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Effect of Layers on Delamination and Tensile Strength of Woven Fiber Composites with Polyester Matrix

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ABSTRAK

Proses penyambungan komposit dapat menggunakan perekat maupun secara mekanik dengan cara diberi lubang. Pada saat proses pemberian lubang pada komposit dapat menimbulkan delaminasi pada komposit. Delaminasi dan ketebalan layer sangat berpengaruh terhadap kekuatan sambungan komposit berlubang. Tujuan dari penelitian ini adalah untuk mengetahui pengaruh faktor delaminasi dan jumlah layer terhadap nilai kekuatan tarik komposit. Material yang digunakan dalam penelitian ini adalah resin polyester dan serat woven fiber glass. Metode yang digunakan adalah vacum bagging dengan variasi jumlah layer yaitu 3 layer, 4 layer, 5 layer, dan 6 layer. Pengujian uji tarik mengacu pada standar ASTM D638. Spesimen yang telah dipotong sesuai dengan standar kemudian akan dilubangi pada bagian tengah dengan diameter lubang 4 mm menggunakan mesin *milling dengan kecepatan putar 1000 rpm dan Feeding speed* 0,050 mm/menit. Nilai kekuatan tarik terbesar didapatkan pada variasi 6 layer sebesar 237,448 MPa dan nilai terendah didapatkan pada variasi 3 layer sebesar 186,221 MPa. Nilai delaminasi sangat berpengaruh terhadap kekuatan tarik komposit, dimana semakin banyak layer maka nilai delaminasi akan semakin menurun dan meningkatkan kekuatan tarik komposit.

Kata Kunci : komposit, delaminasi, lapisan, kekuatan tarik, lubang.

ABSTRACT

The composite joining process can use adhesives or mechanically by making holes. During the process of making holes in the composite, it can cause delamination in the composite. Delamination and layer thickness greatly influence the strength of hollow composite joints. This research aims to determine the effect of delamination factors and the number of layers on the tensile strength value of the composite. The materials used in this research are polyester resin and woven glass fiber. The method used is vacuum bagging with variations in the number of layers, namely 3-layers, 4-layers, 5-layers, and 6- layers. Tensile testing refers to ASTM D638 standards. Specimens that have been cut according to standards will then be perforated in the center with a hole diameter of 4 mm using a milling machine with a rotation speed of 1000 rpm and a feed speed of 0.050 mm/minute. *The highest tensile strength value was obtained in the 6-layer variation of 237.448 MPa and the lowest value was obtained in the 3-layer variation of 186.221 MPa. The delamination value greatly influences the tensile strength of the composite, where the more layers, the delamination value will decrease and increase the tensile strength of the composite.*

Keywords: *composite, delamination, layers, tensile strength, hole.*

INTRODUCTION

Technological developments in the manufacturing industry are very rapid. One of the sciences that is developing in the manufacturing industry is materials science. Metal is an example of a material that is often used, especially in the manufacturing industry, but metal materials have poor properties, namely they are heavy and not resistant to corrosion. The nature of metal being heavy and not resistant to corrosion is of course its own weakness. Because of these weaknesses, new materials are needed in today's industrial world. This is the reason why many manufacturing and automotive companies are switching to using composite materials as alternative materials [1][2].

Composites are a type of material engineering that aims to obtain a new material. Composite comes from the word "to compose" which means to combine[3]. So a composite is a material in the manufacturing industry that consists of several mixtures or combinations of materials both micro and macro where the properties of the material are different in shape and chemical composition from the original substance [4]. Fiber composites continue to be researched and developed because the properties of fiber composites are lighter and stronger compared to metal. This causes the need for components made from light but strong materials to continue to increase. One of the materials commonly used to carry out material engineering is woven glass fiber.

