

Research Paper

Synthesis and Characterization of Hybrid Teak Wood/Water Hyacinth Reinforced Polyester Composites for Eco-Friendly Motorcycle-Brake Pad Application

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Abstract

Non-asbestos materials are developed to replace asbestos as brake pad due to the dangers to human health. Therefore, this study aimed to explore the development of hybrid reinforced polyester composites using natural fibers such as teak wood and water hyacinth for brake pad application. Natural fibers were prepared by drying, cutting, and filtering through a 30-mesh sieve. The quantity of polyester/catalyst resin was fixed at 30 g, while teak wood and water hyacinth fibers were varied (15, 10, and 5 g). Fillers and composites were investigated using Fourier transform infrared (FTIR) and composites were further analyzed through scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS), thermogravimetric analysis-differential scanning calorimetry (TGA-DSC), hardness, and wear resistance testing. The results of FTIR spectra showed that a 5TW-15WH sample had the lowest lignin content, while surface morphology of composites was inhomogeneous with few voids and cracks. Based on EDS investigation, carbon (C) and oxygen (O) were the two most abundant elements, indicating lignin, cellulose, and hemicellulose as the main components in composites. TGA measurement showed that 15TW-5WH sample had lower weight loss compared to others. Increasing water hyacinth caused a significant improvement in material performance, with 5 g teak wood-15 g water hyacinth in the composite, showing the highest hardness at 71.2 Shore D and lowest wear rate of $5.373 \times 10^{-6} \text{ mm}^2/\text{kg}$.

Keywords: IR Spectra; SEM image; Thermal resistance; Hardness; Wear resistance

1. Introduction

Brake system is an essential rule of the automotive vehicle, providing safe deceleration and wheel retardation. This system consists of caliper, brake pad, and brake disc, which collectively function to achieve better braking performance [1]. Brake pad is a consumable part of automotive vehicles and require periodic replacement periodically [2]. Recently, asbestos

brake pad has become widely used globally [3], [4], with good heat and wear resistance [5], [6]. Despite the excellent performance, asbestos brake pad is dangerous to human health, showing the need for eco-friendly alternative.

One promising alternative is the reinforcement of natural fiber in composites to improve mechanical properties [7], while contributing to developing eco-friendly materials [8]. Therefore,



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many studies have explored the development of brake pad using natural fiber and fillers such as cocopeat [9], mango seed [10], sallaca zalacca [11], aegle marmelos shell [12], coconut [13], bamboo [14], elaeocarpus ganitrus [1], palm frond [15], pineapple [16], rice husk [17], water hyacinth [18], and teak wood [19].

Brake pad is designed to function effectively in both extreme friction and fluctuating temperature conditions [20]. This shows the need for in-depth study on thermal stability and wear resistance of composites in brake pad applications [21]. Kanagaraj et al. [22] tested three commercial brake pad and found specific wear values between 1.10×10^{-6} and 2.575×10^{-6} mm³/Nm. Setyawan et al. [9] investigated wear resistance of composites (cocopeat and brass powder), producing the lowest specific wear rate in the least composition of cocopeat. A large amount of Sallaca zalacca fiber has been found to cause a lower specific wear rate [11], alongside with 30% of Aegle marmelos shell particles [12]. Moreover, Ahmed et al. [23] found that the onset of degradation of composites containing Areva javanica fiber was 219 °C. Kumaran et al. [24] found that at 130 °C, cellulose and hemicellulose in Sansevieria ehrenbergii fibers started to decompose.

In the selection of natural fibers for brake pad, several factors should be considered, such as fine filler and lignin content [25], [26]. Introducing fine filler in composites leads to an increase in the hardness [25], while higher lignin content can reduce hardness because of low crosslink density [27] making the material prone to abrasion [28]. However, higher lignin content can also enhance the thermal stability of composites [29]. To address these challenges, several methods have been explored, including the combination of various fibers (hybrid) to achieve better properties.

