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Research Paper

Utilization of Bamboo Powder in The Production of Non-Asbestos Brake Pads: Computational Bibliometric Literature Review Analysis and Experiments to Support Sustainable Development Goals (SDGs)

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Abstract

This study aims to develop asbestos-free and environmentally friendly brake pads using apus bamboo powder (*Gigantochloa apus*). In the experiments, bamboo powder, resin, and catalyst were used as the raw materials and varied to ensure the quality of the prepared brake pads. To analyze the performance of brake pads, the fabricated brake pads are subjected to physicochemical tests (such as microscopic tests and functional group analysis) and mechanical tests (such as puncture tests, compression tests, and friction tests). The research results showed that adjusting the composition of the raw materials allowed a change in the performance of the brake pad, including porosity, morphological structure, and mechanical properties. Indeed, the condition of the low porosity on the inside of the brake pad strategically optimizes the compression strength of the material, making this design ideal for applications that require high resistance to compression loads. This study shows the possibility of apus bamboo powder as an alternative to asbestos in the production of non-asbestos brake pads, offering a safer and environmentally friendly solution as well as giving ideas for supporting current issues in the sustainable development goals (SDGs).

Keywords: Apus bamboo powder; Brake pads; Fabrication; Friendly brake pad; Non-asbestos

1. Introduction

Even though advances in automotive research for propulsion systems have massively developed from conventional combustion to modern combustion systems [1], [2], the use of high-quality and cleaner fuels [3]–[8], control systems [9]–[13], and electrification [14]–[16], the main braking mechanism still relies on the friction system. Specifically, it encouraged researchers to get the effective use of conventional brake pads. The use of this brake pad is to produce frictional force which can reduce or stop the movement of the vehicle's wheels due to friction with other parts of the braking system [17], [18]. In general, brake pads are made of friction materials, which produce friction when they come into contact with other surfaces. Typically, these friction materials are usually made from a mixture of materials such as asbestos fibers, metals, and binders [19]. However, issues are created when using asbestos materials. The impact of friction can create and release particle waste as a side-effect. The existence of particle waste containing asbestos poses a potential hazard in polluting the air, soil, and water, as well as human health [20]. To mitigate this negative effect on the environment, many researchers have been exploring the use of non-asbestos or organic brake pads [21]–[25].

In recent years, the development of brake pads with more environmentally friendly materials has been a major goal of several studies.

Table 1 shows previous studies regarding the use of environmentally friendly materials as brake pad fillers such as banana peels [26], palm kernel [27], [28], periwinkle shell and cow bone [29], hazelnut shell [30], teak powder and clamshell [31], and cow dung [32].

Departing from these previous studies, we demonstrated a method in producing brake pads using bamboo powder (*Gigantochloa apus*) as raw material. In short, the experiments were done by mixing bamboo with resin with different compositions.

Bamboo powder is one of the potential materials. It contains protein 4.72% (stem), fat 6.71% (stem), ash 4.05% (stem), 8.51% (stem), carbohydrate 76% (stem), starch 12.18% (stem), fiber 59.21% (stem), and antioxidant 29.91 ppm (stem) [33]. In addition, apus bamboo has good resistance to compressive and tensile loads. That makes some structural applications, such as building frames, support poles, and floors, suitable for using raw materials from apus bamboo powder [34].

Table 1. Research on fabricating brake pads from organic raw material

Type of Raw Material	Supporting Material	Results	Ref.
Banana peels	• Phenolic resin • Water	The brake pads show levels of thermal stability, hardness, and wear levels that can compete with asbestos-based brake pads	[26]
Palm kernel shell (PKS)	• Phenolic resin • Steel fiber • Silicon carbide • Graphite	The smaller the PKS particle size, the better the resulting brake pads	[27]
Palm kernel shell (PKS)	• Steel slag • Silica sand • Carbon black • Phenolic resin	This research developed a high-quality, eco-friendly palm kernel shell particle composite for automotive brake pad production, with the best performance achieved at 100 m sieved grade.	[28]
Periwinkle shell and cow bone	• Phenolic resin • Aluminium oxide • Copper oxide • Zinc oxide • Graphite	Periwinkle shell and treated cow bone filler in motor vehicle brake pads improve hardness strength, but abrasion resistance decreases with higher filler loading, impact strength decreases, and water absorption increases.	[29]
Hazelnut shell and boron oxide (B_2O_3)	Steel fiber, rock wool, kevlar pulp, graphite, phenolic resin, vermiculite, brass, calcium hydroxide, zirconium silicate, metal sulfide, iron oxide, rubber scrap, barites, rubber, petroleum coke, chalcopyrite, mica, and silica	The hardness values the samples were similar and higher than those of the commercial brake pads. The most important factor affecting hardness resulted from replacing the powder materials contained in the pad composition with hazelnut and B_2O_3	[30]
Teak powder and clamshell	Epoxy resin	Experimental results show that brake pads made of teak sawdust indicate the strength of the brake pads. Brake pads that contain no teak sawdust or only clamshell do not provide balance for testing because they produce brake pads that are too soft to withstand mechanical testing.	[31]
Cow dung	Epoxy resin, calcium hydroxide, calcium carbonate, graphite, molybdenum disulfide, magnesium oxide, calcium oxide, aluminum oxide, and silicon carbide	Cow dung particles reinforced with 15% epoxy resin show promising results in microhardness, tensile strength, stable coefficient of friction, and low wear, offering a low-cost, eco-friendly alternative to carcinogenic asbestos/copper in brake pads.	[32]

To support the analysis, we also added computational bibliometric analysis. Bibliometric analysis is one of the effective methods to understand the current research trend [35]–[38]. Previous studies on bibliometric analysis are shown in **Table 2**. Detailed information regarding how to use bibliometric is shown elsewhere [39].

Table 2. Previous studies on bibliometric analysis

No	Author	Title	Ref.
1	Solihah et al.	Prototype of greenhouse effect for improving problem-solving skills in science, technology, engineering, and mathematics (STEM)-education for sustainable development (ESD): Literature review, bibliometric, and experiment.	[40]
2	Yang et al.	Spatial visualization ability assessment for analyzing differences and exploring influencing factors: Literature review with bibliometrics and experiment.	[41]
3	Angraini et al.	Augmented reality for cultivating computational thinking skills in mathematics completed with literature review, bibliometrics, and experiments for students.	[42]
4	Imaniyati et al.	Neuroscience intervention for implementing digital transformation and organizational health completed with literature review, bibliometrics, and experiments.	[43]
5	Amida et al.	Phylogenetic analysis of Bengkulu citrus based on DNA sequencing enhanced chemistry students' system thinking skills: Literature review with bibliometrics and experiments.	[44]
6	Kadir et al.	The ship's propeller rotation threshold for coral reef ecosystems based on sediment rate indicators: Literature review with bibliometric analysis and experiments.	[45]
7	Ramadhan et al.	The ship's propeller rotation threshold for coral reef ecosystems based on sediment rate indicators: Literature review with bibliometric analysis and experiments.	[46]
8	Shidiq et al.	Bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSviewer.	[47]
9	Lizama et al.	Use of blockchain technology for the exchange and secure transmission of medical images in the cloud: Systematic review with bibliometric analysis.	[48]
10	Al Husaeni et al.	Chatbot artificial intelligence as educational tools in science and engineering education: A literature review and bibliometric mapping analysis with its advantages and disadvantages.	[49]
11	Al Husaeni et al.	How technology can change educational research? Definition, factors for improving quality of education and computational bibliometric analysis.	[50]
12	Laita et al.	Effects of sustained deficit irrigation on vegetative growth and yield of plum trees under the semi-arid conditions: Experiments and review with bibliometric analysis.	[51]
13	Al Husaeni and Al Husaeni	How to calculate bibliometric using VOSviewer with Publish or Perish (using Scopus data): Science education keywords.	[52]
14	Zafrullah and Ramadhani	The use of mobile learning in schools as a learning media: Bibliometric analysis.	[53]
15	Al Husaeni and Munir	Literature review and bibliometric mapping analysis: Philosophy of science and technology education.	[54]
16	Pramanik and Rahmanita	Strengthening the role of local community in developing countries through community-based tourism from education perspective: Bibliometric analysis.	[55]
17	Rasuman et al.	Trends and networks in education for sustainable development (ESD): A bibliometric analysis using vosviewer.	[56]
18	Wirzal and Putra	What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using VOSviewer indexed by google scholar?.	[57]
19	Al Husaeni et al.	Bibliometric analysis of special needs education keyword using VOSviewer indexed by google scholar.	[58]

No	Author	Title	Ref.
20	Al Husaeni	Bibliometric analysis of briquette research trends during the covid-19 pandemic.	[59]
21	Ruzmetov and Ibragimov	Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021.	[60]
22	Sudarjat	Computing bibliometric analysis with mapping visualization using vosviewer on "pharmacy" and "special needs" research data in 2017-2021.	[61]
23	Al Husaeni and Wahyudin	Digital transformation in special needs education: Computational bibliometrics.	[62]
24	Al Husaeni	Bibliometric analysis of research development in sports science with vosviewer	[63]
25	Firdaus et al.	Nutritional research mapping for endurance sports: A bibliometric analysis.	[64]
26	Al Husaeni and Al Husaeni	Computational bibliometric analysis of research on science and Islam with VOSviewer: Scopus database in 2012 to 2022.	[65]
27	Chano et al.	Correlation between meditation and Buddhism: Bibliometric analysis.	[66]
28	Chano et al.	Correlation between meditation and religion: Bibliometric analysis.	[67]
29	Nurrahma et al.	A bibliometric analysis of seed priming: global research advances.	[68]

Although many reports regarding the use of non-asbestos brake pads, it still has weaknesses. The novelty of this study lies in its innovative and sustainable approach to brake pad fabrication, which promises environmental, health, and economic benefits, and paves the way for more research and development in sustainable engineering materials. Through this research, fabricating non-asbestos brake pads from apus bamboo is expected to provide optimal results; thereby, it can be used as an alternative to environmentally friendly non-asbestos brake pads with similar capabilities as asbestos brake pads. This study also offered a safer and environmentally friendly solution as well as giving ideas for supporting current issues in the sustainable development goals (SDGs). Indeed, the SDGs have been one of the hottest issues [69]–[78].

2. Methods

Figure 1 and **Figure 2** show the general and specific flowchart of the experimental procedure.