Woven fiber reinforced composite is a type of composite material that uses woven fibers in mutually perpendicular directions as one of its components because it has strong but light material properties. Woven fibers have advantages, including being resistant to corrosion, high strength, and environmental resistance, so that woven fibers can be used as a reinforcement in synthetic fiber-reinforced polymer composite materials. Woven fibers also have the advantage of being easy to shape according to needs using a mold of a certain size [5]. This is of course a distinct advantage of this woven-based fiber which will later be adapted to the shape of the mold.

The process of making woven fiber composites can be done using the vacuum bagging method. Vacuum bagging is a method of making composite specimens by using an airtight bag to press the material into a mold so that the layers fuse into a structural composite material [6]. Furthermore, the final work in the woven fiber composite machining process is usually also required to make several shapes such as making holes. The holes in the woven fiber composite will later be used for the assembly process between one component and another using bolts. During the hole-making process, delamination occurs. Delamination is a type of damage to laminate composites which affects tensile strength [7].

Research on the effect of making holes in woven fiber composites has also been carried out by Diharjo K., (2006)[5], namely by varying the way holes are made on the tensile strength of glass fiber and plastic sack fiber hybrid composites. In this specimen, a hole will be made in the middle with a diameter of 4 mm, 6 mm, and 8 mm so that it can connect one part to another. In the hole-making process, there are two methods used, namely the drilling process and the molding process. The aim of the research conducted by Diharjo K., et al. (2013)[8] was to determine the effect of making holes with different diameter variations on the tensile properties of hybrid composites of glass and plastic fiber sacks. However, this research still has shortcomings, namely how many layers are used in making composites to get a comparison of the number of layers to get maximum results.

Based on previous research, it was found that there was a deficiency in that there was no variation in the number of layer thicknesses with a hole diameter of 4 mm in the woven fiber composite. Varying layer thickness is very important to compare the tensile strength values of woven fiber composites. Based on this background, this research aims to analyze the value of variations in the number of layers and composite fracture analysis with the addition of a hole diameter of 4 mm on the tensile strength of woven fiber composites with a polyester matrix using the vacuum bagging process.

METHOD

The composites are made from 200 matt woven fiber as a reinforcing material and Yukalac C-108B polyester as a matrix using vacuum bagging process. This process helps to remove excess resin and trapped air so that voids can be minimized [9]. The variations in the number of layers are 3 layers, 4 layers, 5 layers and 6 layers, where a hole will then be made in the center of the woven fiber composite with a hole size of 4 mm. The punching process uses a milling machine with a speed of

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1000 rpm and a feed speed of 0.050 mm/minute. Woven fiber composites that have been formed according to standard sizes and have been perforated are then subjected to tensile testing. Tensile testing was carried out using a Universal Testing Machine using ASTM D638 to obtain tensile strength, strain, and modulus of elasticity. ASTM D638 test standard specimen dimensions which can be seen in Figure 1.

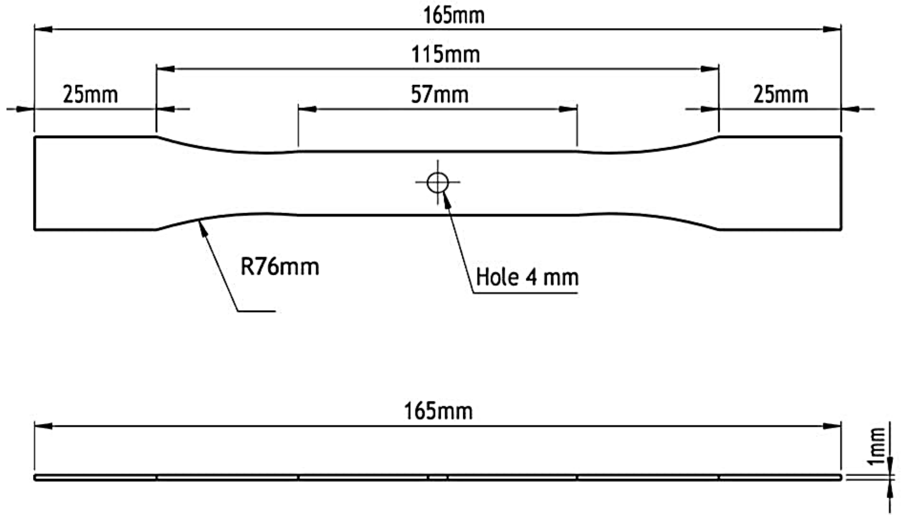


Figure 1. Standard of ASTM D638

The delamination phenomenon was also looked for in this research. Figure 2 shows the delamination phenomenon that occurs in composite materials. The method for measuring the amount of delamination in composite drilling results is by looking for the delamination factor (Fd) [12][13].