Hybrid fibers in composites pose a significant challenge for achieving improved hardness, wear resistance, and thermal properties. Khafidh et al. [30] reported that adding risk husk in hybrid composites could increase the hardness of the specimens. Vekantes et al. [31] investigated composites containing epoxy/kenaf fiber/sisal fiber and found better wear resistance with a composition of 70:10:20%. Furthermore, Sigh et al. [32] fabricated epoxy/sisal fiber/hemp fiber/silica and found that adding 2% silica produced the

highest hardness. Ganesh et al. [9] synthesized epoxy/kenaf fiber/silicon carbide and observed improved thermal conductivity with 10% silicon carbide. Kumar et al. [34] conducted a comparison study on basalt fiber-reinforced, aramid fiber-reinforced, and hybrid composites. The results showed that hybrid composites had better wear resistance and thermal stability. This shows the importance of hybridization by combining the strength of multiple fibers, such as teak wood and water hyacinth overcome the limitations of a single system.

Teak wood and water hyacinth have lignin content of 31.26 and 2.25% [35], [36], with promising properties, respectively. However, the combination of both materials has not been investigated, as most studies only focus on teak wood or water hyacinth as a single filler in composites or combined with others for different purposes. Arivendan et al. [37] varied water hyacinth fillers (20, 25, and 30%) in the epoxy resin and found that the hardness increased with higher composition. Ajithram et al. [38] reported that maximum bonding and high wear resistance were found in the 30 wt.% of water hyacinth filler composition in composites. Suradjaka et al. [39] investigated the incorporation of water hyacinth in the epoxy and found that increasing the water hyacinth filler led to an increase in toughness characteristics. Furthermore, Hongsriphan et al. [40] added 10% of teak wood sawdust into poly(butylene succinate) (PBS), and observed a significant increase in thermal resistance compared to neat PBS. Patel and Rawad [41] added various sagwan teak wood flour at 5, 10, 15, and 20 wt.% in polyester resin, which caused a rise in water absorption by increasing sagwan teak wood flour. In another study, Prashanth et al. [42] applied various teak wood (0, 3, and 6 wt.%) mixed with epoxy between abaca and pineapple leaf fiber mats layers. The results showed a corresponding rise in hardness by increasing teak wood.

The increase in water hyacinth or teak wood in composites has been the focus of investigation, as the majority of studies target incorporating a single natural filler into the matrix. Despite the better hardness, wear resistance, and thermal characteristics, there are no reports on hybrid fillers in polyester, particularly the combination of water hyacinth and teak wood. Therefore, this

study aims to explore the use of teak wood and water hyacinth fillers in polyester matrix to achieve an optimal balance of hardness, wear, and thermal resistance. Polyester resin is selected as the matrix due to low cost, lack of precise mixing compared to epoxy, and suitability for mass production [43]. Furthermore, composite formation is investigated using Fourier transform infrared (FTIR), scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS), thermogravimetric analysis-differential scanning calorimetry (TGA-DSC), hardness, and wear resistance.

2. Methods

2.1. Materials

Natural materials such as water hyacinth and teak wood were prepared as fillers. Specifically, water hyacinth collected from nature was dried in the sun for 10 days and manually separated using a wire brush. Separated fillers were cut and filtered using a 30-mesh stainless steel sieve. Teak wood was collected from furniture manufacturing waste, cut, and filtered using a 30-mesh sieve. Furthermore, commercial polyester was used as the matrix, containing two components, namely Yukalac 157 BQTN-EX resin system and methyl ethyl ketone peroxide catalyst.

2.2. Composites Synthesis

Catalyst was added to polyester resin at a concentration of approximately 1%, blended with teak wood as well as water hyacinth using the composition presented in Table 1, and stirred until homogeneous. Each mixture was poured into the mold and pressed using 2000 psi of pressure for 45 minutes at room temperature. Subsequently, samples were cured in the oven at 150 °C for 45 min and cut for several characterizations.

