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The effect of tapioca starch concentration on mechanical properties of Sansevieria Trifasciata fiber-reinforced composites

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Abstract

This research investigates the impact of varying concentrations of tapioca starch (Manihot esculenta) on the mechanical properties of composites reinforced with Sansevieria trifasciata (Lidah mertua) fibers. The composites were fabricated using the hand lay-up method with SHCP 2668 polyester resin, mekpo catalyst, and alkali-treated fibers (5% NaOH). The fiber weight fraction was 30%, and the catalyst weight was 10% of the total specimen mass. The tapioca starch concentrations were 0%, 10%, 20%, 30%, 40%, and 50%, with a total matrix mass of 50 grams. Mechanical properties were evaluated through tensile tests (ASTM-D3039) and bending tests (ASTM-D790). The results indicated that composites with added tapioca starch exhibited improved tensile strength and a higher modulus of elasticity. However, for bending tests, the composites without added tapioca starch demonstrated better performance, showing a higher elastic modulus and better flexibility. In conclusion, adding tapioca starch enhances the tensile strength of the composites, making them stronger. Conversely, for bending applications, composites without tapioca starch are preferable due to their superior elasticity and bending strength.

***Keywords**: Amilum Manihot Esculenta; ASTM-D3039; ASTM-D790; Hand Lay Up Method; Sansevieria Trifasciata; SHCP 2668 Polyester Resin*

1. INTRODUCTION

Composite technology is currently increasingly developing, one of which is reinforced composites, both laminate composites, particle composites, and fiber composites. The condition for the formation of a composite is that there is a surface bond between the matrix and the filler. This inter-surface bond occurs due to adhesion and cohesion forces. In composite materials, adhesion-cohesion forces occur in three main ways: interlocking between surfaces, electrostatic forces, and Vanderwall forces (1). The advantages of composite materials are that raw materials are easy to obtain, resistant to corrosion, easy to design, have a longer service life, can be recycled, have high durability, are able to absorb heat, and are economical (2). One of the fiber composites is the most widely developed, using both fiber and plant fibers. One of the most developed is composite technology using plant fibers; apart from being easy to find, the material is also easy to find. Natural fibers have been tried to replace the use of synthetic fibers, such as Boron, Aluminum Oxide, Graphite/Carbon, Kevlar-49, Silicone Carbide, and E-Glass. Even though it doesn't completely replace it, the use of natural fibers instead of synthetic fibers is a wise step in saving the environment from waste produced and limited non-renewable natural resources (3).

Adding fibers to composites is an effort to increase mechanical strength. Fiber composites are divided into two categories: natural fiber composites and synthetic fiber composites. Natural fibers have environmentally friendly properties that can be used as an effective alternative reinforcing phase in polymer composite materials compared to synthetic fibers (4). Sansevieria is a tropical plant that has abundant fiber content. Basically, Sansevieria plant fiber has the potential to be used as a reinforcement because it has quite good mechanical properties, but it has not yet been widely researched or studied in its application as a composite reinforcement (5). According to (6),taking plant fiber goes through several stages, namely bleaching, fiber extraction (degumming), and fiber decomposition. The use of natural fibers as reinforcement for composite materials still causes various problems. The disadvantages of natural fibers as composite reinforcements include hydrophilic properties, low mechanical properties, limited processing temperatures, low binding force of the matrix and fiber, and being easily degraded (7). To go beyond this, research has begun to be carried out to improve the properties of natural or plant fibers as reinforcements in composites. According to previous research (8), Natural fibers contain lignocellulose, which is hydrophilic because it contains many hydroxyl groups. According to this research (9) NaOH (Sodium Hydroxide) soaking treatment on mother-in-law's tongue fibers had a significant effect on the elastic modulus value. The fiber was soaked in a 5% NaOH solution for 120 minutes to remove the lignin layer on the fiber (10). By removing this wax layer, the bond between the fiber and the matrix will become stronger, resulting in a higher tensile strength of the composite (11)(12).

