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PARTICLE SIZE AND PORE SIZE OF RICE HUSK ASH ON THE RESIN-BASED BRAKE PADS PERFORMANCE: EXPERIMENTS AND BIBLIOMETRIC LITERATURE REVIEW

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Abstract

The objective of this research was to evaluate the impact of rice husk particle size on the performance of resin-based brake pads. In the experiment, rice husk particles used were measuring 79, 89, 125, and 250 μm. Rice husks are mixed in a resin mixture containing Bisphenol A-epichlorohydrin and cycloaliphatic amines to make brake pads. Then the brake pads were analysed to obtain the compressive strength, the puncture strength, the wear rate, the mass loss, the coefficient of friction, and the physical microstructure using a microscope. Rice husks are highly preferred because they tend to contain cellulose, lignin, pentosan, and silica, making them suitable as friction materials with similar properties to ceramics. The experiment result showed that brake pads with a combination of resin mixtures at a small particle size of rice husks experienced an increase in compressive strength, puncture strength, and density. The analysis showed that the maximum values for the compressive strength of the brake pads supported by rice husk particles of 79, 89, 125, and 250 μm are 0.110; 0.109; 0.105; and 0.109 MPa, respectively. The large rice husk particles formed rough surfaces and had porous structures, reducing the rate of mass loss and increasing the frictional properties (i.e. the wear rate and the coefficient of friction). The coefficient values of friction of the brake pad using rice husk particles of 79, 89, 125, and 250 μm are 0.000397; 0.000392; 0.000381; and 0.000393, respectively. Particle size factors affect the interfacial bonding, pore size, mechanical properties, thermal softening, and reinforcement properties of brake pads. This research utilizes rice husk waste as an environmentally friendly material to replace asbestos material; thus, it has better performance on brake pads.

Keywords: Brake pads; Epoxy resin; Friction; Particle size; Rice husk.

1. Introduction

A brake pad is one of the important components in the braking system and is found in all types of vehicles. The brake pad is equipped with a disc brake. The brake pad generally consists of some asbestos-related fibers embedded in the polymer matrix as a steel support plate with a friction component bonded to the surface facing the brake disc. Different types of brake pad materials are used in different engines [1, 2], There is an impact on the performance of brake pads from various brake friction materials that must be considered, especially the selection of materials into the formulation must be toxic-free in the manufacture of brake pads may consist of a metal-free and copper-free matrix [3]. The main idea is that friction material has an important role in the brake pad system. This is important and found for increasing fastness, controlling friction coefficient, reducing porosity/noise, and increasing strength properties [4].

In research on the development of brake pads using alternative materials, it is highly recommended to use biomass components as a non-asbestos organic component (known as NAO). The use of biomass component (e.g. bagasse [5], banana peels [6], periwinkle shell [7], seashell [8], corn husk [9], rice husk [10], and many others) have been studied on brake pads. Biomass produces fibers with properties that have the potential to make NAO brake pads that are environmentally friendly and of significantly high value [11]. The biomass reliably improves mechanical properties and coefficient of friction. The addition of rice husks in the brake pad formulation has been shown effective for improving the friction properties [12].

Rice husk is the residue from rice milling. Rice husks are quite abundant in the earth's crust Thus, they are used as fillers that function as reinforcement. The main components of rice husks are cellulose, pentosan lignin, and silica. Thus, rice husk as a filler can improve the stiffness of the composite and reduce the strength of the composite due to the low interfacial bond between polymer resin and rice husk [13, 14]. The high silica content makes rice husks accurate as friction materials because of their ceramic-like properties and very low friction coefficient values. surface, iodine number, and the capacitance value of activated carbon.

Mechanical properties are important in automotive and engineering fields [15, 16]. In our previous reports, we focused on the impact of particle size on the mechanical profiles of materials [17-20]. Here, this research investigated the impact of the size of rice husk particles on the performance of brake pads. In our ideas, if they were to be followed up with various variants of particle size, the product will promote good results. Rice husk is used as a friction material in the resin-based brake pad component. The use of resin has an advantage, specifically, the manufacturing process is carried out by involving resin materials at room temperature and pressure.

Brake pads are made using resin made of a mixture (namely cycloaliphatic amine and bisphenol A-epichlorohydrin) and rice husk particles with certain sizes (i.e. 79, 89, 125, and 250 μm). Then, the mechanical profiles were characterized by performing the puncture and the compressive test. Then the friction test was used, which aims to find out heat resistance, mass loss, wear rate, and coefficient of friction on the brake pads that have been made. The research shows the ability of rice husk particles as a friction component in the brake pad. The research also utilizes rice husk waste as an environmentally friendly material to replace asbestos material. Thus, it has better performance on brake pads. This paper is also completed with bibliometric literature review to ensure further development from this study.

