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# Fabrication of Aluminium Matrix Composite Powder Reinforced with Silicon Dioxide Tailings for Non-Asbestos Brake Pads (NOB)

Sukanto[1*], Ilham Ary Wahyudie[1], Erwanto[1], Yudi Oktriadi[1], Rodika[1], Ricky Irwansyah[1], Husman[1], Devrin Dwiki Saputra[1], Haradat Tahrir Algaza[1]

[1] Department of Mechanical Enginering, Bangka Belitung State Manufacturing Polyteknic.

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Corresponding Author:
Sukanto
sukanto@polman-babel.ac.id

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**Abstract:** Tin mining tailings consist of 80-90% sand and the rest mud. The high levels of Silicon Dioxide (SiO2) in these tailings are hard and can be used as an added material in the manufacture of composites. This research aims to study the physical and mechanical properties of metal matrix composites reinforced with SiO2 powder processed by powder metallurgy, as an effort to provide a replacement material for Non-Asbestos (NOB) motorbike brake linings. The impact of hot compaction pressure in the form of two pressing directions, including 4600, 4500 and 4400 Psi, with a pressing hold of 15 minutes and sintering which includes 30, 20 and 10 minutes, at a temperature of 600 $^{o}$C was studied for its effect on hardness and density. Mechanical blending was used with a horizontal ball mill in the ratio of 10:1 at a speed of 90 rpm for 4 hours. The test results showed that the greater the hot compaction pressure and the longer the sintering, the higher the hardness and density values. The highest hardness reached 81.7 HB and the highest density of 2.385 g/cm3 occurred at a bidirectional hot compaction pressure of 4600 Psi, with the lowest wear rate of 0.333 mm3/m. This occurs as a result of the increase in hot compaction has an impact on increasing the contact between powder particles resulting from mechanical alloying to be tighter as a result of which the cavity and porosity decrease.

**Keywords:** Compaction-heat; Density; Hardness; Time-sintering

## Introduction

A total of 67 countries have agreed to ban the use of asbestos-based materials (INA-BAN, 2021), as it has allegedly caused 1,600,000 deaths in Indonesia (INA-BAN, 2017b), however, until now the Indonesian government has not banned it. Since 2003, WHO, the World Health Organisation, has informed that 107,000 people die each year from meshotheliome, an asbestos-related disease (INA-BAN, 2017a). In addition, this asbestos-based material has caused lung cancer and resulted in the death of 230,000 people each year (Arachi et al., 2021; Daly, 2024; Kanarek & Anderson, 2018).

Asbestos-based materials produce fine fibres that can float in the air, so they are easily inhaled by humans, which can lead to dangerous lung diseases (Zandwijk et al., 2020; (Poland & Duffin, 2019). Various parties, such as researchers, the automotive industry, and practitioners have been looking for alternative friction brake replacement materials that are free of asbestos or Brake-Non-Asbestos (NOB) (Shinde et al., 2020; Joshia et al., 2023), such as polymer matrix (resin) composite materials with alloy metal powder reinforcement, for example with iron powder, steel, aluminium, copper powder and others (Kumar et al., 2021); Praveenkumar & Gnanaraj, 2020), or reinforced with carbon powder (Saindane et al., 2021; Selvaraj et al., 2021).

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Some researchers have investigated metallic matrices, while others have investigated ceramic or agro waste ash-based reinforcements, which are processed using stir casting (Kulkarni et al., 2019; Kulkarni et al., 2019). Various fabrication and research efforts on brake linings mentioned above, until now, have not been able to provide suitable brake lining products, because the original brake linings from the principle have a relatively higher price compared to brake linings with a relatively short service life at a relatively cheap price (Dumas, 2016).

Some types of brake linings have widely used bagasse waste or Baggase Ash (BA) and rice husk waste or Rice Hush Ash (RHA) Both types of agricultural waste are very potential to be used as alloys for strengthening friction components (Yekinni et al., 2019; Udoye et al., 2020), because Baggase Ash and Rice Husk Ash contain abrasive silica compounds (SiO2) up to 60%, with a hardness of 7 MOH. Some non-asbestos brake lining reinforcement research has been conducted by combining Silica (SiO2) sand waste from tin mine tailings, BA and RHA agricultural waste with SiC, Al2O3 ceramics with a hardness of up to 9 MOH (Sain, 2021), potentially meeting the specifications required for friction materials.

