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Flammability and morphology of Agel leaf fibre-epoxy composite modified with carbon powder for fishing boat applications

P. Kurniasih [a,*], W.A. Wirawan [b,], A. Narto [a], O.S. Pribadi [b], N.A. Imron [b], N.F. Rachman [b], A. Pradipta [b]**

[a] Semarang Maritime Polytechnic, Jl. Singosari Raya No.2A, Wonodri, Semarang, Jawa Tengah, 50242, Indonesia

[b] Indonesian Railway Polytechnic, Tirta Raya street, Nambangan Lor, Manguharjo, Madiun, Jawa Timur, 63161, Indonesia

* Corresponding e-mail address: pritha@pip-semarang.ac.id

** Corresponding e-mail address: willy@pengajar.ppi.ac.id

ORCID identifier: https://orcid.org/0000-0002-0709-5626 (W.A.W.)

ABSTRACT

Purpose: Fibre Reinforced Polymer Composites have been extensively developed to construct fishing vessels. This study reports on the successful development of the Agel Leaf Fibre (ALF)-Epoxy composite reinforced with carbon powder and fabricated using the Vacuum Infusion method.

Design/methodology/approach: The composites were prepared by varying the carbon powder filler content at volumes of 0%, 10%, and 30%. The fire resistance of the composites was investigated using a burning test according to ASTM D-3014 standards. The morphology of the composites was observed through SEM analysis and analysed using ImageJ software.

Findings: The research findings reveal that adding 30% carbon powder in the HCP composite reduced the burning rate by 42.624 mm/sec and the time to ignition by 17.33 seconds, indicating improved fire resistance properties. The carbon powder inhibited flame propagation and reduced the combustion rate by 0.49%. The SEM examination confirmed that the fibre porosity decreased, resulting in a denser composite with enhanced fibre-matrix adhesion. Therefore, the implementation of fire-resistant composite materials in fishing vessel construction can be realised.

Research limitations/implications: The present study primarily examined the immediate effects of carbon powder additions on the morphology of the composites. However, it is crucial to consider these composites' long-term stability and durability. Future research should investigate the ageing behaviour, considering environmental factors such as humidity, temperature, and UV radiation, to assess their impact on the morphology and flammability resistance of the composites. Additionally, it is essential to acknowledge that other factors, including fibre orientation, fibre length, and matrix properties, can significantly influence the overall performance of the composites.

Practical implications: The enhanced flammability resistance of Agel Leaf Fibre-Epoxy composites with carbon powder additions holds significant benefits for fishing boat applications. In marine environments, the risk of fire incidents on fishing boats is high, making materials with good fire resistance highly desirable. Therefore, implementing fire-resistant composite materials in fishing boat construction can be realised to reduce the risk of fire incidents in high-seas fishing vessels.

Originality/value: Composites with added carbon powder exhibited smaller flames, slower burning rates, and a lack of significant flame propagation. This suggests that adding carbon powder acts as an oxygen barrier and reduces the availability of fuel within the composite.

Keywords: Natural fibre, Agel leaf fibre, Carbon powder, Composite, Fire resistance, Morphology, Fishing boat application

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PROPERTIES

1. Introduction

Maritime transportation plays a crucial role in connecting islands and driving economic growth throughout the entire territory of Indonesia [1]. In this regard, ships serve as transportation means facilitating the movement of goods, fisheries, and agricultural products between regions [2]. In Indonesia, wooden ships are the most commonly utilised type of vessel, serving as cargo carriers, fishing vessels, and passenger ships [3]. The use of wooden ships is motivated by several factors, including the abundant availability of raw materials, simple fabrication processes, affordable costs, as well as sturdy and uncomplicated construction [4]. Consequently, it is not surprising that wooden ships continue to persist and constitute a significant portion of the local maritime fleet dedicated to serving the needs of the populace.