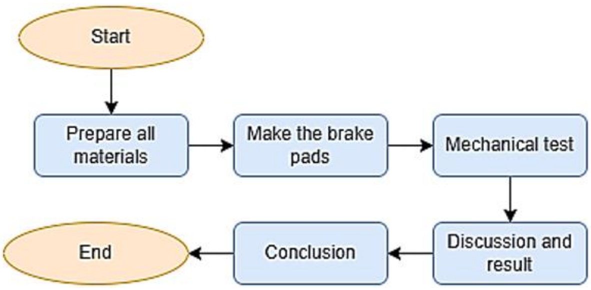


Figure 1. General flowchart of the research procedure

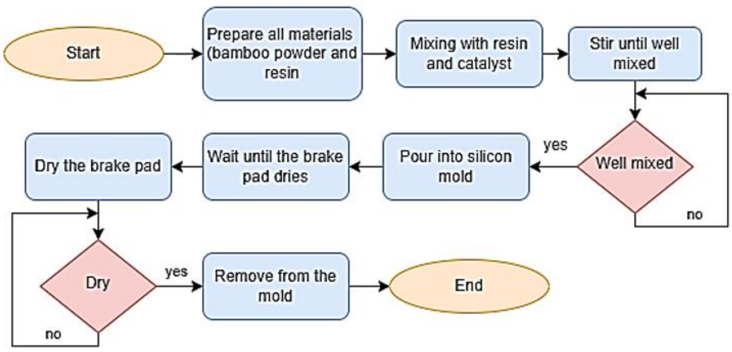


Figure 2. Specific flowchart for the experimental procedure for the production of the brake pad

2.1. *Materials*

In this study, resin (Bisphenol A-Epichlorohydrin), catalyst (Cycloaliphatic amine), and apus bamboo powder (*Gigantochloa apus*) were the main ingredients in fabricating organic brake pads. This type of resin is used as the main binder in the brake pad fabricating. By using epoxy resin, it was possible to produce brake pads that are more resistant to heat and friction, thereby improving the performance and service life of brake pads. The use of epoxy resin also allows for lighter brake pad formulations, reducing the load on the vehicle and improving fuel efficiency. This catalyst was used to initiate the polymerization reaction of epoxy resin. Cycloaliphatic amines are generally more environmentally friendly than conventional catalysts containing heavy aliphatic amines or heavy metals. The use of these environmentally friendly catalysts helps to reduce the negative impact on the environment by reducing the emission of harmful substances during the brake pad production process.

2.2. *Brake Pads Production*

Here, brake pads were fabricated by mixing various raw material compositions such as bamboo apus, Bisphenol A-Epichlorohydrin, and Cycloaliphatic amine. After all the ingredients were mixed in a plastic glass, the ingredients were homogenized until a pasta was formed. After the pasta dough was formed, the pasta dough was transferred to a cube-shaped mold (size 1 x 1 x 1 cm) and then dried at room temperature without exposure to sunlight for 1 week. The main material to replace asbestos in this research is apus bamboo powder. Variations in the composition of the materials are shown in **Table 3**. After the brake pads were successfully fabricated, physicochemical tests and mechanical tests were carried out respectively to analyze the success of brake pads fabrication and analyze the performance of the brake pads.

2.3. *Physicochemical Characterization*

Physicochemical tests were carried out to confirm the success of the fabricated brake pads. Physicochemical tests were carried out by analyzing the morphology and surface of the brake pads using a digital microscope, analyzing the specific gravity of the sample, and analyzing the sample's functional groups using a Fourier Transform Infrared Spectroscopy (FTIR) instrument. Density is a term used in physics and materials science to measure how dense or heavy a substance is in a given volume. In simple terms, density describes how much matter there is in space. Density is expressed in units of mass per volume, such as grams per cubic centimeter (g/cm^3) or kilograms per cubic meter (kg/m^3), depending on the system of units used. The specific gravity calculated in this study is by dividing the unit weight of the brake pad material by the volume of the brake pad material.

2.4. *Mechanical Properties Test*

The mechanical properties of brake pads-based apus bamboo powder were determined through a puncture strength test and a compressive strength test. In the puncture test, the instrument used to perform the puncture test is the Shore Durometer Testing Stand (Serial no. 13031709001). Puncture tests (penetration tests) in the context of mechanical tests are generally used to assess the resistance of materials to deformation or damage due to pressure applied via a puncture tool or penetrator. This process is important in evaluating properties such as hardness, penetration strength, and resistance to penetration of various types of materials, including polymers, rubber, and composite materials. The puncture test was carried out by placing the sample in the sample holder of the test equipment. Then, a load or force was applied through the penetrator to several sample points. Furthermore, the penetration force was recorded during the test. Furthermore,

Table 3. Composition of raw material (in mass) in the brake pad fabrication

Group	Sample Code	Mass (g)			Ratio of Apus Bamboo Powder : Resin : Hardener
		Apus Bamboo Powder	Resin	Hardener	
1	1A	1	2	2	1 : 2 : 2
	1B	1	4	4	1 : 4 : 4
	1C	1	6	6	1 : 6 : 6
2	2A	3	2	2	3 : 2 : 2
	2B	3	4	4	3 : 4 : 4

compression testing is a testing process that evaluates the behavior and properties of materials when subjected to compressive loads until the material fails or is damaged. To perform the compression test using a Screw Test Stand (Model: ALX-J) with a Newton magnitude. The compressive strength test produces a curve from the maximum point to the compressive stress-strain curve. The compression test was carried out by placing the sample in the sample holder on the testing machine. Then, the force was applied gradually to the sample until the sample failed or reached the specified deformation limit. Data about the applied load and displacement or deformation of the sample are recorded during the test. The next mechanical test is the friction test. The friction test on the brake pad-based apus bamboo was carried out to determine the wear rate and the value of the coefficient of friction by sanding on one side of the brake pad for one minute for 10 repetitions. The mass of the brake pad before and after sanding was recorded every minute. The wear rate can be calculated through Eq. (1).

$$M = \frac{(M_a - M_b)}{t \times A} \quad (1)$$

where M is the wear rate, M_a is the initial mass of the brake pad, M_b is the final mass of the brake pad, t is the time (s), and A is the friction cross-sectional area (mm^2)

The coefficient of friction (μ) is the ratio of the frictional force (f; Newtons) to the applied force obtained through Eq. (2).

$$\mu = \frac{f}{N} \quad (2)$$

3. Results and Discussion

3.1. Brake Pads Study Analysis using Bibliometric Analysis

In a search using the keyword "resin based brake pad" in the Publish or Perish software by filtering by publication name "journal," the number of publications indexed by Google Scholar was found in the last 5 years (2018-2023). By using VOSviewer software, it is possible to map publication trends regarding resin-based brake pads over the last 5 years, thus we can see whether there has been an increase or decrease in the number of publications from year to year and identify focus points in the research.

Based on **Figure 3**, there were 64 scientific articles conducting research on resin-based brake pads in 2018. In 2019, there were an additional 82 scientific articles. This number decreased slightly in 2020 to 77 scientific articles. In the following 2 years, that are 2021 and 2022, there was a significant addition, namely 122 scientific articles in 2021 and 184 scientific articles in 2022. Finally, in 2023, when this report was made in August 2023, there were already 166 scientific articles discussing resin-based brake pads.

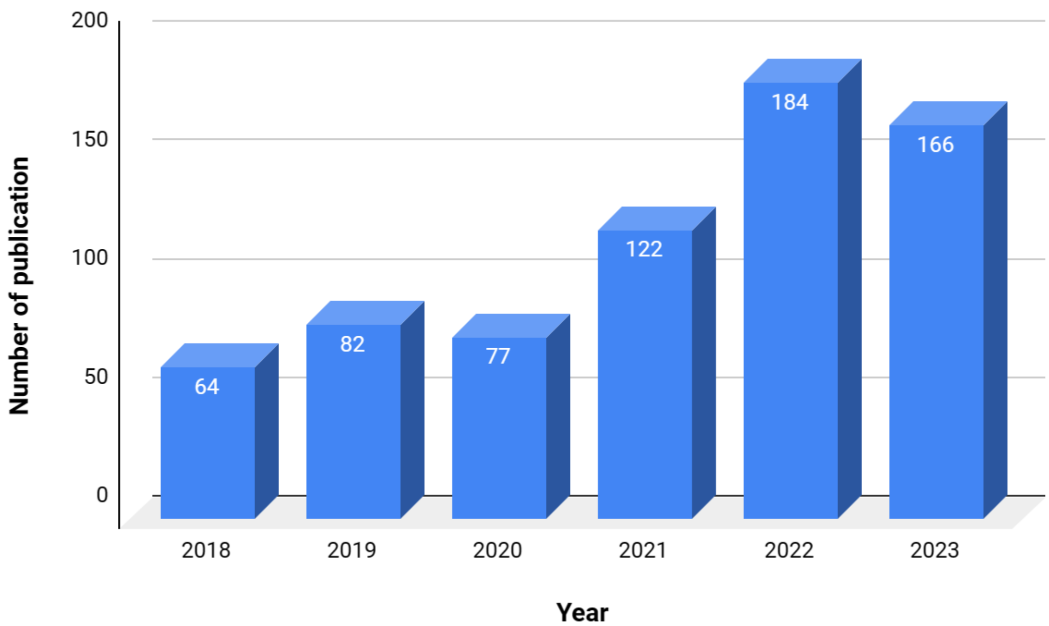


Figure 3. Number of publications regarding resin based brake pads

Based on the results of this analysis, it can be concluded that there is a trend of increasing research on resin-based brake pads from 2018 to 2023. Although this figure had slightly dropped in 2020, this proves that research on resin-based brake pads began to become popular in 2018 until now. The difference between the articles is usually found in the main materials used.

From the search and mapping results using VOSviewer, 8 groups were generated which were depicted in the form of circles with different colors. The size of each circle depends on how often the term occurs. The more often the term appears in scientific journals, the larger the circle size will be.

With the keyword "resin based brake pad", a cluster network visualization of each research topic area is obtained as shown in **Figure 4**.

3.2. Physicochemical Characterization of Brake Pads

Figure 5a shows an image of the results of a microscopy test of bamboo powder particles with a scale of 1 mm. After the microscopy test, we carried out a Ferret analysis to determine the particle size distribution of the bamboo powder. Detailed information for the use of Ferret analysis is explained elsewhere [79]. The results of Ferret analysis show that the particle size of apus bamboo powder ranges from 53-500 µm, as shown in **Figure 5a**.

The physical appearance of bamboo-based brake pads with various variations can be seen in **Figure 6**. **Figure 6a-Figure 6c** is bamboo apus-based brake pads with a composition of 1:2:2; 1:4:4; and 1:6:6, respectively. Meanwhile, **Figure 6d-Figure 6e** is a bamboo apus-based brake pad with a composition of 3:2:2; 3:4:4; and 3:6:6, respectively. Based on **Figure 6a-Figure 6e**, brake pads made of resin and bamboo powder have a shiny brown color with different textures for each variation. **Figure 6a-Figure 6c,** and **Figure 6e** lso show that the flash of color from the resin indicates the better the resin mixture coats the bamboo pulp particles due to the correct proportion of reinforcement and matrix. However, **Figure 6d** does not show that the