Tailings are the residue of leaching in mining or tin ore excavation materials containing 80-90% sand and the rest in the form of tailings mud disposed of by miners. This former tin mining area has abundant reserves of silica sand containing SiO2 or called tailings silica sand, with an estimated area of 64,255 Ha of the former tin mining area of 124,838 Ha (Sukarman & Gani, 2017). Apart from being a water filter Suparno & Simamora (2023), considering that this tailings has a high SiO2 content, it can be used as a reinforcing mixture material in the manufacture of Aluminium Metal matrix composite-based materials.

This research is designed with powder metallurgy process technology, where this process has several advantages, such as more efficiency for material use, which is 97% (minimum) of the finished product, able to be applied to small products even though the shape is complicated and the production process can be carried out at low temperatures (Angelo & Subramanian, 2015; Suprapto & Soenoko, 2024).

Aluminium Metal is the second most widely used metal after iron and steel, because Aluminium Metal has various advantages compared to other metals, such as being lightweight, its density is 2.7 g/cm3, or one third of the density of alloy steel or copper, However, engineered aluminium alloys are capable of having a tensile strength equivalent to steel, which reaches 90 Mpa - 450 Mpa (Ibrahim et al., 2019). So that aluminium alloys can produce strong but lightweight constructions, which are very profitable to be applied to several mobile vehicles, such as fleets of marine vehicles to aircraft as well as land vehicles (motorcycles, cars and trains), (Garg et al., 2019). In addition, the processing of recycled aluminium scrap material only consumes about ±5% of the energy of primary aluminium processing, or saves ±95% (Brough & Jouhara, 2020; Bulei et al., 2020), which only requires about 2.8 kWh/kg of energy, compared to producing primary aluminium from bauxite ore material which needs 45 kWh/kg of energy (Shamsuddin, 1986). In addition, aluminium is therefore the most widely used metal for matrices in the manufacture of metal matrix composites compared to other metals (Bhoi et al., 2020).

Using the hot compaction method, focusing on variations in the composition of the reinforcing fraction, the results show that the 20% silica sand reinforcing fraction obtained the highest hardness of 78 HB (Sukanto et al., 2020) and has met the technical specifications of brake lining materials required by motorbikes, based on SNI 09-0143-197 standards (SNI, 1987). Similar research with a focus on mixing time using Mechanical Alloying technology, where mixing the powder for at least 24 hours has resulted in a change in the phase of SiO2 and Al so that it becomes Alumina after the powder mixture is sintered, resulting in an increase in frictional resistance and hardness of the resulting composite (Sukanto et al., 2022).

A 70% aluminium matrix composite, with a weight fraction of 20% SiC combined with 10% weight Al2O3 is recommended as a replacement for conventional brake pads. The result is a thermal conductivity of 93.3 W/m.K, compressive strength of 1343.3 MPa, wear resistance of 43.22 cm3/cm (Babalola et al., 2022). Samples containing 12 wt% elaeocarpus ganitrus seed powder provide better properties than using other sample composites, because they are very helpful for human health, so this research can be an alternative to asbestos in the manufacture of brake pads (Afiefudin & Widodo, 2023). Wang et al. wrote that research gaps, major challenges in research, and promising potential applications in the future were discussed and articulated in this article (Wang et al., 2024). Research related to aluminium matrix composites reinforced with carbon fibre has also increased recently, where in their research, Yang et al. concluded that the helical structure reinforcement phase of metal matrix composites has higher strength and toughness when compared to the metal matrix itself (Yang et al., 2024).

