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Effect of Coconut Fiber and Coconut Shell Charcoal Composite with PVC Matrix and Hot Press Method on the Tensile Strength and Hardness of Brake Pad

Aap Pandriana [1,3,*], Kurniawan [2], and Sagir Alva [1]

[1]Master of Mechanical Engineering, Faculty of Engineering, Mercu Buana University, Jakarta, Indonesia
[2]Indonesia Fuel Cell and Hydrogen Energy (IFHE), South Tangerang, Banten, Indonesia
[3]Department of Two-Wheel Vehicle Engineering, SMKN 7 Tangerang Regency, Banten, Indonesia

*Corresponding Authors: aappandriana@gmail.com

Abstract

This research aims to develop an eco-friendly brake pad composite using coconut fiber and coconut shell charcoal with a PVC matrix and the hot press method. Conventional asbestos-based brake pads pose health risks, necessitating safer alternatives. Coconut fiber, known for its high tensile strength, and coconut shell charcoal powder, used as a filler, enhance mechanical properties. The composite was processed at 180°C and 7 MPa, with variations in solvent content to assess its impact on tensile strength and hardness. The optimal composition—70% coconut fiber, 5% coconut shell charcoal, and 25% PVC resin—achieved 7.7 MPa tensile strength and 72.2 HD Shore D hardness, meeting SAE J661-1997 standards. The findings confirm that reducing solvent content increases resin viscosity, resulting in a denser, stronger composite. This study highlights the potential for further development of sustainable, high-performance brake pad materials.

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1. Introduction

The braking system's capability in every motor vehicle is crucial as it directly impacts driving safety. The higher the vehicle's speed, the greater the need for an optimal braking system to stop the vehicle [1]. One of the most important components in a vehicle that functions to stop or slow down the vehicle's speed is the brake pad [2]. Brake pads are typically made using asbestos as a reinforcement and resin as a binder [3]. However, asbestos generates toxic dust that can be inhaled by drivers and people nearby. Additionally, asbestos is carcinogenic, posing a cancer risk to users and employees working in the brake pad manufacturing industry [4], [5]. Therefore, to replace asbestos, non-asbestos brake pads are needed that maintain their tribological and mechanical properties [3].

Non-asbestos brake pads are made using biocomposite technology that utilizes natural fibers [3]. Besides being environmentally friendly, composite materials offer many advantages, including lighter weight, higher strength and durability, corrosion resistance, and wear resistance [6]. The non-asbestos brake pad material in this study uses coconut fiber waste and coconut shell charcoal powder as fillers. In addition to the abundance and underutilization of coconut fiber waste, coconut fiber also has high tensile strength and impact resistance [7]. Previous research on brake pad composites used coconut fiber as a reinforcement and epoxy resin as a matrix, employing a conventional pressing method without heating. However, the test results did not meet the requirements set by the Indonesian National Standard [4]. Therefore, efforts are needed to enhance performance to meet the required standards.

To enhance the performance and characteristics of brake pads made from coconut fiber composite, this research will modify the coconut fiber used in previous research. The long, aligned and random fibers will be cut into smaller pieces, as a smaller size will result in a denser composite mixture [8]. In previous research, in making brake pad composites with banana fiber reinforcement material, the composite with 100% mesh had the highest hardness with a value of 79.8 HD (Shore D) compared to 50% mesh with a value of 72.8 HD (Shore D) and 60% with a value of 73.8 HD (Shore D) [9]. In other research, bolting water hyacinth fiber composites showed that shorter fiber lengths consistently produced higher torsional strength with a maximum value of 1,418 Nm and shear stress of 29,348 Mpa [10]. Furthermore, the molding method will switch from a non-heated pressing method to a hot press technique, as the heating process can influence the curing of the binder, resulting in a stronger composite bond [8].

Additionally, the matrix will be changed from epoxy resin to polyvinyl chloride (PVC) resin. PVC exhibits exceptional chemical resistance to various corrosive fluids and possesses greater strength and stiffness compared to most other thermoplastics. The tensile strength of PVC reaches 40 to 60 MPa, which far exceeds the tensile strength standard for brake pads set by SAE J661-1997, ranging from 4.8 to 15 MPa [11], [3]. In another research, using wood powder as reinforcement, PVC as the matrix, and the hot press method in toy composite manufacturing achieved a tensile strength of 11 to 14.5 MPa [12]. Based on this background, further research is needed to develop a brake pad composite material made from coconut fiber and coconut shell charcoal powder using a PVC resin matrix and hot press method.

2. Methods

This research uses an experimental method by mixing composite materials in specific compositions and placing them into molds of predetermined sizes for testing.