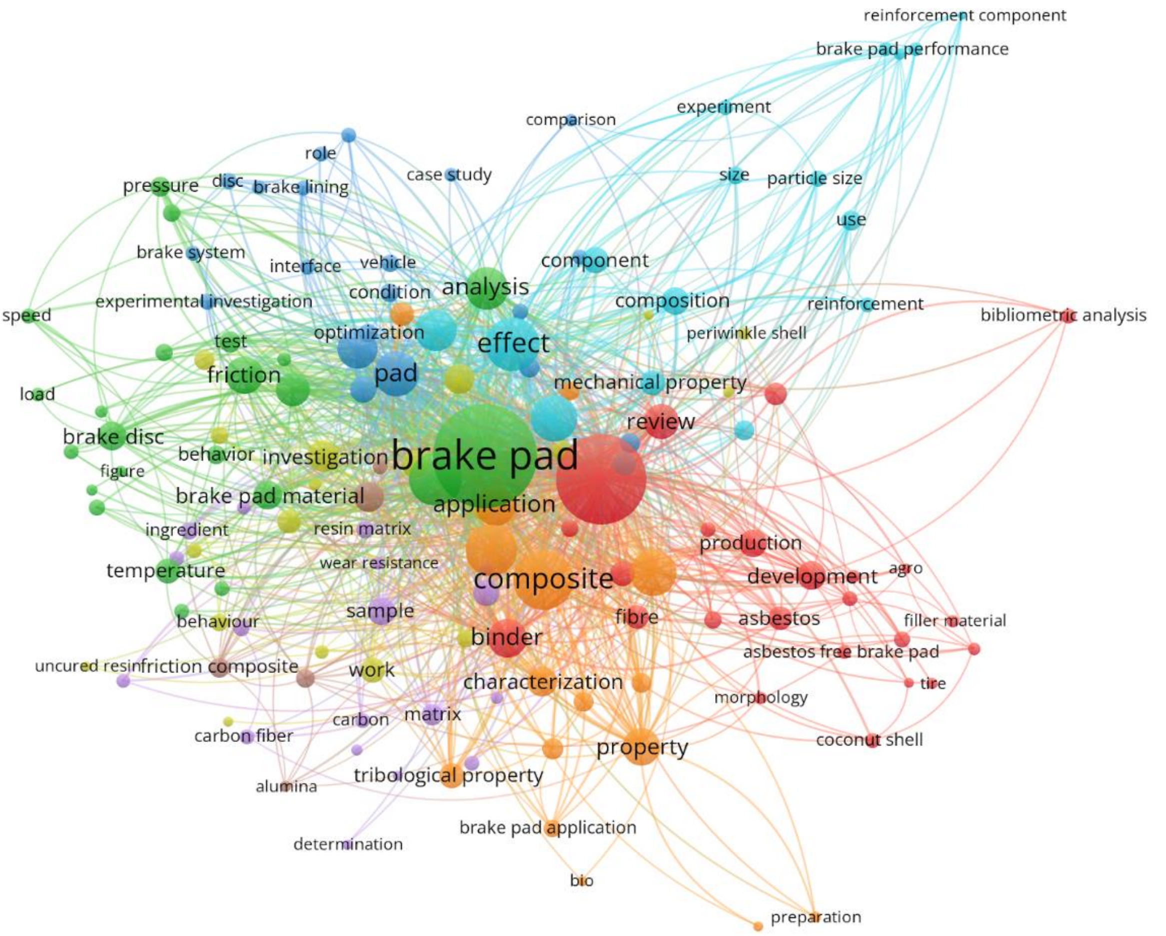


Figure 4. Network visualization of resin-based brake pad keyword

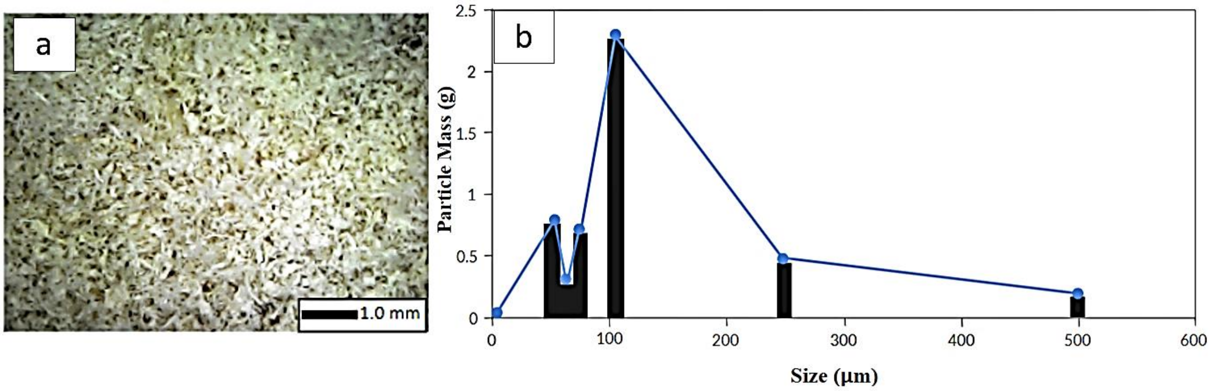


Figure 5. Physical image of apus bamboo particles (a) and ferret analysis of apus bamboo particle size (b)

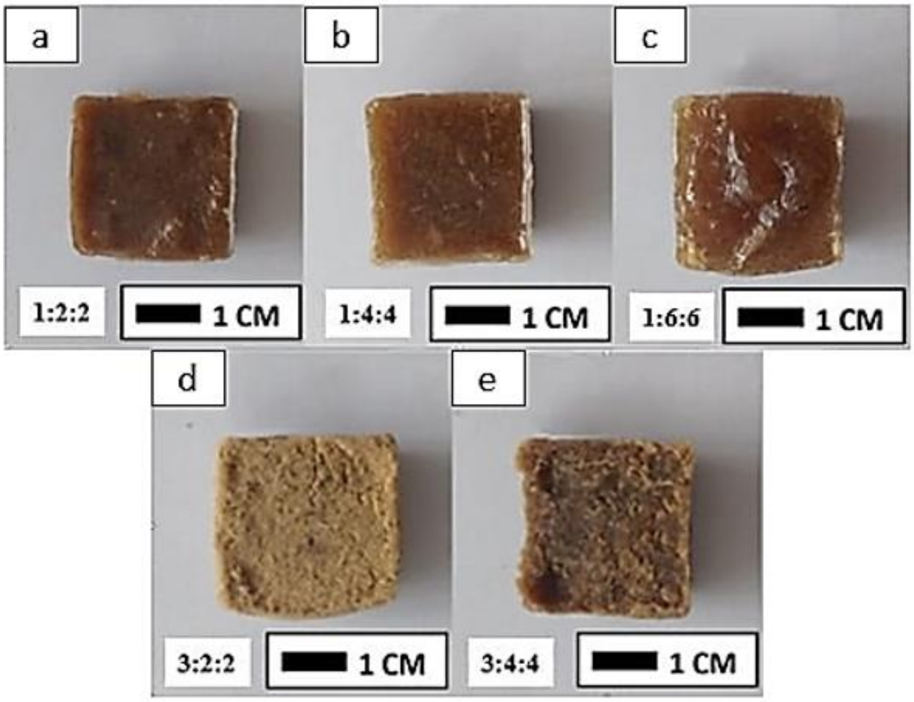
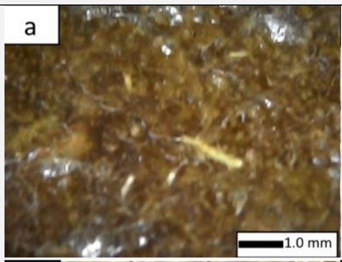
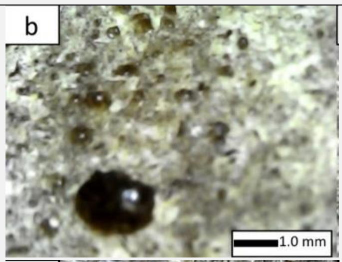
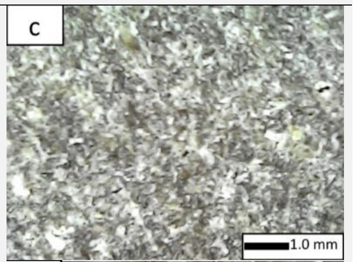
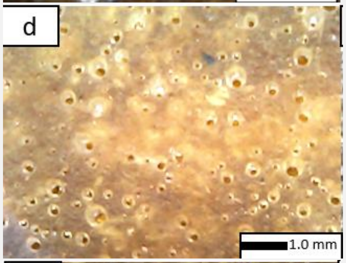
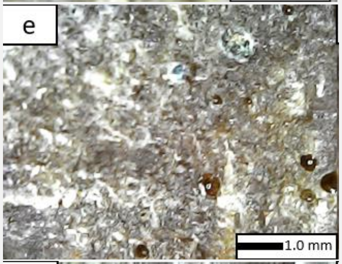
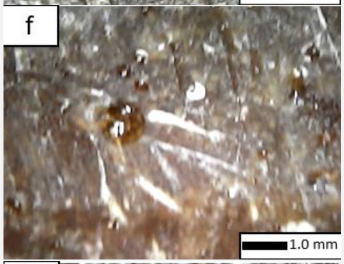
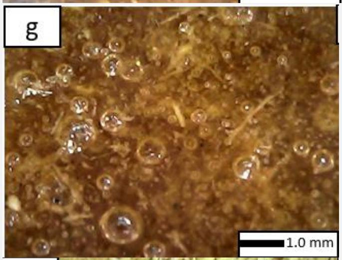
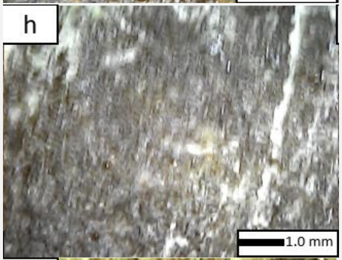
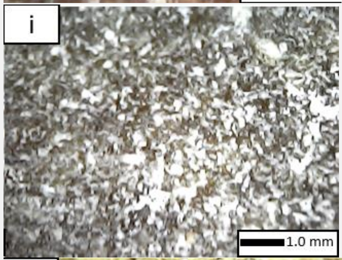
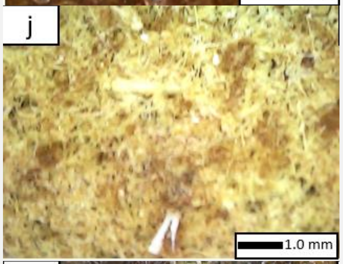
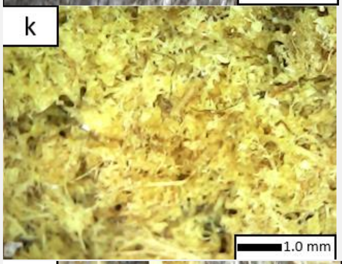
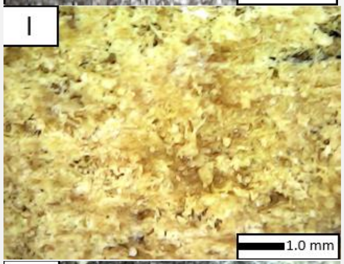
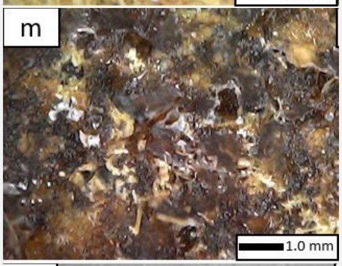
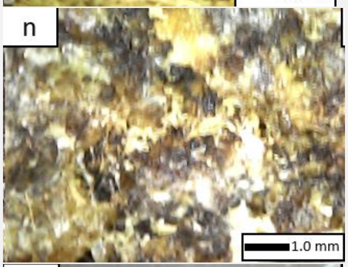
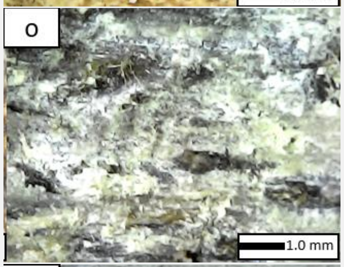
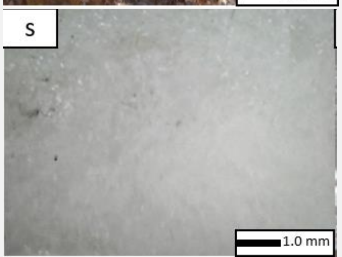
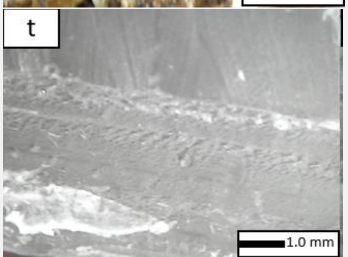
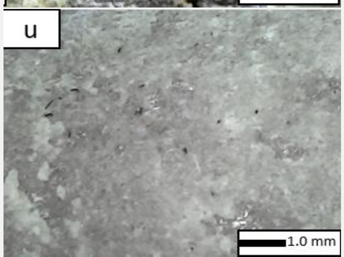
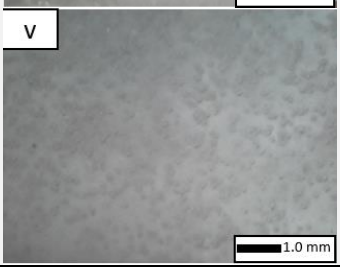
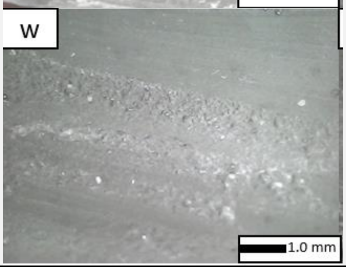
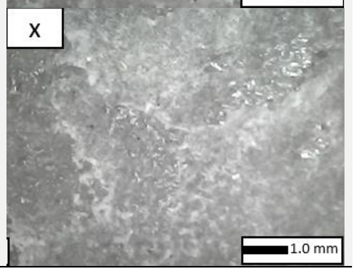


