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ANALYSIS OF THE IMPACT TEST STRENGTH OF SQUID FIBRE-REINFORCED COMPOSITES

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Abstract. This study aims to determine the effect of volume fraction, fibre angle direction, and fibre length on the impact strength of squid fibre-reinforced composites. Squid fibre is a natural animal fibre that has excellent potential in the development of composite materials. The use of squid fibre as a composite reinforcement can be an alternative to reduce organic waste from marine products and produce new composite materials in sustainable manufacturing applications. The research method was conducted with quantitative experiments to determine the effect of fibre volume fraction with variations of 25%, 50%, and 75%; fibre angle direction with variations of 45° and 90°; and fibre length with variations of 20 mm, 30 mm, and 40 mm. This study used the Factorial DOE statistical data analysis method. The results showed that volume fraction and fibre length significantly affected the impact strength of the composite. The higher the volume fraction and fibre length, the higher the impact strength value of the composite. Meanwhile, the direction of fibre did not show a significant effect. The 75% volume fraction produced the highest impact strength of 0,0738 J/mm², and the 25% volume fraction produced the lowest value of 0,066 J/mm². The 45° fibre direction produced an impact strength value of 0,07098 J/mm², and the 90° fibre direction produced a value of 0,07097 J/mm². The 40 mm fibre length produced the highest impact strength value of 0,078 J/mm², and the 90° fibre direction produced a value of 0,07097 J/mm².

Keywords : Composite, Epoxy, Squid Fibre, Impact Test.

1. INTRODUCTION

Technological developments in the materials industry are proliferating, especially in composite materials. Composites have many advantages, including corrosion resistance, structural strength, environmental friendliness, and lightweight, so their utilisation must be maximized. Composites are materials formed by combining two or more separate components to achieve physical and mechanical qualities superior to those of the individual constituent components [1]. In composites, natural fibers are starting to be used as reinforcing materials. Natural fibers are fibers obtained from nature, both plants and animals. Plant-derived fibers are banana leaf, jute, pineapple, and bagasse fiber. Animal-derived fibers are fleece, leather, and squid fiber. Natural fibers have several advantages over synthetic fibers, such as being recyclable, renewable, safe for the environment and human health, having superior mechanical qualities, not causing tool abrasion, cheaper, and lower density [2].

Many natural resources in the sea can be processed to be useful. One of the abundant natural resources is squid, which has a part in the form of squid fiber or squid cranial bone. However, few people know that this animal contains fiber in its squid, which is usually discarded when squid meat is processed [3]. Squid fiber is organic waste, so it needs to be utilized to explore the use of organic waste as reinforcement material in composites. According to data from the Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia, 0.82% of squid fiber is utilized in Indonesian waters [4]. Using squid fiber as a composite material can increase the use value of underutilized squid fiber, thus helping to reduce organic waste.

This study employs organic waste readily available in Indonesia, specifically squid fibre. Due to research restrictions, squid fibre is still infrequently used as a reinforcing material in composites. Squid fibre has not been extensively studied in materials engineering. Thus, its application is less common than natural fibres such as coconut, hemp, or glass fibre. Furthermore, squid fibre's thin, transparent, and flexible nature needs particular treatment to work ideally as reinforcement in composite structures. Processing problems, such as alkalisation treatment, also limit its broad use. Squid fiber is often a waste problem if not utilized properly, so it is processed in a certain way to be used as a basis for composite material engineering. The central concept is converting worthless materials into high-value ones [5]. Several studies have been conducted related to research on composites using animal natural fibers. Fuady et al. [6] researched composites reinforced with rice field snail powder for drone frame applications. The results stated that the highest impact strength value was found in the 75% : 25% ratio of 2,0722 kj/m^2. Asmeati et al. [7] researched free-range chicken eggshell waste. The results explained the highest impact strength value in the 30% fraction of 19,163 kj/m^2. Nayiroh et al. [8] examined the effect of the volume fraction of green mussel shell particle filler on mechanical properties. The results of this study resulted in impact strength ranging from 0,190 to 0,317 J/mm^2, with the highest impact price at 10% filler volume fraction and the lowest at 40% filler volume fraction. Previous research has examined using organic waste such as rice field snail shells, native chicken eggshells, and green mussel shells as reinforcement for composite materials. The research focused on the variation of particle volume fraction and its effect on impact strength. Most studies used powder form as reinforcement material and did not use fibre form; fibre has mechanical characteristics different from particles. Thus, there is still a research gap in using fibres as reinforcement, especially natural fibres that have not been widely studied, such as squid fibres. As has been demonstrated in previous natural fibre-based composites, using squid fibre as a composite reinforcement is expected to boost the material's impact strength while also enhancing volume fraction, fibre length, and appropriate fibre orientation direction.

