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Research Paper

Characteristics of Natural Fiber Composites Materials Reinforced with Aluminum and Copper Powder for The Performance of Automatic Motorcycle Clutch Pad

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Abstract

This article presents a comprehensive investigation into the characteristics of natural fiber composite (NFC) materials reinforced with aluminum and copper powder for performance automatic motorcycle clutch pads. With a focus on environmentally friendly and high-performance materials, this study explores the effects of incorporating aluminum and copper powders into natural fiber composites on key properties such as friction, wear resistance, hardness, oil absorption, and microstructural features for performance clutch pads. The friction characteristic of the composites was evaluated using a pin-on-disc tribometer, while wear resistance was assessed through pin-on-disc wear tests. Hardness properties were determined using standardized methods, and oil absorption behavior was examined by immersing the composites in lubricating oil. Additionally, scanning electron microscopy (SEM) was utilized to study the microstructure of the composites. The performance of the clutch pad sample was tested with an automatic motorcycle by a chassis dyno test. The results revealed that the inclusion of aluminum and copper powders significantly improved frictional characteristics, wear resistance, hardness, and oil absorption capacity of the composites. SEM images displayed effective bonding between the reinforcement particles and the composite matrix. Samples 3-5 have a performance increase of 4.8% at lower rpm than a genuine clutch. The advantages of both low and high speed remain smooth in transmitting power to the wheel. These findings suggest that the developed natural fiber composites show promising potential for enhancing the performance and durability of automatic motorcycle clutch pads, making them attractive alternatives to conventional materials in automotive applications.

Keywords: Natural fiber composites; Friction coefficient; Wear; Hardness; Oil absorption; Clutch pad

1. Introduction

The clutch system is an important component of a motorcycle, which is responsible for transmitting power from the engine to the transmission. Motorcycle clutch pads experience significant wear and tear during operation, requiring frequent maintenance and replacement. Clutch pad performance is affected by factors such as the coefficient of friction, wear rate, and hardness, which are affected by the materials used in their construction. The power transfer transmission on an automatic motorcycle is a function of a centrifugal clutch [1]. Centrifugal force is used to connect several clutch shoes with the outer casing of the drum which serves to deliver kinetic energy from the engine to the transmission [2], [3]. The process of transferring power in the clutch uses frictional force on the surface of the clutch lining material, the friction coefficient is needed to obtain the frictional force [1], [4], The frictional force rotates the shaft from rest, gradually moving without excessive slippage on the lining surface [5]. The clutch gently and quickly engages and disengages engine torque to transmission without bumping. Hence, the clutch lining material must be resistant to friction, have a good friction coefficient, and have a hard surface so that doesn't pad breakage when delivering power from the engine to the transmission [2].

In recent years, natural fiber composites (NFC) have raised public awareness for potential replacements for conventional friction pad materials because of their superior mechanical properties. NFC materials are renewable, sustainable, and biodegradable, making them an eco-friendly alternative to traditional clutch pad materials. Natural fibers are known to have great potential to be produced on a large scale, as a substitute for synthetic composite materials [6]–[8]. This material is biodegradable and environmentally friendly [9]–[11]. Natural fibers from plants naturally multiply and are cheaper than synthetics [7], while they don't have consistent quality as weaknesses. Moreover, this material was found to be heat resistant [9]. Several studies state that natural fibers have the potential to be developed into composites, namely coconut fiber material which has good characteristics for composite applications, such as friction materials for brake pads and clutch pads [12], [13]. In previous studies, natural fiber materials from coconut fiber, wood powder, and clamshell have been developed as natural fiber composites for clutch pads, where the performance results show results that are close to the characteristics of genuine parts, it's just that the mixture of clamshell materials is still not optimal for the quality of the lining for quite a long time [13], [14]. The addition of aluminum and copper powder as reinforcement in coconut fiber and wood powder composites can improve mechanical properties and reduce wear [15]. This composite material is easy to obtain because it comes from waste. Recycling waste into alternative materials in composite production can increase the value of the benefits of materials [16], [17].

The friction material from natural fiber composite reinforced with aluminum and copper powder is an innovative natural material. This material consists of several materials mixed together to achieve maximum performance properties of machine elements such as brakes or clutches [18]. The friction material on the clutch pads has the same characteristics as the brake pads, consisting of binders, reinforcement, fillers, and abrasives. All mixture materials of the pad are held together by binders. To improve the mechanical quality, fibrous material is added as a reinforcement material. This material must be lightweight, resistant to high temperatures, have a high and stable coefficient of friction, and withstand rapid changes in temperature. The type of reinforcement material used will affect the durability of the friction material. Initially, asbestos material was widely used as a reinforcement fiber. After that, the use of asbestos materials was prohibited, because they contain hazardous substances. The gaps between the friction material components are filled with fillers, while abrasive materials are used to change the friction coefficient. The harsh nature of additives is used to increase the friction coefficient of friction pads, such as steel, cast iron, refractory oxides, silicates, or quartz. Increasing the friction coefficient is expected to increase the service life of the friction pads [13], [19]–[22]. Aluminum oxide and magnesium oxide have been used for the prototype of bamboo fibers composites brake pads and coconut fibers composites brake pads, the composite materials made have relatively the same coefficient of friction and wear as commercial brake pads [12]. Meanwhile, aluminum and copper powder-reinforced composites were tested for various mechanical properties and thermal properties [23], [24]. The ability of composites reinforced with polyester resins to absorb water through absorption tests has been investigated [25]. In addition, the ability of fruit fiber composites to absorb water and oil has been evaluated for biomedical applications [26]. The ability of reinforced natural materials to absorb oil also needs attention, especially for brake and clutch pad materials.

Therefore, this study investigates the characteristics of NFC materials reinforced with powder aluminum and copper for the performance of motorcycle clutch pads. The main objective was to determine the impact of NFC materials on the coefficient of friction, wear rate, hardness, and oil absorption of clutch pads and how these properties affect overall motorcycle performance. Microstructural features examined to the composites using scanning electron microscopy (SEM) to understand distribution and feature between the reinforcement particles and the composite matrix. The results of this study can be used to optimize the design of the clutch system and improve overall motorcycle performance and durability.

