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RESEARCH ARTICLE

The effect of Aegle marmelos shell particles volume fraction on hardness, toughness, and wear rate of epoxy matrix composites as motorcycle brake pads

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ABSTRACT - The utilization of Aegle marmelos shell particles is not optimal yet. Composite brake pads are currently being developed because they are eco-friendly and heat resistant compared to non-asbestos brake pads. This research attempt to analyze the volume fraction of Aegle marmelos shell particles on the measure of hardness, toughness, and wear of epoxy matrix composites as an alternative material for motorcycle brake pads. The design of this research uses a true experimental design with a posttest-only design type, there is an experimental group (composite) and a control group (Indoparts brand brake pads). The results show the most optimal measure is found in volume 30% with a hardness measure of 79.5 HRB, toughness 0.01312 J/mm^2, wear 2.008 x 10^{-6} mm^2/kg. It shows that the more particles volume, the composite strength will increase. This measure is closest to the measure of the Indoparts motorcycle brake pads. Therefore, Aegle marmelos shell particles composite can be recommended as an alternative material for motorcycle brake pads.

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1.0 INTRODUCTION

The rapid development of the motorcycle industry makes manufacturers or companies compete to improve services both in terms of performance of the engine, the appearance of the vehicle and the comfort and safety of its users is certainly eco-friendly. In the safety and comfort of motorcycle users, the most frequently encountered is when braking. The optimal braking system will make the driver feel safe and comfy [1]. The braking system is a series of systems that function to slow down the vehicle so that it slows down or stops. One of the most important parts of the braking system is the brake pads. Brake pads function as a tool to slow down or stop a motorized vehicle. Brake pads are sacrificing components that are attached either by adhesive on the steel plate, it is most considered and given priority [2]. The basic material for brake pads that are widely spread in the market is asbestos, which is an inorganic material that is glued together with resin, rubber, or other materials to be used as brake pads.

Brake pads asbestos are relatively cheap, and have good tribological and mechanical properties, but dust from brake pads which are dangerous and toxic and can damage the environment. Therefore, it is necessary to develop non-asbestos brake pads that have good tribological and mechanical properties, high temperatures, and are eco-friendly. The development of composite materials is one of the most important advances in the history of materials and is related to the field of manufacturing technologies [3]. Composite materials use non-asbestos as a comparison with asbestos brake pads and hereafter composite materials can replace the asbestos in brake pad materials [4]. The production of brake pads from composite materials is currently being developed and researched. A hybrid composite is defined as a composite material containing two or more different types of reinforcing components in the matrix material and can be fabricated with hybridization techniques [5]. The types of materials which are frequently analyzed are natural fibers and artificial fibers. Natural fibers have the potential to replace existing conventional materials because of their good characteristics, such as relatively cheap material costs, easy fabrication, high strength, good thermal properties, and surely a renewable material [6]. Therefore, the use of natural fibers which have good quality as a composite filler has a positive impact on the environment, because it can reduce the use of conventional materials which can damage the environment [7]. Research on composites using natural fiber materials is developing, both in terms of industrial applications and fundamental research. Because its availability is renewable and the cellulose substance in natural fibers is convenient to be used as a composite reinforcement material [8]. In composite materials, a proper adhesion force between the fiber and the matrix is required during the composite material manufacturing process [9].

The use of Aegle marmelos is commonly applied in food, medicine, organic fertilizer, and others. In this Aegle marmelos, there is also a shell (hard rind), leaves, and roots that can be used as well. Some parts of the Aegle marmelos plant apply to the development of science and technology, that is the shell as a filler or reinforcing material in composite

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materials. The skin of this Aegle marmelos has a hard rind or can be called a shell. This hard shell is often used as a household utensil material such as a bailer, a measure of rice scoop, and various handicrafts. Composites are not only used to make properties more than those used for electrical, thermal, tribological, and environmental applications. Aegle marmelos shell among other lignocellulosic fibers has a strong level of toughness and hardness [10]. This cellulose substance makes the Aegle marmelos shell advisable as a composite reinforcement material filler in motor brake pads composite materials. The production of composite brake pads certainly requires a binder material (matrix). One of the matrices used in the manufacture of motorcycle brake pads is epoxy resin. As research was conducted by Gbadeyan et al. [11] epoxy resin has good viscosity, so the bond between the resin and the reinforcement is good. The production of composite motorcycle brake pads will add aluminum particles. The addition of aluminum particles aims to increase the hardness and wear resistance of the material. As with the research conducted by Maleque et al. [12] that the addition of aluminum particles as a binder along with coconut fiber can increase the level of hardness of the material. Brake pads must complete requirements that do not emit toxic substances when braking, have corrosion resistance, consistent friction level, moderately low wear, and low noise [13]. The strength of natural fiber/particles as a reinforcing material for composites does not only depend on the matrix but also on several parameters such as a fiber-matrix bond, fiber orientation, particle size, and volume fraction. In addition, particle treatment also affects particle strength [14].

