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Investigation of mechanical properties and dynamic characteristics of OPEFB Fiber Composite

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Abstract

Composite materials is increasingly experiencing an increasing trend, the manufacture of composites currently uses a lot of natural fiber reinforcement, Oil Palm Empty Fruit Bunches (OPEFB) fiber is a fiber that comes from oil palm empty fruit bunches waste that grows a lot in Indonesia and has the potential to be used as reinforcement in the manufacture of composites. With natural fiber reinforcement. The manufacture of composites in this study varied the fiber volume fraction by 5%, 15%, and 25%. Many previous studies on composite materials have focused on studying the physical and mechanical properties of composites. Even though damage to a structure or material is not only caused by static loads but also by dynamic loads. Vibration is a dynamic load experienced by material or structure, so it is necessary to determine the dynamic character of composite materials, one of the dynamic characteristics of materials is their natural frequency, the determination of the natural frequency in this study was carried out by using the finite element method in the ANSYS software. The results of the analysis in the form of tensile strength values and modulus of elasticity were obtained from tensile testing and dynamic characters in the form of natural frequencies and vibration modes were obtained from the analysis modal simulation process. From the results of the tensile test, it was found that the composite with a variation of 15% OPEFB fiber volume had the highest tensile strength and modulus of elasticity, as well as the results of the analysis modal simulation, a composite with 15% OPPEFB fiber, had the highest natural frequency value among the other two variations.

Keywords:
OPPEFB composite, Finite element, ANSYS, Natural frequency, dynamic character.

1 Introduction

The use of composite materials is increasingly experiencing an upward trend since about a decade ago, many industries have looked at the use of composite materials as the main material for making their products. Composites have currently widely utilized the use of natural fibers, namely fibers produced from trees or plants that grow in nature, The use of composites from natural fibers has currently attracted the interest of many researchers from all over the world [1]. Palm oil is in the most cultivated type of plantation commodity in Southeast Asia including Malaysia and also Indonesia, Indonesia's palm oil production is increasingly showing an increase even in 2019 the figure of palm oil production in Indonesia reached 48,417,897 tons, this is increase from the previous year of 42,883,631 tons [2]. The huge production of palm oil every year is also followed by waste generation, which is in the form of waste empty palm oil bunches (OPEFB), in which each one ton of palm oil production produces 1.1-ton empty bunches of palm oil [3]. Currently, the utilization of waste produced by oil palm plants in the engineering field is still small [4].

The abundance of OPEFB waste provides great potential to be used as more in-depth research material. OPEFB has so much fiber content, however, its use still cannot be said to be efficient and is still a waste problem for the environment, so this is also the basis that this OPEFB waste can be used as a manufacturing product, namely composite material from natural fibers in the form of OPEFB fiber.

Previous research on composite materials has focused on studying the physical and mechanical properties of composites. Whereas damage to a material is not only caused by static loads but also by dynamic loads. Vibration is a dynamic load that is experienced by a material or structure, so the determination of dynamic character is very necessary, one of the dynamic characteristics of a material or structure is its natural frequency.

The determination of the natural frequency of a system or material can be used as an effort to reduce vibration because if a system or material is vibrated close to its natural frequency, there will be a resonance that causes vibrations to be greater and adversely affects a system. So, it is necessary to conduct research related to the use of OPEFB fiber as a reinforcing material in composites, which will be studied for mechanical properties and also carried out dynamic character analysis, namely the natural frequency of OPEFB fiber composites which is useful if the material is applied in the world of machinery design, not only static properties but also dynamic characters that will be the measurement parameters.

2 Research Method

2.1 OPEFB Fiber Preparation

OPEFB waste is prepared from oil palm factory wasted. then the extraction process is carried out and soaked in a 5% NaOH solution for 2 hours [5], then washed with water, and then the fiber is dried in the sun for ±2 days to reduce the water content that is still contained in the fiber. OPEFB preparing process show in Fig. 1 and series of fiber preparation processes shown Fig. 2