$$F_d = \frac{D_{max}}{d} \quad (1)$$

Information:
F_d = Delamination
D_{max} = Maximum diameter of delamination (mm)
d = Drill tool diameter (mm)

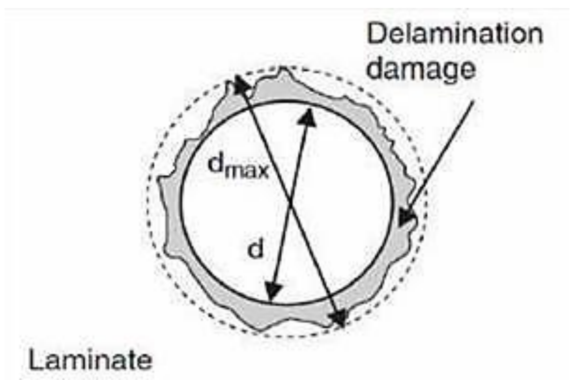


Figure 2. Delamination Phenomenon

RESULTS AND DISCUSSION

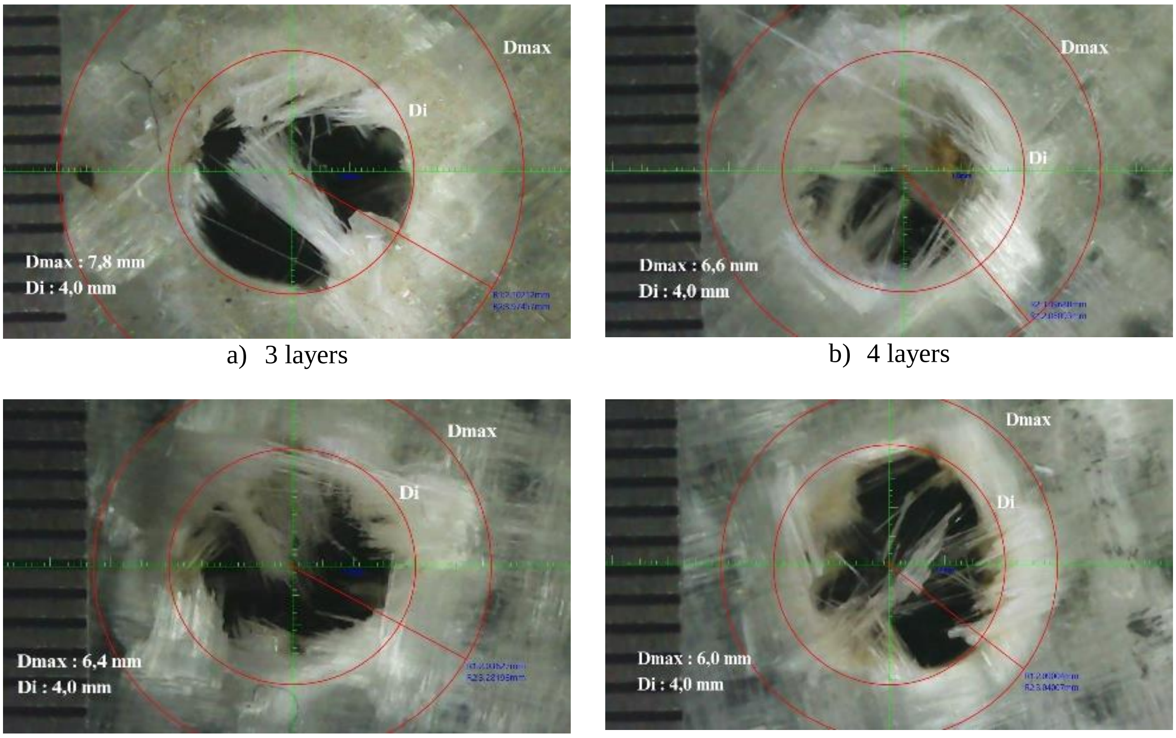
Delamination

Delamination is damage that occurs to a material in the form of cracks. The cause of the delamination factor in this research composite is the process of making holes using a drill press machine. So data was collected regarding delamination that occurred as a result of making holes in the composite. Then delamination measurements were carried out which can be seen in Table 1.

Table 1. Delamination

Layers	Delamination factors
3 Layers	1,6
4 Layers	1,39
5 Layers	1,24
6 Layers	1,2

Based on Table 1, data shows that the number of layer variations affects the delamination value of each composite. The highest delamination factor was obtained from the average results of 3 layers with a value of 1.6. Then the lowest delamination was obtained from the average results of 6 layers with a value of 1.2. The number of layers of woven fiber composite is a factor in determining the delamination value. The greater the number of layers, the smaller the delamination value, this is because the greater the number of layers, the mechanical properties of the composite will become stronger and more brittle [14][15]. Figure 3 shows the results of photos of delamination caused by the punching process with a blade diameter of 4 mm.



a) 3 layers

b) 4 layers

c) 5 layers

d) 6 layers

Figure 3. a)-d) Delamination of Holes