In addition to improving the fiber's properties, it is also done to increase its adhesive power. One method is to use a mixture of materials. Starch is a complex carbohydrate that is insoluble in liquid, in the form of a white powder, tasteless, and odorless. Starch has the chemical formula $(C_6H_{10}O_5)_x$. One of the most commonly used starches is cassava starch. Cassava starch has the ability to act as a better binder compared to corn starch and potato starch (13). Cassava (Manihot esculenta Crantz) is a tuber plant that is easy to grow in tropical areas, including Indonesia. Cassava is the third staple food source in tropical countries after rice and corn. Cassava tubers are generally used in the form of starch or flour (14). Cassava starch can function as a filler, binder, and crusher. Tapioca starch is an organic material from cassava starch that contains polysaccharides, so it can be used as an adhesive because it forms a fairly strong layer (15). Tapioca starch (Manihot esculenta starch) is used as a reinforcement in the composite to be made. The adhesive properties of the starch are expected to maximize the bonding force of the matrix in the composite. The matrix used in making this composite is SHCP 2668 polyester resin and mekpo catalyst. This research on making composites using mother-in-law's tongue fiber (Sansevieria rifasciata) and adding a concentration of tapioca starch (Manihot esculenta starch) used tensile tests with the ASTM D-3039 standard and bending or bending tests with the ASTM D-790 standard. The principle of the tensile test is to apply a regular and uniform tensile load to a test object of a certain size (16). while the bending test is carried out by means of a rod-shaped specimen being supported on both sides, then a load is applied between the two supports until the specimen breaks (17). There is also research on composites reinforced with Arengga pinnata fiber with an epoxi matrix that shows that the tensile and bending properties of composites reinforced with Arenga pinnata fiber show that specimens with a volume fraction of 60% : 40% and a fiber orientation of 0° produce the most optimum test values for both tensile and bending tests. (18). There is also research on making test specimens with thorn pandan fiber and polyester resin in accordance with the tensile test standard ASTM D3039. The results of the research show that the maximum tensile strength value is when the composite composition is 40% by weight of polyester resin and 60%. From all the research on the use of natural fibers in composite manufacturing, fibers play an important role in increasing the strength of the material. This study examined the ability of starch to strengthen composites by adding matrix adhesion. The adhesive properties of starch flour were utilized as an additive to add matrix adhesion with composite reinforcing fibers. The use of starch as a reinforcing additive is an attempt to find a natural material for a better natural fiber binder that can improve the mechanical properties of composites.

2. METHODS

This is experimental research with the aim of investigating the effect of adding tapioca starch concentration on the strength of composite engineering using sansevieria fiber. The matrix used is SHCP 2668 polyester resin, and the sansevieria fiber used is treated with 5% NaOH and a fiber weight fraction of 30%, and the fiber is cut to a size of ±1 cm. The total mass weight of the specimen is 50 grams, where only the weights of the resin and tapioca starch are calculated, while the weights of the fiber and catalyst are not counted in determining the mass weight of the specimen. For fiber, use a weight of 0.95 grams and a catalyst weight of 10% of the total weight of the specimen mass (5 grams). The addition of tapioca starch starts at varying concentrations of 0%, 10%, 20%, 30%, 40%, and 50%. In making this article, the research process was carried out in the mechanical engineering and food technology laboratory at the Muhammadiyah University of Sidoarjo, while material testing was carried out at the Malang State Polytechnic. Experimental methods include data collection methods and composite printing methods.

The materials used include SHCP 2668 polyester resin, mekpo catalyst, Sansevieria trifasciata fiber, and tapioca starch. Meanwhile, the tools used include specimen molds made from RTV 48 silicon, digital scales, plastic cups, and others. This article uses an equation that can be calculated in its research, including: making NaOH or 5% alkali treatment by mixing 500 ml distilled water and 25 gram NaOH, which is written in the following equation:

gr = Alkaline treatment × v =. . .(grams)

Then we can know the dosage of NaOH and distilled water in making alkali with 5% treatment, while for the volume fraction of fiber (Vf) using the following equation:

$$Vf = \frac{Wf/_{Pf}}{Wf/_{Pf} + Wm/_{Pm}} \text{ ....(\%)} \quad (1)$$

Where wf is weight of fiber, ρf is density of fiber, wm is weight of matrix, ρf is density of matrix.
And making composites uses the following equation:
a. Find the mass of the matrix / weight of the matrix

Mk-Va=.......grams (2)

b. Looking for concentration variation (%)

$$\frac{\text{Mamilum}}{Mk} \text{ x } 100\% = \ldots\% \quad (3)$$

c. Find the mass/weight of starch

$$Vk\% = \frac{Vk}{100} \text{ x Mk} = \ldots\text{ Grams} \quad (4)$$

After doing the calculations, you get 45 grams of polyester resin and 5 grams of starch flour or use a varying concentration of 10% tapioca starch. In the composite printing process, the mold is made from RTV 48 silicon with a mold size of 3cm by 20cm and a thickness of 5mm.

