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Effect of Hot Compression Molding Temperature Variation on Coconut Fiber HDPE Hybrid Composite and Sansevieria Trifasciata on Physical and Mechanical Properties

Rene Hario Galih[1], Fajar Paundra[1*], M. Farhan Sidik[1], Abdul Muhyi[1], Eko Pujiyulianto[1], Farid Nanda Syanur[1], Annisa Indah Setyawati[2]

[1] Teknik Mesin, Institut Teknologi Sumatera,
Jln Terusan Ryacudu Desa Way Hui, Jati Agung, Lampung Selatan, Lampung, Indonesia 35365
[2] Agroteknologi, Universitas Satu Nusa
Jl. Zainal Abidin Pagar Alam No 17A Rajabasa, Bandar Lampung, Lampung, Indonesia 35144
*E-mail: fajar.paundra@ms.itera.ac.id

Abstract
Temperature is one of the parameters that is very influential in the process of making HDPE matrix composites. This study aims to determine the effect of variations in heating temperature on tensile strength and bending strength and to analyze the fracture structure of HDPE composites. The materials used in this study were HDPE plastic from used bottles, coconut fiber and Sansevieria fiber with a composite ratio of 90:5:5. The process of making HDPE composites is carried out using the hot press compression method. The pressure used is 30 bar for 30 minutes. The temperature variations used are 150ºC, 160ºC, 170ºC, 180ºC, and 190ºC. This study conducted two tests, namely tensile testing and bending testing using the Universal Testing Machine. The tensile testing process uses the ASTM D 3039 standard and obtains the highest results on specimens of 170ºC with a tensile strength value of 509.80 MPa. The value of tensile strength has increased and decreased. The bending test process was carried out according to the ASTM D 790 standard and the highest results were obtained on the 170ºC specimen with a value of 90.99 MPa.

Keywords: bending, composite, HDPE, hot press, tensile.

1. Introduction

The development of materials engineering technology and environmental issues requires new breakthroughs in the manufacture of high quality and environmentally friendly materials such as composites. Composite is a material that consists of a combination of two or more types of materials that have different shapes or compositions [1][2]. Composites reinforced with natural fibers are environmentally friendly materials compared to synthetic materials. Currently, natural fibers are replacing artificial fibers as reinforcements because they have several advantages that natural fiber-reinforced composites have. This happens because natural fiber-reinforced composites have several advantages such as low prices, low density, can be recycled, are abundant in quantity, and have high mechanical ability. The application of natural fibers is increasingly growing in several sectors such as manufacturing, vehicles, packaging and construction [3]. Natural fibers can be mixed and molded with polymers using high pressure [4].

There are several studies that have been carried out on several types of natural fibers such as kenaf fiber (Hibiscus Cannabinus), coconut, bamboo, and lidah mertua with the aim of studying the effects of the fibers on the mechanical properties of composite materials [5]. Research on natural fiber composites with coconut fiber reinforcements and lidah mertua has been widely carried out [6][7]. Coconut fiber is an agricultural waste whose potential in Indonesia is quite large because the material is quite abundant, versatile and cheap. Coconut fiber is an attractive material because it has the lowest thermal conductivity and bulk density [8]. Coconut fiber also contains lingnocellulose (a binding agent) which can be used as an alternative material for making composites [9]. Apart from coconut fiber, a fiber that can be used as an alternative material for making composites is lidah mertua fiber (Sansevieria Trifasciata). Lidah mertua is a plant that can be used in composites because it has good mechanical and thermal insulating properties [10]. The mother-in-law's tongue plant is the best plant used to improve indoor air quality by absorbing toxins. This plant also has properties similar to pineapple leaf fiber with a lower lignin content [11]. There are several ways to strengthen composites such as varying the weave angle, alkali treatment, and hybridization [5].