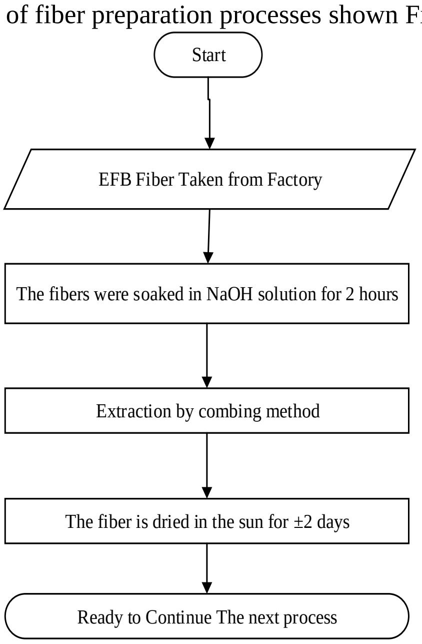


Fig. 1. OPEFB preparing process

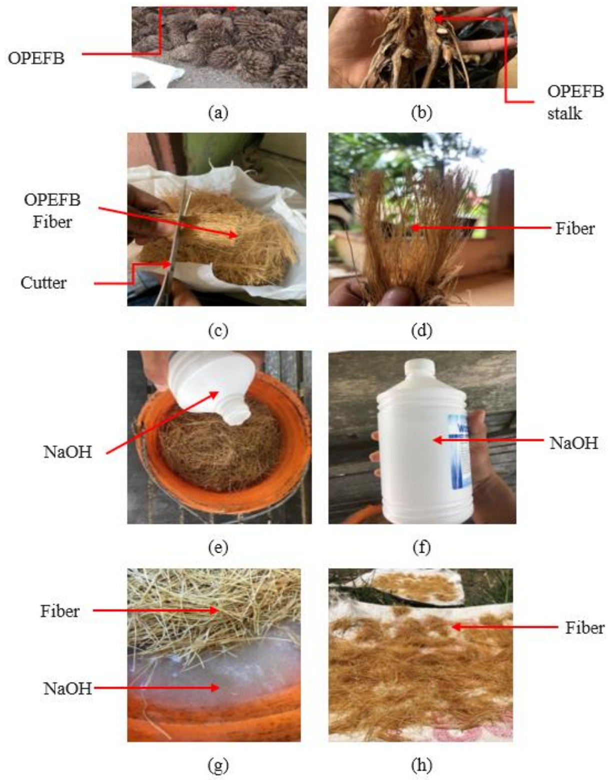


Fig 2. Series of fiber preparation processes. (a) Empty Bunches of oil palm, (b) bunch stal, (c) fibe, (d) fiber cutting , (e) NaOH 5%, (f) pouring NaOH, (g) fiber soaking, and (h) drying fiber.

2.2 Volume Fraction

The manufacture of OPEFB fiber composites is volume fraction variation of fibers is carried out. The amount of fiber present in a composite material with fiber-type reinforcement will be a special concern in its manufacture. In this study the fiber fraction used is with a volume fraction with variations in the ratio of 5%:95%, 15%:85%, and 25%:75%. The process of merging fiber and resin is carried out with a random fiber orientation printed in a glass mold. Variations in the volume fraction of fibers show in Fig. 3 and fiber percentage variation shown in Fig. 4

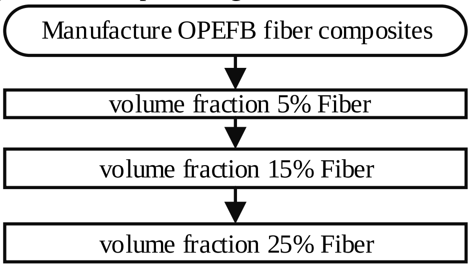


Fig 3. Variations in the volume fraction of fibers

(a) **(b)** ©

Fig4. Fiber Percentage Variation. (a) 5%, (b) 15%, and (c) 25%

2.3 Composite Manufacturing Methods

Here are the tools used in composites: 1. Digital Scales, 2. Resin Stirring bucket, 3. Calipers 4. Glass Molds, and 5. Measuring cups. As well as the tools used in this study are as follows: 1. OPEFB fiber, 2. Resin UPR, 3. NaOH 5%, and 4. Catalyst.