2.3. Characterization

Fillers and composites were investigated using FTIR (Thermoscientific Nicolet iS-10) from 4000 to

500 cm⁻¹. SEM-EDS (Hitachi SU3500) was used to examine composites' surface morphology, while thermal stability of samples was analyzed using TGA-DSC (Setaram Instrument, Type: Labsysevo) at 30 to 800 °C. Mechanical tests were also conducted, while hardness test used digital type Shore D according to ASTM D2240, with five repeatable measurements at room temperature. A wear test was conducted using the Ogoishi high-speed universal wear testing machine type OAT-U based on ASTM G99 [9]. Measured data was inserted into the following equation to find the specific wear rate [15].

$$W_s \left(\frac{\text{mm}^2}{\text{kg}} \right) = \frac{B \times b_o^3}{8 \times r \times P_o \times L_o} \quad (1)$$

In this equation, W_s is the specific wear rate (mm²/kg), B is the revolving disc thickness (mm), r is the revolving disc radius (mm), b_o is the width of the abraded gap (mm), P_o is the contact load (kg), and L_o is the track distance (mm).

3. Results and Discussion

3.1. FTIR

FTIR spectra of fillers and various composites showed similar peaks, indicating the presence of natural filler in composites, as presented in Figure 1. A common natural polymer consisting of lignin, hemicelluloses, and cellulose, which comprises hydroxyl functionality, was found at 3334 cm⁻¹ [44]. The band appeared to be suppressed when comparing fillers with composites, because H₂O evaporated during curing in the oven. Generally, a higher intensity of composites band represents a greater amount of lignin [45], indicating that 5TW-15WH sample has the lowest lignin content. Previous studies reported that teak wood consisted of lignin (31.26%), hemicelluloses (11.38%), and cellulose (43.72%) [36], while water hyacinth composition was 2.25%, 19.54%, and 50.38%, respectively [35]. The band at 2900 cm⁻¹, associated with C–H stretching, is commonly observed in wood structure, suggesting the presence of aliphatic hydrocarbon in cellulose [46]. The peaks between 3000-2800 cm⁻¹ were attributed to CH₂ and CH₃ stretching vibration [47]. The band around the 1730-1230 cm⁻¹ was characteristic of wood, where cellulose and hemicellulose components were observed at 1020 cm⁻¹ band associated with C–O–C vibration [44]. In line with the results, 760 and 700 cm⁻¹ peaks were attributed to the aromatic group [48].

Table 1. Composition of composites for brake pad

Composite	Composition (g)		
	Matrix	Teak wood	Water hyacinth
15TW-5WH	30	15	5
10TW-10WH	30	10	10
5TW-15WH	30	5	15

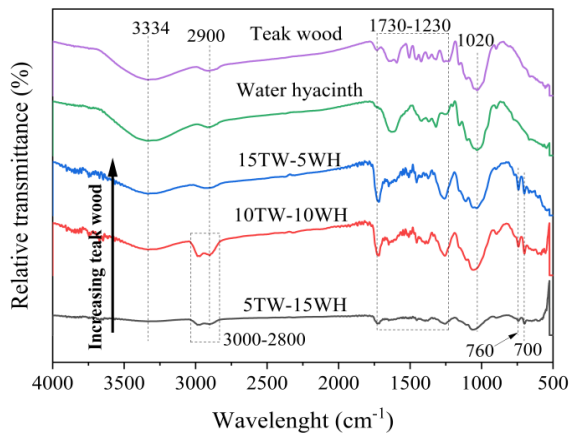


Figure 1. FTIR spectra of filler and composite

3.2. SEM-EDS

Incorporation of teak wood and water hyacinth particles in polyester resin is shown in [Figure 2](#). Although the process was not investigated using the naked eye, SEM image showed a few voids in the 15TW-5WH sample. On the left side of [Figure 2](#), cracks were identified in 10TW-10WH and 5TW-15WH samples, while the right side showed SEM image with 2500× magnification, where well-agglomeration

between fillers and matrix was formed. The large size of the filler in the composite had a characteristic porous structure [35], [44]. A non-uniform filler size was also identified, as smaller size escaped through the sieve. However, the use of only SEM micrographs cannot confirm mechanical characteristics such as hardness behavior and wear resistance, showing the need for complementary experimental tests [46].