Currently, multi-component composite materials consisting of two or more natural fiber components have attracted the attention of researchers. The use of one type of fiber has been proven to be inadequate in treating all types of damage, one of the problems being due to the composition of the fiber. A solution that can be done is using natural fiber hybrid composites, by combining two types of natural fibers can improve the mechanical properties of the composite [12]. Hybridization is a method in composites that combines two component materials or more reinforcing fibers in a single matrix system. Hybrid composites have the potential to be used in applications requiring high shock loads [13]. Apart from that, hybridized High Density Polyethylene (HDPE) composites are starting to be developed in materials engineering technology [14].

Plastic waste is a current problem, according to data from the national waste management information system, there are 30 million tons of waste per year produced from human activities which can have an impact on the surrounding environment [15]. The problem of plastic waste can be overcome, one way is by using it into composites. Research on tool fiber hybrid composites is still rarely carried out, so it is necessary to conduct research on hybrid composites reinforced with natural fibers. The aim of this research is to analyze the effect of temperature variations on the physical and mechanical properties of the hybrid HDPE coconut fiber and Sansevieria Trifasciata fiber composite material.

2. Methodology

The materials used in this research were used shampoo bottles such as HDPE and natural fibers. The natural fibers used as reinforcement are coconut fiber and Sansevieria Trifasciata fiber. The composition ratio used is 90% HDPE, 5% coconut fiber and 5% Sansevieria Trifasciata fiber. Used bottles are cleaned of oil and dirt, then cut to a size of ±10mm. Coconut coir and Sansevieria Trifasciata fibers were cut into 250 mm lengths. Then the fiber is soaked in a 5% alkali solution for 2 hours. This aims to remove oil and dirt that sticks to the surface of the fiber, so that the filler can bind the fiber perfectly [16].

The composite manufacturing process uses the hot press method with a 250x250x5 mm mold. The pressure used is 25 bar. The temperature variations used were 150°C, 160°C, 170°C, 180°C and 190°C with a holding time of 25 minutes. After the composite manufacturing process, density, tensile and bending testing processes are carried out. Figure 1 shows the hot press equipment in the ITERA mechanical engineering laboratory.

Figure 1. Hot Press Machine

This density test aims to obtain density values from temperature variations used in making coconut fiber and Sansevieria Trifasciata composites. Density testing by weighing the density of the composite and finding the actual

volume of the composite [17][18]. To find density, you can use equation 1. Density testing with ASTM C 271 standards. Figure 2 shows ASTM C 271. Apart from that, density testing is also used to obtain porosity values which can be seen in equation (1).

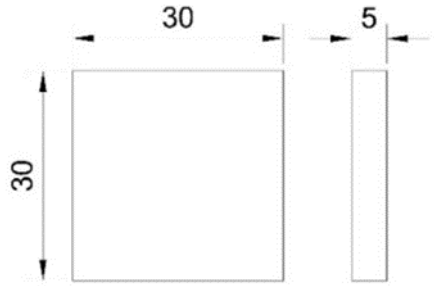


Figure 2. ASTM C 271

$$P = \frac{\rho theoretical - \rho actual}{\rho theoretical} x\ 100\% \qquad (1)$$

Informations:

P = Porosity (%)

$\rho_{theoretical}$ = Theoretical Density (g/cm3)

ρ_{actual} = Actual Density (g/cm3)

Tensile testing aims to obtain the maximum tensile strength and elongation values of the composite. To find tensile strength and elongation, you can use equations (2) and (3). Tensile testing refers to the ASTM D 3039 standard. ASTM D 3039 is shown in figure 3.

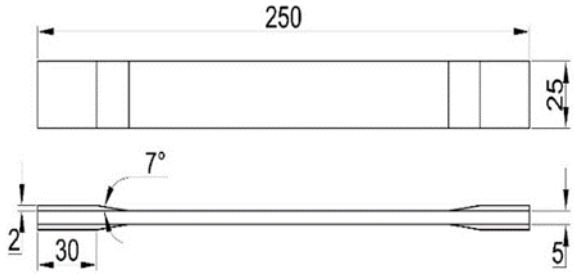


Figure 3. ASTM D 3039

$$\sigma = \frac{F}{A} \qquad (2)$$

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \qquad (3)$$

Bending test specimens were made according to ASTM D 790 standards to obtain bending strength values from the effect of temperature variations on the hybrid composite of coconut fiber and Sansevieria Trifasciata with an HDPE matrix. Data resulting from buckling testing can be calculated using equation (4). Figure 4 shows ASTM D 790.

