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Testing the Fire Resistance of Fiberglass Composite Material with a Mixture of Green Mussel Shell Waste

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Abstract

This study aims to evaluate the effect of adding green mussel shell powder (CKH) on the fire resistance of Fiberglass composite materials used in fishing vessel hulls under 5 GT. The composite was made using the hand lay-up method with variations in CKH composition of 0%, 10%, 20%, 30%, 40%, and 50%. Testing was carried out using the ASTM D635 standard to determine the burning rate. Statistical analysis using logistic regression to determine the linear relationship between variables. Statistically, logistic regression states a p-value <0.05 and is suitable as a reference model to determine the value of CKH powder composition with the burning rate of the material. This study shows that specimens with the addition of 20% CKH increase fire resistance by 8.56% (13.10 mm/min), while the addition of 50% CKH increases up to 19.92% (11.47 mm/min). So that the more CKH composition additions can increase the fire resistance of the material. These results indicate that CKH waste has the potential as an environmentally friendly additive that improves ship safety.

Introduction

As an archipelagic nation with millions of fishermen (KKP, 2022), Indonesia relies on small fishing vessels (<5GT) to support its maritime sector (Annida & Baihaqi, 2025; Choiron et al., 2024; Purnomo et al., 2025). The large number of fishing vessels in Indonesia necessitates anticipating several issues related to ship accidents, including fires and sinkings (Dao et al., 2024; Rahadi et al., 2024; Waskito et al., 2024). According to a report on the National Transportation Safety Committee (KTKT) website, seven ship accidents (both transport and fishing vessels) were reported in 2023, with 85% of these accidents involving ship fires. In the 2024 report, there were six ship accidents, and 83% were ship fires. A particularly serious ship fire occurred in August 2023, the Kurnia Jaya Fire at the Tegalsari Coastal Fishing Port, Central Java. In that incident, the fire spread to ships anchored at the pier, and 52 vessels were recorded as burning. Therefore, the risk of fishing vessel fires is quite high, considering the history of fishing vessel fires in the past five years at several fishing ports in Indonesia, including the Muara Baru, Tegal, and Cilacap Fishing Ports, which caused dozens to burn (KNKT, 2023). Meanwhile, green mussel shell waste (Perna viridis) is abundant due to the rapid increase in mussel production (Rahman & Fitriani, 2024; Rudianto et al., 2024; Prihanto et al., 2024). This waste is rich in calcium carbonate ($CaCO_3$), which has the potential to be used as a filler in fiberglass composites, thus strengthening the material and slowing the combustion rate (Waskito et al., 2024; Cetiner et al., 2023; Naguib, 2023). Fiberglass is often used in fishing vessel hulls because it is lightweight and corrosion-resistant (Okuma et al., 2023; Azhar et al.,

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2025; Muharom et al., 2024). The use of CKH as a mixture is expected to not only reduce waste but also increase the added value of the material and the vessel's fire resistance (Bryll et al., 2023; Crupi et al., 2023; Fernando et al., 2024). However, it is necessary to test how CKH affects the mechanical properties and fire resistance of fiberglass composites. This study experimentally tested the effect of adding CKH to fiberglass fishing vessel materials <5GT commonly used in Indonesia (KKP, 2022; Choiron & Setyarini, 2024; Windyandari et al., 2022). With a certain mixture composition, it is expected to provide good results in reducing the material's combustion rate (Konstantinova et al., 2023; Zhou et al., 2024; Navalino et al., 2024).

Methods

The experiment was conducted in the Polymer Laboratory of BRIN Serpong in January 2025-February 2025 to determine the influence of different percentages of green mussel shell powder (CKH) on the fire resistance of fiberglass composite that was ubiquitous in small fishing vessels not exceeding five gross tonnage. The performance of the work in a controlled laboratory environment allowed the performance of each stage of the procedure (preparation of the material) to the same conditions, thus, increasing the resolution of CKH composition effects and reducing the effects of confounders on the final results of the work.

Various forms of fiberglass reinforcements were used in the study, which included Matt 300 g/m 2, Matt 450 g/m 2, and Woven Roving 600 g/m 2 in combination with unsaturated polyester resin and a catalyst of 1 per cent of the mass of the resin. The shells of Green mussel, produced in the country and use locally, were obtained as waste products, and these were thoroughly cleansed, dried and milled to a fine powder with a particle size ranging between 30 and 50 mesh. The synthesis of fine powder helped in sufficient dispersion in the resin matrix, which is a requirement in terms of precise determination of their effects on combustion behavior. Six CKH preparations were made, namely 0, 10, 20, 30, 40, 50 percent of the mass of the resin.