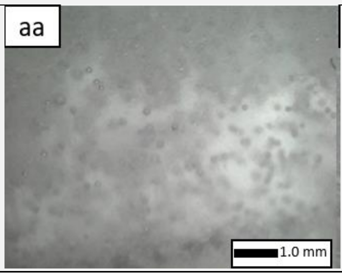
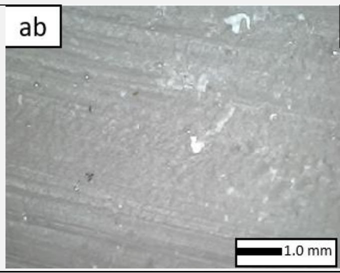
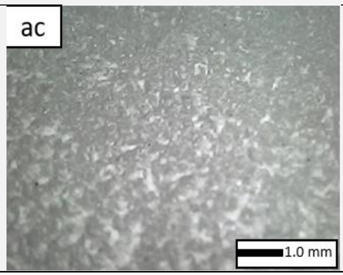
Figure 6. The physical image of apus bamboo-based brake pad. Figures (a), (b), (c), (d), and (e) are the microscope images of samples prepared using a specific ratio. The ratio is attached in the image as explained in **Table 3**.

resin covers the apus bamboo particles better (it does not show a shiny color) because perhaps the proportion of apus bamboo is not suitable. Good coverage can be defined as a homogeneous distribution of reinforcement in the resin matrix, which ensures that the desired properties of the composite, such as strength, stiffness, and environmental resistance, are maximally achieved [80], [81].

Table 4 shows the inner and outer surfaces of the brake pads. The inner and outer surface of brake pads shows that all fabricated brake pads have uneven surfaces and pores. Based on **Table 4**, the brake pad sample with a composition of 1:2:2 shows a smooth outer surface (figure (a) in **Table 4**). Meanwhile, the inner surface consists of several pores which indicate a less homogeneous distribution of reinforcing material in the matrix (figure (b) in **Table 4**). A brake pad with a composition of 1:4:4 shows a porous outer and inner surface, which means that there is an inhomogeneous distribution of filler material in the matrix (figures (d) and (e) in **Table 4**). However, a brake pad with a composition of 1:4:4 has relatively fewer pores than other brake pads samples. A brake pad with a composition of 1:6:6 shows the presence of air spaces on the outside and pores on the inside (figures (g) and (h) in **Table 4**). Air spaces on the outer surface of these composites can be advantageous for certain applications (e.g. reduced weight) [82]. However, this does not directly increase the strength or

Table 4. Research on fabricating brake pads from organic raw material

Sample	Outer Surface	Inner Surface	After Friction
1A			
1B			
1C			
2A			
2B			
R2			
R4			

Sample	Outer Surface	Inner Surface	After Friction
R6			

stiffness of the material. The brake pad sample in the paneled Figures j-l in **Table 4** (brake pad with composition 3:2:2) showed that the filler particles were not covered by the resin, which was indicated by a rough and uneven physical condition due to the filler particles protruding from the resin matrix. Filler particles that are not properly wetted by the resin will not bond well in the matrix, which reduces the load transfer capability between the filler and the matrix [83]. This causes a decrease in the mechanical strength of the composite, such as tensile strength, flexural strength, and elastic modulus [84]. Furthermore, the m-o brake pad sample in **Table 4** (brake pad with a composition of 3:4:4) has relatively larger pores than the other samples. In this context, pores can cause voids or pores in the composite, increasing the porosity of the material. This high porosity can reduce the density of the material and affect its mechanical properties, such as reducing strength and modulus of elasticity [85], [86]. Then, adhesion between the filler particles and the resin matrix can become weak if the particles are not covered properly. This can cause delamination, where layers of material begin to separate, and can reduce the material's ability to transfer loads effectively [87]. Meanwhile, a rough surface due to filler particles protruding from the matrix also indicates an imperfect structure because these protruding filler particles can cause wear on the brake pad and ultimately affect brake pad performance negatively [88]. Based on **Table 4**, the brake pad sample that has better potential in terms of mechanical properties is the brake pad with a composition of 1:4:4 (brake pad sample 1B). This 1B brake pad sample has a design that maintains low porosity on the inside which can maintain good structural integrity. The denser inner part supports the overall mechanical strength of the brake pad, ensuring that the brake pad remains intact and functions effectively despite surface abrasion.

Figure 7 shows the FTIR analysis. Detailed information for the interpretation of FTIR is explained elsewhere [89]–[91]. FTIR analysis was used to determine the functional groups contained in apus bamboo powder brake pads with variations 1B (1:2:2; 1:4:4; and 1:6:6) and 2B (3:2:2 and 3:4:4), and the analysis was compared with the literature [26]. Based on **Figure 7**, brake pads of variations 1B (1:2:2; 1:4:4; and 1:6:6) and 2B (3:2:2 and 3:4:4) have a very similar spectrum. This can happen because the brake pad on each specimen has the same mixture of fillers, namely apus bamboo powder. According to **Figure 7**, it has been determined that brake pad samples made with apus bamboo powder contain amine groups (N-H) at the absorbance of 3416.05 cm^{-1} and 3425.69 cm^{-1}. The content of amines, and not amides, is strengthened by the recording of absorbance in the region of 1240.27 cm^{-1} and 1242.2 cm^{-1}. The reason for this is that amines are composed of C, H, and N atoms, whereas amides are made up of C, H, and O atoms. Absorbance with strong intensity is found in the regions of 2918.4-2920.32 cm^{-1} and 1481.38-1483.31 cm^{-1} indicating the presence of alkane functional groups (C-H). Furthermore, it is a well-established fact that brake pads made from apus bamboo powder contain alkene groups (C=C) that are located at 1612.54 cm^{-1} and have a high intensity [31].

Based on the data in **Figure 8**, brake pads containing apus bamboo powder have a specific gravity range of 0.263-0.268 g/cm^3. This means that brake pads made from apus bamboo powder composite have a lower specific gravity compared to commercial brake pads with a specific gravity of 1.890 g/cm^3. Due to its lower density, using apus bamboo powder as a composite material for brake pads can produce lighter products. Here, brake pads with relatively higher filler and matrix compositions and brake pads with lower filler and matrix compositions have relatively the same

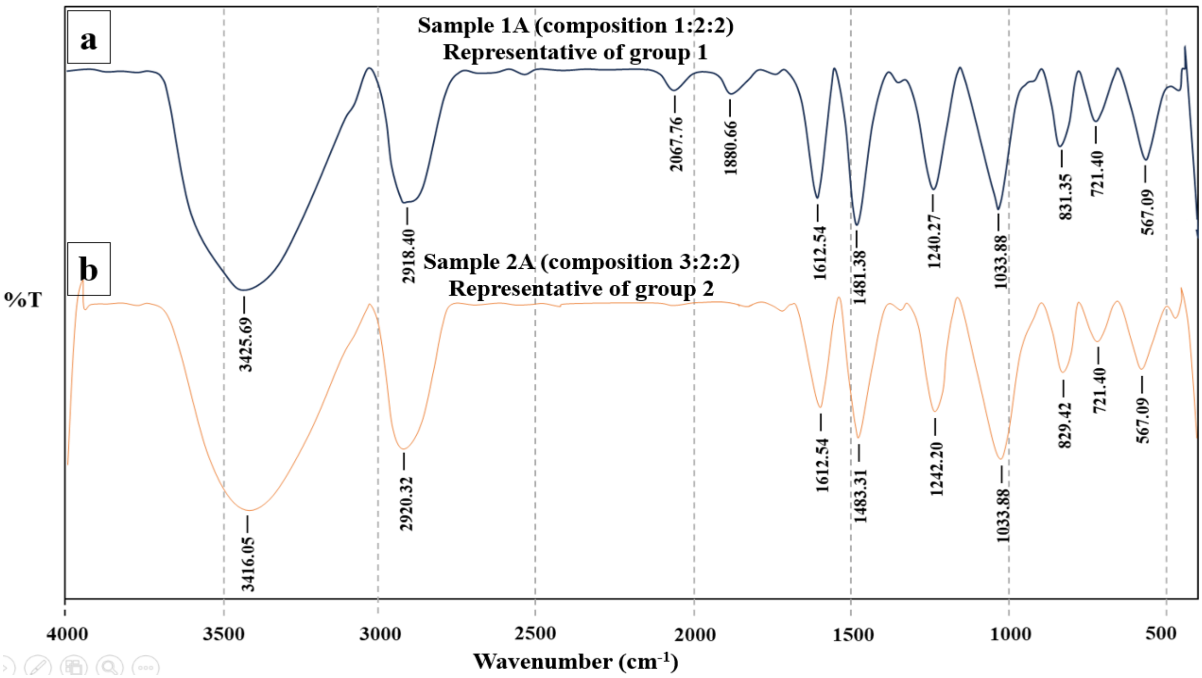


Figure 7. FTIR peaks as representative of fabricated brake pad with composition variation 1:2:2 (a) and composition variation 3:2:2 (b)

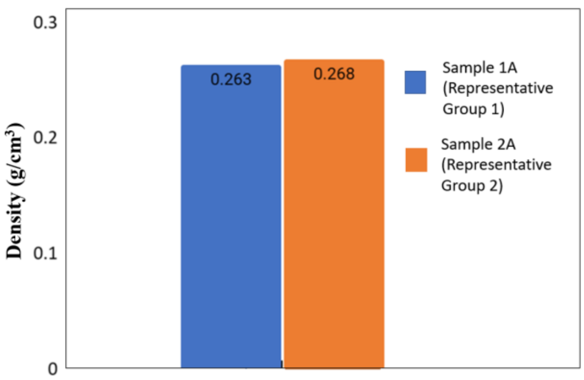


Figure 8. Specific density of fabricated brake pad sample with composition variation 1:2:2 (a) and composition variation 3:2:2 (b).

specific gravity values. If a brake pad with more apus bamboo filler composition and a brake pad with less apus bamboo filler composition have relatively the same specific gravity value, this could happen because several factors interact with each other and balance the effect of the difference in composition. Here are some potential explanations for this phenomenon [92], [93]:

(i) Fiber distribution and orientation
Even though the amount of bamboo filler is different, the way the bamboo fibers are distributed and oriented in the resin matrix can influence the overall density of the composite. If the bamboo fibers are more homogeneously distributed and have an orientation that optimizes space filling in the matrix, even with a smaller amount, this can produce a specific gravity value similar to a composite that has more bamboo but with a less optimal distribution and orientation.

