

The Effect Straw Fiber, Coconut Shell Powder, and Epoxy Composition on Organic Brake Pads

Mutrofin Rozaq¹

Yuniarto Agus Winoko²

Akbar Anugrah Ikhsani³

Muhammad Sahrul Hamid⁴

^{1,2,3,4}Program Studi Teknologi Rekayasa Otomotif, Jurusan Teknik Mesin, Politeknik Negeri Malang

E-mail : mutrofinrozaq@polinema.ac.id, yuniarto@polinema.ac.id, akbaranugrah@polinema.ac.id, sahrul_hamid@polinema.ac.id

Author Correspondence : mutrofinrozaq@polinema.ac.id

ABSTRAK

Penelitian ini bertujuan untuk menganalisis pengaruh variasi komposisi dan ukuran partikel terhadap kekerasan dan laju keausan kampas rem organik berbahan serat jerami, serbuk batok kelapa, dan resin epoxy. Celah penelitian terletak pada masih terbatasnya kajian yang mengombinasikan ketiga bahan tersebut dengan variasi komposisi dan ukuran partikel secara bersamaan. Penelitian ini menggunakan metode eksperimen dengan dua variasi komposisi, yaitu komposisi A terdiri atas 20% serat jerami, 30% serbuk batok kelapa, dan 50% resin epoxy, sedangkan komposisi B terdiri atas 15% serat jerami, 20% serbuk batok kelapa, dan 65% resin epoxy. Setiap komposisi menggunakan ukuran partikel 50, 100, dan 200 mesh. Kekerasan diuji menggunakan Shore D durometer, sedangkan keausan diuji menggunakan disc brake simulator. Hasil menunjukkan bahwa kekerasan komposisi A sebesar 45,9; 51,9; dan 40,3 Shore D, sedangkan komposisi B sebesar 30,4; 75,9; dan 83,7 Shore D. Laju keausan komposisi A meningkat dari $0,28 \times 10^{-6}$ menjadi $7,72 \times 10^{-6}$ g/s mm², sedangkan komposisi B sebesar $1,44 \times 10^{-6}$; $2,56 \times 10^{-6}$; dan $2,26 \times 10^{-6}$ g/s mm². Hasil menunjukkan bahwa respons kekerasan dan keausan berbeda menurut kombinasi komposisi dan ukuran partikel.

Kata kunci: kampas rem organik; serat jerami; serbuk batok kelapa; kekerasan; keausan

ABSTRACT

This study aims to analyze the effect of composition and particle size variations on the hardness and wear rate of organic brake pads made from rice straw fiber, coconut shell powder, and epoxy resin. The research gap lies in the limited studies combining these three materials with simultaneous variations in composition and particle size. An experimental method was employed using two material compositions. Composition A consisted of 20% rice straw fiber, 30% coconut shell powder, and 50% epoxy resin, while composition B consisted of 15% rice straw fiber, 20% coconut shell powder, and 65% epoxy resin. Each composition was prepared using particle sizes of 50, 100, and 200 mesh. Hardness was measured using a Shore D durometer, while wear was evaluated using a disc brake simulator. The results showed that the hardness values of composition A were 45.9, 51.9, and 40.3 Shore D, while composition B produced 30.4, 75.9, and 83.7 Shore D. The wear rate of composition A increased from 0.28×10^{-6} to 7.72×10^{-6} g/s mm², whereas composition B produced 1.44×10^{-6} , 2.56×10^{-6} , and 2.26×10^{-6} g/s mm². The findings indicate that hardness and wear responses varied according to the combination of material composition and particle size.