The method of fabricating specimens complied with SNI 8961:2021 requirements of hand lay-up. First of all, resin, catalyst, and CKH powder were mixed until a homogenous mixture was formed. This compound was then placed into a 40(w)x40(h)cm glass mold and reinforced with fiberglass, one sheet of Matt300, two sheets of Matt450, and one layer of Woven Roving600. In order to reduce the possible effects of voids on flame propagation and structural capability, every layer was pressed by hand to expel any trapped air. The resulting laminated panels were left to dry at ambient temperature over a period of 24 h after which they were cut into standard specimens that could be used to assess the fire-resistance.

Fire resistance was measured through the ASTM D 635 horizontal burning test, which is a standard test used to determine the rate of burning of materials in a horizontal arrangement, as a ratio of the number of millimetres per minute and is commonly used to analyse the flammability of polymer composites. The approach provides realistic representation of linear flame propagation, particularly with the small vessels where fire development and propagation can be very fast. At least three replicate specimens were tested with each CKH formulation and the mean burn rate was used as the primary datum, which increased reliability and reduced the effect of aberrant values.

Analysis was conducted using a linear regression in order to explain the correlation between CKH content and burn rate. This method was considered suitable because the two variables were continuous and the goal was to measure the power of the impact of the CKH proportion on the combustion behavior. Before interpreting the regression output, diagnostic tests were

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conducted to show that the data met the necessary assumptions: it was found that data met the conditions of normality, homoscedasticity, no multicollinearity, and the independence of errors. Checking these assumptions made sure that the resulting regression equation was a very strong predictive model on data of burn rate versus CKH percentage hence giving empirical understanding as well as a practical aid in the construction of future composite designs in the fishing vessels.

Results and Discussion

The results of the mechanical and fire resistance tests are presented in the following table. It can be seen that the burn rate decreases with increasing CKH, thus increasing the fire resistance of the material. Summary data of the results:

Table 1. Test Results of Fire Resistance Test Specimens in the Polymer Laboratory

% CKH	Burn Rate (mm/min)
0%	14,32
10%	13,60
20%	13,10
30%	12,41
40%	12,24
50%	11,47

In general, the specimens with a mixture of CKH powder showed a slower burning rate than the control specimen (0% CKH), so that their fire resistance increased. In table 1 the addition of 20% CKH increased the fire resistance by about 8.56%, and at 50% CKH it reached +19.92% compared to the material without CKH. The results of the study showed that the burning time varied according to the composition of the composite mixture and CKH powder as an additional flame retardant. In the 10% CKH test specimen, the results were 13.60 mm/min, the 20% CKH test specimen obtained results of 13.10 mm/min or more fire resistance 8.5% of the control specimen. Up to the 50% CKH test specimen obtained results of 11.47 mm/min or more fire resistance 19.90% of the control specimen.