Figure 3 shows that each woven fiber composite specimen has a delamination value caused by the drilling process. The delamination factor occurs due to drilling when the blade starts to eat into the specimen, causing the specimen to crack or separate between the fiber layers. In the 6-layer variation, the maximum diameter value was obtained, namely 6.0 mm, then in the 5-layer variation the maximum diameter value was obtained at 6.4 mm, in the 4-layer variation the maximum diameter value was obtained at 6.6 mm, and finally in the 3-layer variation the value was obtained. maximum diameter of 7.8 mm. It can be concluded that the thicker and more layers the composite has, the smaller the delamination value will be [16]. Apart from that, using a sharp drill bit also has a big impact on drilling, so the right method is used when drilling. The value obtained from the delamination results will later be very influential in collecting tensile test data on specimens [12].

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Tensile Stress

Tensile testing used the Universal Testing Machine Zwick Roell All Round Z250R which is located in the Mechanical Engineering Laboratory of the Sumatra Institute of Technology. Tensile testing was carried out on woven fiber composite specimens using the ASTM D638 tensile testing standard. The purpose of tensile testing is to find the effect of the number of layers on the mechanical properties of the composite. The data obtained in the tensile test can be seen in Figure 4.

Figure 4 shows the values of tensile strength and delamination factor concerning variations in the number of layers. The number of layers is very influential in determining the tensile strength value [16]. The highest tensile strength value was obtained in woven fiber composite specimens with variations in the number of layers in the 6-layer, namely 237 MPa, and then the tensile strength value in the 5-layer was obtained, namely 229 MPa. The tensile strength value of the composite with 4-layer is 222, while the lowest tensile strength value is obtained when varying the number of layers with 3 layers, namely 186 MPa.

