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Biocomposite Innovation: Assessing Tensile and Flexural Performance with Maleated Natural Rubber Additives

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Abstract

Fiberglass is the most common reinforcing fiber used in composites, with polymer matrices having high tensile strength and chemical resistance, including an excellent insulating property; however, they are non-degradable. Natural fiber reinforced polymer composites have advantageous properties such as lower density and price, when compared to synthetic composite products. In addition, hybrid composites may be obtained depending on various properties such as the fibers' length, structure, content and orientation, matrix bonding and arrangement. This study was carried out to determine the effect of adding Maleated Natural Rubber (MNR) from natural rubber as a coupling agent, in order to produce the highest tensile and flexural strength. The hand lay-up and vacuum bag methods with the Response Surface Method-Central Composite Design (RSM). -CCD) were used. The composite arrangement pattern was E-glass/OPEFB/E-glass, the volume fraction of OPEFB (oil palm empty fruit bunches):E-glass was 40:60, 50:50 and 60:40, the fraction volume of OPEFB + E-glass:matrix was 40:60, 50: 50, 60: 40 and the coupling agent were added by 9, 10 and 11% of the total epoxy resin used. Furthermore, the composite mold was made of glass with dimensions of 200mm x 50mm x 50mm. The results showed that the composite product obtained from both methods had a tensile strength value, which was influenced by the variable OPEFB fiber and epoxy resin. Meanwhile, the flexural strength was influenced by the OPEFB fiber and the quadratic factor of the epoxy-MNR resin.

1. Introduction

During the early phases of fiber-reinforced polymer composite development, synthetic fibers like carbon and glass emerged as prominent choices for reinforcement. Glass fibers, in particular, have gained widespread use in polymer matrix composites. This preference can be attributed to their advantages such as high tensile strength, chemical resistance, and outstanding insulating properties [1]. Furthermore, due to their outstanding properties, glass fiber reinforced composites have been widely applied in various fields, such as automotive and aeronautics, including the electronic field [2]. Although synthetic fibers provide extraordinary effects on composite properties, their negative impact is still being discussed scientifically. For example, the density of synthetic fiber is directly proportional to the composite density. Therefore, high density composites with high density certainly have an impact on weight when applied to vehicle body and fuel consumption. The disadvantage of synthetic fibers as composite reinforcement is their non-degradability therefore, it is of great importance to substitute natural fibers for synthetic fibers [3].

Previous studies have explored a range of natural fiber-reinforced composites, including pineapple, sisal, jute, kenaf, hemp, coir, banana, bamboo, kapok, oil palm empty fruit bunches (OPEFB) fiber, and more [4–6]. These composites offer advantages such as lower cost and density compared to synthetic products, making them particularly suitable for commercial applications in automotive, building, and construction industries [7]. Additionally, research has investigated polymer hybrid composites combining natural and synthetic fibers, offering improved characteristics dependent on factors like fiber length, structure, content, orientation, matrix bonding, arrangement, and strain failure [8].

Foreign exchange earnings from Indonesia's agriculture industry, particularly oil palm plantations, are rising. The largest supply of oil palm is found in Riau Province, where 1,732,748 hectares of plantations will be present in 2022 [9]. Oil palm yields a variety of goods, such as industrial oil, biodiesel fuel, and edible oil. The market availability of these products rises together with the expansion of oil palm farms. With more than 1.7 million hectares of plantations, Riau Province is the top producer of oil palm, and the country's broad expansion in oil palm cultivation has increased product supply and foreign cash revenues.

Indonesia is currently the largest producer and exporter of palm oil in the world with a total production of 45,861.121 tons in 2019 and 21.47% was contributed by Riau Province [10]. Furthermore, it produces solid waste mostly in the form of palm fronds, followed by OPEFB around 1.1 tons [11]. For every ton of CPO (Crude Palm Oil) produced by the palm oil industry, empty fruit bunches are obtained. In addition, palm fiber is obtained directly from natural resources that are cheap and also renewable, low in cost and easily available [12]. However, OPEFB are hard and tough [13].

Natural fiber reinforced polymer composite materials have emerged in a broad spectrum of polymer science. The composites produced from this material are low wear and non-corrosive, low density, low cost, specific comparable properties and environmentally friendly. Despite its advantages, the main disadvantage is its low compatibility due to its hydrophilic fiber and hydrophobic matrix. Therefore, the adhesion between the fiber and matrix is poor and susceptible to moisture. In order to correct these weaknesses, chemical treatments such as alkaline, silane, acetylation, benzoylation, acrylation and scrylonitrile grafting, maleated coupling agents, permanganate, peroxide and isocyanate are administered [14]. Furthermore, OPEFB modification is carried out by graft copolymerization of hydrophobic vinyl monomers, which is an alternative to improve matrix compatibility with fibers [15]. Machado discovered that malleated anhydride (MAH) grafted into natural rubber molecules improves the interface properties and the adhesion of fillers with polymeric matrices. Therefore, modified natural rubber was used for the manufacture of Thermoplastic Elastomer (TPE) or Thermoplastic Vulcanizate (TPV) [16].

The main objective of this study was to determine the effect of adding Maleated Natural Rubber (MNR) from natural rubber as a coupling agent, producing the highest tensile and flexural strength of OPEFB and E-glass fiber hybrid composites with an epoxy resin matrix. The hand lay-up method and a vacuum bag, with the Response Surface Method-Central Composite Design (RSM-CCD) were used. The utilization of MNR as a coupling agent is expected to improve the interfacial adhesion between the components, leading to enhanced mechanical performance in terms of tensile and flexural strength.

2. Materials and Methods

2.1. Materials

The fiber and ash of empty fruit bunches were obtained from PTPN V Sei Galuh, Riau Province, Indonesia. Natural rubber was obtained from PT. Hervenia Kampar Lestari, Riau Province, Indonesia. Woven glass fibers (mat E-glass) and epoxy resin Eposchon A&B were obtained from PT. Justus Kimiaraya, Surabaya, Indonesia. Furthermore, maleic anhydride (MAH) was produced by Schuchardt OHG 85662 Hohenbrunn, Germany with a purity of 99%. In addition, toluene was produced by KgaA 6427 Darmstadt, Germany, with a purity of ≥ 99%, and xylene was obtained from PT. Brataco, Bandung, Indonesia.

2.2. Preparation and Treatment of Palm Empty Fruit Bunches

The empty fruit bunches were first cleaned, extracted by washing with distilled water and dried in the sun for three days until a moisture content < 10% was obtained. The fibers were cut 3 cm long and stored in a plastic container to prevent mold. Alkaline treatment was used as the previous work [17], where the OPEFB ash was sieved using a 60-80 mesh filter. Furthermore, the ash was dissolved in distilled water with 5% of the content by weight, stirred for 5 minutes and left for 48 hours. The OPEFB ash solution for extraction was obtained by separating the ash precipitate by filtration. In addition,

Table 1. Level of OPEFB, resin epoxy and MNR in this experiment.