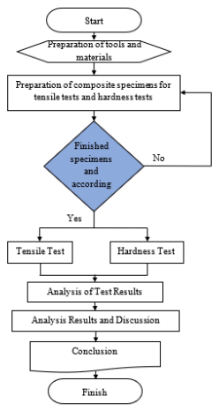

Figure 1. Flowchart of Research on the Development of Coconut Fiber Composite, Coconut Shell Charcoal Powder and PVC Matrix

2.1. Manufacturing and testing instrumentation

The composite fabrication process involves several main tools, including a JLabTech LMS-2003D hot plate stirrer for mixing cyclohexanone solvent and PVC powder at a specific temperature to produce a homogeneous PVC resin. A mold made of SS400 steel is used to shape the composite specimens according to the dimensions specified by testing standards. A TEFA-brand hot press machine is utilized to form the material through heating and pressure. This hydraulic-powered machine has a maximum pressure capacity of 7 MPa.

To evaluate the mechanical properties of the composite, testing is conducted using a Universal Testing Machine (UTM) by VTS with a 5 kN specification to measure the tensile strength of specimens in accordance with ASTM D3039 standards. The surface hardness of the composite is tested using a Shore D durometer with an accuracy of 0.5 HD, following ASTM D2240 standards, to determine the specimen's resistance to permanent deformation. The combination of these tools ensures that the fabrication and testing processes comply with established standards, resulting in accurate and reliable research outcomes.

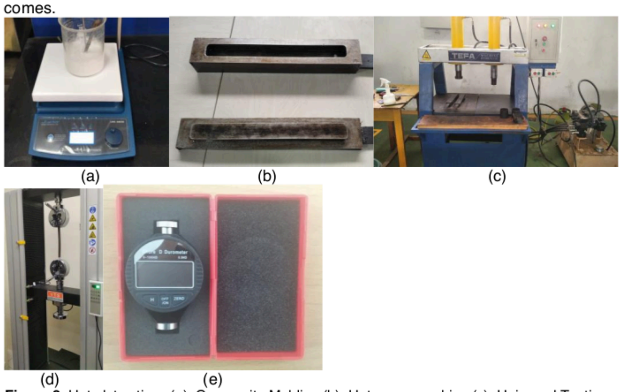

Figure 2. Hot plate stirrer (a), Composite Molding (b), Hot press machine (c), Universal Testing Machine for tensile test (d), Durometer Shore D for hardness test (e)

2.2. Material preparation

The coconut fiber that will be used as reinforcement is cut into small pieces of 5 mm so that the distribution is more even in the matrix. The coconut shell charcoal powder used as filler is powder that has been sifted with a 200 mesh. The matrix material used in this research was PVC powder and the solvent used to dissolve the PVC powder was cyclohexanone.

The preparation of PVC resin begins by adding cyclohexanone into a glass measuring cup, then heating it using a hot plate stirrer at a minimum temperature of 40°C [13]. Once the desired temperature is reached, PVC powder is added to the glass and stirred until both ingredients are thoroughly mixed and the solution appears clear. After mixing is complete, the PVC resin is poured into a glass bottle for storage.

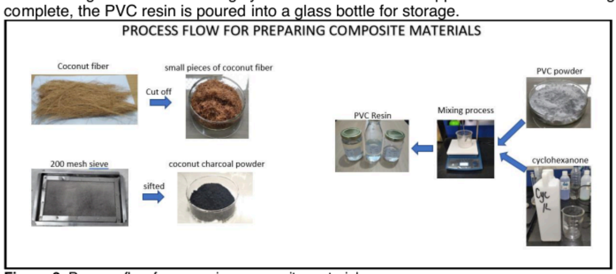

Figure 3. Process flow for preparing composite materials

The PVC resin variation table presents three different formulations used in this study, where each variation consists of a fixed amount of 20 grams of PVC powder, but with different amounts of Cyclohexanone as a solvent. Cyclohexanone functions to dissolve PVC, allowing it to form a homogeneous matrix with coconut fiber and coconut shell charcoal powder. The varying amounts of Cyclohexanone used affect the total mass of the mixture and the density of the PVC resin produced. The difference in PVC resin density is expected to influence the mechanical and tribological properties of the resulting brake pad. Therefore, analyzing these variations is crucial to determining the optimal formulation that can produce brake pads with the best characteristics, meeting the expected performance standards.

