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Analysis of the impact strength on laminated polyester composites reinforced Sugar Palm Fiber (SPF) with fiber orientation: random and woven

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Abstract

Recently, composite materials have attracted the attention of researchers because of their advantages. The utilization of composite materials is widely used in various industrial fields, including in the automotive industry which is used as a car bumper. A car bumper composite material must be resistant to shock loads and good in energy absorption. Due to this, the composite material will be subjected to an impact test. This study aims to analyze the effect of variations in fiber volume fraction on the impact strength of laminated composites with a polyester matrix with sugar palm fiber (SPF) reinforcement with fiber orientation direction: random and woven. Composite fabrication was carried out using the hand layup and press molding methods with variations in fiber volume fractions of 20%, 30%, 40%, 50%, and 60%. Then the Charpy impact test was carried out with ASTM D-6110 standard and analyzed the fracture morphology. The test results show that increasing the fiber volume fraction up to 40% can increase the impact strength. However, the impact strength decreased at 50% and 60% fiber volume fraction. The results of the largest impact test were obtained at the 40% fiber volume fraction of 0.62 J/mm2 while the lowest value at the 20% fiber volume fraction was 0.42 J/mm2. The increase in the impact test value can be due to the uniform distribution of the load by the matrix to the fiber. Based on the morphological analysis carried out through macro photos of the shape of the fracture and the cross-section of the fracture, the results of the impact test showed that fibrous fractures occurred while on the cross-section of the fracture delamination and fiber pullout appeared.

Keywords:
Impact strength, composite, sugar palm fiber (SPF), polyester, fiber volume fraction

1 Introduction

The development of science, especially in the field of materials engineering, has progressed towards the use of renewable and sustainable materials [1][2]. Composite materials are composed of a matrix and reinforcing materials, which can be in the form of fiber, silica, clay, and others. With the addition of reinforcing material at a certain concentration, it can produce better mechanical, thermal, and structural properties than the properties of the constituent material [3]. Composite materials can easily be shaped as needed, by combining the strengths and advantages of the constituent materials. This encourages the use of composite materials as an alternative to metal in various products produced by the industry [1][4]. Industries that have started to use composite materials a lot is the automotive industry [5]. Composite material is often used as a car body, especially on the front and rear bumpers, this is due to the advantages of composite materials, which are lightweight. This results in the mass of the car body will be lighter. There by increasing fuel efficiency and reducing air pollution emissions.

Polymer-based composites are the most widely used composites. In reference [6] conducted a study related to the effect of fiber volume fraction on the mechanical strength of e-glass fiber composites with polyurethane with random orientation directions. It was found that the fiber volume fraction affects the mechanical strength of the composite. Composites usually use resin-based polymers as the matrix and natural fibers as reinforcement [1]. The use of natural fibers as reinforcement has many benefits including biodegradable, easy to obtain, and environmentally friendly [7]. This research used Yukalac 157 BTQN-EX unsaturated polyester resin as the matrix and sugar palm fiber (SPF) as reinforcement. Polyester resin has distinctive characteristics such as being rigid and flexible, transparent, dyeable, water resistant, and chemical and weather resistant. Polyester resin can be used at working temperatures up to 79^{o} C. Density 1.3-1.4 kg/cm^3 [8]. Sugar palm fiber (SPF) is very easy to find in Indonesia because the palm tree is a plant that can grow well in the tropics. Sugar palm fiber (SPF) has an average diameter of 0.5mm, density 1.2-1.3 g/cm^3, tensile strength 15.5 MPa, decomposition temperature 228-312^{o} C, and SPF has biodegradable properties [4][9][10].

The combination of a polyester resin matrix with sugar palm fiber (SPF) as a composite material has been carried out by several previous researchers. In reference [11], conducted research using woven fan palm (WFP) and polyester to determine the effect of chemical treatment on WFP composites on water absorption, and mechanical and thermal strength. It was found that the impact strength after drying from the immersion process did not change significantly. In reference [13], conducted research to make composites from polyester resin reinforced with SPF with variations in the mass fraction of fiber with the mass of the resin. The SPF is arranged at 0 degrees (vertical) and the fabrication is done using the hand layup method. It was found that the greatest impact strength in the mass fraction of fiber vs. resin mass 50%:50% was 198.75 J/cm^2, while the tensile strength was 27.09 MPa. In reference [4], conducted research on the effect of fiber volume fraction on tensile strength, in this study the fibers were arranged randomly and composite material fabrication was carried out by hand layup and press molding methods. This research resulted in the highest tensile strength at 40% volume fraction of 24.7 MPa. Research on the use of fiber volume fraction variations with the orientation of random fibers and woven has never been done before, seeing the potential strength of SPF which can increase the mechanical strength of composite materials. Therefore, researchers will conduct research with a scheme of variation of fiber volume fraction with fiber orientation, namely random and woven, then impact testing using the ASTM D-6110 testing standard [14][15]. Because considering the application of this composite material will later be used in the automotive sector as a car bumper [9].