2. Material and Methods

In this experimental study, we used various NFC material formulations reinforced with aluminum and copper powders for automatic motorcycle clutch pads. NFC materials are selected based on their high coefficient of friction, wear resistance, and hardness properties. Materials are obtained from waste to obtain other beneficial values. To investigate the characteristics of the wear, friction coefficient, and hardness of the clutch pads of NFC materials reinforced with aluminum and copper powder, and their effect for the performance of automatic motorcycles, we conducted a series of tests using a motorcycle dynamometer [1]. Tests are carried out at different loads and speeds to simulate real-world driving conditions. As in previous studies [13], in this work, the materials used were coconut fiber, wood powder, copper powder, aluminum powder, epoxy resin, and hardener. This material is shown in **Figure 1a-Figure 1b**. These materials are obtained from the production of recycled waste, which is used as a source of eco-friendly automotive parts [4], [11]. As in previous research, the material from Sengon wood powder (Albizia Chinensis) obtained from furniture manufacturers is naturally dried. Then it is crushed and sorted from the rough waste through filtering to get fine wood powder. Whereas coconut coir waste obtained from coconut water drink sellers is naturally dried under the hot sun to dry, then grated and mashed into fine fibers [5], [13], [27], [28]. Copper powder and aluminum powder are obtained from crushed metal flakes as a result of cutting and turning. To obtain fine materials, these materials were screening process with a sieve mesh size of 40 (400 microns).

In order to manufacture composites that have strong intermolecular attractions, epoxy resins are used as the composite matrix [29], [30]. Good mechanical properties of this material, such as compressive strength, high hardness, thermal resistance, moderate elongation, and excellent wettability. In addition to its low cost, epoxy resin materials are used as binders in friction material composites [31]. In this study, the proportion of hardener and epoxy resin was 1:1 as in previous studies [13].

The composition of each ingredient is formulated based on weight percentage. Sample 1 contains a mixture of 20% coconut fiber, 20% wood powder, 20% aluminum powder, 0% copper powder, and 40% polyester resin. Sample preparation begins with mixing all the powders in a case, and then stirring until evenly distributed. The material is poured into a mold that has a volume of 161.5 cm^3 as in previous studies [12]. The hydraulic jack pressed the mold at 2-tonne pressure and ambient temperature for 30 minutes, then it is warmed up in an oven for 60 minutes at 130°C. After that, the sample is released from the mold after it has cooled naturally. A similar procedure was carried out for the formulation of the composition of Sample 2-5. The composition formulation for samples 1-5 can be seen in **Table 1**.

2.1. *Wear and Friction Analysis*

Analysis of wear and friction coefficient of this NFC material was evaluated using a pin-on-disc tribometer from Ducom Instruments. Tests for the wear and coefficient of friction were carried out

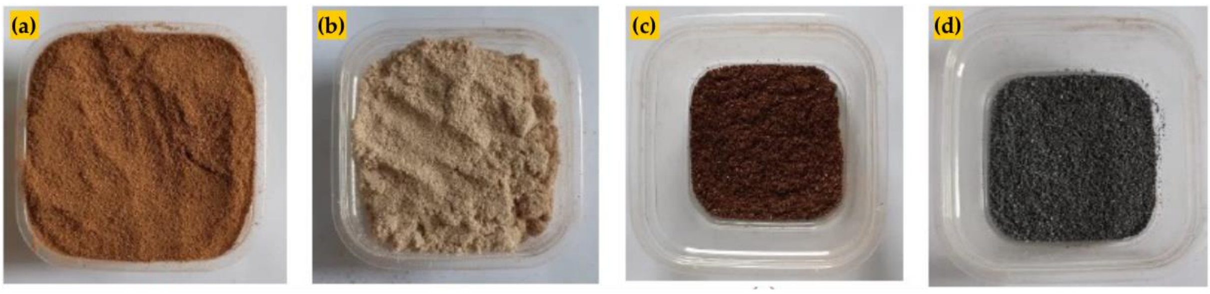

Figure 1. Powder of composites materials: (a) coconut fibre, (b) wood, (c) copper, and (d) aluminum

Table 1. Formulation of the composition of the NFC material samples reinforced with aluminum and copper powder

Samples	Compositions (%)				
	Coconut fiber	Wood powder	Aluminum powder	Copper powder	Polyester resin
Sample 1	20	20	20	0	40
Sample 2	20	20	15	5	40
Sample 3	20	20	10	10	40
Sample 4	20	20	5	15	40
Sample 5	20	20	0	20	40

with a loading of 30 N with a track length of 436 m at 200 rpm rotation which was carried out in dry conditions at room temperature. The samples used were 60 mm in diameter and 8 mm thick as shown in **Figure 2**. Three samples were made for each variation for testing in the pin-on-disc tribometer. Data processing is done statistically by taking the average data and standard deviation.

2.2. *Hardness Testing*

Hardness testing uses the Vickers Hardness (HV) method according to ISO 6507 [32], [33]. Using the same sample preparation method [13], testing with the FV 300e microhardness Vickers tester with a load of 3 kg within 10 seconds [5]. The data taken is the average data from 5 test points with a distance between points of about 3-5 mm.

2.3. *Oil Absorption Analysis*

Absorption test [25] using immersion method in lubricating oil which has specification 10W-30 for 48 hours. The steps taken in the testing process were to prepare a sample measuring 6 cm long, 2.5 cm wide and 3 mm thick. Samples were weighed before and after immersion with digital scales. Measurement of the thickness, length and width of the test specimen before and after immersion with a vernier caliper. The immersion process was carried out for 48 hours. The process of immersing the sample in oil can be seen in **Figure 3**.

Oil absorption of composites is determined by Eq. (1).

$$Oil\ Absorption\ (\%) = \frac{w_1 - w_0}{w_0}\ x\ 100 \quad (1)$$

where w_0 and w_1 are mass before and after immersion (gram).

Change of volume of composites is determined by Eq.(2).

$$\Delta V\ (\%) = \frac{V_1 - V_0}{V_0}\ x\ 100 \quad (2)$$

where V_0 and V_1 are volume before and after immersion (mm³).

