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Effect of Volume Fraction of Polyester Composite Reinforced Human Hair Fibers and Coconut Fibers On Mechanical Properties

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Abstract

Currently, composite applications range from the automotive, marine, and even aircraft sectors. One of the composites that have attracted a lot of attention from researchers is composites with natural fibres because natural fibre composites can be used as an alternative to synthetic or plastic materials. The low-density nature of natural fibres can provide good stiffness and strength as in fiberglass-reinforced composites. Coconut coir fibre and human hair waste are the basic materials for the manufacture of composites in this study. Because the amount is abundant so it is easy to obtain. The purpose of this study was to determine the effect of the variation of the best volume fraction of natural fibre composites with polyester matrix on the mechanical properties. The method used is hand layup with 3 variations of fibre volume fraction and polyester matrix, respectively 10:90, 15:85, and 20:80 and with the size of short hair fibres with a size of 3 cm and long coconut fibres with sizes according to the length of the print. The ratio of human hair fibre and coconut fibber is 1:1. Each fraction was tested 3 times to be more accurate. The results of the average tensile strength test with the largest ASTM D638 standard are at the volume fraction of 10:90 with a tensile strength of 19.2 MPa and the average impact test strength with the largest ISO 179-1 standard at the volume fraction of 20:80 is 17, 67 kJ/m². This study showed that the higher the fibres fraction in the composite, the lower the tensile strength but the higher the impact strength. Vice versa, the lower the fibre fraction in the composite, the tensile strength increases but the impact strength decreases.

Keywords:
human hair; coconut fibre; polyester; volume fraction; mechanical properties

1 Introduction

Currently, composite applications range from the automotive, marine, and even aircraft sectors. Composite material is a material consisting of two or more constituent materials that have very different physical or chemical properties, when combined will produce a new material with different characteristics from the original material. [1]. Composites that use natural fibers have attracted a lot of attention from researchers as an alternative to synthetic or plastic materials. In addition, the use of natural fiber has several advantages such as being easy to obtain, abundant in number, low price, good mechanical properties, not easily corrosive, renewable, low density, biodegradable, environmentally friendly, and able to function as a good sound absorber. [2]–[4]. Even the low-density nature of natural fibers can provide good stiffness and strength in composites such as fiberglass-reinforced composites. [5].

One of the natural fibers that are used and abundant is coconut fiber. Indonesia produces around 1.8 million tons of coir fiber/year [6]The use of coconut fiber is widely used because coconut fiber is durable, very ductile, strong against friction, not easily broken, resistant to water, not easy to rot, resistant to fungi and pests, and not inhabited by termites and rats. Because of this, coconut fiber has become an alternative for composite development, besides being cheap, and easy to get, it is also very abundant [7].

In addition to coconut coir fiber, there is also human hair fiber used in this study. Furthermore, human hair is found in abundance all over the world and is often considered useless in most the society [8]. Most hair fibers are made of keratin, Keratin is a laminated complex formed by different structures, which gives the hair strength, flexibility, durability, and functionality and its degradation time is slow because the keratin present in the hair gives the hair durability and resistance to degradation. , and it remains a waste for a long time [8]–[10].

Previous research on hybrid composites of bamboo, sisal, and human hair fibers has been carried out using epoxy resin. In this study, there were 2 variations of the human hair fiber, namely long and short. And the results of this study showed that the average mechanical properties of the hybrid composite of bamboo, sisal, and human hair showed that human hair fibers with short sizes had better properties than long ones. [11]. The tensile strength of the polyester matrix composite reinforced with human hair fiber with a fiber length variation of 1-5 cm has also been studied. The conclusion is that with a human hair fiber size of 3 cm, the highest tensile strength is 31.45 MPa [12]. Previous studies on the investigation of the mechanical behavior of human hair fibers and the various effects of volume fractions have also been discussed with human hair fiber volume fractions of 0, 5, 10, 15, and 20% on mixing epoxy matrix composites. The results of this study indicate that the percentage of fiber 20% has the best mechanical properties compared to others [13].