This study aims to analyze the impact strength of composite materials with polyester resin reinforced sugar palm fiber (SPF) with a volume fraction variation of SPF 20%, 30%, 40%, 50%, and 60% [4]. The arrangement of the orientation of the fibers is carried out in a random and woven arrangement.

1.1 Fiber Volume Fraction

Fiber volume fraction can be defined as the amount of fiber content in the composite material so that the fiber volume fraction can influence the mechanical properties of the composite material [6]. This is of particular concern in fiber-reinforced composites. The number of fibers and the characteristics of these fibers is one of the key elements in the micromechanical analysis of composites [16]. To obtain high-strength composites, the distribution of fibers with the matrix must be evenly distributed in the mixing process to reduce the occurrence of voids. To calculate the fiber volume fraction, the parameters that must be known are the density of the matrix, the density of the fiber, the weight of the composite, and the weight of the fiber. Fiber volume fraction can be determined using the following equation [3] (it is assumed that there are no voids in the composite material ($V_v = 0$):

$$Vf = \frac{Wf/\rho f}{Vc} x100\% \qquad (1)$$

Where:
Wf, Wm = Weight fraction of fiber and matrix
ρf, ρm = Density of fiber and matrix (g/cm^3)
Vf, Vm = Volume fraction of fiber and matrix (cm^3)
Vc = Volume fraction of composite (cm^3)

1.2 Mechanical Testing: *Impact Test*

Mechanical testing is carried out to determine the mechanical properties of a material, the test is divided into two types, namely destructive testing (DT) and non-destructive testing (NDT) [17]. In this study, a DT was carried out with impact testing using the Charpy method. Impact testing is carried out to determine the value of the toughness of the composite material, which composite material will be applied as a car bumper. Therefore, it is important to know the toughness or ability of the material to absorb energy before fracture. In this study, the impact test used a notch test rod and then hit a pendulum. Two methods can be used, namely the Charpy and Izod methods [14]. The difference between the Charpy and Izod methods is the placement of the specimen. Testing using the Charpy method is more accurate than the Izod method, because the specimen holder also absorbs energy, so the measured energy is not energy that can be fully absorbed by the material [18]. The value of the impact test loading is obtained from the impact of a pendulum hammer released at a height of "h". The tip of the knife on the pendulum hammer will hit the notch in the specimen until it breaks.

In this study, the impact test with the Charpy method was used with the testing standard referring to ASTM D-6110 [15] with the dimensions of the specimen as shown in Fig. 1, the Charpy specimen is rod-shaped with a rectangular cross-section with a "v" notch.

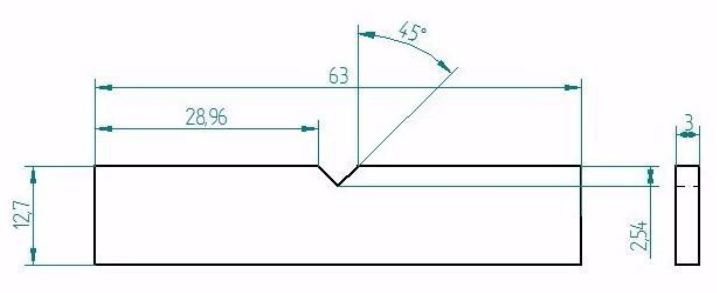


Fig. 1. Impact test specimen dimensions ASTM D-6110 [15]

To calculate the impact strength, the equations in the ASTM D-6110 standard are used. The following equation formula for impact testing:

$$\begin{aligned} Ep &= \text{initial energy} - \text{final energy} \\ Ep &= m.g.h - m.g.h' \\ Ep &= m.g.(R - R\cos\alpha) - m.g.(R - R\cos\beta) \\ Ep &= mg.R.(\cos\beta - \cos\alpha) \end{aligned} \qquad (2)$$

where:
Ep: Potential energy (J)
m: mass of pendulum (kg)
g: gravity (m/s2) = 10 m/s^2
R: Length (m)
α: pendulum angle before swinging
β: pendulum swing angle after breaking the specimen