Table 1. Various PVC resin mixtures

PVC Resin Mixture	PVC Powder (g)	Cyclohexanone (ml)	Cyclohexanone Mass (density 0,936 g/ml) (g)	Total Mass of Mixture (g)	PVC Resin Density (g/ml)
PVC Resin 1	20	200	187.2	207.2	1.036
PVC Resin 2	20	150	140.4	160.4	1.069
PVC Resin 3	20	100	93.6	113.6	1.136

2.3. Specimen preparation

Making specimens requires composition calculations to determine the use of fiber, matrix and filler [14].

Mold volume

Vc= P x L x T (1)

Information:

Vc : Volume molds (cm3)
P : Composite length (cm)
L : Composite width (cm)
T : Composite thickness (cm)

Composite volume (fiber)

Vs=Vc x Ps (2)

Information:

Vs : Fiber volume (g/cm3)
Vc : Molds volume (cm3)
Ps : Fiber percentage (g/cm3)

Composite volume (filler)

Vf=Vc x Pf (3)

Information:

Vf : Filler volume (g/cm3)
Vc : Molds volume (cm3)
Pf : Filler percentage (g/cm3)

Composite volume (matrix)

Vm=Vc x Pm (4)

Information:

Vm : Matrix volume (g/cm3)
Vc : Molds volume (cm3)
Pm : Matrix percentage (g/cm3)

After calculating the volume fraction, then calculate the density of the matrix and filler. The density of an object can be written mathematically as follows [15]:

$$\rho = \frac{m}{v} \quad (5)$$

Information:

ρ : Density of substance (g/cm3)
m : Mass of substance (g)
v : Volume of substance (cm3)

After obtaining the composition calculation, the mold is placed in a hot press machine and heated to a temperature of 180°C. Based on previous research on the manufacturing of brake pad composites using teak wood powder, the optimal results according to standards were achieved at a temperature variation of 180°C. This is because the heating process influences the curing of the resin, maximizing adhesion [16]. Next, PVC resin, finely cut coconut fibers, and coconut shell charcoal powder are mixed in predetermined proportions. The mixture is stirred for 5 minutes until all ingredients are visually well combined. Once the mold reaches the desired temperature, the next step is to pour the mixture into the mold, which is adjusted according to the specimen testing specifications as shown in Figure 4. The mold is then closed, and the hot press machine applies a pressure of 7 MPa, In previous research, the pressure applied using the press machine ranged from 200 to 350 psi, which is equivalent to 2.4 MPa [4]. Meanwhile, this study uses a higher pressure since pressure affects the hardness of the product [16]. The pressure applied is 7 MPa, in accordance with the specifications of the hot press machine. The pressing time for the composite is 60 minutes, this is based on initial experiments, if under 60 minutes the results for making the specimen are not optimal because the PVC resin matrix has not dried optimally. In this research, the PVC and solvent mixture is prepared in three variations to evaluate the effect of different compositions on the mechanical properties of the brake pad composite.

2.4. Testing preparation and equipment set up

In tensile testing, ASTM D 3039 standard is used for evaluating the tensile properties of polymer matrix composite materials. The test specimen for the composite is prepared in accordance with the testing standard. The choice of specimen width and thickness as per ASTM D 3039 affects the statistical representation and failure mode of the test specimen. Additionally, the width and thickness of the specimen influence the structural strength and material strength of the polymer composite [17].

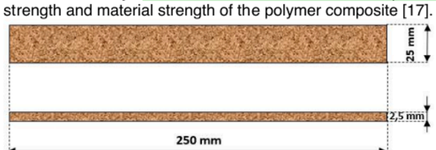

Figure 4. ASTM D 3039 Tensile Test Specimen Size

For hardness testing specimens using the ASTM D2240 standard, the specimen must have a minimum thickness of 6 mm, a minimum distance of 12 mm from the specimen's edge, and a flat, parallel surface to ensure the durometer presser foot can make contact around the indentor within a radius of at least 6 mm [18].

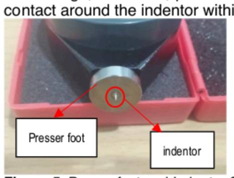

Figure 5. Pesser foot and Indentor Shore D

3. Results and Discussion

3.1. Determination of specimen composition

In this research, the author conducted an initial experiment to determine the optimal composition by creating three test specimens with composition variations.