The mechanical behavior of coconut fiber-reinforced polyester composites using the hand layup method has also been investigated. The study showed that with an increase in the percentage of coco fiber up to 15%, the mechanical properties of the tensile test increased with a tensile strength of 26.5 MPa. [14]. This shows that the addition of coco fiber to the composite material with a polyester matrix improves the quality of the material. Research on hybrid composites of coconut coir fiber and human hair fiber has also been studied previously in which the researchers varied the direction of the fiber; the direction of the hybrid fiber was coconut fiber in a horizontal direction and human hair in a vertical direction. The matrix used in this study is an epoxy matrix with Araldite LY554 type. The results of this study indicate that the mechanical properties of the hybrid composite, a combination of human hair fiber and coconut fiber, improve the quality of the material compared to the combination of the two fibers. [15].

From the background and previous research, this study focuses more on the effect of variations in fiber volume fraction with a polyester matrix on the mechanical properties of tensile tests and impact tests. This research is an update from previous research, namely the research of Nair, et al [15]. The difference lies in the matrix, fiber orientation and the variation in volume fraction between the matrix and the fiber. And the two fibers used in this study were treated first by soaking in alkali (NaOH). Alkali (NaOH) treatment causes the surface to be clean from dirt and other impurities but the surface becomes rough. Therefore, pretreatment with Alkali on the fiber is needed to increase the bond between the fiber and the matrix [16].

The purpose of this study was to determine the effect of variations in the best volume fraction of the composite of coconut coir fiber and human hair fiber with a polyester matrix on the mechanical properties of tensile and impact tests. And the results of the research on composites of coconut coir fiber and human hair waste with the best volume fraction can be an alternative to replace synthetic fibrous materials by utilizing abundant sources, namely coconut coir fiber and human hair waste.

2 Research Methods

This study uses a hybrid composite. Hybrid composites are composites consisting of two different types of fiber and made into one lamina, namely chopped fiber and continuous fiber. The method used in this study is the hand-layup method. The hybrid fiber orientation or two types of fiber orientation, they are namely random fiber in human hair and continuous fiber in coconut fiber. The process of making this method is by pouring the resin by hand into a mold that contains fibers. Then apply pressure while leveling with a roller or brush. This process is repeated until the required thickness is reached. An illustration of making using the hand-layup method can be seen in Fig. 1.

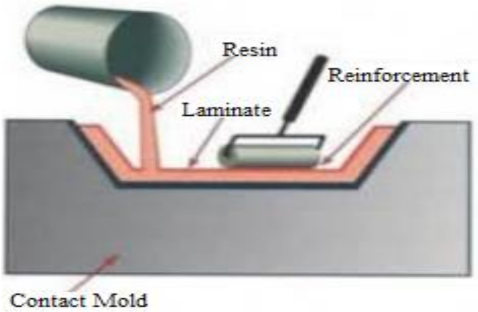

Fig. 1 Hand-layup method [17]

2.1 Fiber

This study used two types of fiber, namely coconut fiber and human hair fiber. Both fibers are obtained from the surrounding environment. Coir fibers and human hair before being used to make composites must be washed thoroughly using clean water until there is no dirt. When the two fibers were washed, they were then treated with a 5% NaOH solution by soaking the fibers in 5% NaOH for 2 hours. Immersion using NaOH liquid with a concentration of 5% is carried out because it can improve the mechanical properties of the composite itself [9]. After treatment, the two fibers were then washed clean until the washing water became clear. After washing, the coconut fiber and human hair were dried at room temperature for 24 hours. Then the human hair fiber is cut at a size of 3 cm because the size of 3 cm has a high tensile strength for human hair fiber [12]. The coco fiber used is a long coir fiber with a length following the size of the composite mold. The ratio of coconut coir fiber and human hair used is 1:1. Human hair fiber and coconut coir fiber can be seen in Fig. 2 and 4.

Fig. 2. Human hair fiber

Fig. 3 Human hair fiber 3 cm

Fig. 4 Coconut fiber

2.2 Matrix

In this research, the matrix used is the yukalac 157 BQTN-EX polyester resin matrix. Unsaturated polyester resins are widely used for composite applications in the industrial world due to their relatively low price, good dimensional stability, fast curing time, and easy handling [18]. Polyester resin has good mechanical strength and is supported at an affordable price because it has the following properties [19]:

1. The adhesion force is quite good
2. Good resistance to heat, acids, bases, and chemicals.
3. Forms good composites with glass fiber, plastic, metal, wood, and natural fibers.

The addition of a catalyst to the polyester resin affects its mechanical properties, in this study the catalyst used was MEKPO (Methyl Ethyl Ketone Peroxide). The MEKPO catalyst used is only 1% of the resin because the addition of a 1% catalyst can provide a high tensile strength value compared to the percentage above or below 1% [20].

