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The Effect of Winding Speed on the Mechanical Properties of Kenaf Fiber Reinforced Geopolymer Composites via Filament Winding Technique

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ABSTRACT

The usage of natural fiber is becoming significant in recent development due to its superior properties such as high specific strength, low weight, low cost, fairly good mechanical properties, non-abrasive, eco-friendly and bio-degradable characteristics. Single and continuous natural fiber have relatively high mechanical properties; especially their young modulus can be as high as glass fiber. Filament winding is known as a technique to produce aligned composites composed of high fibers content. Besides, the usage of geopolymer materials as a matrix resin for the composites produced is convenient since it has environmentally friendly properties in the aspect of low carbon dioxide (CO_2) emission to the environment. This research studied the effect of winding speed on the compression properties of kenaf fiber reinforced geopolymer composites which been produced via filament winding technique. Composites of hoop pattern which produced at high winding speed showed better compression properties than helical pattern winding which produced at low speed.

1. Introduction

Fiber reinforced polymer composite or FRP is quite a new material in the various application such as construction and building industry compared to concrete and steel [1]. Generally, composites possess higher specific modulus and high specific strength so that they will be a valuable material in a huge number of industrialized requests which requires such features [2]. Some conventional fiber such as carbon and glass fiber integrated into the polyester resin is the traditional and common fiber reinforced composite materials. Although these composite materials possess excellent mechanical properties, these materials consist of non-degradability fibers which will cause environmental

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pollution[3]. As a result, natural fiber reinforced composites found to be an alternative solution to the ever depleting petroleum sources thus they receive greater attention, attraction from research scientists and community.

Among other natural fiber reinforcing materials, it is found out that kenaf is comparatively commercially available and economically cheap. Customarily, kenaf denoted as industrial kenaf due to its great interest in the production of industrial raw materials. With the average diameter of the fiber is 67.6μm, kenaf is known as wild dicotyledons plant [4] with hardy, strong and tough plant that consist of a fibrous stalk, resistant to insect damage and requires relatively fewer amount or no pesticide [5]. The three types of fiber: bast, core, and pith constituents the kenaf plant [6]. However, kenaf is characterized by two distinct fibers bast and core comprising 35% and 65% respectively [7]. By using chemical composition anatomical appearances, the bark and core fiber can be distinguished as two distinct types of raw material [6]. The pith commonly composed of parenchymatous cells that are polygonal in shape [8]. Few researchers state that due to the kenaf bast fibers excellent mechanical properties, it has been considered as a replacement material to glass fibers in polymer composites as reinforcing elements [9].

Filament winding is a technique that involves winding continuous fibers onto a rotating mandrel. During the winding process, the fibers are placed on the mandrel, forming several layers that required [10]. The choice of fibers and resin, fibers tension, fibers path, and the winding speed will affect the mechanical properties of a finished part. The mandrel is a mould that controlled the inner geometry of the product. Changing the mandrel parameters will affect the inner properties of the product. For example, the parameters like inner surface roughness, as well as the geometrical values [11]. Easy production of a composite structure with a thick cross-section and able to form flexible design become the main advantages of filament winding technique [12]. In the recent research that been conducted, in order to replace the usage of synthetic fibers such as glass and carbon fibers, new hybrid natural fibers composite materials were fabricated using the filament winding technique.

Geopolymer is a term covering a class of aluminosilicate materials with potential use in a number of areas. In addition, geopolymer materials are attractive because of their mechanical properties, high early strength, freeze-thaw resistance, low chloride diffusion rate, abrasion resistance, thermal stability and fire resistance [13]. Starting material including chemicals and mineral additives, alkali activators, plasticizers, processing condition that usually time and temperature used are the main factors that affect the geopolymerization process and its mechanical properties [14].

2. Methodology

To implement the filament winding technique, continuous kenaf fiber was impregnated ("wet-out") with geopolymeric resin by means of homemade "impregnation machine". The velocity of the fiber during the impregnation process was chosen based on the best penetration on geopolymer resin into the fibers [9]. The winding speed was manipulated in order to see the effect on the kenaf fiber reinforced composite that been produced. The mandrel rotational speed will determine the velocity of the fiber feeding in the resin tank. This will be selected based on the best impregnation of geopolymer resin into the fibers.

Curing process was carried out to the sample that been produced after the appropriate number of the layer has been applied accordingly to fully wounded [15]. Basically, there are two methods that been used in order to solidify the samples which are cured at room temperature for 1 day and followed by curing in the furnace at a temperature around 80°C for 1 day.

All the samples were ready to be tested after the curing process take place. In order to determine the mechanical properties, compressive test are performed on the composite structure. Another important property of samples that been produced through the filament winding technique is microstructure of the geocomposite [16].

3. Results

The sample is tested with compression strength testing. This is because the compression test is a convenient method for determining the stress-strain response. One of the main advantages of compression testing is because the specimen is easy to make and does not need a large number of materials.