2. Experimental Method

2.1. Production of Brake pad

The raw materials used in this study were cycloaliphatic amine and bisphenol A-epichlorohydrin (purchased in a local market in Indonesia), which were used as resin materials and mixed with rice husk particles. Both resin chemicals were mixed in an equal mass ratio (ratio = 1:1). Before use, rice husks ((taken in Bandung, Indonesia) were ground using equipment as reported in previous studies [20-22]. The ground rice husk particles were placed into an electrical sieve shaker (Niaga Kusuma Lestari, Indonesia; based on ASTM D1921) to obtain a certain size. A sieve pans with a certain mesh of 18, 35, and 60 mesh type (particles of rice husks are put into a sieve shaker) was used to classify the rice husk particles with a specific size. In this study, we selected the rice husk particles with a specific size: 79, 89, 125, and 250 μm.

To produce a brake pad from rice husk, rice husk particles (13 g) with a specific size were added to the mixed resin chemicals (22 g). Then, the mixture of rice husk particles and resin was put into silicone moulds with a dimension of 4 x 3 x 1 cm for length x width x depth, respectively. The moulds were then dried at room temperature and pressure. The drying system was kept for two-three days, and we avoid drying from sunlight exposure. For characterization, brake pads that have been prepared are cut into certain sizes.

2.2. Mechanical properties test

Mechanical properties tests, such as compressive and puncture tests, were carried out to examine the mechanical properties of the prepared brake pads. For the compression test, a Screw Mount Test Instrument was used (Model I ALX-J, China) supported by a digital force measuring instrument (Model HP-500, Serial, No. H5001909262). The test was done by adding force with a constant displacement rate (2.6 mm/min) on the brake pad specimen. The compressive forces were recorded during the test, and the recorded data was plotted to get a curve. The curve shows the mechanical properties and the texture profile of the specimen experiencing mechanical test. Then, the analysis was done by analysing the curve for getting the value of the compressive strength of the specimen (gained from the maximum point of the compressive stress-strain curve). Next, the maximum applied force (in Newtons (N)) was obtained to test the hardness of the sample during the test.

The analysis of the puncture test was done using a Shore Durometer instrument (Shore A Hardness, in size, China), which was utilized and equipped with a needle probe. The test was done by puncturing the needle probe into the brake pads until it goes to the deepest position in the brake pad. Finally, the hardness test was recorded and measured on a scale from 0 to 100.

We also measured the bulk density of rice husk particles (ρ), which was done by calculating mass and volume using Eq. (1).

$$\rho = \frac{m}{V} \quad (1)$$

where m and V are, respectively, the mass of the rice husk in the specimen and the volume of the specimen.

2.3. Friction test

This study tested the brake pads after being polished to eliminate the resin layer on the surface of the brake pad. The friction test was carried out by putting and sliding the brake pad specimen against sandpaper (80 grit; Dae Sung CC-80Cw). We applied a mass load of 9 kg on the brake pad specimen. The friction test was done for 20 minutes, and the sliding process was done at a speed of 25 cm/s. The data was taken every 2 minutes for getting the mass of the brake pads. The wear rate (M) was calculated by considering several parameters using Eq. (2).

$$M = \frac{M_a - M_b}{t\ x\ A} \quad (2)$$

where Ma and Mb are, respectively, the initial weight (g) and the final weight (g) of the brake pad specimen. Other parameters are t (the friction testing time (s)), A (the frictional cross-section area (mm^2)), μ (the brake pad specimen friction coefficient), f (the applied friction force), and N (the applied force). All parameters were calculated using Eq. (3).

$$\mu = f/N \quad (3)$$

2.4. Bibliometric analysis

Bibliometric analysis research has 4 stages, namely data search using the publish or perish 7 application, data processing using Ms. Excel, data mapping using VOSviewer application, and data analysis from VOSviewer mapping.

The search for publication data in this study uses the publish or perish application. the data retrieved is data published for the last 5 years, namely the period 2018 - 2022. The keywords used in the data search were "Brake pad" and "rice husk". The number of articles obtained from published or destroyed search results was 678 articles. Data is stored in 2 file formats, namely *.ris format (for VOSviewer data mapping) and csv (for Ms. Excel data processing). Data processing using Ms. Excel is done to get data on the number of articles per year and see the research that has been done by researchers regarding the keywords used.