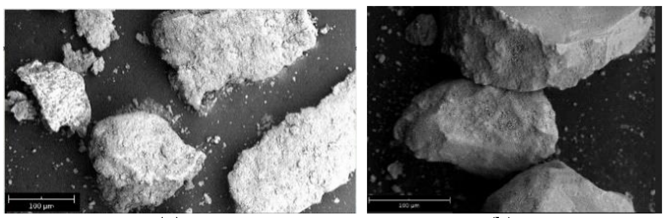
In more detail, research by Nawangsari et al. 2023 concluded that the factor of 5 tonnes of compaction pressure, 165 °C temperature, and 10 hours time showed the optimal parameters to produce the best hardness and porosity values of the sample. The predicted value of hardness and porosity with optimal parameters designed with the Taguchi Method shows consistent /

in accordance with the results of experimental confirmation is with 95% (Nawangsari et al., 2023). This study aims to determine the effect of rice husk powder particle size, and structural mechanism on non-asbestos brake composites. The ratio of reinforcement and matrix as follows 20:80; 30:70; 40:60 with carbonised and uncarbonised conditions. The expected result is that the best wear properties produced from rice husk powder composite brake linings are close to commercial asbestos-based brake linings. The results show that with a particle size of 100 mesh and 20% reinforcement has good wear resistance compared to other fraction composites (Primaningtyas et al., 2019).

Therefore, in this report, the results of research related to environmentally friendly Non-Asbestos friction brakes are presented and in general this friction or friction brake material is very important and must be conveyed early, namely from high school, where students must be given knowledge about the theory and practice of friction (Kamariyah et al., 2023).

## Method

The material used in this research is recycled aluminium powder Zay et al (2014) produced by σβγ Laboratory Malang. The Aluminium Metal powder material used in the manufacture of this composite has technical specifications of 74% Aluminium, 23% Cu (FeO2) and 3% Si. While silica sand tailings from tin mining waste has a chemical composition of 83% SiO2, 12% Fe2O3 and 5% Titanium Oxide. The powder based on the Particle Size Analyzer (PSA) D50 test is 204 microns as the matrix shown in Figure 1 (a) and the powder or silica sand with D50 is 164 microns as the reinforcement shown in Figure 1 (b).



(a) (b)

**Figure 1**. Scanning Electron Microscope image of powder (a) Matrix powder (b) $SiO_2$ reinforcement powder

After powder preparation is carried out (Sukanto et al., 2019) then the mechanical alloying process with a universal ball mill machine with a speed of 90 rpm and carried out for 4 hours. The mechanical alloying process is carried out on the matrix powder and reinforcing powder for 4 hours in the hope that the powder can be mixed perfectly into a solid alloy. Furthermore, the powder was measured again with PSA, the result at D50 was 106 microns, as shown in Figure 2 below. After the Mechanical Alloying process is complete, then compressed two-way pressing force with several variations, namely 4600, 4500 and 4400 Psi at a temperature of 500 $^oC$ with a holding time of 15 minutes. While Sintering is done with a temperature of 600 $^oC$ held for 10 minutes, 20 minutes and 30 minutes.

