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NATURAL ZEOLITE AS THE REINFORCEMENT FOR RESIN-BASED BRAKE PAD USING DUAL PARTICLE SIZE

ASEP BAYU DANI NANDIYANTO[1,*],
SILMI RIDWAN PUTRI[1], TEGUH KURNIAWAN[2]

[1]Departemen Kimia, Universitas Pendidikan Indonesia, Indonesia
[2]Departemen Teknik Kimia, Universitas Sultan Ageng Tirtayasa, Indonesia
*Corresponding Author: nandiyanto@upi.edu

Abstract

This study aims to evaluate the effect of natural zeolite particle size on brake pads. In the experiment, the natural zeolite particles used were 53 and 1190 µm in size with the composition (1/1; 2/1; and 1/2). Natural zeolite is combined with a mixture of Bisphenol A-epichlorohydrin resin and cycloaliphatic amine to make brake pads. Brake pads were analyzed using compressive strength, puncture strength, mass loss, wear rate, coefficient of friction, microscopy, X-Ray Diffraction (XRD), and SEM EDX. The experimental results show that brake pads with a mixture of small and large particle sizes (1/1) are good brake pads because they have good physical properties, compression test, puncture test, and friction test. Particle size affects interfacial bonding, number, and size of pores, mechanical properties, and reinforcement properties of brake pads. The brake pads with small particle size can increase the compressive strength of the brake pads, the pores are smaller and less, the mass loss is less, the friction coefficient is high, and the brake pad surface is smoother. However, the small particle size can also affect human health. This research is expected to provide new information on the use of natural zeolite for friction material in brake pads so that it can replace the use of asbestos in brake pads.

Keywords: Brake pad, Natural zeolite, Particle size.

1. Introduction

The brake system is a very important component in vehicles and machine tools in the industry. Brake pads convert the car's kinetic energy into heat energy through friction. When the brake pad is heated by encountering the rotor disc to provide stopping power, it begins to transfer a small amount of friction material to the disc or bearing [1]. The materials used in automotive brakes are known as friction materials. The brake friction material must exhibit a coefficient of friction that is stable and consistent with the brake disc [2]. The coefficient of friction must be high enough, but most importantly it must be durable during the braking process [3]. The friction material must have a stable level, independent of temperature, humidity, age, degree of wear and corrosion, presence of dirt and water spray from the road, etc. [4]. In addition, the friction material must also be compatible with the rotor material to reduce extensive wear, vibration, and noise during braking [5].

One of the friction materials for the braking process is asbestos. Brake pads generally consist of asbestos fibers embedded in a polymer matrix along with several other materials. Asbestos has several engineering characteristics that make it desirable for inclusion in brake pads. Asbestos is thermally stable up to 500°C, helps regenerate friction surfaces during use, is thermally insulating, strong and flexible, and, for the most part, inexpensive [6]. Asbestos is a well-known carcinogen responsible for pleural and peritoneal cancer (mesothelioma) and lung cancer [7]. Therefore, several countries prohibit the use of the asbestos language. Since the asbestos ban, researchers have struggled to find alternatives that are as efficient as asbestos, including maize husk [8], Fruit shell [9], palm kernel shell [10], Rice husks [11], and many others.

One of the friction materials for the braking process is natural zeolite. Natural zeolite minerals which are alumino-silicate compounds that are widely found in Indonesia are scattered in various areas such as the city of Pacitan [12], Lampung, and Banten [13]. The uses of zeolite include one of the adsorption materials [14], cement complementary materials [15], concrete composite mixtures [16], therapeutic materials anticancer [17], photocatalytic decolorization [18], soil remediation [19], and brake pads [20].

Zeolite contains silica which gives the bearing material a ceramic-like behavior [3]. Thus, zeolite can be considered as a natural organic-inorganic composite material and can potentially be used as a filler element in epoxy polymer composites [21]. Therefore, this study aims to evaluate the effect of natural zeolite particle size on brake pads. The experimental results show that natural zeolite with a composition of 1/1 has good physical properties, compressive test, and friction test. Particle size affects interfacial bonding, amount and pore size, mechanical properties, and reinforcement properties of brake pads. This research is expected to provide new information on the utilization of natural zeolite for friction material in brake pads so that it can replace the use of asbestos in brake pads.