Despite the abundant potential of wood as a raw material for ship construction, its utilisation is deemed inefficient due to its detrimental impact on forests and environmental degradation. Wooden ships, in particular, suffer from various drawbacks, including their susceptibility to fire, decay, and attacks by wood-damaging organisms. Those weaknesses render wooden fishing vessels prone to damage and require prolonged repair time. As a result, efforts have been made to modify or substitute wooden ships with composite materials [5]. For example, fishing vessels like the 30 GT Type Purse Seine often employ composite fibreglass materials to enhance their fish-catching capabilities [6]. Nevertheless, it should be noted that the operational use of composite-based ships carries inherent risks, including the possibility of fire incidents and leaks (Fig. 1) [3].

Fig. 1. Case of wooden ship fire [7]

Technology development has led to the exploration of composite materials, which offer several advantages, such as lightweight properties, high strength, and environmental friendliness [8]. There is a noticeable trend towards using natural fibre composites, shifting away from composites that employ synthetic materials like fibreglass in various applications [9]. However, the shift does not indicate the abandonment of synthetic composites; instead, it highlights the significant potential for developing natural composites [10]. The abundant availability of natural fibres in different countries creates new opportunities for material development, particularly in the realm of natural fibre-reinforced composites. These composites exhibit excellent strength and lower density compared to their counterparts [11-13].

Based on the literature reviewed, there is a need to explore the potential of natural fibre development in producing polymer composites for fishing boat raw material applications. It is of utmost importance to evaluate the flammability properties and morphology of the composites during the development of fishing boat raw materials. The study aims to investigate the utilisation of Agel fibre as a reinforcing material in composite polymer matrices. The composites were manufactured using a vacuum infusion technique, incorporating carbon powder as an additive. The addition of carbon powder aims to enhance the fire resistance and durability of the composites, presenting a promising opportunity for developing improved and environmentally friendly alternatives for boat raw materials.

2. Material and methods

2.1. Material

The Agel leaf fibre was obtained from farmers in Sleman Regency, Yogyakarta - Indonesia. The fibres were extracted from approximately 5-year-old Agel leaves. The fibre extraction process involved separating the leaves from the stem and immersing them in water for 12-18 days. Subsequently, the fibres were cleaned with fresh water and dried at room temperature for approximately 12 days. The fibres were then woven in a 1-1 basket-weave pattern, as shown in Figure 2. The carbon powder used in the study was obtained from PT. Multi Chemical Indotrading, Tangerang, Indonesia, with a particle size of 1000 mesh. The epoxy matrix was supplied by PT. Justus Kimia Raya, Surabaya, Indonesia.

a) b)

Fig. 2. a) Agel plant, b) Agel leaf fibre weaving

2.2. Composite fabrication

The composite specimens were fabricated using the vacuum resin infusion (VARI) method [8]. The fibres were arranged in 5 layers on a mould prepared according to the testing standards. Next, the carbon powder and matrix were weighed according to the composition in Table 1. The composites were air-dried for 24 hours and then heated in an oven at 40 °C for 2 hours. The process of making the specimen is shown in Figure 3.

Table 1.
Composite volume fraction

Sample	Carbon Powder	Epoxy Matric
NCP	0%	100%
LCP	10%	90%
HCP	30%	70%

a) b) c)

Fig. 3. Composite fabrication process a) fibre cutting, b) vacuum infusion process, c) composite demoulding

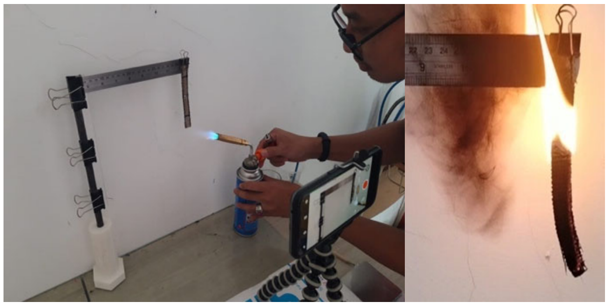

Fig. 4. Flammability test

2.3. Flammability test

The burning test of the composite was conducted using a burning test apparatus based on ASTM D-3014. The test involved burning the composite vertically using a Bunsen burner flame, as depicted in Figure 4. The test procedure involved marking a line at a distance of L 0-100 mm from the sample’s edge. The time of burning was determined by measuring the flame propagation within the range of L: 0-25 mm. The burning rate was observed from the flame propagation between L: 25 mm and L: 100 mm. Data were recorded and observed using a digital camera throughout the burning process. The fire resistance level of the composite was analysed based on the Burning Speed (BS) value, as per Equation 1 [14-16].

$$Bs = L \times \frac{60}{t} \quad (1)$$

L represents the distance from the sample line indicating flame propagation from 25-100 mm, where the flame spreads over a distance of 75 mm, and t represents the measured time per minute based on flame spread on the composite specimen.

