ARTICLE

Exploring biomass-based brake pads from various construction wastes in microparticle sizes: Advancing environmentally friendly solutions and student entrepreneurship for sustainable development goals (SDGs)

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ABSTRACT

This study analyzed the effectiveness of brake pads made from biomass materials, from building construction waste, which was done to find alternative brake pads that are environmentally friendly. This article also examineds the development of entrepreneurship to support sustainable development goals (SDGs). The methods included experiments, verification, and descriptive analysis. We utilized Borneo sawdust, mahogany, and bamboo as biomass materials for making brake pads. The results indicated the prospective construction waste materials as raw materials for brake pad production, assisting the SDGs by providing ecologically friendly solutions and lowering the amount of trash generated during construction. Mahogany wood dust biomass with sizes of 4 µm was the most effective material composition to be used as an environmentally friendly brake pad, compared to Borneo wood dust and bamboo. Mahogany had greater durability and friction qualities. The results also showed the importance of this study for government, business, and academic institutions to work together to foster student

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KEYWORDS

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entrepreneurship and the growth of sustainable innovation, helping achieve the SDGs.

Further, when the samples were compared with pure LLDPE and Polystyrene, there was no C=C bond. This pyrolysis process showed two might reactions: the end chain cracking and random cracking. This study brings ideas in the pyrolysis of plastic wastes, supporting current issues in the sustainable development goals (SDGs).

INTRODUCTION

The Sustainable Development Goals (SDGs) promise to "leave no one behind" during the implementation process and are universal goals that apply to both developed and developing nations. Despite the challenges, they encounter because of the inadequate institutional frameworks (Apostolopoulos et al. 2018; Littlewood and Holt 2018). Entrepreneurship can also support the SDGs by its results in the areas of the economy, society, and the environment (Rahdari et al. 2016). Social entrepreneurs may use scarce resources and operate well under institutional constraints due to their dedication to social ideals (Desa 2012). For example, a business might be the sole viable option for taking long-term action during humanitarian crises. In emerging nations, refugees who are denied access to conventional employment opportunities, services, and social benefits may establish profitable new ventures in the face of extreme hardship to support themselves (Al-Dajani et al. 2015). Nonetheless, the social capital of the host countries is crucial to the refugees' entrepreneurial involvement (Bizri 2017). Thus, entrepreneurship may maximize the SDGs' impact and produce long-term benefits for the environment and society.

To complete the SDGs, green innovation, especially in sustainable development materials, plays a crucial role in addressing environmental challenges. By definition, green innovation means all kinds of innovations that help develop important goods, services, or procedures that reduce environmental harm and destruction while also making the best use possible of available natural resources. Green innovations fall into four categories: technology, management duties, the appearance of the industrial process, and product design. The practice of altering an existing product design to lessen the adverse environmental impact is one example of a green innovation during the product life cycle evaluation (Klassen and Whybark 1999). Regarding the limitations of resources and the environment, green innovation is a key driver of high-quality economic development (Song et al. 2019; Shin et al. 2022). Green innovation is measured by the number of green patents, as per the International Patent Commission's (IPC) classification of patented inventions that are not harmful to the environment (Liu and Li 2022; Luo et al. 2022). The natural logarithm is used to account for the right-skewed data distribution after adding 100 to each value.

Brake pads hold an essential role in a vehicle braking system. The brake component is constructed of a stationary friction element called a pad and a spinning element called a drum or disc. The friction element of a brake pad presses up against a disk or drum during use. The percentage of metals and other substances in metallic and semi-metallic brake pads is higher than that of non-asbestos organic pads. The ingredients that make up a brake pad are abrasive, friction modifier, filler, reinforcement, and binder. The worn debris is tossed into the atmosphere during brake action. There are several components in the brake pad composition. Certain metallic compounds, together with other substances, have toxic characteristics that contaminate the environment. An increase in the amount of certain environmentally harmful poisonous substances. Certain environmental agencies have discovered that the components of brake pads have a negative impact on human health. The Environmental Protection Agency forbids the use of asbestos due to its proven hazardous properties. In addition, additional components of the brake pad cause health problems for humans. The organic component is the best alternative to overcome environmental and health damage caused by chemical components of brake pads, but common organic brakes appear to have some disadvantages. In contrast to alternative kinds the organic brake pads, they are composite. They may need to be changed more frequently due to their tendency to wear out more quickly. Additionally, they usually work best in a narrower temperature range.

This study focused on finding the best alternative for brake pads that are environmentally friendly as an attempt to accelerate SDGs, finding out which organic material can stand the amount of friction, and using the discovery to improve the quality of organic brake pads while creating more entrepreneurs through discovery from this study.

MATERIALS AND METHODS

Bamboo powder, Borneo wood powder, and mahogany wood powder were the main materials used to make this brake lining. These three powders were taken from industrial waste. The resin was used as the main binding matrix to bond the three powders together into a solid unit. To speed up the hardening process, the resin seeped into the pores of the powders and formed a strong and durable bond. Bamboo powder, with its distinct fiber structure, provided tensile strength and flexibility to the brake lining. Borneo wood powder, known for its higher density, increased the hardness and wear resistance of the brake lining, and mahogany wood particles, with their high lignin content, provide thermal stability and resistance to the heat generated during braking. The brake lining, made with resin as a binder and the three types of particles as reinforcement, not only had good braking performance but also was economical and environmentally friendly.