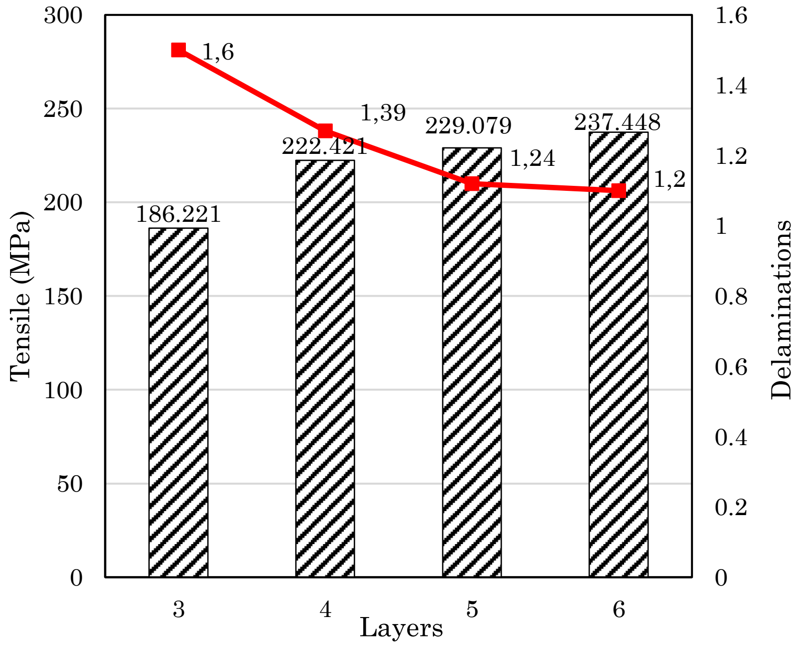

Figure 4. The Effect of The Number of Layers on Tensile Strength and Delamination

Apart from the tensile strength value, the delamination value for each fiber composite specimen was also obtained. The highest delamination value was obtained in the 3-layer variation. Then the lowest delamination value was obtained in the 6-layer variation. The number of layers affects the delamination value. Where the greater the number of layers, the smaller the delamination value obtained. Apart from that, the delamination value influences the tensile strength. This is because an initial crack will form when the hole is made, which will later affect the delamination value. The greater the initial crack, the greater the delamination value obtained, and the greater the delamination value obtained, the smaller the tensile strength value [17].

The delamination phenomenon that occurs in holes does not have a significant effect on the tensile strength value because the large number of layers greatly influences the tensile strength of the composite and the delamination values obtained are not much different. The more layers or layers, the greater the tensile strength of the fiber composite. The number of layers influences the tensile strength value rather than the delamination value in the composite hole. It can be concluded that the delamination value of each specimen does not have a significant effect on the tensile strength of the composite. The tensile strength value of the fiber composite is constant so the delamination value does not have much influence.

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Apart from the tensile strength and delamination values in this research, there are also strain values. The strain values in this study are presented in diagram form. The strain value diagram in composite tensile testing can be seen in Figure 5.

Figure 5 shows the effect of the number of layers of each specimen on the strain value of the woven fiber composite. During tensile testing, each composite specimen will increase in length so that the strain value is obtained. The strain value is obtained from the increase in length of the woven fiber composite specimen when the tensile test is completed. From variations in the number of layers, different strain values are obtained for each specimen [17][18].

The highest tensile strength value of the composite was obtained by varying the number of layers 3, namely 1.611%, layer 4 with a strain value of 1.55%, layer 5 with a strain value of 1.52% and the smallest value was obtained by varying the number of layers of 6 layers, namely 1.38%. The strain value obtained in the research shows that with each increase in the number of layers in the woven fiber composite, the value of the strain will become smaller and vice versa, the fewer the number of layers, the greater the strain value obtained in the woven fiber composite specimen during tensile testing. This is because the more layers in the composite, the more it will affect the mechanical properties of the composite and will make the composite brittle. However, on the contrary, the fewer the number of woven fiber composite layers, the greater the strain value will be because the composite is ductile [14][19].