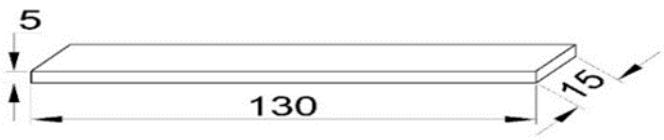


Figure 4. ASTM D 790

$$\sigma_{fs} = \frac{3FL}{2bh^2} \quad (4)$$

Informations:

σ_{fs} = Maximum tensile (MPa)

F = Force (N)

L = Long speciment (mm)

b = Wide speciment (mm)

h = Thicknes speciment (mm)

3. Results and Discussion

Density is a measurement of the mass per unit volume of an object [19]. In this research, composite density testing has been carried out as in Figure 5.

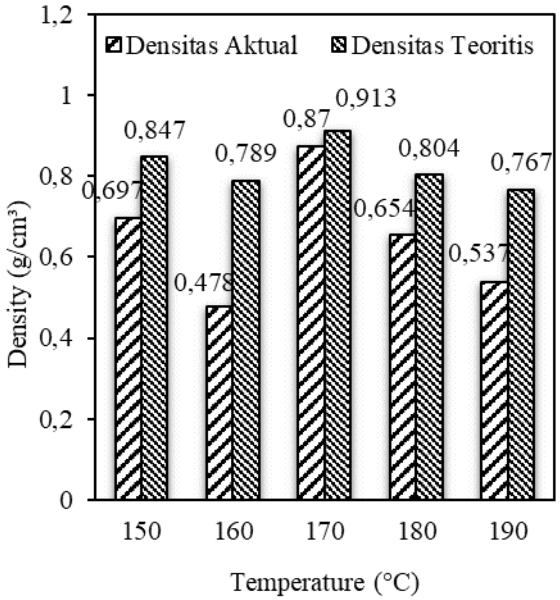


Figure 5. Density Graph

Figure 5 shows that the highest density is at a temperature of 170°C with a value of 0.87 g/cm³, followed by a temperature of 180°C and a temperature of 190°C with a density value of 0.654 g/cm³ and 0.537 g/cm³. This is in accordance with research by Sendawati et al., (2022) which states that the higher the heating temperature, the lower the density value [20]. This occurs because the increase in temperature causes degradation of the material chain during the heating process. So the higher the temperature, the greater the number of material chains that are degraded which causes bond damage.

According to Eqitha Dea Clareyna & Mawarani, (2013) decreasing density is directly proportional to the defects a material has and the higher the density, the fewer defects there are [21]. This occurs at temperatures of 150°C and 160°C with densities of 0.697 g/cm³ and 0.478 g/cm³, both specimens have voids or porosity. After obtaining the composite density, we can determine the porosity. The results of the porosity calculation are shown in Figure 6.