2. Brake Pads Production

Many studies have been conducted on non-asbestos brake pads, including biomass-based brake pads. Table 1 shows the study of brake pads using biomass material, which gives significant results as an alternative of asbestos.

Table 1. Research on biomass-based brake pads.

The main material	Supporting component	Result	Ref.
Maize Huks (MH)	Silica sand, epoxy resin, calcium carbonate, anhydrous iron oxide, talc as a release agent, and powdered graphite.	Composite specimens with 30% MH content have a good coefficient of friction, abrasion resistance, oil and water absorption, density, hardness, tensile strength, compressive strength, and thermal conductivity.	[8]
Chamaerops Fruit Shell (CFS)	Epoxy resin (binder-matrix), Nano hematite (reinforcement), Nano Talc	The results showed that the CFS brake pad samples had resistance to oil and water absorption, the highest tensile and compression properties, and thermal stability.	[9]
Palm kernel shell (PKS)	(cooling) and Nano silicon oxide (abrasives)	The results confirm that the grain size of the PKS has a major influence on the compressive strength, hardness, porosity, and wear rate of the brake pads.	[10]
Rice Huks (EH)	Bisphenol A-epichlorohydrin and cycloaliphatic amine	Small particles of rice husk increase the compressive strength, puncture strength, and bulk density.	[11]
Corn husks (CH)	phenolic resin, steel slag, iron waste dan carbon black	Brake pads produced with finer corn husks provide better compressive strength, porosity hardness, and wear rates.	[22]
Cashew Nut Shells (CNS)	Phenolic Resin (Phenol-Formaldehyde), Silicon Carbide, Steel Dust, dan Graphite	The resulting composite has favorable properties, resistance to pressure, coefficient of friction, wear rate, and exhibits the good thermal capacity of the brake pads.	[23]
Canarium Schweinfurthii Shells (CSS)	Nigerian Gum Arabic grade, Silicon Carbide, Graphite, and Steel Dust	Research findings using CSS show that CSS particles can effectively and efficiently replace asbestos in the manufacture of brake pads.	[24]
Periwinkle's shell (PS)	Calcium carbonate, epoxy resin, and graphite	There is good interfacial bonding, wear rate increases with load, and PS particle size increases. Periwinkle shells can withstand higher temperatures than asbestos.	[25]
Banana peel (BP)	Phenolic resin (phenol-formaldehyde)	The results showed that the friction coefficient increased at higher temperatures and friction and wear characteristics indicated that banana peel powder could be used effectively to increase the binding ability of phenolic resins at higher temperatures.	[26]
Sawdust	Phenolic Resin, $CaCO_3$, $Ca(OH)_2$, Graphite Sb_2S_3, MOS_2, All_2O_3, MgO, SiC, Steel wool, PAN fiber, dan $CaSiO_3$	The sawdust brake pads obtained were compared with commercial brake pads (asbestos-based) and showed a close correlation.	[27]

3. Method

3.1. Brake pads production

The raw materials used in this study were natural zeolite (taken from Banten, Indonesia), bisphenol A-epichlorohydrin (Indonesia), and cycloaliphatic amine (Indonesia). Natural zeolite was ground and placed in a sieve mesh to obtain particles of 53 and 1190 μm in size. Bisphenol A-epichlorohydrin and cycloaliphatic amine were mixed in a mass ratio of 1:1 to make an epoxy mixture. After that, the epoxy mixture was mixed with zeolite particles with a 1:1 composition. The brake pads are made using a mixture of zeolite measuring 53 and 1190 μm with a composition of 1/1; 2/1; and 1/2. After that, the prepared mixture was poured into silicone molds (2.5 x 2 x 2 cm) and dried indoors for two days (avoid exposure to sunlight).