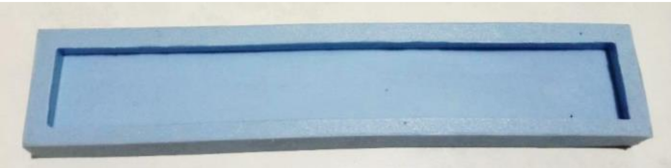


Figure 1. Specimen mold

After the process of calculating the composition of the materials for making the composite, the next thing to do is weigh all the materials, followed by the mixing process using the resin sequence → Tapioca starch → Sansevieria fiber → Catalyst.

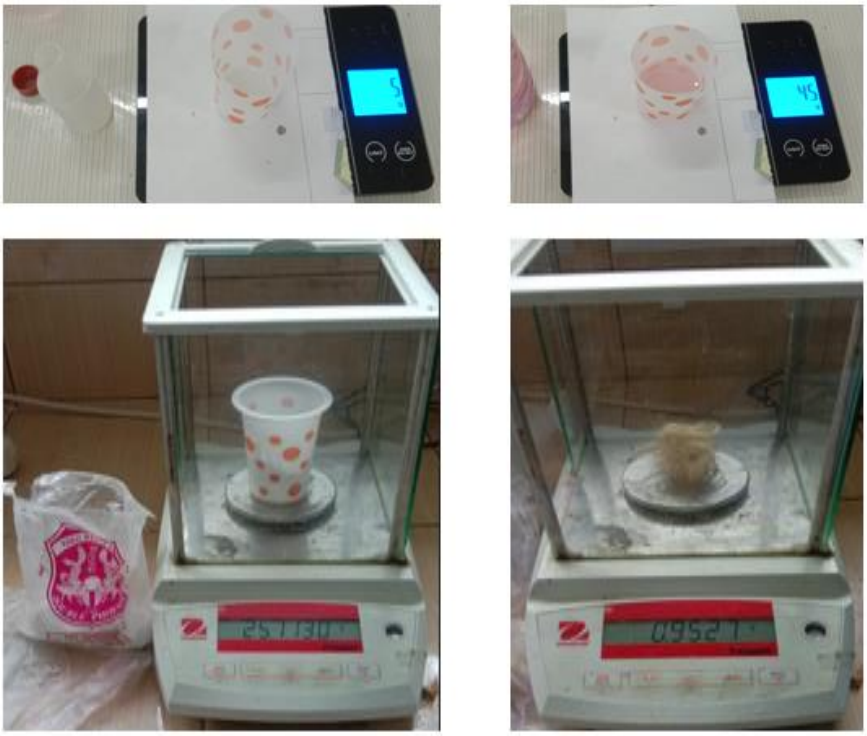


Figure 2. Weighing ingredients

Figure 3. The process of mixing all ingredients

Figure 4. Molding processes

Next, what is carried out is the drying process where the drying process is carried out using room temperature with a drying time of approximately 24 hours, and the drying results are obtained by visual observation as in table 1.

Table 1. Specimen condition data after the drying process

No	Starch Flour Variations	Specimen Condition
1	0 %	• Drying time within 24 hours • Visually, the specimen has no voids/bubbles • Drying of specimens was carried out indoors • The condition of the specimen surface is hard and slightly sticky • The specimen is hard and sticky in the lower area
2	10 %	• Drying time within 24 hours • Visually, the specimen has no voids/bubbles • Specimen drying was carried out indoors • The condition of the specimen surface is hard and sticky • The specimen is hard and sticky in the lower area
3	20 %	• Drying time within 24 hours • Visually, the specimen has no voids/bubbles • Specimen drying was carried out indoors • The condition of the specimen surface is hard and sticky • The bottom area of the specimen mold is sticky
4	30%	• Drying time within 24 hours • Visually, the specimen has no voids/bubbles • Specimen drying was carried out indoors • The condition of the specimen surface is hard and slightly sticky • The condition of the bottom specimen is hard and sticky
5	40%	• Drying time within 24 hours • Visually, the specimen has no voids/bubbles • Specimen drying was carried out indoors • The condition of the specimen surface is hard and slightly sticky • The condition of the bottom specimen is hard and sticky
6	50%	• Drying time within 24 hours • Visually, the specimen has no voids/bubbles • Specimen drying was carried out indoors • The condition of the specimen surface is hard and slightly sticky • The condition of the lower specimen is fragile and slightly sticky