Brake lining was made from several main materials: bamboo sawdust, Borneo wood powder, and mahogany wood powder. Bamboo sawdust, Borneo sawdust, and mahogany sawdust served as the main reinforcing materials in the manufacture of brake linings. Bamboo powder, Borneo wood powder, and mahogany wood powder were pulverized using a saw-milling process and filtered to have some texture. Furthermore, bamboo powder, Borneo wood powder, and mahogany wood powder, with each mass of 2 g, were mixed with 5.8 g of resin and 5.8 g of catalyst. The resin acted as a binding matrix, filled the pores of the particles, and increased durability to produce a strong and dense structure. Meanwhile, catalysts were used to speed up the setting process to ensure that the powder and resin bonded faster and more effectively. The mixture was inserted into a silicon mold with a size of 2 x 2 x 2 cm, stirred at a constant speed for 10 minutes, and heated at 70°C for 2 hours to enhance resin curing. The mixture was then cooled for 14 days. After the brake lining was dry, smoothing was done using emery to remove the resin on the surface.

In this study, three types of main raw materials were used, namely bamboo powder, Kalimantan wood powder, and mahogany wood powder. Each type of raw material was prepared in three different sample sizes, namely 19.7 µm, 9.8 µm, and 4 µm. For each sample size, the mass of powder used was 2 grams. In addition, each composition was added with a resin with a mass of 5.8 grams and a catalyst with a mass of 5.8

grams. This combination was applied consistently for all types of raw materials and sample sizes tested.

Bamboo powder, Borneo wood powder, and mahogany wood powder were tested with a microscope to determine their particle size and morphology. This step was very important to understand the physical properties of the three types of powders. In addition to analyzing the powder particles, microscopic tests were conducted on the surface of the brake lining. Before conducting the microscopic test, the surface of the brake lining was cleaned of the resin covering the surface. The brake pad surface was meticulously cleaned before microscopic testing to eliminate any resins that could mask significant structural elements. To guarantee an accurate study of the brake pad's surface texture and the binding between its powders, this step was crucial. Resin hindered the observation of important details of the brake lining surface structure. After cleaning, the brake lining surface was examined using a digital microscope.

To test the strength and durability of brake linings made from bamboo powder, Borneo wood powder, and mahogany powder, data was recorded, namely:

(i) Ma: Initial mass of brake lining (g)
(ii) Mb: Final mass of brake lining after the test (g)
(iii) Mt: Hand mass (g)
(iv) l: Friction track (cm)
(v) t: Testing time (seconds)
(vi) A: Brake lining surface area (mm²)

In conducting the test, several mechanical methods were carried out, including:

(i) Compression test: To ascertain the brake pad's maximum resistance to the pressure produced while braking and to make sure it has enough strength for safe and effective braking. A Screw Mount test Instrument (Model I ALX-J, China) with a digital force measurement device (Model HP-500, Serial No. H5001909262) was used to perform the compression test. To create a curve that depicts the textural profile, the compressive force was concurrently measured throughout the test. Next, the compressive strength was determined by measuring the compressive stress-strain curve's maximum point.

(ii) Friction Test: Friction testing was done for two purposes. The first was to determine how well the brake pads function to generate the friction necessary to slow or stop the vehicle. The second was to determine how resistant the brake pads are to damage caused by repeated braking. During the test, the brake pads were rubbed for 120 seconds on 28 cm x 11.4 cm sandpaper.

RESULTS AND DISCUSSION

Incorporating Qualitative Data to Support Literature

Previous research on brake pad production has explored the development and optimization of materials and manufacturing techniques aimed at improving performance, durability, and environmental sustainability. Table 1 shows previous research studies that have provided valuable insights into raw material selection, composite structure design, and mechanical property evaluation under various operating conditions.

Table 1: Previous studies on brake-pad production

No	Title	References
1	Fabrication of resin-based brake pad from snake fruit peel as sustainable renewable resources to support sustainable development goals (SDGs)	(Nandiyanto et al. 2024)
2	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)	(Nandiyanto et al. 2024)
3	Green Innovation in Brake Pad Production: Harnessing Teak Powder and Clamshells as Sustainable Alternatives for Subtractive Residual Waste to Support Sustainable Development Goals (SDGs)	(Nandiyanto et al. 2024)
4	Techno-Economic Evaluation of The Production of Resin-Based Brake Pads using Agricultural Wastes: Comparison of Eggshells/Banana Peels Brake Pads and Commercial Asbestos Brake Pads	(Ragadhita et al. 2023)
5	Best Practice in Distance Learning with Experimental Demonstration on the Concept of the Automotive Brake Pad Fabrication from Domestic Waste to Vocational Students for Supporting Education for Sustainable Development	(Ragadhita et al. 2023)
6	Assessment Particle Size and Pore Size of Rice Husk Ash on the Resin-Based Brake Pads Performance: Experiments and Bibliometric Literature Review	(Nandiyanto et al. 2022)
7	Teaching the Concept of Brake Pads Based on Composites of Palm Fronds and Rice Husks to High School Students	(Anggraeni et al. 2022)
8	Natural Zeolite As The Reinforcement for Resin-Based Brake Pad Using Dual Particle Size	(Nandiyanto et al. 2022)
9	Mechanical Properties of Sawdust and Rice Husk Brake Pads with Variation of Composition and Particle Size	(Anggraeni et al. 2022)
10	Resin Matrix Composition on the Performance of Brake Pads Made from Durian Seeds: From Computational Bibliometric Literature Analysis to Experiment	(Nandiyanto et al. 2022)
11	The effect of mangosteen peel compositions as reinforcement components on resin-based brake pad performance with computational bibliometric mapping analysis	(Nandiyanto et al. 2022)
12	Effect of palm fronds and rice husk composition ratio on the mechanical properties of composite-based brake pad	(Nandiyanto et al. 2022)
13	Assessment Resin-based brake pad from rice husk particles: From literature review of brake pad from agricultural waste to the techno-economic analysis	(Nandiyanto et al. 2021)
14	Effects of Particle Size and Composite Composition of Carbon Microparticles as Reinforcement Components on Resin-Based Brake Pad Performance	(Nandiyanto et al. 2021)
15	Effects of Particle Size and Composite Composition of Durian Peels and Banana Midribs' as Reinforcement Components on Resin-Based Brake Pad Performance	(Nandiyanto et al. 2021)