Variable	Coding	Unit	Levels				
			-α	-1	0	1	α
OPEFB	X_1	Percent	33.1	40	50	60	66.8
Resin epoxy	X_2	Percent	33.1	40	50	60	66.8
MNR	X_3	Percent	8.3	9	10	11	11.6

the fibers were soaked for 36 hours and upon completion of alkaline treatment. They were dried in the sun for three days and stored in a closed plastic container.

2.3. Preparation of Coupling Agent

The preparation of a coupling agent from natural rubber (MNR) was referred to in the previous study [18]. The natural rubber (SIR 20) was cut to a diameter of 2 mm and dried in an oven at a temperature of 40 ºC for 24 hours to reduce moisture content and it weighed over 40 grams. Mastication was used in grafting MAH to a natural rubber polymer chain, breaking the molecular chain into shorter units, therefore reducing its viscosity. This was carried out in the internal mixer of the Banbury Type B60 B for 2 minutes with a temperature of 155 ºC and a rotor speed of 60 rpm. Furthermore, after mastication, 8 phr maleic anhydride (MAH) was added and stirred in a mixer for duration of 10 minutes therefore, MNR and inserted into aluminum foil. Ungrafted MAH on natural rubber was removed through an extraction process, putting the heated natural rubber into an Erlenmeyer flask filled with toluene and heated at a temperature of 110 ºC while stirring for 10 minutes. The resulting gel was precipitated with the addition of acetone until the solution became clear and the gel completely removed. In addition, the solid rubber was placed on filter paper connected to a vacuum pump until the toluene and acetone were separated from the MNR. The dry MNR was stored in an oven at 40 ºC for 24 hours.

2.4. Preparation of Composite

Composites were made using hand lay-up and vacuum bag techniques, with the following arrangement pattern E-glass/OPEFB/E-glass, where the volume fraction of OPEFB:E-glass was 40:60, 50:50 and 60:40, the volume fraction of OPEFB + E-glass: epoxy resin was 40:60, 50:50 and 60:40 and the coupling agent was added by 9, 10 and 11% of the total epoxy resin used. Furthermore, the composite mold was made of glass with dimensions of 200 mm x 50 mm x 50 mm.

MNR was heated until it melted, while the epoxy and hardener resins were mixed with a ratio of 2:1, according to the desired percentage. Afterwards, the fibers were arranged into the mold using the hand lay-up method with the arrangement of E-glass/OPEFB/E-glass and the resulting composite was left for 24 hours. Meanwhile, for the vacuum bag technique, the composites were formed in the mold using the hand lay-up method, placing them in a flexible bag where negative pressure was obtained using a vacuum pump for 2 hours. Furthermore, the curing cycle was carried out at room temperature for 24 hours. Table 1 listed the range and levels of the three independence variables which were studied in this experiment.

2.5. Tensile and Flexural Tests

Tensile tests for composites were carried out using a Universal Tensile Machine (TENSILON RTF-2430, Capacity 30 KN, Japan). The test was carried out as specified in ASTM D 638-14 Type I: Test method for tensile properties of plastic with a crosshead speed of 5 mm/minute. Meanwhile, flexural tests were carried out using the Universal Tensile Machine (TENSILON RTF-2430, Capacity 30 KN, Japan), as specified in ASTM D 790-17 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.

2.6. Analysis of Variance (ANOVA) Response Surface Method and Statistical Analysis

Statistical and mathematical analysis was obtained from the experimental RSM-CCD design [19]. Furthermore, a second-order regression model (Equation 1) was used to relate variable effects and responses. The model analysis of variance was calculated using Design Expert® 11.0.0 software to check the suitability based on the F and P-value.

$$y = \beta_0 + \sum_{i=1}^{3} \beta_i x_i + \sum_{i=1}^{3} \beta_{ii} x_i^2 + \sum_{i<j} \sum \beta_{ij} x_i x_j + \epsilon \qquad (1)$$

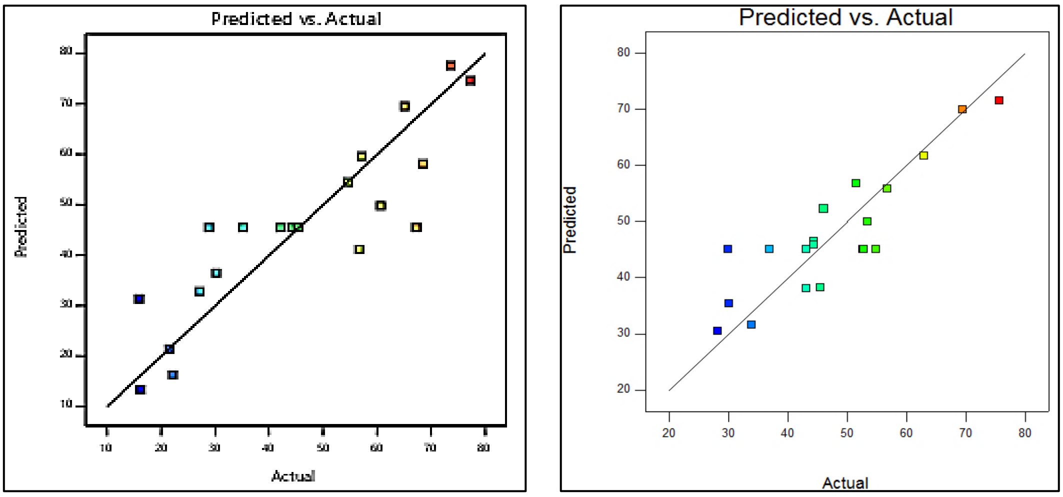
where y is response, β_0, β_0, β_0, is coefficient, and x_i is coded variable.

3. Results and Discussion

Table 1 shows the experimental designs obtained in each response to tensile and flexural strength at various percentages of OPEFB/E-glass fibers (X1). The percentage of hybrid fibers/epoxy resin (X2) and coupling agent (MNR) (X3) were processed using one of the methods in the RSM. Table 2 showed the summary of response of the tensile and flexural strength, which was processed using

Table 2. Experiment design and test results.