Motorcycle brake pads aftermarket were circulated still use asbestos material, where the material is not eco-friendly and the dust produced by braking is toxic. Therefore, in this research, making brake pads from filler Aegle marmelos shell particles using matrix epoxy as an alternative material for motorcycle brake pads. Composite brake pads or non-asbestos motorcycle brake pads are surely eco-friendlier and more heat resistant than asbestos brake pads. Therefore, it is necessary to investigate the hardness, toughness, and wear rate of composite shell particles Aegle marmelos using matrix epoxy, so expect the results of this research to the composites can be recommended as an alternative material for motorcycle brake pads.

2.0 METHODS AND MATERIALS

2.1 Aegle Marmelos Shell Particles

Aegle marmelos plant with other names Wood apple, Golden apple, Bael is a plant of the Rutaceae family. The spread of this plant is in South Asia and Southeast Asia, including Malaysia, India, Bangladesh, Burma, Pakistan, Sri Lanka, Thailand, and Indonesia [15]. The process of making Aegle marmelos shell particles (AMSP) is done by washing the shell with clean water so that the dirt attached to the Aegle marmelos shell is clean. After that, the shells were dried using an oven at 80 °C for 12 hours and the process was carried out grinding until they got the desired size. In this research, the raw material was sieved using an 80-sieve mesh, then dried again using an oven at 110 °C for 12 hours, so that the water content will also decrease. The specific gravity of Aegle marmelos shell particles is 1.068 g/cm^3 [16].

Table 1. Chemical composition and tensile properties of Aegle marmelos [17]

Properties	Value
Cellulose (*wt.*%)	65.07
Hemicellulose (*wt.*%)	31.25
Lignin (*wt.*%)	21.59
Density (gr/cm^3)	1.068
Tensile Strength (MPa)	88.2
Young modulus (GPa)	13.1
Elongation at break (%)	0.97

2.2 Epoxy Resin

The applied matrix used is an epoxy resin with bisphenol A-epichlorohydrin type and the epoxy hardener used is a type polyaminoamide. Saba et al. [18], stated that epoxy resin is used as a bonding material because it has several advantages over other thermoplastic resins, such as minimum shrinkage during molding, relatively cheap and abundant, increased mechanical strength and fatigue resistance, moisture resistance, good chemical resistance, good chemical properties better electricity matter, good adhesion, non-magnetic properties, long shelf life, impact resistance, and corrosion resistance. Therefore, it is necessary to innovate composites that are reinforced with Aegle marmelos shell particles and an epoxy matrix, one of which is then used as an alternative material for motorcycle brake pads.

Table 2. Material properties of epoxy resin [19]

Properties	Value
Elongation at break (in %)	5
Heat distortion Temperature (in °C)	120
Tensile Strength (MPa)	85
Density (gr/cm^3)	1.11 – 1.23
Compressive Strength (MPa)	11
Tensile elastic modulus (GPa)	3.2
Flexural Strength (MPa)	130
Linear expansion coefficient (in 10^{-6} /°C)	60
Water absorption/24 h (%)	0.14
Rockwell hardness/6.35 mm, 100 kgf	100
Shrinkage rate (%)	1-2

(a) (b)

Figure 1. (a) Aegle marmelos shell particles and (b) Epoxy resin

2.3 Methods

The method used in this research is experimental, which is the method used to find a causal relationship between factors that were deliberately caused by the researcher. The design used in this research is the category True Experimental Design with the Posttest-Only Control Design type. There are two groups in this research, namely the experimental group and the control group. The experimental group consisted of several specimens that experienced the addition of a volume fraction of Aegle marmelos shell particles, then was given the addition of aluminium particles with a size of 320 mesh. Aluminum particles have good corrosion resistance and have good thermal conductivity and hardness below the drum brake pads, so brake pads absorb heat well and release heat quickly. Therefore, aluminum particles are suitable for use as brake pad material. While the control group is a specimen of Indoparts brake pads. The composition of Aegle marmelos shell particles, epoxy resin, and aluminum powder is shown in Table 3.

Table 3. Composite formulation

No	AMSP	Epoxy	Aluminium Particles
1	10%	70%	20%
2	20%	60%	20%
3	30%	50%	20%

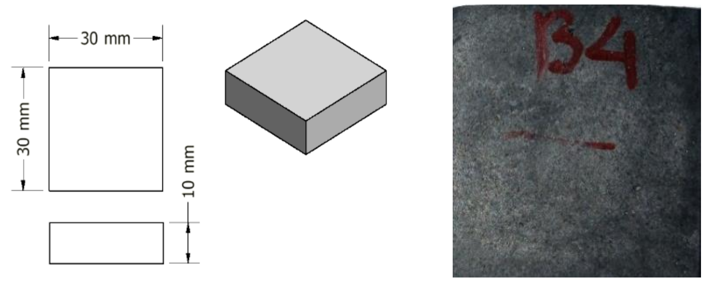
2.4 Composite Preparation

Equipment used in this research were grinder, oven, digital scale, 80 sieve mesh, hacksaw, sandpaper, measuring cup, vernier caliper, wood mold, press machine, polishing machine, brush, Rockwell ball hardness tester, GOTECH impact tester, Ogoshi wears tester. While the materials used are Aegle marmelos shell particles, epoxy resin, aluminum powder, woodblocks, and wax. This research started from the preparation stage, namely the shell of the Aegle marmelos was washed using clean water, so that the dirt on the shell disappeared. Then the shells were dried in an oven at 80°C for 12 hours [20]. To make particles using a grinder, then sieve using an 80-sieve mesh. After that, it was dried again using an oven at a temperature of 110°C for 12 hours. Before making composites, first, calculate the volume fraction that will be used. Specimens will be made according to the volume fraction calculation which is shown in Table 4.

