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Effect Of Morphology And Percentage Of Second Phase Content Of Coconut Coir On The Impact Strength Of Epoxy Resin Composites

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Abstract

The morphology of the second phase used as reinforcement in the composite material can be in the form of particles (powder), short fibers, or charcoal ash which affects the mechanical properties of the composite material. There have been many studies conducted on the mechanical properties of composite materials. However, it is still rare to present research results in the form of a regression model. This study was intended to examine the effect of the percentage of second phase content on the epoxy resin matrix composite that was displayed by the regression model for different morphology. From this study, it was found that the content of coconut coir in the resin matrix composite material was proven increased the impact strength 200% to 400% compared to pure resin. The percentage content (x) of the second phase has been shown to affect the impact strength (Y) of the specimen for every second phase morphology, which are expressed in the regression models. The regression model for short fiber is: Y=0.0969x3-1.2367x2+4.8216x+1.3705, for charcoal ash is: Y=0.14789x3-1.6467x2+5.1311x+1.3705, and coconut coir powder is: Y=0.0757x3- 0 .9789x2+3.7955x+1.3705. The most optimum specimen in this study was a specimen with a second phase of 4 wt.% short fiber.

Keywords: Morphology, the second phase, impact strength, epoxy resin

Introduction

The use of composite materials as a substitute for metal materials is increasingly widespread. Along with these developments, it is necessary to improve the mechanical properties of composite materials, considering that their use is widespread in load-bearing structural materials. The use of charcoal composite materials also for structural materials that withstand various types of loading on automotive components [1], ship components, or even aircraft components [2]. Types of loads on structural materials can be static loads, dynamic (fluctuating) loads, or shock loads, where the assessment of the material's ability to withstand these loads can be carried out in the laboratory by testing its mechanical properties. The ability of the material to static loads is usually done by testing the tensile strength of the material. To determine the ability of a material to withstand dynamic loads, it is carried out by using a fatigue test, while to determine the ability of the material to impact load, it is carried out by an impact test.

Therefore studies related to the mechanical properties of composite materials have been widely studied by researchers around the world, such as an investigation related to mechanical performance of matrix natural fiber composites [3], study on the structure and performance of composite polylactic reinforced with oil palm empty fruit bunches with alkaline and ultrasonic treatments has also [4], investigation on the mechanical, damping, and chemical resistance properties of banana fiber hybrid composites [5], and investigation on the mechanical performance and resistance of castings reinforced with treated fibers [6]. Other researchers, a study on the mechanical properties of natural fiber-reinforced composites for engineering applications [7]. A study on the Effect of percentage of oil Palm Fiber on fatigue cycle of Axial Load on Resin Matrix Composites also has been conducted [8].

Composite materials whose utilization has recently increased sharply and dramatically are mainly polymer matrices. This is because the polymer has its own advantages despite its disadvantages. The second phase (reinforce) which is currently being widely studied by world researchers is from natural fiber materials. It is said that natural fiber comes from natural materials which are usually not used or underutilized and even tend to become waste. Among them are palm fiber, coconut coir fiber, water hyacinth fiber, oil palm fiber, and so on. By utilizing these natural fibers as reinforcement in composite materials, it will not only increase income but also reduce organic waste, so that the environment will be cleaner.

Coconut coir is one type of natural fiber that is underutilized so it tends to become waste. Even though its availability is abundant due to the use of coconut for various needs of the community every day and continuously, especially for cooking needs.

In rural areas, coconut coir waste may not be a problem, because some rural people use it for various purposes such as making brooms, cooking as a substitute for firewood, and so on. However, in urban communities, this coconut coir is almost of no use. So that this coconut fiber becomes one of the sources of waste problems in big cities. Therefore, it is urgent to develop efforts to expand the use of coconut coir as reinforcement for composite materials, to assist the government in reducing the volume of waste, especially in urban areas.

From the results of research conducted by several researchers, many factors affect the mechanical properties of composite materials. The effect of coconut coir fiber powder content and hardener weight fractions on mechanical properties of an epr-174 epoxy resin composite has been investigated [9]. From the results of these studies it is found that pure resin has the lowest impact strength of 1.37 kJ/m^2 . The fiber content of 6 wt.% powder produces the highest impact strength, which is 4.92 kJ/m^2. Meanwhile, the ratio of the best resin and hardener composition, which produces the highest impact strength of 4.55kJ/m^2 is 1:1, which mean 50% resin and 50% hardener. The content of fiber powder that produces the highest shear strength of 1 MPa is 8%[9].