Although composites in this study were amorphous, EDS was conducted to identify any impurities from crystalline material, with results shown in [Figure 3](#). Based on quantitative results of EDS spectra in [Table 2](#), the two most abundant elements were carbon (C) and oxygen (O), indicating lignin, cellulose, and hemicellulose as the main components in composites [49]. Silicon (Si) was also identified composites, with an amount between 2.44 and 4.59 wt.%. Other elements such as natrium (Na), magnesium (Mg), aluminium (Al), chloride (Cl), kalium (K), calcium (Ca), iron (Fe), and nickel (Ni) were present in amounts <1.47 wt.%, indicating small impurities.

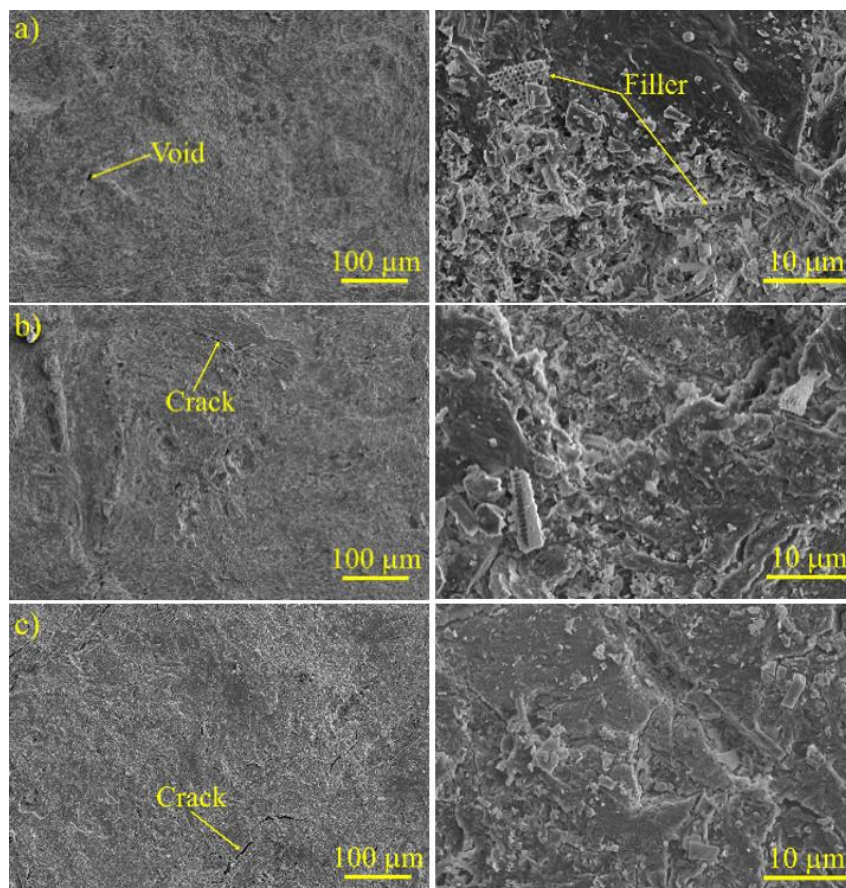


Figure 2. SEM image of various samples a) 15TW-5WH, b), 10TW-10WH, and c) 5TW-15WH