The data that has been mapped is then analysed to see the development of research on brake pads and rice husks. The data from this mapping is analysed to obtain existing research trends and the results of terms that are often used as study material to find novelty for further research. Detailed information how to search and use bibliometric analysis using VOSviewer is shown in previous reports [23, 24].

3. Results and Discussion

3.1. Bibliometric literature review

3.1.1. Article search matrix on brake pad and rice husk

Bibliometric is one of the best methods to understand research trend. This has been applied in many areas and subjects [25-37]. Based on the search results using the Publish or Perish (PoP) application found 678 articles. Table 1 shows the 15 articles with the highest number of citations. Based on Table 1, an article entitled

"Characterization and properties of natural fiber polymer composites: A comprehensive review" was written by Sanjay et al. published in 2018 has the most citations with a total of 964 citations.

Table 1. Publications on brake pad rice husk with the highest number of citations.

Authors	Title	Year	Citations
Sanjay et al.	Characterization and properties of natural fiber polymer composites: A comprehensive review	2018	964
Girijappa et al.	Natural fibers as sustainable and renewable resource for development of eco-friendly composites: a comprehensive review	2019	384
He et al.	Antimony speciation in the environment: Recent advances in understanding the biogeochemical processes and ecological effects	2019	236
Li et al.	Recent advancements of plant-based natural fiber-reinforced composites and their applications	2020	207
Mittal et al.	Reinforcements in multi-scale polymer composites: Processing, properties, and applications	2018	206
Li et al.	Antimony contamination, consequences and removal techniques: A review	2018	197
Samal et al.	Recent progress in aluminum metal matrix composites: A review on processing, mechanical and wear properties	2020	142
Riber et al.	Review of environmental enrichment for broiler chickens	2018	116
Rajeshkumar et al.	Environment friendly, renewable and sustainable poly lactic acid (PLA) based natural fiber reinforced composites-A comprehensive review	2021	114
Okolie et al.	Chemistry and specialty industrial applications of lignocellulosic biomass	2021	110
Jin et al.	Nanogenerator as new energy technology for self-powered intelligent transportation system	2019	104
Costa et al.	Recycling and environmental issues of lithium-ion batteries: Advances, challenges and opportunities	2021	100
Liu et al.	Influence of silane treatment on the mechanical, tribological and morphological properties of corn stalk fiber reinforced polymer composites	2019	97
Nawaz et al.	Geopolymers in construction-recent developments	2020	91
Manikandan and Arjunan	Studies on micro structural characteristics, mechanical and tribological behaviours of boron carbide and cow dung ash reinforced aluminium (Al 7075) hybrid.	2020	91

3.1.2. Development of publication of brake pad and rice husk 2018 to 2022

Figure 1 shows the development of "brake pad" and "rice husk" publications from 2018 to 2022. Research on keywords used is increasing every year. The highest research occurred in 2022 with a total of 174 publications (25.66%) In the previous 4 years, namely 2018, 2019, 2020, and 2021, publications regarding brake pads totalled 105 (15,495), 108 (15.93%), 122 (17.99%), and 169 (24.93%) respectively.

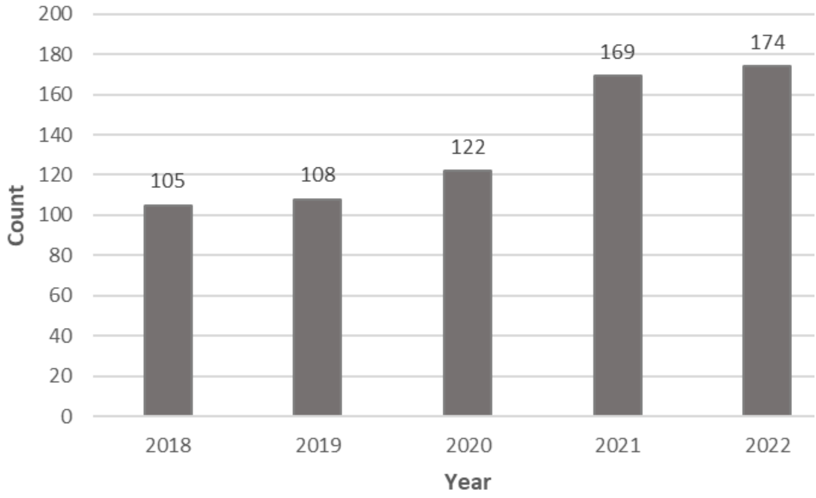

Fig. 1. Publication of brake pad and rice husk (2018-2022).