No	Title	References
16	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	(Nandiyanto et al. 2021)

After conducting a thorough review of previous studies on brake pads, this research proceeded with an in-depth analysis aimed at examining the findings of studies that specifically focus on the utilization of natural materials in the development and application of brake pads. Table 2 presents a summary of the results of previous studies on brake pads made from natural materials.

Table 2: Previous research related to brake linings from natural materials

Title	Supporting Materials	Results	References
Pengaruh Penambahan Karbon Pada Karakteristik Kampas Rem Komposit Serbuk Kayu	1. Wood Powder 2. Carbon Powder	Material characteristics testing shows that the specimens have thermal stability in TGA testing up to a temperature of 1500°C. The hardness test results show that the hardness value decreases when carbon is added. Specimen C10KY40 had a hardness value of 31.6 VHN, which is close to the standard brake lining, and the mass reduction test results showed that the lowest mass reduction rate was found in specimen C10KY40. The results of the material characteristics test show that the C10KY40 specimens have indications close to standard brake linings.	(Dwiyati et al. 2017)
Pembuatan Kampas Rem Menggunakan Serat Pelepah Pisang Dengan Variasi Butiran Alumunium Silicon (Al Si) Mesh 50, 60, 100 Terhadap Tingkat Kekerasan, Keausan, Dan Koefisien Gesek	1. Banana Stem Fiber 2. Calcium Carbonate 3. Barium Sulfate 4. Phenolic Resin 5. Teak Wood Carbon 6. Aluminum Silicon	Tested for hardness using a Durometer shore D tool with ASTM D2240 standards. Tested with a load of 16 kg for 3 h in dry, wet, salt water, brake fluid, and oil conditions. Then the wear and friction coefficient were calculated. The hardness test results show that the aluminum-silicon (Al-Si) (5.9 µm) has the highest hardness value with a value of 80.23 with Shore D. In friction testing under all conditions, the lowest wear value was found for aluminum-silicon (Al-Si) (5.9 µm) of 256.25 mm^3/h, water of 196.88 mm^3/h, oil of 345.83 mm^3/h, salt water of 258.33 mm^3/h, and brake fluid of 342.71 mm^3/h. The highest coefficient of friction was achieved in dry conditions, which was 0.651 for 5.9 µm and the marketed lining, while for the 11.7 and 9.8 µm, the highest coefficient of friction values were 0.657 and 0.612, respectively. Thus, the use of 11.7, 9.8, and 5.9 µm affects the level of hardness, wear, and coefficient of friction.	(Purboputro 2021)
Pengujian Sifat Mekanik dan Sifat Termal pada Kampas Rem Komposit Serbuk Gelas dengan Penambahan Serat Kulit Pisang	1. Glass Powder 2. Areca Nut Fiber 3. Epoxy Resin	The hot isostatic hardening method was used for 3 h in this study. The temperature was 160°C and the pressure was 9 tons. The volume fraction of areca nutshell fiber of each sample was 2, 5, 8, 11, and 14%. TMA testing (mechanical heat analysis) was conducted on the areca nut shell fiber composite brake lining. The results showed a hardness of 77 HRB, wear of 5.16 $\times 10^{-4}$ mm/kg, friction coefficient of 0.240 - 0.625, water absorption of 3.49%, and a decrease in disc speed. The highest thermal expansion coefficient was 48.79. 10^{-6} $°C^{-1}$ and the lowest thermal expansion coefficient was 19.3. 10^{-6} $°C^{-1}$.	(Febryana 2022)
Pengaruh Variasi Temperatur Pirolisis Tempurung Kelapa Sawit dengan Penambahan Resin Epoxy terhadap Uji Kekerasan pada Kampas Rem	1. Palm Shell Powder 2. Epoxy Resin	As an alternative to brake linings made from asbestos, this research addresses the industry's need for environmentally friendly brake linings. This experiment aims to optimize the hardness of brake lining by combining palm shell powder with epoxy resin as the matrix. The experiment involved changing the pyrolysis temperature and volume fraction to produce reduced palm shell powder at 400, 450, and 500°C, respectively, yielding results for the manufacture of brake linings. Hardness testing with a durometer showed that the blend formulation of 50% palm shell powder and 50% epoxy resin at 400°C provided the highest hardness (72 HD), but decreased at 500°C (53.3 HD). This study also found that the formulation of a mixture of 50% palm shell powder and 50% epoxy resin at 450°C gave the lowest hardness with a value of 72 HD.	(Muliyaddi et al. 2024)
Analisa Keausan Kampas Rem Non Asbes Terbuat Dari Komposit Polimer Serbuk Padi Dan Tempurung Kelapa	1. Resin 2. Catalyst 3. Rice husk powder 4. Crushed coconut shell	In motorcycle brake linings made from polymer composites, the composition of 50% rice husk, 25% coconut shell, and 25% resin has the highest wear value of 4.27 x 10-6 grams/mm^2.second. The composition of 40% rice husk, 30% coconut shell, and 30% resin had the lowest wear value of 3.75 x 10-6 grams/mm^2.second. The brake lining made of 50% rice husk, 25% coconut shell, and 25% resin lasted for 53 h. While the composition of 40% rice husk, 30% coconut shell, and 30% resin lasted 52 h, the composition of 25% rice husk, 25% coconut shell, and 50% resin lasted 48 h due to the large mixture of rice husk.	Suhardiman and Syaputra 2017)