The impact strength can be calculated by:

$$HI = Ep/A_o \qquad (3)$$

where:
HI: Impact Strength (J/mm^2)
Ep: Potential energy (J)
A_o: cross-sectional area (mm^2)

2 Research Methods

2.1 Material

The materials used in this research are: a matrix using unsaturated polyester Yukalac 157 BTQN-EX which will be added as a catalyst to accelerate the formation and curing process. The catalyst used is *Methyl Ethyl Ketone Peroxide* (MEKPO). The reinforcement in this study used sugar palm fiber (SPF) obtained from palm trees.

2.2 Matrix and Fiber Preparation

The matrix solution was prepared by mixing Yukalac 157 BTQN-EX polyester resin with MEKPO catalyst (MEKPO catalyst 1% of the resin volume). Then, it stirred using a hot plate magnetic stirrer for 1 hour at a temperature of 60^{o}C. After the stirring process, the matrix solution was allowed to stand for 45-60 minutes to remove the bubbles formed due to the stirring process. Then the matrix is ready for use in the manufacture of composite materials.

Preparation of sugar palm fiber (SPF) begins by taking the fiber from the palm tree, then cleaning it with a machete to remove the sticks. Then the messy fibers are trimmed using a steel brush. Then the selection of fibers that have a uniform diameter is carried out. Fibers that have a uniform diameter are washed with water until clean and then dried at room temperature for 48 hours in the room. The fiber was dried again using an oven at 90^{o}C for 15 minutes. The fiber is ready to be used for the manufacture of composite materials.

After the matrix and sugar palm fiber were ready, the fiber volume fraction was calculated with variations of 20%, 30%, 40%, 50%, and 60% [4], then continued with the fabrication of composite materials using hand layup and press molding methods..

2.3 Fabrication of Composite

The manufacture of composite materials is carried out using the hand layup method with 3 layers consisting of a matrix-woven-matrix-random-matrix, as shown in Fig. 4. a with an illustration as shown in Fig. 2. After the hand layup process is complete, proceed with press molding process for 24 hours at room temperature with a press molding process mechanism as shown in Fig. 4. b with an illustration of the manufacturing mechanism as shown in Fig. 3. The manufacture of composite materials is carried out with variations in fiber volume fraction, namely 20%, 30%, 40%, 50%, and 60%. The composite material that has been made is then released from the mold so that it becomes a sheet as shown in Fig. 4.c. Then the curing process is carried out in an oven at a temperature of 60^{o}C for 30 minutes which aims to make the hardening process on the composite material perfectly hard both on the surface and on the inside.

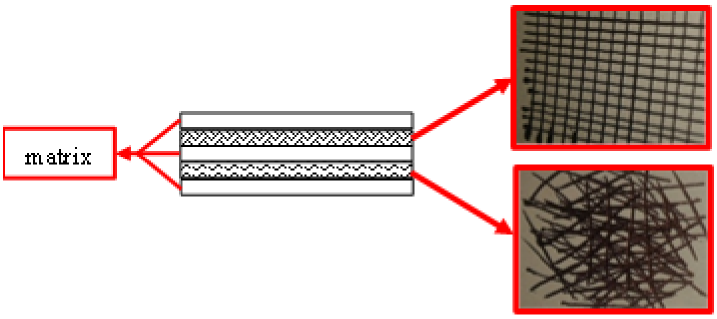


Fig. 2. Schematic order of hand layup

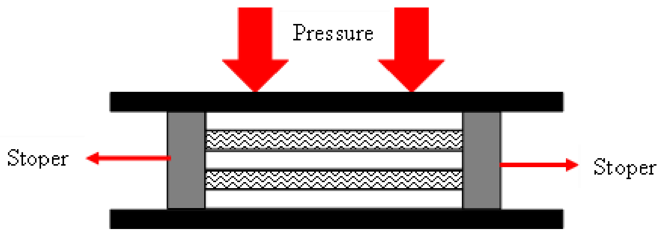
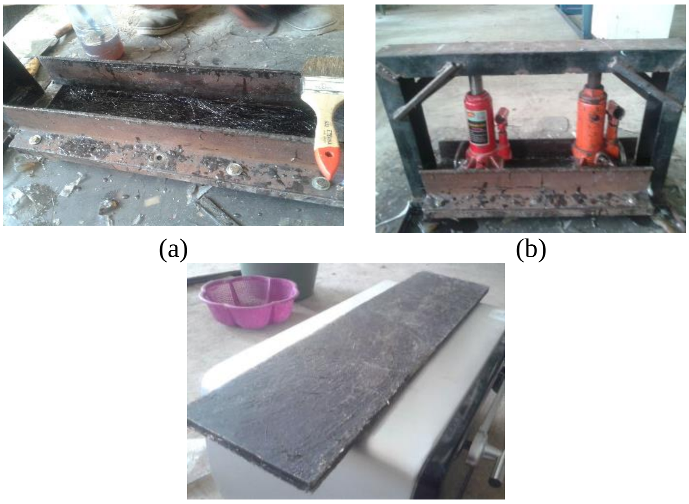