Table 4. Weight of each volume fraction

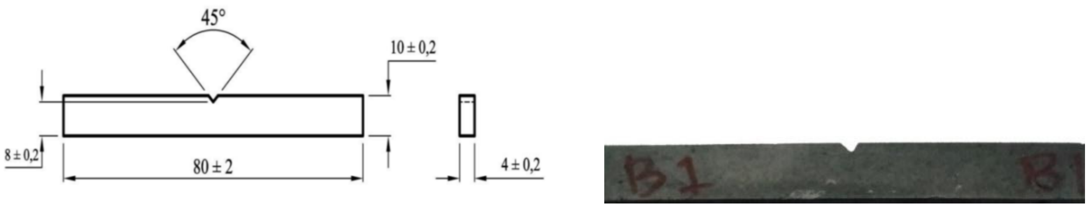
Test	AMSP Mass (gr)	Epoxy Mass (gr)	Al Particles Mass (gr)
Impact	0.50	3.92	2.07
	1.05	3.37	2.07
	1.50	2.81	2.07
Hardness and Wear Rate	1.13	8.87	4.67
	2.26	7.61	4.67
	3.38	6.34	4.67

Aegle marmelos shell particles, epoxy resin, and aluminum powder were mixed according to the required weight for each variation. The ratio between epoxy resin and hardener is 1:1. Make sure the mixture is stirred evenly. Then the composites were fabricated using a method of compacting, that is the method of pouring batter into the mold and the composite is then given a pressure of 2.000 kg for one hour using a press machine [21]. It is intended that the composite material is denser so that the bond between the matrix and filler is better. After the composite is printed, the specimens are made according to the applicable standard size. The size of the Rockwell ball hardness test specimens uses the ASTM E15 standard [22]. As for the impact test specimens size using the ISO 179-1 standard [23]. For the size of the wear test specimens according to the Ogoshi testing machine manual book [24].



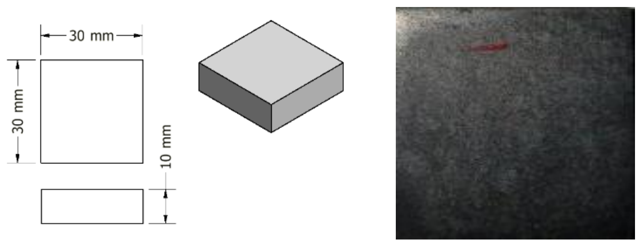
(a) (b)

Figure 2. Standard Rockwell ball hardness test specimens: (a) ASTM E15 and (b) Composite test specimens



(a) (b)

Figure 3. (a) Standard specimens for impact test Charpy and (b) composites test specimens



(a) (b)

Figure 4. (a) Standard for Ogoshi wear test and (b) Composites test specimens

2.5 Hardness Test

The hardness test aims to determine the hardness value of a specimen where the test object is emphasized on the test material (specimens). The hardness test uses a Rockwell ball hardness testing machine which is located in the Mechanical Engineering material testing laboratory of Universitas Negeri Semarang. The emphasis is 100 kgf. The Rockwell ball hardness value can be directly identified on the measurement scale. In each variation, three test specimens will be made.

2.6 Impact Test

An impact test is carried out to simulate the toughness of the test object against a (sudden) shock load. The result of impact testing is the amount of energy that can be absorbed from a material until the material is brittle or ductile. These results can be known as brittle or ductile material. In this research, the method of impact testing used is the Charpy method using an impact testing machine for the brand GOTECH type GT-7045-MD which is found in the Mechanical Engineering Laboratory of Universitas Negeri Semarang. The energy given to the test specimens is 25 joules with a pendulum speed of 3.46 m/s. In each variation, four test specimens will be made.

Impact strength is obtained from the Eq. (1):

$$Is = \frac{E}{A} \tag{1}$$

I_S = Impact Strength (J /mm^2)

E = Energy absorption (J)

A = Cross-sectional area (mm^2)

2.7 Specific Wear Rate

This research uses a method of testing the wear with Ogoshi. Ogoshi wears test is where the test object frictional load from a revolving disc. Frictional loading will result in repeated contact between the two surfaces so that the test object material will be eroded. The wear test uses Ogoshi wear testing machine located at the engineering materials testing laboratory, Department of Mechanical and Industrial Engineering, Universitas Gajah Mada, Yogyakarta. In each variation, three test specimens will be made. The specific wear value is calculated after the width of the stroke on the test specimens can be seen under a microscope. The wear width can be calculated for the specific wear value with the following equation:

$$W_s = \frac{B.b^3}{8r.p_o.l_o}(\mathrm{mm}^2/\mathrm{kg}) \tag{2}$$

where:

B = Width of revolving disc (mm)
B = Width of wear on the test object (mm)
r = Radius of revolving disc (mm)
p_o = Compressive force on ongoing wear (kg)
l_o = Distance traveled in the wear process (mm)
W_s = Specific wear rate (mm2/kg)

3.0 RESULTS AND DISCUSSION

3.1 Hardness Test

The result from the Rockwell ball hardness test is the hardness value with HRB notation. For each test specimen, data were collected from five points/specimen. After that, the three closest points are taken. The results of the hardness test Rockwell ball on variation 1 (specimens A), variation 2 (specimens B), variation 3 (specimens C), and control specimens (specimens K) is shown in Table 5. Figure 5 shows the variation of hardness value of different specimen type.