Keywords: organic brake pads; rice straw fiber; coconut shell powder; hardness; wear rate

INTRODUCTION

Brake pads are important components of vehicle braking systems because they generate frictional force to reduce or stop disc rotation. The development of brake pad materials continues to obtain suitable braking characteristics while reducing the use of materials that may have environmental impacts. One approach that has received considerable attention is the utilization of natural fibers and agricultural waste as constituents of friction materials. Natural fibers have been studied as potential constituents of brake pad materials because their incorporation can influence mechanical and tribological properties, including hardness and wear rate (Irawan et al., 2022; Yashwanth et al., 2021; Ammar et al., 2023). The use of natural-based materials in brake pads also provides opportunities to utilize available resources and reduce dependence on certain conventional materials.

Rice straw is one type of agricultural waste that can be utilized as a reinforcement material in brake pad composites. Mutlu (2009) investigated the use of rice straw and rice husk dust in brake pad materials and evaluated their tribological characteristics. In addition to agricultural fibers, coconut shell also has potential as a filler material in composite materials. Singh et al. (2013) demonstrated that coconut shell powder can be used as reinforcement in epoxy composites and can influence their mechanical properties depending on the material composition. These findings indicate that agricultural waste and biomass have potential for further development as constituents of brake pad materials.

The characteristics of natural fiber composites are also influenced by the interaction between the reinforcement, matrix, and material structure. Natural fiber composites involve relationships between material structure, fabrication, and resulting properties, while filler-reinforced composites can exhibit different characteristics depending on the constituent materials and their arrangement (Nawab et al., 2022). Therefore, the selection and proportion of constituent materials are important considerations in developing composite brake pad materials.

In addition to material composition, particle size is another factor that may affect the characteristics of composite materials. Differences in particle size can influence material distribution, interfacial contact, and the resulting material characteristics. In composite brake pad materials, particle-size variations have also been

investigated to evaluate changes in hardness and wear rate. Kristianta et al. (2017), for example, investigated the effect of coconut shell powder particle size in epoxy composites for brake pads on hardness and wear rate. Olorunfemi et al. (2024) also examined particle size in agro-waste-based brake pad composites and reported that particle size was related to the resulting mechanical and wear characteristics. Therefore, brake pad characteristics are not only related to the types of materials used but also to the composition and particle size of their constituents.

Although natural fibers, agricultural waste, coconut shell powder, and epoxy have been investigated as composite and brake pad materials, further research is needed on the specific combination of rice straw fiber, coconut shell powder, and epoxy resin with variations in composition and particle size evaluated through hardness and wear testing. Previous studies have generally examined different natural fibers, filler materials, or formulations, while the combination of rice straw fiber and coconut shell powder with epoxy under different composition and particle-size variations remains a relevant area for investigation. Thus, a direct experimental evaluation is needed to identify the resulting hardness and wear characteristics.

Based on this condition, this study investigates the effect of composition and particle size on the hardness and wear of organic brake pads made from rice straw fiber, coconut shell powder, and epoxy resin. Composition A consisted of 20% rice straw fiber, 30% coconut shell powder, and 50% epoxy resin, while composition B consisted of 15% rice straw fiber, 20% coconut shell powder, and 65% epoxy resin. Each composition was prepared using particle sizes of 50, 100, and 200 mesh. Hardness was measured using a Shore D durometer, while wear was evaluated using a disc brake simulator. The results are expected to provide information on the hardness and wear characteristics of organic brake pads under the investigated composition and particle-size variations.

LITERATURE REVIEW

Organic Brake Pads

Brake pads are components of braking systems that generate friction against the disc surface, thereby reducing the kinetic energy of a vehicle. Brake pad materials generally consist of several components with different functions, including binders, reinforcements, fillers, and additives used

to control friction characteristics. Differences in the types and compositions of constituent materials can affect the mechanical and tribological properties of brake pad materials (Irawan et al., 2022).

The development of organic brake pads utilizes natural-based materials and agricultural waste as alternative constituents of friction materials. Natural fibers have potential for use in brake pad materials because they can function as reinforcement and influence the overall material properties. The utilization of natural materials is also one approach to developing more environmentally friendly brake pad materials (Yashwanth et al., 2021).