In this section, the compression strength test result for all the samples are presented in two major group which is vertical and horizontal testing. The compression properties that been presented are compressive strength, compressive strain, and maximum load. Every compression properties show the performance of the sample.

Table 1
Results of compression testing for the vertical position

Winding Speed	Compressive Strength, MPa	Compressive Strain, mm/mm	Maximum Load, kN
1	3.022	2.42	1.54
2	7.328	4.65	3.48
3	10.705	5.61	6.67
4	14.278	9.69	10.19

Figure 1, 2 and 3 above shows the graph reading of compressive strength, compressive strain, and maximum load for the sample in a vertical position in order to know their strength. From the result, we can see that sample 4 (winding speed 4) give a higher strength with reading 14.278 MPa compared to others. On the other hand, the highest strain for the vertical position is sample 4 (winding speed 4) which is 9.69 mm/mm while the lowest strain is sample 1 (winding speed 1) which is 2.4 mm/mm.

However, the results data of compression strength varies with the different position of samples tested. As a result, the vertical position test for compressive strength obtains higher value compared to the horizontal position. Table 2 below shows the results under compression testing in the horizontal position.

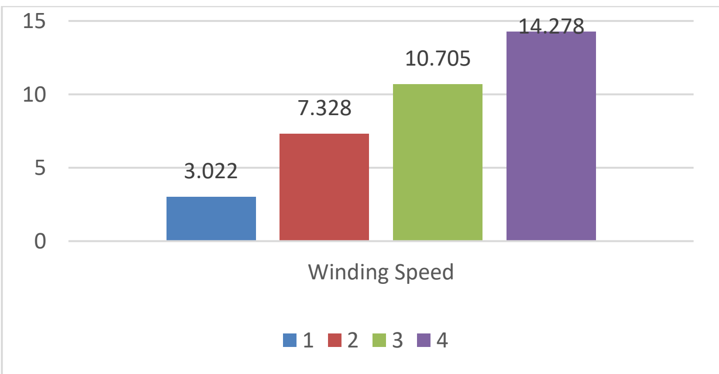

Fig. 1. The graph of compressive strength of each sample in a vertical position

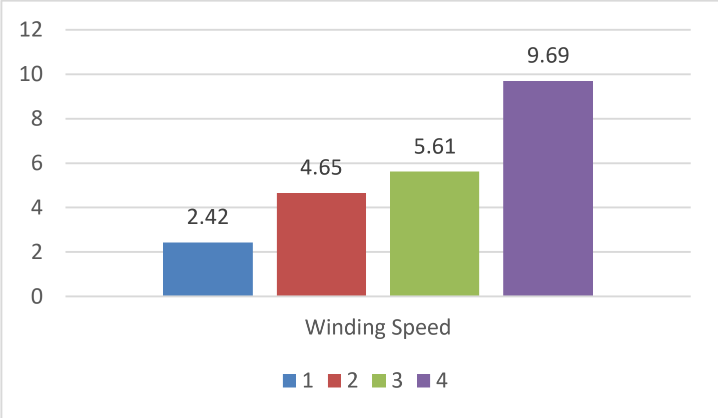

Fig. 2. The graph of a compressive strain of each sample in a vertical position

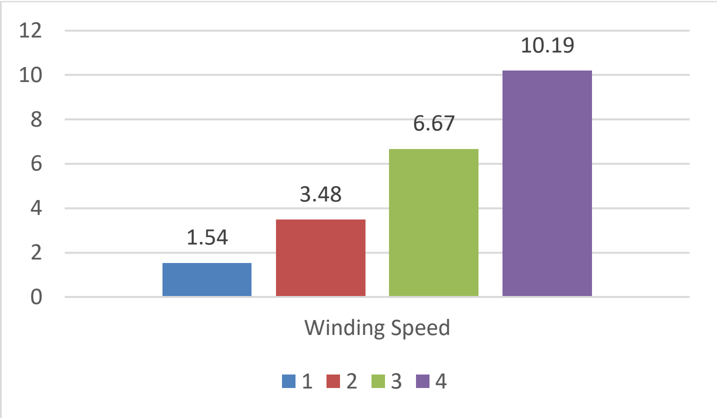

Fig. 3. The graph of the maximum load of each sample in a vertical position

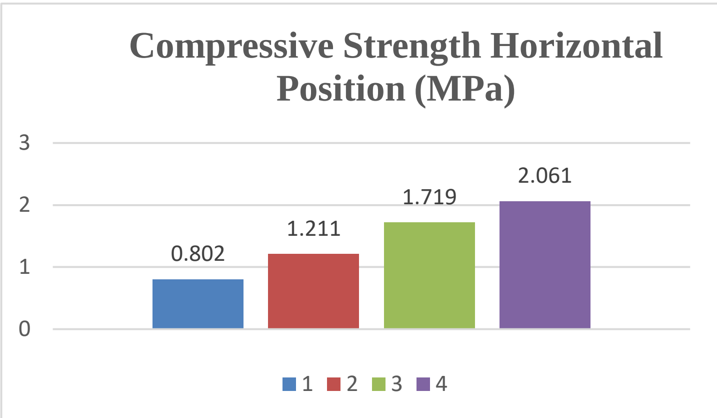

Fig. 4. The graph of compressive strength of each sample in a horizontal position

