Infotekmesin
Vol.15, No.02, Juli 2024
p-ISSN: 2087-1627, e-ISSN: 2685-9858
DOI: 10.35970/infotekmesin.v15i2.2216, pp.216-222

The Effect of Angle Orientation on Delamination Factors and Tensile Strength Values in the Drilling Process of Polyester Matrix Woven Fiberglass Composites

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Info Naskah:
Naskah masuk: 18 Januari 2024
Direvisi: 28 Mei 2024
Diterima: 3 Juni 2024

Abstrak

Komposit merupakan suatu material yang terbentuk dari kombinasi 2 atau lebih material. Orientasi sudut kemiringan anyaman dan lubang pada komposit berpengaruh terhadap nilai kekuatan tarik. Penelitian ini bertujuan untuk menganalisa pengaruh variasi sudut kemiringan anyaman dan fenomena delaminasi terhadap nilai kekuatan tarik. Proses pembuatan komposit serat *woven fiberglass* dan campuran resin dan katalis menggunakan metode *vacuum bagging*. Variasi yang digunakan pada penelitian ini yaitu sudut kemiringan anyaman 0°, 15°, 30° dan 45°. Spesimen uji tarik menggunakan standar ASTM D638. Spesimen yang telah dipotong selanjutnya akan dilubangi dengan diameter 4 mm menggunakan mesin *Milling*. Pengujian tarik yang dilakukan menggunakan *Universal Testing Machine*. Nilai kekuatan tarik tertinggi terdapat pada sudut 0° dengan nilai sebesar 189,30 MPa dan kekuatan tarik terendah pada sudut 45° dengan nilai sebesar 34,25 MPa dan untuk nilai faktor delaminasi kurang berpengaruh terhadap nilai kekuatan tarik.

Keywords:
composite;
vacuum bagging;
fiberglasss;
corner orientation;
delamination.

Abstract

Composite is a material that is formed from a combination of 2 or more materials. The orientation of the inclination angle of the webbing on the composite affects the tensile strength value. This research was conducted to determine the effect of variations in the angle of inclination of the webbing and the phenomenon of delamination on the value of tensile strength. The process of making fiberglass woven fiber composites and a mixture of resin and catalyst uses the vacuum bagging method. The variations used in this study are the angle of inclination of the webbing 0°, 15°, 30° and 45°. Tensile test specimens using the ASTM D638 standard. The specimens that have been cut will then be perforated with a diameter of 4 mm using a milling machine. Tensile testing was carried out using a Universal Testing Machine. The highest tensile strength value is at an angle of 0° with a value of 189.30 MPa and the lowest tensile strength is at an angle of 45° with a value of 34.25 MPa and for the value of the delamination factor has little effect on the value of tensile strength.

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1. Introduction

The development of technology today not only benefits humans but also impacts the environment. In the world today, countries create environmentally friendly products and maintain the main benefits of these products. The strength of materials with a higher density and resistance to stress also attracts more attention, as they have greater elasticity, resistance to corrosion, cost efficiency, and more.

Composites are a type of material that consists of the combination of two or more materials. The constituent components of a composite consist matrix material that acts as a binder and reinforcement material[1]. By combining at least two materials in one by combining at least two materials in one composite entity, new material characteristics will be produced that have superior quality. One example of a material that is often applied in the process of composite manufacturing process is fiberglass fibers arranged in a woven manner[2].

When performing manufacturing processes on components, both made of metal or non-metallic materials, a joining step is required with other components with other components. In the context of metal components, joining methods include welding, bolting, and riveting. However, in the case of non-metallic materials such as composites, welding cannot be used for joining. be used for joining. Alternatively, one effective way to connect composite materials is by using bolts and rivets. In this joining process, holes need to be made for the placement of the bolts or rivets[3]. However, it is important to remember that there is a risk of defects such as delamination that can occur when making holes. Delamination refers to damage around the hole, and a significant degree of delamination can reduce the strength of the structure. can significantly reduce the strength of the structure. Defects such as delamination that arise as a result of the hole-making process have the potential to cause structural failure because they concentrate tension in the area of the hole[4][5]. From this research, the delamination factor greatly influences the mechanical strength of the composite.