There were many studies have been carried out by researchers to improve the mechanical properties of composite materials. Among them, a study of using the alkali treatment of oil palm empty fruit bunches [10][11], and also henequen fibers [12] have been conducted. From those studies, different results have been obtained. Alkali treatment of certain fibers can improve their mechanical properties significantly, but on the other fibers, the effect is not significant, or even reduce the mechanical properties of the composite material. It can be concluded that the effect of the alkali treatment on the fiber during manufacturing the composite materials on each type of fiber is different.

The above studies have not examined the effect of second phase morphology on the mechanical properties of resin composite materials. There are several types of the morphology of the second phase used as reinforcement in composite materials, i.e.: particle form, short fiber form continuous fiber form and so on [13].

Composites that are reinforced with natural fibers are likely to be influenced by the shape (morphology) of the second phase even though the second phase comes from the same material because when the morphology of the fibers has changed, the adhesion to the matrix will be different. Apart from that, the morphology of the second phase also affects the stress concentration that occurs. The second phase, which is spherical, has almost no stress concentration on its surface. On the other hand, in the second phase, which has a sharp surface, there will be a stress concentration on the sharp part. These will all result in internal residual stresses. The residual stress on the material within a certain limit will result in the material becoming stronger. but if the residual stress is too high, it will result in the material becoming more brittle as a result of which it breaks easily. For this reason, it is necessary to study the morphological form and the percentage of the second phase (coconut coir) which has the most optimum mechanical properties.

Utilization of composite materials for structural materials

Among the types of loading experienced by the structural material in terms of its loading rate, among others, static load, dynamic load, shock load (impact), They could be compressive or sliding.

For the metallic materials, the nature of the load (tensile, compressive, and shear) may have almost no effect on the failure of the material, because metallic materials are relatively homogeneous. However, in composite materials, due to the presence of the second phase as a reinforcement, the effect of load properties on material failure can be very different. This could be due to either the influence of the size, or the concentration or the morphology (shape) of the second phase.

Mechanical Properties of Composite Materials

Tests that are included in the category of destructive testing in the laboratory can determine the mechanical properties of the composite material by testing the response of the material to a given loading. The categories for the classification of damaging tests on polymer materials [14] are as follows:

1. Classification based on the rate of testing: Static, Quasi-Static, and dynamic.
2. Classification based on the type of load:

a. Compressive tension, bending, torsion, and shear loads.

b. Uniaxial, biaxial and multiaxial loads.

3. Type of material studied: Polymer and fiber composite materials.
4. Types of physical properties: thermal, optical, and electrical.

Impact testing, as well as fatigue testing, fall under the classification of dynamic load testing. Many studies have been carried out on composite materials related to the impact strength of the material, including research on the effect of fiber content on the mechanical properties of composite materials [15][16]. This study found that, when the fiber content is too low, the composite material will not improve the mechanical properties of the material.

The fiber length of the composite material also affects the mechanical properties of the resulting composite material. If the fiber length is too short, the fiber does not function as reinforcement, but only as a filler [17].

Research on the mechanical properties of materials, especially the impact strength of composite materials, was also carried out who researched the impact strength of coconut fiber reinforced resin composite materials to then create a regression model from the results of this study [18]. However, this study has not examined the morphological effect of coconut coir fibers.

The purpose of this study was to obtain the impact strength value of the fiber-reinforced epoxy resin composite material with different coconut coir morphological shapes, to determine the effect of morphology and the percentage of the second phase content on the impact strength, and also to determine the morphological shape and the percentage content of the second phase (coconut coir) which has the most optimum mechanical properties.

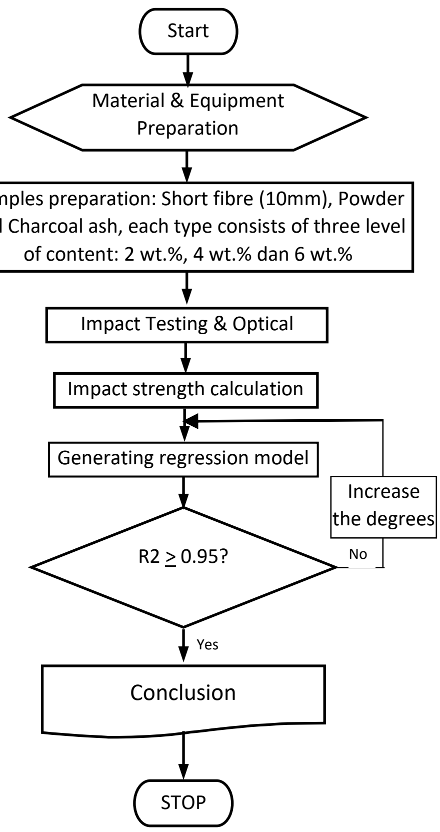
In this study, Epoxy resin type EPR174 and hardener V-140 were used as the matrix. The morphology of the second phase (coconut coir) used is in the form of fiber (10mm length), particles (powder) coconut fiber, and ash from coconut coir charcoal, the percentage content of the second phase consists of 3 levels, i.e.: 2 wt.%, 4 wt.%, and 6 wt.%. From the test results, the regression models were generated which is the relationship between the content of the second phase and the resulting impact strength for each morphology. Then the optimum morphology and percentage of the content of the second phase was determined, which had the highest impact strength.