3.1.3. Mapping visualization publication on brake pad and rice husk

The nodes in the network map visualization show an entity, including articles, authors, countries, institutions, keywords, journals [38]. Figure 2 shows a network visualization of publications on brake pad and rice husk. Based on the case in Fig. 2 it is known that: The size of the cover colour indicates the occurrence of the keyword (that is, the number of times the keyword appears) [39], Relationships between nodes represent co-occurrence between keywords (that is, keywords that occur together or occur together), The thickness of the link shows the co-occurrence between keywords (i.e., the number of times the keywords appear or occur together), The bigger the node, the bigger the keywords that appear, and The thicker the links between nodes, the greater the co-occurrence between keywords [40].

Based on Fig. 2, it is known that brake lining is the type of adsorption that has been studied the most and is related to the research theme of rice husk brake pads. The term brake pad has a total link strength of 1157 with a total of 206 occurrences and the number of links with other terms is 131. In addition, the term brake pad is in cluster 4. Besides that, Fig. 2 shows the relationship between the protein adsorption term and other terms, which consist of the number, brake, brake disc, brake fiction material, brake lining, brake pad material, brake rotor, coefficient, composite material, friction, coefficient of friction, friction material, phenolic resin, rice husk dust, grit, tribological performance, tribological property, and vehicle.

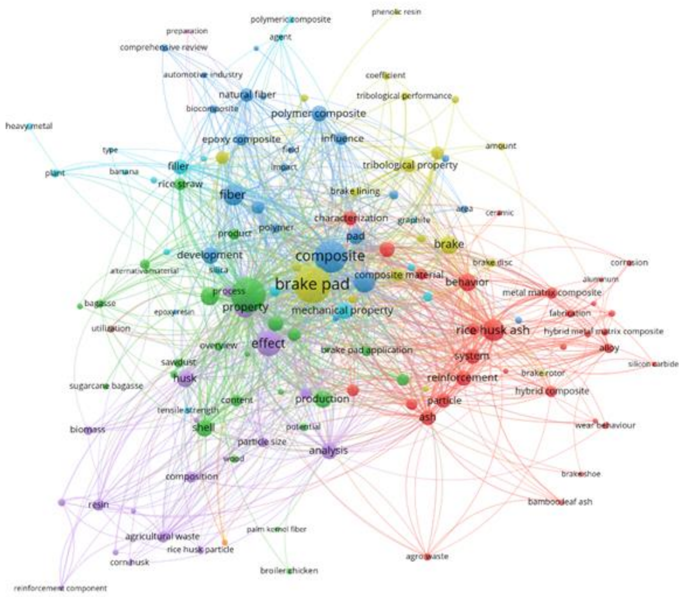

Fig. 2. Network visualization of brake pad and rice husk.

Figure 3 shows the overlay visualization of brake pad and rice husk publications. visualization overlay shows the novelty of using the term in related research [40]. Figure 3 shows that most research with the terms brake pads and rice husks was carried out in 2020. This shows that the popularity of the terms ren canvases and rice husks occurred recently, namely about 2 years ago.

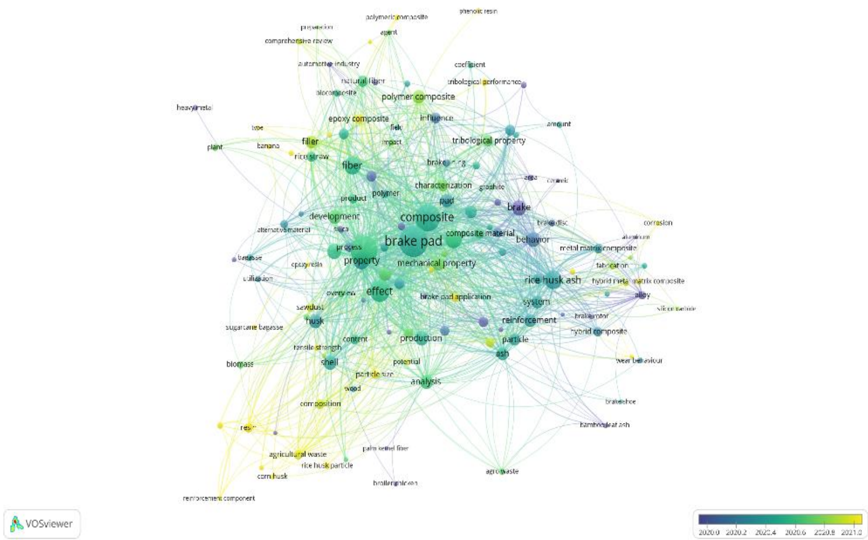

Fig. 3. Network visualization of brake pad and rice husk term.