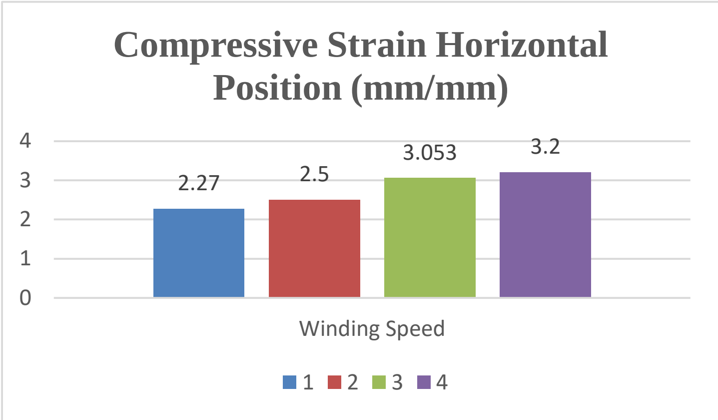

Fig. 5. The graph of a compressive strain of each sample in a horizontal position

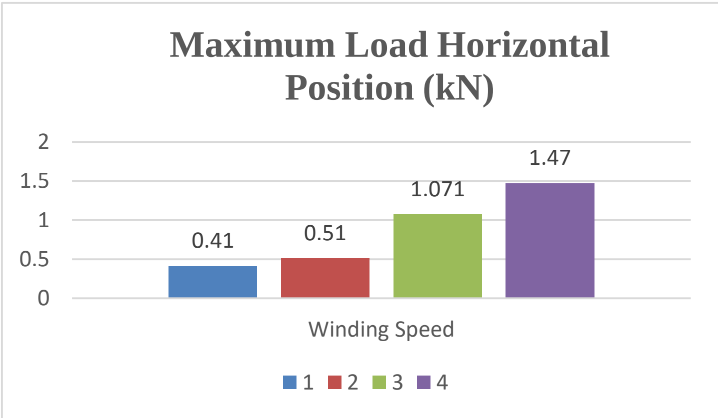

Fig. 6. The graph of the maximum load of each sample in a horizontal position

Table 2
Results of compression testing for the horizontal position

Winding Speed	Compressive Strength, MPa	Compressive Strain, mm/mm	Maximum Load, kN
1	0.80	2.27	0.41
2	1.21	2.50	0.51
3	1.72	3.05	1.07
4	2.06	3.20	1.47

The graph reading of compressive strength, compressive strain and maximum load of the tested samples in a horizontal position can be observed as shown in Figure 4, 5 and 6 above in order to know their strength. From the result, we can see that sample 4 (winding speed 4) give the highest strength with reading 2.061 MPa compared to others. The highest strain for the horizontal position is sample 4 (winding speed 4) which is 3.2 mm/mm while the lowest strain is sample 1 (winding speed 1) which is 2.27 mm/mm. The maximum load for a horizontal position for compression is sample 4 which is 1.47kN.

It can be discussed from all the figure that under compression, the performance of compressive strength, compressive strain, and maximum load increase within increasing of winding speed for both whether vertical and horizontal position. The result of compression testing for both position in increasing winding speed as expected. The result performance for vertical position show higher than horizontal position are because of the composite show an anisotropic behavior. The sample which is anisotropic a likely to exhibit the best mechanical properties when loaded in direction of the fiber alignment.

This result is shown above also can relate to the density of filament wound product. The increasing of winding speed will increase the density. Sample with high density shows that it has fewer pores compared to low-density sample. This is the reason why sample with winding speed 4 has more compressive strength compared to the sample with winding speed 1.

The reasons why increasing winding speed can increase the performance such compressive strength, compressive strain, and maximum load is because of the pattern of winding itself. The speed of winding had affected the pattern of winding, thus it also will affect the thickness of filament wound product thus will affect the mechanical properties of the filament wound product.

The hoop pattern gives the more rotational of kenaf fiber than helical pattern even though all the samples are the same number of layer (11 layers). This is one of the reasons why the sample with high speed is stronger than the slower of winding speed.

4. Conclusions

From this research, it can be concluded that the combination of geopolymer material and filament winding technique was found to be applicable to be used as an industry component. This is because, that method not only offer an environmentally friendly product but also ease the production process where automatically, more cost savings can be done. The experimental result shows the performance of the product through the compressive strength. From the result, it can be concluded that the increasing of winding speed also increase the mechanical properties of filament wound composites. The sample of filament winding at speed of 4 gives the highest compressive strength compared to other winding speed samples. In addition, from this research, it can be seen that samples tested on a vertical axis position give a better compressive strength compared to the samples on the horizontal axis position. Last but not least, geopolymer material has a bigger potential to be used in idea replacement matrix of the composite with glass fiber in filament winding technique due to their excellent properties.

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