# Effect of Webbing Angle on Tensile and Bending Strengths in Human Hair Fiber Reinforced Composites

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**Abstract**

Composite is a combination of two or more materials that have different basic properties. This study aims to analyze the effect of woven angle on hair fiber composites on tensile and bending strength. The composite is composed of polyester resin and human hair waste. Hair was soaked in 5% NaOH solution for 1 hour and woven with angle orientation 0°/90°, 15°/105°, 30°/120° and 45°/135°. The process of making composites is made by the Compression Molding method for 24 hours. After making the composite, a density test was carried out with the ASTM C271 standard, tensile test with ASTM D3039 standard and bending test with the ISO 178 standard. The results of the density test obtained an increase in the density value with the lowest density value of 0.82 g/ml and the highest 0.85 g/ ml to produce a lighter composite. Then the tensile test results show the highest tensile strength value of 16.47 MPa which occurs at an angle of 0°/90°. The results of the bending test obtained an increase in bending strength with the highest bending strength value of 47.1 MPa which occurred at an angle of 0°/90°.

**Keywords:** hair composite, tensile, bending

***Abstrak***

*Komposit merupakan perpaduan dari dua buah material atau lebih yang memiliki sifat dasar yang berbeda. Penelitian ini bertujuan untuk menganalisa pengaruh sudut anyaman pada komposit serat rambut terhadap kekuatan tarik dan bending. Komposit tersusun dari resin polyester dan limbah rambut manusia. Rambut direndam pada larutan 5% NaOH selama 1 jam dan dianyam dengan orientasi sudut 0°/90°, 15°/105°, 30°/120° dan 45°/135°. Proses pembuatan komposit dibuat dengan metode Compression Moulding selama 24 jam. Setelah pembuatan komposit, dilakukan pengujian densitas dengan standar ASTM C271, pengujian tarik standar ASTM D3039 dan pengujian bending dengan standar ISO 178. Hasil dari pengujian densitas diperoleh peningkatan nilai densitas dengan nilai densitas terendah 0,82 g/ml dan tertinggi 0,85 g/ml sehingga menghasilkan komposit yang lebih ringan. Kemudian hasil pengujian tarik menunjukkan nilai kekuatan tarik tertinggi sebesar 16,47 MPa yang terjadi pada sudut 0°/90°. Hasil dari pengujian bending diperoleh peningkatan kekuatan bending dengan nilai kekuatan bending tertinggi 47,1MPa yang terjadi pada sudut 0°/90°.*

***Kata kunci:*** *komposit rambut, tarik, bending*

## 1. Introduction

The development of research and application of composites in the fields of industry and renewable materials science is advancing. Composite is a material mix consisting of a matrix or fiber and reinforcement [1][2]. Fibers can consist of one or more materials arranged as reinforcement to increase the strength and mechanical properties of the material so that it is superior. While reinforcement is a material that can increase the stiffness and strength of the matrix or fiber used [3][4].

Composites have advantages, namely lightweight materials, corrosion resistance and low production costs[5]. Composites can be used for various applications such as auto parts, building materials, aircraft materials and others [6]. Currently, a lot of research has been done on composites with natural fiber materials to meet future needs. There are several ways to increase the strength of the composite.

Webbing treatment is one of the methods used to increase the mechanical strength of composites. Several models of woven patterns or angles that can be used include basketball, plain, twill, satin, and other combinations of angles and patterns [7]. The tensile stress will be greater if the webbing angle given to the fiber has an angle direction that is parallel to the applied tensile force. Therefore, the woven angle with an angle of 0°/90° has more tensile strength than the woven angle of 45°/135° on pineapple leaf fiber [8].

Hair is a natural fiber that is often found, because the fiber grows naturally in several living things, one of which is humans. Human hair is a natural fiber that has excellent durability. Human hair has a very high durability, even though it has been thrown away, buried for years and burned, it does not rot but only clumps like plastic, hair is not easily damaged and rotted. Hair fiber has a constituent structure consisting of keratin which forms long and regular chains that make hair fibers have strong and flexible mechanical properties [9]. Keratin is a protein consisting of long chains of amino acids. Hair contains high amounts of sulfur because the amino acid cysteine is the main component of the keratin protein in hair fibers [6].

Human hair waste has not been utilized optimally. Hair fiber composite is one example of the utilization of hair waste. However, the use of human hair fiber composites is still rarely used, even though hair has good enough strength to be made into composites. Many researches on hair-reinforced composites have been carried out, but research on the effect of webbing angles on physical and mechanical properties has never been done. So it is necessary to do further research to determine the effect of the angle of the composite woven human hair fiber on the tensile and bending strength.