Table 2 shows the number of clusters found in the network visualization, namely 9 clusters. Table 2 shows several other terms that are usually associated with research on brake pads and rice husks. Table 2 can also assist future researchers in determining the focus of research to be carried out.

Table 2. VOSviewer Distribution of term mapping cluster.

Cluster	Items	Colour
1	agro waste, alloy, alumina, aluminium metal matrix composite, aluminium, aluminium alloy, ash, automobile industry, bamboo leaf ash, behavior, brake shoe, ceramic, characteristic, characterization, corrosion, fabrication, fly ash, hybrid metal matrix, composite, matrix, mechanical, mechanical behavior, metal matrix composite, microstructure, particle, reinforcement, research, rice husk ash, silicon cardible, system, wear behaviour	Red
2	alternative material, automotive brake pad, bagasse, binder, brake pad application, broiler chicken, coconut, content, evaluation, ever view, palm kernel, palm kernel fiber, palm kernel shell, performance, periwinkle shell, potential, product, production, rice, rice husk, rice straw, sawdust, shell, sugarcane bagasse, waste, wood	Green
3	Application, area, asbestos, automotive industry, biocomposite, car, chemical treatment, clutch, composite, comprehensive review, development, environment, epoxy composite, epoxy resin, fiber, field, impact, influence, manufacturing, mechanical properties, natural fiber, pad, polymer, polymer composite	Dark Blue
4	amount, brake, brake disc, brake fiction material, brake lining, brake pad, brake pad material, brake rotor, coefficient, composite material, friction, friction coefficient, friction material, phenolic resin, rice husk dust, sand, tribological performance, tribological property, vehicle	Yellow
5	addition, agricultural waste, analysis, biomass, brake pad performance, brake pad production, coconut fiber, composition, corn husk, effect, eggshell, husk, particle size, process, property, reinforcement component, resin, rice husk particle	Violet
6	agent, banana, filler, graphite, hardness, heavy metal, mechanical property, mixture, optimization, plant, polymeric composite, ratio, silica, tensile strength, type, variation, water	Light Blue
7	automotive application	Orange
8	utilization	Brown
9	preparation	Pink

3.2. The physical appearance of brake pads

Figure 4 presents the prepared resin-based brake pads with rice husk particles. Resin-based brake pads reinforced with rice husks appear black, and rough, containing porous structures. Particle size factors are colour, size, and several cavities (shafts) in the brake pads. Brake pads with the smallest particle size (79 μm) have a darker colour than brake pads with larger particle sizes. In addition, samples with particle size compositions of 79, 89, 125, and 250 μm showed different properties. Brake pads with a composition of 79 and 250 μm have the same characteristics in the form of a mixture of small and large particle sizes. Likewise, brake pads with a composition of 89 and 125 μm have characteristics according to their dominant shape composition. If a certain particle size is dominantly used in a mixture, then the mechanical properties are similar to the particle size [10].

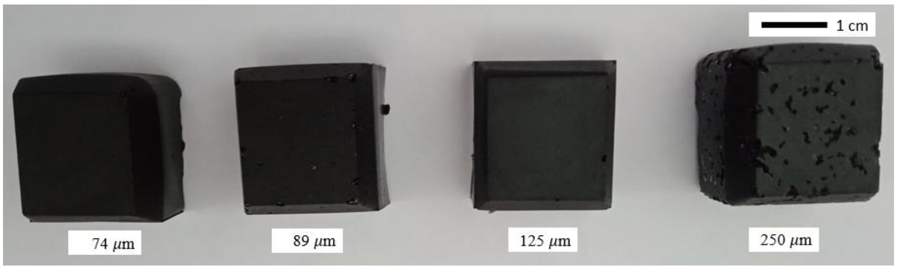

Fig. 4. The photograph image of the prepared resin-based brake pad specimen.