Materials and Methods

Review Stage

The flow of the implementation of this research is as shown by the flow diagram in Figure 1.

Figure 2: Research Flowchart



The research began with the preparation of tools and materials for specimens preparation. Then proceed with the impact test and OM (Optical Microscopy). The Impact test results were used to calculate the impact strength of the specimen and then analyzed for generating the impact strength regression model. The variable in the regression model is the weight percentage of each morphology of the second phase.

Then it was determined what percentage of the optimum weight content of the second phase for each type of morphology, and also determined which morphology of the second phase (coconut coir) had the highest average impact strength

Specimen Preparation

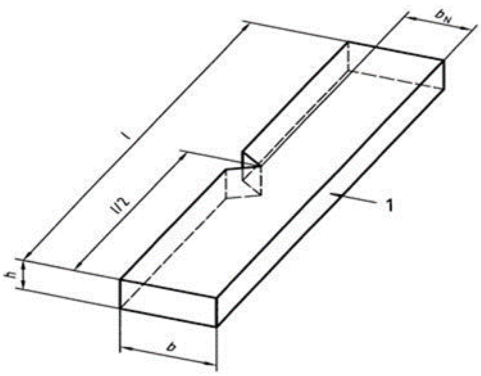
Coconut coir is washed with water, then dried under the sun until it is completely dry. Then the clean coconut coir are divided into 3 groups. The first group of fibers is cut into 10mm lengths. The second group of fiber is crushed in a blender so that it becomes a powder. Then the third group of fibers is burned to ashes.

Specimen manufacturing is carried out to obtain specimen sizes according to ISO 179-1: 2000 standards. There are 2 factors studied, namely the form of the second phase which consists of 3 levels of fiber, particles, and ash, and the content of each second phase which consists of 3 levels as follows:

1. Fiber (10mm long) with a percentage content of 2 wt.%, 4 wt.%, and 6 wt.%.
2. Particles (powder) of coconut coir with a porosity of content of 2 wt.%, 4 wt.%, and 6 wt.%.
3. Particles of coconut coir charcoal ash with a percentage content of 2 wt.%, 4 wt.%, and 6 wt.%.

The study was designed to use the full factorial design method, therefore the number of sample type combinations that must be prepared is: 3 X 3 = 9 type combinations. Each type was made of 5 samples. So that the total number of samples is 45 samples.

Figure 2: Dimensions of the Charpy impact specimen according to ISO 179 standard, type no.1 type B notch [19].



Based on the ISO 179 standard, the shape of the Charpy impact test specimen is as shown in Figure 2. This study used Type number 1, notch (notch) B [19]. Furthermore, the specimens were made with the following procedure:

The resin is poured into a mold and then mixed with coconut coir according to the size and content that has been determined. The mixture is stirred to ensure that the fibers are evenly distributed throughout the mold, then add Hardener according to the instructions on the material and stir until evenly, then poured into the mold and allowed to harden the material, then removed from the mold with specimen size according to ISO 179-1: 2000 standard.

Testing and Characterization

The specimen impact testing is carried out using an impact test tool specifically for polymer and composite materials at the Mechanical Engineering Laboratory of the University of Mercu Buana. Likewise, OM observation also be carried out using the OM tool in the Mechanical Engineering Lab at Mercu Buana University.

The result of the impact test is the impact energy of each specimen. This data is then used to calculate the impact strength of each specimen and the average impact strength for each condition. Furthermore, the test results are displayed in graphical form and then analyzed using SPSS to obtain a regression model for the relationship between phase morphology and the percentage content of the second phase to the impact strength of the specimen.

The regression model is a model in the form of a mathematical equation obtained from the results of research data processing. This model consists of independent variables and dependent variables. With this model, it is possible to simulate the value of the independent variable to get the value of a certain dependent variable. In this study, the independent variable is the percentage weight of the content of the second phase for each morphology of the second phase, while the dependent variable is the impact strength. So by using a regression model it can be simulated how much fiber content must be made to get a certain value of the impact strength of the composite material for each of the second phase morphology.

Results and Discussion

Specimens preparation were carried out to obtain specimen sizes according to ISO 179-1: 2000 standards for impact testing. The results of making specimens are as follows:

Figure 3 Impact test specimen.

As mentioned before, the study was designed to use the full factorial design method, where the number of samples combinations prepared were: 3 X 3 = 9 combination types. Each type/condition was made of 5 samples. So that the total number of samples is 45 samples for the impact test.