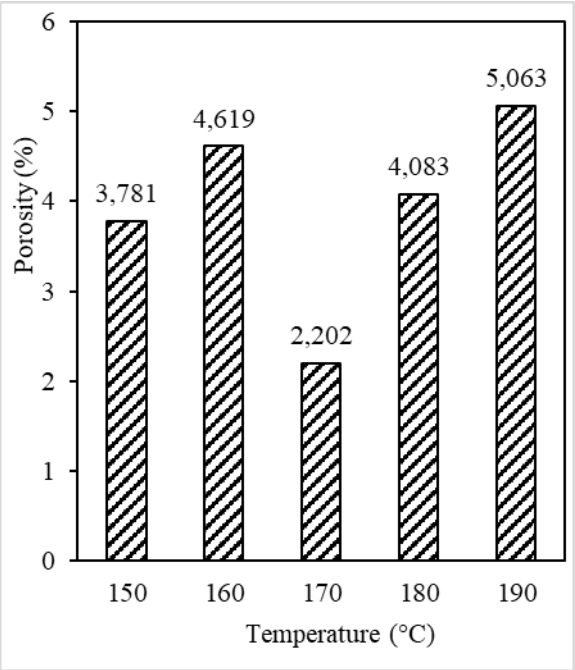


Figure 6. Porosity Graph

Figure 6 shows the porosity value relative to temperature. The higher the heating temperature, the higher the porosity value. However, Figure 14 shows a temperature value of 170°C with a value of 2.202% which has a low porosity value. The low value is because the material does not experience material failures such as voids and fiber pullouts. This has an impact on the high strength of the specimen. Meanwhile, the highest value was shown at a temperature of 190°C with a value of 5.063%. High porosity is caused by the large number of defects in the specimen, such as voids and fiber pullouts, giving rise to high porosity which results in decreased specimen strength. This also occurred in specimens with temperatures of 150°C, 160°C and 180°C with values of 3.781%, 4.619% and 4.083%. The porosity value is inversely proportional to the density value, the higher the density value, the lower the porosity value. The lower the porosity value, the higher the strength of the material [22].

3.1. Tensile Test

Tensile testing aims to find maximum tensile strength and elongation. The tensile test results can be seen in Figure 7. Figure 7 shows a graph of tensile strength against temperature. The temperature values of 150°C and 160°C experienced a decrease in strength due to the large number of material failures at that temperature and at a temperature of 160°C the fibers were arranged unevenly so that the strength of the specimen was low. Figure 6 shows the porosity value at a temperature of 160°C which is quite high at 4.619%. The strength of the material is related to the porosity value of the material because the higher the porosity, the lower the strength. Meanwhile, the highest value for tensile strength is 509.80 MPa, namely at a temperature of 170°C. Then temperatures of 180°C and 190°C with values of 460.76 MPa and 457.12MPa. The decrease in strength is influenced by heating temperature. The number of material failures in the specimen greatly influences the strength. The strength of a material is directly proportional to its density value, the higher the density, the higher the tensile strength of the material. According to Eqitha Dea Clareyna & Mawarani, (2013) decreasing density is directly proportional to the defects a material has and the higher the density, the fewer defects there are.

The heating temperature used in this research greatly influences the tensile strength. The highest tensile strength value is at a temperature of 170°C with a tensile strength value of 509.8 MPa, while the highest value is at a temperature of 160°C with a tensile strength value of 453.05 MPa. This happens because at low temperatures the HDPE matrix has not yet reached the melting point evenly, whereas the higher the temperature, the lower the tensile strength value of the material.

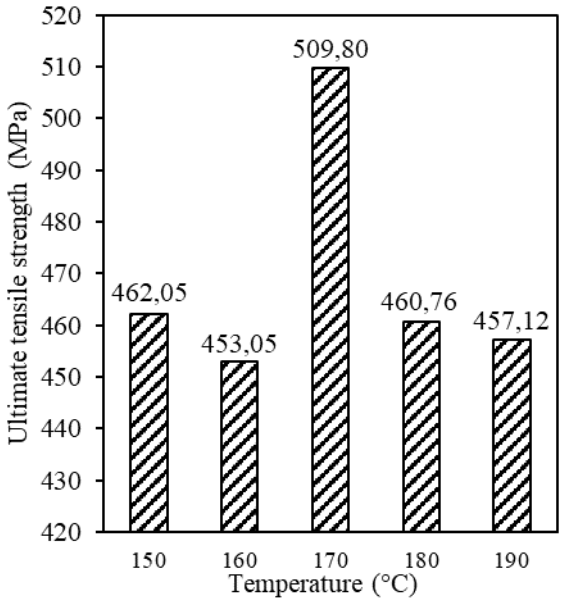


Figure 7. Tensile Graph

This also happened in the research of Sendawati et al., (2022) who conducted research with a variation of five temperatures, namely 150°C, 160°C, 170°C, 180°C, and 190°C with the lowest strength value being 190°C. This happens because the fiber and adhesive bonds are not integrated enough, causing the specimen to become brittle and the ability to withstand the load decreases. Meanwhile, if the temperature used is low, the adhesive does not work optimally so the resulting tensile strength is low.