Table 3: Previous research on bibliometrics

Title	Result	References
Analisis Bibliometrik: Fokus Penelitian Problem Based Learning Dalam Pembelajaran Matematika	Through bibliometric analysis of 105 primary studies conducted between 2017-2022, this research provides a complete picture of the application of problem-based learning (PBL). PBL is increasingly used in mathematics learning. However, the analysis shows that some topics remain under-researched, especially those related to mathematics. Further research has the opportunity to explore and develop more specialized and in-depth PBL approaches in the context of mathematics learning. This research aims to make a greater contribution to educational practice and a better understanding of how effective PBL is.	(Lestary et al. 2023)
Analisis Bibliometrik Terhadap Motivasi Belajar Berbasis VOS Viewer	Based on the results of an analysis using VOS Viewer software of scientific publications in Google Scholar from 2019-2023, 2001 had the highest number of publications with 335 publications, while 2023 had the lowest number with 23 publications. Network visualization identified 10 variables divided into 4 clusters, showing the relationship between topics. Overlay visualization and density visualization showed that in 2020-2021, research focused mostly on the topic of children, indicating that this topic has been widely studied by other researchers. Meanwhile, the variable related to Learning Motivation that still has opportunities and novelty for future research is the facility variable.	(Sianipar et al. 2023)
Bibliometric and Literature Review of Financing Risk in Islamic Banking	The results show a significant increase in the number of journal publications addressing financing risk in Islamic banking from 1999 to 2022, totaling 227 articles. The study is divided into five main clusters, consisting of 28 items, 21 items, 20 items, and 5 items, respectively. Among the eight main themes discussed in this study are risk management, definition and objectives, risk oversight, strategy and policy, identification and control, risk measurement, risk mitigation, risk determinants, and risk issues and impacts. In addition, this study also identified some gaps that may be the focus of future research, such as financing portfolio analysis, financing quality evaluation, risk management strategies, and lending.	(Budianto 2023)
Upaya Penanganan Stunting di Indonesia: Analisis Bibliometrik dan Analisis Konten	According to the results of bibliometric analysis, efforts to address stunting in Indonesia have resulted in 103 articles published in journals over the past 14 years. In 2021, the highest number of published articles was 33. These studies mostly came from the health field, especially health and care, with 85 articles. “Stunting” was the most frequently occurring keyword 20 times, indicating that this is the main subject of related research. In addition, other popular keywords included Indonesia, children, malnutrition, and sanitation. All of these reflect the main issues addressed in addressing stunting. This shows that the term stunting is the most discussed in previous research. This suggests that the issue of stunting in Indonesia is given a lot of attention in the scientific literature.	(Rahman et al. 2023)
Analisis Bibliometrik: Tren Penelitian Etnomatematika dalam Pembelajaran Matematika Di Indonesia (2017 – 2022)	The results showed that publications related to ethnomathematics in mathematics learning in Indonesia increased every year from 2017 to 2022. According to Hardiarti (2017), most documents were found in the institution “Indraprastha PGRI University”, the journal “Jurnal Cendekia Journal of Mathematics Education”, and articles. The most used ethnomathematics keyword is game; new themes are module development, local wisdom learning videos, and mosque decoration.	(Muhammad et al. 2023)
Analisis Bibliometrik tentang Perkembangan Penelitian tentang Ekonomi Berbasis Pengetahuan	The results of the bibliometric analysis show that knowledge-based economic research is increasingly relevant and receiving widespread attention in the academic literature. With globalization and technological advancements, knowledge and innovation have become critical to improving productivity, competitiveness, and sustainable economic growth. The citation analysis underscores the importance of the knowledge-based economy's understanding of concepts such as industrial competitiveness, knowledge management, and national innovation systems. Key findings include the discovery of research clusters focusing on economic aspects, knowledge management, research methodology, and geographical-social aspects.	(Harsono and Tarmidi 2024)
Analisis Bibliometrik: Penelitian Game-Based Learningpada Sekolah Menengah 2005-2023	The results show that publications on Game Based Learning (GBL) in secondary schools from 2005 to 2023 have increased significantly, with a peak of 399 citations in 2013. The United States is the most influential country in this field. The main focus of GBL research includes computational thinking and understanding, science, technology and development, and experience and environment. Emerging themes include self-efficacy, computational creativity, inquiry, AR technology, and mathematical problems. However, keywords such as games and middle school students have not been directly related to AR technology and	(Muhammad et al. 2023)

Title	Result	References
	achievement, and self-efficacy with mathematical problems. This research is limited to data from Scopus until January 11, 2023, so it does not include publications after that date and there are still many other databases that can be used as references.	