Research that has been conducted by Nguyen (2020)[6] focuses on the tensile strength of carbon fiber and fiberglass materials depending on the orientation. tensile strength of carbon fiber and fiberglass fiber materials depending on the orientation of the fibers with various angles including 0°, 30°, 45°, 60°, and 90°. of the fibers with various angle variations, including 0°, 30°, 45°, 60°, and 90°. The results showed that the long fibers had the highest tensile strength values. Tensile strength values seen at 90° fiber orientation in both, which is about 500 N/mm^2 for fiberglass and 620 N/mm^2 for carbon fiber. Orientation variation fiber angle in fiberglass and carbon fiber composites at orientations of 0°, 45°, and 90° produce higher tensile strength than fiberglass, while at 30° and 60° fiber orientation, fiberglass is superior to carbon fiber.

Research that has been conducted by Pramono (2019)[7]this research analyzes the impact of the effect of single lap type mechanical joints on the tensile strength of polyester composites reinforced with banana stem fibers. Tensile strength of polyester composites reinforced with banana stem fibers. The results of the test results show that the tensile strength of the composite joint specimens that are perforated and perforated with 5% additional fiber experience an increased from 4.911 to 4.990 N/mm^2, while in the specimens that are molded with the addition of 5% fiber increased from 4.174 to 4.602 N/mm^2.

Based on the above explanation, the orientation of the corners and holes in the composite affect the tensile strength and stress distribution. Therefore, it is important to conduct an in-depth research that aims to investigate the effect of variation in fiber direction orientation of fiberglass woven composites with holes on tensile strength values. on the tensile strength value. The results of this study will provide recommendations for the best hole-making position to be applied in industry.

2. Methode

The materials used in this research are yucalac C-108B polyester resin as the matrix and 200 gsm woven glass fiber as the reinforcement. The process of making composites using the vacuum bagging method, this is because the results of the composite manufacturing process can reduce voids[8]. The variations used in this study are 15°, 30°, and 45° woven angle orientations. This can be seen in figure1.

The process of making specimens was carried out experimentally according to the research flow listed in Figure 2. The test to be carried out is a tensile test with ASTM D638 standard with a 4 mm hole in the center which functions as a concentration stress in tensile testing.

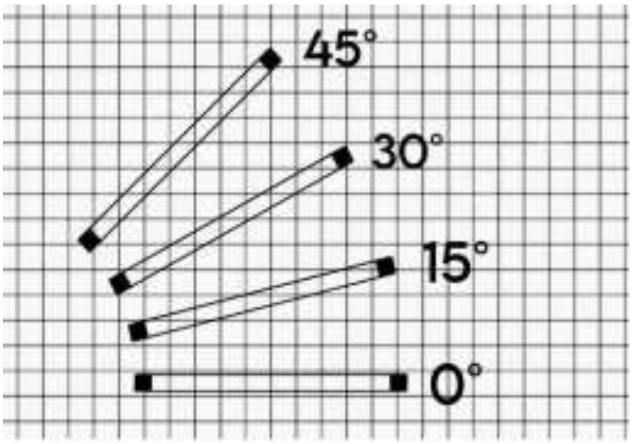


Figure 1. Variation of tilt angle

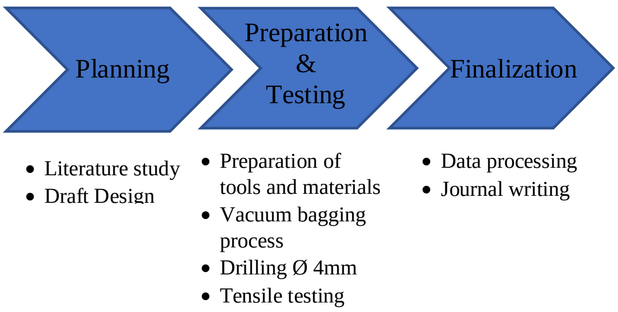


Figure 2. Flowchart diagram

The perforation process is carried out by performing an HSS drill bit with a rotation of 1000 RPM and a feeding rate of 10 mm/s woven with a 4 mm diameter hole This can be seen in Figure 3.