Table 5. Average of hardness Rockwell ball

Formulation	Specimens	Average of Hardness Rockwell Ball	Average
	A1	74.5	
10% AMSP	A2	76.2	75.1
	A3	74.5	
	B1	75.7	
20% AMSP	B2	76.8	77.7
	B3	80.5	
	C1	78.5	
30% AMSP	C2	83.3	79.5
	C3	76.7	
	K1	83.0	
Indoparts Brake Pads	K2	80.8	79.7
	K3	75.3	

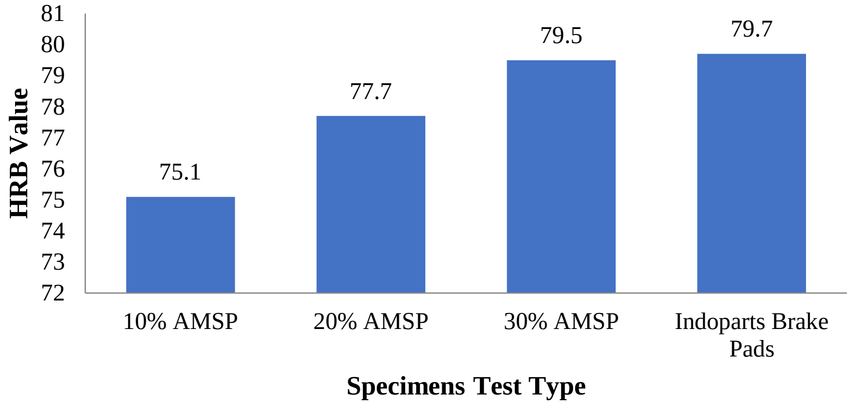


Figure 5. Graph of the average Rockwell ball hardness value

(a) (b)

Figure 6. (a) Rockwell ball hardness test specimens results and (b) Rockwell ball hardness tester

The results of the hardness test research obtained show that the addition of the volume fraction of Aegle marmelos shell particles affects increasing the composite hardness value. The more volume fraction of Aegle marmelos shell particles, the higher the hardness value of the composite. It can be seen from the average value of composite hardness, it can be seen that the percentage increase in the average hardness value between variation 1 (75.1 HRB) and variation 2 (77.7 HRB) is 3.46%. While the percentage increase in the average value of hardness between variation 2 (77.7 HRB) and variation 3 (79.5 HRB) is 2.32%. So that the increase in the value of hardness is influenced by variations in the addition of Aegle marmelos shell particles.

Calculation of the volume fraction between the matrix, epoxy resin, and Aegle marmelos shell particles (AMSP) and the addition of aluminum powder affect the value of composite hardness. The more Aegle marmelos shell particles, the hardness value will increase. Ojha et al. [25] said that the more natural particles added, the higher the hardness value. This is also in line with the research of Akaluzia et al. [26] that the more hardwood charcoal is added to the composite, the measure of composite hardness will increase. So that it can be interpreted that the more fiber/particles, the more optimal the hardness value will be. The bond between matrix and fiber will be better if the mixture between matrix and fiber/particles is not excessive and not deficient. The addition of natural particles to the composite material can increase the hardness of the material [27].

The manufacture of Aegle marmelos shell particles with a size of 80 mesh or 180 µm and the oven of Aegle marmelos shell particles affect the hardness value of the composite material. In addition, the compaction process carried out when making specimens can also affect the density of the composite so that it will have low porosity and the composite material has optimum mechanical properties. That is relevant to the research of Soundararajan et al. [28] that the compaction and sintering process carried out causes the void fraction of the composite to decrease and the material to become compact so that the hardness and density value will be high. Based on the hardness test value in Figure 5 shows the average value of composite hardness with variation 3 (79.5 HRB) which is closest to the average value of Indoparts brand brake lining hardness (79.7 HRB), the difference between composite and comparator brake pads is 0.25%. This is also following the hardness standard safety brake pads which are 65-101 HRB [29].

3.2 Impact Strength

In the Charpy impact test, the resulting data is absorption energy (J) which is then used to find the impact strength (J/mm2) using Eq. (1). Each composition is tested four times. The average results of impact testing on variation 1 (specimens A), variation 2 (specimens B), variation 3 (specimens C), and control specimens (specimens K) can be seen in Table 6.