Research on composites is growing due to their sustainability, low environmental impact, and various possible uses. A common strategy is to use natural fibers, especially animal fibers, as fillers in composite materials. Natural fibers are the right choice to create lightweight, strong, environmentally friendly, cost-effective composite materials [9]. Composite materials from natural fibers are as strong as metal composites [10]. Using animal fibers as composite reinforcement is expected to produce composite materials that have good mechanical performance and help reduce the amount of waste produced. In this study, the authors used a method to test the mechanical properties of composites, namely the impact test. This impact test measures the energy a material absorbs until the material breaks, where the load comes suddenly and does not occur gradually. This energy absorption process produces material responses such as plastic deformation, inertial effects, friction, and hysteresis [11].

Based on these problems, a solution is needed to produce a strong material with good mechanical properties. Through impact testing, this research aims to analyse squid fibre-reinforced composite materials with variations in fibre volume fraction composition, fibre angle direction, and fibre length in an epoxy resin matrix. In quantitative research, it is necessary to formulate a hypothesis that aims to provide a clear direction from the beginning of the study. Hypotheses are formulated based on temporary conjectures to answer the problems raised. In this study, the hypothesis was formulated to examine the effect of squid fibre on composite strength, especially in impact strength testing.

2. METHODS

2.1 Research Methods

This research is experimental, namely, by making specimens and conducting tests with a type of quantitative research methodology, analysing the impact strength of the specimens using statistical software.

2.2 Research Concept Framework

The following is a conceptual research framework using an input-output diagram, as shown in Figure 1.

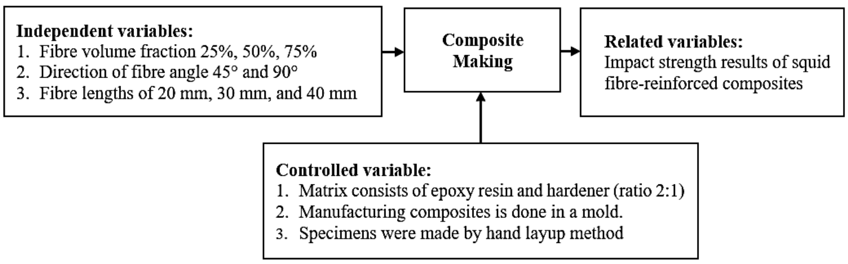

Figure 1. Research concept framework

The conceptual framework of this research describes the relationship between variables. It aims to determine the effect of fibre volume fraction, fibre angle direction, and fibre length on the impact strength of squid fibre-reinforced composites as the dependent variable. In this study, the composite manufacturing process becomes the intermediary, while the controlled variables to ensure the validity of the results are the matrix used with a ratio of 2:1 between resin and hardener, manufacturing in composite manufacturing, and making specimens by hand layup method.