Table 4 presents a summary of previous research on the SDGs, with a particular emphasis on how these global goals relate to the development and innovation of environmentally friendly materials, such as the natural components used in brake pads. The table also illustrates how the adoption of sustainable practices can contribute to achieving broader goals, such as environmental sustainability.

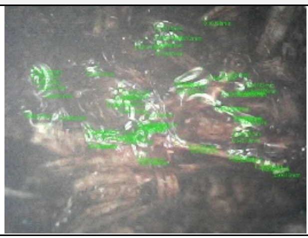
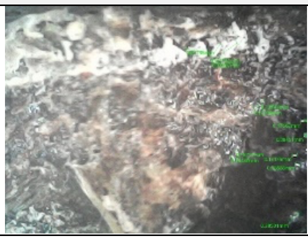
Table 4: Previous studies on SDGs

No	Title	References
1	Low-carbon food consumption for solving climate change mitigation: A literature review with bibliometric and simple calculation application for cultivating sustainability consciousness in facing sustainable development goals (SDGs)	(Nurramadhani et al. 2024)
2	Towards sustainable wind energy: A systematic review of airfoil and blade technologies over the past 25 years for supporting sustainable development goals (SDGs)	(Krishnan et al. 2024)
3	Assessment of student awareness and application of eco-friendly curriculum and technologies in Indonesian higher education for supporting sustainable development goals (SDGs): A case study on environmental challenges	(Djirong et al. 2024)
4	Effect of substrate and water on cultivation of Sumba seaworm (nyale) and experimental practicum design for improving critical and creative thinking skills of a prospective science teacher in biology and supporting sustainable development goals (SDGs)	(Kerans et al. 2024)
5	Smart learning as transformative impact of technology: A paradigm for accomplishing sustainable development goals (SDGs) in education	Makinde et al. 2024)
6	The relationship of vocational education skills in agribusiness processing agricultural products in achieving sustainable development goals (SDGs)	(Gemil et al. 2024)
7	The influence of environmentally friendly packaging on consumer interest in implementing zero waste in the food industry to meet sustainable development goals (SDGs) needs	(Haq et al. 2024)
8	Sustainable packaging: Bioplastics as a low-carbon future step for the sustainable development goals (SDGs)	(Basnur et al. 2024)
9	Implementation of sustainable development goals (SDGs) no. 12: Responsible production and consumption by optimizing lemon commodities and community empowerment to reduce household waste	(Maulana et al. 2023)
10	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	(Nurnabila et al. 2023)
11	Efforts to improve sustainable development goals (SDGs) through education on diversification of food using infographic: Animal and vegetable protein	Awalussillmi et al. 2023)
12	Safe food treatment technology: The key to realizing the sustainable development goals (SDGs) zero hunger and optimal health.	(Rahmah et al. 2024)
13	Analysis of student's awareness of sustainable diet in reducing carbon footprint to support sustainable development goals (SDGs) 2030.	(Keisyafa et al. 2024)
14	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis	(Maryanti et al. 2022)

Brake Pad Performance Test with Natural Material Composition

The pore size and distribution of Borneo, Bamboo, and Mahogany wood exhibit distinct differences based on the mesh size (19.7, 9.8, and 4 µm) and treatment (cut and sanded). Generally speaking, especially after cutting and sanding, the finer and denser the wood's pores, the higher the mesh number.

Table 5: Microscopic images of various Borneo brake pad processes taken from the outer, inner and friction surfaces

Sample	Pores	Pores after cutting	Pores after sanding
Borneo (19.7 µm)			

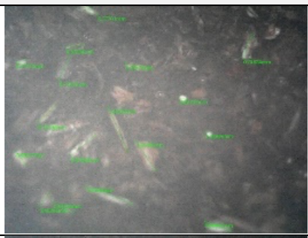
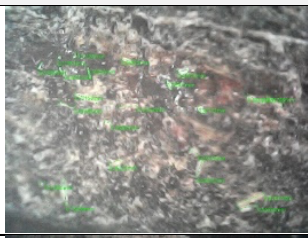
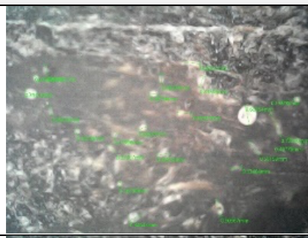
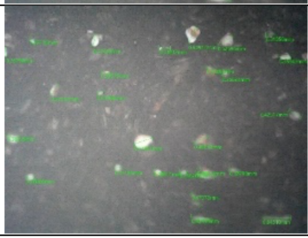
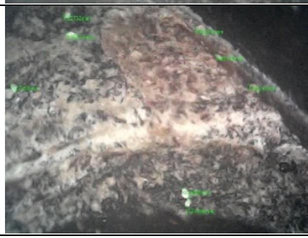
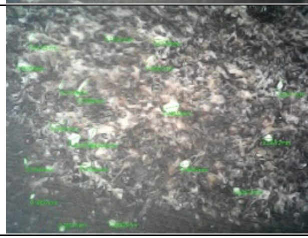
Sample	Pores	Pores after cutting	Pores after sanding
Borneo (9.8 µm)			
Borneo (4 µm)			