After the specimen drying process, the next thing to do is form the specimen according to the test standards carried out, namely according to the shape of the ASTM D-3039 tensile test specimen and the ASTM D-790 bending test specimen.

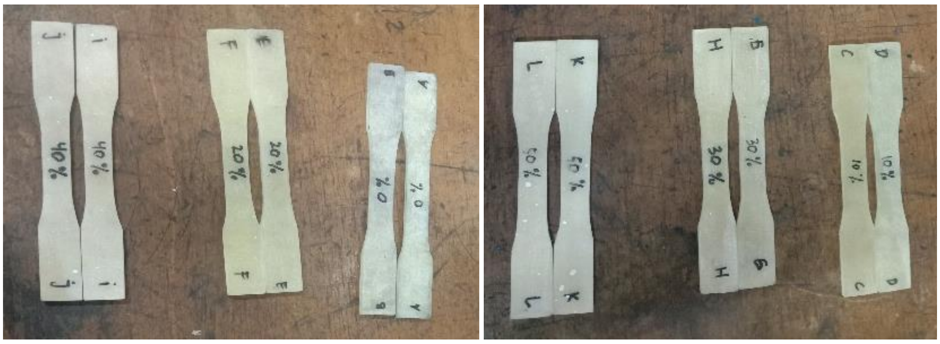


Figure 5. Test Object Specimens

After forming the specimen, the condition or visual observation of the specimen is obtained as in table 2.

Table 2. The condition of the specimen after being formed

No	Variations of Tapioca Starch Flour	Specimen Condition
1	0%	There are no voids and homogeneous
2	10%	There are no voids and homogeneous
3	20%	There are no voids and homogeneous
4	30%	There are voids and heterogeneous
5	40%	There are voids and heterogeneous
6	50%	There are voids and heterogeneous

In tensile testing, parameter data will be obtained, and the results can be used to calculate stress, strain, and the tensile modulus of elasticity. So, to calculate them, use the following equation:

a. Cross-sectional area

$$A0 = t \times l \tag{5}$$

where,
$A0$ = Initial Cross-sectional Area ($mm2$).
t = Thickness (mm)
l = Width (mm)

b. Stress (Tension)

$$\sigma = \frac{P}{A0} \tag{6}$$

or

$$\sigma = \frac{P \times 9.81}{A0} \tag{7}$$

where,
P = Load (Kgf).
$A0$ = Initial Cross-sectional Area ($mm2$).
σ = Voltage (Kgf/$mm2$).
9.81 = 1 kgf to Newton

c. Strain (Strain)

$$\varepsilon = \frac{\Delta L}{L0} \times 100\% \tag{8}$$

where,
ΔL = Difference in Length Increase
$L0$ = Initial Length.
ε = Strain (%)

d. Modulus of Elasticity

$$E = \frac{\sigma}{\varepsilon} \tag{9}$$

where,
σ = Voltage (Kgf/$mm2$)
E = Strain (%).

For bending or bending tests, the data parameters are obtained using the following equation:

a. Calculation of bending modulus of elasticity

$$Eb = \frac{1\ x\ L^3 x\ P}{4\ x\ bd^2 x\ \sigma} \quad (10)$$

where,
Eb = Bending modulus of elasticity
P = Load (N)
L = Length between bottom support points (mm)
σ = Bending stress (Mpa)
b = Width of test object (mm)
d = Thickness of the test object (mm)

b. Three Point Bending Calculation

$$\sigma = \frac{3PL}{2bd^2} \quad (11)$$

where,
σ = Bending stress (kgf/mm2)
P = Load or Force that occurs (kgf)
L = Point distance (mm)
b = Width of test object (mm)
d = Thickness of the test object (mm)

From the equations above, the results obtained can be used to draw curves or graphs for both tensile test results and bending tests.