Impact Testing and The Impact strength

From the results of the Charpy impact test, the impact energy value of each sample is obtained which is then used to calculate the impact strength of each sample. then the average impact strength is made for each condition. As a comparison, the impact test and the calculation of the impact strength were also carried out for pure resin. A summary of the results of the impact test and The Impact strength are shown in Table 1

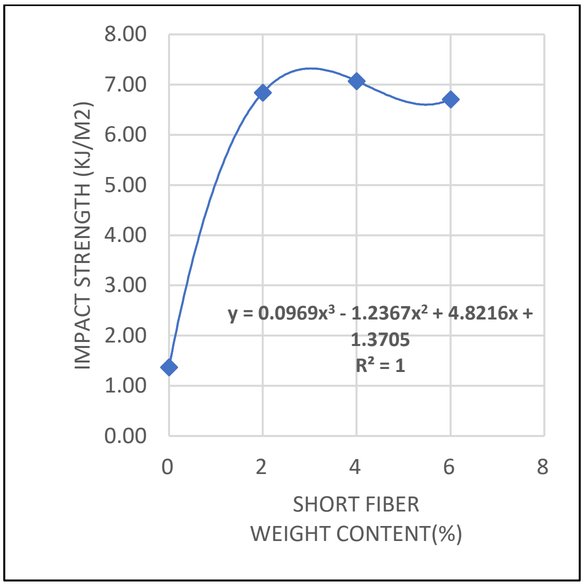
Table 1 Recapitulation of Impact testing results

No	Sample code	Second phase morphology	Content (%)	Impact Energy (J)	Impact Strength (kJ/m²)
1	SF2	Short Fiber	2	0.28	6.4
2	SF4		4	0.27	**7.07**
3	SF6		6	0.26	6.71
4	AB2	Charcoal Ash	2	0.25	**6.22**
5	AB4		4	0.20	4.96
6	AB6		6	0.19	4.65
7	PD2	Powder	2	0.22	5.65
8	PD4		4	0.23	**5.74**
9	PD6		6	0.21	5.26
10	**Pure Resin**	-	0	0.06	1.37

From Table 1, it can be seen that the impact strength of the material reinforced with coconut coir short fibers, coconut coir charcoal ash, and also coconut coir powder dramatically increases its impact strength above 200% to 500% compared to pure resin. Which for composite materials the impact strength varies from 4.65 kJ/m^2 to 7.07 kJ/m^2. While the impact strength of pure resin was only 1.37 kJ/m^2. The highest impact strength value was obtained from the second phase sample in the form of short fibers with a content of 4 wt.%, which was 7.07 kJ/m^2. Overall, short fibers have the highest impact strength, which is above 6.4 kJ/m^2 when compared to the second phase in the form of coir charcoal ash, where the impact strength is below 5. While the impact strength of the powder is relatively stable, all on average between 5 kJ/m^2 and 6 kJ/m^2.

Furthermore, from data table 1 using Microsoft Excel graphs and 3rd order polynomial regression models for each second phase morphology complete with the coefficient of determination (R^2) as shown in Figures 4, 5, and 6. The consideration of using polynomial order 3 is due to the regression model. This order 3 polynomial is the most accurate proven coefficient of determination 1. Previously, I was tried linear regression and second-order polynomial regression but the efficiency of determination was very low, only ranging from 0.3 to 0.8. Therefore, it was decided to use polynomial regression of order 3.

Figure 4 the impact strength regression model for the second phase in the form of coconut coir short fibers



From Figure 4, it appears that the regression model for the morphology of the second phase in the form of short fibers is:

$$Y = 0.0969x^3 - 1.2367x^2 + 4.8216x + 1.3705 \quad (1)$$

Where: y = impact strength (kJ/m^2)

x = percentage of content (%)

The coefficient of determination (R^2) of the regression model is = 1. This indicates that the percentage of short fiber content 100% affects the impact strength of the resulting composite material. Or in other words, the variation in the percentage of short fiber content in the composite material in this research is 100% able to explain variations in impact strength.