In the development of brake pad materials, the material characteristics need to be appropriate for braking functions. Hardness and wear resistance are among the characteristics that can be used to evaluate brake pad materials. Therefore, the use of natural materials as constituents of brake pads needs to be evaluated based on their mechanical and tribological characteristics.

Constituent Materials of Organic Brake Pads

Organic brake pad materials consist of several constituents with different functions that interact with one another and influence the final characteristics of the material. In this study, the materials consist of rice straw fiber, coconut shell powder, and epoxy resin. Rice straw fiber functions as a natural fiber-based reinforcement, while coconut shell powder is used as a lignocellulosic filler. Epoxy resin acts as a binder that holds the constituent particles together, forming a more compact composite material (Fiore, 2020).

The use of coconut shell powder as a reinforcement or filler in epoxy-based composites has been investigated in studies of the mechanical properties of coconut shell powder-epoxy composites. The addition of coconut shell powder and variations in particle size can affect the mechanical properties of the resulting composites. This indicates that the characteristics of the constituent materials and their particle conditions need to be considered in the fabrication of epoxy-based composites (Singh et al., 2013).

In brake pad materials, the interaction between the binder and the filler or reinforcement is also related to mechanical and wear characteristics. Therefore, the combination of rice straw fiber, coconut shell powder, and epoxy resin

in this study is considered not only in terms of the types of materials used but also their respective compositions. Differences in composition may subsequently produce different hardness and wear characteristics (Sheldon, 2020).

Particle Size

Particle size is one of the factors that can affect the characteristics of composites used as brake pad materials. Differences in particle size can influence particle packing, the bonding between fillers and the matrix, and the pore structure of the material. These structural changes may subsequently affect the mechanical properties and wear resistance of brake pads.

Ossia et al. (2021) investigated the effect of coconut shell particle size on the physicomaterial properties of brake pads produced from waste coconut shells. The study used several particle sizes and showed that increasing particle size was associated with decreases in hardness, compressive strength, and density of the investigated material. The authors also reported that smaller particles could provide improved interfacial bonding between coconut shell particles and the binder.

Ridwan and Hartono (2025) also demonstrated that particle size is related to the characteristics of non-asbestos brake linings. Variations in sengon wood powder particle size resulted in changes in the hardness and wear rate of the material. Their findings indicated that smaller particle sizes could increase hardness at certain composite compositions.

Based on these previous studies, particle size was used as one of the factors examined in the present study. The particle sizes used were 50 mesh, 100 mesh, and 200 mesh for each composition. These variations were applied to examine changes in the hardness and wear rate of the brake pads at each combination of composition and particle size.

Brake Pad Hardness

Hardness is an important mechanical characteristic of brake pad materials because it is related to the ability of the material to maintain its shape and withstand loading during braking. Hardness values can also be used to describe the structural condition of a material formed by the combination of its constituents. In natural-fiber-based brake pad materials, changes in material type and composition can result in different hardness values (Nawab et al., 2022).

Raghunathan et al. (2024) evaluated the

mechanical and tribological characteristics of brake pads reinforced with *Mimosa pudica* fibers. The study showed that fiber treatment and variations in material formulation could produce differences in mechanical characteristics, including hardness. These findings indicate that the interaction between the fiber and matrix is an important aspect in determining the mechanical characteristics of brake pad materials.

Another study by Gore and Bhosale (2025) on natural-fiber-reinforced friction materials also evaluated the hardness of brake pad materials. The study employed mechanical and tribological tests to characterize the developed materials, with hardness being one of the parameters used to evaluate the brake pad materials.

In this study, brake pad hardness was measured using a Shore D durometer. The test was conducted for each combination of material composition and particle size, consisting of compositions A and B with particle sizes of 50, 100, and 200 mesh. The resulting hardness values were used to describe differences in the mechanical characteristics of the brake pads for each material variation.