2.4. SEM (Scanning Electron Microscopy) analysis

Scanning Electron Microscopy (SEM), analysis was employed to observe the morphology of each composite variation. The observations were performed using an SEM instrument, specifically the FEI Type inspect S-50, with a resolution of 200 µm, a magnification of 75x, and operating in 10 kV SE mode. The SEM images obtained were subsequently analysed using ImageJ software. The resulting images from ImageJ were focused on confirming the qualitative observations of the burning process.

3. Results and discussion

3.1. Fire resistance of composites

The fire resistance of composites can be analysed based on the burning speed and time to ignition values depicted in Figure 5 and Table 2. The analysis reveals that the combustibility of the composite can increase with the concentration of carbon powder. The composite with 0% carbon powder tends to have quicker ignition and combustion. However, with the addition of 10% and 30% carbon powder, a substantial improvement in the fire resistance of the composite can be demonstrated.

Figure 5a shows the burning rate values for the NCP composite at 63.694 mm/min, LCP composite at 54.679 mm/min, and HCP composite at 42.624 mm/min. The effective enhancement in the fire-resistant properties of Agel leaf fibre-Epoxy composites can be attributed to the thermal conductivity of the carbon powder. The carbon powder efficiently absorbs and conducts heat, inhibiting flame propagation and slowing down the combustion process in the composite [17]. Adding carbon powder leads to incomplete combustion, eliminating oxygen and hydrogen [18,19]. In the configuration, carbon remains as charcoal and reduces the burning rate in LCP and HCP composites. These findings are consistent with the study conducted by Karunakaran et al., where the burning rate decreases with the increasing content of kenaf fibres [20]. The weaving of the composite on the outer layer can further delay the burning rate due to the formation of charcoal by the weave, which protects the layers from heat and volatile penetration [21,22].

a)

b)

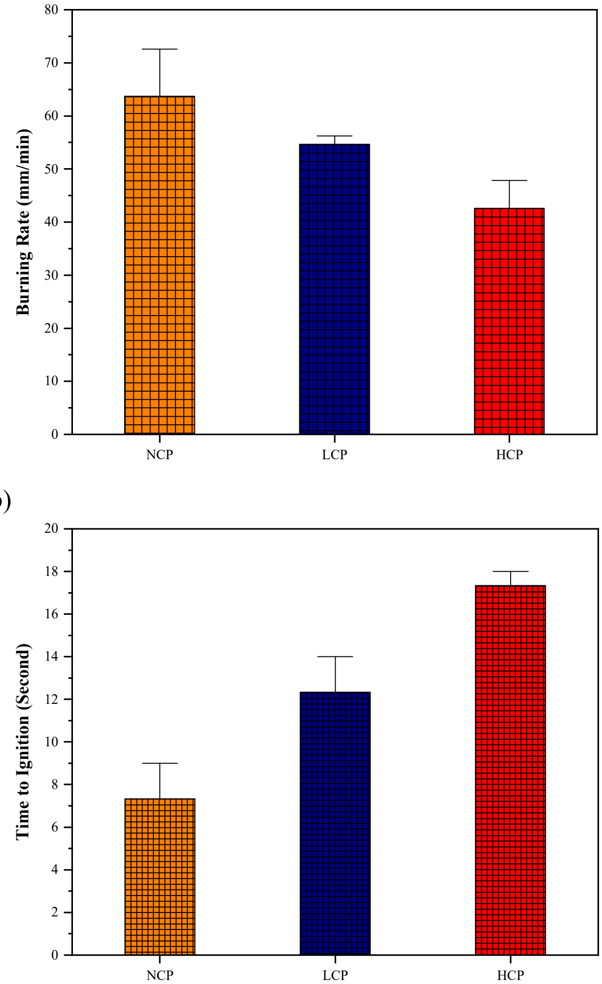

Fig. 5. a) Burning rate, b) Time to ignition composite

Table 2.
Burning speed

Code	Length, mm	Time, sec	Burning Speed, mm/sec
NCP	75	71.33333 ± 8.326664	63.694 ± 7.85
LCP	75	82.33333 ± 2.081666	54.679 ± 1.39
HCP	75	106.3333 ± 10.69268	42.624 ± 4.54