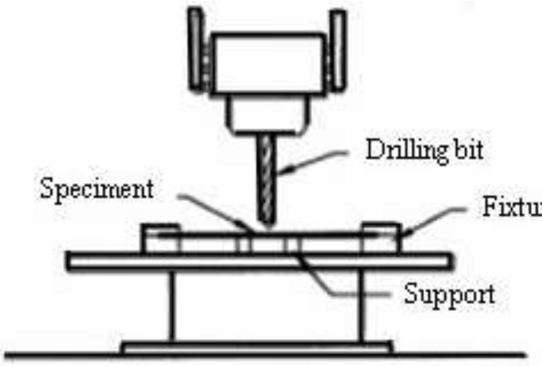


Figure 3. Hole making process drilled

Research on cutting speed in the drilling process composite materials shows that the cutting speed and high feed speed of the drill bit can have an impact on the the occurrence of delamination. Delamination can be seen in Figure 4.

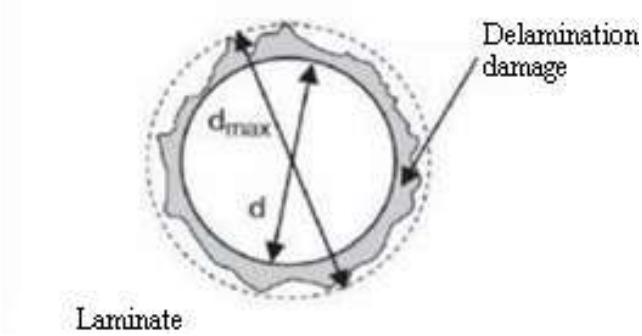


Figure 4. Delamination

$$Fd = \frac{dmax}{d} \qquad (1)$$

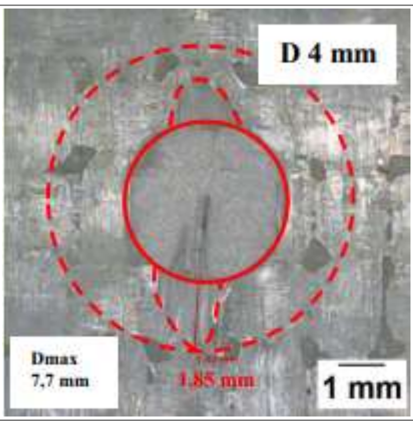
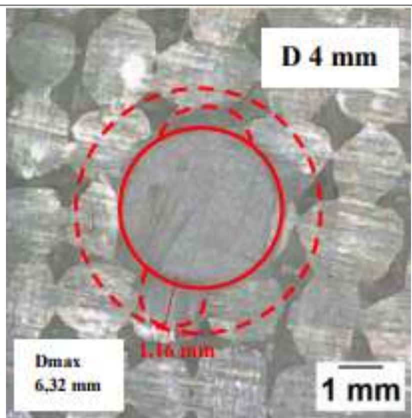
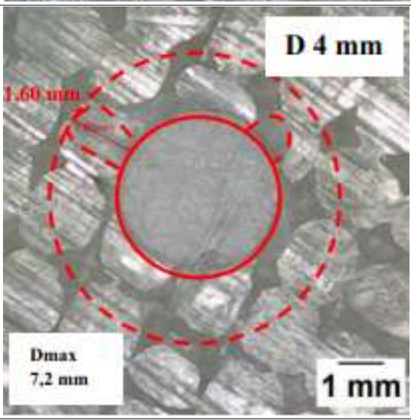
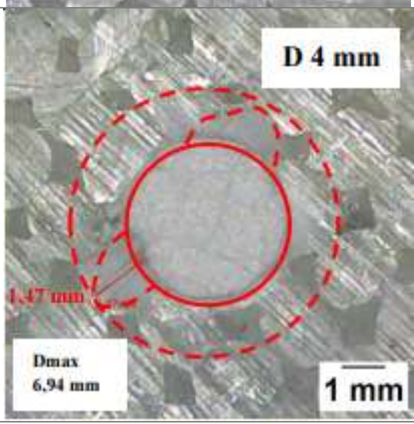
Information:
Fd : Delamination Factor
d_{max} : Maximum Delamination Diameter (mm)
d : Diameter of Drilling Tool (mm)