(ii) The presence of void in porosity
The quantity and quality of the composite manufacturing process can affect the number of voids or porosity in the composite. A composite with more bamboo but a lot of voids due to a less-than-optimal kneading or drying process can have a density similar to a composite with less bamboo but produced with a process that produces very few voids.

(iii) Property compensation
In some cases, the proportions of bamboo filler and resin may be adjusted to achieve certain properties other than density, such as mechanical strength, stiffness, or environmental resistance. This can result in adjustments in the composite formulation which indirectly results in similar specific gravity values between composites with different compositions.

3.3. *Mechanical Characterization of Brake Pads*

The mechanical properties of the brake pad were determined through three tests, namely the compressive strength test, puncture strength test, and friction wear test. Figure 9a and Figure 9b are the result of the compressive test that has been carried out and the detailed value of the compressive test result, respectively. Based on the test results in **Figure 9a** and **Figure 9b**, the brake pad sample that shows the best compression strength is brake pad sample 1B with a composition of 1:4:4. This is because the structure of the 1B brake pad sample has a design that maintains low porosity on the inside due to several reasons, including:

(i) Efficient load distribution
Low porosity in a composite material indicates that the material has fewer air voids. This is important because a dense material without voids can distribute the compression load more efficiently and evenly throughout the structure. When compression loads are applied, materials with higher density and low porosity can resist deformation better than materials with many voids, which tend to experience stress concentrations around those voids.

(ii) Structural integrity
Composite materials with low porosity on the inside have better structural integrity. This is because the higher material density provides better structural support, allowing the material to withstand internal loads or stresses without suffering structural damage such as cracks or delamination, which can occur in materials with high porosity.

(iii) Reinforcement side effect
In some composites, a dense and even distribution of reinforcement in a low-porosity matrix can maximize the reinforcement effect. This is because the interaction between the matrix and the reinforcement becomes more effective under compression conditions, with little or no interference from voids or air cavities.

The puncture test was conducted to corroborate the data from the compression test results which can be seen in **Table 5**. According to Nandiyanto, et al. [31], the puncture test value is inversely proportional to the compressive test value. The greater the compressive test value, the smaller the puncture test value, and vice versa. Specimen 1B is the strongest brake pad compared to the other five brake pad samples as evidenced by the compressive test results and the third strongest in the puncture test. In addition, the pores seen in this sample are smaller and relatively few, thus increasing the strength of the brake pad. The brake pad is not good if it has pores that tend to be more and vice versa, a brake pad with relatively few pores makes better brake pad performance.

Figure 10 shows the performance of the change in brake pad mass after rubbing with sandpaper. The friction of the brake pad and sandpaper produces debris that reduces the initial mass of the brake pad. The reduced mass of the brake pad is influenced by the composition ratio of bamboo powder and resin used in each sample. **Figure 10** shows the performance of the change in brake pad mass after rubbing with sandpaper. The friction of the brake pad and sandpaper produces debris that can reduce the initial mass of the brake pad. **Table 6** shows the mass loss rate, wear rate, and friction coefficient after normalization. The brake pad variation with the highest mass loss rate is 100% in variation 2A (with the composition of 3:2:2) while the lowest mass loss rate is only 6.6% in sample 2B (with composition of 3:4:4) which has wear rates of 2.98 and 0.48, respectively. This corresponds to the fact that the sample with 100% wear (sample 2A) has a high wear rate due to inhomogeneous structural integrity as the reinforcing material is not covered by the matrix (as shown in **Table 4**).

Table 5. Puncture strength test result

Sample	Durometer Shore Brake Pad Hardness Scale
1A	77.3
1B	77.7
1C	83.3
2A	77.5
2B	86.2
R2	65.8
R4	96.8
R6	97.0
Commercial	88.5

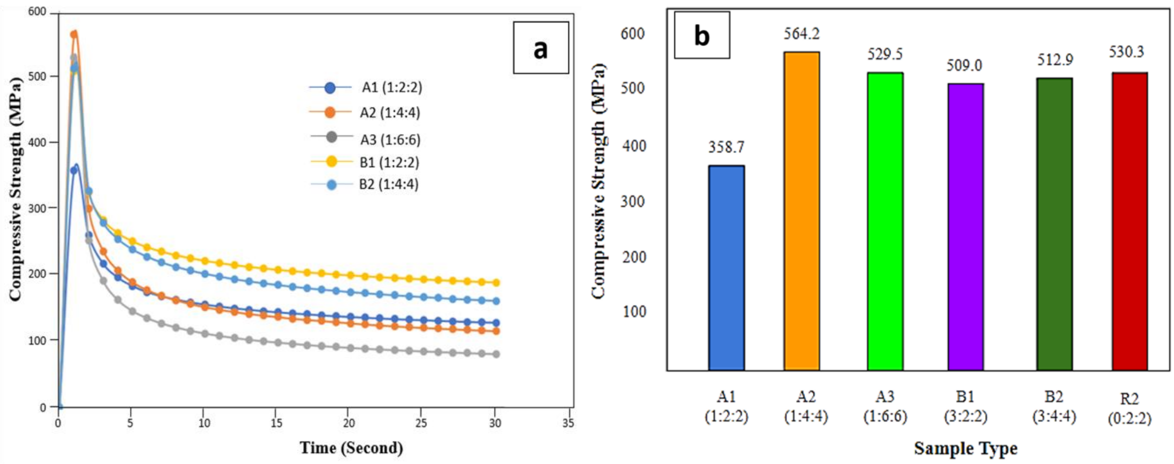


Figure 9. Compression test results: (a) compressive stress-strain curve and (b) detail compressive strength value of each sample

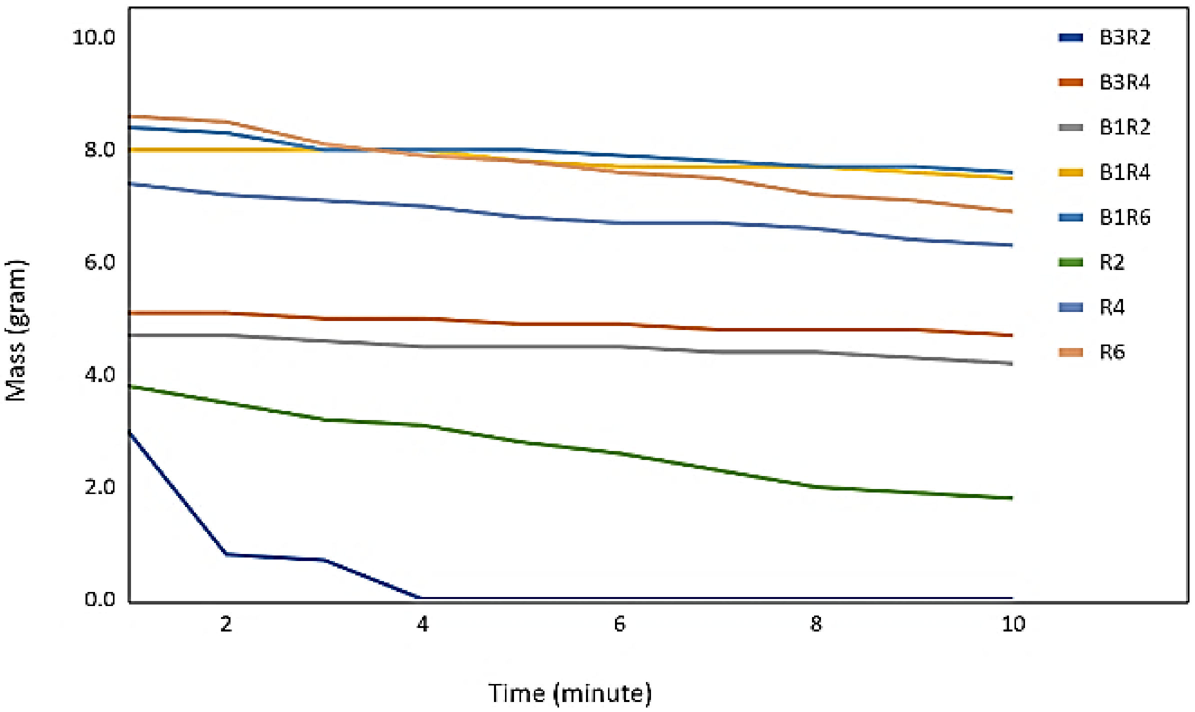


Figure 10. Change in brake pad mass during friction test

Table 6. Mass loss rate, wear rate, and friction coefficient of the specimen with different compositions

Sample	Initial Mass (g)	Final Mass (g)	Mass Loss Rate (%)	t (s)	A (mm²)	Wear Rate (g/s.mm²)	Friction Coefficient After Normalization
1A	6.7	4.2	37.3	600	576	2.40	1.2
1B	8.1	7.5	7	600	576	0.58	1.5
1C	8.5	7.6	10	600	576	0.87	1.5
2A	3.1	0	100	240	576	2.98	1.2
2B	5.2	4.7	9,6	600	576	0.48	0.9
R2	4	1.8	55	600	576	2.11	7.2
R4	7.4	6.3	14	600	576	1.06	1.3
R6	9	6.9	23	600	576	2.01	1.6

Fillers that are not fully covered by the matrix tend to have weaker adhesion with the matrix. Strong adhesion between the filler and the matrix is key to ensure effective load transfer and prevent crack initiation or separation. When fillers are not fully covered, crack initiation points can form more easily, which increases wear as the cracks facilitate material separation [94]. In addition, fillers that are directly exposed to the surface or that are not completely covered by the matrix are more susceptible to direct abrasion. Under friction conditions, exposed filler particles can easily erode or detach from the matrix, increasing the rate of mass loss and wear. Fillers that are well covered by the matrix are protected from direct contact with abrasion agents or the friction surface, thereby reducing wear [95].

A high mass loss rate can also indicate not only abrasive but also adhesive wear, where material actually "sticks" and then detaches from one surface to another. This often occurs under high friction conditions and can cause significant wear due to the transfer of material from one component to another or the loss of material to the environment [96]. Overall, a high mass loss rate is a clear indicator of a high wear rate, indicating that the material is experiencing significant damage or degradation under certain operating or test conditions.

