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The effect of variations in the volume of areca fiber and pumice powder filler on the bending strength of sandwich composites with styrofoam cores

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ABSTRACT:*A sandwich composite with a styrofoam core and skin reinforced with areca fiber and pumice powder filler offers potential as a lightweight and strong construction material. This study aims to investigate the effect of variations in the volume of areca fiber (5%, 10%, and 15%) and pumice powder filler (5%, 10%, and 15%) on the bending strength of sandwich composites. Sandwich composites are fabricated using the hand lay-up method. Three-point bending tests were carried out to determine the bending strength and flexural modulus of the composite. The results showed that the bending strength of the sandwich composite increased with the addition of the pumice filler volume. The increase in filler volume helps distribute the load evenly and increases the density of the composite. Increasing the volume of areca fiber reduces the bending strength of the composite. This is influenced by too much fiber volume in one material so that there is little resin to fill the space to combine. For bending strength, the highest value was obtained at the volume fraction (10%S:5%BA) of 3.516 MPa and the lowest was at the ratio (15%S:5%BA) of 2.879 MPa. This composite has the potential to be applied as a lightweight structural panel in various fields such as building construction, transportation and industry.*

NOMENCLATURE

Symbol	Description	Unit
σ	tensil strength	*MPa*
F	tensile force	*N*
A	cross sectional area	*mm²*
ε	strain	-
ΔL	increase in length	*mm*
L_0	initial length	*mm*
E	modulus elastisity	*MPa*
σ_b	bending strength	*MPa*
P	maximum bending load	N
L	span length	mm
h	specimen thickness	mm
b	specimen width	mm
t	thickness of the skin	mm
d	thickness of the sandwich composite	mm
c	thickness of the core	mm

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I. INTRODUCTION

Sandwich composites are materials composed of three layers, two of which are a face sheet called the skin and a middle layer called the core, Librescu and Hause (2000). The application of composite materials has been widely used in various sectors such as construction, transportation, and manufacturing because they have several advantages over traditional materials, such as lightness, strength, and good thermal insulation. To increase these requirements, sandwich composite structures can be applied.

As the need for more economical and environmentally friendly, sandwich composite construction increased. Therefore, the use of natural fibers as skin in sandwich structures can be used to obtain lightweight, heat and corrosion resistance but high stiffness. Natural fibers not only function to increase stiffness and strength but can also reduce the weight of the resulting composite material, Alsubari et.al (2021). One type of natural fiber that has the potential to be used as skin for sandwich structures is areca fiber (Areca Catechu). Areca fiber is strong, stiff, and environmentally friendly. Apart from that, the development of this fiber can also increase its economic value and usefulness. The advantages of areca fiber are that it can reduce environmental pollution, is cheap, does not damage the environment, and is easy to find, Staples and Bevacqua (2006).

Hapiz et al. (2018) researched on the mechanical properties of areca fiber composites. He states that there are differences in mechanical properties between areca fiber in the tensile test and compression test. In the tensile test with a fiber concentration of 50%, the fiber had the best mechanical properties because it had the highest tensile strength, length increase, and load, namely 16.35 MPa, 2.06 mm, and 3147.45 N respectively. Meanwhile, in the compression test, Areca fiber composite with a concentration of 30% has the highest modulus of fracture strength (MOR), namely 30.43 kg/cm², and modulus of elasticity of 1980.2 MPa. Because areca fiber has very diverse components, Kencanawati et al. (2018) showed that NaOH treatment can remove several components that make up the fiber. The percentages used are NaOH 2.5%, 5%, 7.5% and 10%. The experimental results showed that there was a decrease in the density of areca fiber due to the alkaline treatment process. The highest tensile strength of the fiber was found in 5% NaOH of 165 MPa for 2 hours of soaking at room temperature.

The quality of natural fibers is greatly influenced by environmental factors, therefore the use of pumice as a filler can improve the properties of natural fibers, as well as being able to act as a matrix reinforcement material and reduce the volume fraction of resin. In fact, pumice is able to improve the properties of natural fibers, become a matrix strengthening material and reduce the volume fraction of resin. Ridha (2016) conducted research on the use of pumice on Lombok Island as a composite filler material which has the potential to improve physical and mechanical material properties such as tensile strength, flexural strength and thermal stability. Meanwhile, the use of styrofoam as the core material is an effort to achieve light weight. In addition, the use of cores can absorb impact energy and save material weight.