2.3 Specimen Making

Squid fiber used as composite reinforcement needs an alkali process. In this process, a 3 N NaOH solution was added to 100 g of squid fiber in a ratio of 1:10, stirred for one hour at 90°C, and then washed with distilled water [12]. Then, specimen molding was carried out; at this stage, the fibers were calculated and weighed according to the variables, and epoxy resin and hardener were mixed in a ratio of 2:1 for each fiber variable. Brush the mold with mirror glaze. The mold used Teflon material with dimensions of 60 mm long by 50 mm wide and 10 mm thick. The method used in making specimens is hand lay-up. Fibre embedding is done to arrange the fiber in the mold. After that, pour the mixture of epoxy resin and hardener into the surface of the mold until it is evenly distributed, as shown in Figure 2. The specimen is dried until it becomes hard. The next step is to remove the specimen from the mold, cut the specimen, and make notches according to ASTM E23 impact testing standards. The ASTM E23 impact testing standard has a specimen dimension of 55 mm long, 10 mm wide, and 10 mm high, a notch 2 mm deep, and a notch angle of 45°.

Figure 2. Specimen making

Impact testing is based on the absorption of potential energy from a pendulum load that swings from a certain height and strikes the test object, causing the test load to deform [13]. It is considered strong when a material can withstand high shock loads without being easily broken or distorted [14]. This study used the Charpy impact test method to determine the energy absorbed in testing specimens. This Charpy impact test method produces more accurate test values [15].

Figure 3. Impact testing machine

Figure 3 is a Charpy impact testing machine with specifications. It has a maximum capacity of 200 Joules of impact energy, a pendulum weighing 8,3 kg, and an arm length of 0,62 metres. The test is performed by starting the pendulum swing from an angle of 130°, which then strikes the specimen to measure the energy absorbed at fracture. It can be used to test various types of materials, including composites and metals. The impact energy can be calculated in equation 1, while the impact price can be calculated by equation 2 [16].

$$\boldsymbol{Energy\ impact = m.g.R\ (\cos\beta - \cos\alpha)} \quad (1)$$

$$\boldsymbol{Impact\ price = \frac{Energy\ impact}{A}} \quad (2)$$

E*impact* = Energy absorbed (Joules)
R = Radius of the center to the center of gravity of the pendulum (m)
m = Pendulum mass (kg)
g = Gravity (m/s^2)
β = Angle of swing breaking the test piece (°)
α = Angle of swing without test piece (°)

Impact price = Impact toughness (J/mm^2)
A = Cross-sectional area (mm^2)

3. RESULTS AND DISCUSSION

3.1 Research Results

Data collection in this study used Charpy impact test equipment at the Malang State Polytechnic Mechanical Engineering Material Testing Laboratory. The results of the research on the effect of volume fraction, angular direction, and fibre length on the impact strength of squid fibre-reinforced composites are as follows:

Table 1. Impact test results

No.	Volume Fraction	Fiber Direction	Fiber Length	Result (J/mm^2)			Average Impact Strength (J/mm^2)
				1	2	3	
1.	25%	45°	20 mm	0.0352	0.0692	0.0626	0.0556
			30 mm	0.0725	0.0714	0.0604	0.0681
			40 mm	0.0659	0.0714	0.0746	0.0706
		90°	20 mm	0.0506	0.0495	0.0439	0.0479
			30 mm	0.0735	0.0659	0.0823	0.0739
			40 mm	0.0746	0.0823	0.0779	0.0783
2.	50%	45°	20 mm	0.0549	0.0517	0.0648	0.0571
			30 mm	0.0658	0.0866	0.0757	0.076
			40 mm	0.0997	0.0714	0.0812	0.084
		90°	20 mm	0.0637	0.0692	0.0735	0.0688
			30 mm	0.0823	0.0659	0.0866	0.0783
			40 mm	0.0703	0.0768	0.0823	0.0764
3.	75%	45°	20 mm	0.0659	0.0899	0.0856	0.0804
			30 mm	0.0921	0.0703	0.0549	0.0724
			40 mm	0.0658	0.0757	0.0823	0.0746
		90°	20 mm	0.0692	0.0571	0.0615	0.0626
			30 mm	0.0626	0.0669	0.0681	0.0659
			40 mm	0.0964	0.0909	0.0724	0.0866

Based on the research results in, Table 1 shows that the composite with a variable volume fraction of 75% in the direction of 90° fibre angle and 40 mm length produces the highest impact strength of 0,0866 J/mm^2. Meanwhile, the 25% fraction with a fibre angle of 90° and a fibre length of 20 mm produced the lowest impact strength of 0,0479 J/mm^2.

