Avanza," *Surya Teknika*, vol. 4, no. 2, pp. 32–38, 2020, doi: https://doi.org/10.48144/suryateknika.v4i2.1308.

[26] S. I. Haris, F. Ahmad, M. H. C. Hassan, and A. K. M. Yamin, "The Experimental Evaluation of Cone Wedge Shape based Electronic Wedge Brake Mechanism in Vehicle Braking System," *Automotive Experiences*, vol. 5, no. 3, pp. 433–451, 2022, doi: https://doi.org/10.31603/ae.7112.

[27] S. Yashwhanth, M. Mithun Mohan, R. Anandhan, and S. K. Selvaraj, "Present knowledge and perspective on the role of natural fibers in the brake pad material," *Materials Today: Proceedings*, vol. 46, pp. 7329–7337, 2021, doi: https://doi.org/10.1016/j.matpr.2020.12.995.

[28] G. Sathyamoorthy, R. Vijay, and D. L.

Singaravelu, "A comparative study on tribological characterisations of different abrasives based non-asbestos brake friction composites," *Materials Today: Proceedings*, vol. 56, pp. 661–668, 2022, doi: https://doi.org/10.1016/j.matpr.2022.01.065.

[29] X. Tang *et al.*, "Study on the mechanism of expanded graphite to improve the fading resistance of the non-asbestos organic composite braking materials," *Tribology International*, vol. 180, p. 108278, 2023, doi: https://doi.org/10.1016/j.triboint.2023.108278.

[30] S.-H. Woo, H. Jang, M. Y. Na, H. J. Chang, and S. Lee, "Characterization of brake particles emitted from non-asbestos organic and low-metallic brake pads under normal and harsh braking conditions," *Atmospheric Environment*, vol. 278, p. 119089, 2022, doi: https://doi.org/10.1016/j.atmosenv.2022.119089.

[31] A. B. D. Nandiyanto, D. N. Al Husaeni, R. Ragadhita, M. Fiandini, D. F. Al Husaeni, and M. Aziz, "Resin matrix composition on the performance of brake pads made from durian seeds: From computational bibliometric literature analysis to experiment," *Automotive Experiences*, vol. 5, no. 3, pp. 328–342, 2022, doi: https://doi.org/10.31603/ae.6852.

[32] A. B. D. Nandiyanto, D. F. Al Husaeni, R. Ragadhita, and T. Kurniawan, "Resin-based Brake Pad from Rice Husk Particles: From Literature Review of Brake Pad from Agricultural Waste to the Techno-Economic Analysis," *Automotive Experiences*, vol. 4, no. 3, pp. 131–149, 2021, doi: https://doi.org/10.31603/ae.5217.

[33] A. B. D. Nandiyanto *et al.*, "The effects of rice husk particles size as a reinforcement component on resin-based brake pad performance: From literature review on the use of agricultural waste as a reinforcement material, chemical polymerization reaction of epoxy resin, to experiments," *Automotive Experiences*, vol. 4, no. 2, pp. 68–82, 2021, doi: https://doi.org/10.31603/ae.5217.

[34] O. R. Adetunji, A. M. Adedayo, S. O. Ismailia, O. U. Dairo, I. K. Okediran, and O. M. Adesusi, "Effect of silica on the mechanical properties of palm kernel shell based automotive brake pad," *Mechanical Engineering for Society and Industry*, vol. 2, no. 1, pp. 7–16, 2022, doi: https://doi.org/10.31603/mesi.6178.