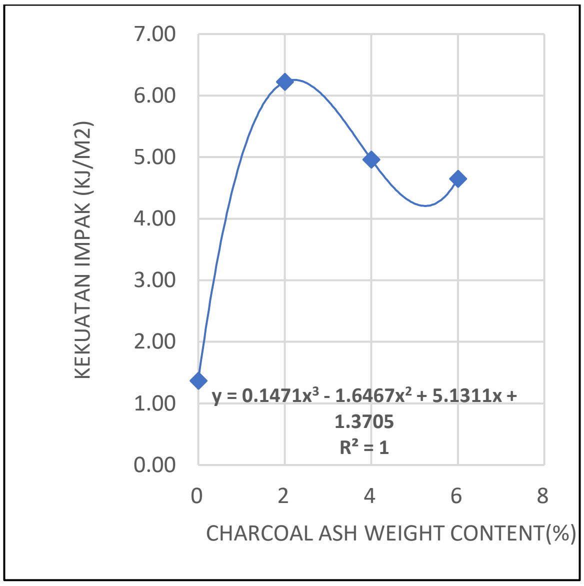
From Figure 5 it appears that the regression model for the second phase morphology in the form of coconut coir charcoal ash is:

$$Y = 0.1471x^3 - 1.6467x^2 + 5.1311x + 1.3705 \quad (2)$$

Where: y = impact strength (kJ/m^2)

x = percentage of content (%)

Figure 5 the impact strength regression model for the second phase in the form of coconut coir charcoal ash.



The coefficient of determination (R^2) of the regression model is = 1. This indicates that the percentage of coconut coir charcoal ash content 100% affects the impact strength of the resulting composite material. Or in other words, the variation in the percentage of coconut coir charcoal ash content in the composite material in this study is 100% able to explain variations in impact strength.

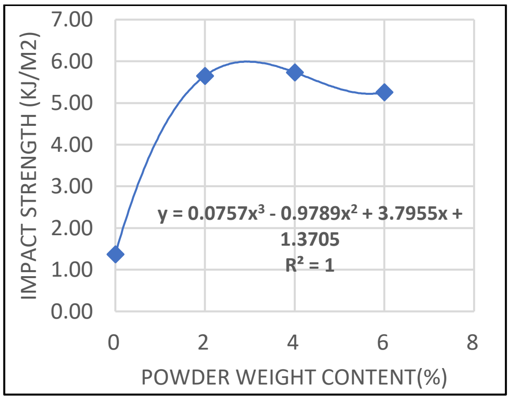
The regression model for the impact strength for the second phase in the form of coconut coir powder is shown in Figure 6. From Figure 6 it can be seen that the regression model for the second phase morphology in the form of coconut coir powder is:

$$Y = 0.0757x^3 - 0.9789x^2 + 3.7955x + 1.3705 \qquad (3)$$

Where: y = impact strength (kJ/m2)

x = percentage of content (%)

Figure 6 The regression model for the impact strength for the second phase in the form of coconut coir powder.



The coefficient of determination (R^2) of the regression model is = 1. This indicates that the percentage of coconut coir powder content 100% affects the impact strength of the resulting composite material. Or in other words, the variation in the percentage of coir powder content in the composite material in this study is 100% able to explain variations in impact strength.

For further ensure the validity of the regression model, it will be tested manually by comparing the material impact strength calculated using the regression models (1), (2), and (3) with the impact strength of the test results. The results of this validity test are shown in Table 2.

Table 2 Test the validity of the regression model

No	Sample code	Content (%)	Impact Energy (J)	Impact Strength (kJ/m^2) (Experiment)	Impact Strength (kJ/m^2) (regression)	Deviation
1	SF2	2	0.28	6.4	6.4	**0.00**
2	SF4	4	0.27	7.07	7.07	0.00
3	SF6	6	0.26	6.71	6.71	0.00
4	AB2	2	0.25	6.22	6.22	0.00
5	AB4	4	0.20	4.96	4.96	0.00
6	AB6	6	0.19	**4.65**	**4.63**	**0.02**
7	PD2	2	0.22	5.65	5.65	0.00
8	PD4	4	0.23	**5.74**	**5.73**	**0.01**
9	PD6	6	0.21	**5.26**	**5.25**	**0.01**
10	**Pure Resin**	0	0.06	1.37	1.37	0.00

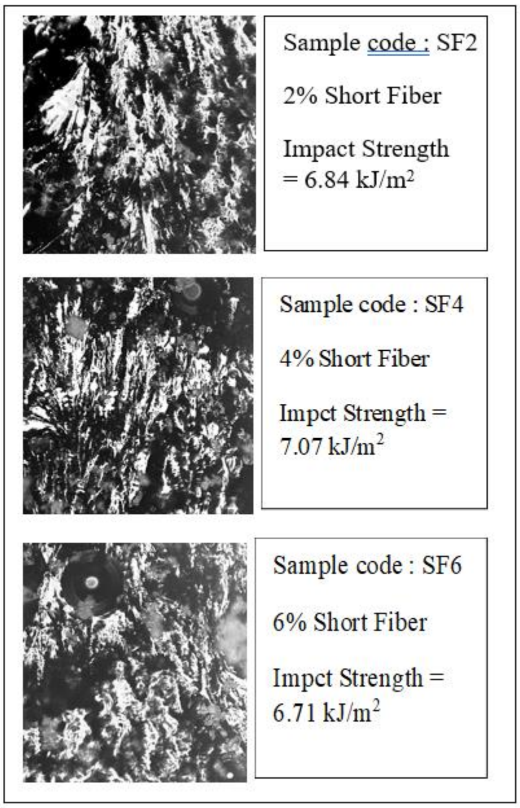
From table 2 it appears that almost all the points tested are the same between the impact strength of the test results and the impact strength of the results calculated using the regression model, there are only 3 points where the difference is very small, namely 0.01 and 0.02. With so clearly it is clear that the regression model generated from this study is truly valid.