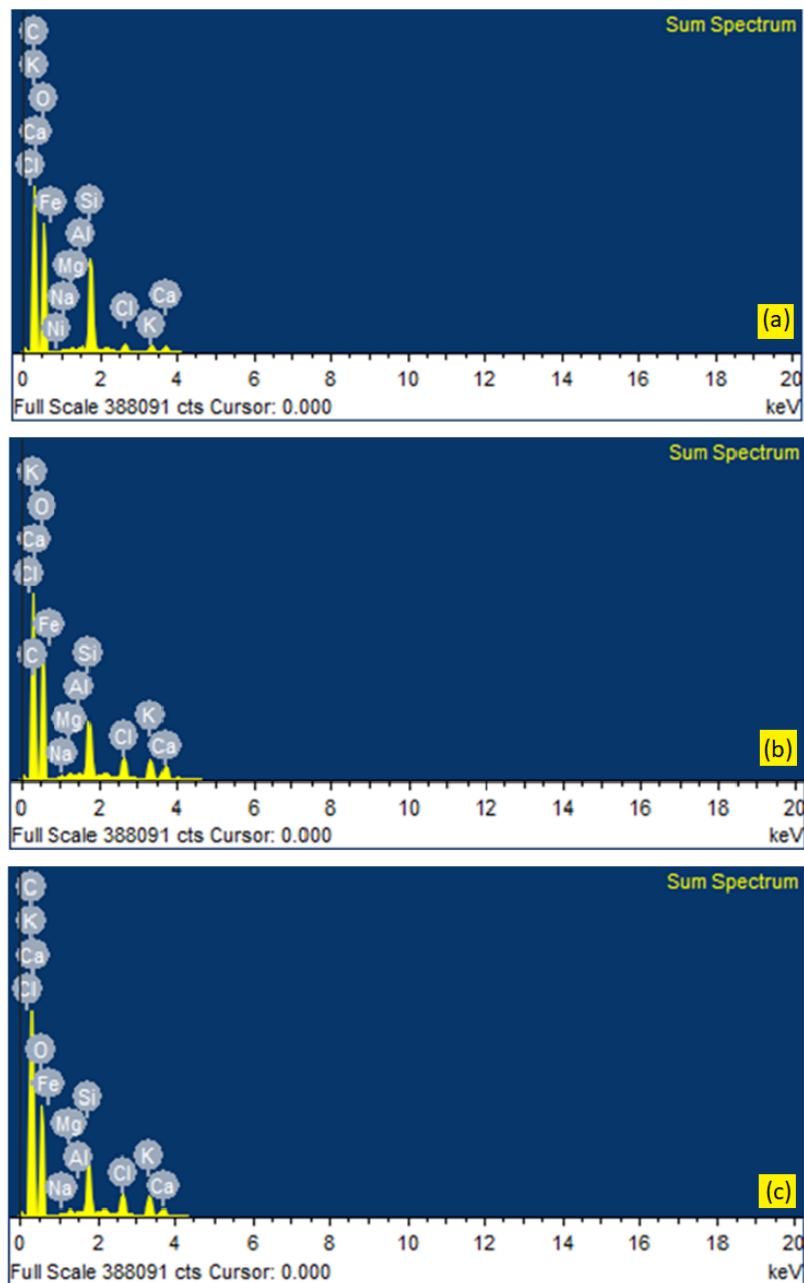


Figure 3. EDS image of various samples a) 15TW-5WH, b), 10TW-10WH, and c) 5TW-15WH

Table 2. Elements contained in various composites

Element	Composition (Wt.%)		
	15TW-5WH	10TW-10WH	5TW-15WH
C	51.31	51.26	55.56
O	42.12	41.76	38.26
Na	0.13	0.12	0.10
Mg	0.13	0.21	0.21
Al	0.11	0.14	0.07
Si	4.59	2.54	2.44
Cl	0.44	1.36	1.28
K	0.51	1.47	1.42
Ca	0.51	1.03	0.59
Fe	0.09	0.12	-
Ni	0.06	-	0.06
Totals	100.00	100.00	100.00

3.3. TGA, DTA, and DSC

TGA and DSC were measured from 30 to 800 °C. TGA, DTA, and DSC results are presented in Figure 4a, 4b and 4c, respectively. TGA measurement results of the three composites showed a similar trend with four stages. At the first stage, with approximately 30-100 °C, minor reduction across all samples showed free and bound moisture evaporation [50]. The second stage at 140-275 °C experienced weight loss due to hemicellulose [24], while the third stage (275-436 °C) was the significant decomposition of cellulose [51]. The fourth stage (436-800 °C) was the

decomposition of lignin, cellulose (complete mass loss), and other impurities at high temperature [46].

According to Figures 4a and b, the initial (T_i), final (T_f), and maximum degradation temperatures (T_{max}) of composites are summarized in Table 3. There were different onset and onset temperature for all samples, but T_{max} values were approximately similar, particularly for 15TW-5WH and 5TW-15WH. This showed that increasing water hyacinth to approximately 10 g did not affect T_{max} , although a significant reduction was observed at 15 g.