2.3.1 Composite Manufacturing Methods

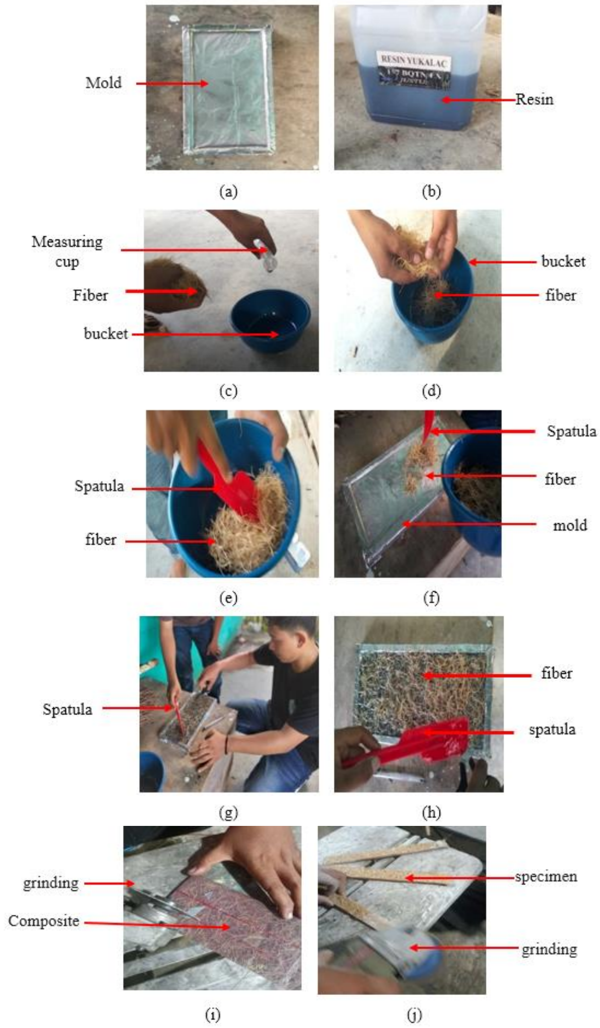


Fig 5. The OPEFB composite manufacturing process. (a) glass mold, (b) resin, (c) resin poured into the bucket, (d) fiber sowing, (e) stirred fiber, (f) printing, (g) leveling fibers in molds, (h) tidying up the remaining fibers, (i) composite cutting and (j) specimen formation.

The manufacture of composite materials is carried out by the *hand lay-up* method, the system used is a glass mold with a size following the size of the material shown in Fig 6.

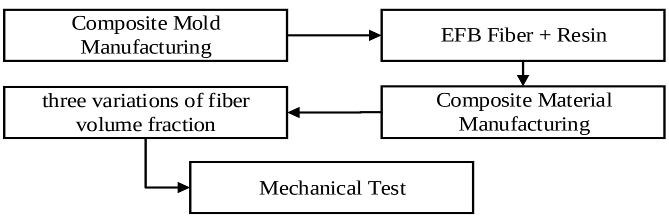


Fig 6. OPEFB composite manufacturing scheme

To obtain a high-strength composite, the distribution of fibers with a matrix must be carried out evenly in the mixing process to reduce the incidence of *voids.*

The composites manufacturing process begins with a glass mold that has been pre-made on the bottom cover using aluminum voil as seen in Fig. 5(a), this is useful for making it easier to remove the composite material after the curing process has occurred, which is for 24 hours. Then drawn (b) is a resin with a type of polyester (matrix) used in the manufacture of this composite.

Furthermore, in figure (c) the pouring of resin from the measuring cup is carried out. Then after that, it is poured TKKS fiber into a container to stir with resin to which the catalyst has also been added before. After the stirring process is felt to be evenly distributed between the fibers and resin, it will be poured into the mold while being flattened using the help of a spatula as shown in pictures (f, g,) and (h). After the printing process is complete, the composite will be closed and left at room temperature for the hardening process.

After one time 24 hours, the composite material that has been printed will be able to be lifted from the mold for the specimen-making process using the predetermined ASTM D3039 standard using the help of a cutting grinding tool and also a grinder to level the surface of the composite as shown in figure (i), and figure (j).

2.4 Mechanical Testing

Mechanical testing of material is carried out to see the level of strength to the load that occurs on the material and recognizes the strength characteristics of the material. The test carried out in this study is a *tensile test.* The tests carried out refer to the ASTM D3039 standard with the dimensions of the test specimen as seen in Fig. 7.