Table 6: Microscopic images of various Bamboo brake pad processes taken from the outer, inner and friction surfaces

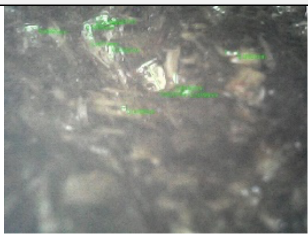
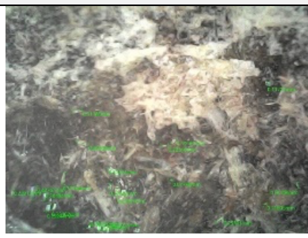
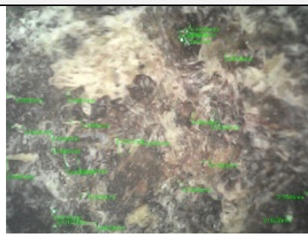
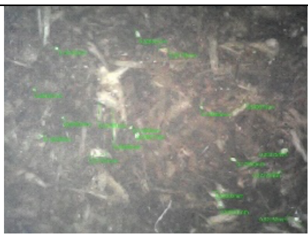
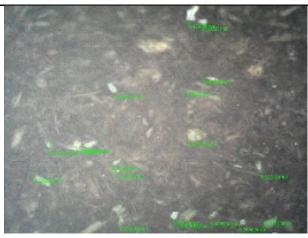
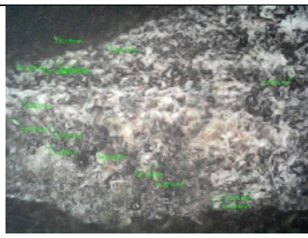
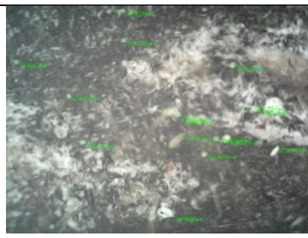
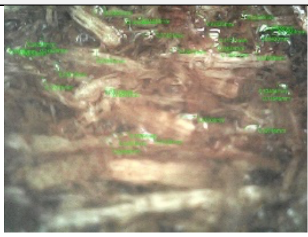
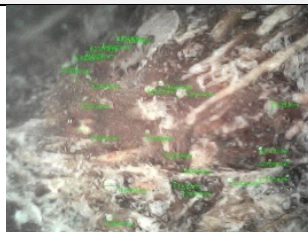
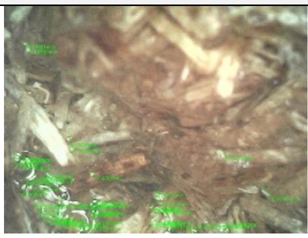
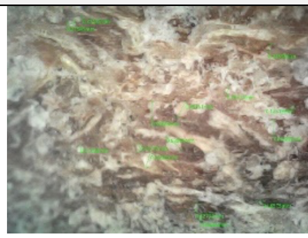
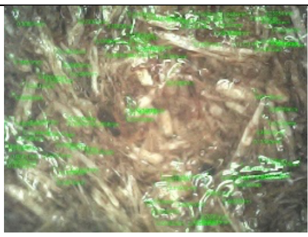
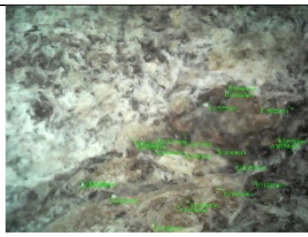
Sample	Pores	Pores after cutting	Pores after sanding
Bamboo (19.7 µm)			
Bamboo (9.8 µm)			
Bamboo (4 µm)			

Table 7: Microscopic images of various Mahogany brake pad processes taken from the outer, inner and friction surfaces

Sample	Pores	Pores after cutting	Pores after sanding
Mahogany (19.7 µm)			

Sample	Pores	Pores after cutting	Pores after sanding
Mahogany (9.8 µm)			
Mahogany (4 µm)			

Considering **Table 7**, compared to sizes of 19.7 and 9.8 µm, 4-µm particles produce finer and more consistent porosity results on all types of wood. Mahogany wood, out of the three, performs the most consistently and smoothly in every mesh, particularly at 4 µm. For applications like brake pads that need strength and smoothness, the pores appear to be very tiny and even. Although Borneo wood is not as smooth as Mahogany, it still produces acceptable results at 4 µm. On the other hand, bamboo wood is less suitable for applications requiring strength and even pressure distribution because of its bigger and distorted pores, particularly at 19.7 and 9.8 µm.

According to this investigation, the smooth texture and uniform pores of mahogany wood with 4 µm make it appear to be the ideal option for breakpad applications. Mahogany will help optimal heat dispersion and offer more reliable friction while braking. Though less ideal than mahogany, Borneo wood with sizes of 4 µm might also be a viable substitute. However, because of its big pores and rough texture, which might impact the effectiveness of the brake pads, low-mesh Bamboo might not be the best choice for this application.