Run	Natural variables			Response (Y)			
				Hand lay-up method		Vacuum bag method	
	A	B	C	Tensile strength (MPa)	Flexural strength (MPa)	Tensile strength (MPa)	Flexural strength (MPa)
1	50	50	8.32	60.64	20.41	51.43	50.29
2	33.2	50	10	73.61	147.45	69.46	44.32
3	50	50	10	42.12	73.85	36.89	40.83
4	40	40	11	65.09	102.98	56.73	66.36
5	50	50	10	35.21	46.02	30.01	41.24
6	60	40	11	22.16	34.85	28.15	56.78
7	66.8	50	10	16.21	45.18	33.85	40.59
8	40	60	11	54.57	90.53	46.02	53.10
9	60	40	9	30.22	34.96	43.04	45.45
10	50	50	10	44.18	52.61	54.88	42.19
11	50	66.8	10	27.15	55.43	53.40	51.82
12	50	50	10	45.31	82.18	52.82	42.89
13	50	50	10	67.25	61.62	52.67	41.12
14	50	50	10	28.84	53.08	43.09	39.10
15	60	60	11	15.95	27.78	30.09	51.65
16	40	40	9	77.25	62.78	62.82	149.11
17	50	33.2	10	68.50	68.20	44.34	74.36
18	60	60	9	21.52	65.01	44.31	8056
19	40	60	9	57.12	73.93	75.54	64.56
20	50	50	11.68	56.67	26.66	45.45	30.01



(a) (b)

Figure 1. Predicted and actual value of tensile strength, a) hand lay-up method, b) vacuum bag method.

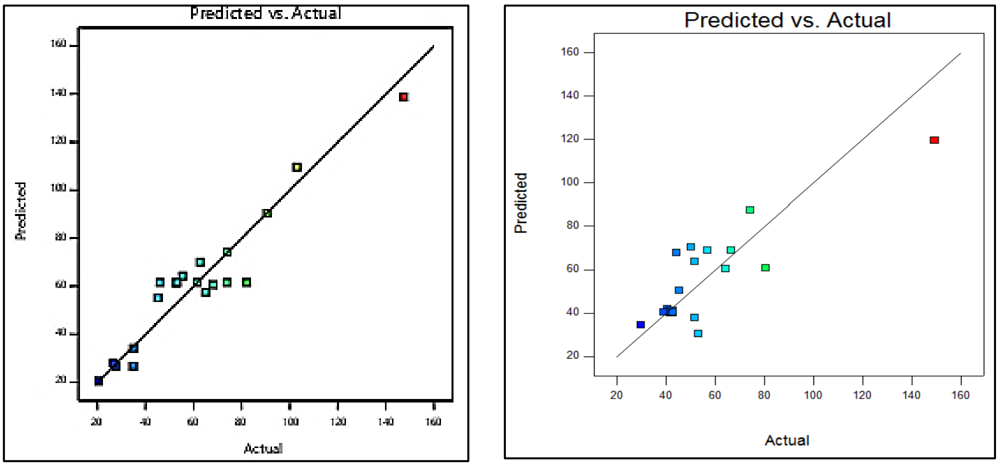
one of the methods in the response surface method (RSM) that resulted in this experiment. The method was CCD with three factors. The factors were Volume Fraction of OPEFB/E-glass (A), Volume Fraction of resin epoxy B), and % MNR (C).

The model accuracy was seen from the comparison between the actual values of the study with the prediction of the standard deviation. The results from the predicted model were expressed as straight lines and the actual data from this study results were represented in the form of scattered boxes, as shown in Figures 1 and 2, with very good precision.

The response to tensile and flexural strength are shown in Tables 3, 4, 5, 6 and Figures 4, 5, 6, 7, 8, 9, 10. It can be seen that the fit p-value was not significant. This implies that the error caused by the model selection was negligible.

3.2. Tensile Strength

Tables 7 and 8 show a summary of each response for the hand lay-up and the vacuum bag method. For the hand lay-up method, the tensile strength value was affected by OPEFB fibers and epoxy resin. Therefore, a mathematical



(a) (b)

Figure 2. Predicted and actual value of flexural strength, a) hand lay-up method, b) vacuum bag method.

Table 3. Summary of F-Value for each variable of the Tensile Strength model with hand lay-up method.

Source	Sum of Square	DF	Mean Square	F-value	p-value Prob>F
Model	5771.53	9	641.281	5.752	0.006
A-%OPEFB/E-glass	4404.09	1	4404.092	39.499	0.000
B-% Resin epoxy	1021.87	1	1021.873	9.165	0.013
C-% MNR	27.95	1	27.948	0.251	0.627
AB	20.14	1	20.142	0.181	0.680
AC	34.26	1	34.263	0.307	0.592
BC	10.26	1	10.260	0.092	0.768
A^2	10.85	1	10.848	0.097	0.762
B^2	0.38	1	0.377	0.003	0.955
C^2	229.49	1	229.493	2.058	0.182
Residual	1114.98	10	111.498		
Lack of Fit	262.35	5	52.469	0.308	0.889
Pure Error	852.63	5	170.527		
Cor Total	6886.51	19			

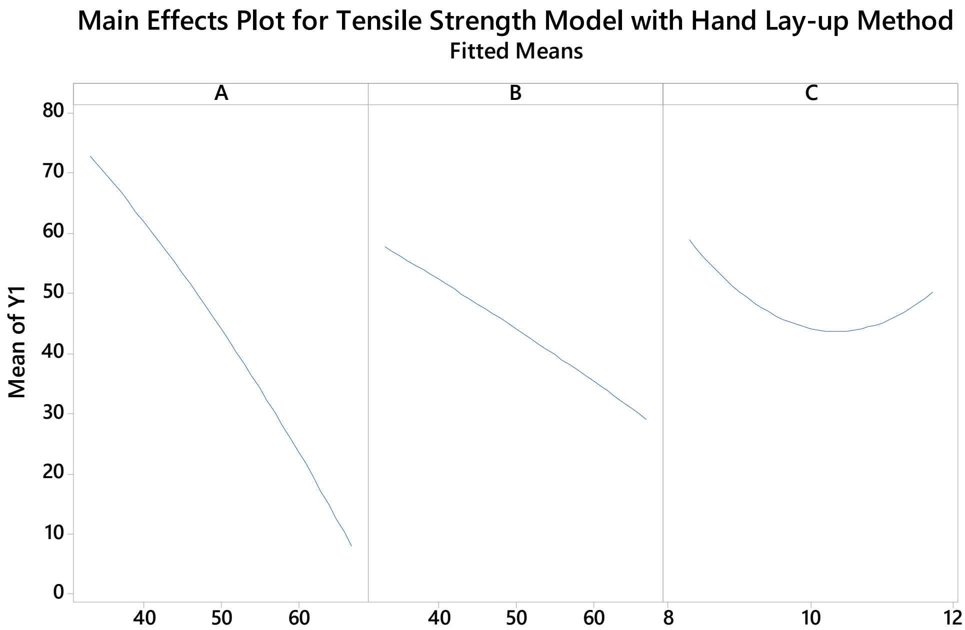


Figure 3. The main effect of process condition on the tensile strength with hand lay-up method.