The addition of carbon powder allows the density between particles to be higher. Adding charcoal can limit combustion gas and reduce thermal conductivity so that the ability to burn can decrease. The charcoal formed on the outside can reduce the concentration of O_2 around the composite to inhibit the occurrence of flames. It is to the theory of the fire triangle, where one element is disrupted due to the presence of carbon powder burning [23,24].

The addition of carbon powder also affects the time to ignition in the Agel leaf fibre-epoxy woven composites, as shown in Figure 5b. The respective time-to-ignition values are NCP at 7.33 seconds, LCP at 12.33 seconds, and HCP at 17.33 seconds. The high addition of carbon powder increases the time to ignition in the composites. It is because carbon powder possesses high thermal conductivity, efficiently absorbing heat and reducing heat accumulation on the composite surface [25,26]. Additionally, carbon powder can act as a barrier to oxygen access into the composite. Its presence can reduce the rate of oxidation reactions and inhibit combustion [14,16,27]. Thus, it can be concluded that the addition of carbon powder inhibits flame propagation, reduces the intensity of combustion, enhances the fire resistance of the composite, and extends the time to ignition. Those results are also confirmed by the full burning time data shown in Table 3.

Table 3.
Time fully burnt

Code	Time for the flame front to reach 100 mm mark, sec	Remarks
NCP	78.666 ± 7.094	Fully Burnt
LCP	92.666 ± 3.055	Fully Burnt
HCP	123.666 ± 11.015	Fully Burnt

Table 3. presents the overall flammability properties data of the Agel leaf fibre-epoxy composite. In the HCP composite with a high carbon powder content of 30% (wt.), the longest time was recorded for the flame to reach combustion at a distance of L 100 mm. This result is further confirmed by the flame observation on the composite (Fig. 6).

Observations of the flame during the combustion of the composite with added carbon powder indicate inhibition in flame propagation. The composites containing carbon powder exhibited smaller flame sizes than those without carbon powder. It indicates that the presence of carbon powder has reduced the availability of easily combustible fuel within the composite, thereby inhibiting flame propagation. Carbon powder acts as an oxygen barrier and can reduce the rate of oxidation reactions within the composite [20,28]. As a result, combustion in the composites with added carbon powder tends to occur slower than in the composites without carbon powder. It can be observed through the reduced flame intensity and slower flame movement during combustion. It is significant regarding fire safety and flame resistance, as it can reduce the risk of fire and provide more time to respond to and control the situation when applied.