Table 6. Average of absorption energy and impact strength

Composition	Specimens Name	Absorption Energy Average (J)	Impact Strength Average (J/mm^2)
10%	A	0.3850	0.01207
20%	B	0.4075	0.01266
30%	C	0.4275	0.01312
Brake Pads	K	0.3725	0.01489

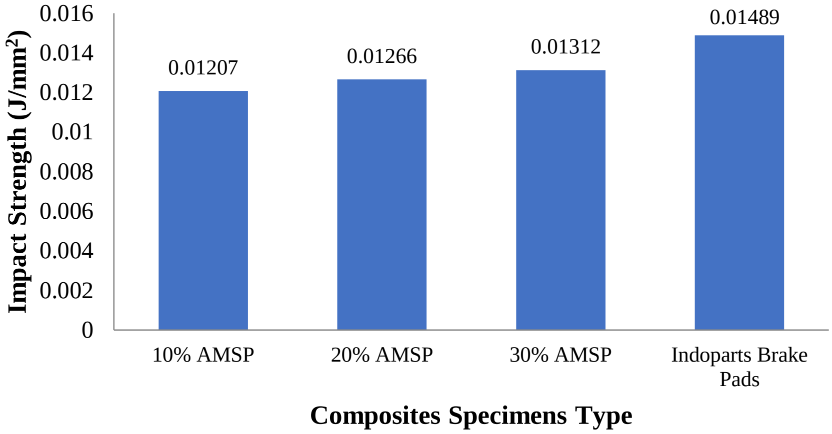


Figure 7. Graph the average value of the impact strength

Figure 8. Specimens impact testing results

Based on the results of testing the impact it can be seen the average value of the composite toughness variation 1 (0.01207 J/mm^2), variation 2 (0.01266 J/mm^2), and variation 3 (0.01312 J/mm^2). The average value of toughness increased in each variation. This increase can be seen in the increase in the percentage between each variation. The percentage increase in variation 1 and variation 2 is 4.88%, while the percentage increase in variation 2 and variation 3 is 3.63%. In this research, the composite which has the most optimum toughness/impact value is the volume fraction variation of 30% Aegle marmelos shell particles, 50% epoxy, and 20% aluminum powder. The more Aegle marmelos shell particles, the more optimum the toughness value will be. Research conducted by Arumuga Prabu et al. [30] states that the more particles of red mud are added, the value of the impact strength will increase. In line with the results of the impact testing research that has been carried out, the more volume fraction percentage of Aegle marmelos shell particles added, the higher the impact toughness/strength. This is following research conducted by Rampur et al. [31] that the composite with 30% Aegle marmelos shell particles and 0% coconut shell particles have the highest absorption energy value of 0.8 J. This value is directly proportional to the addition of shell particles Aegle marmelos and the reduction of coconut shell particles. The higher the impact strength occurs because the matrix and the particles are bonded together, and the filler composite treatment is given [32].

Based on the impact test value in Figure 7, which shows the average value of composite impact toughness/strength with variation 3 (0.01312 J/mm^2) which is closest to the average value of Indoparts brand brake lining hardness (0.01489 J/mm^2), the difference between the composite and the comparator brake pads is 13.49%.

3.3 Specific Wear Rate Wear

A wear test was performed to determine the wear value of a material. This test uses the Ogoshi wear test with the OAT-U type. The results of this test are the width of the wear stroke of the test material and then the average wear width is taken. In each test specimen, data were collected three times or three points to obtain valid data. The calculation of the specific wear value is following Eq. (2). The results of the calculation of the wear test value for variation 1 (specimens

A), variation 2 (specimens B), variation 3 (specimens C), and the brake pads of the Indoparts motorcycle brand (specimens K) can be seen in Table 7.

Table 7. Average of specific wear rate

Specimens Code	Specific Wear Rate (mm^2/kg)	Average Specific Wear Rate (mm^2/kg)
A1	4.035×10^{-6}	
A2	3.766×10^{-6}	3.545×10^{-6}
A3	2.834×10^{-6}	
B1	1.668×10^{-6}	
B2	2.937×10^{-6}	2.386×10^{-6}
B3	2.552×10^{-6}	
C1	1.321×10^{-6}	
C2	3.239×10^{-6}	2.008×10^{-6}
C3	1.464×10^{-6}	
K1	7.436×10^{-7}	
K2	7.063×10^{-7}	6.748×10^{-7}
K3	5.746×10^{-7}	