In Indonesia, areca fiber is simply thrown away after the seeds are used, so its use as a composite reinforcement must be developed further. Therefore, it is necessary to develop a areca fiber sandwich composite with pumice filler and Styrofoam core to be engineered into an optimal sandwich composite. This research aims to determine the effect of variations in the volume of areca fiber filler and pumice powder on the flexural strength of sandwich composites using a styrofoam core.

II. EXPERIMENTAL SETUP

Sandwich composites have two components, namely skin and core. Sandwich composite skin is made from areca fiber which has been treated with 5% NaOH for 2 hours, pumice stone which has been sifted with a 200 mesh sieve and polyester resin as the matrix. Meanwhile, the sandwich composite core uses styrofoam (figure 1). For sandwich composite skin, there are variations in the volume fraction of areca fiber (S) and pumice fillers (BA) of 5%, 10% and 15% respectively.

Figure 1 (a) Areca fiber (b) Pumice stone (c) Styrofoam

In making a sandwich composite, you start by making a skin by weighing fiber and pumice filler as reinforcement and polyester resin and catalyst as the matrix. The reinforcement and matrix are weighed based on the weight of each volume fraction. The matrix and pumice are mixed and stirred until evenly distributed in the container. The mixing process will produce air bubbles. In order for the air bubbles to disappear, it is necessary to carry out a vacuum chamber process. The mixed matrix and pumice are partially poured into a mold measuring 5 mm thickness, 300 mm long and 200 mm wide as the base layer. Fiber as reinforcement is spread evenly over the surface of the matrix. The remaining mixture is poured back into the mold and leveled and then covered with glass. The sandwich composite skin is left to sit for 10 to 24 hours. After that, the test objects are cut according to the number and size of the testing standards (figure 2).

Figure 2 (a) Vacuum chamber process (b) Sandwich composite skin molding (c) Tensile test specimen (d) Sandwich composite skin

To perfect the sandwich components, a core or styrofoam is needed. EPS as a sandwich composite core has mechanical properties that are able to absorb impact energy and have low thermal conductivity. Styrofoam is cut to the following sizes (figure 3).

Figure 3 (a) Styrofoam composite sandwich shape (b) Styrofoam of composite sandwich dimensions

Sandwich making is done manually by preparing the skin and core. One surface of the skin is smeared with epoxy and glued to the core. with two skins, then glued to the top and bottom of the core. For a perfect sandwich composite it takes 24 hours to be ready for test (figure 4).

Figure 4 (a) Skin sanded on the surface (b) Sandwich composite components that have been glued (c) Sandwich composite form

To determine the characteristics of the sandwich composite skin, tensile testing was carried out using the ASTM D 3039 standard. The tensile testing equipment used was the Universal Testing Machine Tensilon (figure 6). The dimensions of the specimen can be seen in Figure 5.

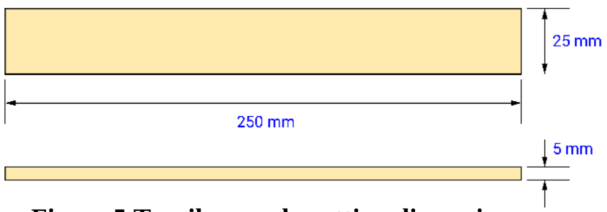

Figure 5 Tensile sample cutting dimension

Tensile testing is intended to obtain stress and strain so that the mechanical properties of the material are known. Then the equation can be calculated using (1), as follows:

$$\sigma = \frac{F}{A} \tag{1}$$

σ is the tensile strength (MPa), F is the maximum load (N), and A is the cross-sectional area (mm²).Strain and modulus of elasticity can be formulated (2) and (3):

$$\varepsilon = \frac{\Delta L}{Lo} \tag{2}$$

$$E = \frac{\sigma}{\varepsilon} \tag{3}$$

ε is the strain, E is the modulus of elasticity, ΔL is the increase in length (mm) and Lo is the initial length (mm).

