Effects of Particle Size and Composite Composition of Durian Peels and Banana Midribs' as Reinforcement Components on Resin-Based Brake Pad Performance

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ABSTRACT

This study aims to determine the effect of particle size and material composition on the performance of resin-based brake pads. Experiments were carried out by mixing 75% UPR with durian peel and banana midribs fibers using ratios of 1/1, 3/2, and 2/3 at particle sizes of 104 and 250 μm. The experimental results shows that decreasing the particle size improves the mechanical properties of brake pads, but gives a high wear value and a low coefficient of friction. In addition, an increase in the percentage of banana midrib fibers as a whole provides better brake pad performance. The results of the comparison between commercial-based brake pads confirm that agricultural waste is potential as an alternative to friction materials in brake pads. Brake pad with a fiber ratio of 2/3 104 μm had highest values of hardness, wear and friction coefficient, namely 20.33 N/cm^3, 2.02 x 10^{-4} g/s.mm^2, and 0.2465. while the 1/1 250 μm and 3/2 250 μm had the lowest coefficient values and compressive strength of 0.1195 and 9.14 N/cm^3. This study demonstrates the use of biomass waste as an alternative to friction material to overcome the dangerous problem of using asbestos in brake pads.

Key words: brake pad; particle size; durian peels; banana midribs; unsaturated polyester resin.

INTRODUCTION

The composition of brake pad material generally consists of 60% of asbestos, creating problems in polluting environment and health issues. Many studies have developed alternative materials to replace asbestos in brake pads by utilizing natural fiber-reinforced biocomposites (Dwiyati et al., 2017) (See Table 1).

Durian has a distinctive skin with a weight percentage reaching 60-75% (Rahman, 2018). This skin contains 50-60% of cellulose, 5% of lignin, and 5% of low starch. Therefore, durian peel can be used as a mixture of raw materials for various compress products (Tausif et al., 2017). Banana midrib has a composition of 60-65% of cellulose, 6-8% of hemicellulose, 5-10% of lignin, and 10-15% of water (Vaisanen et al., 2016). The lignin content of these two natural ingredients can make brake pads have optimal quality according to ASTM (Effendy et al., 2017). The use of resin is effective to allow the process under room temperature and pressure.

Natural fiber reinforced polymer biocomposite technology is currently in great demand because it is environmentally friendly, low production costs, and high availability of materials (Mallick, 2007). Several studies have been carried out on the manufacture of brake pads using durian peel or banana midribs fibers. Table 1 shows a state of the art research on the manufacture of resin-based brake pads.

Table 1. The State of The Art

References	Material	Methode	Result	Differences With This Study
Masturi dkk., (2018)	• Durian rind fiber • MgO • Teak leaves • Polyester resin	Physical and Chemical treatment.	Samples with a composition of 40% durian rind fiber, 10% magnesium oxide, 40% teak leaves, and 10% polyester resin are identical to brake pads that have been circulating in the market and comply with SNI 09-0143 standards.	Using a mixture of raw materials and different test parameters.
Idris dkk., (2015)	• Banana peels • Phenolic resin	Carbonization and reduction of particle size.	The compressive strength, hardness and density of the resulting samples were seen to increase with the addition of the resin percentage, while the oil immersion, water immersion, wear rate and burn percentage decreased along with the increase in resin percentage.	Using a different type of resin binder.
Prayoga (2016)	• Banana midrib • Grafhite • Barite • $CaCO_3$ • Epoxy resin	Sintering	Brake pads using banana tree frond fibers are suitable for use because they have a wear rate close to that of the factory brake pads, namely 2.5 x 10^{-6} grams / mm^2.	Using different raw materials, methods and types of polymers.
Bashir dkk.,	• Banana Peel	Pressure	Banana stalk powder can be used	Using

(2015)	• $CaCO_3$ • $CaOH_2$ • Graphite • Sb_2S_3 • MoS_2 • Al_2O_3 • MgO • SiC • Steel Wool • PAN fiber • $CaSiO_3$	Moulding	effectively to increase the binding capacity of phenolic resins at higher temperatures.	different resin types and methods.
Ossia dkk., (2020)	• Coconut shells • CaCO3 • Carbon • Phenol formaldehyde resin • MEKP catalyst	Moulding and curing process	The brake Pad has better thermal conductivity and properties at particle sizes below 90 μm	Using a different materials