Apart from the tensile strength graph, there is a graph of the modulus of elasticity in Figure 8. The graph shows that the highest value is at a temperature of 170°C with a value of 38.544 GPa, followed by temperatures of 180°C and 190°C with a value of 35.353 GPa and 34.967 GPa. Meanwhile, at a temperature of 150°C it has a value of 35.613 GPa and the lowest modulus value is at a temperature of 160°C with a value of 34.640 GPa. Figure 7 shows a decrease in tensile strength caused by several things such as changes in temperature and less even distribution of fibers.

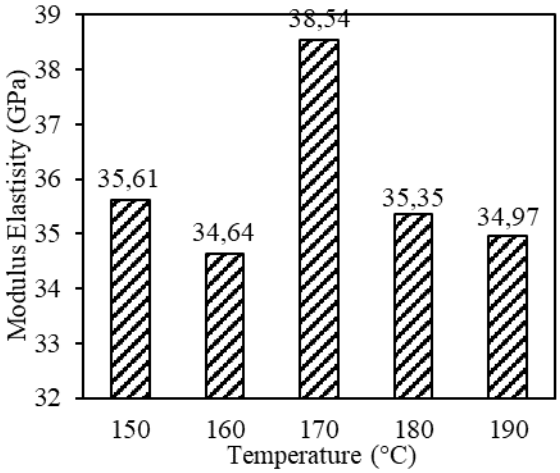
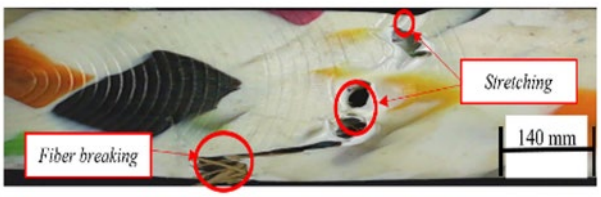


Figure 8. Modulus Elastisity Graph

Changing temperatures in the specimen will cause material fatigue [23]. Material fatigue is caused by temperatures that are too high. Meanwhile, uneven fibers in the composite cause the bond between the fibers and HDPE plastic to be less than optimal. The tensile strength value is directly proportional to the elastic modulus value [4]. Macro structure observations were carried out on the fracture surface of the test object as in Figure 8. The results of macro composite testing with a volume fraction of 90% HDPE plastic and 10% natural fiber had differences in the composition of the fiber composite structure and mechanical property values. Macrostructure observations were carried out on composites at temperatures of 150°C, 160°C, 170°C, 180°C, and 190°C. There are several factors that influence the results of specimen testing, such as the heating time of the hot press machine which is less than optimal in reaching the desired temperature [24][6].

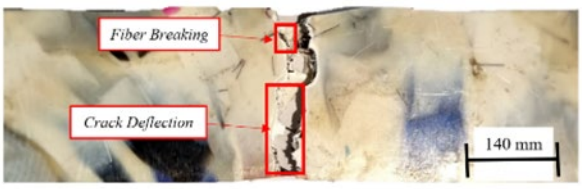
The type of fracture in each sample is quite varied in terms of the shape of the fracture. Fractures of the type void, fiber pullout, and overload are the most common, overload is a fracture that occurs due to fiber breaking caused by the strength of the fiber boundaries and the strength of the bond between the fiber and the matrix [25]. In this fault, it can be seen that the fault is slightly flatter on the surface and has visible break fibers. Fiber pullout is a connection between the fiber and the matrix that is not strong, so that the fiber is pulled out of the matrix connection, at the same time a void occurs in each specimen. Voids are air trapped during the manufacture of HDPE composite specimens, resulting in cavities which indicate a weak bond between the fiber and the matrix [26].

a. Temperature 150°C



b. Temperature 150°C

c. Temperature 170°C



d. Temperature 180°C

Figure 9. Fracture of Tensile

3.2. Bending Test

Bending stress indicates the resistance of a material to bending loads [27]. In this bending test, the test specimen experiences springback with different average values. Springback is a force caused by the influence of the elasticity of the composite undergoing the testing process [28].