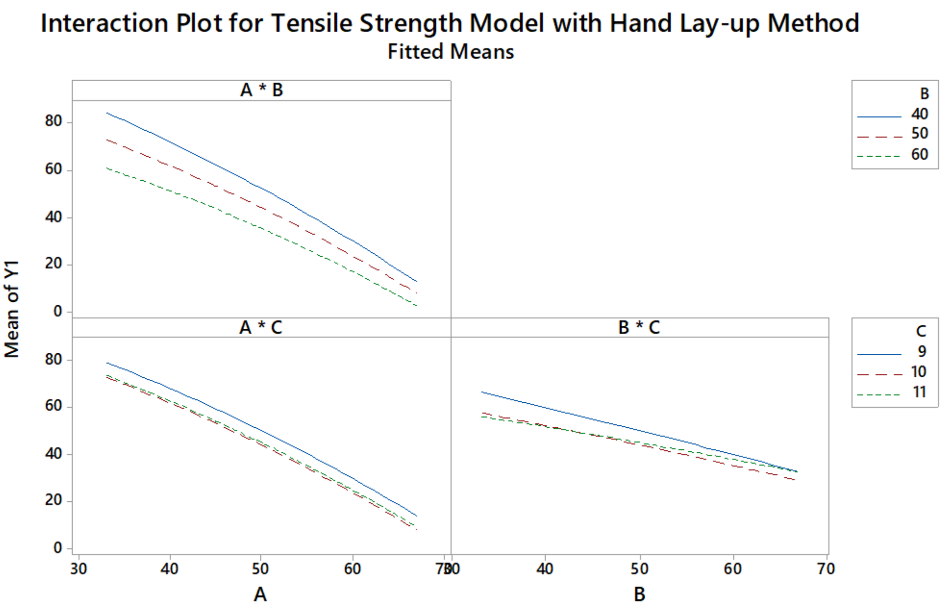


Figure 4. Two factors interaction effect of process conditions on the tensile strength with hand lay-up method

Table 4. Summary of F-Value for each model variable tensile strength with vacuum bag method.

Source	Sum of Square	DF	Mean Square	F-value	p-value Prob>F
Model	2305.78	9	256.20	7.55	0.0020
A-%OPEFB/*Glass*	1768.32	1	1768.32	52.14	<0.0001
B-% Resin epoxy	20.15	1	20.15	0.59	0.4587
C-% MNR	409.56	1	409.56	12.08	0.0060
AB	0.90	1	0.90	0.026	0.8742
AC	5.31	1	5.31	0.16	0.7006
BC	88.68	1	88.68	2.61	0.1369
A^2	4.63	1	4.63	0.14	0.7194
B^2	2.50	1	2.50	0.074	0.7916
C^2	4.65	1	4.65	0.14	0.7189
Residual	339.17	10	33.92		
Lack of Fit	216.17	5	43.23	1.76	0.2755
Pure Error	122.99	5	24.60		
Cor Total	2644.94	19			

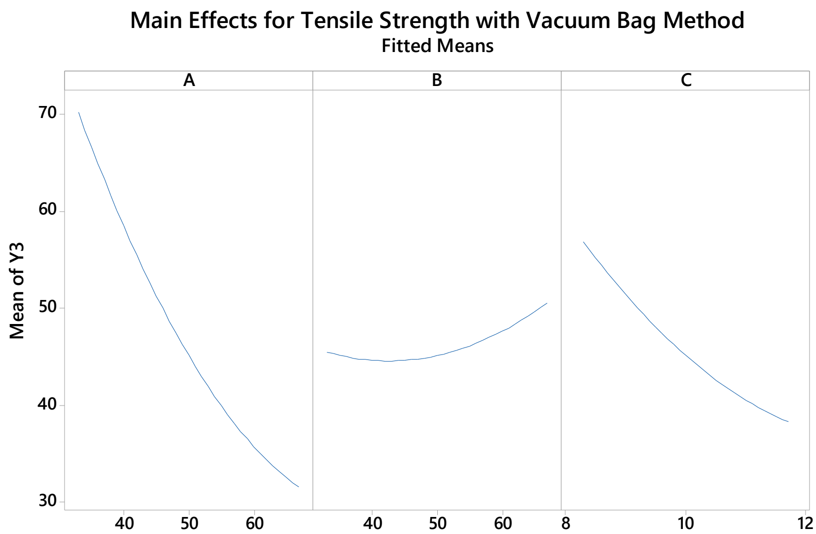


Figure 5. The main effect of process condition on the tensile strength with vacuum bag method.

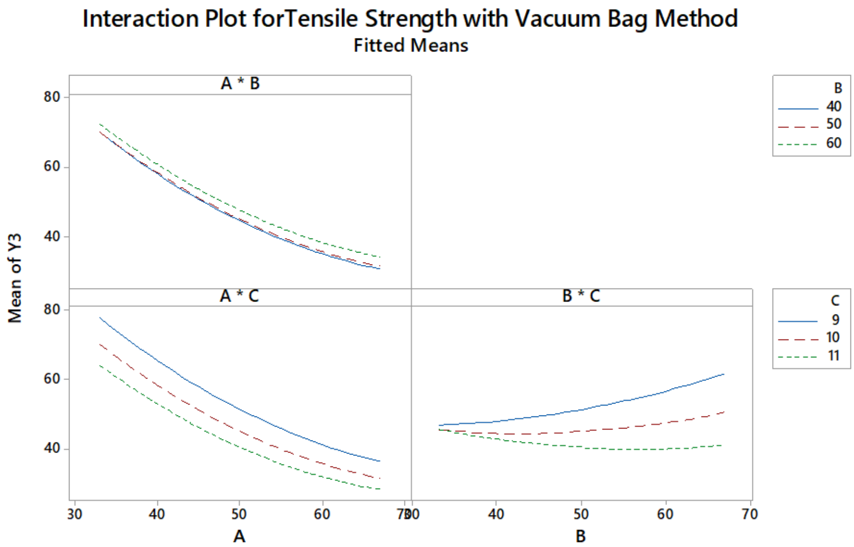


Figure 6. Two factors interaction effect of process conditions on the tensile strength with vacuum bag method.

Table 5. Summary of F-Value for each variable model flexural strength with hand lay-up method.