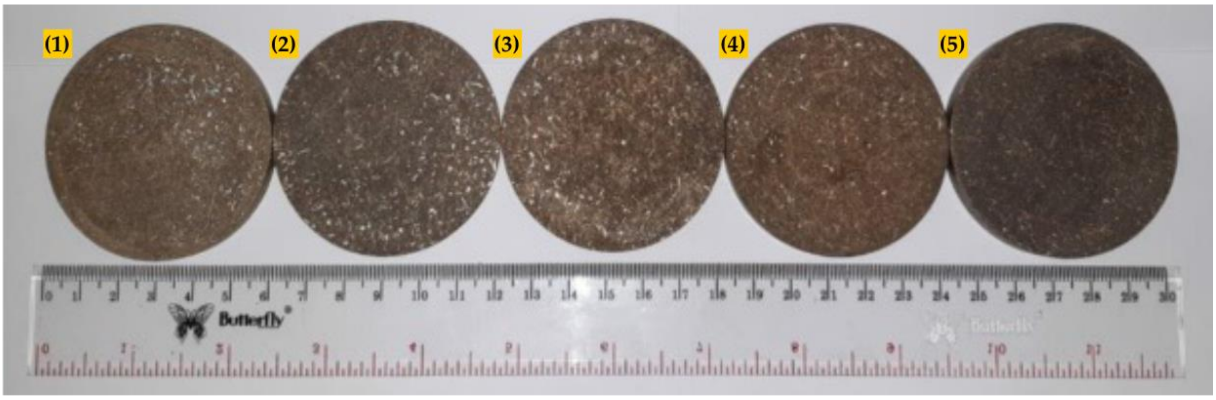

Figure 2. Samples for wear and friction testing of NFC materials reinforced with aluminum and copper powder

Figure 3. The process of immersing the samples in lubricating oil

Density of composite is determined by Eq. (3).

$$Density\left(\frac{g}{cm^3}\right) = \frac{mass}{volume} \tag{3}$$

2.4. Scanning Electron Microscopy (SEM)

The microstructure of the natural fiber composites, including the distribution of reinforcement particles, is examined using SEM. The micrographs provide insights into the bonding characteristics and dispersion of aluminum and copper powders within the composite matrix. SEM image was performed on the sample surface with Quanta 650 at high voltage of 10 kV.

2.5. Clutch Pad Performance Testing

NFC material reinforced with aluminum powder and copper powder was prepared [13] to become a centrifugal clutch shoe from a 150-cc automatic motorcycle. Performance test carried out via a motorcycle chassis dynotest. Clutch shoe samples for performance testing can be seen in **Figure 4 a-e**. The genuine part of the clutch (**Figure 4f**) is used as a comparison in this study.

3. Results and Discussion

3.1. Wear and Coefficient of Friction

The results of testing the coefficient of friction and wear on the NFC material reinforced with aluminum powder and copper powder show that the values of the wear and coefficient of friction for each test object are different. **Figure 5** shows the variation of friction coefficient with sliding distance for different composite formulations. It was observed that the incorporation of aluminum and copper powders led to improved frictional properties compared to composites reinforced with only copper powders. The results indicated that the addition of aluminum and copper powders significantly reduced the wear rate. Wear resistance showcasing their suitability for prolonged clutch pad lifespan in harsh operating conditions and friction coefficient indicating its potential for effective engagement in the automatic motorcycle clutch system.

3.2. Hardness Vickers

Figure 6 displays the hardness values of the natural fiber composites with different reinforcement concentrations. Vickers hardness value of NFC material reinforced with aluminum powder and copper powder varies between 19.16 HV to 22.94 HV. This variation is not much different from the hardness value for genuine parts, which is 22.74 HV.

3.3. Oil Absorption

The oil absorption behavior of the composites was investigated by immersing them in lubricating oil for a specific duration. **Figure 7** shows the investigations results of oil absorption

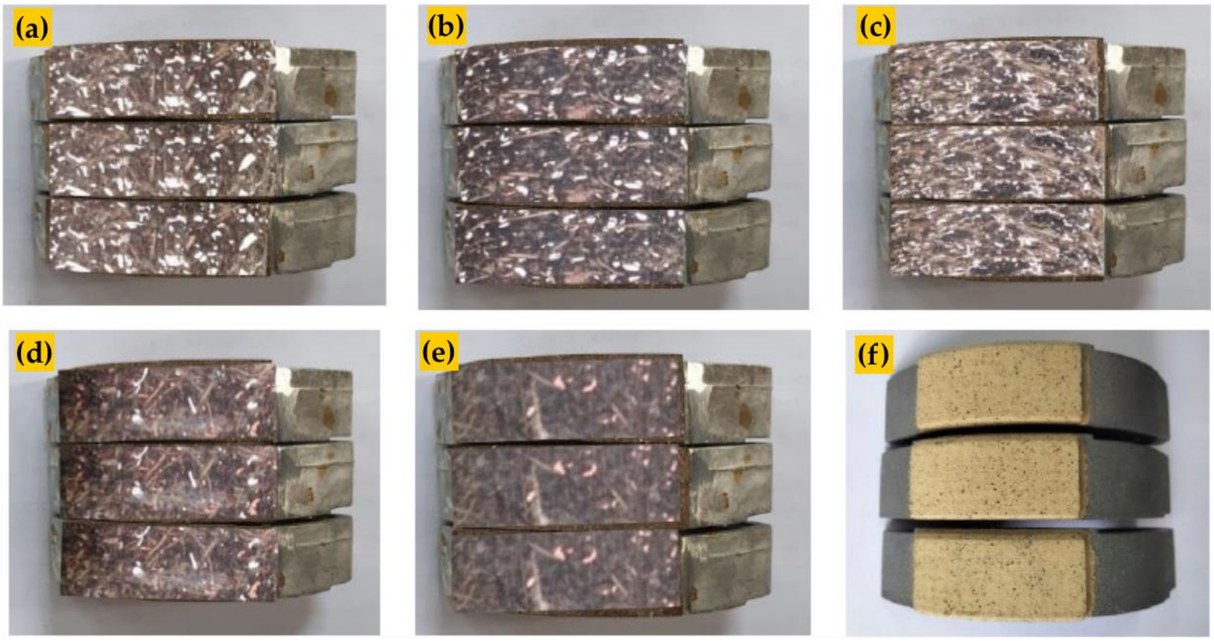

Figure 4. Samples for clutch pad performance test: (a-e) NFC samples of 1-5, (f) genuine part

capacity of the composites. Mass of samples 1-5 of composite before and after immersion (**Figure 7a**), Change of volume of samples 1-5 of composite before and after immersion (**Figure 7b**), Density of samples 1-5 of composite before and after immersion (**Figure 7c**), and Oil absorption of samples 1-5 of composite before and after immersion (**Figure 7d**).