2.3 DoE (Design of Experiment)

Design Of Experiment is information about the experimental design that will be carried out in this research. In this study, there were 18 specimens consisting of 9 specimens for tensile tests and 9 specimens for impact tests. The basis for taking this DoE is in previous research, namely the research of Nanda, et al [13]. Table 1 is a sample design for tensile testing and impact testing.

Table 1. DOE *(*Design Of Experiment*)*

2.4 Tools and Materials

In this study there are several tools and materials used by researchers, these tools and materials are as follows: Measuring cup, Scales, Paintbrush, Composite molding, Coconut fiber, Human hair fiber, Yukalac 157 polyester resin BQTN-EX, MEKPO Catalyst, NaOH 5%, and Wax

2.5 Testing

The tests carried out by researchers are 2 types of tests including tensile testing and impact testing. This test took place at the ATMI Surakarta Polytechnic Laboratory (Table 1)

Table 1. Tensile dan impact test result

Name	Testing	Human Hair Fiber (%)	Coconut Fiber(%)	Resin Polyester(%)
Fraktion 10:90	1 2 3	5	5	90
Fraktion 15:85	1 2 3	7,5	7,5	85
Fraktion 20:80	1 2 3	10	10	80

2.5.1 Tensile Testing

The tensile test is used to measure the resistance of a material to a statically applied force gradually. The purpose of tensile testing is to determine the strength, strain, and tensile modulus of the composite board that has been made [21]. In this study, the standard used is the ASTM D638 standard The form of the Dimension [22] can be seen in Fig. 5 and tensile test sample can be seen in Fig. 6.

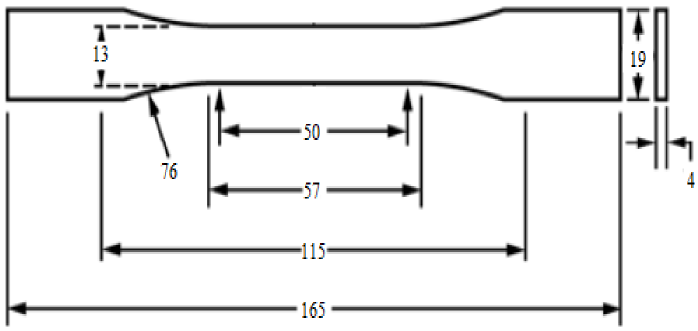

Fig. 5. Dimension ASTM D638[22]

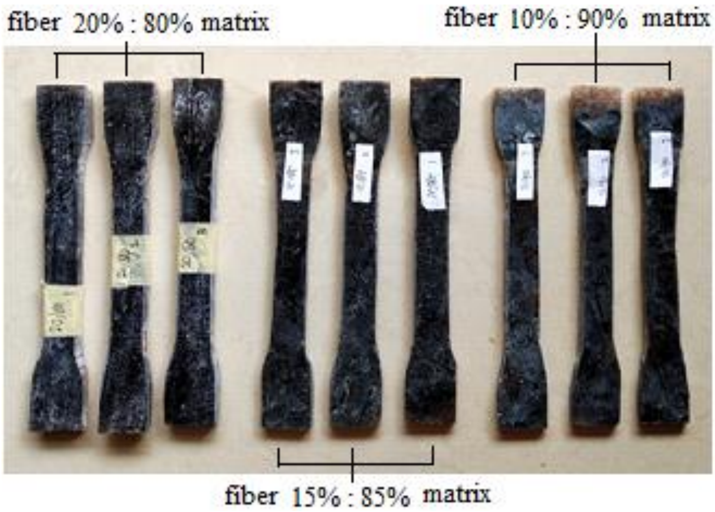

Fig. 6 Tensile test sample ASTM D638

2.5.2 **Impact** Testing

Impact testing aims to measure the amount of energy that can be absorbed by a material until the material breaks. This impact test is a material response to a sudden load, which aims to determine the toughness of a material or material against dynamic loading so that it can be known whether the material or material being tested is brittle or strong. This impact test is the absorption of potential energy from a pendulum of a load that swings from a certain height and strikes the test object or specimen so that the test object or specimen is deformed. The more energy absorbed, the greater the impact strength of a load [17]. In this study, the standard used for impact testing is ISO 179-1. shape dimension are shows fig. 7 and shape of the he shape of the impact test sample can be seen in Fig.8.