## 2. Materials and Methods

The materials used in this study were human hair waste as reinforcement and Yukalac C-108B Polyester Resin as a matrix. The hair was soaked in a 5% NaOH solution for 60 minutes [10]. This soaking is done to remove the remnants of chemicals and oils attached to the hair [10]. It aims to strengthen the bond between the hair fiber and the matrix [11][12]. After that, it was washed 5 times so that the NaOH was completely removed from the hair fiber and dried in the room for 2-3 days. The hair is made of rope with a length of 25 cm and a diameter of 0.3 cm, then woven. The webbing angle variations used in this study were 0°/90°, 15°/105°, 30°/120° and 45°/135°. Figure 1 shows the variation of the webbing orientation in 2D.

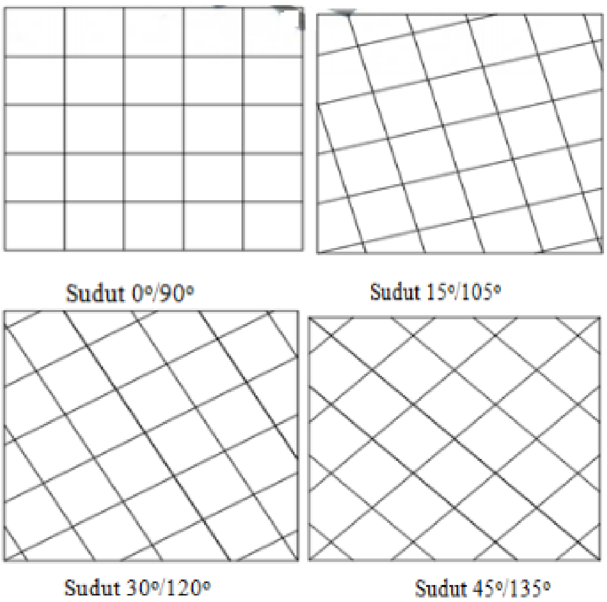


**Figure 1.** Webbing orientation [13].

The ratio used in the composite manufacturing process is 60% matrix and 40% human hair fiber. The mold used is 250 x 20 x 5 mm. The composite manufacturing process is carried out by hydraulic pressing for 24 hours [4]. After being removed from the mold, in order for the composite to dry completely, it was left for 7 days in an open room [3]. The density testing process is carried out with the ASTM C271 standard, the Tensile test with the ASTM D3039 standard and the bending with the ASTM ISO 178 standard.

## 3. Result and discussion

### 3.1. Tensile test

The purpose of the tensile test is to determine the resistance of the material to tensile loads. The results of the tensile test of the hair fiber composite are shown in Figure 2.

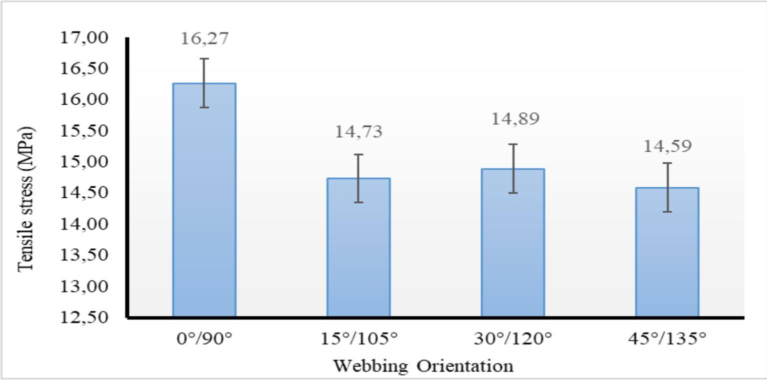


**Figure 2.** Tensile strength testing results.

Figure 2 shows a graph of the tensile test results on the composite. The figure shows webbing angle 0°/90° achieving the highest tensile strength with a tensile strength value of 16.27 MPa. Then at the woven angle of 15°/105° it decreased with a tensile strength value of 14.37 MPa. While at the webbing angle of 30°/120° the strength increased but not significant with a tensile strength value of 14.89 MPa. Then the strength decreases again at the webbing angle of 45°/135° with a tensile strength value of 14.59 MPa. The highest tensile test value was obtained on a composite with a webbing angle of 0°/90° with a tensile strength value of 16.27 MPa. While the lowest tensile strength value was obtained in the composite with a webbing angle of 45°/135° with a tensile strength value of 14.59 MPa.