3.4. SEM Image

SEM images (**Figure 8a-Figure 8e**) reveal the microstructure of samples 1-5 of natural fiber composites reinforced with aluminum and copper powders. The micrographs at magnification of 50x and BSE images shows distribution and bonding between the reinforcement aluminum and copper

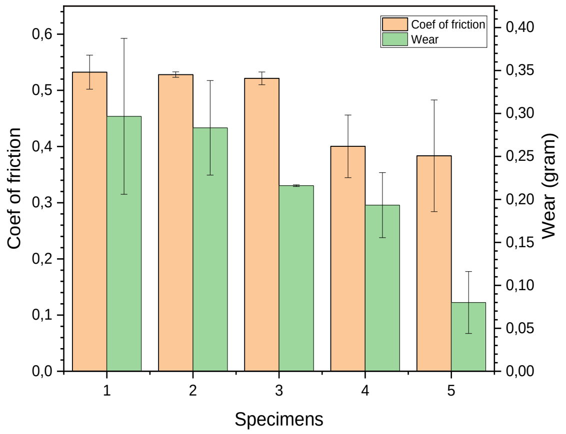

Figure 5. Friction coefficient and wear of NFC materials reinforced with aluminum and copper powders

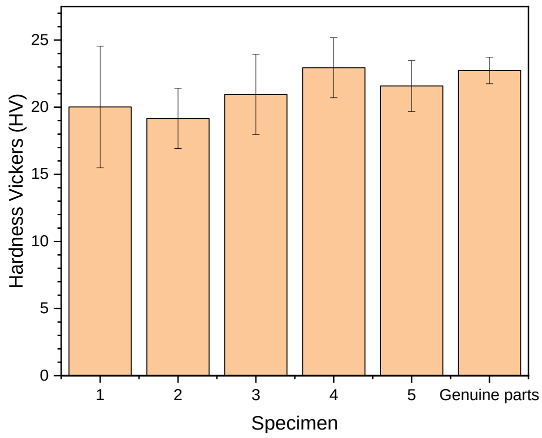

Figure 6. Hardness Vickers of NFC materials reinforced with aluminum and copper powders

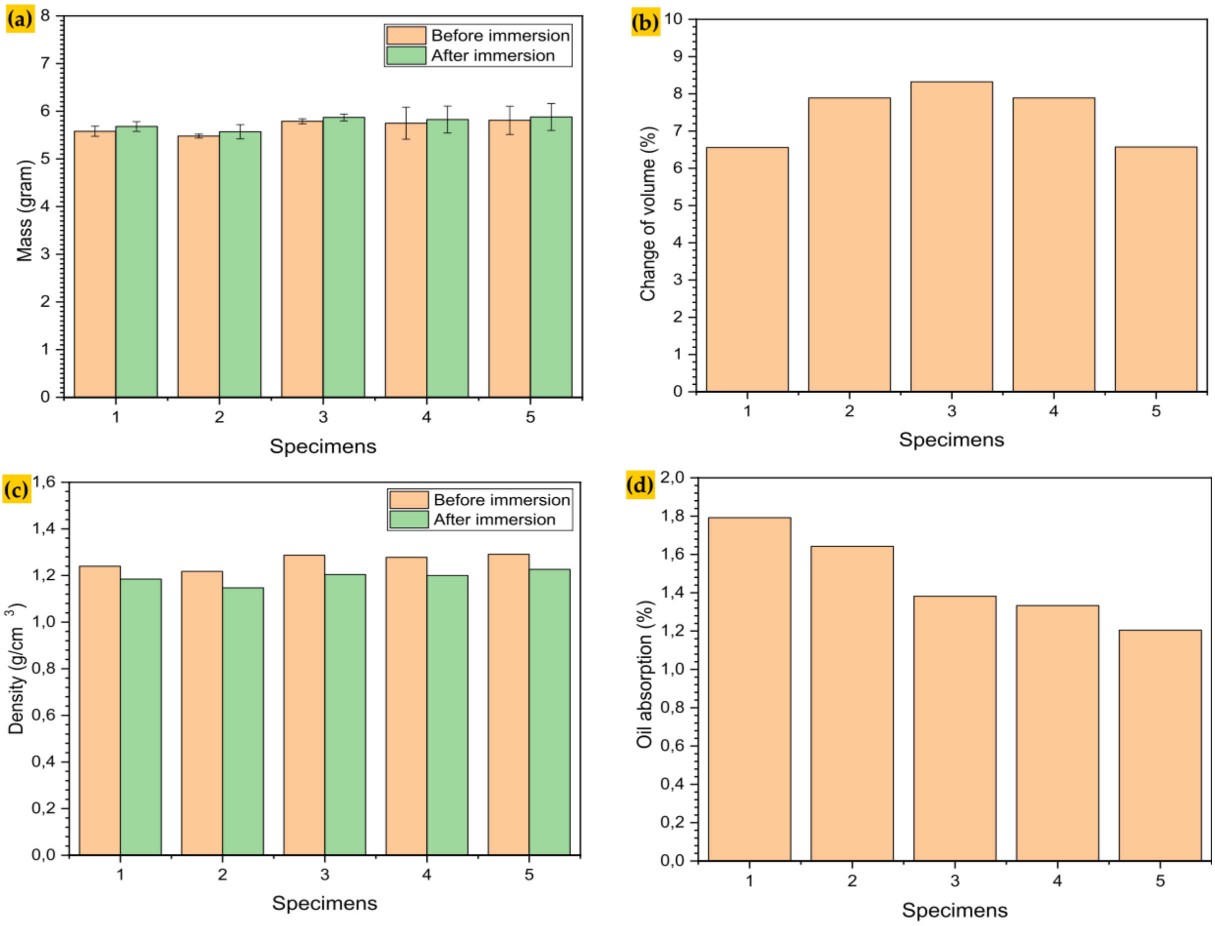

Figure 7. (a) mass, (b) change of volume, (c) density, and (d) oil absorption of NFC before and after immersion

powders with the composite matrix. The improved interfacial adhesion between the components contributes to the enhanced mechanical properties observed in the composites.