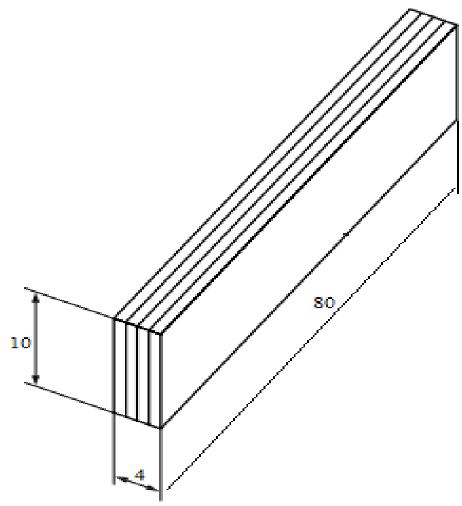

Fig. 7 Dimension ISO 179-1[23]

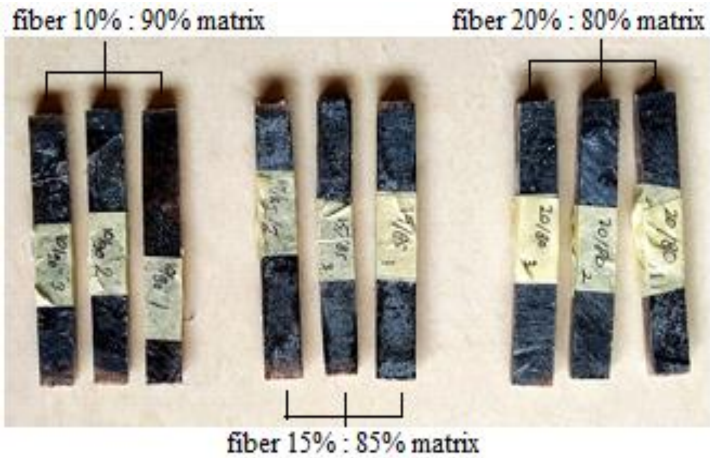

Fig. 8 Impact test sample ISO 179-1

2.6 Sample Making Procedure

The procedure or steps in making hybrid composite samples in this study are as follows:

1. Prepare human hair fiber and coconut fiber.
2. Soak human hair fiber and coconut fiber with 5% NaOH for 2 hours and then wash it clean.
3. Then dry for 24 hours.
4. Prepared tensile and impact test sample molds according to predetermined standards, namely the ASTM D638 standard for tensile tests and ISO 179-1 standard for impact tests that have been coated with wax for easy removal of the composite from the mold when it is dry.
5. Making samples in molds by placing fibers and resins in molds according to a predetermined volume fraction, in the preparation of coconut fibers is done lengthwise according to the mold while human hair fibers are done randomly with a length of 3 cm.
6. Leave the mold for 24 hours.
7. Then remove the sample from the mold when it is dry.

3 Results and Discussion

The following are the results and discussion of each test carried out, namely tensile testing using the ASTM D638 standard and impact testing using the ISO 179-1 testing standard described below.

3.1 Tensile Testing

From the results of the tensile testing of the hybrid fiber composite material, there are several variations in its tensile strength. The volume fraction of 10% fiber and 90% matrix that has been carried out has different values in the first, second, and third tests. In testing the hybrid composite material with a ratio of 10:90 fiber and matrix, it can be seen in the tensile test stress-strain curve in Fig. 9.