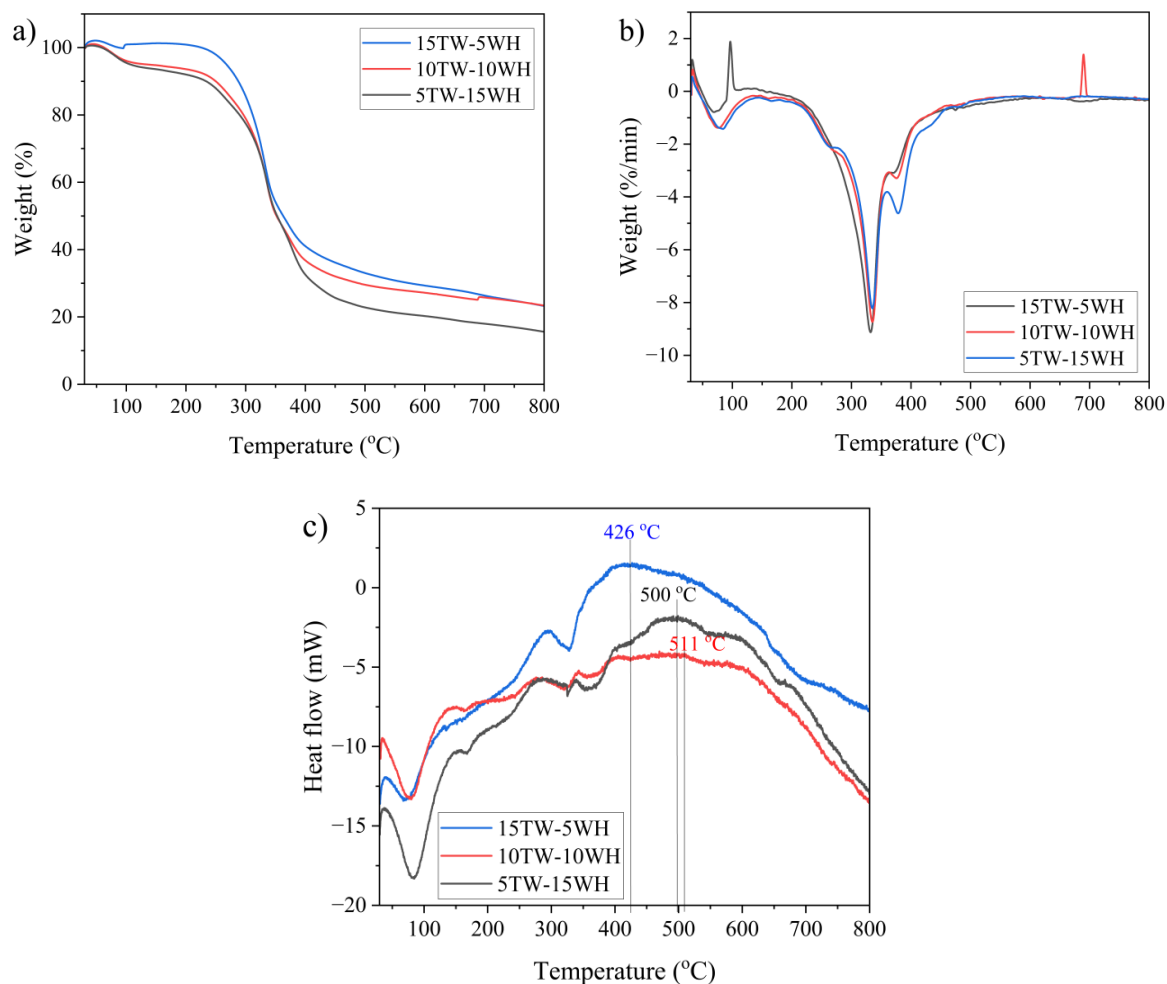


Figure 4. Thermal behavior of various composites a) TGA, b) DTA, and c) DSC

Table 3. Initial, final, and maximum degradation temperatures of composites

Composite	T_i (°C)	T_f (°C)	T_{max} (°C)
15TW-5WH	275.78	436.76	335.12
10TW-10WH	260.51	433.43	335.47
5TW-15WH	255.76	428.87	332.31

As shown in **Figure 4a**, 15TW-5WH sample had better thermal stability due to the highest teak wood composition. This suggests that a decrease in teak wood filler in composites can reduce thermal stability. Henn et al. [29] stated that increased lignin content caused a significant rise in thermal stability.