Source	Sum of Square	DF	Mean Square	F-value	p-value Prob>F
Model	15392.13	9	1710.24	11.42	0.000
A-%OPEFB/E-glass	8445.80	1	8445.80	56.382	0.000
B-% Resin epoxy	15.04	1	15.04	0.100	0.758
C-% MNR	65.75	1	65.75	0.439	0.523
AB	184.53	1	184.53	1.232	0.293
AC	1108.06	1	1108.06	7.397	0.022
BC	271.09	1	271.09	1.810	0.208
A^2	2259.24	1	2259.24	15.082	0.003
BA^2	1.51	1	1.51	0.010	0.922
C^2	2514.82	1	2514.82	16.788	0.002
Residual	1497.97	10	149.80		
Lack of Fit	527.93	5	105.59	0.544	0.740
Pure Error	970.05	5	194.01		
Cor Total	16890.10	19			

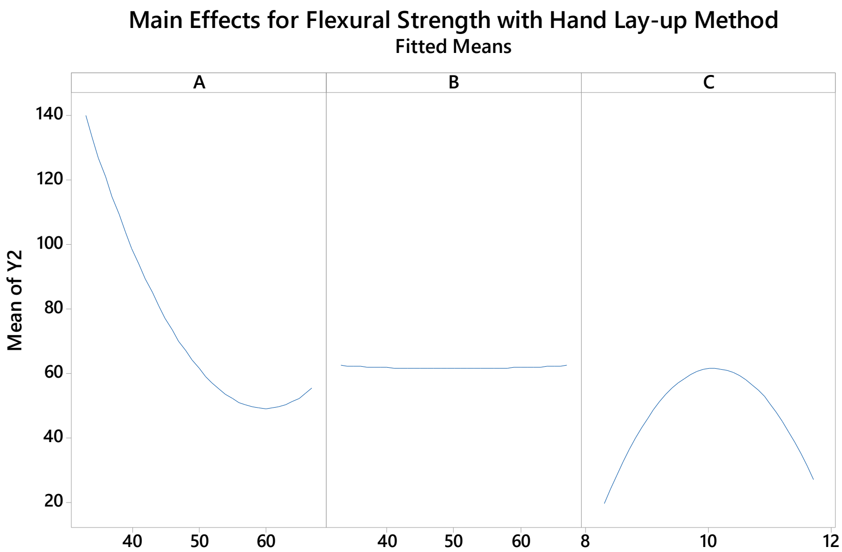


Figure 7. The main effect of process condition on the flexural strength with hand lay-up method.

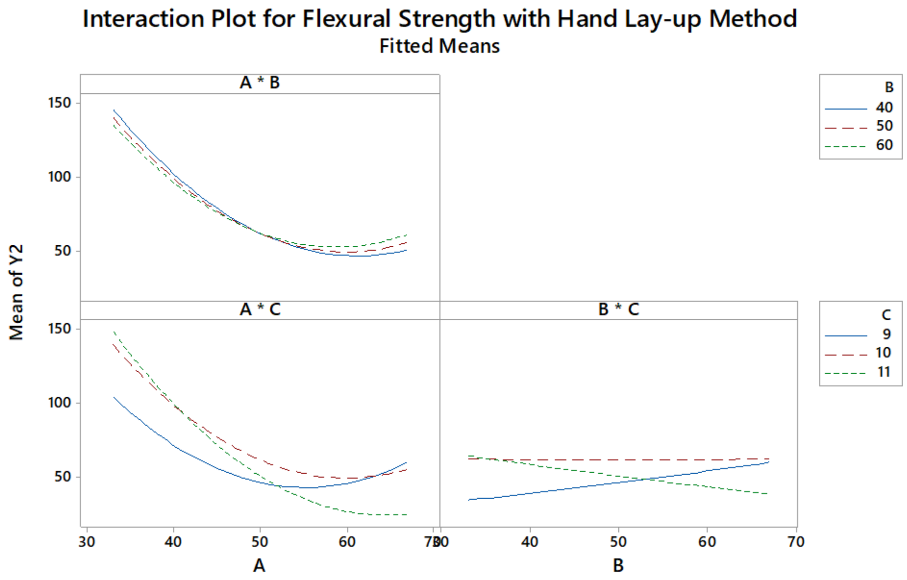


Figure 8. Two factors interaction effect of process conditions on the flexural strength with hand lay-up method.

Table 6. Summary of F-Value for each variable model flexural strength with vacuum bag method

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	39504601	4389400	2.06	0.138
Linear	3	13900180	4633393	2.17	0.155
A	1	4535774	4535774	2.13	0.176
B	1	4534882	4534882	2.13	0.176
C	1	4829524	4829524	2.26	0.163
Square	3	1708562	569521	0.27	0.848
A*A	1	668885	668885	0.31	0.588
B*B	1	714954	714954	0.34	0.575
C*C	1	663834	663834	0.31	0.589
2-Way Interaction	3	23895859	7965286	3.73	0.049
A*B	1	8207792	8207792	3.85	0.078
A*C	1	7798900	7798900	3.65	0.085
B*C	1	7889167	7889167	3.7	0.083
Error	10	21337654	2133765		
Lack-of-Fit	5	21337645	4267529	2544350.63	0
Pure Error	5	8	2		
Total	**19**	**60842254**			

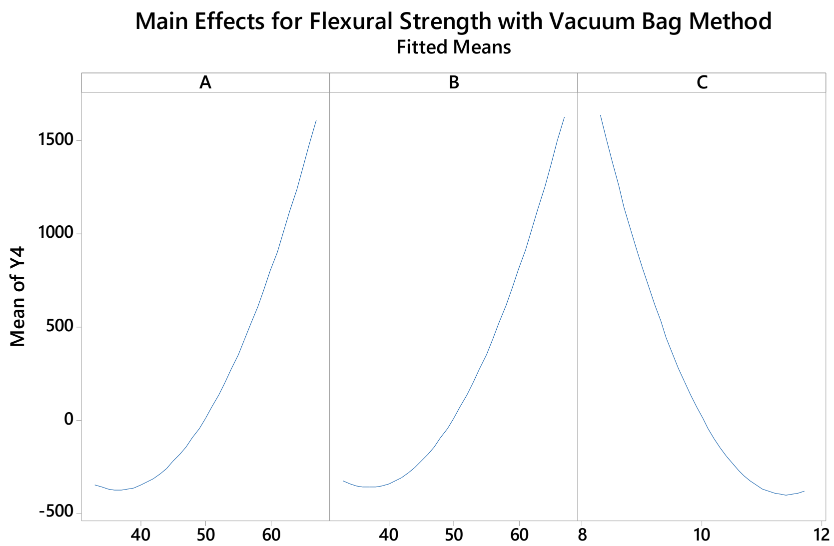


Figure 9. The main effect of process condition on the flexural strength with vacuum bag method.