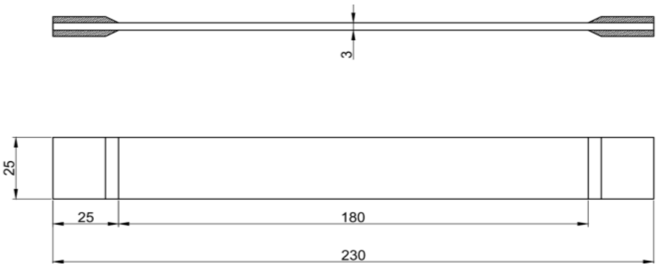
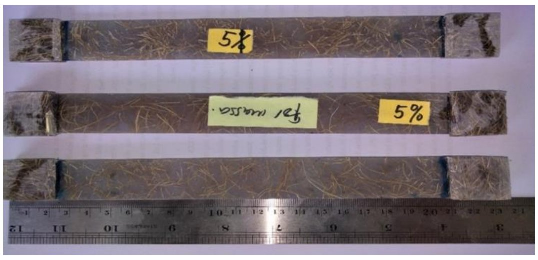
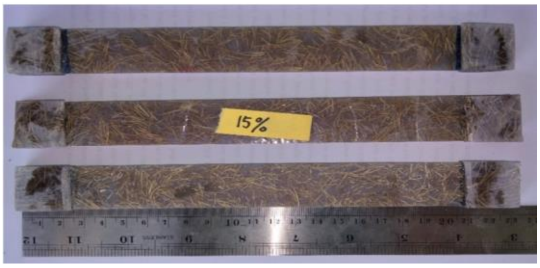


Fig 7. ASTM D3039 Standard Testing



(a)



(b)

(c)

Fig 8. Test Specimens. (a) 5% fiber, (b) 15% fiber and (c) 25% fiber

Fig 9. Tensile testing is carried out to obtain tensile strength, which is by distributing the tensile force with the material area unit using Eq. 1 [44], wher σ is Stress or stress (MPa), P is Tensile Force(N), and A is Cross-sectional Area (length x width) mm^2.

$$\sigma = P/A \tag{1}$$

The maximum force is obtained from the tensile testing machine which is then divided by the cross-sectional area, that is, the thickness of the specimen is multiplied by the width of the specimen. And to find out the tensile strain by using Eq. 2, where: ε is strain (%) ΔL is p increase in length (mm), Lo is Length of the initial specimen (mm). ΔL is Length gain in specimens can be found by reducing the specimen length value after tensile tests are performed on the initial length of the specimen.

$$\varepsilon = \Delta L/LOx100\% \tag{2}$$

And the modulus of elasticity, that is, the ratio between this stress and strain can be known using Eq. (3).

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

Then the benefit of simulated material data and density measurements will be carried out. The density of the material can be determined by dividing the mass of the composite material that has been made against the volume of the composite material, namely the multiplication of the length, thickness, and width of the composite. The weight of composite will be weighed using a digital scale. And the density of the composite material to be made using Eq. (4) [6][7][8], where, ρ = Density (gr/cm3), M = Mass (gr), V = Composite volume (cm^3).

$$\rho = m/V \tag{4}$$

The poison Ratio can also be modeled using Eq (5) [9] i.e. by transversely dividing the strain against the longitudinal strain, the strain value is obtained by sharing the increase in length or width against the initial length or width, where is Poisson's ratio, εt is transverse strain (ΔL/L), and εl is longitudinal strain (ΔT/T).

$$\mu = \varepsilon t/\varepsilon l \tag{5}$$

The Poisson ratio in this study in the input data V_{12} (Poisson's ratio) allowed in polymer composites is 0.3 and also as carried out by Zulfahmi[10] limitations of testing equipment that can measure strain in the transverse and longitudinal directions.

2.5 Vibration Simulation Methods of Composite Materials in ANSYS

Vibration in the structure of the machine has long been a concern in the world of design; one of the aspects of vibration is the natural frequency. Determining the natural frequency of a system that experiences vibration is very important to do. The natural frequency is determined by the value of its mass and the distribution of its rigidity, the condition of the vibrational oscillations that occur will also be caused by the rigidity of a vibrating system. The dynamic character of a material or structure can be expressed by the damping ratio, natural frequency, and vibrating mode possessed by the system itself. So this needs to be known able to prevent excessive vibrations in a material or during a system when working.