3.2. Physical properties

The analysis was supported by several characterizations, including analysis of sample morphology by a scanning electron microscope (SEM) instrument and analysis of the sample phase using X-Ray Diffraction (XRD). The analysis of particle size using SEM was done using the same procedure with the previous study [28], and that using XRD analysis was done using the previous literature [29]. Physicochemical properties of natural zeolite particles were also analyzed using a Digital Microscope (BXAW-AX-BC, China).

3.3. Mechanical properties

3.3.1. Bulk density

Bulk density is the ratio between the mass of a mixed sample and its volume. In addition, the bulk density of the prepared brake pads is calculated using Eq. (1)

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

where m is the brake pad's mass and V is the volume of the brake pad.

3.3.2. Compressive test

The compression test was carried out with a Screw Mount Tester (Model I ALX-J, China) equipped with a digital force gauge (Model HP-500, Serial, No. H5001909262). The test involves applying a compressive force to the brake pads producing a curve. The peak value of the curve is used to determine the hardness during the test.

3.3.3. Puncture test

The friction test was carried out by 1) removing the resin layer on the surface of the brake pads, 2) the friction test was carried out by sliding the brake pads on sandpaper for 20 minutes at a speed of 24 cm/s. The brake pad mass is recorded every 2 minutes. The wear rate (M) is calculated using Equation (2):

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

where M_a is the brake pad initial weight (g), M_b is the brake pad final weight (g), t is the testing time (s), and A is the frictional cross-section area (mm^2).

3.3.4. Coefficient fiction

The friction coefficient (μ) was calculated using Eq. (3):

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

where μ is the brake pad friction coefficient, f is friction force, and N is applied force.

4. Results and Discussion

4.1. Physical appearance of brake pads

4.1.1. Microscope analysis

Figure 1 shows the prepared brake pads. Natural zeolite-based brake pads reinforced by epoxy have a green color. Particle size affects the color, size, and several cavities (shafts) in the brake pads. Brake pads with small particle sizes (53 µm) appear to have a darker color than brake pads with large particle sizes. In addition, samples with particle size composition (1/1; 1/2; and 2/1) showed different properties. Brake pads with a composition of 1/1 have mixed characteristics between small and large particle sizes. While brake pads with a composition of 1/2 or 2/1 have characteristics according to the composition of the material that is more dominant. When a certain particle size is dominantly used in a mixture, the mechanical properties are identical to those of the particle size [11].

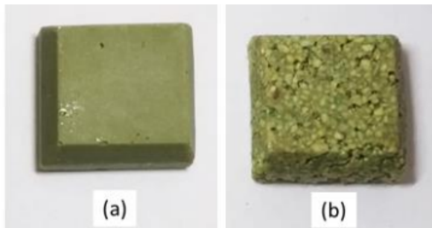
Based on observations (see Fig. 2), brake pads with small particle sizes (53 µm) have fewer and smaller pores than brake pads with large particle sizes. Porosity is a characteristic of the pore structure present in a material. Porosity acts as an absorber of energy and heat generated in the braking process. In the braking process, it is important to maintain porosity to obtain a compact and dense composite material that improves mechanical properties [6].

4.1.2. X-Ray Diffraction (XRD) and SEM EDX.

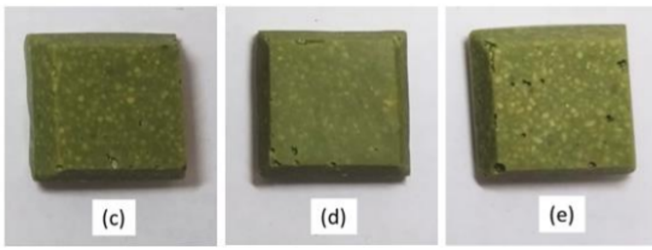
Figure 3 shows the XRD comparison results of natural zeolite with zeolite standards. The diffraction pattern of natural zeolites was compared with the standard zeolites diffraction patterns according to the IZA (International Zeolite Association) which can be found in the literature [30]. The peaks intensity was relatively lower than the synthetic zeolites, which suggested that the natural zeolites have lower crystallinity. The clinoptilolite phase most likely was the dominant phase as almost all peaks were clearly detected. The quantitative XRD method is required to determine the percentage of each zeolite's phase. Overall, this is in agreement with literature that reported that the natural zeolites were identified as mordenite and clinoptilolite [31]. It is most likely those two zeolites phase intergrow during the natural hydrothermal or sedimentation process [32].