3. Results and Discussion

3.1 Delamination

Delamination is a potential that exists in composite materials. A contributing factor is the drilling process[9]. The coating on the surface of the composites can

Table 2. Delamination Factor Photograph Results

Delamination Factor Results Image			
Angles Tilt (°)		**Angles Tilt (°)**	
0		30	
15		45	

experience uplift or detachment, causing partially peeled off the inner layer of the composite. To obtain accurate data on delamination resulting from the drilling process, more detailed measurements need to be made. drilling process, more detailed measurements need to be taken. By Thus, more in-depth observations can be made to determine.

Table 1. Delamination Factor Measurement Results Data

Number	Tilt Angle (°)	Delamination Factors
1	0	1.36
2	15	1.26
3	30	1.24
4	45	1.38

Based on Table 1, it can be seen that the Delamination factor of each hole has a similar value. Each hole has a value that is not much different, the highest delamination factor is at an inclination angle of 45°. The highest delamination factor is found at an inclination angle of 45°of 1.38 and the lowest is at an angle of 30° of 1.34. This is because during the drilling process, the angle of the webbing greatly influences delamination. at a drilling angle of 30° the woven can resist damage to the composite layer thereby reducing the delamination factor, whereas at an angle of 45° the opposite is true [10].

The presence of a hole in the center of the specimen decreases the tensile strength of the composite, because it causes a notch effect or acts as a stress concentrator. In composites with 4 and 6 mm diameter holes, hole making by molding is better than drilling. This is due to the absence of delamination damage as occurs when making holes drilled and in the area around the printed hole there is no fiber poor area (rich matrix). However, composites with a drilled hole diameter of 8 mm have a higher tensile strength. The effect of increasing the tool diameter is smaller than the increase in delamination so that the value of l/W3 drops, The average width of delamination and the value of l/W3 as shown in table 1. The graph of the decrease in tensile strength of the composite can be seen damage during the manufacturing process in the drilled hole is delamination damage. The tensile test failure of the hybrid composite combination of glass fiber and hollow plastic sack fiber is the presence of cracks and delamination damage concentrated around the hole. The following are the photo results of the specimen punching process using a milling machine with a diameter of 4 mm which can be seen in Table 2.

Based on Table 2, it can be seen that every specimen that is punched there must be delamination. Delamination is a phenomenon that caused by the separation of the bond between the fiber layers due to larger cutting force. Delamination caused by drilling occurs both when entering and exiting the workpiece, so there is a wound around the hole [11]. The delamination factor value at an inclination angle of 0°has a value of 1.85, then at an angle of inclination of 15° has a value of 1.16, then at an angle of inclination of 30° has a value of 1.60 and at an inclination angle of 45° has a value of of 1.47. The delamination factor is influenced by the punching process, so the right method is needed in the drilling process. Such as using a sharp drill bit, maintaining the cleanliness of the drill bit and using the appropriate rotation for drilling specimens so that delamination can be maintained or minimized. The delamination factor will affect the tensile strength value [8].

3.2 Tensile Strength

Some of the mechanical properties analyzed include tensile strength, strain, and modulus of elasticity. The sample used in the test is a composite material that has gone through the manufacturing process by mixing polyester resin[12]. The results obtained from this tensile test can be seen in Table 3.