The natural frequency of composite material can be found by simulating Modal analysis using software that supports finite element computation. Finite elements are numerical methods that are commonly used when in a numerical way it is no longer possible to do due to limitations, this method is done by dividing an object to be analyzed into several parts with finite quantities, and then mathematical equations will be constructed to be a representation of each element. The part is with an element and each element with another element is connected with a nodal. And in the mathematical equations, the determination of natural frequencies will be able to be written with the Eq. (6)[11], where ω is natural frequency (Hz), K is stiffness (cm/kg), and m = mass (gr). Modeling at ANSYS uses the ASTM E756 standard [52] with specimen dimensions, 200mm x 20mm x 3mm usage as in Fig 10.

$$\omega = \sqrt{(k/m)} \qquad (6)$$

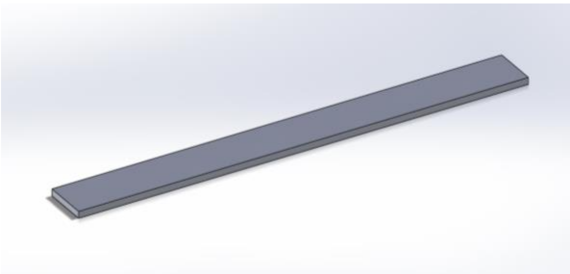


Fig 10. Cantilever beam ASTM E756 model di Ansys

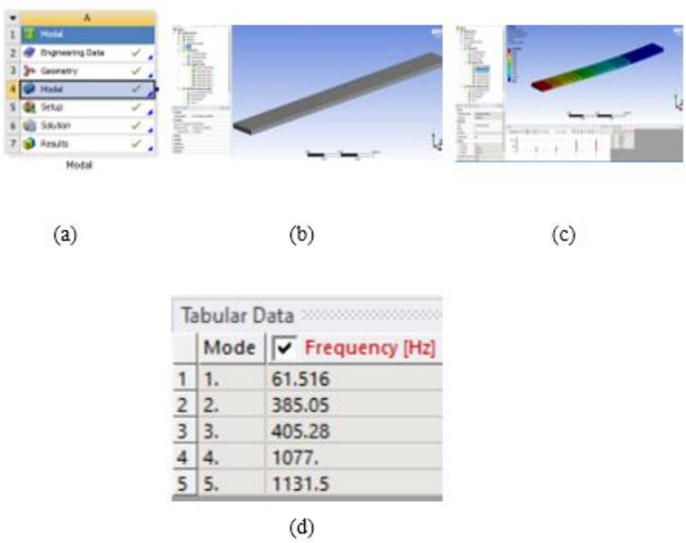


Fig 11. Steps of simulation in ANSYS. (a) simulation steps, (b) meshing process, (c) Mode shape and (d) Natural frequency

3 Result and Discussion

3.1 Composite Density Value Results

The value of the three masses that have been obtained will be divided by the volume obtained from the multiplication of the length, width, and height (thickness) of the three types of composite fractions using a press (4), as presented in table 1.

Table.1 TKKS fiber composite material density data

No	Composite	Weight (m) grams	Volume (cm^3) (L x W x T)	Density (gr/cm^3)
1.	5% OPEFB Fiber	23 grams	23x2.5x0.3 = 17.25	1.300
2.	15% OPEFB Fiber	21 grams	23x2.5x0.3 = 17.25	1.217
3.	25% OPEFB Fiber	28 grams	23x2.59x0.45=26.806	1.044

The density of a material is defined as a measurement of mass in each unit of volume of an object, so that the higher the density value of an object, the greater the mass in each volume, and as shown in table 3.1 the density of a composite with 25% fiber has a lower density value than 15% of fiber, which is 1,044 (gr/cm 3) while in a 15% fiber composite it is 1,217 (gr / cm^3), which is lower than the density of the composite with 5% fiber with a value of 1,300 (gr/cm^3).