Figure 4 presents the SEM EDX. Elemental composition based on SEM EDX analysis is shown in Table 2. There are two types of natural zeolite element composition, major and minor components. Silica was the major component with 68.45% wt. followed by alumina with 15.46%. wt (Fig. 5). Thus, the mol ratio of

Si to Al of natural zeolites was nearly 4. Minor components detected were FeO, K_2O, CaO, and MgO (Fig. 6). It is most likely the balanced cations within the zeolite framework were K^+, Ca^{2+}, and Mg^{2+}.

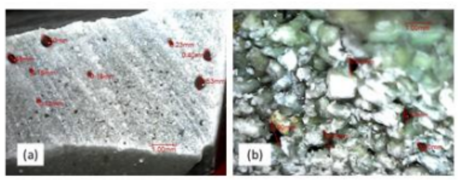


(a) 53 µm. (b) 1190 µm.

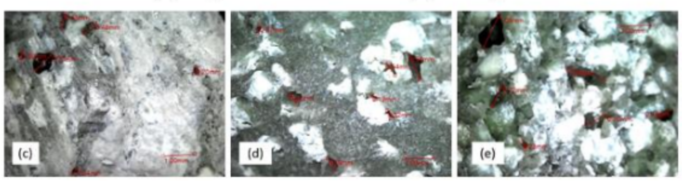


(a) composition ratio 1/1. (d) 2/1. (e) 1/2.

Fig. 1. The photograph of prepared brake pad samples: (a)53 µm, (b) 1190 µm, (c) 1/1, (d) 2/1, dan (e) 1/2.



(a) 53 µm. (b) 1190 µm.



(a) composition ratio 1/1. (d) 2/1. (e) 1/2.

Fig. 2. Microscope observation brake pad samples: (a)53 µm, (b) 1190 µm, (c) 1/1, (d) 2/1, dan (e) 1/2.

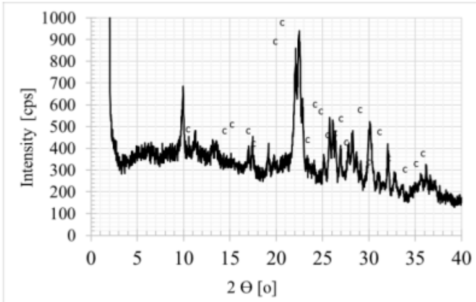


Fig. 3. The X-ray diffraction (XRD) of natural.

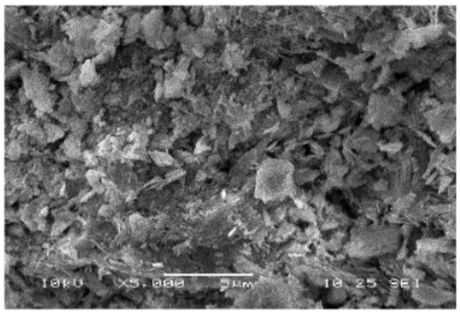
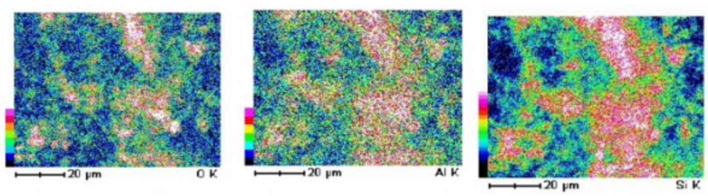
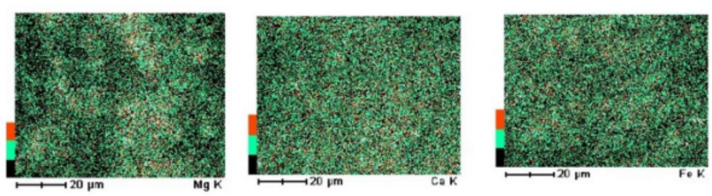


Fig. 4. The SEM image of natural zeolites.