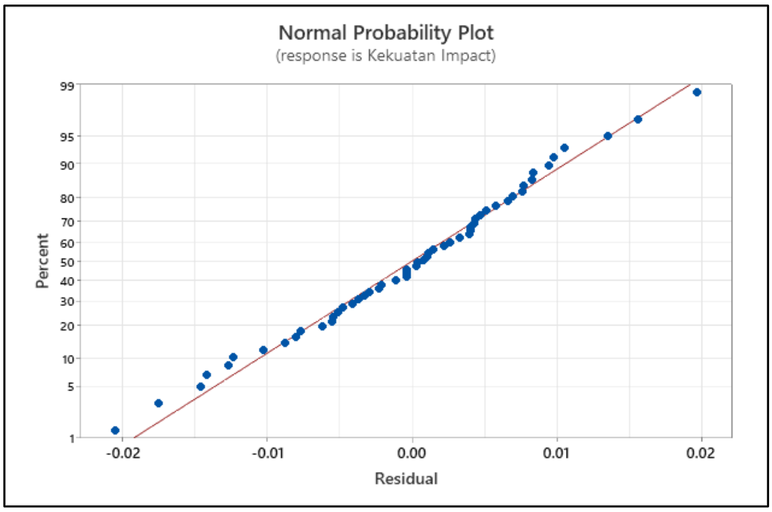

Figure 4. Graphic normal probability plot

Figure 4 normal probability plot graph shows the distribution of data based on the standard line drawn from the data on the replication of each variable. The graph results, which are close to the standard line, indicate the normal distribution of data. Figure 4 shows that the points on the graph are close to the diagonal line, so it can be stated that this data is usually distributed and fulfills the requirements for normal data distribution.

Table 2. Analysis of variance (ANOVA)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	17	0.005263	0.000310	3.08	0.002
Linear	5	0.003196	0.000639	6.35	0.000
Volume Fraction	2	0.000740	0.000370	3.68	0.035
Fiber Direction	1	0.000000	0.000000	0.00	0.986
Fiber Length	2	0.002455	0.001228	12.20	0.000
2-Way Interactions	8	0.001067	0.000133	1.33	0.262
Volume Fraction*Fiber Direction	2	0.000114	0.000057	0.57	0.573
Volume Fraction*Fiber Length	4	0.000785	0.000196	1.95	0.123
Fiber Direction*Fiber Length	2	0.000169	0.000084	0.84	0.441
3-Way Interactions	4	0.001001	0.000250	2.49	0.061
Volume Fraction*Fiber Direction*Fiber Length	4	0.001001	0.000250	2.49	0.061
Error	36	0.003623	0.000101		
Total	53	0.008886			

To assess whether the research hypothesis is acceptable, the P-value analysis of the Analysis of Variance test is used. This study set a significance level (α) of 0,05 or 5%, which is the maximum acceptable error limit for an alternative hypothesis to be declared significant. Based on the results presented in Table 2, the fiber volume fraction variable has a P-value of 0,035, so it can be stated that the fiber volume fraction variable has a significant effect on impact strength. The fiber direction variable has a P-value of 0,986, so it can be noted that the fiber direction variable has no significant effect on impact strength. The fiber length variable has a P-value of 0,000, so it can be stated that the fiber length variable has a significant effect on impact strength. The interaction variable of volume fraction and fiber direction has a P-value of 0,573, so it can be stated that the interaction variable of volume fraction and fiber direction has no significant effect on impact strength. The interaction variable of volume fraction and fiber length has a P-value of 0,123, so it can be stated that the interaction variable of volume fraction and fiber length has no significant effect on impact strength. The interaction variable of fiber direction and fiber length has a P-value of 0,441, so it can be stated that the interaction variable of fiber direction and fiber length has no significant effect on impact strength. The interaction variable of volume fraction, fiber direction, and fiber length has a P-value of 0,061, so it can be stated that the interaction variable of volume fraction, fiber direction, and fiber length has no significant effect on impact strength.