Furthermore, the fracture morphology of the impact test specimens was also observed using optical microscopy (OM). The results of these observations are shown in Figure 7 an increase of more than 200%. However, too high a fiber content also does not result in higher impact strength. A proven sample that has impact strength. the highest is the fiber content of 2 wt.% compared to 4 wt.% and 6 wt.%.

Figure 7 shows the fracture surface of 3 samples of specimens containing 2 wt.% (SF2), 4 wt.% (SF4, and 6 wt.% (SF6) samples. The highest impact strength was obtained in specimens with 4 wt.% fiber content, which was the impact strength of this specimen is also the highest compared to all specimens in this study.

When viewed from the figure, it appears that on the fracture surface of the SF4 specimen with a fiber content of 4 wt.%, the fibers are evenly distributed, so that the bond between the fibers and the matrix is also uniform, resulting in high impact strength. When compared with the surface of the SF2 specimen with 2 wt.% fiber content, it appears that certain parts of the fracture surface are less fibrous so that the impact strength is lower than that of the SF4 specimen.

Figure 7 The fracture surface morphology of the impact test specimen of the composite resin material with the second phase in the form of coconut coir short fibers which function as reinforcement. Observations were made using Optical Microscopy with a magnification of 100x.



Likewise specimen SF6 with 6 wt.% fiber content, it appears that the fiber distribution is not evenly distributed. This is not due to the uneven distribution of the fibers, but it could be because the fiber content has exceeded the limit so that some fibers lack a matrix and gather in certain parts of the specimen. As a result, the fiber lacks a matrix, so that the bond between the fibers and the matrix is less than perfect. As a result, the impact strength of the SF6 specimen is lower than that of the SF4 specimen.

Figure 8 shows the fracture surface of 3 sample specimens that contain coconut coir charcoal ash content of 2 wt.% (code AB2), 4 wt.% (code AB4, and 6 wt.% (code AB6). The highest impact strength was obtained in specimens with a fiber content of 2 wt.%, namely amounting to 6.22 kJ/m2 where the impact strength of this specimen is almost equal to the specimen with the second phase in the form of short fibers. However, for higher content AB4 (4 wt.%) and AB6 (6 wt.%), the impact strength fell by more than 20% to 4, 96 kJ/m2 and 4.65 kJ/m2.

Actually, the bond between the charcoal ash and the matrix can produce a high impact strength, but it seems that because the solubility limit of coconut coir charcoal ash in the resin matrix is low, so even the 2 wt.% content is already excess as a result of the accumulation of charcoal ash in several places in the specimen. Therefore, for specimens containing 4 wt.% (AB4) and 6 wt.% (AB6), the impact strength is lower, because the accumulation of charcoal occurs more

Figure 8 The fracture surface morphology of the impact test specimen of the composite resin material with the second phase in the form of coconut coir charcoal ash which serves as reinforcement. Observations were made using Optical Microscopy with a magnification of 100x