Fig. 3. Schematic process of press molding



(a) (b) (c)

Fig. 4. Manufacturing of composite; (a) hand layup process; (b) press molding process; (c) composite material of polyester and SPF.

Furthermore, the composite material is cut according to the standard dimensions of the ASTM D-6110 impact test as shown in Fig. 1. A total of 15 specimens will be subjected to impact testing as shown in Fig. 5.

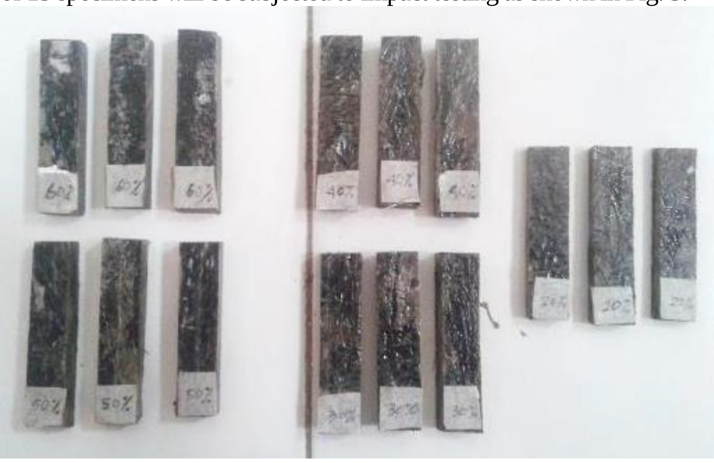


Fig. 5. Impact test specimens

2.4 Testing and Characterization

impact testing using a Universal Impact Tester Machine type HT-8041. Impact testing uses a test object that is given a notch with a depth of 2 mm. The impact test specimen is shaped according to the ASTM D-6110 standard. To determine the morphology of the types of fractures and defects that occurred after the test, macro photos were carried out using a digital camera with 18MP (f/1.2).

3 Result and Discussion

3.1 Effect of Fiber Volume Fraction on Impact Strength

The fiber volume fraction (Vf) is the amount of fiber content in the composite material, meaning that the fiber used as reinforcement in the composite material has a mass that can be calculated using equation 1. Based on the calculation results, the fiber mass was obtained in each variation of the fiber volume fraction. The calculation results are presented in Table 1.

Table 1. SPF mass in each variation of fiber volume fraction

No.	Fiber volume fraction (%)	Mass of SPF (gram)
1	20	34,1
2	30	51,1
3	40	68,2
4	50	85,2
5	60	102,2

Impact test specimens according to the ASTM D-6110 standard with dimensions as shown in Fig. 1. In each variation of the fiber volume fraction, there are 3 specimens, then the average value is calculated and taken. The total specimens of this study were 15 specimens.

The absorbed energy is calculated using equation 2 while the impact strength is calculated using equation 3, then presented in table 2. Based on the data in table 2, the researcher made two curves. The first curve compares the potential energy absorbed by the composite material compared to the SPF volume fraction as shown in Fig. 6. The second curve compares the impact strength with the SPF volume fraction as shown in Fig. 7.