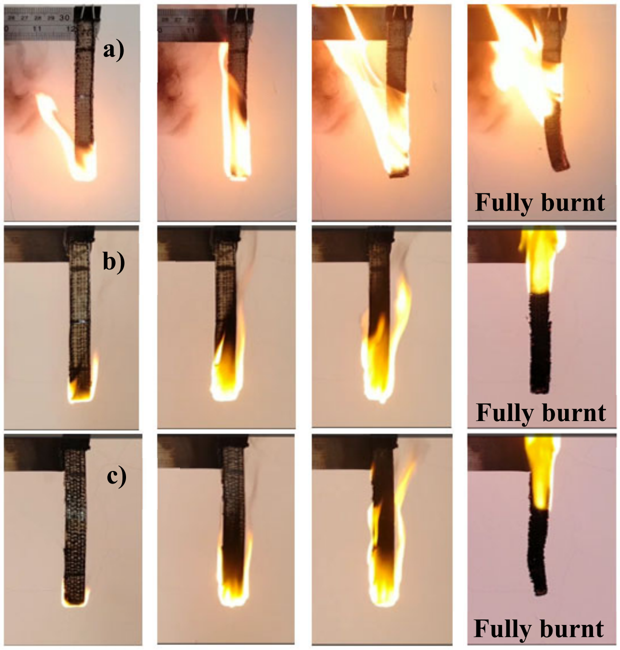

Fig. 6. Flame of the composite combustion a) NCP, b) LCP, c) HCP

3.2. Composite density

Table 4 presents the measured density values of the Agel leaf fibre-epoxy composites. The NCP composite has a density value of 0.28 g/cm^3, the LCP composite has a density of 0.32 g/cm^3, and the HCP composite has a density of 0.37 g/cm^3. The increase in density is attributed to the addition of carbon powder, which contributes to the volume fraction and affects the density between the fibres and the matrix. The theoretical calculations indicate that the density values are higher than the experimental results, suggesting the presence of voids during the composite manufacturing process [23]. Furthermore, the moisture content in the Agel leaf fibre and the higher addition of carbon powder can increase the excess hydroxyl groups, leading to more water molecule absorption. A significant amount of water molecules can result in the formation of voids during the curing process [29]. When related to the combustion flame, these voids can facilitate oxygen access to the composite and promote the oxidation reaction during combustion. It has been observed that composites with lower density, such as NCP, exhibit higher burning rates.

Table 4.
Composite density

Sample	Density, g/cm^3	
	Teoritis	Experiment
NCP	0.30	0.28 ± 0.0038
LCP	0.36	0.32 ± 0.0336
HCP	0.38	0.37 ± 0.0469

3.3. SEM and ImageJ analysis

The Agel leaf fibre-Epoxy composite morphology analysis with varying carbon powder additions was conducted using scanning electron microscopy (SEM). The SEM results were used to confirm the improvement in fire resistance with increasing carbon powder content. In the composite without carbon powder (0%). SEM images revealed a less uniform distribution of Agel Leaf Fibres in the epoxy matrix. along with some voids and gaps at the fibre-matrix interface. Those observations indicated a weaker interfacial bond between the fibres and the matrix [24]. However. significant improvements in the composite morphology were observed as the carbon powder content increased to 10% and 30%. The composites appeared denser. more uniform and showed filled voids with carbon powder.