Brake Pad Wear Rate

Wear is an important tribological characteristic for evaluating brake pad materials. Wear represents material loss from a surface and sliding velocities. The results showed that the type and treatment of the filler could affect material loss during wear testing. Differences in surface morphology were also observed after the materials underwent friction, as a result of interaction and friction during contact with a counter surface. In polymer-based composite materials, wear characteristics can be influenced by the type of matrix, filler materials, composition, surface conditions, and testing conditions.

Suthan et al. (2020) investigated the wear characteristics of epoxy composites reinforced with several natural fillers, including rice husk and coconut shell powder. The wear tests were conducted using a pin-on-disc method under different loads and sliding velocities. The results showed that the type and treatment of the filler could affect material loss during wear testing. Differences in surface morphology were also observed after the materials underwent friction.

For brake pad applications, Wihardias et al. (2025) evaluated the effect of matrix type on the wear rate of composite materials used for brake pads. The study compared epoxy and polyester as

matrix materials and showed differences in the wear rates of the resulting composites. These findings indicate that matrix characteristics are one of the factors that need to be considered in determining the wear resistance of brake pad materials.

Effects of Composition and Particle Size on Brake Pad Characteristics

The characteristics of brake pads are not determined by a single material but result from the interaction of various constituents and their particle characteristics. Organic brake pad materials generally consist of binders, fibers, fillers, and friction modifiers. Changes in the proportion of each constituent can alter the structure as well as the mechanical and tribological properties of the resulting material. Imran et al. (2024) explained that the use of natural fibers and particles in friction materials needs to consider material composition and interactions among constituents because these factors are related to the mechanical and tribological characteristics of brake pads.

In addition to material composition, changes in matrix formulation can also produce different brake pad characteristics. Nandiyanto et al. (2022) developed brake pads using durian seeds as the base material and varied the resin composition. The study evaluated physical and mechanical properties, including particle size, surface roughness, density, hardness, wear rate, and friction coefficient. The results indicated that changes in resin composition were associated with changes in the physical, mechanical, and frictional characteristics of the resulting materials.

Based on these studies, material composition and particle size can be considered interrelated factors in determining brake pad characteristics. In the present study, these factors were varied through two material compositions, namely compositions A and B, and three particle sizes, namely 50 mesh, 100 mesh, and 200 mesh. These combinations were used to examine changes in the hardness and wear rate of the resulting brake pads.

METHODS

This study employed an experimental method to investigate the effect of composition and particle size on the hardness and wear rate of organic brake pads. The study was conducted from April to November at the Mechanical Engineering Workshop of Politeknik Negeri Malang and the TRO Workshop of PSDKU Lumajang. The materials consisted of rice straw fiber, coconut

shell powder, epoxy resin, and G adhesive, while the equipment included a digital scale, pressure gauge, disc brake simulator, tachometer, and Shore D durometer. Two material compositions were used: composition A consisted of 20% rice straw fiber, 30% coconut shell powder, and 50% epoxy resin, while composition B consisted of 15% rice straw fiber, 20% coconut shell powder, and 65% epoxy resin. Each composition was prepared using particle sizes of 50, 100, and 200 mesh.

The materials were weighed according to the predetermined compositions, mixed, placed into a brake pad-shaped mold, and compacted. The specimens were then heated through a sintering process to assist material bonding. The specimen thickness was measured after forming, and when necessary, the specimens were attached to a brake pad plate using adhesive. Hardness was measured using a Shore D durometer based on ASTM D2240. The specimens were placed on a flat, hard surface, and measurements were performed perpendicular to the specimen surface. Each specimen was tested at five different points, and the obtained values were averaged.

Wear testing was conducted using a disc brake simulator for 60 seconds. The specimens were weighed before testing, installed on the apparatus, and subjected to pressure through the brake lever. The pressure was controlled using a pressure gauge, while the disc rotational speed was monitored using a tachometer. Each variation was tested five times, and the results were averaged. The wear rate was expressed in $\text{g/s}\cdot\text{mm}^2$ based on specimen mass loss during testing and a surface area of 1665.8 mm^2 . tetapi semua informasi yang dibutuhkan template tetap masuk dan metode The rotational speed and pressure were controlled to maintain consistent testing conditions for all variations.