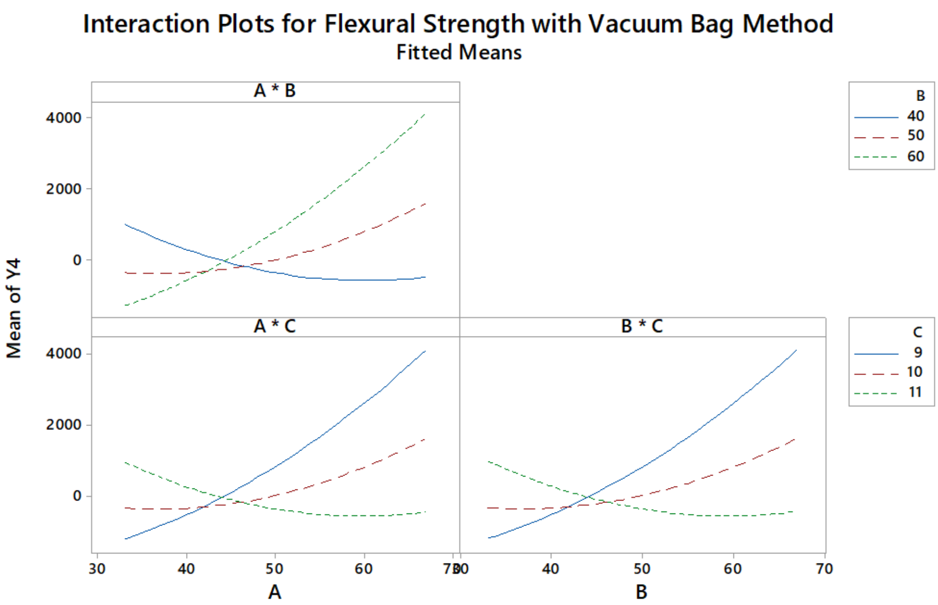


Figure 10. Two factors interaction effect of process conditions on the flexural strength with hand vacuum bag method.

Table 7. ANOVA summary of coded coefficient for hand lay-up method for tensile strength.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	45.48	2.19	20.80	0.000	
A	-19.09	2.65	-7.21	0.000	1.00
B	-8.43	2.65	-3.18	0.005	1.00

Table 8. ANOVA summary of coded coefficient for vacuum bag method for tensile strength.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	47.75	1.64	29.07	0.000	
A	-11.38	1.99	-5.73	0.000	1.00
C	-5.48	1.99	-2.75	0.014	1.00

model for this response was made as shown in Equation 2.

$$Y_1 = 183.1 - 1.909A - 0.843B \qquad (2)$$

Meanwhile, for the vacuum bag method, the tensile strength value was affected by OPEFB fibers and epoxy resin therefore, a mathematical model for this response was made as shown in Equation 3.

$$Y_3 = 159.4 - 1.138A - 5.48C \qquad (3)$$

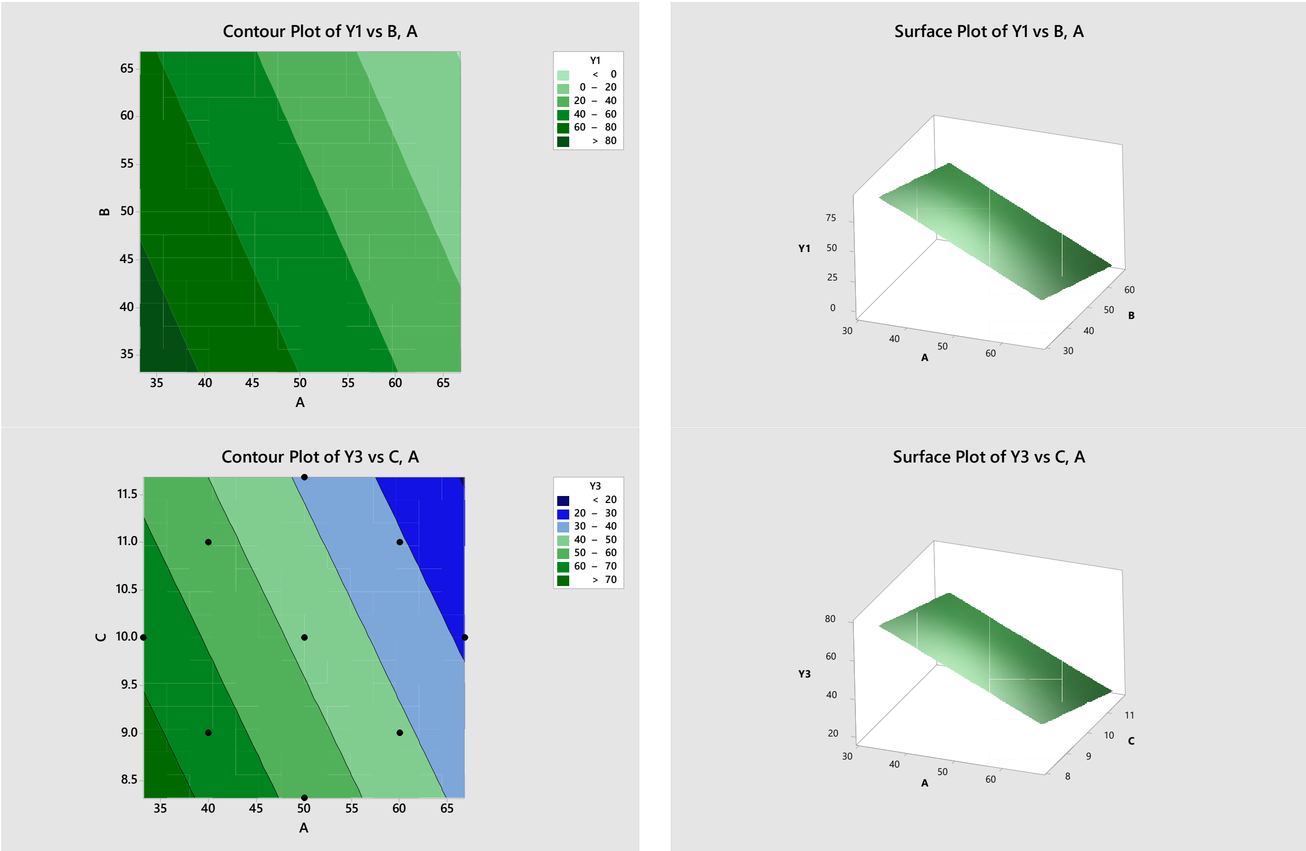
The plot of the response surface as a function of adding MNR and OPEFB volume fraction to tensile strength is presented in Figure 11. For the hand lay-up method, it was discovered that the tensile strength decreased with an increase in the volume fraction of OPEFB fibers and amount of MNR added. The maximum tensile strength i.e., 77.25 MPa was obtained at the fiber volume fraction OPEFB of 40%:60% E-glass, volume fraction of 40% epoxy resin and addition of 9% MNR. However, for the vacuum bag method, the highest tensile strength was 75.54 MPa produced at a volume fraction of 60% epoxy resin, with the addition of 9% of the same MNR.