However, until now, research on the use of banana midribs or durian peels as raw material for brake pad has not been carried out. In fact, wastes' potential in Indonesia is very large. This study aims to determine the effect of particle size and composition of brake pad based on resin. Its performance was analyzed using a test of wear rate, mass loss, coefficient of friction, heat resistance, compressive strength, and puncture strength. The method used is non-pressure, occurs at room temperature, and involves a polymerization reaction. It is expected that the crosslink polyester reaction with the MEKP catalyst can occur when the resin has interacted with the fibers in the molding to harden. It is also expected to discover the brake pads quality.

METHOD

Brake Pad Production

Brake pads are made by collecting durian peels' and banana midribs' waste in Tasikmalaya, Indonesia. This ingredients are cut into small pieces and dried in the sun for 3 days. To get a specific size, the particle of durian peels and banana midribs that have been ground are put into a mesh filter according to ASTM D1921. Pan sieves with special mesh sizes of 60 and 150 were used to obtain 104 and 250 μm particles of durian peel and banana midrib, respectively. Brake pads are made using two variations in size (104 and 250 μm) where each size has three ratios of durian skin fiber/banana stalk, namely 1/1, 3/2, and 2/3.

75% UPR was added as matrix and 10% MEKP by weight of UPR was added as a catalyst. The mixture was poured into a silicone mold (2.4x2.3x1.8 cm) and dried in room (at room temperature) for 3 days. Prior to testing, all brake pads are sanded to remove the resin effect on the surface.

Mechanical Properties Test

The mechanical properties of brake pads are obtained from testing the compressive strength and puncture strength. The Screw Mount Test Instrument (Model I ALX-J, China) equipped with a digital force gauge (Model HP-500, Serial, No H5001909262) was used for the compression test. While the puncture strength test was carried out using the Shore Durometer instrument (Shore A Hardness, In size, China). Density can be calculated using Eq. (1):

$$\rho = \frac{m}{V} \tag{1}$$

Friction Test

In this test, the brake pad is rubbed against sandpaper (80 grit) for 20 minutes at a speed of 25 cm/s. Its mass is recorded every 2 minutes. Its wear rate (M) can be calculated using Eq. (2) (Sukrawan et al, 2019):

$$M = \frac{(M_a - M_b)}{t \times A} \tag{2}$$

where M_a is the initial mass of the brake pad (g), M_b is the mass of the final brake pad (g), t is the test time, and A is the friction cross-sectional area (mm^2). The ratio of the f (N) friction force to the normal force N (N) is the coefficient of friction (μ) which can be expressed in Eq. (3) (Burris and Sawyer, 2009):

$$\mu = f/N \tag{3}$$

RESULTS AND DISCUSSION

Proposal Chemical Polymerization Reaction during the Formation of UPR-Based Brake Pad

The concept of making UPR matrix brake pads uses the involvement of polymerization at room temperature which can bind and compact the fiber components. This polymerization mechanism involves the addition of free radicals that attack the double bonds in the UPR chain (Bartoli, 2019). Figure 3-6 shows the curing reaction mechanism in the UPR chain. The overall reaction mechanism is as follows (Nadilah, 2003):

a. Peroxide catalyst (MEKP) breaks down as free radical tert-butyldioxy-O$^{\cdot}$ (RO$^{\cdot}$) which acts as an initiator (will attack the double bond on UPR).

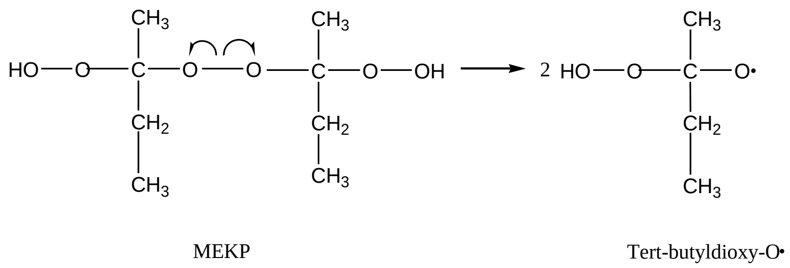


Figure 3. The reaction of free radical formation from the MEKP catalyst

b. Free radical attack (RO$^{\cdot}$) will result in the formation of unpaired electrons in the UPR chain.