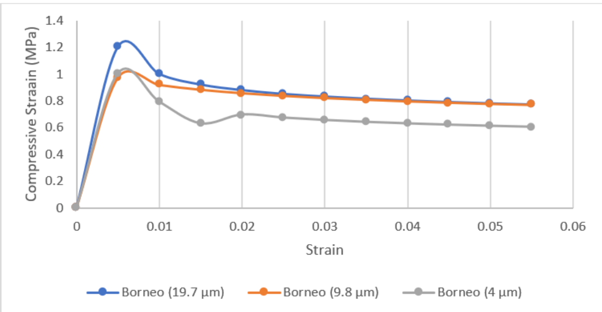


Figure 1: Borneo compressive stress-strain curve

The research shows **(see Figure 1)**, that out of the three samples, Borneo (19.7 µm) had the highest compressive strength, peaking at about 1.2 MPa. Because of this, it is perfect for applications where a strong resistance to compressive stresses is needed. However, with its smaller profile, this material is more prone to deformation over time. Borneo (9.8 µm) is an excellent option for applications that need a compromise between compressive strength and deformation resistance since it provides a more steady performance and has a little lower compressive strength of about 1.0 MPa. However, even though Borneo (4 µm) is the thickest material, it has a low compressive strength, peaking at around 1.0 MPa. Greater sizes do not necessarily result in higher compressive strength and could potentially have the opposite effect.

Overall, the test findings show that, as Borneo (4 µm) demonstrates, increasing sizes do not always result in an improvement in compressive strength. As a result, while choosing materials, the sizes must be appropriate for the particular requirements of the application. Borneo (9.8 µm) can be used as a more balanced substitute, although Borneo (19.7 µm) is best suited for lightweight buildings and high-compressive stress applications. Borneo (4 µm), despite its greater sizes, performs better in circumstances requiring accurate measurements as opposed to robust resistance to compressive loads.

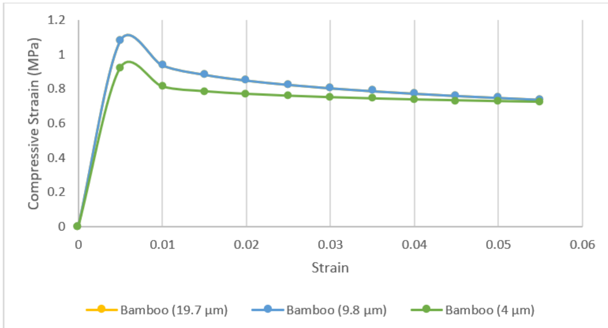


Figure 2: Bamboo compressive stress-strain curve

Based on **Figure 2**, the graph shows that, in terms of compressive strength and strain resistance, Bamboo (19.7 µm) and Bamboo (9.8 µm) display extremely comparable properties. Considering that both are stronger than Bamboo (4 µm) at the maximum compressive stress, they are better able to bear compressive loads. Bamboo 19.7 and 9.8 µm exhibit a consistent stress reduction after attaining the peak stress at a strain of roughly 0.01; this suggests that they retain their mechanical strength well even when deformed.

Conversely, as compared to Bamboo (19.7 and 9.8 µm), Bamboo (4 µm) has a lower compressive strength. This suggests Bamboo (4 µm) might not be as appropriate for uses where greater compressive strength is needed. However, the stress decrease pattern following the peak is comparable to that of the other two varieties of bamboo, indicating that Bamboo (4 µm) can still be employed in circumstances where a lower compressive strength is acceptable. As a result, Bamboo (19.7

and 9.8 μm) is advised as the best option for applications requiring a high degree of compressive stress resistance.

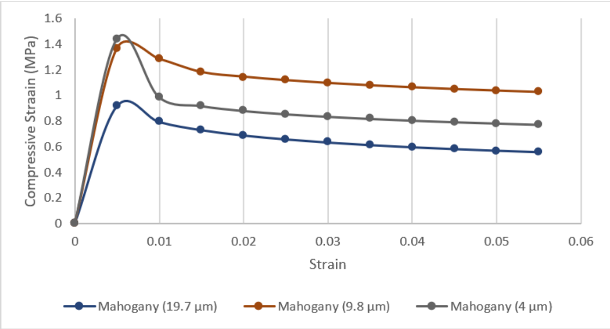


Figure 3: Mahogany compressive stress-strain curve

Based on the graph above **(Figure 3)**, Mahogany (4 μm) has the highest compressive strength of the three wood species, with a peak stress of around 1.4 MPa. After peaking at a strain of 0.01, Mahogany (4 μm) has a steady decrease in stress, although it remains higher than Mahogany (9.8 μm) at each subsequent strain level. This indicates that because Mahogany (4 μm) is more resilient to pressure and deformation, it is a better material choice for applications needing a high compressive load-bearing capability.

As opposed to Mahogany (19.7 μm), Mahogany (9.8 μm) exhibits a substantially more consistent stress drop and peak stress of around 1.3 MPa. Mahogany (19.7 μm) has a quicker drop in stress and a lesser compressive strength than other materials. Its lowest peak stress is around 0.9 MPa. This result indicates that Mahogany (4 μm) is most suited for uses needing high compressive strength, whereas Mahogany (9.8 μm) and 19.7 μm can be taken into consideration for uses requiring less strength.