Figure 9a-Figure 9e shows the SEM image of samples 1-5 of natural fiber composites reinforced with aluminum and copper powders at magnification of 1000x and BSE images shows bonding between the reinforcement aluminum and copper powders with the composite matrix more clearly. Irregular forms of aluminum and copper powder are seen on the composite.

3.5. Clutch Pad Performance

The results of the performance testing of motorcycles using the chassis dynotest on each sample show that the power and torque values are different for each change in rotation. **Figure 10** shows the results of motorcycle performance as seen from the power and torque values between the genuine clutch pad and the sample clutch pads made of NFC material reinforced with aluminum powder and copper powder. The figure seen the trendline of the torque and power that is transmitted to the motorcycle wheels, where the x-axis is a function of engine speed (rpm) and the

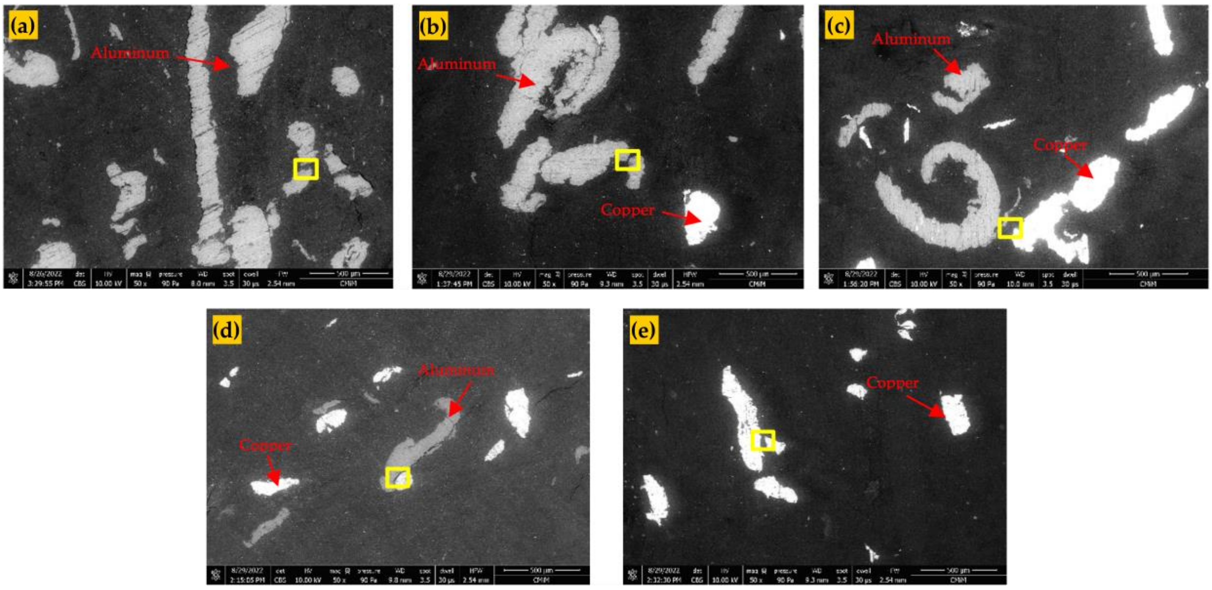

Figure 8. SEM image of sample 1-5 (a-e) at magnification of 50x and BSE images

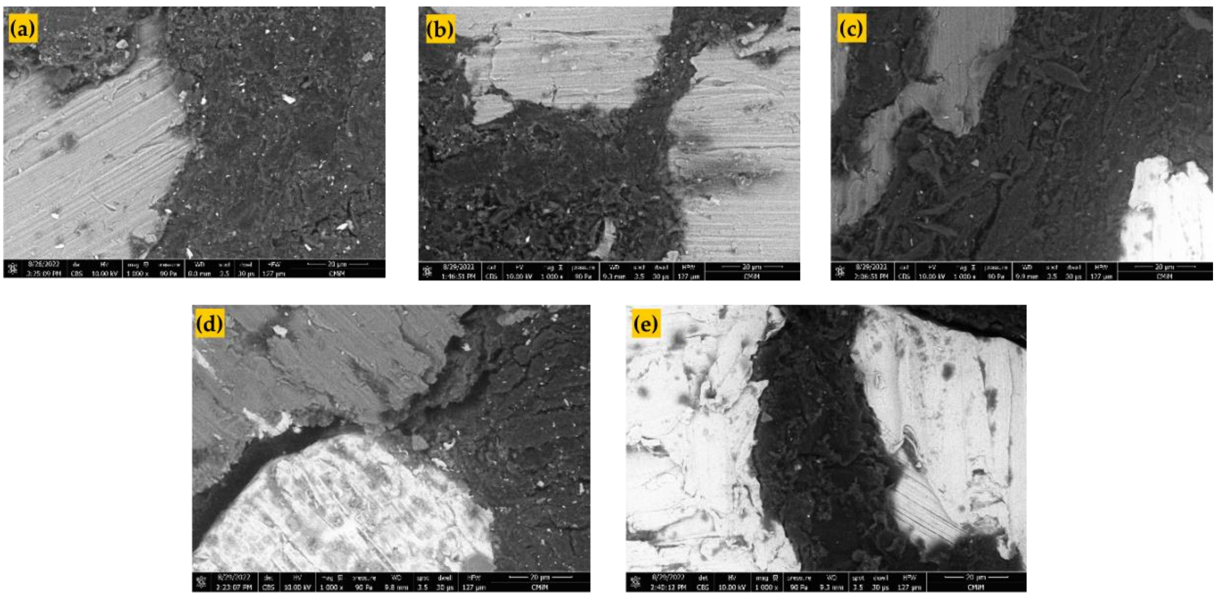

Figure 9. SEM image of sample 1-5 (a-e) at magnification of 1000x and BSE images.