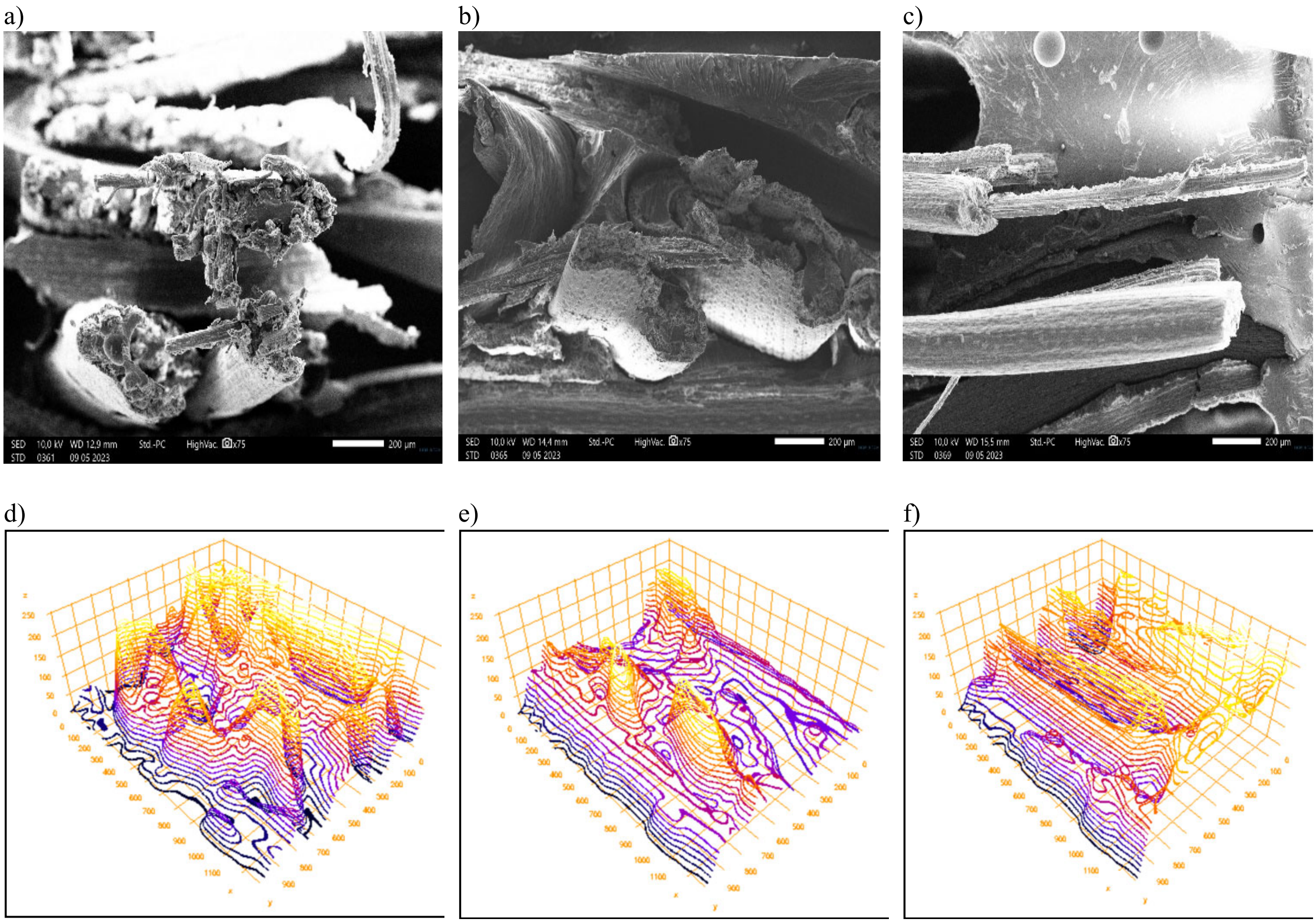

Fig. 7. a) Scanning Electron Microscopy (SEM) Analysis NCP, b) Scanning Electron Microscopy (SEM) Analysis LCP, c) Scanning Electron Microscopy (SEM) Analysis HCP, d) Image Analysis with ImageJ NCP, e) Image Analysis with ImageJ LCP, f) Image Analysis with ImageJ HCP

The ImageJ observations also provided important insights. indicating the colour of the combustion flame. It was observed that the NCP composite exhibited a lower fire resistance. which was confirmed by both the ImageJ analysis and the flame observations in Figure 7. The dominance of yellow peaks in the NCP composite was higher than the LCP and HCP composites.

The addition of carbon powder showed a more uniform dispersion of Agel leaf fibres throughout the epoxy matrix. with reduced voids and gaps. Additionally. improved interfacial bonding between the fibres and the matrix was observed in the composite. The carbon powder acted as a filler. facilitating better dispersion of Agel leaf fibres and promoting increased adhesion between the fibres and the epoxy matrix. The enhanced interfacial bonding leads to improved load transfer and overall structural integrity. ultimately contributing to the increased fire resistance of the composite. The more uniform fibre distribution and stronger interfacial bonding contribute to the reduction of easily combustible paths and the potential for flame propagation within the composite [30]. The SEM observations align with the overall research findings. supporting the notion that increasing the carbon powder content leads to improved fire resistance in the composite.

4. Conclusions

The finding can potentially open opportunities for developing safer and fire-resistant composites in the fishing boat industry. The study demonstrates that the addition of carbon powder to the Agel leaf fibre-Epoxy composite has a positive effect on improving the fire resistance of the composite. The incorporation of 30% carbon powder in the HCP composite resulted in an increased burning speed value of 42.624 mm/min and a time to ignition of 17.33 seconds in the fire resistance properties of the composite. Qualitative flame observations indicated that composites with added carbon powder exhibited smaller flames. slower burning rates. and a lack of significant flame propagation. It suggests that adding carbon powder acts as an oxygen barrier and reduces the availability of fuel within the composite. The confirmed results from SEM observations showed that the evenly dispersed carbon powder in the epoxy matrix assists in inhibiting flame propagation. Therefore. implementing fire-resistant composite materials in fishing boat construction can be realised to reduce the risk of fire incidents in high-seas fishing vessels.

Acknowledgements

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