3. RESULT AND DISCUSSION

From the research process of making composites using sansevieria fiber with 5% NaOH treatment, a 30% fiber weight fraction and fiber cut to a size of ±1 cm, and with a SHCP 2668 polyester matrix with the addition of a concentration of tapioca starch (manihot esculenta starch) varying from 10%, 20%, 30%, 40%, and 50%. The data obtained will be presented in figures 7 and 8 to make it easier to observe the results that have been obtained.

Figures 7 and 8 show the tensile test results from the specimens without additional concentration of tapioca starch (manihot esculenta starch) at 0% and those with additional concentration of tapioca starch (manihot esculenta starch). It varies from 10%, 20%, 30%, 40%, and 50%. Specimen 1 is added with an additional amylum concentration of 0%, specimen 2 at 10%, specimen 3 at 20%, specimen 4 at 30%, specimen 5 at 40%, and specimen 6 at 50%. The figures show the load received, elongation, stress, strain, and modulus of elasticity. The data results in the following diagram.

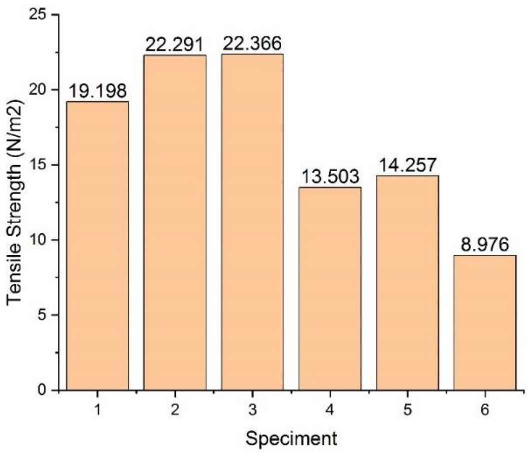


Figure 6. Tensile Test

From Figure 6 above, the highest tensile stress value is shown in specimen 3 (20%), namely 22.366 N/mm^2. while the lowest tensile stress value was shown in specimen 6 (50%) with a value of 8.976 N/mm^2.

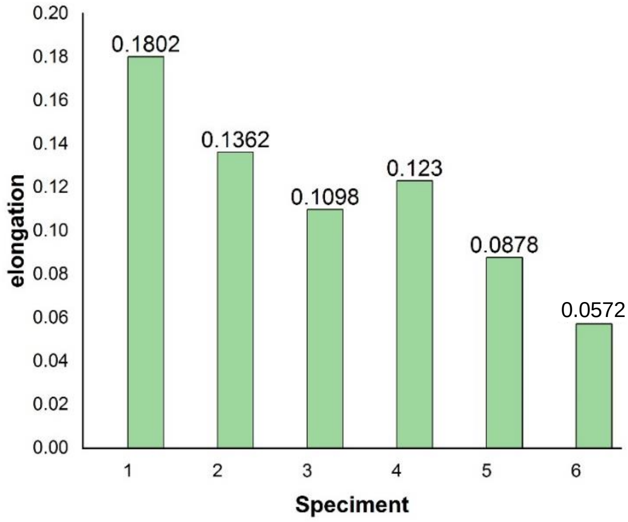


Figure 7. Tensile Test Strain Line Graph

From Figure 7, the highest strain value is shown in specimen 1 (0%), namely 0.1802, while the lowest strain value is shown in specimen 6 (50%) with a value of 0.0572.