Table 3. Composite Tensile Testing Results

Num	Angle (°)	Power Tensile Maximum (MPa)	Strain (%)	Modulus Elasticity (GPa)	Factors Delami nation
1	Without Hole	315.45	1,84	27,83	-
2	0°	189.30	1.12	25.93	1.36
3	15°	75.56	1.8	22.22	1.26
4	30°	36.83	1.87	14.22	1.24
5	45°	34.25	2.82	11.90	1.38

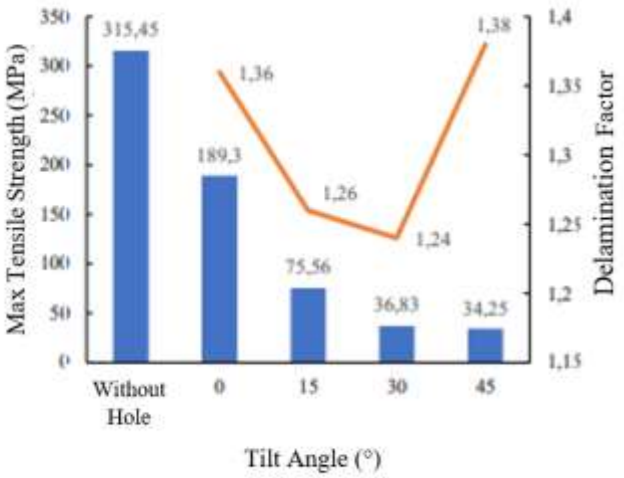


Figure 5. Tensile Strength and Delamination Graph against Angle Tilt

Table 3. is the result of tests that have been carried out on tensile testing samples. From the tensile test data above, a diagram of tensile strength, strain and elastic modulus can be made. Graph of the effect of the angle of inclination of the webbing on tensile strength can be seen in Figure 5.

The tensile strength and delamination factor values against the orientation angle of the composite webbing can be seen in Figure 5. Orientation angle of the webbing and the presence of holes in the specimen have a significant impact on the tensile strength values. significant impact on the tensile strength values. Specimens without holes have highest tensile strength value, reaching 315.45 MPa, while at a 0° angle, the tensile strength value was 189.30 MPa. At an angle of 15°, the tensile strength was 75.56 MPa, followed by a 30° angle with a value of 36.83 MPa, and the lowest at an angle of 45°, which was 34.25 MPa. Although delamination of the holes did not have a significant effect, the variation of the fiber orientation angle shows a significant influence on tensile strength values, as seen in the graphical results [13].

Composites that utilize woven fibers as reinforcement have maximum strength when the fibers are oriented at 0° orientation. This is because the fibers have the optimum ability to handle the load applied to the composite at this orientation. However, the strength of the composite material slowly decreases up to reaches 45° orientation, where the tensile strength value of the composite material reaches its lowest point [14][15].

The tensile strength of the composite experiences a significant decrease when orientation reaches an angle of 45°, which can be considered a critical angle. Avoiding this orientation angle is important so that the composite structure can withstand the applied load. structure can withstand the applied load. Variation in orientation angle orientation provides the ability to adjust the strength of the the composite according to the desired loading direction in the design [15]. In addition to the above tensile strength values in this study there are also strain value against the angle of inclination of the webbing which can be seen in Figure 6.

From the picture above it can be seen that the strain value of the composite orientation angle variation has a diverse value but not much different. The strain value on the specimen without holes has a strain value of 1.84%, then at an angle of 0 ° decreased in value to 1.12% decrease in strain value that occurs because in the 0° specimen there is a hole that has a strain value of 1.84%. Strain value that occurs because in this 0° specimen there is a hole that makes the makes the width of the specimen decrease, thus causing the specimen can be broken faster, then at an angle of 15° experienced increase to 1.80%, then at an angle of 30° experienced an increase of 1.88%. Back to 1.88% and then at an angle of 45° experienced increased to 2.28%. The increase in strain that occurs at an angle of 45° degrees is due to the wider the angle of inclination of the of the webbing against the force exerted by the machine, the resulting strain value will be greater due to the nature of the specimen. Value produced will be greater because the nature of the specimen away from brittle [16].

In addition to the strain value, in this study there is also the modulus value elasticity modulus value against the angle of inclination of the composite webbing which can be seen in seen in Figure 7.