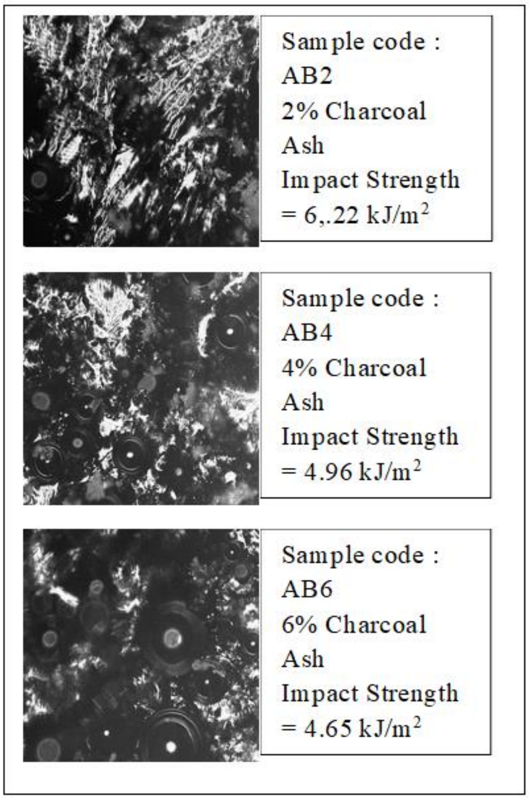
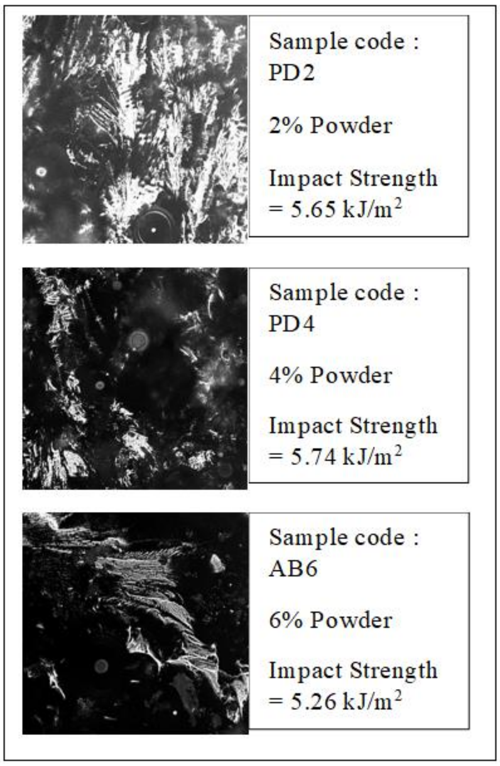


Figure 9 shows the fracture surface of 3 specimen samples containing coconut coir powder of 2 wt.% (PD2 code), 4 wt.% (PD4 code, and 6 wt.% (PD6 code). The highest impact strength was obtained in specimens with 4 wt.% fiber content.

When viewed from the figure, it appears that on the fracture surface of the PD4 specimen with 4 wt.% fiber content, the powder is evenly distributed, so that the bond between the fibers and the matrix is evenly distributed, resulting in high impact strength. When compared with the surface of the PD2 specimen with 2 wt.% fiber content, it appears that certain parts of the fracture surface are less fibrous so that the impact strength is lower than that of the PD4 specimen.

Likewise, the PD6 specimen with 6 wt.% fiber content, it appears as if the fiber distribution is not evenly distributed. This is not due to the uneven distribution of the fibers, but it could be because the fiber content has exceeded the limit so that some fibers lack a matrix and gather in certain parts of the specimen. As a result, the fiber lacks a matrix, so the bond between the fiber and the matrix is less than perfect. As a result, the impact strength of the PD6 specimen is lower than that of the PD4 specimen.

Figure 9 The fracture surface morphology of the impact test specimen of the composite resin material with the second phase in the form of coconut coir powder which serves as reinforcement. Observations were made using Optical Microscopy with a magnification of 100x



Conclusion

The conclusions obtained from this study are:

1. The content of coconut fiber in the resin matrix composite material in the form of short fibers, charcoal ash, and coconut coir powder has been shown to increase its impact strength compared to pure resin between 200% to 400%, from 1.37 kJ/m^2 to 4.65 kJ/m^2 to 7.07 kJ/m^2.
2. Morphology The second phase is proven to affect the impact strength of the specimens in this study. The best morphology is short fiber, followed by fiber powder and coconut coir charcoal ash, respectively.
3. The percentage content of the second phase also has a strong effect on the impact strength of the composite material. In this study, the effect of the weight content percentage of the second phase is expressed in the regression model, where x is the percentage of content, while Y is the impact strength, then the regression model is as follows:

a. The second phase is in the form of short fibers:

$$Y = 0.0969x^3 - 1.2367x^2 + 4.8216x + 1.3705$$

b. The second phase is coconut coir charcoal ash:

$$Y = 0.1471x^3 - 1.6467x^2 + 5.1311x + 1.3705$$

c. The second phase is in the form of coconut coir powder:

$$Y = 0.0757x^3 - 0.9789x^2 + 3.7955x + 1.3705$$

The most optimum specimen in this study is the specimen with the second phase in the form of short fibers with a percentage content of 4 wt.%.

REFERENCES

M. Fitri, S. Mahzan, and F. Anggara, "The Mechanical Properties Requirement for Polymer Composite Automotive Parts - A Review," Int. J. Adv. Technol. Mech. Mechatronics Mater., vol. 1, no. 3, pp. 125–133, 2021, doi: 10.37869/ijatec.v1i3.38.

D. Gay, Composite Materials Design and Applications, Third Edit. Boca Raton: CRC Press, 2015.

R. Joffe and J. Andersons, "Mechanical Performance of Thermoplastic Matrix Natural Fibre Composites," in Properties and Performance of Natural Fibre Composites, Boca Raton: Woodhead Publishing Limited, 2008, pp. 402–459.