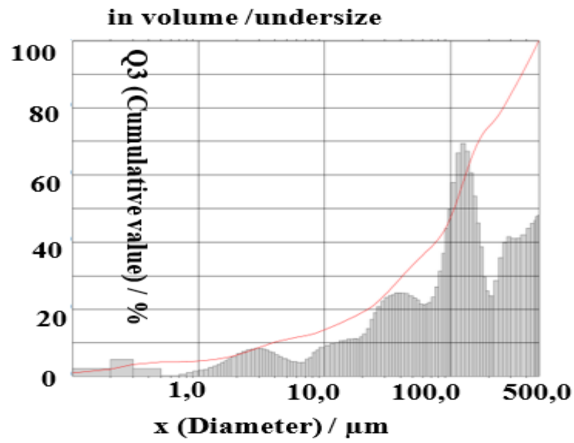



**Figure 2**. Particle Size Analyser Distribution Chart of the 4-Hour Mechanically-Fused Powder

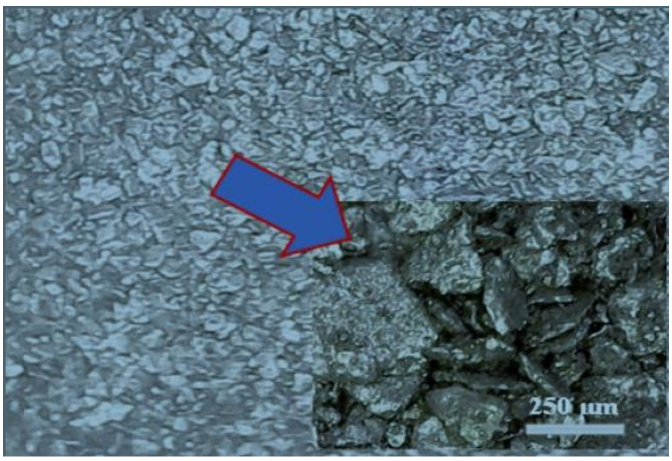



**Figure 3**. Microphoto image of powder resulting from mechanical alloying for 4 hours.

After the hot compaction and sintering processes are carried out, the specimens are then subjected to density tests, hardness tests and friction ability tests. The density test uses the Archimedes method ASTM B962-17 (I. ASTM, 2013). First the sample is weighed dry and then weighed in water using a basket or picnometry, and then the calculation is carried out by the formula, as shown in equation 1-1 below. The composite density (ρ_Composite) of the sample is calculated on the dry scale (wa), divided by the dry scale minus the wet scale (wb) multiplied by the density of distilled water, where (wsa) is the weight of the picnometry.

$$\rho_{composit} = \frac{w_a}{w_a-(w_{sa}-w_b)} x \rho_w \quad (1\text{-}1)$$

The hardness test used ASTM E110-14 (Astm, 2017), which uses a microhardness tester for metal-matric composites. Hardness testing with this method is more suitable for composites made of metal alloys and ceramics. While the friction test uses the pin-on-disc method with ASTM: G99-17 (G.-17. ASTM, 2023). This wear test uses a 28 mm diameter 3 mm thick friction disc at a machine rotation of 370 rpm, or a roll speed of 0.542 m.s-1. The friction roll disc material was made of hardened steel 25 HRC with a hardness (Ra) of 4.57 µm. The applied friction test load was 19.6 N (2 Kg) for 2 minutes. The abraded volume can be calculated by equation 1-2. When the abraded volume (W) is [mm3], B is the thickness of the revolving disc [mm], b is the width of the abraded gap [mm], r is the radius of the disc, and w is the rotating speed, the wear rate (V) can be calculated by equation 1-3. Where the wear rate is calculated by comparing the abraded divided by the distance travelled (x), or it can also convert it into specific gravity (ρ) and mass (m), [zhang et eal 2019]. Each specimen was tested 3 times and then averaged.

$$w = \frac{B\, b^3}{12\, r} \quad (1\text{-}2)$$

$$V = \frac{W}{x} = \frac{B.b^3}{12.r.x} = \frac{m}{\rho.x} \quad (1\text{-}3)$$

## Result and Discussion

*Density and Hardness of Compressed Specimens*

The specimen size is the inner diameter d = 20 mm, the outer diameter is D = 50 and the average thickness is 8 mm, as shown in Figure 4. Making specimens using the full factorial method with a total of 9 specimens and then repeated 3 times so that there are 27 specimens shown in Figure 5.

Figure 4. Composite Moulds and Specimens

The numbering in Figure 5 is using codes 1 to 27, a combination of the amount of compaction pressure with sintering holding time, where 4600, 4500 and 4400 Psi are the compaction pressure and 30, 20 and 10 are the sintering holding time, the specimen time is repeated, each up to 3 times so that the detailed codefication is as shown in Table 1.