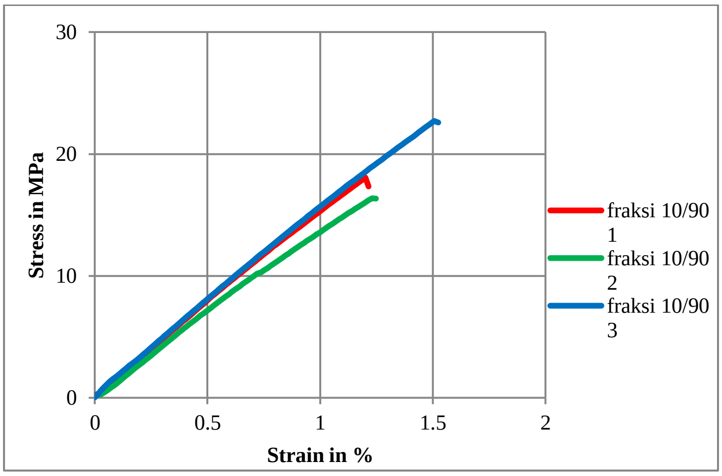

Fig. 9 Strain stress curve tensile test fiber composite 10%: 90% matrix

In the curve above, the first test has a tensile strength value of 18.2 MPa with an elongation of the sample or its strain as much as 1.2% of the initial length of the sample. Then the second test with the same fraction of fiber and matrix 10:90 has a tensile strength value of 16.5 MPa with an elongation of the sample or the strain of 1.2% of the initial length of the sample. In the third test, the variation of the fiber volume fraction and the matrix of 10:90 has a tensile strength value of 22.9 MPa with an elongation of the sample or the strain of 1.5% of the initial length of the sample.

Subsequent testing with different fractions, namely with fiber volume fraction and matrix 15:85. The tensile stress-strain curve of the composite tensile test with fiber and matrix volume fraction 15:85 can be seen in Fig. 10.

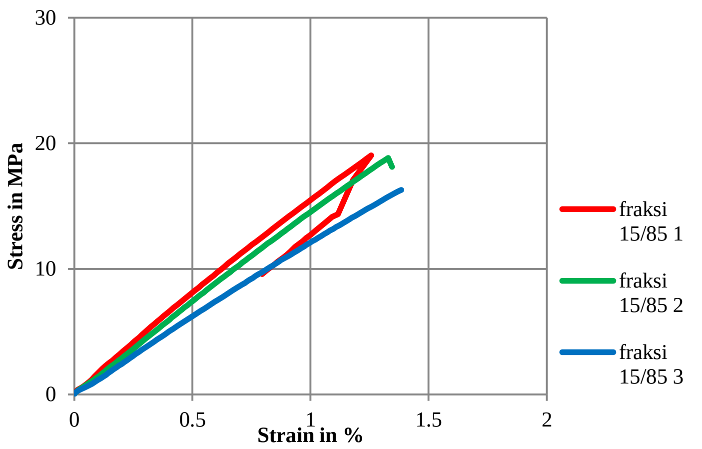

Fig. 10. Strain stress curve tensile test fiber composite 15%: 85% matrix

The first test on the fiber and matrix volume fraction of 15:85 has a tensile strength value of 19.2 MPa with an elongation of the sample or its strain along 1.3% of the initial length of the sample. Then the second test has a tensile strength of 19 MPa with a strain of 1.3% of the initial length of the sample. Then the last test has a tensile strength of 16.3 MPa and a strain of 1.4% of the initial length of the sample.

Then the tensile test of the hybrid composite material with the last volume fraction, with variations in the volume fraction of fiber and matrix 20:80. The stress-strain curve of the composite tensile test with fiber and matrix volume fraction 20:80 can be seen in Fig. 11.

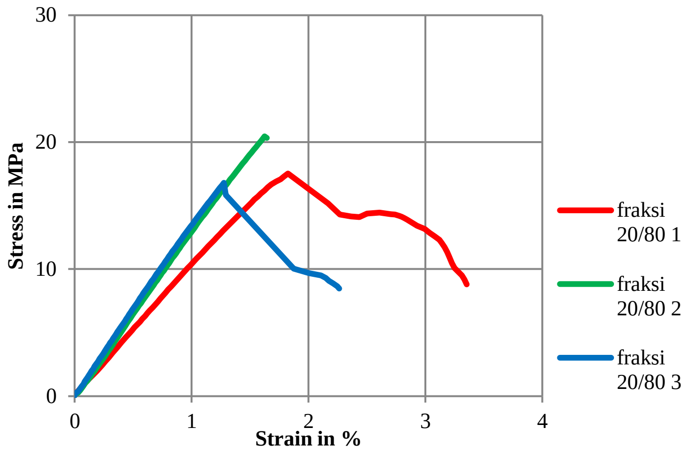

Fig. 11 Strain stress curve tensile test fiber composite 20%: 80% matrix

In the first test, the fiber and matrix volume fraction of 20:80 had a tensile strength value of 17.6 MPa with an elongation of the sample or the strain of 1.8% of the initial length of the sample. Then the second test with the same fraction, namely fiber and matrix 20:80 has a tensile strength value of 20.6 MPa with the resulting strain of 1.6% of the initial length of the sample. The last test is the third one with the same fraction having a tensile strength of 16.9 MPa with an elongation of the sample or the strain of 1.3% of the initial length of the sample.