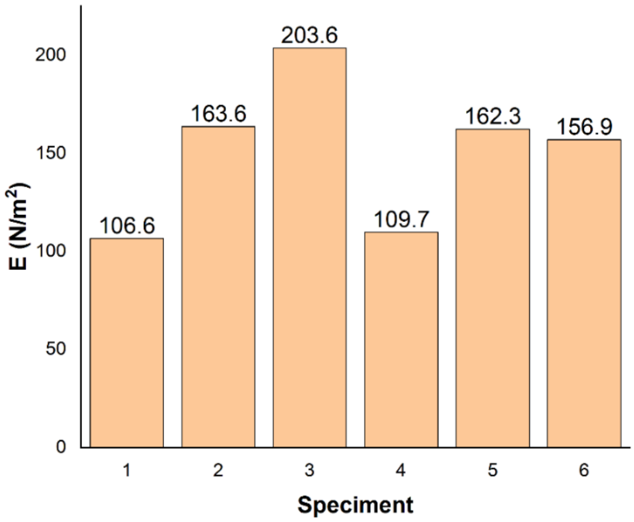


Figure 8. Modulus Elasticity of Tensile Test

From Figure 8, it is found that the highest elastic modulus value is shown in specimen 3 (20%), namely 203.6 N/mm^2. while the lowest elastic modulus value was shown in specimen 1 (0%) with a value of 106.6 N/mm^2.

In the tensile test results of the specimens, each specimen is analyzed to determine how high and low the values are on the specimen, as shown in the table below. The image of the specimen is taken by lining it with a size of 2 cm, as in Table 4 and the following description:

Table 3. Fracture morphology of tensile test

Image of tensile specimen	Variation	Information	Fracture image of tensile specimen	Information
	0%	There are no voids		In a fault there are no voids
	10%	There are no voids		In a fault there are no voids
	20%	There are no voids		In a fracture there are no voids but there are lumpy fibers
	30%	There are 30 small and medium sized voids		In the fault there is a medium sized void
	40%	There are 20 small and medium sized voids		In the fracture there are small voids and lumpy fibers
	50%	There are 8 medium and large size voids		In the fault there is a void of large size

And the bending test results data are as follows:

Table 5. Bending Test Result Data

Specimen	P(N)	σ (N/mm^2)	L(mm)	Eb (Mpa)
0%	107,873	519,149	61.70	4,512
10%	82,375	131,203	20.42	0.494
20%	66,685	142,779	27.45	0.893

Specimen	P(N)	σ (N/mm^2)	*L*(mm)	Eb (Mpa)
30%	56,878	179,233	40,40	1,934
40%	43,149	35,473	10.54	0.131
50%	43,149	35,473	10.54	0.131

From table 5 above, the results of bending or bending tests for specimens ranging from 0% to 50% are obtained, which contain the value of the load received, bending stress value, strain distance, and bending modulus of elasticity. From this data, a diagram is then created as follows:

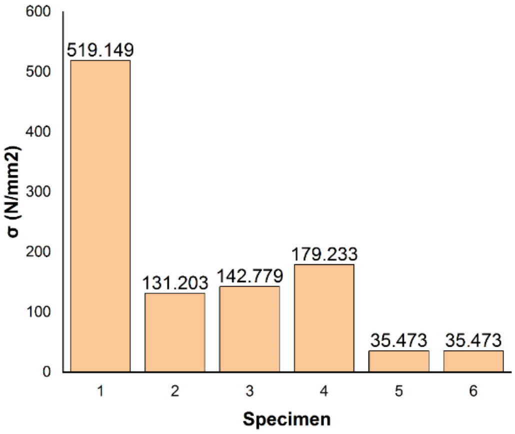


Figure 9. Bending Test Curved

From Figure 9, it is found that the highest bending stress value is shown in specimen 1 (0%), namely 519.149 N/mm^2. while the lowest bending stress value was shown in specimens 5 (40%) and 6 (50%) with the same value, namely 35.473 N/mm^2.

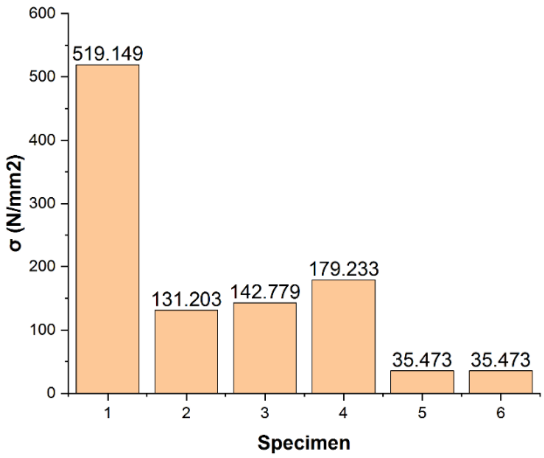
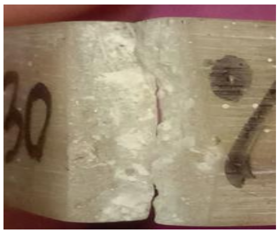


Figure 10. Bending Test Modulus of Elasticity Line Graph

In Figure 10 above, it is found that the highest elastic modulus value is shown in specimen 1 (0%), namely 4.512 MPa, while the lowest elastic modulus value is shown in specimens 5 (40%) and 6 (50%) with the same value, namely 0.131 MPa.