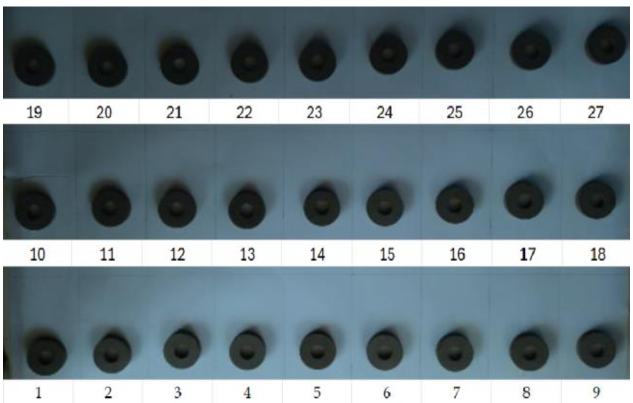



**Figure 5**. Full picture of the 27 specimens

**Table 1**. Codefication of Composite Specimens

| Sintering Pressure/Time/Repeat Specimen Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4600/30/3 | 4600/20/3 | 4600/10/3 | 4500/30/3 | 4500/20/3 | 4500/10/3 | 4400/30/3 | 4400/20/3 | 4400/10/3 |
| 4600/30/2 | 4600/20/2 | 4600/10/2 | 4500/30/2 | 4500/20/2 | 4500/10/2 | 4400/30/2 | 4400/20/2 | 4400/10/2 |
| 4600/30/1 | 4600/20/1 | 4600/10/1 | 4500/30/1 | 4500/20/1 | 4500/10/1 | 4400/30/1 | 4400/20/1 | 4400/10/1 |

Based on the codification, the compaction process is carried out and after 14 days of compaction, the specimens are tested for density and hardness, considering that if it is less than 14, the specimen is still unstable or still continues to change. The results of the density and hardness tests on the 27 specimens were then averaged according to the compression pressure, and are shown in Figure 6 below. From the figure, it can be seen that the lower the compression pressure, the lower the density and hardness, with the highest density value of 2.15 g/cm3 and hardness at 51.25 HRB.

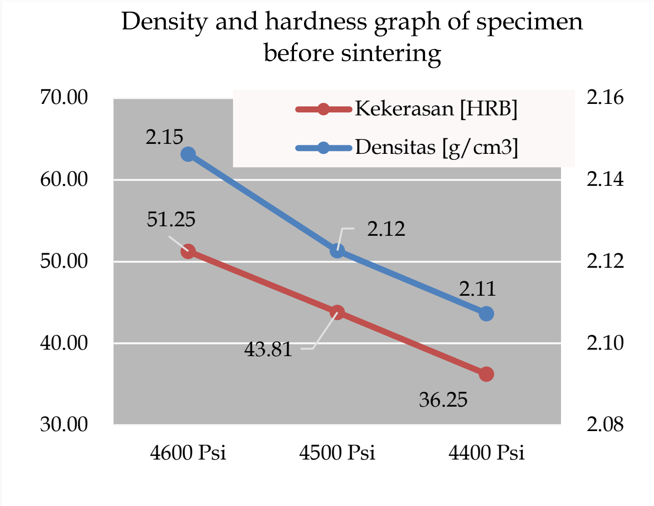



**Figure 6**. Graph of density and hardness of specimen's before sintering.

*Density and Hardness of Sintered Specimens*

After sintering at 600 ºC with varying holding times of 10, 20 and 30 minutes, density and hardness testing was then carried out. The sintering temperature was taken at 600 ºC due to a shift in the melting point which is most likely not 660 ºC, but has shifted slightly up between 670-680 ºC, because the matrix material used is recycled with a portion of 12% Si.

The theory used in determining the sintering temperature refers to Suprapto and Soenaka's book [24] which states that the appropriate sintering temperature is between 70-90% of the boiling point temperature of aluminium or its matrix. The results of the density test and hardness test as shown in Figure 7 below, Graph of Density and Hardness of Specimens after Sintering, which shows that the higher the sintering temperature and holding time when sintering shows the highest niali, yaoti at a hardness of 81.70 and at a density of 2.30 g/cm3.