Table 3. Model summary

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0100316	59.23%	39.98%	8.27%

Based on Table 3 shows that the coefficient of determination (R-sq) has a scale of 100%, if the coefficient of determination is closer to 100%, the more significant the influence between the independent variables on the dependent variable. In the results of data analysis obtained, the coefficient of determination R-sq has a value of 59,23%, which means that the independent variable affects the dependent variable or the strength of the impact is influenced and the rest is influenced by other factors.

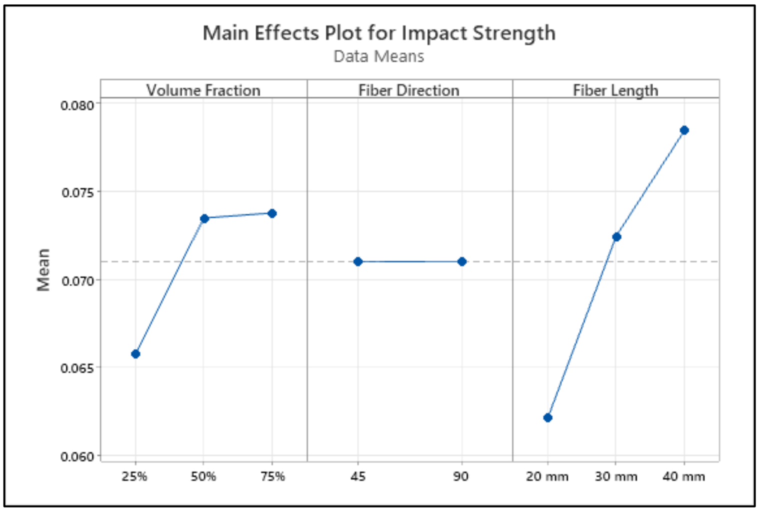

Figure 5. Main effects plot for impact strength

The graph has two main lines, horizontal and vertical; the horizontal line is the independent variable, and the vertical line is the dependent variable. Figure 5 shows that the variation of fibre volume fraction affects the impact strength linearly, and the impact strength increases as the fibre volume fraction increases. In the variation of fibre direction, the average value of impact strength is the same for both levels, so fibre direction does not significantly affect impact strength. The fiber length variation affects the impact strength linearly, and the impact strength increases as the fiber length increases.