Figure 6 Tensile strength testing of skin material

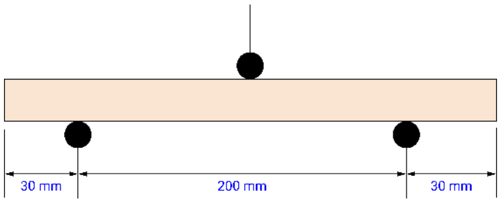

Figure 7 Schematic of loaded sample

The amount of bending stress in the core (styrofoam) can be calculated using the following equation, referring to the ASTM D790 standard. The location of the load is at a distance of ½ L from the support with a span of 200 mm (figure 7), where the specimen has the following dimensions.Styrofoam core bending strength using the equation (4):

$$\varepsilon = \frac{3PL}{2bh^2} \quad (4)$$

P is the maximum load (N), L is the span length (mm), h is the specimen thickness (mm), and b is the specimen width (mm).Sandwich composite bending testing uses the three-point bending method referring to the ASTM C393 standard. The location of the load is at a distance of ½ L from the support with a span of 200 mm, where the specimen has the following dimensions (figure 8).

Figure 8 (a) Top view of the cutting dimensions of the bending sample, (b) schematic of the loaded of thethree-point bending

In the bending test, it is known to what extent the bending capability of the composite is able to withstand the load until the composite breaks or the bending load decreases.Sandwich composites bending strength using the equation (5):

$$\sigma_b = \frac{PL}{2t\,(d+c)b} \quad (5)$$

Figure 9 (a) Flexural strength testing of sandwich composites (b) Flexural strength testing of sandwich composite cores

P is the maximum load (N), L is the span length (mm), t is the thickness of the skin (mm), d is the thickness of the sandwich composite (mm), c is the thickness of the core, and b is the specimen width (mm).The bending testing equipment used was the Universal Testing Machine Tensilon (figure 9).

III. RESULTS AND DISCUSSION

3.1 Tensile strength of skin material

The tensile strength in Figure 10 (a) shows that there is a decrease in the tensile strength value of the composite skin due to the increase in the percentage of fiber volume. From the volume S (5%) it can be seen that there is an increase in the tensile strength value with increasing pumice filler. The volume of 5% fiber and pumice filler has a value of 21.06 MPa, increasing the volume of BA (10%) causes the tensile strength to increase by 21.16 MPa. At BA (15%), the tensile strength value is greater than before at 22.81 MPa. This situation indicates that the greater the volume of pumice filler, the greater the tensile strength value.S (10%) increased but was not very consistent, the volume of BA (5%) had a value of 20.86 MPa, as the volume of BA (10%) increased, the tensile strength decreased by 20.61 MPa. At BA (15%), the tensile strength value again increases to 21.17 MPa. This inconsistent situation can occur due to uneven fibers during the moulding process and the location of the fracture during the tensile test. In sample S (15%) the graph shows a value that is directly proportional to the increasing percentage of pumice filler. It is known that the tensile strength value for variations in the volume fraction of BA (5%) is 18.82 MPa, then at the volume fraction of BA (10%) it increases by 19.55 MPa, followed by the volume fraction of BA (15%) which has a value of 21.01 MPa. This increase in tensile strength occurred due to an increase in the volume percentage of pumice filler.

If we look again at each fiber sample, the tensile strength value tends to decrease as the fiber percentage increases. This is influenced by too much fiber volume in a material so that only a small amount of resin fills the space to melt, but with the addition of composite pumice filler, the tensile strength increases, because the filler is able to perfect the matrix structure. This is in accordance with the results of research from Pratama (2022) which stated that, increasing the volume fraction of areca fiber in the composite will decrease, this is because the more fiber volume used, the more difficult it is for the resin to bond with the fiber, causing the composite material to become weak. This situation is also caused by the uneven distribution of areca fiber. The addition of pumice filler will improve the matrix structure, but also change the physical properties of the material such as its elastic modulus. This can be observed further by looking at Figure 10 (a).

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Figure 10 (a) The relationship between fiber and filler volume variations on the tensile strength of sandwich composite skin (b) The relationship between fiber and filler volume variations on the tensile strain of sandwich composite skin

Figure 10 (b) shows that the strain value decreases as the overall amount of fiber and pumice filler increases. This decrease in strain value was caused by the influence of the addition of pumice powder composition. This is because the filler material is very brittle and difficult to bear the load on the matrix. So the strain will decrease if the material is brittle because a brittle material is unable to undergo significant plastic deformation before fracture occurs.From Figure 11 it can be seen that (15%S:15%BA) has the highest elastic modulus value, namely 20.76 MPa, while the lowest elastic modulus is obtained at (15%S:5%BA) of 17.29 MPa. The elastic modulus value increases due to the influence of increasing the volume of pumice filler material. As the percentage of filler increases, the material will experience strength and stiffness. This situation occurs due to a locking reaction between the resin and filler which become one unit, thereby changing the physical properties of the material. The bonding reaction between the rough and porous surface of the pumice stone and the resin causes a wide contact surface. A large contact surface will create strong chemical bonds that bind each other.