A. K. M. M. Alam, M. D. H. Beg, D. M. R. Prasad, M. R. Khan, and M. F. Mina, "Composites : Part A Structures and performances of simultaneous ultrasound and alkali treated oil palm empty fruit bunch fiber reinforced poly (lactic acid) composites," Compos. PART A, vol. 43, no. 11, pp. 1921–1929, 2012, doi: 10.1016/j.compositesa.2012.06.012.

V. Arumuga, M. Uthayakumar, V. Manikandan, N. Rajini, and P. Jeyaraj, "Influence of redmud on the mechanical , damping and chemical resistance properties of banana / polyester hybrid composites," Mater. Des., vol. 64, pp. 270–279, 2014, doi: 10.1016/j.matdes.2014.07.020.

N. Gozde, B. Ahsan, S. Mansour, and S. R. Iyengar, "Mechanical performance and durability of treated palm fiber reinforced mortars," Int. J. Sustain. Built Environ., vol. 2, no. 2, pp. 131–142, 2014, doi: 10.1016/j.ijsbe.2014.04.002.

T. Adekanye, O. D. Samuel, S. Agbo, and T. A. Adekanye, "Assessing Mechanical Properties of Natural Fibre Reinforced Composites for Engineering Applications," J. Miner. Mater. Charact. Eng., no. January 2012, pp. 780–784, 2015.

Nurato and M. Fitri, "Pengaruh Prosentase Serat Kelapa Sawit Terhadap Umur Fatik Beban Aksial Komposit Matriks Resin," Rotasi, vol. 21, no. 4, p. 215, 2019, doi: 10.14710/rotasi.21.4.215-223.

M. Fitri, S. Mahzan, and I. Hidayat, "THE EFFECT OF COCONUT COIR FIBER POWDER CONTENT AND HARDENER WEIGHT FRACTIONS ON MECHANICAL PROPERTIES OF AN EPR-174 EPOXY RESIN COMPOSITE," Sinergi, vol. 25, no. 3, pp. 361–370, 2021.

M. Fitri and S. Mahzan, "The effect of fibre content, fibre size and alkali treatment to Charpy impact resistance of Oil Palm fibre reinforced composite material," IOP Conf. Ser. Mater. Sci. Eng., vol. 160, no. 1, pp. 0–12, 2016, doi: 10.1088/1757-899X/160/1/012030.

M. A. N. Izani, M. T. Paridah, U. M. K. Anwar, M. Y. M. Nor, and P. S. H'ng, "Effects of fiber treatment on morphology , tensile and thermogravimetric analysis of oil palm empty fruit bunches fibers," vol. 45, pp. 1251–1257, 2013, doi: 10.1016/j.compositesb.2012.07.027.

A. May-pat, A. Valadez-gonzález, and P. J. Herrera-franco, “Effect of fi ber surface treatments on the essential work of fracture of HDPE-continuous henequen fi ber-reinforced composites,” Polym. Test., vol. 32, no. 6, pp. 1114–1122, 2013, doi: 10.1016/j.polymertesting.2013.06.006.

W. D. J. Callister and D. G. Rethwisch, Fundamentals of materials science and engineering, Seventh. New York: John Wiley & Sons, Inc., 2007.

W. Grellmann, S. Seidler, and P. I. Anderson, Polymer testing: Second edition, Second edi. Cicinnati: Hanser Publications, 2014.

Y. A. El-shekeil, S. M. Sapuan, K. Abdan, and E. S. Zainudin, “Influence of fiber content on the mechanical and thermal properties of Kenaf fiber reinforced thermoplastic polyurethane composites,” Mater. Des., vol. 40, pp. 299–303, 2012, doi: 10.1016/j.matdes.2012.04.003.

A. I. Al-mosawi, “Mechanical properties of composite material reinforcing by natural-synthetic fibers,” Acad. Res. Int., vol. 3, no. May, pp. 108–112, 2014.

T. Joffre, A. Miettinen, F. Berthold, and E. K. Gamstedt, “X-ray micro-computed tomography investigation of fibre length degradation during the processing steps of short-fibre composites,” Compos. Sci. Technol., vol. 105, pp. 127–133, 2014, doi: 10.1016/j.compscitech.2014.10.011.

M. Fitri and S. Mahzan, “The Regression Models of Impact Strength of Coir Coconut Fiber Reinforced Resin Matrix Composite Materials,” Int. J. Adv. Technol. Mech. Mechatronics Mater., vol. 1, no. 1, pp. 32–38, 2020, doi: 10.37869/ijatec.v1i1.12.

International organization for standardization, “Plastics – Determination of Charpy impact properties,” ISO 179-1, no. 1110, 2001.

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