RESULTS AND DISCUSSION

Hardness of Organic Brake Pads

Based on Figure 1, the hardness values showed different patterns between compositions A and B at each particle size. For composition A, the hardness increased from 45.9 Shore D at 50 mesh to 51.9 Shore D at 100 mesh, before decreasing to 40.3 Shore D at 200 mesh. In contrast, composition B showed a more consistent increase, from 30.4 Shore D at 50 mesh to 75.9 Shore D at 100 mesh and 83.7 Shore D at 200 mesh. Therefore, a finer particle size did not automatically result in higher hardness for all compositions.

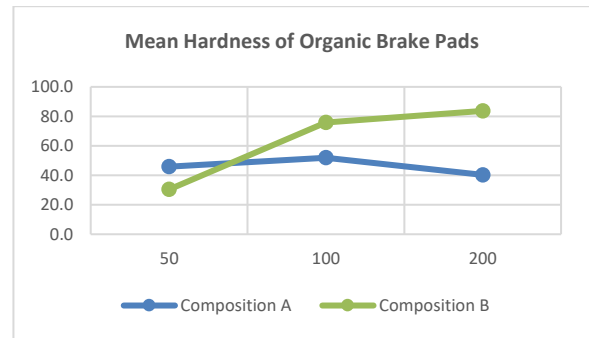


Figure 1. Mean hardness of organic brake pads at different compositions and particle sizes

The different patterns indicate that particle size interacted with material composition in determining the hardness of the composite. In composition A, the 100-mesh particle size produced the highest hardness, whereas the 200-mesh size resulted in a decrease. In composition B, however, hardness continuously increased as particle size changed from 50 to 200 mesh. This indicates that the resulting composite characteristics cannot be explained by particle size alone because the proportions of rice straw fiber, coconut shell powder, and epoxy resin also differed between compositions A and B.

At 50 mesh, composition A produced a hardness of 45.9 Shore D, which was higher than the 30.4 Shore D obtained for composition B. However, this condition changed at 100 mesh, where composition B reached 75.9 Shore D, compared with 51.9 Shore D for composition A. The difference became greater at 200 mesh, with 83.7 Shore D for B3 and 40.3 Shore D for A3. This pattern indicates that changes in material composition substantially affected the hardness response at the same particle size.

These results are consistent with the study by Ossia et al., which investigated the effect of coconut shell particle size on the physicomechanical properties of green automotive brake pads. Their study demonstrated that particle size was associated with changes in composite properties, indicating that particle size should be considered together with material formulation.

The results can also be compared with the study by Ammar et al. (2024) on brake pad composites containing palm frond midrib fiber, epoxy, and calcium carbonate. Their study reported hardness values ranging from 75 to 87 HRB and found no simple relationship between hardness and the percentage of an individual constituent. The authors indicated that

interactions among the components of the formulation could affect hardness.

This is relevant to the present study because compositions A and B differed simultaneously in the proportions of rice straw fiber, coconut shell powder, and epoxy resin.

The study by Tammima et al. (2026) also demonstrated that the addition of natural-based material to epoxy-matrix brake pad composites could affect hardness and wear characteristics. Their study used *Casuarina equisetifolia* fruit powder as one of the constituents and evaluated hardness together with wear properties.

Thus, the use of biomass-based materials in the present study is consistent with recent research on natural-material-based composite brake pads.

In addition, Olorunfemi et al. developed composite materials for tricycle brake pads using variations in material constituents and evaluated the resulting material characteristics. Their findings support the consideration of the overall material formulation when developing alternative brake pad materials rather than focusing on a single reinforcement component.