Table 2. Composition variations

Composition	Coconut Fiber	Charcoal Powder	PVC Resin
Composition A	70%	5%	25%
Composition B	60%	10%	30%
Composition C	50%	15%	35%

In Composition A (70% coconut fiber, 5% charcoal powder, and 25% PVC resin), the resulting composite shows denser and stiffer properties. This is due to the high content of coconut fiber, which provides tensile strength and stiffness, while the balanced proportion of resin effectively binds the fibers without significantly affecting flexibility. Visually composition A composite looks denser. Composition B (60% coconut fiber, 10% charcoal powder, and 30% PVC resin) produces a more flexible composite. Reducing the fiber content in this composition decreases the stiffness, while increasing the PVC resin improves the viscoelastic and flexible characteristics of the material. It can be seen in Figure 6 that a fracture occurred in the composite specimen when it was removed from the mold. This shows that the lack of reinforcing fibers reduces the strength of the composite. Composition C (50% coconut fiber, 15% charcoal powder, and 35% PVC resin) with a lower fiber content will reduce the stiffness of the composite. It can be seen from Figure 6 that composition C looks more flexible.

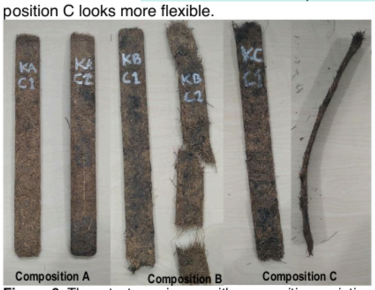

Figure 6. Three test specimens with composition variations

This aligns with previous research on brake pad manufacturing, which utilized 74% reinforcement material and 26% binder material. Hardness testing on the composite showed a value of 25.1 BHN, equivalent to the factory-made RCA brake pad, which also exhibited a hardness of 25.1 BHN [16]. Another study on brake pad composites using 70% sugarcane bagasse as reinforcement and 30% resin as a binder yielded a hardness of 100.5 BHN, close to the quality of factory-made brake pads [19]. Based on these findings, the optimal composition used as a reference in this study is 70% reinforcement material in the form of coconut coir fiber, 5% coconut shell charcoal as filler, and 25% PVC resin as a binder.


(a) (b)
Figure 7. Tensile test specimen (a) Hardness test Specimen

3.2. Solvent effect

Solvents play an important role in making composites, especially in the preparation stage of matrices such as resin. Solvents are used to dissolve the resin base material, thereby facilitating the mixing process and uniform distribution of reinforcing and filler materials in the matrix. However, the amount of solvent used can significantly influence the physical and mechanical properties of the composite.

The tensile test was conducted to evaluate the mechanical strength of coconut fiber-based composites with the same composition, namely 70% coconut fiber, 5% coconut shell charcoal powder, and 25% PVC resin, but with variations in the amount of solvent in the PVC resin. This variation aimed to understand the effect of the solvent amount on the maximum stress that the composite could withstand.

(a) (b)

Figure 8. Tensile test (a), Specimen fracture (b)

Table 3. Tensile test results

Specimen	Maximum Stress (MPa)	Average (MPa)	PVC Resin Density (g/ml)
	5		
PVC Resin 1	5	4.3	1.036
	3		
	5		
PVC Recin 2	8	5.7	1.069
	4		
	7		
PVC Resin 3	8	7.7	1.136
	8		
SAE J661- 1997	4.8 - 15	-	-

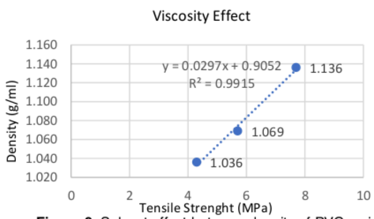

Figure 9. Solvent effect between density of PVC resin and tensile strength

In PVC Resin 1 (20 grams of PVC powder and 200 ml of solvent), the tensile test showed a maximum stress (Rm) of 4.3 MPa. This value indicates that the higher amount of solvent made the PVC resin mixture more diluted, reducing the density and the bonding strength between the components in the composite, making the specimen less optimal in withstanding tensile forces.

In PVC Resin 2 (20 grams of PVC powder and 150 ml of solvent), the maximum stress (Rm) obtained was 5.7 MPa. Compared to PVC Resin 1, the tensile strength increased because the lower amount of solvent resulted in a thicker PVC resin. This created a denser structure and stronger intermaterial bonding, thereby improving the specimen's resistance to tensile loads.

In PVC Resin 3 (20 grams of PVC powder and 100 ml of solvent), the maximum stress (Rm) reached 7.7 MPa, the best result among the three compositions. The smallest amount of solvent produced a resin with high viscosity, allowing for stronger bonding between coconut coir fibers, charcoal powder, and PVC resin. As a result, the composite exhibited better tensile strength compared to the other two compositions.

The amount of solvent in the PVC resin mixture significantly affects the tensile strength of the composite. PVC Resin 3, with the least amount of solvent, achieved the highest tensile strength of 7.7 MPa, which meets the SAE J661-1997 standard of 4.8 to 15 MPa [3]. For brake pad applications, PVC Resin 3 is the most feasible option, although further optimization may be necessary to approach the upper limit of the standard.