Based on Figs. 5(a) and (b), it shows when rice husk particles were mixed with resin and packaged into a brake pad. The packaged material was observed by a microscope. The microscope image showed rice husk particles with sizes of 79 and 89 μm. It was clear that the particles were small, making them have fewer and smaller pores and resulting in a finer pore structure than brake pads with large particle sizes. Figures 5(c) and (d) show rice husk particles with sizes of 125 and 250 μm, respectively.

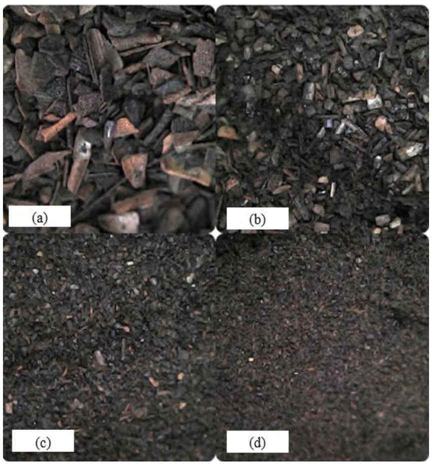

Fig. 5. Microscope observation surface of specimens containing rice husk particles in the brake pad. Figures were classified as (a) 79, (b) 89, (c) 125 and (d) 250 μm).

The porous structure was shown in Fig. 6. It shows a marked red circle of the largest pores found in the prepared brake pads with a particle size of 79 µm, Fig. 6(a). Then when using rice husk particles with sizes of 150 µm, smaller pores were observed, refer to Fig. 6(c); red circle. In addition, brake pads made with 250 µm rice husk particles have fewer pore numbers. Porosity is a characteristic of the pore structure that exists in a material and acts as an absorber of energy and heat generated in the braking process [41].

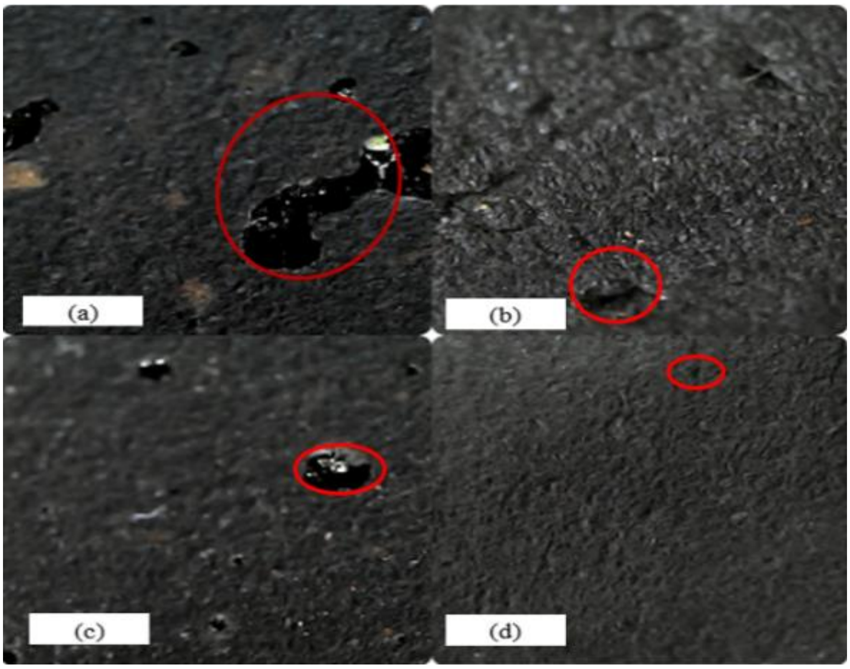

Fig. 6. The microscope images of sliced specimens containing rice husk particles in the brake pad system. The specimen contained particles: (a) 79, (b) 89, (c) 125, and (d) 250 µm. A red circle area shown in the figure is the appearance of a large pore structure in the specimen.

If larger size rice husk particles are used, it creates more space in the brake pads because the larger rice husk particles make a weak bonding area of the resin-rice husk and rice husk-rice husk. The structure of large pores in the brake pad increases the chance of cracking and reduces brake pad performance. In contrast, the smaller husk particle size increases the bonding area of the resin-rice husk and rice husk-rice husk to create more homogeneous packing particle structures.