*Wear Rate of Sintered Specimens*

After sintering at 600 ºC with varying holding times of 10, 20 and 30 minutes, density and hardness tests were conducted. The sintering temperature was taken at 600 ºC due to a shift in the melting point which is most likely not 660 ºC, but has shifted slightly up between 670-680 ºC, because the matrix material used is recycled aluminium with a portion of 12% Si.

In addition, wear rate testing was also carried out for special specimens that have a certain hardness, namely specimens with 4400 Psi hydraulic press pressure with sintering for 10 minutes, 4500 Psi with sintering for 20 minutes, and specimens with 4600 Psi compaction pressure with sintering for 30 minutes. The wear test results are as shown in the following graph. Based on the graph, it can be seen that the higher the compaction pressure applied, as well as the longer the sintering waiting time, the lower the wear rate

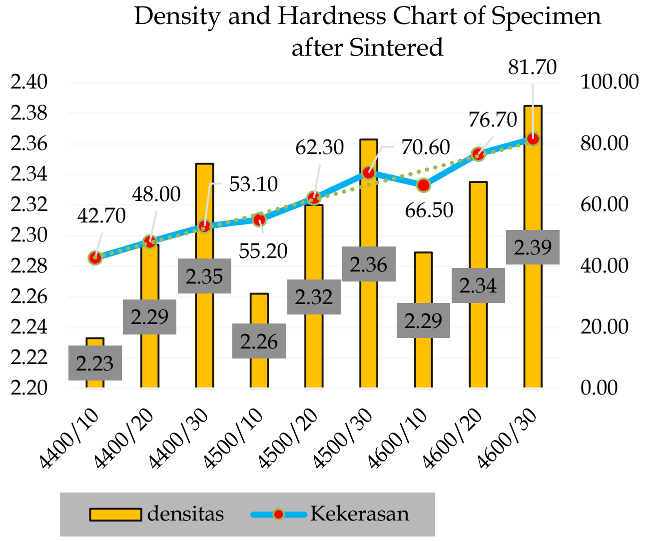



**Figure 7.** Density and Hardness Graph of Specimens after Sintered

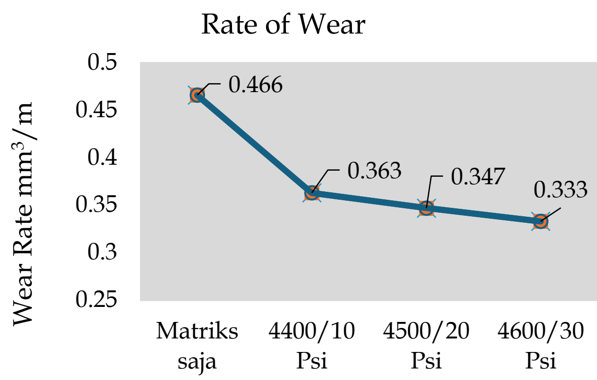



**Figure 8.** Graph of Wear Rate of Specimens after Sintering

*Microstructure Analysis of Specimens*

The specimens after the friction test were then subjected to microstructure test. There are three microstructure images tested, namely specimens with a compaction pressure of 4400 Psi, 4500 Psi and 4600 Psi with a sintering time of 30 minutes, as shown in Figure 9. Based on the Scanning Electron Microscope image, it can be explained that Figure 11 has the smallest porosity or the highest density. This is because the relatively high pressing process of 4600 Psi, with a sintering holding time of 30 minutes is able to make the specimen arrange its particle arrangement tighter and denser.

In contrast to Figure 9 which shows the material is less dense or less dense and even shows some areas there are particles that are less dense and cracked with relatively higher porosity compared to Figure 11. Likewise, Figure 10 also shows a little tighter than Figure

11, so the hardness, density and wear rate are in a moderate position.