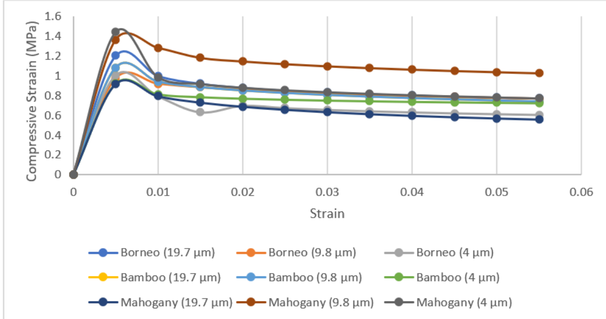


Figure 4: The results of the compressive stress-strain curve

Based on **Figure 4**, as opposed to Borneo and Bamboo, which fall into the intermediate range, Mahogany (9.8 μm) exhibits a substantially more consistent stress drop and peak stress of around 1.3 MPa. Mahogany (19.7 μm) has a quicker drop in stress and a lesser compressive strength than other materials. This result indicates that Mahogany (4 μm) is most suited for uses needing high compressive strength, whereas Mahogany (9.8 μm) and 19.7 μm can be taken into consideration for uses requiring less strength.

Mahogany wood has the highest overall performance, according to the analytical findings of the compressive strain curves versus strain for three different species of wood (Borneo, Bamboo, and Mahogany) with varying sizes (19.7, 9.8, and 4 μm). Mahogany wood approaches 1.6 MPa, the maximum value for compressive strain, especially when its size is between 9.8 and 4 μm. This demonstrates that mahogany is best suited for situations requiring great resistance to large loads since it has the highest capacity to sustain compressive stresses. Out of the three types of wood, Borneo wood performs the worst; in particular, Borneo wood has the lowest compressive strain value and measures 9.8 and 4 μm in size. Bamboo wood falls in the center, exhibiting steady performance and a compressive strain of around 0.9 to 1.0 MPa, suggesting that it is a more cost-effective substitute with respectable compressive strength.

All aspects considered Mahogany (4 μm) wood is the kind that works the best in situations when maximum compressive strength is needed. Mahogany (4 μm) is a better option for structural applications where maximum stress resistance is required.

Table 8: Test object composition differences in terms of loss rates for mass, speed, wear, and coefficient swipe

Sample	Initial Mass (g)	Force	Final Mass (g)	Mass Loss	time (s)	Surface Area (mm²)	Friction Track	Friction Coefficient after Normalization
Borneo (19.7 μm)	10.92	0.107125	10.64	0.28	120	1600	259	0.000859843
Borneo (9.8 μm)	11.03	0.108204	10.88	0.15	120	1600	294	0.000868504
Borneo (4 μm)	11.59	0.113698	11.4	0.19	120	1600	330	0.000912598
Bamboo (19.7 μm)	12.52	0.122821	12.34	0.18	120	1600	398	0.000985827
Bamboo (9.8 μm)	12.16	0.11929	12.05	0.11	120	1600	343	0.00095748
Bamboo (4 μm)	11.68	0.114581	11.29	0.39	120	1600	394	0.000919685

Sample	Initial Mass (g)	Force	Final Mass (g)	Mass Loss	time (s)	Surface Area (mm^2)	Friction Track	Friction Coefficient after Normalization
Mahogany (19.7 µm)	11.07	0.108597	10.41	0.66	120	1600	388	0.000871654
Mahogany (9.8 µm)	12.01	0.117818	11.96	0.05	120	1600	367	0.000945669
Mahogany (4 µm)	12.8	0.125568	12.41	0.39	120	1600	430	0.001007874

Based on the collected data in **Table 8**, Mahogany (19.7 µm) had a rather high coefficient of friction and suffered the most mass loss (0.66 g). This means Mahogany (19.7 µm) might not be as good a material for uses where a high level of friction resistance is required. The reduced mass loss and coefficient of friction of Borneo (9.8 µm) and Mahogany (9.8 µm) suggest that these materials are more stable and have superior resistance to friction.

According to the "Friction Coefficient After Normalization" chart, some test coefficient values that can be said to be low such as in Borneo (19.7 µm), Borneo (9.8 µm), and Mahogany (19.7 µm), materials with low test coefficient values have weaker stopping power. This means that brake pads made from this material may require a longer distance to stop the vehicle effectively. This may be less than ideal for applications that require fast or sudden braking. Conversely, this low friction may indicate that the material is more durable due to the smaller frictional force resulting in less wear on the brake pad surface. On the other hand, Mahogany (4 µm) and Bamboo (19.7 µm) have the highest value indicating that the material has a better ability to produce friction. In the context of brake pads, this means that the material can produce better stopping power, providing much greater braking effectiveness. Overall, Mahogany (4 µm) with the highest value of 0.001007874 is the best material composition that can provide the best braking effectiveness.

CONCLUSION

The difference in the composition of raw materials contributes significantly to the results of mechanical tests on the manufacture of brake pads with various types of wood base materials. The results of the analysis showed that brake pads with a composition of mahogany (4 µm) have the best composition compared to other types. Based on physical tests using a microscope, brake pads with mahogany (4 µm) have the fewest pores, which contributes to their structural strength. In terms of mechanical properties, mahogany (4 µm) in brake pads has superior performance compared to other types, as seen from the results of the compression test, where this type of brake pad shows the highest resistance value. Thus, brake pads made from mahogany (4 µm) are the best choice for producing effective, strong, and environmentally friendly brake pads.

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CONFLICT OF INTEREST

The authors affirm that there are no conflicts of interest associated with this research.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

The first to seventh authors contributed to all stages of the study, from planning to writing, and focused on each specific work, such as concept, technique, and content verification for correctness, completeness, and accuracy. ESS reviewed and edited the manuscript, particularly adding the entrepreneurial context, while SL prepared the initial draft and edited it to include the economic/entrepreneurship context.

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