From the tensile tests that have been carried out, there are 9 tensile test samples and 3 variations in the volume fraction of fiber and matrix composites ranging from fiber and matrix variations of 10:90, 15:85, and 20:80. The overall tensile test results diagram along with the average of each volume fraction can be seen in Fig. 12.

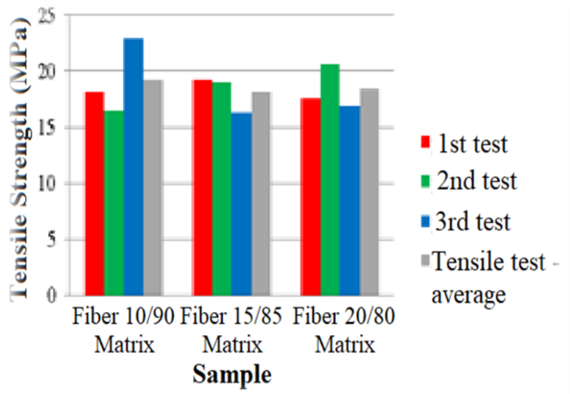

Fig. 12 Average tensile strength diagram

From the three variations of the volume fraction, various values of tensile strength and strain were obtained. This is due to the difference in volume fraction. In this case, the tensile test that has been carried out has an average tensile strength value. The average tensile strength in the fiber and matrix volume fraction of 10:90 is 19.2 MPa with a strain of 1.3% of the initial length of the sample. The average tensile strength in the second volume fraction with a ratio of fiber and matrix 15:85 was 18.2 MPa and the strain was 1.3% of the initial length of the sample. Then the average tensile strength of fiber and matrix volume fraction 20:80 is 18.4 and the strain is 1.6% of the initial length of the sample. From the tests that have been carried out, it can be seen that the tensile strength with the addition of more than 10% fiber in the composite of human hair hybrid fiber and coconut fiber with a polyester matrix reduces the tensile strength value. This is due to improper fiber impregnation when the fiber is more than 10%. And the addition of high fiber for tensile strength results in poor fiber efficiency causing a decrease in tensile strength [10].

3.1 Impact Testing

Impact testing of hybrid human hair and coconut fiber composites using a polyester matrix has variations in the test results. The results of the first test with a ratio of fiber volume fraction and matrix 10:90 can be seen in Fig. 13.

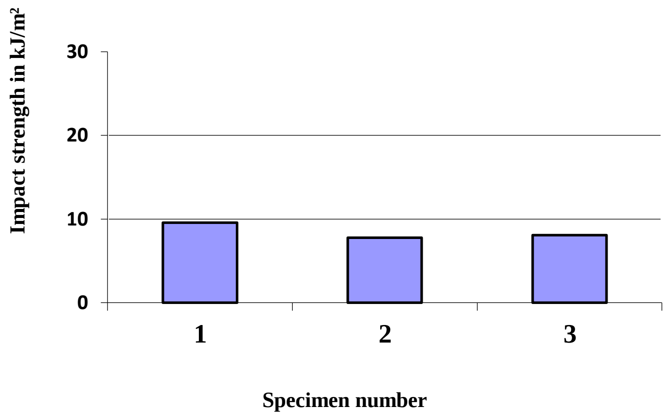

Fig. 13 Composite impact test diagram with 10% fiber and 90% matrix

Fig. 13 shows the results of the first test with a ratio of fiber volume fraction and matrix of 10:90 having an impact value of

9.57 kJ/m². Then the second test with fiber volume fraction and 10:90 matrix got an impact value of 7.77 kJ/m². The third test on the same volume fraction had an impact value of 8.09 kJ/m².

Then in the hybrid composite impact test with a fiber volume fraction of 15:85, the matrix that has been carried out can be seen in Fig. 14.