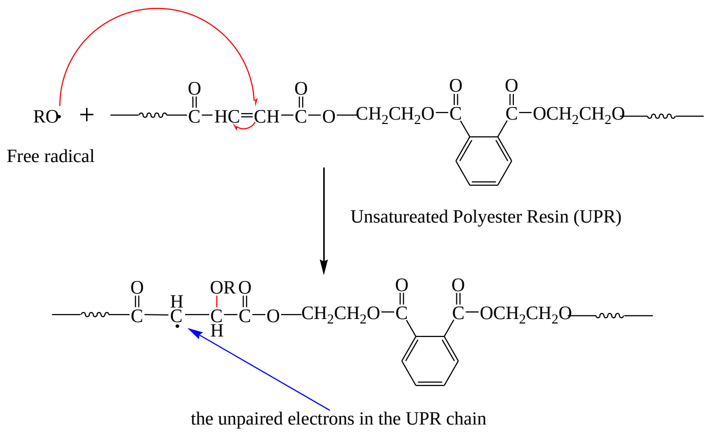


Figure 4. Tert-butyldioxy-O$^{\cdot}$ free radical (RO$^{\cdot}$) attack on the UPR chain

c. The unpaired electrons on the UPR will attack the double bond in styrene, thus forming a crosslink bond. This crosslink bond results in the formation of unpaired electrons in styrene.

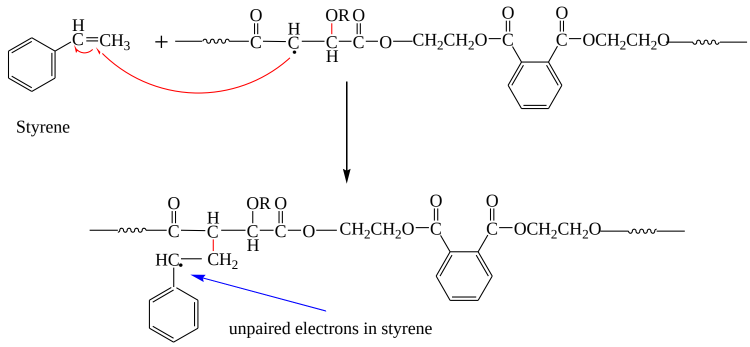


Figure 5. The reaction of crosslink formation between UPR and styrene molecules

d. The unpaired electrons will then attack other UPR molecules, forming new free radicals that will attack other styrene molecules. This reaction continuous until the UPR molecule hardens (cured).

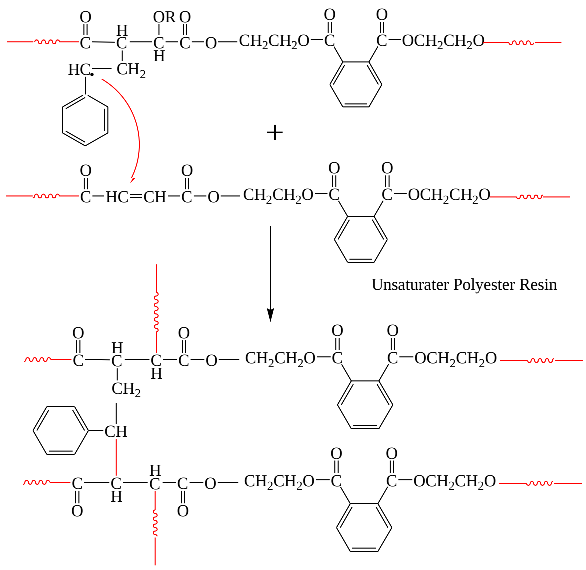


Figure 6. UPR chain polymerization and curing reactions.