The brake pad sample that has the lowest wear rate of the brake pad group 1 (1A-1C) is brake pad 1B (composition 1:4:4) because it has a lower wear rate than samples 1A (composition 1:2:2) and 1C (composition 1:6:6). It has also been explained previously that the 1B brake pad sample has good physical properties. In addition, from the testing aspects of the compressive test and puncture test, brake pad sample 1B is better than others. Therefore, the results of this friction test are consistent with the results of the previously conducted mechanical tests that samples with good mechanical strength often show low wear rates because materials with high mechanical strength have better resistance to plastic or elastic deformation under load [97]. This means that the material can withstand load or stress without undergoing significant deformation, which can reduce the risk of wear due to friction or contact with other materials.

Good mechanical strength also means that the material has a higher resistance to crack initiation and propagation. Cracks are often a precursor to wear because they facilitate the separation of material from the surface. Stronger materials tend to have higher crack energies, which means they require more energy to form and expand cracks. In addition, good mechanical strength often reflects strong adhesion between the matrix and the filler or between the fiber and the matrix. This strong adhesion reduces the possibility of separation or delamination under load, which can significantly reduce wear [98]. Since this brake pad sample 1B has a low wear rate, it is appropriate that the brake pad sample 1B has a high coefficient of friction value. The high coefficient of friction indicates that the brake pad has a good ability to generate the friction force required for effective braking, reduce the braking distance, and ensure better vehicle control during the braking process.

4. Conclusion

The results of this study show that the brake pad sample 1B (with a composition of 1:4:4) has good physical and mechanical characteristics. The results show that the physical characteristics of sample 1B exhibit a porous outer surface but low pores on the inner surface which has implications for efficient load distribution, structural integrity, and side reinforcement effects. These good physical characteristics imply good mechanical characteristics as well (indicated by good compression test and puncture test values, as well as high friction test values). Based on the compression test, brake pad sample 1B has a compression value of 564.2 MPa. Then, the puncture test also showed a small value for brake pad sample 1B, which indicates that better brake pad sample 1B resists puncture. Furthermore, brake pad sample 1B has a low wear rate of 0.58 and a high coefficient of friction of 1.5.

This paper demonstrated a development in asbestos-free and environmentally friendly brake pads prepared from apus bamboo powder (*Gigantochloa apus*). The mixed bamboo powder, resin, and catalyst resulted in excellent performance. Adjusting the composition of the raw materials allowed a change in the performance of the brake pad. This study shows the possibility of apus bamboo powder as an alternative to asbestos in the production of non-asbestos brake pads, offering a safer and environmentally friendly solution as well as giving ideas for supporting current issues in the sustainable development goals (SDGs).

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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References

[1] I. Veza *et al.*, "Strategies to achieve controlled auto-ignition (CAI) combustion: A review," *Mechanical Engineering for Society and Industry*, vol. 3, no. 1, pp. 22–34, 2023, doi: 10.31603/mesi.7568.

[2] T. Kocakulak, T. A. Arslan, F. Şahin, H. Solmaz, S. M. S. Ardebili, and A. Calam, "Determination of optimum operating parameters of MWCNT-doped ethanol fueled HCCI engine for emission reduction," *Science of The Total Environment*, vol. 895, p. 165196, Oct. 2023, doi: 10.1016/j.scitotenv.2023.165196.

[3] L. M. Olalekan, O. Olatunde, F. I. Olufemi, and A. A. Olamide, "Mathematical modeling and cost comparison for electricity generation from petrol and liquified petroleum gas (LPG)," *Mechanical Engineering for Society and Industry*, vol. 2, no. 2, pp. 56–62, 2022, doi: 10.31603/mesi.6697.

[4] R. Anggrainy, W. Ruslan, D. L. Zariatin, R. A. Gilart, and T. Syam, "Effect of gasoline vaporizer tube (GVT) with magnetic field on spark-ignition engine: Investigation, discussion, and opinion," *Mechanical Engineering for Society and Industry*, vol. 2, no. 2, pp. 98–106, 2022, doi: 10.31603/mesi.7075.

[5] S. M. N. Rahayu *et al.*, "A Review of automotive green technology: Potential of butanol as biofuel in gasoline engine," *Mechanical Engineering for Society and Industry*, vol. 2, no. 2, pp. 82–97, 2022, doi: 10.31603/mesi.7155.

[6] M. Setiyo, "Alternative fuels for transportation sector in Indonesia," *Mechanical Engineering for Society and Industry*, vol. 2, no. 1, pp. 1–6, 2022, doi: 10.31603/mesi.6850.

[7] A. Kolakoti, M. Setiyo, and B. Waluyo, "Biodiesel Production from Waste Cooking Oil: Characterization, Modeling and Optimization," *Mechanical Engineering for Society and Industry*, vol. 1, no. 1, pp. 22–30, 2021, doi: 10.31603/mesi.5320.

[8] D. Yuvenda *et al.*, "Combustion and Emission Characteristics of CNG-Diesel Dual Fuel Engine with Variation of Air Fuel Ratio," *Automotive Experiences*, vol. 5, no. 3, pp. 507–527, 2022, doi: 10.31603/ae.7807.

[9] S. Munahar, M. Setiyo, R. A. Brieghtera, M. M. Saudi, A. Ahmad, and D. Yuvenda, "Fuel Control System on CNG Fueled Vehicles using Machine Learning: A Case Study on the Downhill," *Automotive Experiences*, vol. 6, no. 1, pp. 173–187, Apr. 2023, doi: 10.31603/ae.8107.

[10] S. Munahar, B. C. Purnomo, and H. Köten, "Fuel Control Systems for Planetary Transmission Vehicles: A Contribution to the LPG-fueled Vehicles Community," *Mechanical Engineering for Society and Industry*, vol. 1, no. 1, pp. 14–21, 2021, doi: 10.31603/mesi.5263.

[11] J. Karjanto, N. M. Yusof, J. Terken, F. Delbressine, and M. Rauterberg, "Level of motion sickness based on heart rate variability when reading inside a fully automated vehicle," *Mechanical Engineering for Society and Industry*, vol. 2, no. 2, pp. 72–81, 2022, doi: 10.31603/mesi.7083.

[12] R. M. Susanto, T. Nurrochman, S. Munahar, and A. I. Ramadhan, "Design and application of electronic tracking control systems (ETCS) to improve vehicle safety," *Automotive Experiences*, vol. 2, no. 3, pp. 67–72, 2019, doi: 10.31603/ae.v2i3.2766.

[13] M. Arsalan and F. Akbar, "Infrared sensor-based remote controlled driving system for

people with lower body disability and leg impairment," *Mechanical Engineering for Society and Industry*, vol. 3, no. 1, pp. 12–21, 2022, doi: 10.31603/mesi.7871.

[14] Y. D. Herlambang *et al.*, "Application of a PEM Fuel Cell Engine as a Small-Scale Power Generator for Small Cars with Different Fuel Concentrations," *Automotive Experiences*, vol. 6, no. 2, pp. 273–289, Aug. 2023, doi: 10.31603/ae.9225.

[15] H. Maghfiroh, O. Wahyunggoro, and A. I. Cahyadi, "Low Pass Filter as Energy Management for Hybrid Energy Storage of Electric Vehicle: A Survey," *Automotive Experiences*, vol. 6, no. 3, pp. 466–484, 2023, doi: 10.31603/ae.9398.

[16] M. Noga, P. Gorczyca, and R. Hebda, "The Effects of Use of the Range Extender in a Small Commercial Electric Vehicle," *Automotive Experiences*, vol. 4, no. 1, pp. 5–19, 2021, doi: 10.31603/ae.4137.

[17] S. H. Gawande, A. S. Banait, and K. Balashowry, "Study on wear analysis of substitute automotive brake pad materials," *Australian Journal of Mechanical Engineering*, vol. 21, no. 1, pp. 144–153, Jan. 2023, doi: 10.1080/14484846.2020.1831133.

[18] R. Majuma, M. H. Bin Peeie, K. Ondong, and O. A. Hassan, "Investigation of Brake Pad Wear Effect due to Temperature Generation Influenced by Brake Stepping Count on Different Road Terrains," *Automotive Experiences*, vol. 6, no. 2, pp. 234–244, May 2023, doi: 10.31603/ae.8869.

[19] J. Abutu, S. A. Lawal, M. B. Ndaliman, R. A. Lafia-Araga, and M. A. Oluleye, "Tribological Properties of Friction Materials Developed from Non- Asbestos Materials using Response Surface Methodology," *International Journal of Engineering Materials and Manufacture*, vol. 5, no. 2, pp. 40–49, Jun. 2020, doi: 10.26776/ijemm.05.02.2020.02.

[20] D. Saha, D. Sharma, and B. K. Satapathy, "Challenges pertaining to particulate matter emission of toxic formulations and prospects on using green ingredients for sustainable eco-friendly automotive brake composites," *Sustainable Materials and Technologies*, vol. 37, p. e00680, Sep. 2023, doi: 10.1016/j.susmat.2023.e00680.

[21] A. B. D. Nandiyanto, D. F. Al Husaeni, R. Ragadhita, and T. Kurniawan, "Resin-based Brake Pad from Rice Husk Particles: From Literature Review of Brake Pad from Agricultural Waste to the Techno-Economic Analysis," *Automotive Experiences*, vol. 4, no. 3, pp. 131–149, 2021, doi: 10.31603/ae.5217.

[22] A. B. D. Nandiyanto *et al.*, "The effects of rice husk particles size as a reinforcement component on resin-based brake pad performance: From literature review on the use of agricultural waste as a reinforcement material, chemical polymerization reaction of epoxy resin, to experiments," *Automotive Experiences*, vol. 4, no. 2, pp. 68–82, 2021, doi: 10.31603/ae.4815.

[23] M. Afiefudin, R. D. Widodo, and R. Rusiyanto, "Fabrication and Characterization of Asbestos Free Brake Pads Composite using Elaeocarpus Ganitrus as Reinforcement," *Automotive Experiences*, vol. 6, no. 2, pp. 359–371, Aug. 2023, doi: 10.31603/ae.9367.

[24] A. B. D. Nandiyanto, D. N. Al Husaeni, R. Ragadhita, M. Fiandini, D. F. Al Husaeni, and M. Aziz, "Resin matrix composition on the performance of brake pads made from durian seeds: From computational bibliometric literature analysis to experiment," *Automotive Experiences*, vol. 5, no. 3, pp. 328–342, 2022, doi: 10.31603/ae.6852.

[25] M. Khafidh *et al.*, "A Study on Characteristics of Brake Pad Composite Materials by Varying the Composition of Epoxy, Rice Husk, Al2O3, and Fe2O3," *Automotive Experiences*, vol. 6, no. 2, pp. 303–319, Aug. 2023, doi: 10.31603/ae.9121.

[26] U. D. Idris, V. S. Aigbodion, I. J. Abubakar, and C. I. Nwoye, "Eco-friendly asbestos free brake-pad: Using banana peels," *Journal of King Saud University-Engineering Sciences*, vol. 27, no. 2, pp. 185–192, 2015, doi: 10.1016/j.jksues.2013.06.006.

[27] Z. U. Elakhame, O. Alhassan, and A. Samuel, "Development and Production of Brake Pads from Palm Kernel Shell Composites," *International Journal of Scientific and Engineering Research*, vol. 5, no. 10, pp. 735–744, 2014.