Based on the results of the tensile test, it was found that the greater the degree of the webbing angle, the less the tensile strength [7][8]. This happens because the structure at 0°/90° woven angle has an angle that is in the direction of the pull direction and at 0°/90° woven angle the fiber is not easily shifted so that the force received by the matrix can be transmitted properly by the fiber [13][7]. While at the webbing angle of 15°/105°, 30°/120° and 45°/135° the results were not significant and tended to be stable with each other. This phenomenon occurs as a result of the given load is not in the direction of the webbing angle causing the load to be not well distributed on the fiber and matrix, thereby reducing the tensile stress [14][8]. After calculating the tensile strength, the fracture shape of the composite is observed. Figure 3 shows a photo of the composite fracture observations from the Tensile test.

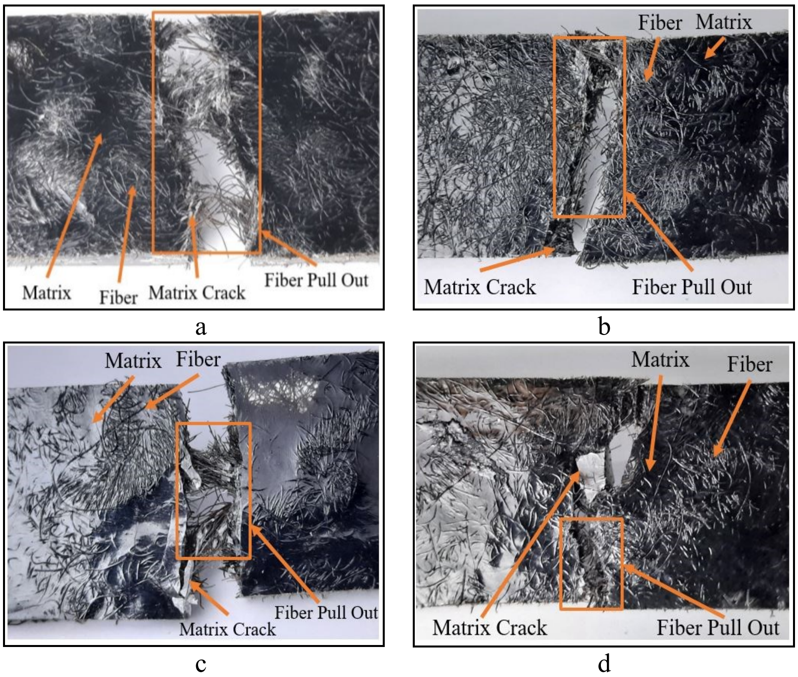


**Figure 3.** Hair composite tensile test fracture (a) 0º/90º; (b) 15º/105º; (c) 30º/120º; (d) 45º/135º

Figure 5 shows that the fracture that occurs in the specimen is a brittle fracture. Brittle fracture can be seen from the fracture of the specimen is not uniform, shiny on the matrix and the fibers are still bound [3][15]. The fracture starts from the matrix because there are fractures or matrix fractures in the fracture results, but the fibers are still connected to the fracture of the specimen. This happens because the matrix fails and the fiber withstands the load that was previously held by the matrix [15].

The fibers appear to have fiber fracture. Fiber fracutre is a failure experienced by the fiber when carrying the load given by the matrix with an indication on the fracture image that brush fracture occurs [16]. Brush fracture is a fault in which the fibers gather at one point to become like a brush[17]. Brush fracture seen from the fibers that come out of the surface like a brush. This fracture occurs due to the fiber getting a load that exceeds its capacity and the lack of bonding with the matrix[16]. Brush fracture is the main indication in the specimen fracture that the fracture occurs in fiber pull out. Fiber pull out is a failure of the bond between the matrix and the fiber which causes the fiber to come out of the matrix[7]. Fiber pull out occurs as a result of poor bonding between the fiber and the matrix and the fiber is delaminated. Delamination is a condition where the fiber is not completely coated with resin [15][16]. Fiber delamination is caused by several things including too tight fiber density, viscosity of the matrix, and low fiber absorption. This causes a decrease in the strength of the composite material during testing.

### 3.2. Bending test

Bending strength is one of the supporting tests for strain and stress carried out on a material. The results of the hair fiber composite bending test are shown in Figure 4.