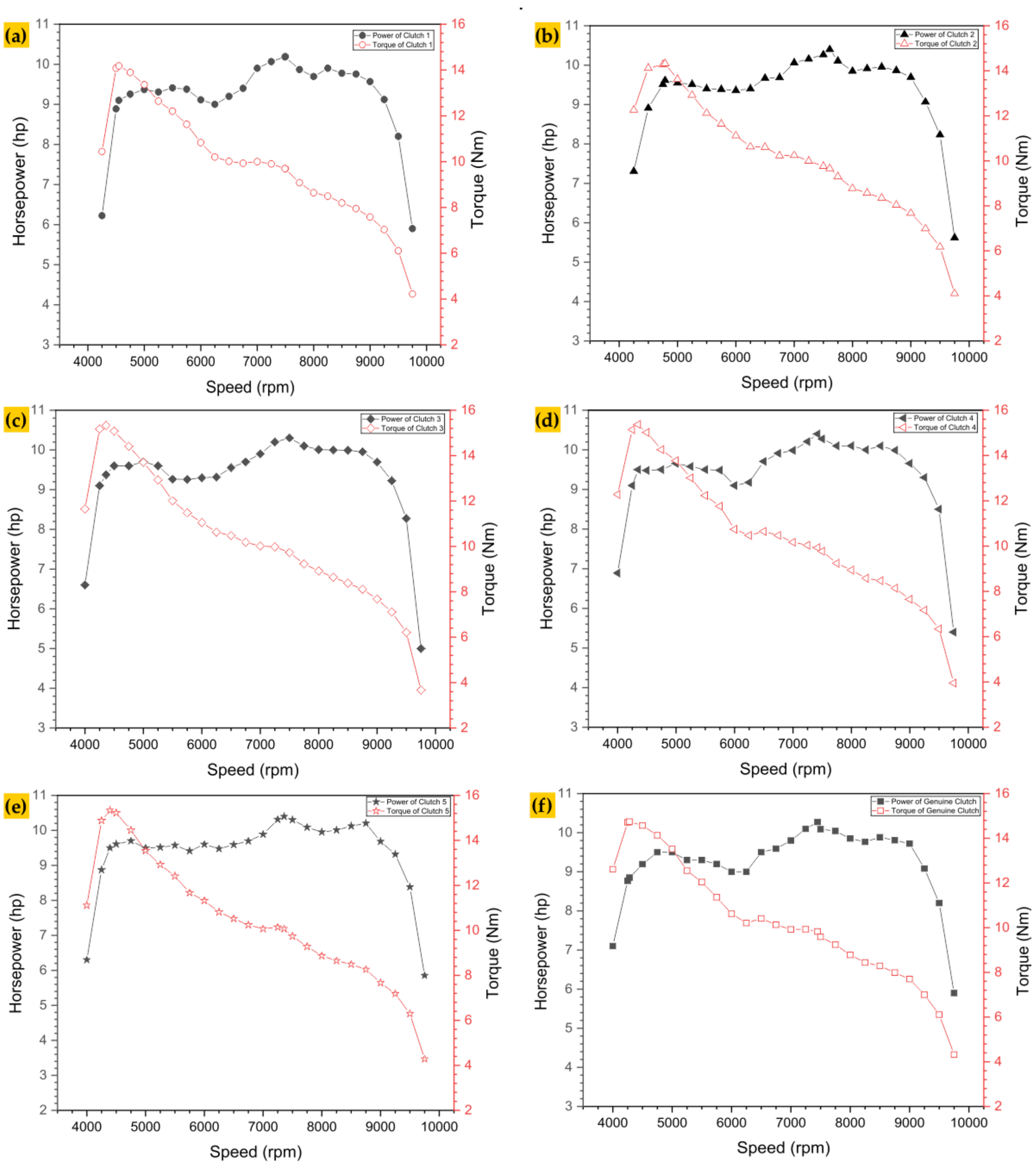

Figure 10. Power and torque of the clutch pad samples of NFC material reinforced with aluminum powder and copper powder: (a) Cluth 1; (b) Cluth 2; (c) Cluth 3; (d) Cluth 4; (e) Cluth 5; (f) Genuine clutch

y-axis is a function of torque (Nm) and power (hp). The sample of clutch 1 (**Figure 10a**), the highest torque of 14.2 Nm is generated at 4550 rpm and the highest power of 10.2 hp is generated at 7500 rpm. The sample of clutch 2 (**Figure 10b**), the highest torque of 14.3 Nm is generated at 4780 rpm and the highest power of 10.4 hp is generated at 7600 rpm. The sample of clutch 3 (**Figure 10c**), the highest torque of 15.3 Nm is generated at 4360 rpm and the highest power of 10.3 hp is generated at 7500 rpm. The sample of clutch 4 (**Figure 10d**), the highest torque of 15.4 Nm is generated at 4350 rpm and the highest power of 10.4 hp is generated at 7420 rpm. The sample of clutch 5 (**Figure 10e**), the highest torque of 15.3 Nm is generated at 4390 rpm and the highest power of 10.4 hp is generated at 7360 rpm. The genuine clutch (**Figure 10f**), the highest torque of 14.6 Nm is generated at 4500 rpm and the highest power of 10.3 hp is generated at 7450 rpm. The maximum torque and power that is transmitted to the wheels from the clutch pad in each sample varies with engine speed. This is influenced by the friction between the clutch pad material and the drum. The coefficient of friction and hardness affects the performance results of the clutch pads.

3.6. Discussions

The comprehensive analysis of the characteristics of natural fiber composites materials reinforced with aluminum and copper powder for automatic motorcycle clutch pad applications has provided valuable insights into their potential as eco-friendly alternatives. The incorporation of aluminum and copper powders in the composites led to notable improvements in various performance attributes.