Physical Appearance of Brake Pad

The surface view of brake pad was observed under a microscope and is presented in Table 3. Based on the observations, brake pads with a pore size of 250 μm had larger and larger pores compared to 104 μm (see table 5). Brake pads with a smaller particle size result in fewer pores with a finer structure.

Table 3. Surface View of Brake Pad

Particle Size	Fiber Composition Ratio

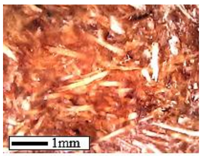
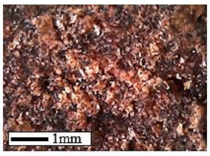
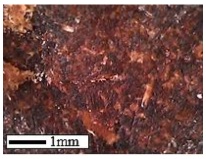
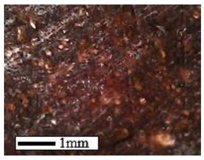
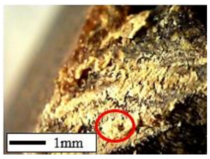
	1/1	3/2	2/3
250 µm			
104 µm			

Table 4 shows a microscope image of the pores in the brake pad matrix which can support the texture profile analysis. It's shows that the 1/1 composition of durian peels and banana midribs produced smaller and fewer pores. The particle size also greatly affects the pores of the brake pads. Brake pad with large particle sizes have larger pores as well since there are less bonds between the materials thus creating more space. With larger pores, the performance of the brake pad is decreasing, and vice versa. This happens because the outer bond between the materials is higher and makes the performance of the brake pads increase.

Table 4.

Particle Size	**Fiber Composition Ratio**		
	1/1	3/2	2/3
250 µm			
104 µm			

Microscope image of the pores in the brake pad matrix

Mechanical Properties

Figure 8 and 9 shows the results of the compression test for brake pad. In Figure 8, it can be seen that 104 μm; ratio 2/3 has the greatest compressive resistance, while the 250 μm; ratio 1/1 has the smallest compressive resistance. Meanwhile, in Figure 9 it can be seen that the highest compressive strength value is at 104 μm; ratio 2/3 and the lowest is at 250 μm; ratio 3/2. Brake pads that have a low level of hardness can be caused by the low bond between the constituents, so that when pressed, the stress distribution will increases and spread to all parts where the part that is not too bonded will be deformed first. Thereby, it it can be understood here that the hardness of brake pad is also impacted by the particle size and composition of the constituent materials (Athif, 2018).

Table 5 shows the results of the brake pads compression test. Smaller numbers on the scale indicates a high indentation tolerance. From the table, it can be seen that the puncture force in brake pad increases in conjunction with decreasing particle size. Brake pad with 104 μm; ratio 2/3 has the greatest puncture strength, while 250 μm: ratio 1/1 has the smallest puncture strength. The size and number of pores in the material correlate with the particle size of the fibers. The larger particle size can trap air during the mixing process which creates pores, thereby increasing the crack path and stress intensity which makes brake pads susceptible to pressure and indentation (Rezanezhad et al, 2019). This is reinforced by the correlation between particle size and bulk density, where in the table it can be seen that the smaller the particle size, the greater the bulk density value. This also makes it has higher density, less pores and hard because the particle size and distribution affect the bulk density value (Tausif et al., 2017).