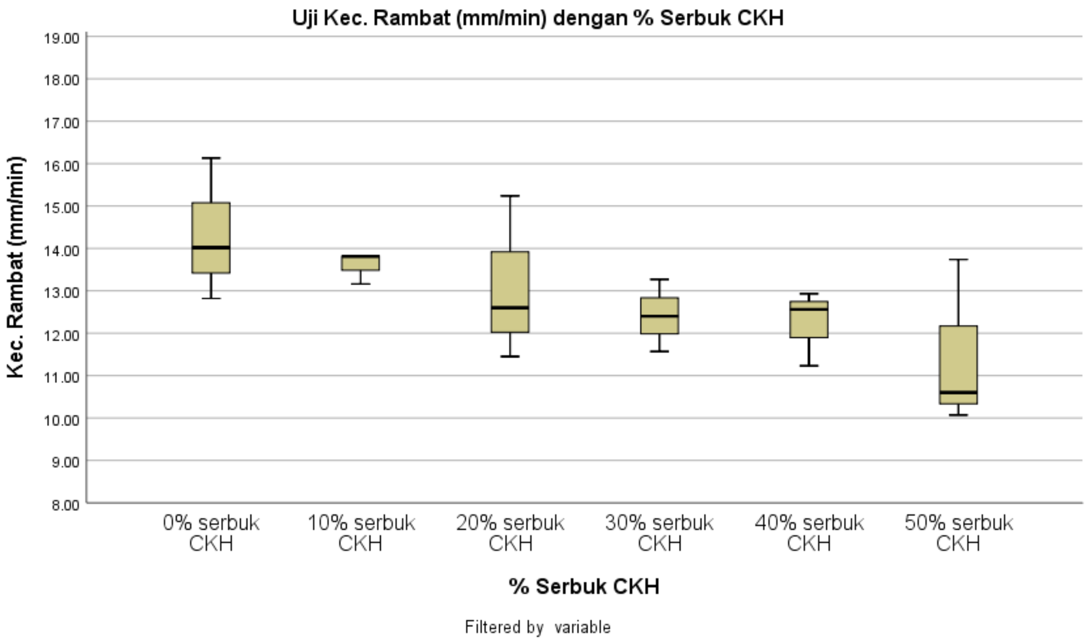

Figure 1. Relationship between fire resistance and % green shell powder

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In Figure 1, the control specimen (without the green mussel powder mixture) produced a burn rate of 14.32 mm/min, meaning the specimen without the CKH mixture had the fastest fire spread. Statistical analysis was performed using linear regression because the data were continuous numerically and to determine the linear relationship or influence between the CKH composition variable and the burn rate. The requirements for the regression test were that the data had normal residuals, homoscedasticity, no multicollinearity, no autocorrelation, and no outliers.

Table 2. Normality Test

Variables	Shapiro-Wilk p-value	Information
Unstandardized Residual	0,793	Normal Distribution

In Figure 2, the results of the homoscedasticity test show a scattered and random pattern so that the data meets the homoscedasticity criteria.

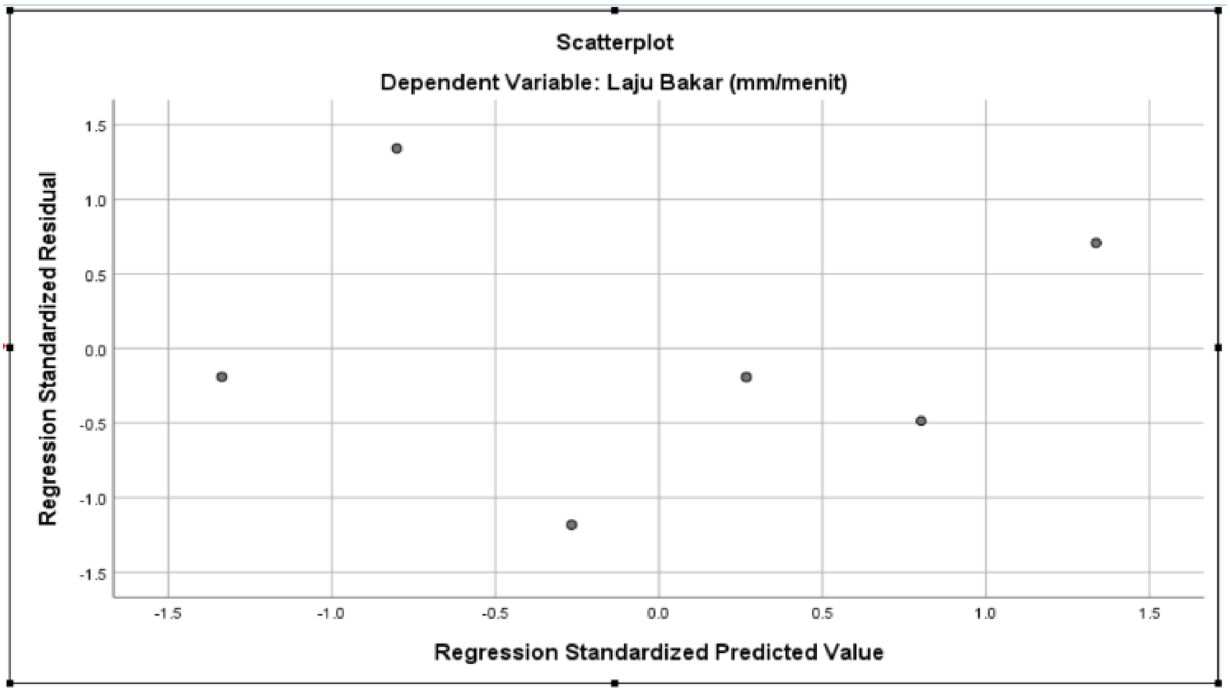

Figure 2. Homoscedasticity Test

Table 3. Multicollinearity Test

Model	Dimension	Condition Index	Variance Proportions	Information
1	1	1.000	0.05 & 0.05	No problem
	2	4.330	0.95 & 0.95	Still within safe limits