The value of the friction coefficient of the NFC material varies from each sample. The coefficient of friction values ranges from 0.38 to 0.53 with a test loading of 30 N. The highest friction coefficient comes from sample 1 which contains 20% wood powder, 20% coconut fiber, and 20% aluminum powder. Sample 5 has the lowest coefficient compared to the others because the composition of this composite contains 20% wood powder, 20% coconut fiber, and 20% copper powder. Reduction of the aluminum composition of samples 1-5 causes a decrease in the coefficient of friction. Meanwhile, the standard friction coefficient for clutch and brake friction materials ranges from 0.3-0.5 [5], [18]. This shows that samples 1-5 have values that fall within the standard friction coefficient range.

Wear values ranging from 0.080-gram to 0.297-gram along the track 436 m. This value means that the average wear is around 1.83 x 10^{-4} grams/m to 6.82 x 10^{-4} grams/m. The effect of formulation of the aluminum and copper powder composition of the NFC material on the wear value can be seen in **Figure 5**. Of course, these results need to be compared with genuine clutch. These results indicate that the clutch with the NFC material reinforced with aluminum powder and copper powder has very small average wear. The average clutch wear interval is around 15,000-20,000 km, or about 2 years in normal use according to the motorcycle product manual. For future research, it is necessary to carry out actual testing to see wear and tear until maximum use. Previous studies have shown that the wear and tear of natural composite materials is still higher than that of genuine clutch pad [4].

The varying hardness (**Figure 6**) can also be caused by natural composite materials, namely wood powder and coconut fiber, whose characteristics can change. The addition of aluminum and copper powders led to a remarkable enhancement in the hardness of the composites. Compared to natural fiber composite reinforced with shellfish shells, the hardness of natural fiber composite reinforced with aluminum and copper increased significantly. Notably, the composite with the highest reinforcement content exhibited the highest hardness value, making it a desirable option for withstanding high contact pressures during clutch engagement.

The enhanced frictional properties of the composites enable efficient torque transmission during clutch engagement, which is vital for smooth gear shifting and improved vehicle control. The superior wear resistance exhibited by the composites ensures reduced material loss and increased durability, making them suitable candidates for demanding clutch applications. The significant increase in hardness values demonstrates the ability of the composites to withstand high contact pressures without undergoing plastic deformation, highlighting their structural stability under severe operating conditions. Moreover, the consistent oil absorption behavior of the composites ensures effective lubrication between the clutch surfaces, mitigating wear and noise during operation.

Figure 7 demonstrates the oil absorption behavior of the composites shows a decreasing trend. The oil absorption capacity of the composite with copper powder reinforcement has the lowest absorption, this shows the ability of this composite to retain oil lubrication. Meanwhile, the larger volume change is seen in the composite with aluminum and copper powder reinforcement. This characteristic ensures continuous lubrication between the clutch surfaces, reducing wear and enhancing the overall performance and efficiency of the automatic motorcycle clutch system. It would be more interesting if the coefficient of friction and wear was tested with lubricating oil on this NFC sample. Further research may be carried out to obtain more comprehensive data.

The SEM images (**Figure 8** and **Figure 9**) confirm the uniform distribution and effective bonding of aluminum and copper powders within the composite matrix, which contributes to the overall improvement in mechanical properties. The reinforcement particles act as strengthening agents, reinforcing the natural fibers and enhancing the composite's structural integrity.

The maximum torque (**Figure 10**) generated by the original clutch at 4282 rpm is 14.74 N.m lower than the 3-5 samples in a row at 15.33 N.m at 4361 rpm, 15.37 N.m at 4352 rpm, and 15.33 N.m at 4394 rpm. This happens because the reinforcement of aluminum and copper in the composite which is more dominant causes hardness on the surface and provides a greater grip on the drum [32]. The trend of increasing torque starts from low speed up to 4300 rpm engine speed which then decreases with increasing rotation, this applies to all samples including original parts [34]. When compared with previous studies with amplifiers from clam shells, it shows higher values but at a lower rpm of around 4000 rpm. This is quite difficult to control the speed of the motorcycle at low rpm because it can cause the engine to stop suddenly.

The performance characteristics of all clutch pad samples are presented in one figure. **Figure 11** shows the torque and power characteristics at each rpm for all clutch samples of NFC reinforced with aluminum and copper powder. **Figure 11** shows that this composite material has higher power and torque values compared to genuine parts. **Table 2** shows maximum power and torque of samples 1-5 compared with genuine clutch. Sample 3-5 has high torque and power compared to sample 1-2 as well as a genuine clutch. The advantages of both low and high speed remain smooth in transmitting power. In terms of wear, samples 3-5 have a lower wear rate when compared to other samples, this is indicated by a higher performance relationship than samples 1-2. Likewise, the hardness of sample 3-5 has a value that is close to that of a genuine clutch. Based on the data, samples 3-5 have a performance increase of 4.8% at lower rpm than genuine clutch. This prove that the composite sample can be applied to the clutch pad material.