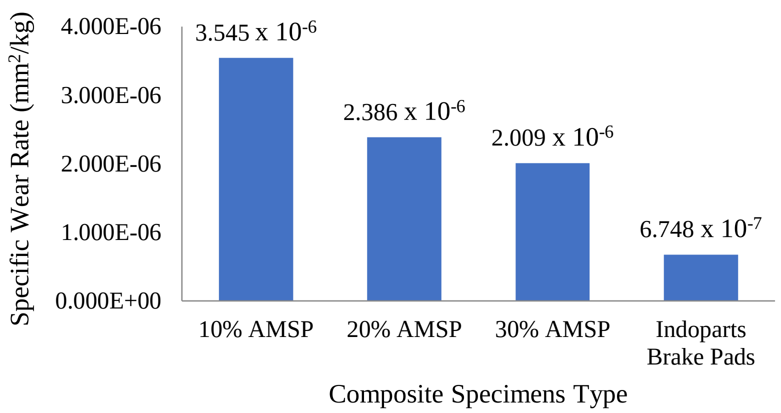
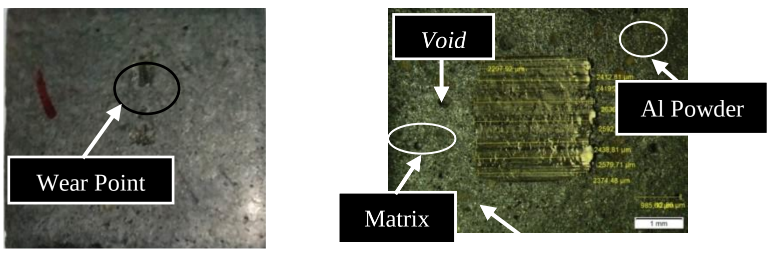


Figure 9. Graph of the average specific wear value



(a) (b)

Figure 10. (a) Specimens of the results of the Ogoshi wear test and (b) 50x magnification on wear width

Based on the results of the Ogoshi wear test it can be seen that the average value of the specific wear of the composite variation 1 is 3.545×10^{-6} mm^2/kg, variation 2 is 2.386×10^{-6} mm^2/kg, variation 3 is 2.008×10^{-6} mm^2/kg. The average value of wear decreased in each variation. This decrease can be seen in the decrease in the percentage between each variation. The decrease in the percentage of variation 1 and variation 2 is as much as 32.7%, while the decrease in the percentage of variation 2 and variation 3 is 15.8%. The results of the specific wear test show that there is a relationship between the specific wear value and the effect on the addition of the volume fraction of the Aegle marmelos shell particles. The specific wear value is also related to the hardness value of the material, the higher the hardness value of the test specimens, the lower the wear value. As with the research conducted by Liao et al. [33] that the smaller the wear value, the higher the hardness value. The wear rate gets smaller with increased hardness with the addition of filler [34]. This is because the hard material will be difficult to abrade so that the test specimens have good wear resistance.

The graph in Figure 9 shows the specific wear value with variation 3 having the lowest specific wear value compared to other composite variations. Variations with the addition of a volume fraction of 30% Aegle marmelos shell particles have a wear value of 2.008 x 10^{-6} mm^2/kg. This evidence is relevant to research conducted by Ademoh and Olabisi [35], that the more corn husk particles, the lower the hardness, tensile strength, compressive strength, wear value, and thermal conductivity of the composite.

Figure 10 represents the macro and micrographic image of AMSP composite specimens. Figure 10 (a) represents the macro image of AMSP composite specimens. The macro image shows the wear point of specimens, where the point of wear will be observed using a microscope to determine wear width. Figure 10 (b) represents the micrographic image of the AMSP composite specimens at 50x magnification. The AMSP particles evenly on the surface represent the reduced wear rate of the composite specimens. The process of making Aegle marmelos shell particles with a size of 80 mesh or 180 μm and the oven of Aegle marmelos shell particle affect the wear value of the composite material. As stated by Afolabi et al. [36] that the smaller the particles size of the natural particles, the smaller the wear value will be. In addition, the compaction process carried out when making specimens can also affect the density of the composite so that it will have low porosity and the composite material has optimal mechanical properties. This is also following the research of Sukanto et al. [37] that the wear properties of composites increase along with the high hardness, high density, and low porosity of the material.

Based on the graphic of the specific wear value in Figure 9, shows the average composite wear value with variation 3 (2.008 x 10^{-6} mm^2/kg) which is closest to the average value of Indoparts brand brake lining hardness (6.748 x 10^{-7} mm^2/kg) the difference between composite and comparator brake pads is still quite high at 66.4%. This can be because the manufacture of composite materials does not use the sintering process after the compaction process. The sintering process can increase the hardness value, so the wear value is also lower. In addition, the Indoparts brand brake pads are also given other metal materials, such as brass so that the Aegle marmelos shell particles (AMSP) composite material still has a higher wear value. Composite brake pads have to wear value requirements at the standard safety between 5x10^{-4} - 5x10^{-3} mm^2/kg. To obtain maximum results, it is recommended that further research add other metals and use the sintering process after the compaction molding process is carried out.