Table 2. Charpy impact test results

No.	Fiber volume fraction (%)	Mean of Ep (J)	Impact Strength (J/mm^2)
1	20	12,8	0,42
2	30	16,1	0,53
3	40	18,9	0,62
4	50	18,2	0,59
5	60	16,7	0,55

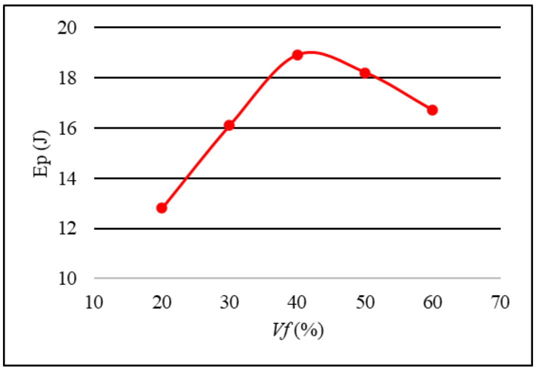


Fig. 6. Potential energy vs fiber volume fraction curve

Fig. 6 shows that there is a positive trend. absorbed energy increased from 20% to 40% fiber volume fraction. then decreased in the fiber volume fraction by 50% and 60%. Based on Fig. 5, it can be seen that the largest potential energy absorption is in the 40% fiber volume fraction of 18.9 J and the lowest energy absorption is in the 20% fiber volume fraction of 12.8 J.

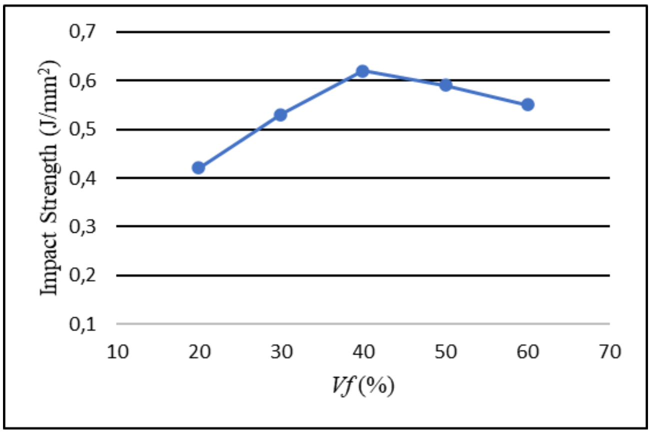


Fig. 7. Impact strength vs fiber volume fraction curve

Fig. 7 shows that the curve of impact strength vs fiber volume fraction. impact strength increased from 20% to 40% fiber volume fraction. However, the impact strength value decreased at 50% fiber volume fraction and decreased again at 60%. The highest impact strength was obtained at 40% fiber volume fraction of 0.62 J/mm^2, while the lowest impact strength was obtained at 20% fiber volume fraction at 0.42 J/mm^2.

The highest impact strength value obtained in this study was 0.62 J/mm^2. The impact strength value is still below when compared to the impact strength value in the research conducted by Tauvama, et al. [16], using pineapple fiber and epoxy resin of 0.76 J/mm^2. However, the impact strength value using SPF with polyester resin is still higher when compared to banana midrib fiber 0,04 J//mm^2 [12], coco fiber with epoxy resin 0,0069 J/mm^2 [19] and conducted by Mawardi, et al. 0,02 J/mm^2 [20].

Based on Fig. 6 and 7, it can be said that the volume fraction of sugar palm fiber affects the impact strength of the composite material. The effect is obtained from increasing the impact strength of the composite material up to the SPF 40% volume fraction and then decreasing at the 50% and 60% volume fraction. The decrease in the impact strength of the composite may be caused by the number of fibers used as reinforcement having reached the limit, while the number of matrices is decreasing which causes the polyester resin as a matrix to not be able to wet the entire fiber surface. This phenomenon can trigger the formation of voids in the composite structure and the fracture morphology of the fiber pullout.

3.2 Morphology Analysis of Impact Test Results

Based on the macro photo in Fig. 8, it can be seen that the faults that occur in all specimens are in the form of fiber fractures. This can be indicated that the interface between the matrix and the fiber is still not very strong. The strength of the interface between the fiber and the matrix can be increased by pre-treating the fiber before it is made into a composite material. The treatment can be done by soaking the fiber in an alkaline solution which is useful for removing the lignin content in the fiber so that the interface between the matrix and the fiber can increase.