In order to prove the effect of MNR addition, a composite tensile test was carried out with the ratio 40% OPEFB: 60% E-glass: 60% epoxy resin without the addition of MNR using the hand lay-up method and a tensile strength of 26.231.19MPa was obtained. Furthermore, it was seen that the addition of MNR to the hybrid composite had a significant effect on tensile strength. This was in accordance with the study carried out by Hariharan and Rozman et al. where the coupling agent maleic-anhydride-modified PP (Epolene, E-43) and 3-(trimethoxysilyl) -propylmethacrylate (TPM) provided a significant improvement in tensile properties [20].

3.3. Flexural Strength

The next characteristic tested was the flexural strength of the composite product. Tables 9 and 10 show a summary for each response for the hand lay-up and the vacuum bag method.

For the hand lay-up method, the variables which affected the model were A, AC, A^2 and C^2 having a small p-value of



(a) (b)

Figure 11. Effect of OPEFB and MNR on tensile strength, a) Hand lay-up method; b). vacuum bag method.

Table 9. summary of coded coefficient for hand lay-up method for flexural strength.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	61.79	4.11	15.05	0.000	
A	-24.87	3.21	-7.75	0.000	1.00
C	2.19	3.21	0.68	0.505	1.00
A*A	12.49	3.11	4.02	0.001	1.01
C*C	-13.24	3.11	-4.26	0.001	1.01
A*C	-11.77	4.19	-2.81	0.014	1.00

Table 10. ANOVA summary of coded coefficient for vacuum bag method for flexural strength.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	454	298	1.53	0.151	
A	576	360	1.60	0.134	1.00
B	576	360	1.60	0.134	1.00
C	-595	360	-1.65	0.123	1.00
A*B	1013	471	2.15	0.051	1.00
A*C	-987	471	-2.10	0.056	1.00
B*C	-993	471	-2.11	0.055	1.00

α = 5%. Therefore, the new equation stating the dependent variable Y was made, as shown in Equation 4.

$$Y_2 = -1436 - 3.21A + 325.9C + 0.1249A2 - 13.24C2 - 1.177AC \quad (4)$$

The variables AB, B^2 significantly affected the vacuum bag method therefore, new equation was made to express the dependent variation of Y, as show in Equation 5.

$$Y_4 = -73059 + 539A + 544B + 9307C + 10.13AB - 98.7AC - 99.3BC \quad (5)$$

Figure 12 shows a plot of the response surface as a function of MNR addition, OPEFB volume fraction and matrix volume fraction on flexural strength. For the hand lay-up method, it was discovered that the flexural strength value decreased with increasing EFB volume fraction and number of MNR. Furthermore, the highest flexural strength 147.45MPa was obtained at 33.18% OPEFB fiber volume fraction, 50% epoxy resin volume fraction and 10% MNR addition. Meanwhile, for the vacuum bag method, the highest flexural strength 80.57 MPa were obtained at 60% OPEFB fiber volume fraction, 60% epoxy resin volume fraction and 9% MNR addition.

In order to prove the effect of MNR addition on the flexural strength of composites, a composite flexural test was performed with the ratio 40% OPEFB:60% E-glass:60% epoxy resin without MNR addition by using the hand lay-up method. The result of the tensile strength obtained was 31,213.34 MPa. Furthermore, it was observed that the addition of MNR to the hybrid

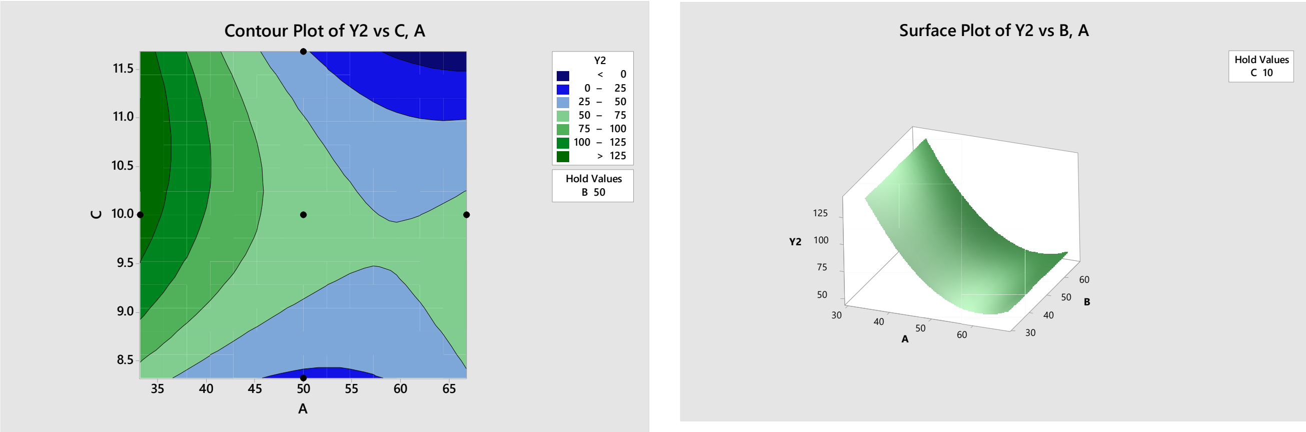


Figure 12. Effects of % OPEFB fiber and % MNR on flexural strength, a) Hand lay-up method, b). Vaccum bag method.

composites increased the flexural strength by 39%. However, the highest flexural strength value obtained from this study was far from the 163.3 MPa obtained by Karina et al. 2008 [21]. This was due to the composite making process carried out by Karina using a mold with a pressure of 7.4 MPa for 24 hours. Furthermore, another possibility was that the load distribution to the fibers was uneven, because not all fibers received loads uniformly. Therefore, the fiber could not withstand the stress transferred from the epoxy matrix well [22].

4. Conclusions

Hybrid composites were successfully produced from OPEFB and MNR fibers as coupling agents. The tensile strength response produced by hand lay-up and vacuum bag methods was significantly affected by the ratio of OPEFB fibers and epoxy resin composites, where the highest tensile value of 75.54 MPa was obtained at 9% variation in the number of MNR, the ratio of OPEFB fibers:E-glass 40:60 and 60% epoxy resin using the vacuum bag method. Conversely, the lowest tensile strength value was obtained at 16.21 MPa, using the hand lay-up method at 10% variation in the number of MNR, OPEFB fibers:E-glass 66.81% and 50% epoxy resin. Furthermore, the response of Flexural strength was closely related to the epoxy resin factor and the interaction of the epoxy-MNR resin, where the highest value was obtained using the hand lay-up method of 102.98 MPa at 11% MNR, 40:60 ratio of OPEFB:E-glass fiber and 40%epoxy resin. Conversely, the lowest flexural value was obtained at 14.91 MPa, using the vacuum bag method, which was carried out with an MNR of 9%, 40:60 of OPEFB: E-glass fibers and 40% epoxy resin.