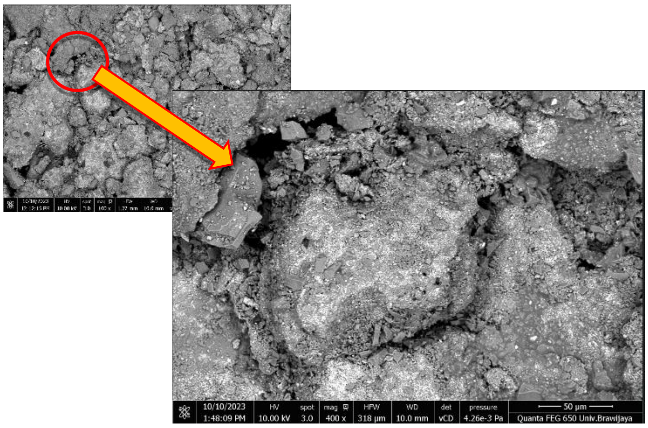


**Figure 9**. Pressurisation 4400 Psi, sintering 600 °C and sintering holding time 10 min.

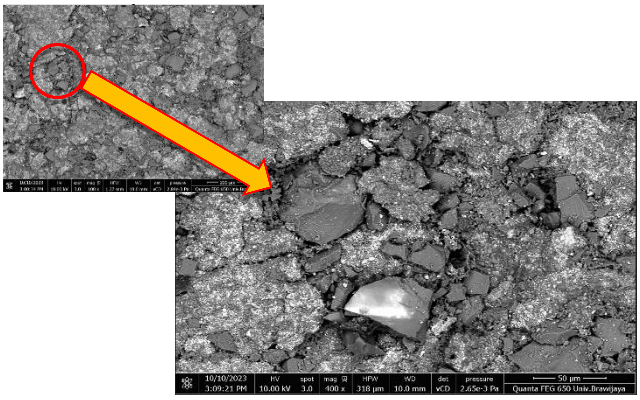


**Figure 10**. Pressurisation 4500 Psi, sintering 600 °C and sintering holding time 20 min.

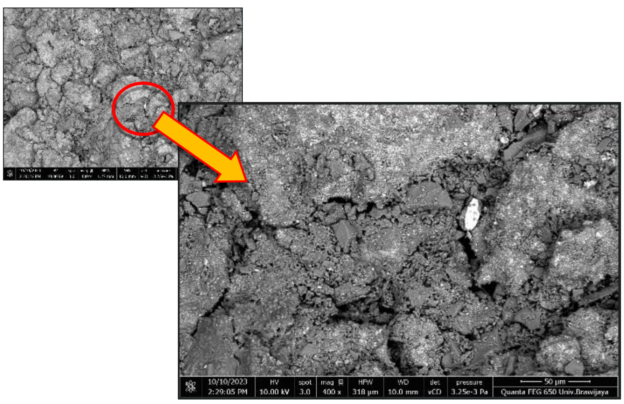


**Figure 11**. Pressurisation 4600 Psi, sintering 600 °C and sintering holding time 30 min.

Based on previous research, related to the fabrication of Non-Asbestos brake pads, which has been carried out by Taka (2027) has a hardness of 63.66 HRB, then Nawangsari's research (2023) has a hardness of 85.55 HRB, while this study has a maximum hardness of 81.7 HRB. So this study has moderate hardness, between the two previous studies.

The standard of friction brake hardness for motor vehicles is between 29-62 HRB (Taka, 2017), and 56 - 98 HRB friction brake hardness for minibuses (Akkus & Yegin, 2014). Furthermore, the wear rate of asbestos-based friction brakes is 0.3-0.5 while for grey cast iron friction brakes it is between 0.15-0.2 (Purboputro, 2014).

## Conclusion

Based on these standards, the achievement of this study in terms of hardness is between 42.7 and 81.7 HRB, meaning that the results of this study have met the requirements for motorbike friction brakes and minibus friction brakes, although the wear rate has not been able to meet. While the highest density of 2.385 g/cm3 occurred at a two-way hot compaction pressure of 4600 Psi, with the lowest wear rate of 0.333 mm3/m.

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**Author Contributions**

SO, IAW: Developing ideas, analyzing, writing, reviewing, responding to reviewers' comments; EW, YO, RK, HM, RI, DDS, HTA: analyzing data, overseeing data collection, reviewing scripts, and writing.

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**Conflicts of Interest**

The authors declare no conflict of interest.

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