[28] O. R. Adetunji, A. M. Adedayo, S. O. Ismailia, O. U. Dairo, I. K. Okediran, and O. M. Adesusi, "Effect of silica on the mechanical properties of palm kernel shell based automotive brake pad," *Mechanical Engineering for Society and Industry*, vol. 2, no. 1, pp. 7–16, 2022, doi: 10.31603/mesi.6178.

[29] E. I. Kevin, A. M. Olukemi, I. Uche, and A. M. Uzochukwu, "Thermo-Mechanical Properties of Motor Vehicle Brake Pad Using Periwinkle Shell and Treated Cow Bone as Filler," *International Journal of Bio-Science and Bio-Technology*, vol. 10, no. 11, 2018.

[30] G. Akıncıoğlu, H. Öktem, I. Uygur, and S. Akıncıoğlu, "Determination of Friction-Wear Performance and Properties of Eco-Friendly Brake Pads Reinforced with Hazelnut Shell and Boron Dusts," *Arabian Journal for Science and Engineering*, vol. 43, no. 9, pp. 4727–4737, Sep. 2018, doi: 10.1007/s13369-018-3067-8.

[31] A. B. D. Nandiyanto, A. F. Fitriani, R. A. Pradana, R. Ragadhita, K. Azzaoui, and E. Piantari, "Green Innovation in Brake Pad Production: Harnessing Teak Powder and Clam Shells as Sustainable Alternatives for Subtractive Residual Waste," *Moroccan Journal of Chemistry*, vol. 12, no. 2, 2024, doi: 10.48317/IMIST.PRSM/morjchem-v12i2.45531.

[32] N. Balaji, A. M. Elgorban, A. H. Bahkali, and N. S. S. Zaghloul, "Biodegradable cow dung for brake friction material: a preliminary investigation," *Materials Research Express*, vol. 10, no. 1, p. 015102, Jan. 2023, doi: 10.1088/2053-1591/acb1f6.

[33] V. K. V. and S. K. S., "Characterization of Various Properties of Chemically Treated Allium sativum Fiber for Brake Pad Application," *Journal of Natural Fibers*, vol. 19, no. 2, pp. 523–535, Feb. 2022, doi: 10.1080/15440478.2020.1745130.

[34] B. Shu *et al.*, "Review on the Application of Bamboo-Based Materials in Construction Engineering," *Journal of Renewable Materials*, vol. 8, no. 10, pp. 1215–1242, 2020, doi: 10.32604/jrm.2020.011263.

[35] D. I. Setyanansyach, M. Setiyo, and T. Raja, "Review and Bibliometric Analysis of Biogas Power Plants in Indonesia," *Advance Sustainable Science, Engineering and Technology (ASSET)*, vol. 5, no. 3, p. 2303015, 2023, doi: 10.26877/asset.v5i3.16806.

[36] M. Setiyo and M. L. Rochman, "Literature review: An effective method for identifying science and technology updates," *Mechanical Engineering for Society and Industry*, vol. 3, no. 3 Special issue, pp. 114–118, 2023, doi: 10.31603/mesi.10787.

[37] M. Setiyo, D. Yuvenda, and O. D. Samuel, "The Concise Latest Report on the Advantages and Disadvantages of Pure Biodiesel (B100) on Engine Performance: Literature Review and Bibliometric Analysis," *Indonesian Journal of Science and Technology*, vol. 6, no. 3, pp. 469–490, 2021, doi: 10.17509/ijost.v6i3.38430.

[38] A. Kolakoti, M. Setiyo, D. Novia, A. Husaeni, and A. B. Dani, "Enhancing heat transfer performance of automotive car radiator using camphor nanoparticles : experimental study with bibliometric analysis," *Teknomekanik*, vol. 6, no. 2, pp. 47–67, 2023, doi: 10.24036/teknomekanik.v6i2.25072.

[39] D. F. Al Husaeni and A. B. D. Nandiyanto, "Bibliometric Using Vosviewer with Publish or Perish (using Google Scholar data): From Step-by-step Processing for Users to the Practical Examples in the Analysis of Digital Learning Articles in Pre and Post Covid-19 Pandemic," *ASEAN Journal of Science and Engineering*, vol. 2, no. 1, pp. 19–46, 2022, doi: https://doi.org/10.17509/ajse.v2i1.37368.

[40] P. A. Solihah, I. Kaniawati, A. Samsudin, and R. Riandi, "Prototype of Greenhouse Effect for Improving Problem-Solving Skills in Science, Technology, Engineering, and Mathematics (STEM)-Education for Sustainable Development (ESD): Literature Review, Bibliometric, and Experiment," *Indonesian Journal of Science and Technology*, vol. 9, no. 1, pp. 163–190, Nov. 2023, doi: 10.17509/ijost.v9i1.66773.

[41] W. Yang, C. Chookhampaeng, and J. Chano, "Spatial Visualization Ability Assessment for Analyzing Differences and Exploring Influencing Factors: Literature Review with Bibliometrics and Experiment," *Indonesian Journal of Science and Technology*, vol. 9, no. 1, pp. 191–224, Nov. 2023, doi: 10.17509/ijost.v9i1.66774.

[42] L. M. Angraini, A. Susilawati, M. S. Noto, R. Wahyuni, and D. Andrian, "Augmented Reality for Cultivating Computational Thinking Skills in Mathematics Completed with Literature Review, Bibliometrics, and Experiments for Students," *Indonesian Journal of Science and Technology*, vol. 9, no. 1, pp. 225–260, Nov. 2023, doi: 10.17509/ijost.v9i1.67258.

[43] N. Imaniyati, M. A. Ramdhany, R. Rasto, S. Nurjanah, P. A. Solihah, and A. Susilawati, "Neuroscience intervention for implementing digital transformation and organizational health completed with literature review, bibliometrics, and experiments," *Indonesian Journal of Science and Technology*, vol. 9, no. 2, 2024, doi: 10.17509/ijost.v9i2.67763.

[44] N. Amida *et al.*, "Phylogenetic analysis of Bengkulu citrus based on DNA sequencing enhanced chemistry students' system thinking skills: Literature review with bibliometrics and experiments," *Indonesian Journal of Science and Technology*, vol. 9, no. 2, 2024, doi: 10.17509/ijost.v9i2.67813.

[45] A. Kadir, I. Istadi, A. Subagio, W. Waluyo, and A. Muis, "The ship's propeller rotation threshold for coral reef ecosystems based on sediment rate indicators: Literature review with bibliometric analysis and experiments," *Indonesian Journal of Science and Technology*, vol. 9, no. 2, 2024, doi: 10.17509/ijost.v9i2.67894.

[46] D. F. Ramadhan, A. M. Fabian, and H. M. Saputra, "Dental suction aerosol: Bibliometric analysis," *ASEAN Journal of Science and Engineering*, vol. 2, no. 3, 2022, doi: 10.17509/ajse.v2i3.50658.

[47] A. P. Shidiq, "A bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSviewer," *ASEAN Journal of Science and Engineering*, vol. 3, no. 1, pp. 31–38, 2023.

[48] M. G. Lizama, J. Huesa, and B. M. Claudio, "Use of Blockchain technology for the exchange and secure transmission of medical images in the cloud: Systematic Review with Bibliometric Analysis," *ASEAN Journal of Science and Engineering*, vol. 4, no. 1, pp. 71–92, Dec. 2023, doi: 10.17509/ajse.v4i1.65039.

[49] D. F. Al Husaeni, N. Haristiani, W. Wahyudin, and R. Rasim, "Chatbot Artificial Intelligence as Educational Tools in Science and Engineering Education: A Literature Review and Bibliometric Mapping Analysis with Its Advantages and Disadvantages," *ASEAN Journal of Science and Engineering*, vol. 4, no. 1, pp. 93–118, Oct. 2022, doi: 10.17509/ajse.v4i1.67429.

[50] D. F. Al Husaeni *et al.*, "How technology can change educational research? Definition, factors for improving quality of education and computational bibliometric analysis," *ASEAN Journal of Science and Engineering*, vol. 4, no. 2, 2024, doi: 10.17509/ajse.v4i2.62045.

[51] M. Laita *et al.*, "Effects of sustained deficit irrigation on vegetative growth and yield of plum trees under the semi-arid conditions: Experiments and review with bibliometric analysis," *ASEAN Journal of Science and Engineering*, vol. 4, no. 2, 2024, doi: 10.17509/ajse.v4i2.64600.

[52] D. N. Al Husaeni and D. F. Al Husaeni, "How to calculate bibliometric using VOSviewer with Publish or Perish (using Scopus data): Science education keywords," *Indonesian Journal of Educational Research and Technology*, vol. 2, no. 3, 2022, doi: 10.17509/ijert.v4i1.57213.

[53] Z. Zafrullah and A. M. Ramadhani, "The use of mobile learning in schools as a learning media: Bibliometric analysis," *Indonesian Journal of Educational Research and Technology*, vol. 4, no. 2, 2024, doi: 10.17509/ijert.v4i2.65586.

[54] D. F. Al Husaeni and M. Munir, "Literature review and bibliometric mapping analysis: Philosophy of science and technology education," *Indonesian Journal of Multidiciplinary Research*, vol. 3, no. 2, 2023, doi: 10.17509/ijomr.v3i2.56242.

[55] P. D. Pramanik and M. Rahmanita, "Strengthening the role of local community in developing countries through community-based tourism from education perspective: Bibliometric analysis," *Indonesian Journal of Multidiciplinary Research*, vol. 3, no. 2, 2023, doi: 10.17509/ijomr.v3i2.57948.

[56] M. A. Rasuman, N. Nandi, A. J. Astari, and A. B. Ashie, "Trends and networks in education for sustainable development

(ESD): A bibliometric analysis using vosviewer," *Indonesian Journal of Multidiciplinary Research*, vol. 4, no. 1, 2024, doi: 10.17509/ijomr.v4i1.68093.

[57] M. D. H. Wirzal and Z. A. Putra, "What is The Correlation Between Chemical Engineering and Special Needs Education from The Perspective of Bibliometric Analysis Using VOSviewer Indexed by Google Scholar," *Indonesian Journal of Community and Special Needs Education*, vol. 2, no. 2, pp. 103–110, Mar. 2022, doi: 10.17509/ijcsne.v2i2.44581.

[58] D. N. Al Husaeni, A. B. D. Nandiyanto, and R. Maryanti, "Bibliometric Analysis of Special Needs Education Keyword Using VOSviewer Indexed by Google Scholar," *Indonesian Journal of Community and Special Needs Education*, vol. 3, no. 1, pp. 1–10, Mar. 2022, doi: 10.17509/ijcsne.v3i1.43181.

[59] D. N. Al Husaeni, "Bibliometric analysis of briquette research trends during the covid-19 pandemic," *ASEAN Journal for Science and Engineering in Materials*, vol. 1, no. 2, 2022.

[60] A. Ruzmetov and A. Ibragimov, "Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021," *ASEAN Journal for Science and Engineering in Materials*, vol. 2, no. 1, 2023.

[61] H. Sudarjat, "Computing bibliometric analysis with mapping visualization using vosviewer on 'pharmacy' and 'special needs' research data in 2017-2021," *ASEAN Journal of Community and Special Needs Education*, vol. 2, no. 1, 2023.

[62] D. N. Al Husaeni and M. Rahmat, "Digital transformation in special needs education: Computational bibliometrics," *ASEAN Journal of Community and Special Needs Education*, vol. 2, no. 2, 2023.