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References

1. Mallick, P. K. (2007). *Fiber-Reinforced Composites: Materials, Manufacturing, and Design*, CRC press.
2. Sathishkumar, T., Satheeshkumar, S., and Naveen, J. (2014). Glass fiber-reinforced polymer composites – a review, *Journal of Reinforced Plastics and Composites*, Vol. 33, No. 13, 1258–1275. doi:10.1177/0731684414530790.
3. Joshi, S. ., Drzal, L. ., Mohanty, A. ., and Arora, S. (2004). Are natural fiber composites environmentally superior to glass fiber reinforced composites?, *Composites Part A: Applied Science and Manufacturing*, Vol. 35, No. 3, 371–376. doi:10.1016/j.compositesa.2003.09.016.
4. Amraini, S. Z., Nazaris, N. N., Andrio, D., Mardhiansyah, M., and Helwani, Z. (2023). Utilization of Empty Palm Fruit Bunches as a Carbon Source for Cellulase Production to Reduce Solid Waste from Palm Oil, *Leuser Journal of Environmental Studies*, Vol. 1, No. 1, 34–38. doi:10.60084/ljes.v1i1.41.
5. Helwani, Z., Amraini, S. Z., Asmura, J., Siregar, T. N., Triwahyuni, V. E., and Abd, A. A. (2023). Palm Frond Waste as a Carbon Source in the Synthesis of CaO/Biochar Catalysts for the Biodiesel Production Process, *Heca Journal of Applied Sciences*, Vol. 1, No. 1, 8–13. doi:https://doi.org/10.60084/hjas.v1i1.9.
6. Amraini, S. Z., Sari, S., Andrio, D., Fatra, W., and Susanto, R. (2023). Optimizing Raw Material Pre-Treatment for Bioethanol Production from Empty Fruit Bunches: A Comparative Study, *Grimsa Journal of Science Engineering and Technology*, Vol. 1, No. 1, 17–23.
7. Mohammed, L., Ansari, M. N. M., Pua, G., Jawaid, M., and Islam, M. S. (2015). A Review on Natural Fiber Reinforced Polymer Composite and Its Applications, *International Journal of Polymer Science*, Vol. 2015, 1–15. doi:10.1155/2015/243947.

8. Mishra, S., Mohanty, A. ., Drzal, L. ., Misra, M., Parija, S., Nayak, S. K., and Tripathy, S. S. (2003). Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites, *Composites Science and Technology*, Vol. 63, No. 10, 1377–1385. doi:10.1016/S0266-3538(03)00084-8.

9. Badan Pusat Statistik Provinsi Riau. (2019). Luas Areal Tanaman Perkebunan (Hektar), 2020-2022, from https://riau.bps.go.id/indicator/54/217/1/luas-areal-tanaman-perkebunan.html.

10. Ministry of Agriculture. (2019). Tree Crop Estate Statistics of Indonesia 2018-2020, from https://ditjenbun.pertanian.go.id/.

11. Idroes, G. M., Syahnur, S., Majid, M. S. A., Idroes, R., Kusumo, F., and Hardi, I. (2023). Unveiling the Carbon Footprint: Biomass vs. Geothermal Energy in Indonesia, *Ekonomikalia Journal of Economics*, Vol. 1, No. 1, 10–18. doi:10.60084/eje.v1i1.47.

12. Zuhri, M. Y. M., Sapuan, S. M., and Ismail, N. (2009). Oil Palm Fibre Reinforced Polymer Composites: A Review, *Progress in Rubber, Plastics and Recycling Technology*, Vol. 25, No. 4, 233–246. doi:10.1177/147776060902500403.

13. Jawaid, M., and Abdul Khalil, H. P. S. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review, *Carbohydrate Polymers*, Vol. 86, No. 1, 1–18. doi:10.1016/j.carbpol.2011.04.043.

14. Li, X., Tabil, L. G., and Panigrahi, S. (2007). Chemical Treatments of Natural Fiber for Use in Natural Fiber-Reinforced Composites: A Review, *Journal of Polymers and the Environment*, Vol. 15, No. 1, 25–33. doi:10.1007/s10924-006-0042-3.

15. Raju, G., Ratnam, C. T., Ibrahim, N. A., Rahman, M. Z. A., and Yunus, W. M. Z. W. (2008). Enhancement of PVC/ENR blend properties by poly(methyl acrylate) grafted oil palm empty fruit bunch fiber, *Journal of Applied Polymer Science*, Vol. 110, No. 1, 368–375. doi:10.1002/app.28662.

16. Machado, A. V., van Duin, M., and Covas, J. A. (2000). Monitoring polyolefin modification along the axis of a twin-screw extruder. II. Maleic anhydride grafting, *Journal of Polymer Science Part A: Polymer Chemistry*, Vol. 38, No. 21, 3919–3932. doi:10.1002/1099-0518(20001101)38:21<3919::AID-POLA90>3.0.CO;2-L.

17. Fatra, W., Rouhillahi, H., Helwani, Z., and Asmura, J. (2016). Effect of Alkaline Treatment on the Properties of Oil Palm Empty Fruit Bunch Fiber-reinforced Polypropylene Composite, *International Journal of Technology*, Vol. 7, No. 6.

18. Wati, R., and Irdoni, H. S. (n.d.). Modifikasi Karet Alam menjadi Maleated Natural Rubber melalui Proses Grafting dengan Variasi Kadar Maleat Anhidrida dan Temperatur, *Jurnal Teknobiologi*, Vol. 3, No. 2.

19. Nisah, K., Fahrina, A., Rizki, D. R., and Puspita, K. (2023). Optimization of Starch—κ-Carrageenan Hybrid Film as Drug Delivery System using Response Surface Method, *Heca Journal of Applied Sciences*, Vol. 1, No. 1, 19–23. doi:https://doi.org/10.60084/hjas.v1i1.10.

20. Rozman, H. D., Tay, G. S., Kumar, R. N., Abusamah, A., Ismail, H., and Mohd. Ishak, Z. A. (2001). Polypropylene-oil palm empty fruit bunch-glass fibre hybrid composites: A preliminary study on the flexural and tensile properties, *European Polymer Journal*, Vol. 37, No. 6, 1283–1291. doi:10.1016/S0014-3057(00)00243-3.

21. Karina, M., Onggo, H., Abdullah, A. H. D., and Syampurwadi, A. (2008). Effect of oil palm empty fruit bunch fiber on the physical and mechanical properties of fiber glass reinforced polyester resin, *Journal of Biological Sciences*, Vol. 8, No. 1, 101–106.

22. Oksman, K., Wallström, L., Berglund, L. A., and Filho, R. D. T. (2002). Morphology and mechanical properties of unidirectional sisal– epoxy composites, *Journal of Applied Polymer Science*, Vol. 84, No. 13, 2358–2365. doi:10.1002/app.10475.