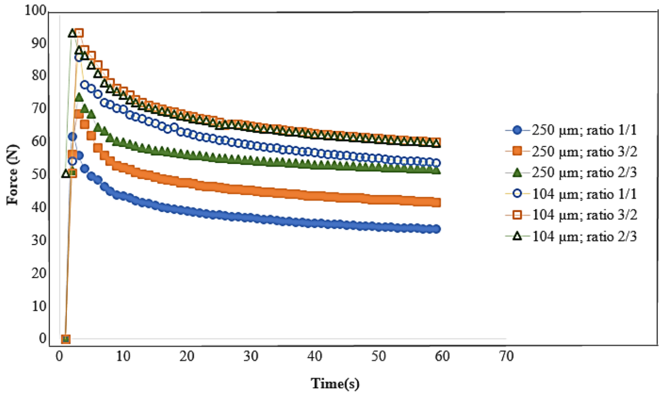


Figure 8. Compressive Test Results

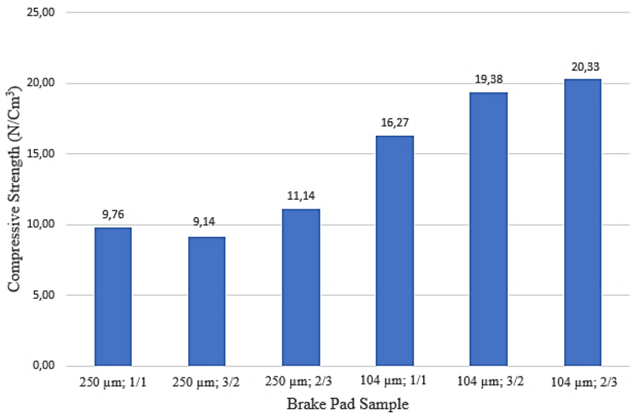


Figure 9. Compressive Strength Result

Sample	Durometer Shore Hardness Scale	Average Size of Pore (µm)	Bulk density (g/cm^3)
250 µm; ratio 1/1	80.56	335	3.0168
250 µm; ratio 3/2	84.39	531	3,1953
250 µm; ratio 2/3	88.00	628	3.0200
104 µm; ratio 1/1	90.94	191	3.4665
104 µm; ratio 3/2	93.00	306	3.3716
104 µm; ratio 2/3	95.56	317	3.5759

Table 5. Puncture Strength and Bulk Density Results

Friction Properties

Figure 10 and Table 6 show the results of the friction test which includes the level of mass loss, wear and friction coefficient of brake pad. The brake pad mass change is caused by repeated contact between the brake pad surface with sandpaper which in turn will take some of the material on the surface of the brake pads and cause mass loss.

The mass loss rate of all brake pads in this study was almost the same, only it can be seen that at larger particle sizes, the value of mass loss was smaller as in the 250 μm ratio 3/2 brake pad. This indicates that the wear rate of brake pads measuring 250 μm is better than 104 μm. This is inversely related to the hardness data because the extent of the particle-matrix interface interaction at a smaller particle size allows small particles on the surface of the brake pad to escape, and vice versa (Saravanan et al, 2013).

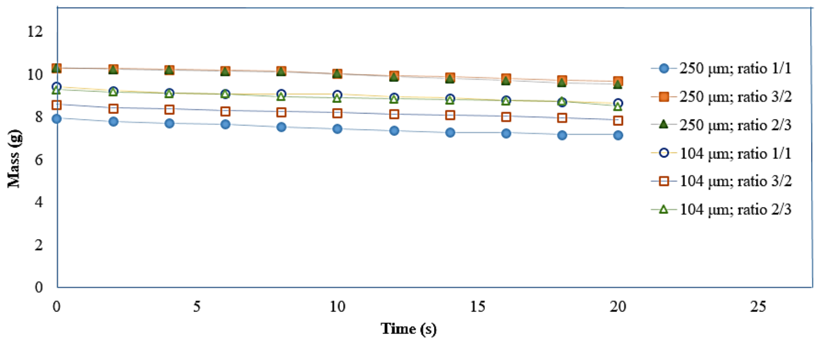


Figure 10. Loss of brake pad mass prepared as a function of time

The particle size and fiber composition also affect the friction coefficient. The friction coefficient of the material area depends on the smooth or rough surface of the brake pad. From the table, it can be seen that brake pads with a larger particle size have a higher friction coefficient. This occurs because the large particles are more difficult to remove during the friction test. Therefore, brake pads with a particle size of 104 μm have a lower coefficient of friction than 250 μm. The difference in fiber composition affects the variation in the value of the friction coefficient. The higher the fiber composition, the higher the friction coefficient value so that it is more resistant to water disturbances (Suhadirman and Mukmin, 2017).