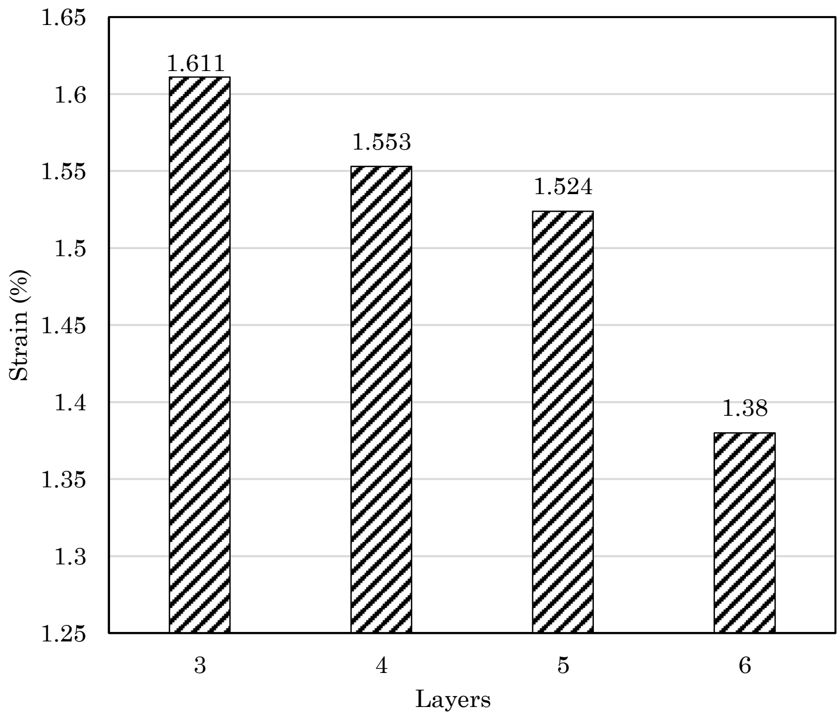

Figure 5. Strain Value

Apart from looking for the strain value, the elastic modulus value was also looked for in this research. The modulus of elasticity is a value obtained from the result of tension divided by strain. The elastic modulus is the value of the resistance of a material to experiencing elastic deformation or changes in shape to the material when a tensile force is applied to the material [14]. Data obtained from research results regarding woven fiber composites, the elastic modulus value can be seen in Figure 6, the following graph of the effect of the number of layers on the elastic modulus value.

The modulus of elasticity is the value of an object that shows the resistance of the object. The modulus of elasticity value shows that the greater the value obtained, the less likely it is that the composite specimen will experience changes in shape or deformation. In Figure 6, the elastic modulus with the 6 layer variation has the largest value, namely 22.76 GPa, then with the 5 layer variation the elastic modulus value is 17.94 GPa, then with the 4 layer variation the elastic

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modulus value is 16.09 GPa and the smallest value is in the 3 layer variation, it is 15.91 GPa. So the greater the number of layers will make the elastic modulus value greater and the fewer the number of layers in the composite, the smaller the elastic modulus value will be. Varying the number of layers results in the thickness of the specimen increasing in number of layers, making the fiber composite specimen have strong and brittle properties. Meanwhile, the fewer the number of layers, the more ductile the mechanical properties of the composite will be, so that the elastic modulus value becomes smaller [12]. Then, after obtaining the tensile test data, the next step is to create a diagram from the data. A graph of the effect of the number of woven fiber composite layers on tensile strength can be seen in Figure 4.