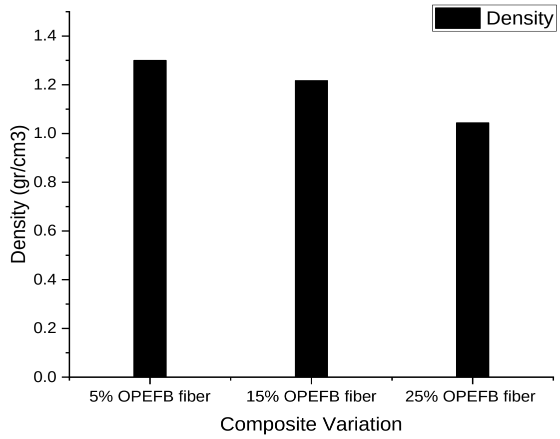


Fig 12. Composite Density Graph of OPEFB fibers

This also makes it clear that the resin density value higher than the density of OPEFB fibers can affect the density of this in line with research conducted by Eric [12]. The density value obtained in this study was also not much different from the study conducted by [13] the study found that the density value of the largest OPEFB fiber composite was valued at 1.1972 (gr / cm^3).

The density value in composites is one of the important indicators to know because it affects the properties of composites, the density of composites indicates the lightness of the composite. So that the lighter the composite indicates the lighter the material and vice versa if the density value of the composite is greater, the heavier it will be. Lightweight properties are necessary for various manufacturing industries such as for the application of *drones* that require lightweight materials for the manufacture of parts from *drones*.

3.2 Tensile Test Results

After the density data collection is completed, tensile testing is then carried out at the Lhokseumawe state polytechnic Damaging test laboratory using the UTM Galdabini tensile testing machine with the results as shown in table 2.

Table. 2 Values Modulus of Elasticity and tensile stress of OPEFB fiber Composites

Types of Composites	σ (MPa)	E (MPa)
5% OPEFB Fiber	28.635	38.95
15% OPEFB Fiber	37.50	40.32
25% OPEFB Fiber	28.929	18.309

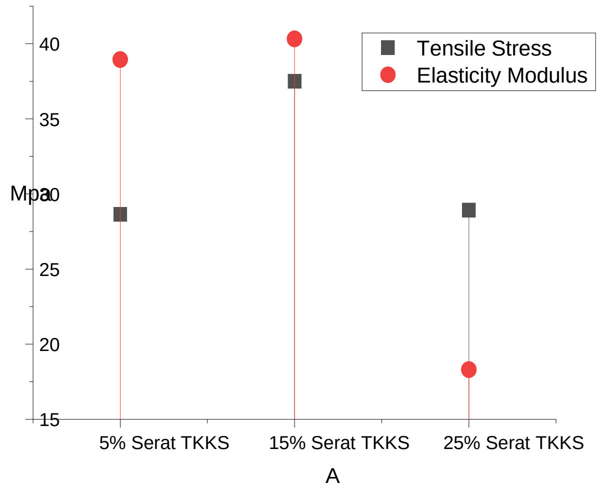


Fig 13. The relationship of the number of fractions of fiber volume to tensile stress and modulus of elasticity.

From Table 2 and fig. 13. it was shown that the mechanical properties of the composite in the form of tensile stress values and the modulus value of elasticity of OPEFB fiber composites with a volume of 15% fibers have a greater value than two other variations, namely with an average tensile stress value of 37.50 (MPa) while in the 5% volume fraction of 28,635 (MPa) and 25% fiber the tensile stress is 28,929 (MPa). And the average elasticity modulus value in composites with a fiber volume of 15% is with a value of 40.32 (MPa), while in composites with a fiber volume of 5% it is worth 38.95 (MPa). And in a composite 25% of fibers have an average value and Modulus of Elasticity of 18,309(MPa).

In this study, it was found that the modulus value of elasticity of OPEFB fiber reinforcing composites is not linear with the addition of fiber volume, this is also in line with previous research conducted by Ady et, al [14] in their study it was also found that the modulus value of elasticity of OPEFB fiber composites is not linear with the addition of fiber volume. This is also influenced by the value of tensile stress which is also found to have the largest value in the fraction of 15% of fiber volume, where it is known that the greater the stress value in the composite, the greater the value of the composite's strength in withstanding the load until it breaks.

The mechanical properties of composites are also influenced by the distribution of fibers and also the volume fraction of their fibers. And from the results of this study, shows that the modulus value of elasticity in the 15% OPEFB fiber composite has the highest value among the two other variations, this gives the result that the modulus value of elasticity of the OPEFB fiber composite has a maximum elasticity modulus value, where the OPEFB fiber composite has the highest elasticity modulus value then will fall back after crossing the maximum value threshold.