Table 6. Loss of mass, wear rate and coefficient of friction of the prepared brake pads

Sample	M_a (g)	M_b (g)	Mass loss rate (g/min)	t (s)	A (mm^2)	M ($g/s.mm^2$)	Friction coefficient
250 μm; ratio 1/1	7.95	7.17	0,039±0,266	1200	3.6	1.81×10^{-4}	0.1195

250 µm; ratio 3/2	10.30	9.69	0,031±0,220	1200	4.14	1.23 x 10^{-4}	0.3204
250 µm; ratio 2/3	10.31	9.54	0,039±0,268	1200	4.14	1.55 x 10^{-4}	0.3210
104 µm; ratio 1/1	9.43	8.65	0,039±0,233	1200	3.36	1.93 x 10^{-4}	0.2577
104 µm; ratio 3/2	8.59	7.87	0,036±0,212	1200	3.08	1.95 x 10^{-4}	0.1851
104 µm; ratio 2/3	9.29	8.51	0,039±0,224	1200	3.22	2.02 x 10^{-4}	0.2465

Figure 10 shows the comparison of the mass loss rate during the friction test between the 250 µm; ratio 2/3 brake pads and conventional brake pads. Brake pads from 250 µm; ratio 2/3 was chosen because it has the best performance at a particle size of 250 µm. From the graph, it can be seen that the mass loss rate is insignificant.

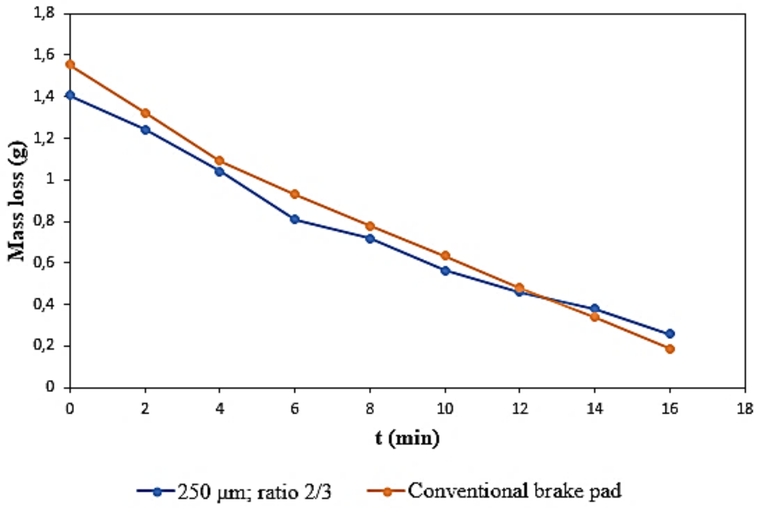


Figure 10. Comparison of the rate of mass loss of 250 µm; ratio 2/3 with conventional brake pads using a 2 x 0.4 cm friction test contact area

Table 4 show the comparison of the wear rate and friction coefficient of 250 µm; ratio 2/3 brake pads with conventional brake pads. It can be seen that 250 µm; ratio 2/3 brake pads has a better wear rate with a lower friction coefficient value of 10% compared to conventional brake pads. Its result indicates that durian peels and banana midribs have the potential to be used as reinforcing fibers in the manufacture of non-asbestos brake pads.

Table 7. Comparison the level of mass loss and friction coefficient of 250 µm; ratio 2/3 brake pad with conventional brake pads. Where M_a is the initial mass, M_b is the final mass, t is the friction time, A is the contact area of the friction test, and M is the wear rate.

Sample	M_a (g)	M_b (g)	Mass loss rate (g/min)	t (s)	A (mm^2)	M ($\times 10^{-6}$ g/s.mm^2)	Friction coefficient
250 μm; ratio 2/3	1.405	0.258	0.063±0.069	60	81	1.48	0.1832
Conventional brake pad	1.555	0.187	0.076±0.067	60	85	1.68	0.2099

CONCLUSION

The particle size of the UPR matrix brake pad affects the mechanical and frictional properties of the brake pad. Smaller particles can increase the hardness of the brake pad resulting in mechanical properties. However, it has a high wear rate with a low coefficient of friction. Overall, increasing the banana midrib fiber composition can improve the brake pad performance. Of all brake pads from 250 μm; ratio 2/3 had the best performance. Although the wear rate is high, it is not significantly different from the others. The comparison result between brake pads made in this study with conventional brake pads also show that the friction material which is reinforced with durian peel and banana midribs has the potential to be used as environmentally friendly brake pads.

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