The results of the multicollinearity test in Table 3 show no multicollinearity in the regression model. The maximum Condition Index value is 4.330 (well below the critical limit of 30), and there are no combinations of high variance proportions in dimensions with high Condition Indexes. Therefore, the model is free from multicollinearity problems.

Table 4. Autocorrelation Test

Model	R	R Square	F Change	Sig. F Change	Durbin-Watson

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1	.992[a]	.983	235.639	.000	2.796

Table 4 shows the results of the autocorrelation test, which shows a very strong and positive relationship between the composition of CKH powder (%) and the burning rate (0.992 and 0.983). 98.3% of the change in the burning rate value was caused by changes in the composition of CKH powder (%), while 1.7% was due to other factors not explained in this study. A significance value of <0.05 indicates that the addition of CKH powder composition as a predictor has a significant effect on the burning rate. The Durbin-Watson value of 2.796 indicates a slight negative autocorrelation but is still within the tolerance limit (below the threshold of 3).

Table 5. Logistic Regression Analysis of CKH Composition on Burn Rate

Model		**B**	**Std. Error**	**Beta**	**t**	**Sig.**	**Tolerance**	**VIF**
1	(Constant)	14.32	.138		107.049	.000		
	CKH powder composition (%)	-.0543	.035	-.992	-15.351	.000	1.000	1.000

Logistic regression analysis in table 5 shows a constant data of 14.32, that is, if the specimen does not contain CKH powder composition, the burn rate is predicted to be 14.32 mm/minute. The coefficient value of CKH powder composition is -0.0543, meaning that for every 1% increase in CKH powder composition, the burn rate decreases by 0.0543 mm/minute, and is negatively/inversely related. The strength of the relationship between the two variables, namely the CKH powder composition, has a very large effect on the burn rate (Beta value -0.9)..