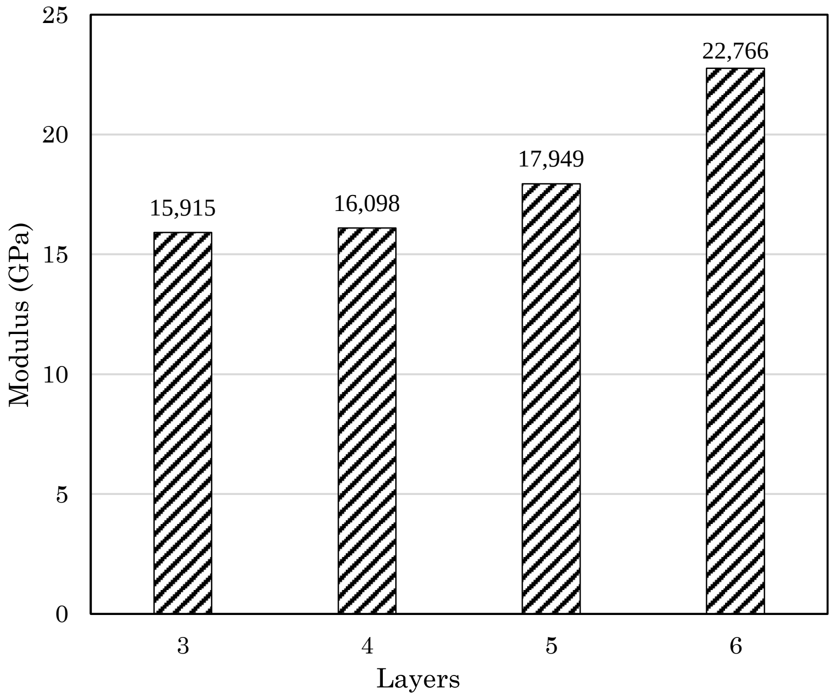

Figure 6. Elastic modulus value

Composite Failure

Fractures that occur in composites are failures that occur due to pressure in tensile testing. In this research, fracture results were obtained from tensile testing. Where as a result of the fracture, a pressure core is found around the hole, resulting in failure at the fracture such as cracks, fibers coming out of the matrix and also delamination. We can see photos of the fracture results that occur in the composite during tensile testing in Figure 7.

Figure 7 shows that each composite specimen will experience fractures that occur around the hole. Fiber fracture and tension are failures that often occur in woven fiber composites. Woven fiber composites have failure forms, namely delamination, cracks, and fibers coming out of the matrix. The failure that occurs is because the fiber pattern in the woven fiber composite has vertical and horizontal fiber directions, whereas if the composite is pulled until it breaks, the composite will lose its shape and structure, resulting in the fibers being pulled out and separated from the matrix or binder. Fractures that occur in the composite are around the hole because the tensile force applied during testing will be concentrated in the middle of the test object where the middle is the weakest point because it has delamination due to making the hole. The separation of the fibers and matrix in the composite causes the matrix to crack, resulting in the composite losing its structural properties and changing shape [20][10].

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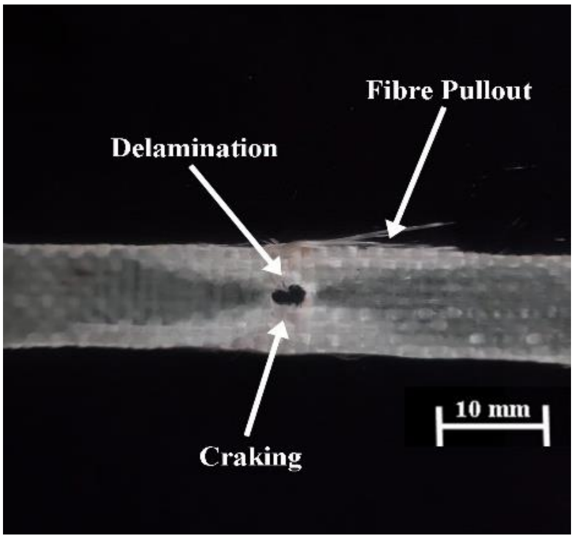
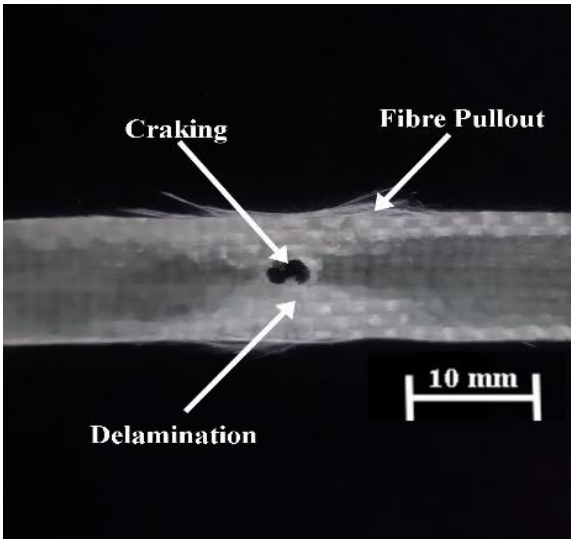
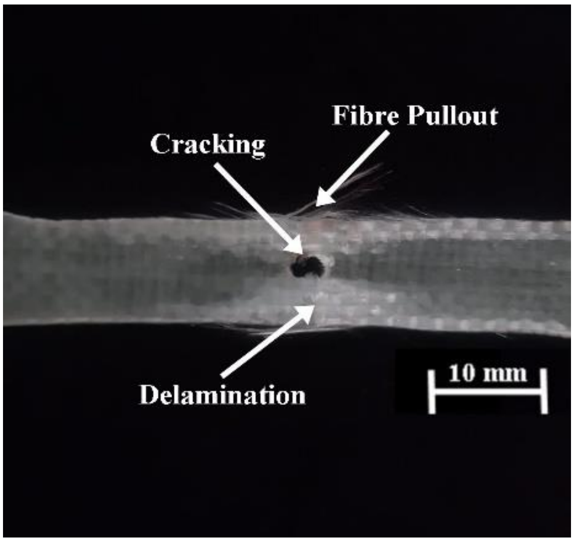