Kosedag (2023) states that increasing the volume of pumice filler will increase the maximum stress and strain by a percentage of 10%. Due to the nature of pumice, it is micro-porous and has a strong inter-surface bond with the matrix. This is also similar to what was done by Nayiroh (2021) who used green shell filler as a reinforcing material for polyester resin. With increasing filler volume the tensile strength increases but ductility decreases as the amount of filler added increases.

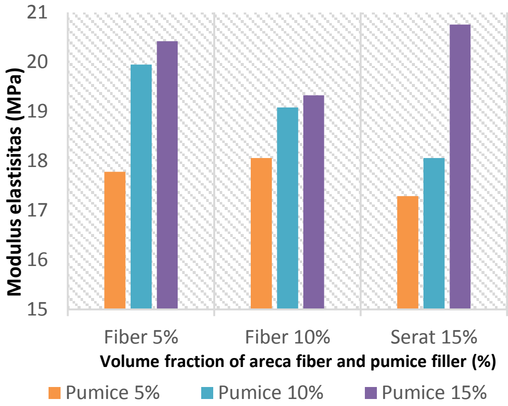

Figure 11 The relationship between fiber and filler volume variations on the elastic modulus of the sandwich composite skin

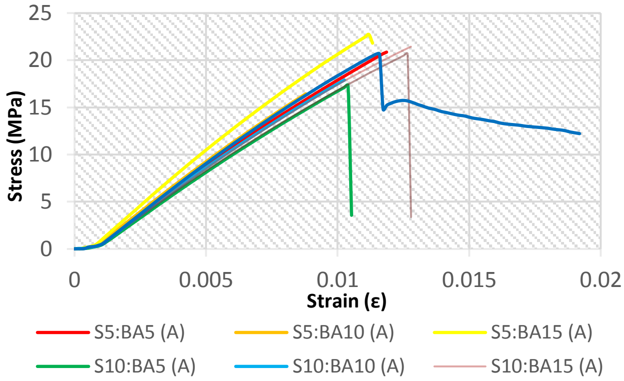

Figure 12 The relationship between tensile stress and strain of composite skin

From Figure 12, this material predominantly experiences fracture at lower stresses. This is because the material is brittle. This brittle property is characterized by sudden fracture without experiencing significant plastic deformation. The largest tensile stress is found in the volume fraction (15%S:5%BA) with a value of 22.72 MPa and the lowest tensile stress is found in the pumice volume fraction (10%) with a value of 16.44 MPa. By having brittle properties, this material is able to provide strength and resistance to heavy loads, but is susceptible to shock or impact loads. Sutrisno (2023) stated that the addition of compounds contained in fly ash will cause the material to have hard but brittle properties. Fly ash itself has a chemical composition similar to pumice. This is characterized by fractures that occur in the test object. The following is an image of the fracture of the test object with each volume fraction of fiber and pumice filler as shown in the image below.

Figur 13 Fracture in the specimens tensile test of composite skin with volume fraction of areca fiber : pumice filler (a) 5%:5%, (b) 5%:10%, and 5%:15%

Figure 14 Fracture in the specimens tensile test of composite skin with areca fiber : pumice filler (a) 10%:5%, (b) 10%:10%, and (c) 10%:15%

Figure 15 Fracture in the specimens tensile test of composite skin with areca fiber : pumice filler (a) 15%:5%, (b) 15%:10% and 15%:15%

In Figure 13, it can be seen that the fracture form of the tensile test specimen of polyester resin composite material with areca fiber reinforcement and pumice filler experienced a brittle fracture, because the fracture surface had an irregular and rough shape. And it can also be seen that the fiber is full out at the fracture, because the matrix is not able to withstand the load, causing the fiber to be pulled out of the matrix.Based on Figure 14, the specimen experienced brittle fracture, because the surface of the specimen was in the form of flakes and had fracture propagation perpendicular to the direction of tensile stress. Specimens with 10% fiber experienced more fiber pull out than 5% fiber. This fiber pull out occurs due to a more dominant fiber fraction.