Based on DSC curve in **Figure 4c**, an exothermic reaction occurred until 40 °C, followed by an endothermic reaction at 100 °C, and an exothermic response at approximately 450 °C. This reaction occurred due to degradation residue in fillers, cross-linking reaction, and the moisture release [46], [52], [53]. Additionally, exothermic response between 100 and 511 °C occurred when composites reached the melting temperature [52], [54], [55]. Among all samples, 15TW-5WH showed the highest melting temperature due to larger lignin content [26].

A previous study by García-León et al. [56] tested three commercial metal brake disc using speeds of 65-100 km/h, and found temperature between 72.90-167.17 °C. Further investigation conducted by Sagar et al. [57] in various rotation engine speeds (800-2000 rpm) found temperature of cast iron and AMC 6061 brake disc between 38-55 °C and 30.5-39.5 °C. Based on the results, composites used in this study could be considered acceptable, as a minor weight loss only occurred at 275 °C. In both conditions, endothermic and exothermic reactions occurred in three composite samples.

3.4. Average Hardness

Hardness properties were measured using a digital type of Shore D with five repeatable measurements. As shown in **Figure 5**, the hardness values of the 15TW-5WH, 10TW-10WH, and 5TW-15WH samples were 50.6, 66.7, and 71.2 Shore D, respectively. This indicated that an increase in water hyacinth filler in composites caused a rise in hardness. Arivendan et al. [37] also reported a similar trend in the variation of water hyacinth fillers at 20, 25, and 30%. However, hardness was found to be inversely proportional to teak wood content. Crosslink density, lignin content, and hardness have shown a significant relationship [58], [59], [60]. In this study, increasing lignin content caused a reduction in hardness of composites because the filler agglomerates hindered molecular chain mobility, leading to a

decrease in crosslink density [27], [61]. Teak wood and water hyacinth have lignin content of 31.26% and 2.25% [35], [36]. This suggests that higher content of water hyacinth leads to a greater hardness due to the lowest lignin in composites. According to FTIR, the lowest lignin content is observed in 5TW-15WH, leading to the highest hardness value.

3.5. Wear Resistance

Table 4 shows wear test parameters and results using the Ogoshi high-speed universal wear testing machine type OAT-U. As presented in **Table 4**, the specific wear rate was calculated using data inserted into Equation (1), with results shown in **Figure 6**. A higher value indicated that a large portion of the composite was lost due to poor particle bonding during wear test [16]. Although the specific wear rate varied due to water hyacinth fiber percentage rise in composites [38], an excessive amount of water hyacinth could have a significant impact [18]. Widodo et al. [17] stated that wear resistance of composites was improved due to a substantial decrease in specific wear rate.