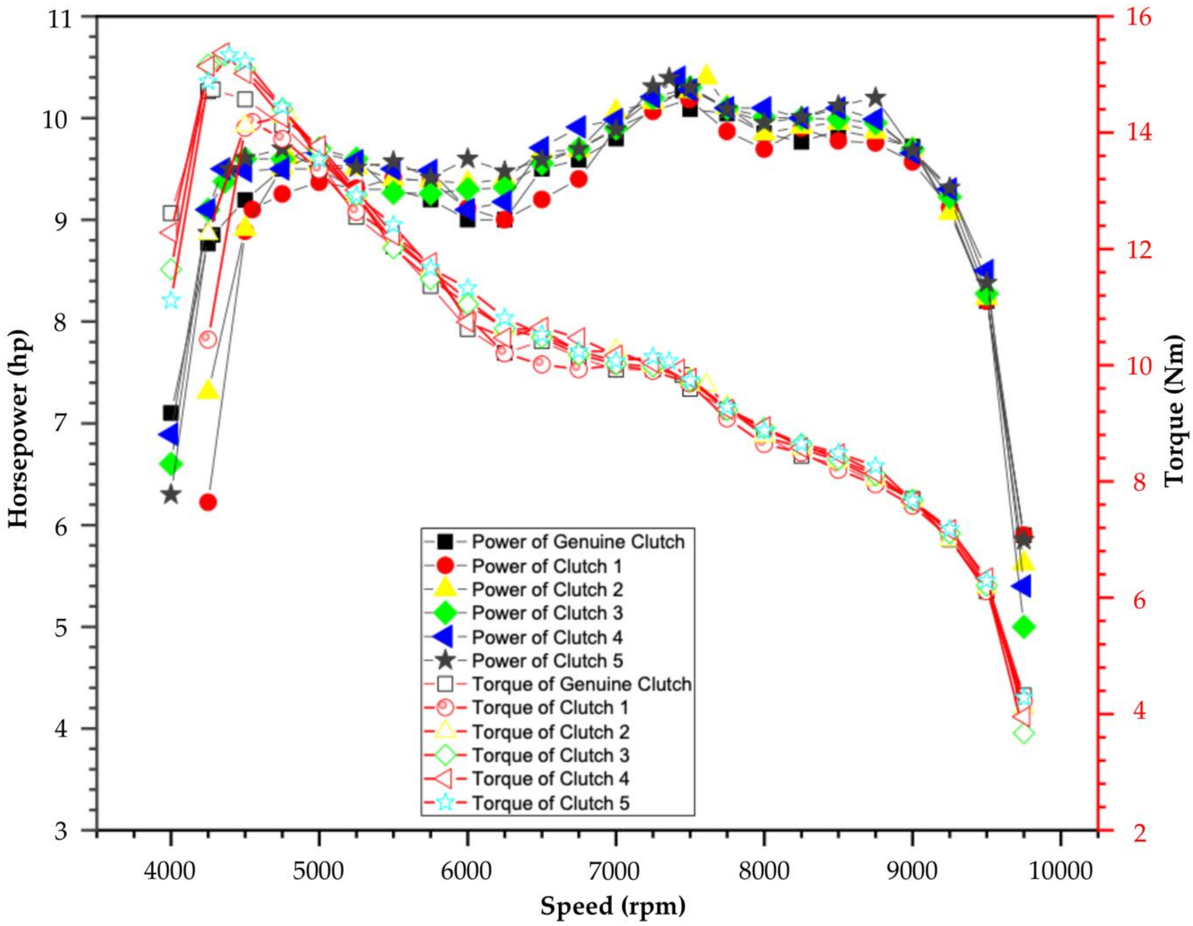

Figure 11. Characteristics of power and torque for each rpm from clutch samples and genuine part

Table 2. Maximum power and torque of samples and genuine clutch

Samples	Max Torque	Max Power
Clutch 1	14.2 Nm at 4550 rpm	10.2 hp at 7500 rpm
Clutch 2	14.3 Nm at 4780 rpm	10.4 hp at 7600 rpm
Clutch 3	15.3 Nm at 4360 rpm	10.3 hp at 7500 rpm
Clutch 4	15.4 Nm at 4350 rpm	10.4 hp at 7420 rpm
Clutch 5	15.3 Nm at 4390 rpm	10.4 hp at 7360 rpm
Genuine clutch	14.6 Nm at 4500 rpm	10.3 hp at 7450 rpm

The results of this study indicate that the addition of aluminum and copper powder materials to NFC significantly increases the hardness, wear resistance, and friction coefficient of the resulting composite material. NFC clutch pads reinforced with aluminum and copper powder show significantly better performance compared to genuine clutch pad materials in terms of performance. This study provides valuable insights into the mechanical properties of NFC materials reinforced with aluminum and copper powder and their impact for the performance of motorcycle clutch pads. This insight can be used to optimize clutch system design and improve overall motorcycle performance and durability. Future research may focus on further optimizing the material properties of NFC materials reinforced with aluminum and copper powder to improve wear resistance while maintaining a high coefficient of friction. In addition, the impact of these materials on the overall durability and reliability of the motorcycle clutch system can be further investigated. Optimization of the composite formulation can lead to even more favorable results and broader applications in the automotive industry.

4. Conclusion

This study investigated the characteristics of natural fiber composites materials reinforced with aluminum and copper powder for the performance of motorcycle clutch pads. The evaluation focused on friction, wear resistance, hardness, oil absorption, microstructural features, and performance of clutch pads of the developed composites.

a. The results demonstrated that the incorporation of aluminum and copper powders significantly enhanced the performance of the natural fiber composites. The composites exhibited improved frictional properties, ensuring efficient torque and power transmission and smooth engagement during clutch operation from lower to high rpm. The incorporation of reinforcement materials led to remarkable improvements in wear. Samples 3-5 have a performance increase of 4.8% at lower rpm than genuine clutch. The advantages of both low and high speed remain smooth in transmitting power to wheel.
b. The hardness values of the composites were notably increased by the presence of aluminum and copper powders. Samples 3-4 have a hardness value close to genuine part, indicating their ability to withstand high contact pressures and resist plastic deformation during clutch engagement. This characteristic is crucial for maintaining the structural integrity of the clutch pads under heavy loads.
c. The oil absorption behavior of the composites shows a decreasing trend. The oil absorption capacity of the composite with copper powder reinforcement has the lowest absorption, this shows the ability of this composite to retain oil lubrication. Meanwhile, the larger volume change is seen in the composite with aluminum and copper powder reinforcement. This characteristic ensures continuous lubrication between the clutch surfaces, reducing wear and enhancing the overall performance and efficiency of the automatic motorcycle clutch system.
d. The SEM images further supported the superior performance of the composites, revealing distribution and feature between the reinforcement particles and the composite matrix. The effective interfacial adhesion contributed to the enhanced mechanical properties, validating the potential of these materials for demanding automotive applications.

In conclusion, the natural fiber composites reinforced with aluminum and copper powders showcased desirable characteristics for automatic motorcycle clutch pad applications. The improved frictional behavior, wear resistance, hardness, oil absorption capacity, and microstructural integrity make these composites promising eco-friendly alternatives to conventional materials. The findings from this study open new avenues for future research and optimization of the composite formulation to further enhance their properties and expand their applications in various automotive components. The development and adoption of these advanced materials hold the promise of not only improving the performance of automatic motorcycle clutch systems but also contributing to sustainable and environmentally conscious engineering practices in the automotive industry.

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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

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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.

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