The Shore D hardness test aims to measure the surface hardness of the composite produced from a mixture of coconut fiber, coconut shell charcoal powder, and PVC resin.

This test is conducted to evaluate the material's ability to resist permanent deformation under applied pressure or force.

(a) (b) (c) (d)

Figure 10. Hardness test composition 1 (a), Composition 2 (b), Composition 3 (c), Factory brake pad (d)

Table 4. Hardness Shore D test results

PVC Resin	Hardness Shore D (HD)		PVC Resin Density (g/ml)
	Test Result	Average	
PVC Resin 1	59.5	57.7	1.036
	58.5		
	55		
PVC Resin 2	66	66.5	1.069
	66		
	67.5		
PVC Resin 3	69.5	72.2	1.136
	77		
	70		
Factory brake pad	75.5	77.5	-
	77		
	80		
SAE J661- 1997	68 – 105 (Rockwell R) 66 – 88 (Shore D)		-

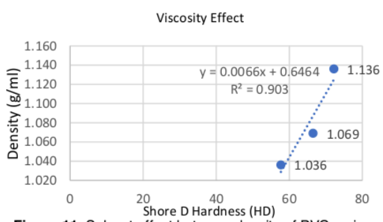

Figure 11. Solvent effect between density of PVC resin and hardness shore D

In PVC Resin 1 (20 grams of PVC powder and 200 ml of solvent), the hardness value obtained was 57.7 HD. This relatively low value is caused by the high amount of solvent which makes the resin thinner, resulting in a composite structure that is less dense and the bond between materials is less than optimal. Low hardness indicates that this composite is softer and less strong than other compositions.

In PVC Resin 2 (20 grams of PVC powder and 150 ml of solvent), the hardness increased to 66.5 HD. Reducing the amount of solvent produces a thicker resin, allowing the formation of a denser structure and increasing the bond strength between composite components. The higher hardness of this composition indicates better resistance to deformation.

In PVC Resin 3 (20 grams of PVC powder and 100 ml of solvent), the hardness reached 72.2 HD which is the best result among the three compositions. The smaller the amount of solvent, the higher the viscosity resin will be, thereby increasing the bond strength between coconut fiber, charcoal powder and PVC resin. As a result, the composite achieves a denser structure and higher hardness.

When compared with the SAE J661-1997 brake pad hardness standard, namely 68–105 (Rockwell R) [20] which is equivalent to 66 - 88 HD (conversion to Shore D) [21], PVC Resin 1 with an average hardness of 57.7 HD is still below the standard and too soft for brake pad applications. PVC Resin 2 with a value of 66.5 HD is reaches the minimum limit of the standard but still requires improvement in mechanical characteristics. Meanwhile, PVC Resin 3 with an average hardness of 72.2 HD meets the minimum standards of SAE J661-1997, making it a worthy choice for brake pad applications.

4. Conclusions

The tensile test results indicate that the amount of solvent in the PVC resin mixture significantly affects the tensile strength of the composite. Compositions with less solvent produce resin with higher viscosity, enhancing intermaterial bonding within the composite and resulting in greater tensile strength. With a maximum tensile strength of 7.7 MPa, PVC Resin 3 meets the SAE J661-1997 standard (4.8-15 MPa) and is the best option for brake pad applications. However, further optimization may be needed to approach the upper limit of the standard and improve material performance.

Based on the results of the Shore D hardness test, it can be concluded that the amount of solvent in PVC resin has a significant effect on the hardness of composites made from coconut fiber, coconut shell charcoal powder, and PVC resin. The less solvent used, the higher the hardness of the composite. PVC Resin 3, with 100 ml of solvent, exhibited the highest hardness (72.2 HD). When compared with the SAE J661-1997 standard (66-88 HD), PVC Resin 3 meets the required hardness range, making it the best choice for brake pad applications. However, commercial brake pads, particularly those used in high-performance applications, often have hardness values closer to the upper limit of the standard. Further investigation is needed to determine how this composite performs under prolonged braking conditions, including thermal stability and wear resistance.

This study contributes to the development of eco-friendly brake pads by utilizing natural fiber-based composites as an alternative to asbestos-containing materials, reducing health risks associated with conventional brake pads. The findings demonstrate that coconut fiber and coconut shell charcoal powder, when combined with PVC resin, can produce a composite with mechanical properties that meet industry standards. However, practical implementation requires further optimization, particularly in terms of durability, heat resistance, and long-term wear performance. Future research should focus on refining the composite formulation, testing under real-world braking conditions, and evaluating its environmental impact compared to conventional brake pad materials.

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