From the tests, it is known that not always adding a fiber volume fraction to the composite manufacture will give greater strength to the composite, as shown in the variation of the 25% fiber volume fraction which undergoes a decrease in tensile stress value and elasticity modulus. The strength of the composite from the test shows that it is not only influenced by the amount of fiber added to the composite composition but can also be influenced by the matrix that binds it because a good bond between the fibers and the matrix will give good strength to the composite.

In the process of making OPEFB fiber composites, the variation in volume fraction, the higher the fiber fraction, the reduced resin volume fraction, so that with the reduction of resin volume, the fiber binding process is not able to bond properly, and when the load is given there will be an uneven distribution of the load on the composite due to the weak bond between the matrix and the fiber. In the manufacture of composites, the distribution of fibers must also be done well so that no air is trapped which will cause when the load has exerted no part of the composite imperfectly withstands the load and will reduce the mechanical properties of the composite material [15].

From tensile testing carried out on composites with OPEFB fiber reinforcement, it can be seen that a small volume of fiber will provide small strength, and the more fibers, the higher the strength value, but if the fiber given is too much, the strength of the composite will also weaken due to the imperfect bonding of the fibers with the matrix. This is also similar to the research conducted by Ninis[16] which also gets the tensile strength value greater as the fiber is added but when the fiber given is too much, the tensile strength value of the composite decreases.

3.3 Finite element Simulation Results

The Modal analysis carried out in this study used the finite element method. Modal simulation analysis is carried out to see the response of composite materials to dynamic characters, simulations are carried out by assuming the material as a beam cantilever with clamp-free mode, namely by simulating one end of the beam given fixed support. In modal simulations, external force factor analysis is not required for the course of the simulation, this is because, the value of the natural frequency of a material is influenced by its mass, and also its rigidity. And the following data is entered in the Ansys *software* for modal simulation of TKKS fiber composite analysis.

Table 3. Material input data on Finite element simulation

Types of Composites	Density (gr/cm^3)	E (MPa)	Poisson Ratio
5% OPEFB Fiber	1.300	38.95	0.3
15% OPEFB Fiber	1.217	40.32	0.3
25% OPEFB Fiber	1.044	18.309	0.3

After the simulation process is complete, the simulation results are obtained in the form of natural frequencies of the two composite materials with 5 shape modes as shown in Table 3.4.

Table 4. Natural frequency simulation results of OPEFB fiber composites

Types of Composites	Natural frequency (Hz)				
	1	2	3	4	5
5% Fiber	2.1095	13.205	13.898	36.934	38.802
15% Fiber	2.2183	13.885	14.615	38.838	40.803
25% Fiber	1.6216	10.15	10.683	28.391	29.827

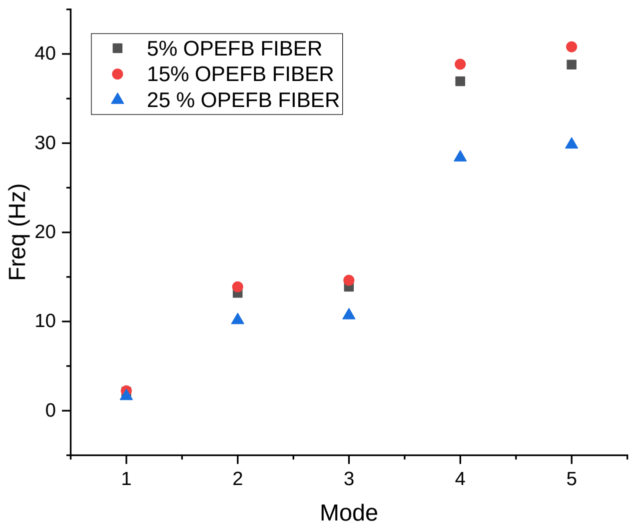


Fig 14. the natural frequency of OPEFB fiber composite

And Fig. 15 are the results of the five vibration shape modes of the composite with 5% OPEFB fiber reinforcement. Fig. 16 andFig. 17 are the results of the modal simulation analysis on a composite with a 15% and 25% OPEFB fiber reinforcement