(a) (O). **(b) (Al)** **(c) (Si).**

Fig. 5. Major components detected in the zeolite.



(a) (Mg). **(b) (Ca).** **(a) (Fe).**

Fig. 6. Minor components detected in the zeolite

Table 2. Elemental composition based on SEM EDX analysis

Element	(kaV)	Mass%	Error%	Al%	Compound		Mass	Cation
O		47.36						
Mg K	1.253	0.61	0.75	1.65	MgO	1.01	0.20	0.8622
Al K	1.486	8.13	0.80	9.91	Al_2O_3	15.36	2.44	12.8234
Si K	1.739	32.00	0.83	74.96	SiO_2	68.45	9.24	58.4528
K K	3.312	4.24	0.75	3.57	K_2O	5.11	0.88	9.8096
Ca K	3.690	1.89	1.01	3.11	CaO	2.65	0.38	4.5919
Fe K	6.398	5.77	1.95	6.80	FeO	7.42	0.84	12.4602
Total		100.00		100.00		100.00	13.98	

4.3. Mechanical properties

4.2.1. Bulk density

Table 3 shows the effect of particle size and variations in the composition of natural zeolite on brake pads. The density value depends on the components in the brake pads material. Brake pads with small particle sizes (53 µm) have the largest bulk density value compared to large particle sizes. This is because the zeolite particles and the epoxy mixture interact physically, the 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. This is in line with previous research [11].

4.2.2. Compressive test

Compression testing involves applying a compressive force to the brake pads, which results in a curve (indicating the texture profile of the brake pads). The peak value of the curve is used to determine the hardness during the test. Figure 7 shows the compressive test value of natural zeolite brake pads.

The results show that the highest compression test value is shown in brake pads with a composition of 1/1 of 51.4 N while the lowest compression test values are indicated by brake pads with a small particle size of 36.1 N. When the same particle size is used, the particles are spread evenly, making them more compact and resistant to pressure. In the compression test, the low interface strength can cause the stress to not transfer properly and crack propagation in the brake pad [11].

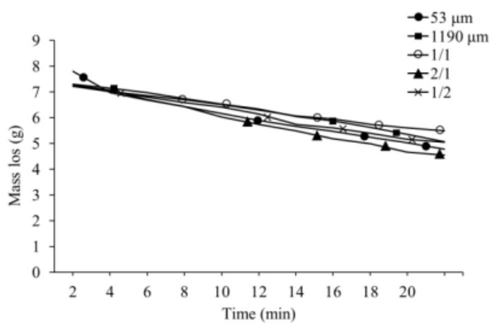


Fig. 7. Compression test results on zeolite brake pads.

4.2.3. Puncture test

Table 3 shows the puncture test values on brake pads with variations in particle size and different compositions. The lowest puncture test value is indicated by brake pads with a small particle size (53 μm), while the highest puncture test value is indicated by brake pad 1/2. When the same particle size is used, the particles are spread evenly, making them more compact and resistant to pressure. For samples with different particle size ratios, different mechanical properties were observed. When a certain particle size is used predominantly in a mixture of various particle sizes, the mechanical strength follows the properties of the particle size. The puncture test results show that the characteristics of the brake lining are influenced by the particle size of the matrix. Brake pads with a single particle size tend to have a low puncture test value. While the natural zeolite brake lining with a mixture of particle sizes has a high puncture test value. This difference can be caused by the amount of composition and surface area of the zeolite. The mechanical characteristics of the material were influenced by the compositions of the substance [11].

Table 3. The puncture strength result, compressive test, and bulk density.