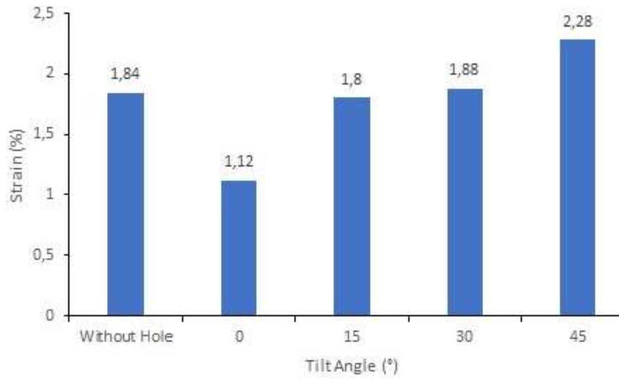


Figure 6. Graph of Strain

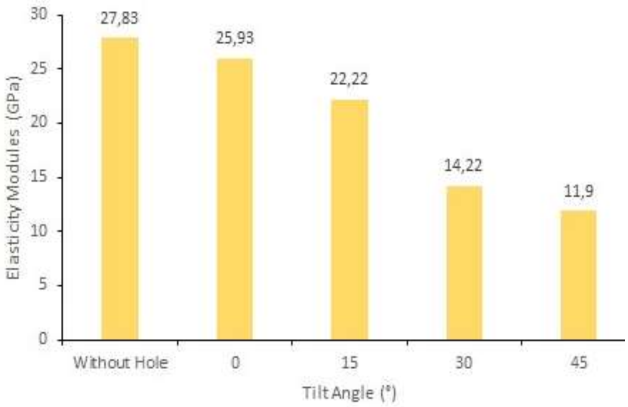


Figure 7. Graph of Modulus of Elasticity versus Tilt Angle Webbing

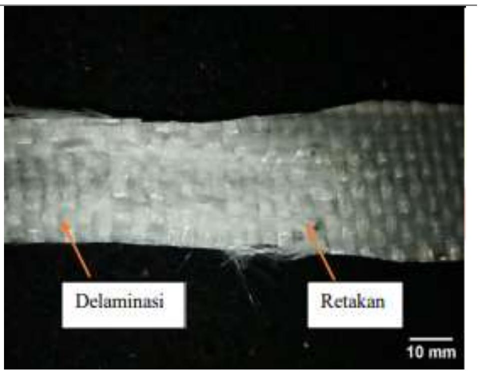
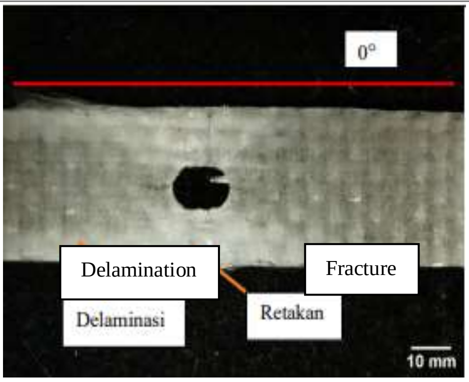
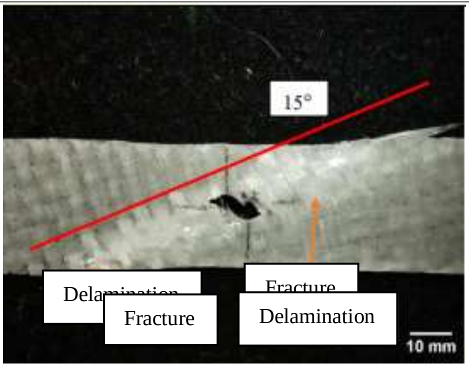
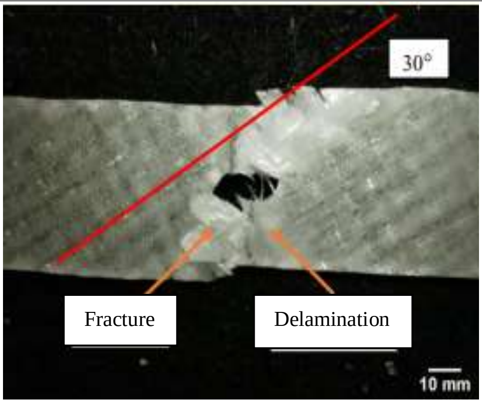
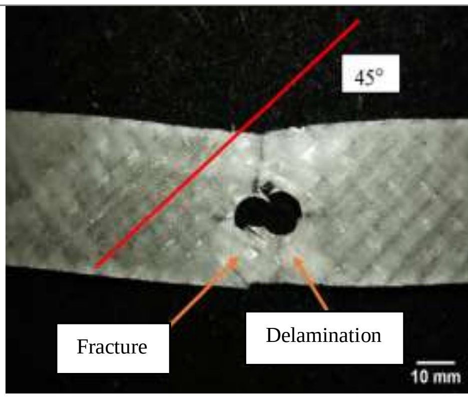
Figure 3. shows the value of the modulus of elasticity versus the angle of inclination of the composite. The modulus of elasticity is a measure of the resistance material to elastic deformation [17]. The graph above shows. The highest modulus of elasticity value in specimens without holes are of 27.83 GPa, then at an angle of inclination of 0° has a value of of 25.93 GPa, then at an angle of inclination of 15 ° has a value of 22.22 GPa, then at an angle of 30° has a value of 14.22 GPa and at an angle of inclination of 45° has the lowest elastic modulus value of 11.9 GPa. The elastic modulus value at an angle of 0° to 45° has a continuous decrease in value, this is due to the nature of the specimen which is getting more and more elastic. Due to the nature of the specimen which is increasingly moving away from brittle properties due to the large angle due to the large angle. The modulus of elasticity indicates stiffness or resistance to elastic deformation. The greater the modulus of elasticity, the stiffer the material [18].