Based on the results of the bending or bending test of the specimen, each specimen is analyzed to determine how high and low the value of the specimen is, as shown in the table below. The image of the specimen is taken by lining it with a size of 2 cm, as in Table 6 and the following description:

Table 6. Image of specimen and bending test specimen fracture

Image of bending specimen	Variation	Information	Image of bending specimen fracture	Information
	0%	There are no voids		In a fault there are no voids
	10%	There are no voids		In a fault there are no voids
	20%	There are 15 small voids		In the fault there are small voids
	30%	There are 45 small and medium sized voids		In the fracture there are small voids and clumped fibers
	40%	There are 22 medium and large voids		In the fault there are small voids
	50%	There are 10 medium and large size voids		In the fault there is a void of large size

In the tensile test, the addition of tapioca starch increased the modulus of elasticity value, indicating that the interaction between the matrix and the fiber is getting stronger with the addition of tapioca starch concentration. This can be explained because tapioca starch acts as an additional binding agent that improves the adhesion between the polyester matrix and the sansevieria fibers. Tapioca starch molecules may interact chemically or physically with the fiber and matrix surfaces, reducing voids and improving stress transfer from the matrix to the fiber (19).

However, in the bending test, increasing the concentration of tapioca starch decreased the elastic modulus value. This indicates that tapioca starch can reduce the flexibility and ability of the matrix to spread the bending load. Composites with a high concentration of tapioca starch tend to be stiffer, which reduces their ability to bend without cracking or breaking. Further analysis of the improvement of fiber-matrix bonding with the addition of starch or tapioca starch could include microscopic examination of the fiber-matrix interface region. Additional research could be conducted to understand the molecular interaction mechanisms between tapioca starch and other composite components. Identification of potential chemical bonds, such as hydrogen bonds or van der Waals interactions, could provide deeper insight into how tapioca starch increases adhesion on the one hand but decreases flexibility on the other. This deeper understanding can help in designing composites with more balanced and desirable mechanical properties for specific applications (17).

Tapioca starch-added natural fiber composites have interesting potential applications in various industries due to their combination of strength and material sustainability. In the automotive industry, these composites can be used to make car interior panels and dashboard components that require high tensile strength while remaining lightweight. In the construction industry, these composites are suitable for wall and ceiling panels that require structural strength and environmentally friendly insulation materials. In addition, these composites can also be utilized in the manufacture of household furniture such as chairs, tables, and shelves that require strength and natural aesthetics.

In the electronics industry, these composites can be used for the casing of devices such as laptops, cell phones, and tablets that require mechanical strength and lightness. Consumer products such as sports equipment, including tennis rackets, surfboards, and bicycles, can also benefit from the strength and impact resistance of these composites. Garden supplies such as plant pots and park benches can also be made from these composites, offering weather resistance and structural strength. The packaging industry can use composites of natural fibers and tapioca starch to produce biodegradable packaging materials, reducing the environmental impact of plastic waste. In textiles and fashion, these composites can be applied to accessories such as bags and belts that require strength and a natural aesthetic appearance, as well as shoe soles that provide added strength and comfort with eco-friendly benefits. The sustainability and eco-friendly properties of these composites make them an attractive option for a wide range of applications, replacing conventional materials that are less environmentally friendly and providing innovative solutions to material challenges in various industries.

4. CONCLUSION

The addition of tapioca starch to natural fiber composites enhances tensile strength by improving fiber-matrix adhesion while reducing flexibility in bending applications. These composites, combining strength and sustainability, are ideal for diverse industries, including automotive, construction, household furniture, electronics, sports equipment, garden supplies, packaging, and fashion accessories. Understanding the bonding mechanisms can guide the development of balanced, eco-friendly materials, offering innovative solutions to material challenges across various sectors.

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