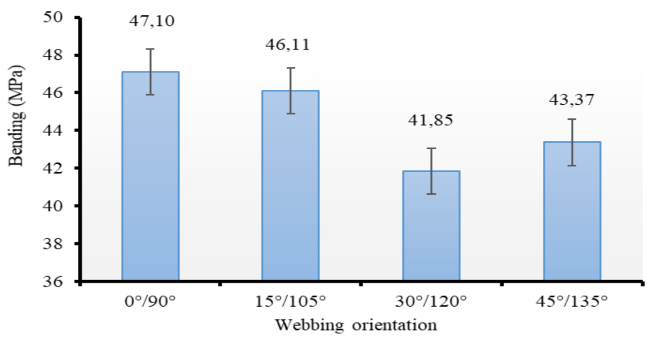


**Figure 4.** Flexural testing results.

Figure 6 shows that the greater the degree of the webbing angle, the less the flextureal. This happens because the structure at 0°/90° woven angle is able to withstand the compressive load caused by the good bond between the fibers and the matrix so that the composite becomes stronger [14][16][18]. The webbing angle of 30°/120° experienced a significant decrease in strength due to mechanical bonding or the bond between fibers and the matrix was very low so that the force received by the matrix could not be transmitted properly by the fibers[7]. Meanwhile, at the webbing angle of 15°/105° and 45°/135° experienced a significant decrease in bending strength as a result of the bond between the fibers and the matrix being quite good but the load given was not in the same direction as the webbing angle causing the load to be not distributed with the fiber and matrix so that reduce its strength[5][7]. After calculating and analyzing the bending test, the bending test fracture was observed. Figure 7 shows the fracture of the bending test results.

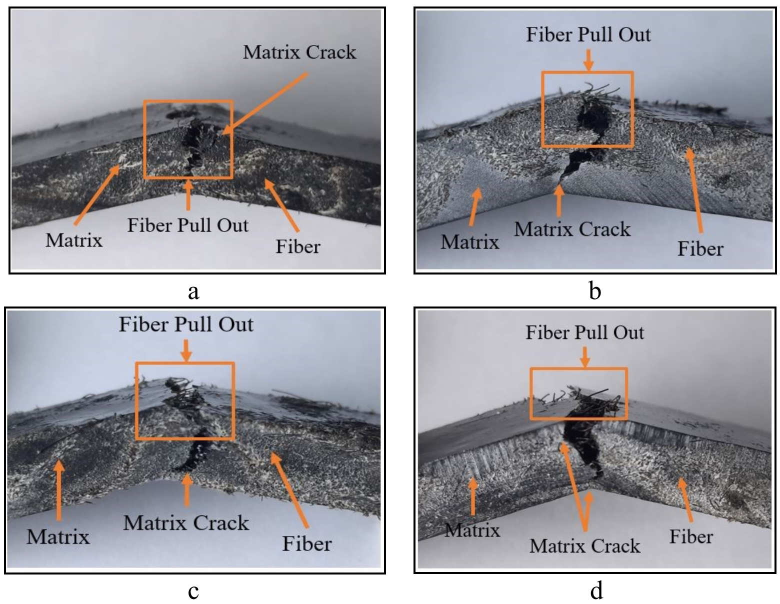


**Figure 7.** Hair composite tensile test fracture (a) 0º/90º; (b) 15º/105º; (c) 30º/120º; (d) 45º/135º

Based on the results of the macro structure photos, it can be said that the fractures that occur in the specimen are brittle fractures and brush fractures. Brittle fractures can be indicated from specimen fractures which have fine grains on the specimen and coarse fibers depending on the specimen[10] [19]. From the macro photo, the fracture starts from the matrix because there is a matrix fracture in the fracture but the fiber has not failed completely so that it can still withstand loads with low intensity[20].

Figure 7 shows the occurrence of imperfect fractures due to the fiber still being bound to the matrix. This fault is characterized by the occurrence of fiber pull out. Fiber pull out occurs as a result of poor bonding between the fibers and the matrix or debonding [17][21]. This is due to several things, including fiber density that is too tight, the viscosity of the matrix, and fiber absorption. This results in reduced strength of the composite material during testing [7][22].

## 4. Conclusion

Based on the results of data and research analysis and discussion in this study it can be concluded that: (1) Tensile test results show the highest tensile strength value occurs at 0°/90° webbing angle variations with a value of 16.27 Mpa. This is because the composite structure has an angle that is in the direction of the tensile force. In addition, at 0°/90° webbing angles the fibers do not shift easily so that the force received by the matrix can be transmitted well by the fibers; (2) The results of the bending test showed that the hair composite with woven angles of 0°/90° had a high bending strength compared to the others. This happens because at 0°/90° woven angle the load is evenly distributed on the composite so that it can withstand the load better.

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