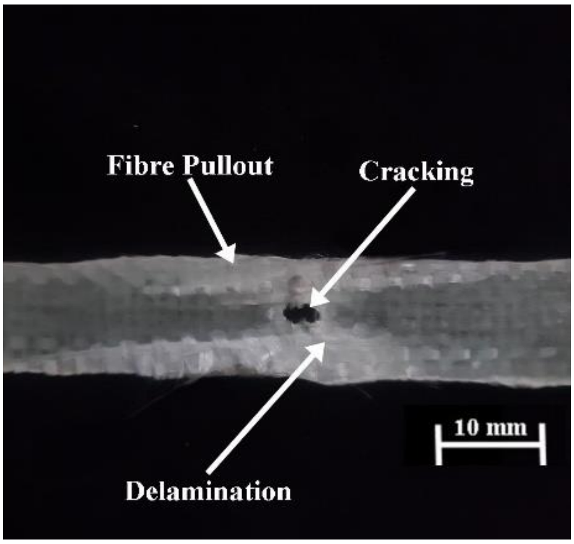
a) 3 layer



b) 4 layer



c) 5 layer



d) 6 layer

Figure 7. Specimens failure

CONCLUSION

After collecting and analyzing the data in the research, it can be concluded that the highest tensile strength value was obtained in the 6-layer specimen with a variation of 237.44 MPa, while the lowest tensile strength was obtained in the 3-layer specimen with a value of 186.22 MPa. Tests on the specimens also obtained strain data, where the highest value was for the 3-layer specimen, namely 1.61% and the lowest value was 1.38% for the 6-layer specimen. Meanwhile, the largest elastic modulus value was obtained in the 6-layer specimen, namely 22.76 GPa and the smallest value was obtained in the 3-layer specimen, namely 15.91 GPa. This is because the greater the number of layers will make the specimen have strong and brittle properties. So it can be concluded that the greater the number of layers, the greater the value of tensile strength and modulus of elasticity because the nature of the specimen becomes strong and brittle so that the specimen does not experience deformation, while the fewer the number of layers, the greater the strain value because the nature of the specimen is ductile and will deform when tensile testing is carried out. The highest delamination value was obtained in the specimen with a 3-layer variation, namely 1.6, while the lowest delamination value was obtained in the composite specimen with a 6-layer variation, namely 1.2. The greater the delamination value, the lower the tensile strength of the composite, and the smaller the delamination value, the greater the tensile strength value of the composite. However, the delamination values obtained were not much different between specimens,

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so the delamination values in the specimens did not have much influence on the tensile test. The biggest factor that influences tensile strength is the variation in the number of layers in the woven fiber composite.

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