3.3 Composite Fracture Mode

Table 4. below shows the damage patterns that occurred on the composite due to tensile testing carried out.

p-ISSN: 2087-1627, e-ISSN: 2685-9858

Table 4. Photos of Composite Damage

Angle Orientation (°)	Photo of the Fault
Without Hole	
0	
15	
30	
45	

From Table 4 we can be seen that the composite has a fracture in the area around the hole. This happens because with the addition of holes, the area around the hole will get concentration of stress when tensile testing is carried out, so that the area around the hole will experience fracture [19][6].

The image of the fracture observation results indicates that the orientation of the orientation of the webbing affects the shape of the fracture when subjected to tensile force. Fracture at 0° webbing orientation occurs parallel to the direction of pull. This is because the fiber arrangement in the x-axis has an orientation of 0°, which is parallel to the direction of pull. which is parallel to the direction of pull, and the fiber arrangement on the y-axis has an orientation of 90° which is perpendicular to the direction of pull. Meanwhile in the orientation between 0° to 15°, the webbing is no longer perpendicular to the direction of the applied pull, but the fracture that occurs in the specimens still follow the perpendicular orientation of the webbing [4][20].

The fracture at 0° orientation direction in the composite is included in the brittle fracture damage category. This is due to the continuity of the interface strength between the fiber and the matrix that remains good. strength of the interface between the fiber and the matrix that remains good, the Matrix still has the capability to distribute and support the load received by leveling the load to the surrounding area [8]. If the matrix is still able to bear the shear force and pass it on to other fibers, there will be an increase in the number of fibers. which is broken, resulting in the composite experiencing a brittle fracture type of damage [21].

Fracture in composites with fiber orientation direction angles between 15° to 45° is caused by the inability of the matrix to withstand the shear force, resulting in the debonding phenomenon. Fracture in composites with orientation angles of 15°, 30°, and 45° are in line with the direction of orientation of the fibers, as seen in the table above, involves a process of delamination and the formation of cracks that follow the direction of the webbing [8].

4. Conclusions

After data collection and analysis in this research, it can be concluded that can be concluded that the value of the delamination factor around the hole does not really affect the tensile strength value, because the value of the delamination factor formed has a value that is not much different. The biggest factor that influences the tensile strength value is the angle of inclination of the webbing. The larger the angle on the specimen, the resulting tensile strength value will decrease, the smaller the angle, the stronger the tensile strength.

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