Overall, the results indicate that composition B showed the most consistent increase in hardness as particle size changed from 50 to 200 mesh, whereas composition A reached its highest hardness at 100 mesh. These findings indicate that the hardness of the brake pads in this study was associated with the combined variations in material composition and particle size. However, because both factors were varied simultaneously, the observed hardness changes cannot be attributed exclusively to particle size or to a single material constituent.

Wear Rate of Organic Brake Pads

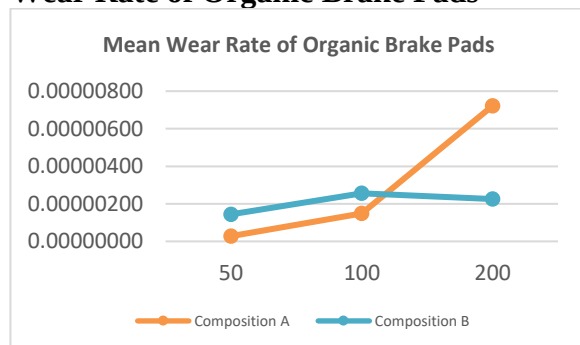


Figure 2. Mean wear rate of organic brake pads at different compositions and particle sizes

Based on Figure 2, the wear rate showed different patterns between compositions A produced the highest. This indicates that composition A with a 200-mesh particle size experienced the greatest

material loss among the tested variations. In composition B, however and B. In composition A, the wear rate increased as the particle size changed from 50 to 200 mesh. The mean value increased from 0.00000028 g/s·mm² for A1, to 0.00000148 g/s·mm² for A2, and reached 0.00000772 g/s·mm² for A3. In contrast, composition B increased from 0.00000144 g/s·mm² for B1 to 0.00000256 g/s·mm² for B2, followed by a slight decrease to 0.00000226 g/s·mm² for B3. Therefore, changes in particle size produced different wear responses in the two compositions.

A lower wear rate indicates lower mass loss during testing. In this study, A1 produced the lowest wear rate, whereas A3 produced the highest. This indicates that composition A with a 200-mesh particle size experienced the greatest material loss among the tested variations. In composition B, however, the use of 200-mesh particles resulted in a slight decrease in wear rate compared with the 100-mesh particles.

When compared at the same particle size, A Their study showed that changes in particle volume fraction resulted in different specific wear rates. The 30% particle variation produced an average specific wear rate of 2.008×10^{-6} loss was considered more suitable for brake pad application. This supports the present finding that changes in composition can produce different wear responses. However, the wear values study used rice husk as a natural ingredient in friction materials and showed that particle characteristics, particularly silica content, could contribute to the formation of a friction layer on the contact surface. Under certain formulations, the rice-husk-containing material showed low wear behavior. This indicates that the characteristics of biomass-based materials can influence friction and wear processes, although the materials and testing conditions specific wear rate of brake pad composites. Their study showed that bio-based treatment of hemp fibers improved fiber–matrix interaction and altered the wear behavior of the composite. This indicates that the interaction between reinforcement and matrix is an important aspect in determining composite wear resistance. Although no chemical treatment was applied to the rice straw fiber in the present study, differences in the proportions of rice straw fiber the particle size changed from 50 to 200 mesh. In contrast, composition B showed an increase up to 100 mesh followed by a slight decrease at 200 mesh. These1 produced a wear rate of 0.00000028 g/s·mm², which was lower than the 0.00000144

g/s·mm² obtained for B1. At 100 mesh, A2 also showed a lower value of 0.00000148 g/s·mm², compared with 0.00000256 g/s·mm² for B2. However, a substantial difference occurred at 200 mesh. A3 reached 0.00000772 g/s·mm², whereas B3 produced only 0.00000226 g/s·mm². These results indicate that the wear response to particle size cannot be separated from material composition.

These findings are consistent with the study by Fuad and Yudiono (2023), which investigated an epoxy-matrix composite containing Aegle marmelos shell particles as an alternative brake pad material. Their study showed that changes in particle volume fraction resulted in different specific wear rates. The 30% particle variation produced an average specific wear rate of 2.008×10^{-6} mm²/kg, while other variations produced different values. This demonstrates that changes in filler proportion can affect the wear characteristics of a composite.