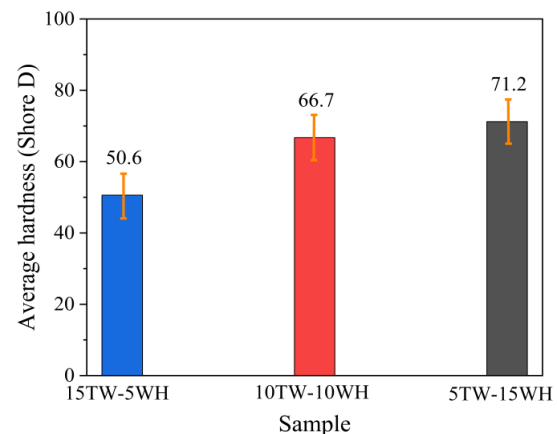


Figure 5. Average hardness of the composite

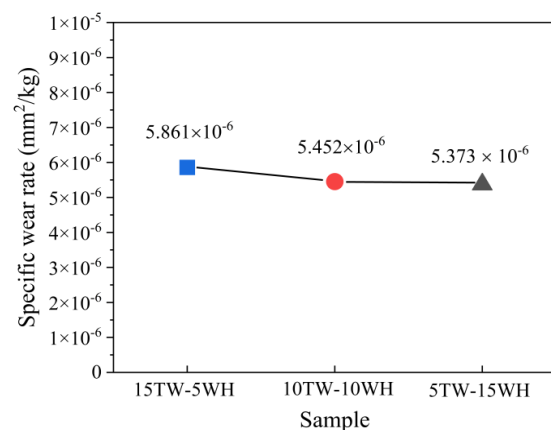


Figure 6. Specific wear rate of composites

Table 4. Wear test parameters and results of various composites

Composite	bo (mm)	B (mm)	r (mm)	Po (kg)	Lo (mm)
15TW-5WH	4.20	3	15	3.16	1×10^5
10TW-10WH	4.10	3	15	3.16	1×10^5
5TW-15WH	4.08	3	15	3.16	1×10^5

In this study, more water hyacinth filler in composites caused a decrease in specific wear rate, indicating that the material was more resistant to wear. This condition is significantly due to higher hardness behavior, which causes more resistance to abrasion [28]. Madnasri et al. [16] found that the specific wear rate of natural fiber was inversely proportional to hardness.

The highest specific wear rate was observed in 15TW-5WH sample, while 5TW-15WH showed the lowest. Setyawan et al. [9], who investigated wear resistance of OEM and OES disc, found specific wear rates of 6.5×10^{-7} and 6.85×10^{-6} mm²/kg. Although the values obtained are slightly different from this study, composites samples are still acceptable for brake pad application.

The comparison of results with other studies, particularly for wear resistance, is shown in Table 55. The 5 g teak wood-15 g water hyacinth sample in this study shows better performance compared to Madnasari et al. [16], [62]. It should be noted that, in some respects, the parameters used in the wear test differ, such as the load. For example, Yulianto et al. [15] used 2.12 kg of load, while this

study applied 3.16 kg of load. Therefore, variation in parameters should be considered to compare the specific wear rate.

4. Conclusion

In conclusion, this study successfully synthesized composites using teak wood and water hyacinth. According to EDS investigation, the two most abundant elements are C and O, indicating that lignin, cellulose, and hemicellulose are the main components in composites. All samples show inhomogeneous surfaces with few voids and cracks as observed by SEM. However, the use of only SEM micrographs cannot confirm mechanical characteristics such as hardness and wear. The results show that increasing water hyacinth improves hardness and wear, while higher teak wood enhances thermal resistance due to lignin content in the fillers. Among all samples, the 5 g teak wood with 15 g water hyacinth composite shows the highest hardness and lowest wear rate, serving as the best candidate for brake pad application. Although the composition shows the lowest thermal resistance, it is acceptable because minor degradation occurs at 275 °C. This value is higher when compared to disc brake that reach 167.17 °C during operation. Therefore, further performance validation is recommended to test composites under various brake loads and weather conditions closely to real brake pad application.

Table 5. Composites brake pad comparison of this study with others

Composites	Specific wear rate	Reference
12% Elaeocarpus ganitrus in composites	1.577×10^{-7} mm ² /kg	[1]
10% Cocopeat and 90% brass powder	4.17×10^{-7} mm ² /kg	[9]
25% Manggo seed, 45% brass, 20% MgO, and 10% epoxy	2.52×10^{-7} mm ² /kg	[10]
55% Sallaca fiber and 45% phenolic	4.30×10^{-7} mm ² /kg	[11]
Commercial brake pad, and 30% AMSP	6.748×10^{-7} and 2.008×10^{-6} mm ² /kg	[12]
50% Palm frond fiber, 20% Aluminum powder, 30% Polyester	8.431×10^{-6} mm ² /kg	[15]
2 vol.% Pineapple fiber in composite	Approximately 1.65×10^{-4} mm ² /kg	[16]
Epoxy-Rice husk-Aluminum oxide-Iron oxide (curing temperature variation)	$3.39 - 15.08 \times 10^{-7}$ mm ² /kg	[17]
50 wt.% Epoxy 25 wt.% Iron oxide 25 wt.% Aluminum oxide	7.6×10^{-7} mm ² /kg	[30]
2 vol.% Carbon of mahogany fruit peel in the composite	Approximately 2.55×10^{-4} mm ² /kg	[62]
5 g teak wood-15 g water hyacinth	5.373×10^{-6} mm ² /kg	Present work

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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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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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