3.3. Mechanical properties test

3.3.1. Bulk density

The results of the mechanical properties of bulk density with different particle sizes of rice husks, namely the compressive and the puncture tests, are presented in Table 1. Also, Fig. 4 shows that there are factors that affect particle size and variations in the composition of rice husks on brake pads. The density value depends on the sample or component of the brake pad material. Brake pads with a large particle size of 250 µm have the largest bulk density value compared to the smaller particle size. This is because there is a physical interaction between the brake pads particles and the epoxy mixture so that large particles tend to trap air during the mixing process, and form pores when the epoxy hardens. As a result, large samples have larger volumes and smaller density values. So this research is following previous research [42].

3.3.2. Compressive test

Figure 7 shows the results of testing the compressive test value of rice husk brake pads which showed the highest value with a particle size of 74 µm of 52.2 N. This means that the compressive resistance is greater in the material, while the lowest compression test value was indicated by brake pads with a small particle size of 250 µm, which is 34.9 N. Thus, the maximum value for the compressive strength of the brake pads with rice husk particles with sizes of 79, 89, 125, and 250 µm are 0.110; 0.109; 0.105; and 0.109 MPa, respectively. We also considered that smaller values on the scale during the puncture test indicated a higher indentation tolerance (as shown in Table 3). The particle size is evenly distributed, making the structure more compact and resistant to pressure. In the compression test, low interfacial strength can allow the stress to not be channelled properly and crack propagation in the brake pads [42].

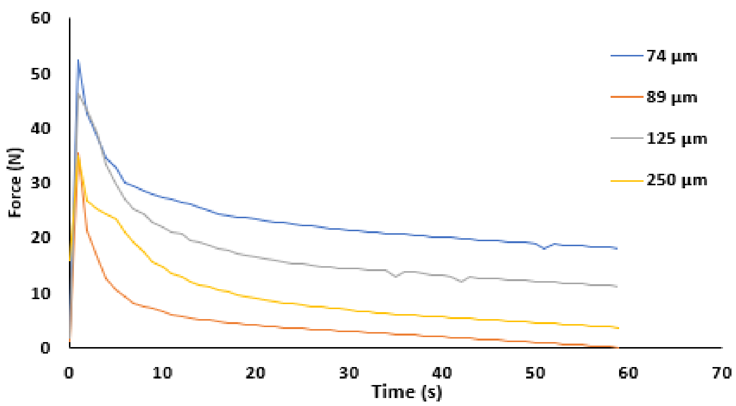

Fig. 7. Compression test results from rice husk brake pads.

We obtained the greater compressive resistance of the material, which is due to the higher value of compressive stress. The main reason is due to the uniformity of dispersion of filler rice husk particles, which has affected the mechanical behavior and hardness of the specimen in the brake pad system [42]. The smaller particles have larger surface areas, giving advantages in the bonding properties of the resin. The distance between packs decreases when the rice husk particle size decreases. The factors are because of the precise distribution of the rice husk particles in the brake pad and the appropriate bond between rice husk particles and resin.

The pores have decreased because this did not occur because of the formation of cracks in the resin matrix. The factor is because of the concentration of stress, so it is stronger and more successful. On the other hand, if the porosity increases, it is more susceptible to failure under compressive loads [24-25]. There is a comparison between compressive and puncture strength tests, in which this parameter has no proportional relationship due to the uncommon phenomenon compared to common components/materials [43].

Table 3. The results of the puncture strength, compressive test, and bulk density of brake pad from rice husk particles.

Sample	Bulk density of particles (g/cm^3)	Puncture Strength	Compressive test (N)
74 µm	1.0051	59.5	52.2
89 µm	1.1887	71.6	35.5
125 µm	1.0753	75.4	46.4
250 µm	1.2246	77.9	34.9

Regarding the compressive test, the compressive load is resisted simultaneously by the strength of the rice husk, resin, and interface. As we know, the strength of the rice husk particles is higher than that of the resin. Also, the interface of the rice husks particle and resin is the weakest strength. To endure the load, it can be done with the stress in the resin, which has to be transferred to rice husks (having higher strength). But, the interfacial strength causes the stress cannot be transferred, and crack propagation [44].

3.3.3. Puncture test

Puncture test by taking a 1-mm diameter probe as the test equipment, which will look at the ratio of higher particle strength of rice husk with resin and interfacial strength to design the particle size of the composite relating the micromechanical profiles of the particles which will evaluate the mechanical behavior and properties of the compressive and puncture strength [19]. The highest puncture test value was shown in 250 µm brake pads, because when the same particle size is used, the particles are evenly dispersed, making them more compact and resistant to pressure so that the mechanical strength follows the particle size properties. The results of the prick test show that the characteristics of the brake pads are influenced by the particle size of the matrix and the value of the variation in the particle size of rice husks is obtained.