The study by Yigrem et al. (2022) also demonstrated a relationship between material formulation and mass loss in waste-based brake pad composites. Their composites used banana peel powder and carbon at different compositions. The composition producing the lowest mass loss was considered more suitable for brake pad application. This supports the present finding that changes in composition can produce different wear responses. However, the wear values from the two studies should not be directly compared because the testing methods and units were different.

The study by Nogueira et al. (2022) provides additional insight into possible wear mechanisms in agricultural-based brake materials. Their study used rice husk as a natural ingredient in friction materials and showed that particle characteristics, particularly silica content, could contribute to the formation of a friction layer on the contact surface. Under certain formulations, the rice-husk-containing material showed low wear behavior. This indicates that the characteristics of biomass-based materials can influence friction and wear processes, although the materials and testing conditions differed from those used in the present study.

Meanwhile, Lawan et al. (2024) demonstrated that treatment of natural fibers could affect surface characteristics, mechanical properties, and the specific wear rate of brake pad composites. Their study showed that bio-based treatment of hemp fibers improved fiber-matrix interaction and altered the wear behavior of the

composite. This indicates that the interaction between reinforcement and matrix is an important aspect in determining composite wear resistance. Although no chemical treatment was applied to the rice straw fiber in the present study, differences in the proportions of rice straw fiber, coconut shell powder, and epoxy may result in different reinforcement-matrix interactions.

Overall, the increase in wear rate from A1 to A3 indicates that composition A experienced progressively greater material loss as the particle size changed from 50 to 200 mesh. In contrast, composition B showed an increase up to 100 mesh followed by a slight decrease at 200 mesh. These different patterns indicate that particle size did not produce a uniform effect on wear across all compositions. Material composition and particle size were jointly associated with the wear characteristics of the resulting brake pads.

CONCLUSION

Based on the experimental results, variations in composition and particle size produced differences in the hardness and wear rate of organic brake pads made from rice straw fiber, coconut shell powder, and epoxy resin. For composition A, hardness increased from 45.9 Shore D at 50 mesh to 51.9 Shore D at 100 mesh and then decreased to 40.3 Shore D at 200 mesh. In contrast, composition B showed an increase in hardness from 30.4 Shore D at 50 mesh to 75.9 Shore D at 100 mesh and 83.7 Shore D at 200 mesh. These results indicate that the effect of particle size on 1.48×10^{-6} and 7.72×10^{-6} g/s·mm² at 50, 100 and 200 mesh, respectively. The different wear patterns between the two compositions indicate that the response to particle size was particle sizes, and hardness and wear measurements. Other characteristics, such as friction coefficient, thermal resistance, post-test surface characteristics, and fiber-matrix interfacial interaction, were not investigated in detail. Future research should consider wider variations in material composition and particle size and include friction coefficient, braking temperature hardness varied depending on the material composition.

The wear test showed that composition A had an increasing wear rate from 0.28×10^{-6} to 1.48×10^{-6} and 7.72×10^{-6} g/s·mm² at 50, 100, and 200 mesh, respectively. Composition B produced wear rates of 1.44×10^{-6} , 2.56×10^{-6} , and 2.26×10^{-6} g/s·mm² at 50, 100, and 200 mesh, respectively. The different wear patterns between the two compositions indicate that the response to

particle size was associated with the composition of the material. A lower wear rate represents lower material loss during testing.

This study is limited to two material compositions, three particle sizes, and hardness and wear measurements. Other characteristics, such as friction coefficient, thermal resistance, post-test surface characteristics, and fiber–matrix interfacial interaction, were not investigated in detail. Future research should consider wider variations in material composition and particle size and include friction coefficient, braking temperature, and surface morphology analyses to obtain a more comprehensive understanding of organic brake pad performance.

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