The situation in Figure 15 experienced fiber pull out which was very dominant compared to the previous fracture, because the volume percentage of areca fiber reached 15%. This fiber pull out fracture is caused by an imperfect bond between the fiber and the matrix in the composite. Insufficient fiber shape also greatly influences the tensile strength of the composite. With more dominant fibers, the interfacial bond between the fibers and the matrix decreases. This situation shows that the greater the percentage of areca fiber makes it difficult for the sample to be broken or broken because the fiber volume is too much.From the results of the macro photos, this fault can be specified as a brittle fracture. Brittle fractures are caused by the brittle nature of the matrix and filler which allows them to fracture before the plastic area. Meanwhile, fractures are dominated by fiber pull out due to imperfect bonding between the fibers and the matrix in the composite material.

3.2 Styrofoam flexural

The styrofoam bending test was carried out using three-point bending. This styrofoam sandwich core functions as a load support for the sandwich composite. Because the core is one of the main components of sandwich composites, it is important to carry out tests to determine the mechanical properties of the styrofoam. From Figure 16 it can be seen that the curve from 3 repetitions of the bending test shows quite consistent values. Based on bending strength data, Styrofoam with a thickness of 20 mm has an average bending stress value of 0.135 MPa.

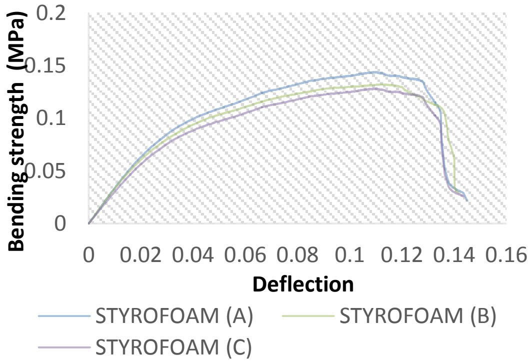

Figure 16 the relationship between bending stress and deflection of Styrofoam

3.3 Sandwich composite flexural

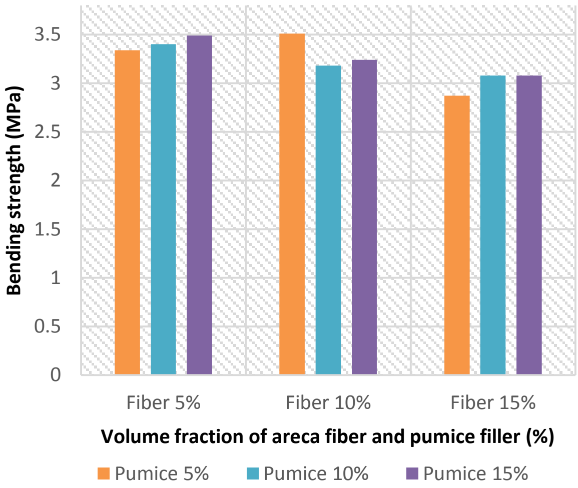

Figure 17 bending strength of sandwich composites

From Figure 17 it can be seen that there is a increase in the bending strength value of the 5 % areca fiber sandwich composite (S) and pumice filler (BA) with volume variations (5%, 10% and 15%). In sandwich composites, the ratio of S (5%) to BA (5%) has a value of 3.34 MPa, increasing the BA volume percentage (10%), the average bending strength is obtained at 3.4 MPa, followed by the BA volume fraction (15%) has a bending value of 3.49 MPa. Bending strength increases as the volume fraction of BA supplied increases. The greater the percentage of BA used, the higher the strength in receiving the load.

Meanwhile, the bending strength of the volume fraction S (10%) with BA (5%) has the highest bending strength value of 3.51 MPa. For the BA volume fraction (10%) it has a bending strength of 3.18 MPa, so this has decreased. The BA volume fraction (15%) increased by 3.24 MPa. The value of S (10%) is not very consistent, influenced by uneven fiber factors and asymmetric core cutting. However, the bending strength value decreases compared to S (5%).