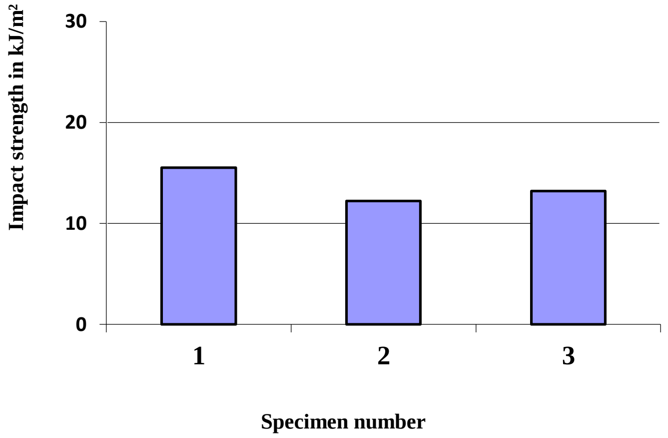

Fig. 14. Composite impact test diagram with 15% fiber and 85% matrix

In the diagram above, a hybrid composite with a fiber volume fraction of 15:85 matrix shows that the first test has impact strength of 15.54kJ/m². Then in the second test of the fiber and matrix volume fraction 15:85, it has impact strength of 12.23kJ/m². The third test of this volume fraction has impact strength of 13.21kJ/m².

The results of the Charpy impact test of the hybrid human hair and coconut fiber composites with a polyester matrix at the fiber volume fraction and the matrix 20:80 can be seen in Fig. 15.

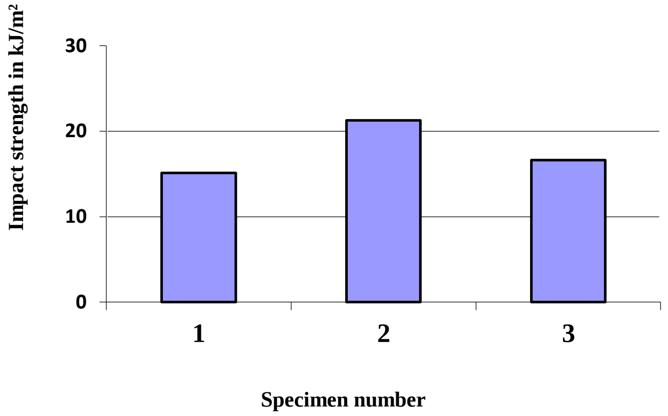

Fig. 15 Composite impact test diagram with 20% fiber and 80% matrix

In Fig. 15 it is known that the impact strength is 15.12kJ/m² in the first test. Then in the second test, the 20:80 fractions has an impact strength of 21.27 kJ/m². The third test of the same fraction of fiber and matrix 20:80 has impact strength of 16.62kJ/m².

Charpy impact testing that has been carried out on hybrid composites of human hair fiber and coconut fiber using a polyester matrix with 3 variations of fractions has various impact strengths. Fig. 16 is an overall bar chart of the Charpy impact test that has been carried out.

The increase in fiber content in the composite has an impact on the impact strength. The higher the fiber content, the higher the impact strength. This can be seen in Fig. 16. The diagram shows that the average impact strength of the fiber and matrix fractions is 10:90 and has impact strength of 8.48kJ/m². Then the test on the second volume fraction of fiber and matrix composition 15:85 has average impact strength of 13.66kJ/m².

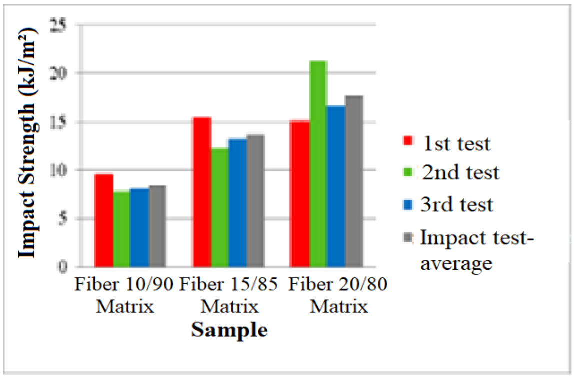

Fig. 16 Average impact strength diagram

The third volume fraction with fiber and matrix composition of 20:80 has impact strength of 17.67kJ/m². The addition of fiber up to 20% in the impact test is different from the tensile test where the impact test gives an inverse value to the tensile test. The impact test gave the greatest value at 20% fiber composition. This is because 20% of the fiber can blend optimally with the matrix and provide good impact strength.

4 Conclusion

Based on the research that has been done, the variation of the volume fraction of the hybrid composite of coconut fiber and human hair waste with a polyester matrix greatly affects the mechanical properties of the tensile test and impact test. The highest tensile strength of the composite lies in the composition of the small fiber volume fraction, namely the fiber volume fraction and the matrix is 10:90 with a tensile strength of 19.2 MPa. The highest impact strength lies in the composition of the largest fiber volume fraction, namely the variation of the fiber volume fraction and the matrix is 20:80 with an impact strength of 17.67 kJ/m².

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