4.0 CONCLUSIONS

Based on the research, observations, explanations, and data analysis conducted, it can be concluded that the addition of the volume fraction of the Aegle marmelos shell particles affects the average value of hardness, toughness, and specific wear on composite specimens. The highest average value of hardness of Rockwell ball is found in the volume fraction variation of 30% of Aegle marmelos shell particles with a measure of 79.5 HRB. Meanwhile, the average hardness value of Indoparts brake lining specimens is 79.7 HRB. For the average value of absorption energy in the composite specimens, the highest was found in the volume fraction variation of 30% of Aegle marmelos shell particles with a value of 0.4275 Joule. The highest impact toughness/strength value in composite specimens was also found in the 30% volume fraction variation of Aegle marmelos shell particles with the impact toughness/strength value of 0.01312 $\mathrm{J/mm^2}$. Meanwhile, the toughness value of the Indoparts brand brake pad control specimens is 0.01489 $\mathrm{J/mm^2}$. Meanwhile, the lowest specific wear average value is found in the volume fraction variation of 30% of Aegle marmelos shell particles with a measure of 2.008 x 10^{-6} mm^2/kg. Meanwhile, the average specific wear value of Indoparts brake pad specimens is 6.748 x 10^{-6} mm^2/kg. That shows the value of hardness, toughness, and wear of the Aegle marmelos shell particles composite is close to the value of Indoparts brake pads so that the composite material can be recommended as an alternative material for motorcycle brake pads. The suggestions to be considered in further research are to use variations in particle size, the addition of other metals such as brass, compaction loads, and the use of the sintering process. Then, do research on the physical properties and other mechanical properties such as density, porosity, tensile strength, bending strength, coefficient of friction, and compressive strength.

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6.0 REFERENCES

[1] R. Vasquez and B. Farooq, "Multi-objective autonomous braking system using naturalistic dataset," *2019 IEEE Intelligent Transportation Systems Conference ITSC 2019*, pp. 4348–4353, 2019.

[2] V. V. Kumar and S. S. Kumaran, “Friction material composite: Types of brake friction material formulations and effects of various ingredients on brake performance-a review,” *Materials Research Express*, vol. 6, no. 8, 2019.

[3] P. Deepak, H. Sivaraman, R. Vimal, S. Badrinarayanan, and R. Vignesh Kumar, “Study of wear properties of Jute/Banana fibres reinforced molybdenum disulphide modified epoxy composites,” *Materials Today: Proceedings*, vol. 4, no. 2, pp. 2910–2919, 2017.

[4] D. Shinde and K. N. Mistry, “Asbestos base and asbestos free brake lining materials: comparative study,” *World Scientific News*, vol. 61, no. 2, pp. 192-198, 2017.

[5] B. Ergene and Ç. Bolat, "A review on the recent investigation trends in abrasive waterjet cutting and turning of hybrid composites," *Sigma Journal of Engineering and Natural Sciences*, vol. 37, no. 3, pp. 989-1016, 2019.

[6] M. N. P. Sastry, K. D. Devi, and D. Bandhu, “Characterization Aegle marmelos fiber reinforced composite,” *International Journal of Engineering Research*, vol. 5, no. 2, pp. 345-349, 2016.

[7] J. Sahari, S. M. Sapuan, E. S. Zainudin, and M. A. Maleque, “Mechanical and thermal properties of environmentally friendly composites derived from sugar palm tree,” *Materials Design*, vol. 49, pp. 285-289, 2013.

[8] C. Elanchezian, B. V. Ramnath, G. Ramakrishnan, M. Rajendrakumar, V. Naveenkumar, and M. Saravanakumar, “Review on mechanical properties of natural fiber composites,” *Materials Today: Proceedings*, vol. 5, no. 1, pp. 1785-1790, 2018.

[9] L. Prasad, G. Singh, and M. Pokhriyal, “A comparative study on physical and mechanical behaviour of functionally graded composite materials reinforced with natural fillers,” *Advances in Materials & Processing: Challenges & Opportunities* (AMPCO), vol. 5, no. 9, pp. 16990-16994, 2017.

[10] O. Shakuntala, G. Raghavendra, and S. K. Acharya, “Characterization of wood apple shell particles,” *Conference Proceedings of the Second International Conference on Recent Advances in Bioenergy Research, Springer Proceedings in Energy*, pp. 139-146, 2018.

[11] O. Gbadeyan, K. Kanny, and T. P. Mohan, “Influence of the multi-walled carbon nanotube and short carbon fibre composition on tribological properties of epoxy composite,” *Tribology-Materials, Surface & Interfaces*, vol. 11 no. 2, pp. 1-7, 2017.

[12] M. A. Maleque, A. Atiqah, R. J. Talib, and H. Zahurin, “New natural fibre reinforced aluminium composite for automotive brake pad,” *International Journal of Mechanical and Materials Engineering*, vol. 5, no. 2, pp. 166-170, 2012.

[13] K. Satikbaša *et al.*, “Effect of steel family fibers on friction and stiction behavior of brake pads,” *FME Transactions*, vol. 47, no. 4, pp. 856-864, 2019.

[14] S. Sathish, K. Kumaresan, L. Prabhu, and S. Gokulkumar, “Experimental investigation of mechanical and ftir analysis of flax fiber/epoxy composites incorporating sic, al2o3 and graphite,” *Romanian Journal of Materials*, vol. 48, no. 4, pp. 476-482, 2018.

[15] K. Bhar, S. Mondal, and P. Suresh, “An eye-catching review of Aegle marmelos L. (golden apple),” *Pharmacognosy Journal*, vol. 11, no. 2, pp. 207-224, 2019.

[16] S. Ojha, G. Raghavendra, and S. K. Acharya, “A comparative investigation of bio-waste filler (wood-apple coconut) reinforced polymer composite,” *Polymer Composite*, vol. 35, no. 1, pp. 180-185, 2014.