And for the results of variations S (15%) with BA (5%, 10%, and 15%) respectively, the results were 2.87 MPa, 3.088 MPa, and 3.080 MPa. This is quite consistent, where when the filler percentage increases, the bending strength increases. Sandwich composites can withstand higher bending loads compared to the loads supported by the core. With filler volume fraction it can increase the bending strength of the composite. From the data regarding the bending test above, it can be assumed that increasing the fiber volume fraction in the sandwich composite can cause a decrease, and increasing the filler volume fraction can increase the bending strength of the composite.

As is known, pumice contains silica which can increase the strength of composite materials and improve the structure of the polyester resin. Sari et.al (2022) also stated that adding a small percentage of filler and fiber volume will increase the strength of the composite. The presence of filler in large quantities and mixed homogeneously creates a strong interfacial bond. The addition of fibers will actually reduce the bending strength of the composite due to the weak interfacial bond. The results obtained in this research are still better when compared to the results of sandwich composite research, Sandi (2019) when seen from the bending strength of sandwich composites which use natural fibers and pumice.

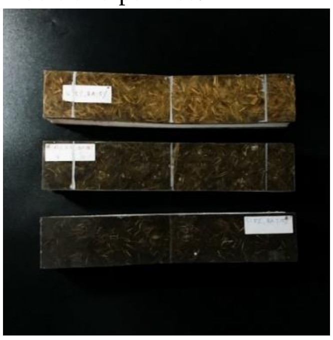

Figure 18 Specimen color is different in the 5% areca fiber volume fraction and 5%, 10% and 15% pumice filler

This is also supported by the visual representation in Figure 18 which shows that changes in the color of the sandwich composite occur, along with an increase in the percentage ratio of pumice filler. This darker color occurs due to the homogeneous mixing of polyester resin with pumice filler. This color change creates a good interfacial bond with the polyester matrix. The higher the percentage of filler used, the darker the color and thicker the texture. This is what gives strength to the sandwich composite because the pumice filler contains Silica (SiO_2). To assess the material characteristics of the sandwich composite that has been tested, it can be seen in Figure 19.

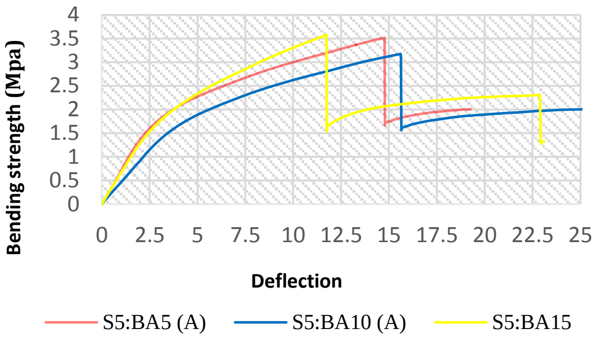

Figure 19 Relationship between bending strength and deflection of sandwich composites with volume fraction areca fiber 5% and pumice filler 5%, 10% and 15%

In general, this indicates that the material is ductile. This ductile nature can be characterized in Figure 19 as shown by the plastic deformation which becomes very large before fracture occurs in the sandwich composite. The skin holds the load to its maximum limit then the load reaches the core. When the sandwich composite is subjected to stress, the skin resists the load and causes the skin to react. The core will withstand the shear loads that arise due to skin deformation. This causes the core to experience plastic deformation, so the sandwich composite S (5%) with BA (5%, 10% and 15%) tends to have ductile properties.

IV. CONCLUSION

Based on the results of the test, analysis and discussion obtained, there are several conclusions as follows:

1. Variations in volume fraction of fiber and pumice filler for sandwich composite skin have a positive effect on tensile strength of skin material. The tensile strength increases as the volume of pumice filler increases, but increasing the fiber volume causes the tensile strength to decrease.
2. That there is an influence in sandwich composites of variations in fiber volume fraction and pumice filler on bending strength. Due to the increase in the volume of pumice filler and the increase in fiber volume fraction it can cause a decrease. The ability to withstand bending loads is also higher if the skin and core are combined into a sandwich composite component.
3. The highest tensile strength was obtained with a value of 22.81 MPa with the volume fraction of fiber and pumice filler (5%S:15%BA) while the lowest tensile strength was at the volume fraction (15%S:5%BA) with a value of 18, 82 MPa. Then the bending strength with the highest value was obtained at the volume fraction (10%S:5%BA) of 3.516 MPa and the lowest was at the ratio (15%S:5%BA) of 2.879 MPa **.**

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