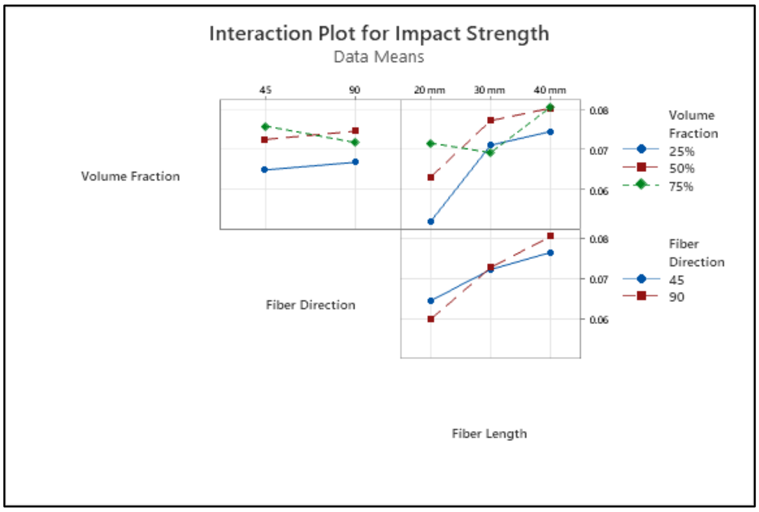

Figure 6. Interaction effect plot for impact strength

Based on Figure 6, it is known that the interaction graph of volume fraction and fibre angle direction has the highest impact strength value found in the 75% volume fraction and 45° fibre angle direction which is 0,0758 J/mm^2, at 25% volume fraction and 45° fibre angle direction has a low impact strength value of 0,0647 J/mm^2. In the interaction between volume fraction and fibre length, the highest impact strength is found in the 75% volume fraction and 40 mm fibre length of 0,0806 J/mm^2, and the lowest impact strength in the interaction of volume fraction and fibre length is found in the 25% volume fraction and 20 mm length of 0,0517 J/mm^2. In the interaction between fibre direction and fibre length, the highest impact strength is found in the 90° fibre direction and 40 mm fibre length of 0,0804 J/mm^2. In comparison, the 90° fibre direction and 20 mm length have the lowest impact strength value of 0,0643 J/mm^2.

3.2. Discussion

Effect of fibre volume fraction on impact strength

Based on the results of data processing, the volume fraction variable has a significant effect on the dependent variable, namely impact strength. The results of the volume fraction variation show that the 75% fiber volume fraction with the composition (75% fiber and 25% resin) shows the highest impact strength. An increase in the volume fraction of squid fiber can increase the strength of the composite due to the increased bond between the fiber and the matrix; this occurs because a higher squid fiber composition produces more fiber bonds, thus increasing the strength of the composite when withstanding shock loads. While the composition of less fiber than the matrix makes the function of fiber as reinforcement in the composite less than optimal, if the larger matrix composition shows the rigid but brittle nature of the matrix obtained at 25% fiber volume fraction with a composition (25% fiber and 75% resin) shows a low impact strength value so that it does not require significant energy to break the composite. The relationship between increasing fiber volume fraction and impact strength is not always linear. Several factors, such as uneven fiber distribution and poor interaction between fiber and matrix, can cause this. The volume fraction of squid fibre in the composite increases along with the rise in the number of volume fractions, as supported by research conducted by Asmeati et al. (2024) [7] with the title "Analysis of Impact Test and Microstructure of Polyester Resin Matrix Composites Filled with Hometown Chicken Egg Shells" said that the more the volume fraction increases, the more the strength of the specimen increases, so that variations in the volume fraction of squid fibre affect the mechanical properties of the specimen.

Effect of fibre direction on impact strength

Based on data processing, the results show that the variable fiber angle direction does not have a significant influence on the dependent variable, namely impact strength. The variation of fiber angle direction shows that the 90° fiber angle direction shows the highest impact strength. This is because fibers arranged perpendicular to the direction of impact make a greater contribution to reducing energy. After all, the impact force directly hits the surface and fiber structure in parallel to absorb more energy before damage occurs. Meanwhile, the 45° angle direction, which has a fiber arrangement crossing or not parallel to the direction of impact loading, makes the fiber detached from the matrix and makes the load distribution less efficient because when given an impact load, it tends to experience interfacial shear failure. However, the 90° fiber angle direction variation showed the lowest impact strength results. So, it can be concluded that the variable fiber angle direction does not affect the impact strength because only the 90° angle direction affects the impact strength.

Squid fibres tend to have an amorphous structure that is not regularly arranged compared to synthetic fibres, such as carbon fibres, which are highly anisotropic. Anisotropic has different material properties in all directions at a point in the object [17]. Thus, when tested from various directions, anisotropic fibres show different mechanical properties (impact strength, tensile strength). The opposite of anisotropic isotropic is where isotropic has the same material properties in each direction. Based on the research results, the angular direction of squid fibre does not significantly affect the impact strength. Squid fibre does not show strong anisotropic in its mechanical properties, so the change in fibre angular direction does not produce significant differences in response to impact strength. So, it can be identified that the squid fibre is isotropic, where the properties of the fibre are the same in all directions. If the squid fibres are isotropic, then changing the fibre angle direction in the composite will not significantly change impact strength.