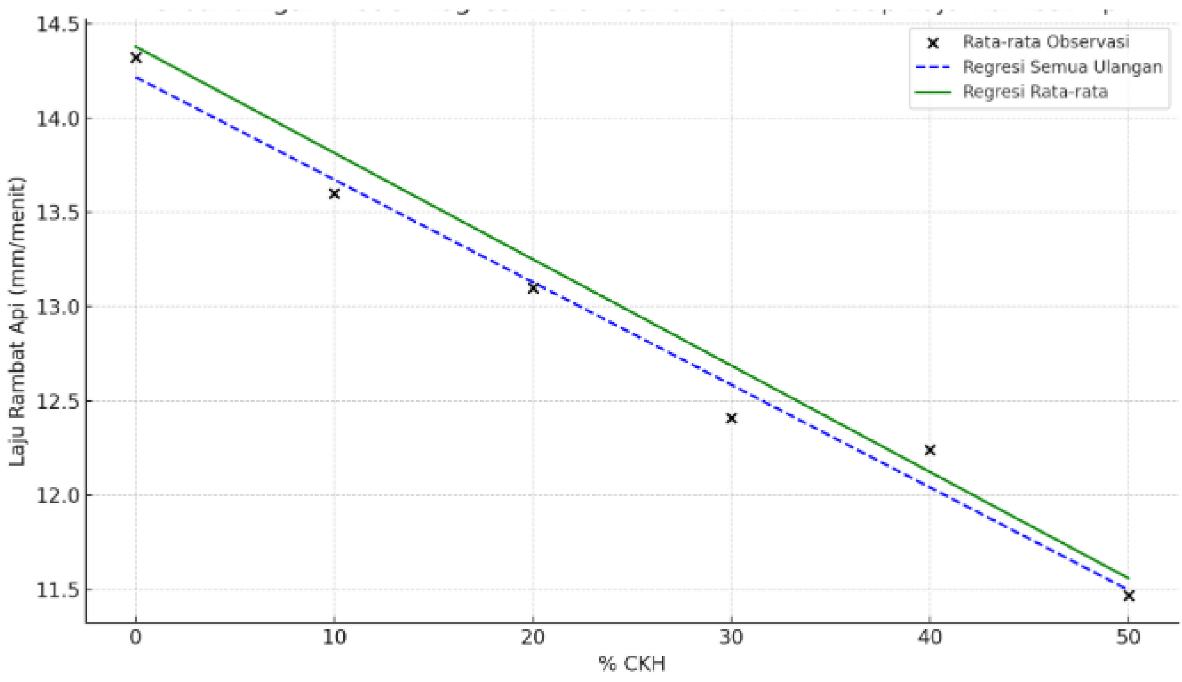

Figure 3. Regression graph of CKH addition on burning rate

Figure 3 presents the results of the regression analysis of CKH composition on the burning rate, where the average observation results are not far from the results of the regression of all

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repetitions or the regression of the average test. The logistic regression equation model on the variable of CKH powder composition (%) with the burning rate is:

Burn Rate (mm/min) = 14.32 – 0.0543 x CKH powder composition (%)

Based on the regression equation, every 1% increase in CKH powder composition reduces the burn rate by 0.0543 mm/min. The more CKH added to the composite, the slower the burn rate. Meanwhile, in a study conducted by G. Sakhti Balan et al. (2021) using the same burn test method, fiberglass mixed with 5% jute fiber produced the lowest burn rate of 10.2 mm/min (Balan et al., 2022). In a study conducted by Banar et al. (2024), on fiberglass fishing boats, the addition of aluminum trihydrate (ATH) filler significantly increased fire resistance and reduced the burn rate to 8 mm/min (Wicaksono et al., 2024; Ramesh & Deepa, 2024; Zainudin et al., 2022).

A study by Grayson showed that adding calcium carbonate as a filler to HW 607M propylene copolymer can improve fire resistance (especially in reducing droplets and suppressing smoke production) although it did not significantly change the overall combustion behavior in small-scale tests. On a large scale, this filler significantly reduces smoke production and limits lateral fire spread, while also increasing the energy required for ignition. (Grayson & Smith, 1984; Godakandage et al., 2023; Dalfi et al., 2024).

Research conducted by A.A. Mahmoud et al. (2000) found that adding bromine to a PE/St resin coating effectively reduced the flame spread distance in wood specimens. The higher the bromine content, the shorter the burning distance. The best burn rate was 14.60 mm/min. In fact, uncoated wood had a higher burn rate than coated wood, particularly the bromine-free wood, with a burn rate of 6,731 mm/min. Thus, the burn rate reduction was very significant (Mahmoud et al., 2001; Chukamei et al., 2021; Onorati et al., 2022; Bakar et al., 2024).

The addition of CKH powder to reduce the burn rate in shipbuilding materials also requires consideration of the material's standard tensile and flexural strength limits (Rahmawati et al., 2024; Bouanani et al., 2025; Fragassa et al., 2025). Based on the BKI Rules for Non-Metallic Materials, 2006, the minimum tensile and flexural strength limits are ≥ 40 MPa and ≥ 80 MPa, respectively. The higher the tensile and flexural strength of a material indicates the stronger the material. Research conducted by Adhi Paska in 2025, related to the strength value of Fiberglass material with a mixture of green mussel powder produced optimal tensile and flexural strength in a mixture of 20% CKH powder, and showed negative results in tensile and flexural strength between the CKH composition and the tensile and flexural strength of the material.

Conclusion

To reduce the burn rate of fiberglass material mixed with green mussel shell powder, the higher the green mussel shell content, the lower the burn rate of the fiberglass. The regression equation in this study can be used as a reference for determining the desired burn rate based on the amount of CKH powder mixture in the manufacture of composite fishing vessels <5GT. Recommendation: The composition of the green mussel shell powder mixture takes into account the strength of the vessel material (tensile and flexural strength values). This can be considered for parts of the vessel at risk of fire by adding more green mussel shell powder than other parts. Further research is needed, especially exploring the use of other additives or the treatment and content of green mussel shell powder, which can also be studied to improve its compatibility with the fiberglass matrix and enhance its fire resistance properties.

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