3.3.4. Friction properties

Figure 8 and Table 4 present the friction test on the brake pads experiencing a change in mass. The brake pads were applied forces to touch the sandpaper (as a drum/brake disc model). Thus, it causes the kinetic energy to change into heat energy, which then produces heat and friction [45]. The mass-loss rate, the wear rate, and the brake pad coefficient are shown in Table 4. The results of the friction coefficient values for the brake pads with rice husk particles with sizes of 79; 89; 125; and 250 µm are 0.000397; 0.000392; 0.000381; and 0.000393, respectively.

Medium particle size brake pads (125 µm) lose more mass and produce more dust. Meanwhile, brake pads with large particle sizes (250 µm) have large pores, which make the brake pads rough, so the friction test is less stable. This means that the mass-loss rate is high, the wear rate is poor, and the friction coefficient is quite low. The effect of the wear rate is poor due to small particles in a large matrix interface area. These particles have good particle distribution in the brake pad particle size for friction resistance, and small particles exit the matrix at a large particle-matrix surface area [46]. Particles make different contributions to mechanical strength, thus exhibiting different properties. With the addition of larger particles, the brake pads are more susceptible to compression and puncture forces. As a result, the addition of a smaller particle size makes the brakes more resistant, because particle size affects the coefficient of friction. The coefficient of friction has meaning as the ratio of the force needed to move and shift two sliding surfaces against each other, and the force that resists them.

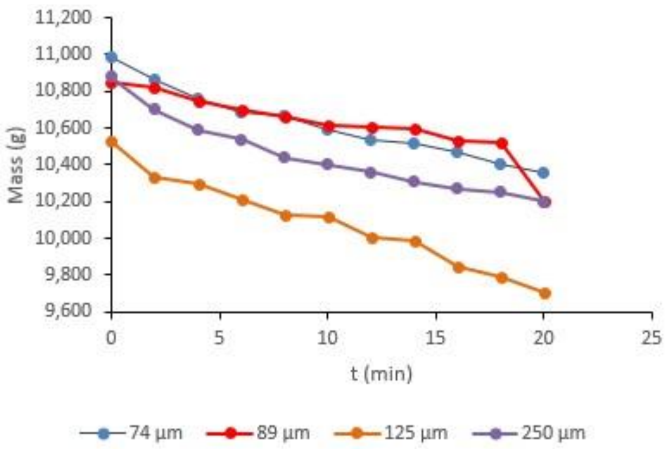

Fig. 8. The mass loss based on the variation of rice huck particles size in brake pads

Brake pads with a particle size of 125 µm have a lower coefficient of friction. This means that there is a particle size factor that must be investigated to understand the particle size of the brake pads that can cover all cavities or gaps in the material as well as the strength of rice husks and resin adhesion also greatly affect the value of the wear rate on the brake pads, the bond in the composite will become more strong and not easily abraded when friction occurs because the material has good resistance characteristics to the wear properties of the brake pads, which softens the resin. The effect of thermal softening on the wear properties and properties of rice husk particles with a matrix (resin) material is lower. This study is in line with previous reports [47-49]

Table 4. The mass loss and the friction coefficient result.

Sample	M_a (g)	M_b (g)	Mass loss rate (g/min)	t (s)	A (mm^2)	M (g/s.mm^2)	Friction coefficient
79 µm	10.99	10.36	0.029 ± 0.035	1200	52.8	9.94×10^{-6}	0.000397
89 µm	10.85	10.20	0.029 ± 0.092	1200	55.2	9.81×10^{-6}	0.000392
125 µm	10.53	9.71	0.037 ± 0.048	1200	55.2	1.23×10^{-5}	0.000381
250 µm	10.88	10.2	0.030 ± 0.048	1200	52.8	1.07×10^{-5}	0.000393

Note: *Ma* and *Mb* are the initial and final masses, respectively. *t* is the friction time. *A* is the friction test's contact area. *M* is the wear rate

4. Conclusion

Based on the experimental results, it is shown that brake pads with small and large particle sizes of 79 and 250 μm can be used as an alternative good brake pad because they have good physical properties, compression test, puncture test, and friction test. Particle size effects were also found, which influence interfacial bonding, size of pores, mechanical behavior, and reinforcement behavior of the brake pad. The reduced particle size forms less number of pores, less mass loss during the friction test, better wear rate during the friction test, higher friction coefficient, and smoother brake pads surfaces.

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