Sample	Bulk density of particles (g/cm^3)	Compressive test (N)	Puncture test
53 μm	1.3541	39.6	83.8571
1190 μm	1.0846	36.1	89.0000
1/1	1.2736	51.4	91.4285
2/1	1.3245	36.4	89.7142
1/2	1.2281	42.4	94.5714

4.2.4. Friction test

Figure 8 and Table 4 show the results of changes in the mass of the brake pads in the friction test. During testing the brake pads are forced to touch the dregs (as a drum/disc model) which results in a change of kinetic energy into heat energy. The amount of mass loss for small, large, 1/1, 2/1, and 1/2 samples is 0.01 ± 0.0165; 0.01 ± 0.0145; 0.01 ± 0.0105; 0.01 ± 0.0205; and 0.01 ± 0.0195 g/min. Brake pads made predominantly with small particle size (2/1) lose more mass and produce more dust. Pores in large samples and 1/2 (samples dominated by large particle size) make the surface of the brake pads rougher, and large and many pores also make the brake pads unstable during friction tests. Smaller particles can also shift to fill the pores during the friction test, making the structure unstable.

The heat generated during the process also aids the shifting process as it makes the epoxy structure softer. As the bearing heats up during braking, the resin tends to expand at very high temperatures; and the resin turns into glassy carbon. Carbonized resin weakens the matrix and accelerates brake pads wear [3]. Porosity is very important in automotive brake pad materials because it absorbs energy and heat. Higher porosity results in a faster cooling rate of the friction material due to the larger volume of inflow and fluid flow. After the application of the wet friction material, the liquid trapped in the pores must be immediately released from the friction material. The combined particle 1/1 has a better particle distribution than other brake pads.

Despite using different particle sizes, different characteristics can be observed when using the same ratio. Each particle contributes differently to the mechanical strength, thus exhibiting different properties. The addition of larger particles makes the brake pad more susceptible to compression and puncture forces. As a result, the addition of a smaller particle size makes the brakes more resistant. In addition, the particle size affects the coefficient of friction. The coefficient of friction is defined as the ratio of the force required to move two sliding surfaces over each other, and the force holding them together Brake pads with small particle size (53 μm) have a lower coefficient of friction than other brake pads. Particle size is an important factor that must be investigated to understand how particles can affect human health, especially in brake pads [11].

In addition, for getting more understanding regarding the effectiveness of this method for improving brake pads, we must control morphology, adjust number of components, as well as add some other materials to the brake pads, and it will be done in our future work. Indeed, the improvements must be supported by understanding and searching more literature, in which this will be conducted based on previous studies [33-38].

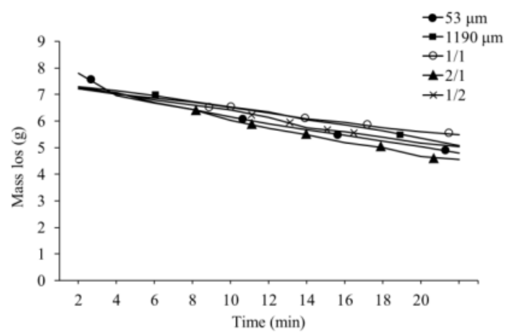


Fig. 8. The mass loss on the variation of zeolite particles size in brake pads.

Table 4. The puncture test result, compressive test, and the bulk density.

Sample	Ma (g)	Mb (g)	Mass loss rate (g/min)	t(s)	A (mm^2)	M ($g/s.mm^2$)	Friction coefficient
53 μm	7.30	4.79	0.01±0.0165	1200	0.529	0.03954	0.001202
1190 μm	7.42	5.07	0.01±0.0145	1200	0.529	0.03701	0.000027
1/1	7.24	5.49	0.01±0.0105	1200	0.529	0.02756	0.000085
2/1	7.28	4.56	0.01±0.0205	1200	0.529	0.04284	0.000125
1/2	7.28	5.05	0.01±0.0195	1200	0.529	0.03512	0.000103

5.Conclusion

The experimental results show that brake pads with a mixture of small and large particle sizes (1/1) are good brake pads because they have good physical properties, compression test, puncture test, and friction test. Particle size affects interfacial bonding, number, and size of pores, mechanical properties, and reinforcement properties of brake pads. The brake pads with small particle size can increase the compressive strength of the brake pads, the pores are smaller and less, the mass loss is less, the friction coefficient is high, and the brake pad surface is smoother.

However, the small particle size can also affect human health. This research is expected to provide new information on the use of natural zeolite for friction material in brake pads so that it can replace the use of asbestos in brake pads.

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