Effect of fibre length on impact strength

The results of the data analysis show that the composite fiber length variable significantly influences the dependent variable, impact strength. According to the impact test results, the 40 mm fiber length variation shows the highest impact strength, an average of 0,0784 J/mm^2. Fibers can absorb and distribute impact energy more effectively than short fibers. Long fibers allow for greater deformation before fracture so that impact energy can be adequately absorbed and does not immediately cause the composite to fracture. The increase in the length of squid fibers can increase the strength of the composite so that the impact force can be distributed evenly along the fibers. In composites, cracks tend to propagate through the matrix, so longer fibers inhibit crack propagation in the composite. Longer fibers require greater energy to be uprooted, thus absorbing more impact energy and providing greater structural stability to the composite. Meanwhile, On average, the 20 mm fiber length shows a low impact strength value of 0,062 J/mm^2. Short fibers tend to detach faster from the matrix when exposed to impact, so the energy is not spread evenly; the short fibers cause imperfect interface bonding, thus reducing the ability to withstand impact loads. Short fibers do not have sufficient length to develop a strong and stable bond around the matrix, so when the composite receives an impact load, the stress from the matrix cannot be efficiently transferred to the fibers. Most of the load is borne by the matrix, which causes the matrix to become brittle. Shorter fibers are also less effective in inhibiting crack propagation, so cracks can easily pass through or cut through the fibers, causing failure. The variation of squid fibre length in the composite increases with increasing fibre length, as supported by research conducted by Maryanti et al. (2019) [15] with the title "Impact Strength Characteristics of Coconut Fiber Composites with Fiber Length Variations" said that fibre strength is significantly influenced by the matrix used when making composites, so that the longer the fibre, the higher the impact price. This is consistent with the research findings, which show that the impact price achieved increases along with the length of the fibre.

4. CONCLUSION

Based on the data analysis and discussion on the effect of volume fraction, fiber angle direction, and fiber length on the impact strength of squid fiber composites, it can be concluded that:

1. The volume fraction of squid fibre significantly influences the impact strength of the composite, where the 75% volume fraction produces the highest impact strength. In comparison, the 25% volume fraction produces the lowest impact strength. There is an increase in the bond between the fibre and the matrix as the fibre volume fraction increases, which contributes to the strength of the composite when withstanding shock loads. However, the relationship between fibre volume fraction and impact strength is not always linear, influenced by factors such as uneven fibre distribution and potential porosity due to imperfect composite manufacturing methods.
2. The angular direction of the fibres has no significant effect on the impact strength of the composite. Although the 90° angular direction shows the highest impact strength because fibres perpendicular to the direction of impact are more effective in reducing energy, the results show that changes in fibre angular direction do not produce significant differences in response to impact strength. This is due to the isotropic nature of squid fibres, where the mechanical properties are not significantly different in various directions, in contrast to synthetic fibres, which are anisotropic. Thus, it can be concluded that the squid fibre's angular direction does not significantly impact impact strength.
3. The fibre length significantly influences impact strength, where 40 mm fibre length produces the highest impact strength, and 20 mm fibre length produces the lowest impact strength. This is due to the ability of long fibres to absorb and distribute impact energy more effectively, as well as inhibiting crack propagation in the composite. This shows that the longer the fibre length, the higher the impact value. Thus, increasing fibre length can improve the structural stability and resistance of the composite to impact loads.

The application of squid fibre composites in this research is used as a drone frame, which has been reviewed in previous research. Using squid fibre composites as reinforcement produces higher mechanical properties than composites reinforced with rice snail powder used as drone frames. With the environmentally friendly nature of squid fibre, this material also supports sustainability in the manufacturing process.

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