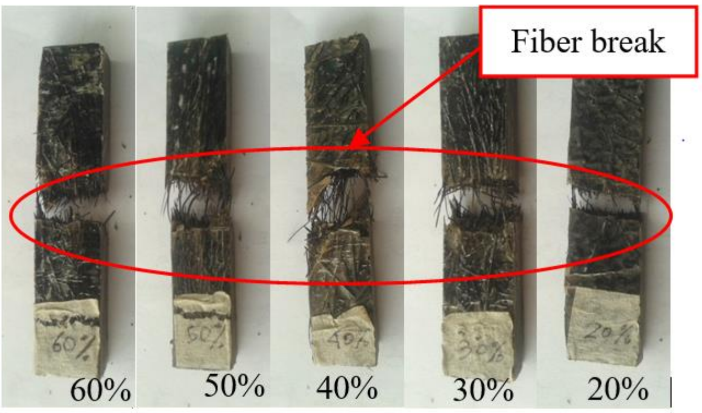


Fig. 8. Macro foto of impact testing result

Based on the macro photo of the cross-section of the fracture shown in Fig. 8, shows that there is delamination and fiber pull-out. In delamination, the matrix appears to be broken into small pieces, this is possible because the mixture between resin and hardener is still not balanced, causing the matrix to become more brittle. Another possibility that causes delamination is the occurrence of clumping of fibers in the composite material so that the load is not evenly distributed to the matrix [21]. In addition to delamination, fracture results in the form of fiber pullout also appear. Fiber pullout is a phenomenon where the fibers are pulled from the matrix caused by the lack of bonding between the matrix and the fiber [22]. Fiber pullout occurs because the load transfer by the fiber to the matrix is not perfect. When the given load can still be accepted by the fiber but the matrix is no longer able to accept it the matrix breaks but the fiber can still hold it so that the fiber is pulled out and causes fiber pull-out.

Based on fig. 9 on the SPF 40% volume fraction, there is only slight delamination. This is possible because the composition between the matrix and the fiber is balanced so that the interfacial bond between the fiber and the matrix can be evenly interwoven which causes the shock load resulting from the impact test received by the fiber to be evenly distributed to the matrix.

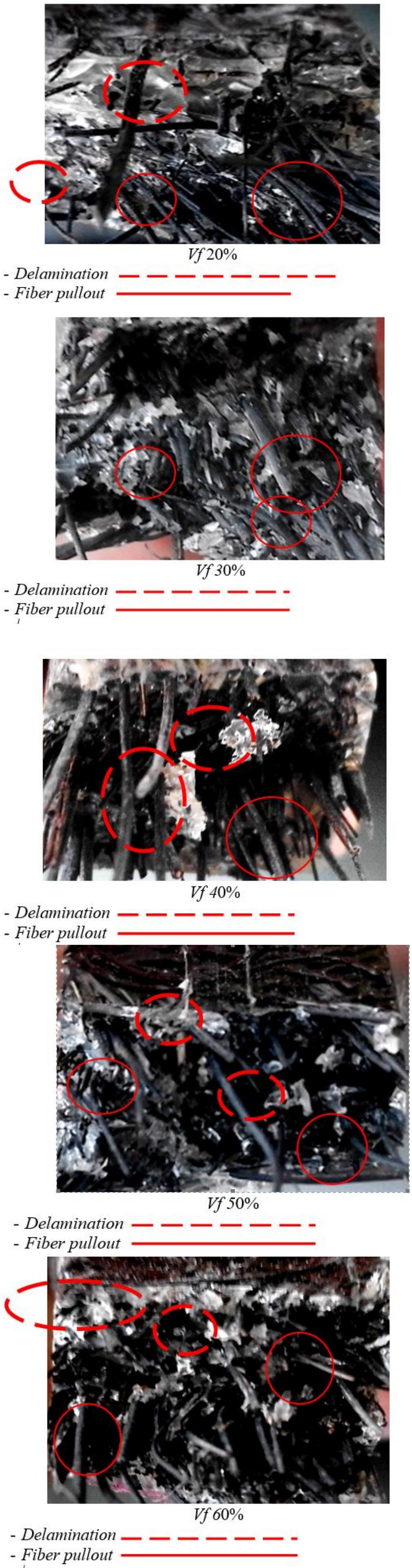


Fig. 9. Morphology Analysis of Impact Test Results

4 Conclusion

Based on the results of impact testing and analysis that has been done. it can be concluded that the SPF volume fraction influences the impact strength. The highest impact strength was obtained at the 40% fiber volume fraction of 0.62 J/mm^2 while the lowest impact strength was at the 20% fiber volume fraction at 0.42 J/mm^2. Morphological analysis of the shape of the fault and the cross-section of the fracture on the impact test results showed that there was a fibrous fracture. while the cross-section of the fracture appears delamination and fiber pullout. delamination and fiber pull-out appear because the mixture between resin and hardener is still not balanced, causing the matrix to become more brittle.

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