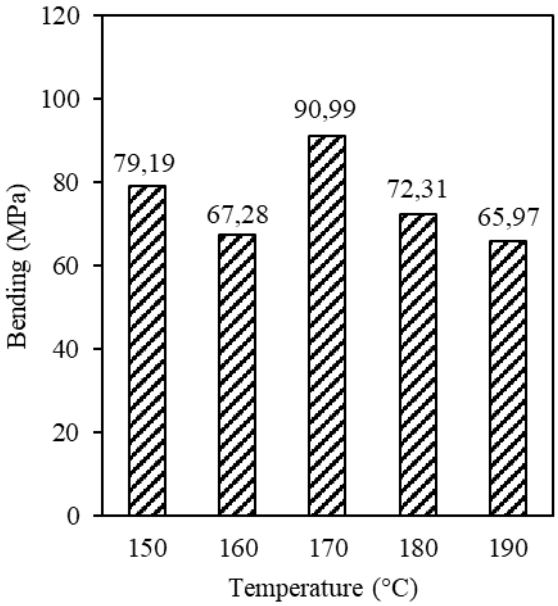


Figure 10. Bending Graph

Figure 10 shows the results of the bending strength of natural fiber HDPE composite which has the highest value at 90.99 MPa at a temperature of 170°C. In figure 10 the strength increases to a temperature of 170°C and then decreases to a temperature of 190°C. This is because the mechanism of increasing strength or decreasing strength is related to the number of pores and bonds between particles [4]. This also happened in research by penelitian Karso et al., (2012) which had graphic results that increased and then decreased as temperature increased. This is because HDPE undergoes thermal cycling treatment, causing the HDPE material to undergo a phase change from solid to liquid phase. This results in the interfacial bond between HDPE and natural fibers becoming weaker and leaving more pores as the thermal cycle increases [29].

The heating temperature used in this research greatly influences the bending strength. The highest bending strength value is at a temperature of 170°C with a tensile strength value of 90.99 MPa, while the highest value is at a temperature of 160°C with a tensile strength value of 67.28 MPa. This happens because at low temperatures the HDPE matrix has not yet reached the melting point evenly, whereas the higher the temperature, the lower the bending strength value of the material.

The pores that appear greatly influence the bending strength, because the pores are the initial place where cracks occur. Weakened interfacial bonds will cause the bending resistance of HDPE composites to decrease. Apart from that, the length of time at high temperatures can also cause a decrease in composite strength [30].

4. Conclusion

After data collection and analysis in this final research project, it can be concluded that:

a. The heating temperature used in this research greatly influences the tensile strength. The highest tensile strength value is at a temperature of 170°C with a tensile strength value of 509.8 MPa, while the highest value is at a temperature of 160°C with a tensile strength value of 453.05 MPa. This happens because at low temperatures the HDPE matrix has not yet reached the melting point evenly, whereas the higher the temperature, the lower the tensile strength value of the material.

b. The heating temperature used in this research greatly influences the bending strength. The highest bending strength value is at a temperature of 170°C with a tensile strength value of 90.99 MPa, while the highest value is at a temperature of 160°C with a tensile strength value of 67.28 MPa. This happens because at low temperatures the HDPE matrix has not yet reached the melting point evenly, whereas the higher the temperature, the lower the bending strength value of the material.

c. The faults that occurred during the research were crack deflection, stretching, fiber breaking, fiber pullout, voids, and matrix breaking. These fractures can occur due to several things, such as the inappropriate position of the fibers, the presence of air in the composite during the composite manufacturing process, and the fibers still contain lignin so that the fibers do not bind optimally with the matrix.

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