[17] N. C. Sandeep, H. Raghavendra Rao, and K. Hemachandra Reddy, “Extraction and Characterization of Physicochemical and Tensile Properties of Aegle Marmelos fiber,” *Materials Today: Proceedings*, vol. 4, no. 2, pp. 3158–3165, 2017.

[18] N. Saba *et al.*, “Recent advances in epoxy resin, natural fiber-reinforced epoxy composite and their appllications,” *Journal of Reinforced Plastics and Composite*, vol. 35, no. 6, pp. 447-470, 2016.

[19] C. Verma *et al.*, “Epoxy resins as anticorrosive polymeric materials: A review,” *Reactive and Functional Polymers*, vol. 156, p. 104741, 2020.

[20] R. Gottipati and S. Mishra, “Preparation of microporous activated carbon from *Aegle marmelos* fruit shell by koh activation,” *The Canadian Journal of Chemical Engineering*, vol. 91, no. 7, pp. 1215-1222, 2013.

[21] I. K. A. Atmika, I. D. G. A. Subagia, I. W. Surata, and I. N. Sutantra, “Hardness and wear rate of basalt/alumina/shellfish powder reinforced phenolic resin matrix hybrid composite brake lining pads,” *IOP Conference Series: Materials Science and Engineering*, vol. 539, no. 1, pp. 012012, 2019.

[22] ASTM E18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*, American Society for Testing and Materials, 2015.

[23] ISO 179-1, *Plastics–Determination of Charpy Impact Properties*, International Organization for Standardization, Geneve: Switzerland, 2010.

[24] Tokyo Testing Machine Mfg. Co., Ltd, *Ogoshi High Speed Universal Wear Testing Machnine Instruction Manual*. Manual Instruction Book, Japan.

[25] S. Ojha, S. K. Acharya, and G. Raghavendra, “Mechanical properties of natural carbon black reinforced polymer composites,” *Journal of Applied Polymer Science,* vol. 132, no. 1, pp. 1-7, 2014.

[26] R. O. Akaluzia *et al.*, “Evaluation of the effect of reinforcement particle sizes on the impact and hardness properties of hardwood charcoal particulate-polyester resin composites,” *Materials Today: Proceedings,* vol. 38 no. 2, pp. 570-577, 2021.

[27] S. Pujari and S. Srikiran, “Experimental investigations on wear properties of palm kernel reinforced composites for brake pad applications,” *Defence Technology,* vol. 15, no. 3, pp. 295-299, 2019.

[28] R. Soundararajan, S. Karthik, and S. Sivaraman, “Automotive brake pad by using, functionally graded hybrid composites and their behaviour,” *International Journal of Mechanical Engineering and Technology,* vol. 9, no. 9, pp. 318-328, 2019.

[29] Y. Sukrawan, A. Hamdani, and S. A. Mardani, “Effect of bamboo weight faction on mechanical properties in non-asbestos composite of motorcycle brake pad,” *Materials Physics and Mechanics,* vol. 42, no. 3, pp. 367-372, 2019.

[30] P. V. Arumuga *et al.*, “Usage of industrial wastes as particulate composite for environment management: hardness, tensile and impact studies,” *Journal of Environmental Chemical Engineering*, vol. 5, no. 1, pp. 1289-1301, 2017.

[31] V. V. Rampur, A. R. Banagar, U.L. Ganesh, C. V. Srinivas, and S.C. Reur, “Mechanical characterization of wood apple shell powder and coconut shell powder reinforced hybrid composite,” *AIP Conference Proceedings,* vol. 2247, no. 1, pp. 04001, 2020.

[32] B. T. Mulyo and H. Yudiono, “Toughness analysis of pineapple leaves fiber composite as alternative material for SNI helmet,” *Journal of Mechanical Engineering and Sciences,* vol. 13, no. 4, pp. 5961-5972, 2019.

[33] Z. Liao, N. Hua, W. Chen, Y. Huang, and T. Zhang, “Correlations between the wear resistance and properties of bulk metallic glasses,” *Intermettalics,* vol. 93, pp. 290-298, 2018.

[34] Z. S. Kiran, V. S. Babu, and K. V. L. Soma Sekhar, “Study of the microhardness and erosive wear behavior of organo-modified nanoclay filled glass-epoxy composites and optimization,” *Journal of Mechanical Engineering and Sciences,* vol. 13, no. 2, pp. 4794-4815, 2019.

[35] N. A. Ademoh and A. I. Olabisi, “Development and evaluation of maize husks (asbestos-free) based braked,” *Industrials Engineering Letters,* vol. 5, no. 2, pp. 67-80, 2015.

[36] M. Afolabi, O. K. Abubakre, S.A. Lawal, and A. Raji, “Experimental investigation of palm kernel shell and cow bone reinforced polymer composites for brake pad production,” *International Journal of Chemistry and Material Research,* vol. 3, no. 2, pp. 27-40, 2015.

[37] Sukanto, R. Soenoko, W. Suprapto, and Y. S. Irawan, “Characterization of aluminium matrix composite of Al-ZnSiFeCuMg alloy reinforced with silica sand tailings particles,” *Journal of Mechanical Engineering and Sciences,* vol. 14, no. 3, pp. 7094-7108, 2020.