[63] D. N. Al Husaeni, "Bibliometric analysis of research development in sports science with vosviewer," *ASEAN Journal of Physical Education and Sport Science*, vol. 2, no. 1, 2023.

[64] I. R. Firdaus, M. F. Febrianty, P. N. Awwaludin, M. N. F. Ilsya, Y. Nurcahya, and K. Sultoni, "Nutritional research mapping for endurance sports: A bibliometric analysis," *ASEAN Journal of Physical Education and Sport Science*, vol. 2, no. 1, pp. 23–28, 2023.

[65] D. F. Al Husaeni and D. N. Al Husaeni, "Computational bibliometric analysis of research on science and Islam with VOSviewer: Scopus database in 2012 to 2022," *ASEAN Journal of Religion, Education, and Society*, vol. 1, no. 1, 2022.

[66] J. Chano, C. Tungtawee, and M. Luo, "Correlation between meditation and Buddhism: Bibliometric analysis," *ASEAN Journal of Religion, Education, and Society*, vol. 2, no. 2, 2023.

[67] J. Chano, C. Tungtawee, and M. Luo, "Correlation between meditation and religion: Bibliometric analysis," *ASEAN Journal of Religion, Education, and Society*, vol. 3, no. 1, pp. 11–22, 2024.

[68] A. H. I. Nurrahma, L. Nuraini, H. H. Putri, and R. M. Syahada, "A bibliometric analysis of seed priming: global research advances," *ASEAN Journal of Agriculture and Food Engineering*, vol. 3, no. 1, 2024.

[69] A. Nurramadhani, R. Riandi, A. Permanasari, and I. R. Suwarma, "Low-carbon food consumption for solving climate change mitigation: Literature review with bibliometric and simple calculation application for cultivating sustainability consciousness in facing sustainable development goals (SDGs)," *Indonesian Journal of Science and Technology*, vol. 9, no. 2, pp. 261–286, 2024, doi: 10.17509/ijost.v9i1.67302.

[70] S. O. Makinde, Y. A. Ajani, and M. R. Abdulrahman, "Smart learning as transformative impact of technology: A paradigm for accomplishing sustainable development goals (SDGs) in education," *Indonesian Journal of Educational Research and Technology*, vol. 4, no. 3, 2024, doi: 10.17509/ijert.v4i3.66097.

[71] K. W. Gemil, D. S. Na'ila, N. Z. Ardila, and Z. U. Sarahah, "The relationship of vocational education skills in agribusiness processing agricultural products in achieving sustainable development goals (SDGs)," *ASEAN Journal of Science and Engineering Education*, vol. 4, no. 2, pp. 181–192, 2024, doi: 10.17509/ajsee.v4i2.65676.

[72] M. R. I. Haq, D. V. Nurhaliza, L. N. Rahmat, and R. N. A. Ruchia, "The Influence of

Environmentally Friendly Packaging on Consumer Interest in Implementing Zero Waste in the Food Industry to Meet Sustainable Development Goals (SDGs) Needs," *ASEAN Journal of Economic and Economic Education*, vol. 3, no. 2, 2024.

[73] J. Basnur, M. F. F. Putra, S. V. A. Jayusman, and Z. Zulhilmi, "Sustainable Packaging: Bioplastics as a Low-Carbon Future Step for the Sustainable Development Goals (SDGs)," *ASEAN Journal for Science and Engineering in Materials*, vol. 3, no. 1, 2024.

[74] I. Maulana, M. A. Asran, and R. M. Ash-Habi, "Implementation of Sustainable Development Goals (SDGs) No. 12: Responsible Production and Consumption by Optimizing Lemon Commodities and Community Empowerment to Reduce Household Waste," *ASEAN Journal of Community Service and Education*, vol. 2, no. 2, 2023.

[75] A. T. Nurnabila, J. Basnur, R. Rismayani, S. Ramadhani, and Z. Zulhilmi, "Analysis of the Application of Mediterranean Diet Patterns on Sustainability to Support the Achievement of Sustainable Development Goals (SDGs): Zero Hunger, Good Health and Well Beings, Responsible Consumption, and Production," *ASEAN Journal of Agricultural and Food Engineering*, vol. 2, no. 2, pp. 105–112, 2023.

[76] I. Awalussillmi, K. R. Febriyana, N. Padilah, and N. A. Saadah, "Efforts to improve sustainable development goals (SDGs) through education on diversification of food using infographic: Animal and vegetable protein," *ASEAN Journal of Agricultural and Food Engineering*, vol. 2, no. 2, pp. 113–120, 2023.

[77] F. A. Rahmah, N. Nurlaela, R. Anugrah, and Y. A. R. Putri, "Safe food treatment technology: The key to realizing the sustainable development goals (SDGs) zero hunger and optimal health," *ASEAN Journal of Agriculture and Food Engineering*, vol. 3, no. 1, pp. 57–66, 2024.

[78] A. Keisyafa, D. N. Sunarya, S. M. Aghniya, and S. P. Maula, "Analysis of student's awareness of sustainable diet in reducing carbon footprint to support sustainable development goals (SDGs) 2030," *ASEAN Journal of Agriculture and Food Engineering*, vol. 3, no. 1, pp. 67–74, 2024.

[79] Y. D. Yolanda and A. B. D. Nandiyanto, "How to read and calculate diameter size from electron microscopy images," *ASEAN Journal of Science and Engineering Education*, vol. 2, no. 1, pp. 11–36, 2022, doi: 10.17509/ajsee.v2i1.35203.

[80] P. B. Anand *et al.*, "Kenaf fiber and hemp fiber multi-walled carbon nanotube filler-reinforced epoxy-based hybrid composites for biomedical applications: morphological and mechanical characterization," *Journal of Composites Science*, vol. 7, no. 8, p. 324, 2023, doi: 10.3390/jcs7080324.

[81] P. Zhu, Z. X. Lei, and K. M. Liew, "Static and free vibration analyses of carbon nanotube-reinforced composite plates using finite element method with first order shear deformation plate theory," *Composite Structures*, vol. 94, no. 4, pp. 1450–1460, 2012, doi: 10.1016/j.compstruct.2011.11.010.

[82] S. Sharma, P. Sudhakara, J. Singh, S. Singh, and G. Singh, "Emerging progressive developments in the fibrous composites for acoustic applications," *Journal of Manufacturing Processes*, vol. 102, pp. 443–477, 2023, doi: 10.1016/j.jmapro.2023.07.053.

[83] K. Olonisakin *et al.*, "Key improvements in interfacial adhesion and dispersion of fibers/fillers in polymer matrix composites; focus on pla matrix composites," *Composite Interfaces*, vol. 29, no. 10, pp. 1071–1120, 2022, doi: 10.1080/09276440.2021.1878441.

[84] L. O. Ejeta, "The mechanical and thermal properties of wood plastic composites based on heat-treated composite granules and HDPE," *Journal of Materials Science*, vol. 58, no. 48, pp. 18090–18104, 2023, doi: 10.1007/s10853-023-09169-w.

[85] I. Barbaros, Y. Yang, B. Safaei, Z. Yang, Z. Qin, and M. Asmael, "State-of-the-art review of fabrication, application, and mechanical properties of functionally graded porous nanocomposite materials," *Nanotechnology Reviews*, vol. 11, no. 1, pp. 321–371, 2022, doi: 10.1515/ntrev-2022-0017.

[86] A. A. Abadel, "Physical, mechanical, and microstructure characteristics of ultra-high-

performance concrete containing lightweight aggregates," *Materials*, vol. 16, no. 13, p. 4883, 2023, doi: 10.3390/ma16134883.

[87] D.-L. Yang, Q. Sun, H. Niu, R.-L. Wang, D. Wang, and J.-X. Wang, "The properties of dental resin composites reinforced with silica colloidal nanoparticle clusters: Effects of heat treatment and filler composition," *Composites Part B: Engineering*, vol. 186, p. 107791, 2020, doi: 10.1016/j.compositesb.2020.107791.

[88] M. Ito, H. Liu, A. Kumagai, X. Liang, K. Nakajima, and H. Jinnai, "Direct visualization of interfacial regions between fillers and matrix in rubber composites observed by atomic force microscopy-based nanomechanics assisted by electron tomography," *Langmuir*, vol. 38, no. 2, pp. 777–785, 2021, doi: 10.1021/acs.langmuir.1c02788.

[89] A. B. D. Nandiyanto, R. Ragadhita, and M. Fiandini, "Interpretation of Fourier transform infrared spectra (FTIR): A practical approach in the polymer/plastic thermal decomposition," *Indonesian Journal of Science and Technology*, vol. 8, no. 1, pp. 113–126, 2023, doi: https://doi.org/10.17509/ijost.v8i1.53297.

[90] S. Sukamto and A. Rahmat, "Evaluation of FTIR, macro and micronutrients of compost from black soldier fly residual: In context of its use as fertilizer," *ASEAN Journal of Science and Engineering*, vol. 3, no. 1, pp. 21–30, 2023, doi: 10.17509/ajse.v3i1.42798.

[91] E. M. Obinna, "Physicochemical properties of human hair using Fourier transform infra-red (FTIR) and scanning electron microscope (SEM)," *ASEAN Journal for Science and Engineering in Materials*, vol. 1, no. 2, pp. 71–74, 2022.

[92] N. M. Nurazzi *et al.*, "Mechanical performance evaluation of bamboo fibre reinforced polymer composites and its applications: a review," *Functional Composites and Structures*, vol. 4, no. 1, p. 15009, 2022, doi: 10.1088/2631-6331/ac5b1a.

[93] X. Gao, D. Zhu, S. Fan, M. Z. Rahman, S. Guo, and F. Chen, "Structural and mechanical properties of bamboo fiber bundle and fiber/bundle reinforced composites: a review," *Journal of Materials Research and Technology*, vol. 19, pp. 1162–1190, 2022, doi: 10.1016/j.jmrt.2022.05.077.

[94] A. Guchait, A. Saxena, S. Chattopadhyay, and T. Mondal, "Influence of nanofillers on adhesion properties of polymeric composites," *ACS omega*, vol. 7, no. 5, pp. 3844–3859, 2022, doi: 10.1021/acsomega.1c05448.

[95] D. Dionysopoulos and O. Gerasimidou, "Wear of contemporary dental composite resin restorations: a literature review," *Restorative dentistry & endodontics*, vol. 46, no. 2, 2021, doi: 10.5395/rde.2021.46.e18.

[96] E. Milanese, T. Brink, R. Aghababaei, and J.-F. Molinari, "Role of interfacial adhesion on minimum wear particle size and roughness evolution," *Physical Review E*, vol. 102, no. 4, p. 43001, 2020, doi: 10.1103/PhysRevE.102.043001.

[97] M. M. Trexler and N. N. Thadhani, "Mechanical properties of bulk metallic glasses," *Progress in Materials Science*, vol. 55, no. 8, pp. 759–839, 2010, doi: 10.1016/j.pmatsci.2010.04.002.

[98] G. Wang, D. Yu, A. D. Kelkar, and L. Zhang, "Electrospun nanofiber: Emerging reinforcing filler in polymer matrix composite materials," *Progress in Polymer Science*, vol. 75, pp. 73–107, 2017, doi: 10.1016/j.progpolymsci.2017.08.002.