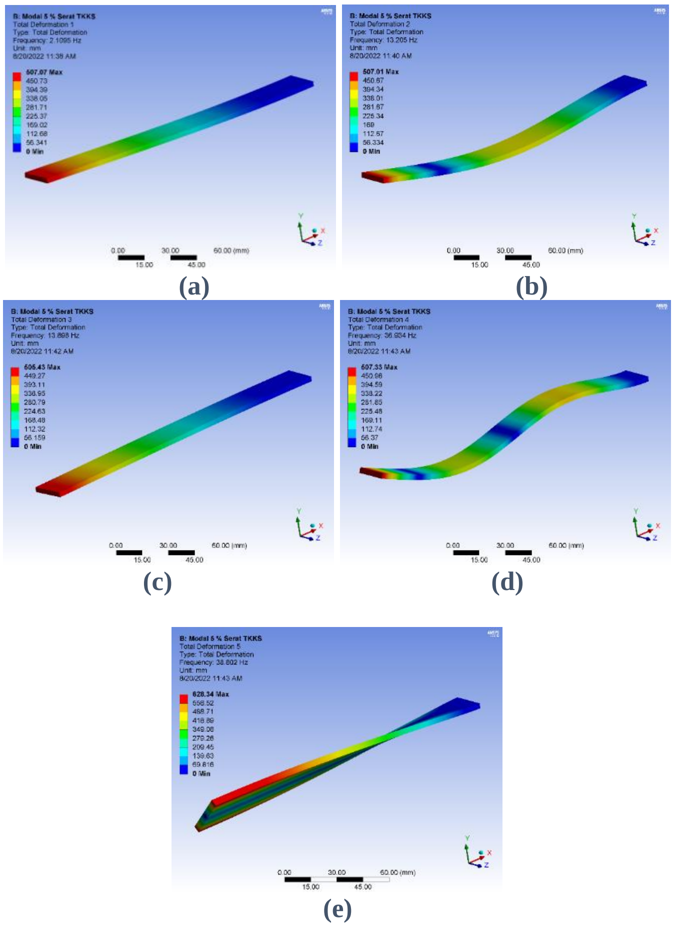


Fig 15. The results of the modal simulation of composite analysis of 5% OPEFB fiber. (a) mode 1, (b) mode 2, (c) mode 3, (d) mode 4, and (e) mode 5.

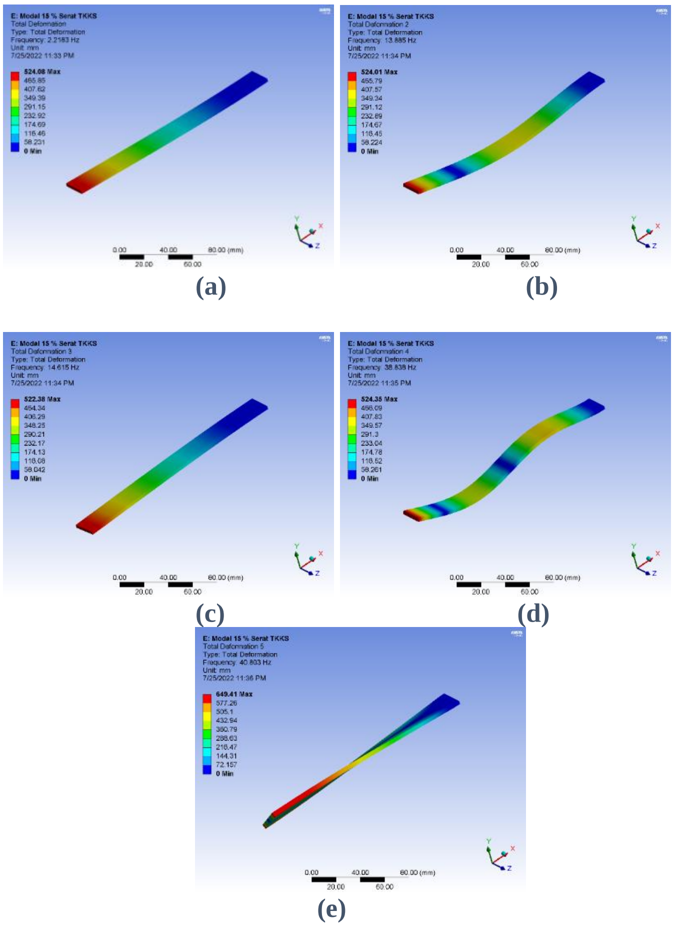


Fig 16. Modal analysis results composite 15% OPEFB fiber. (a)mode 1, (b) mode 2, (c) mode 3, (d) mode 4, and (e) mode 5.

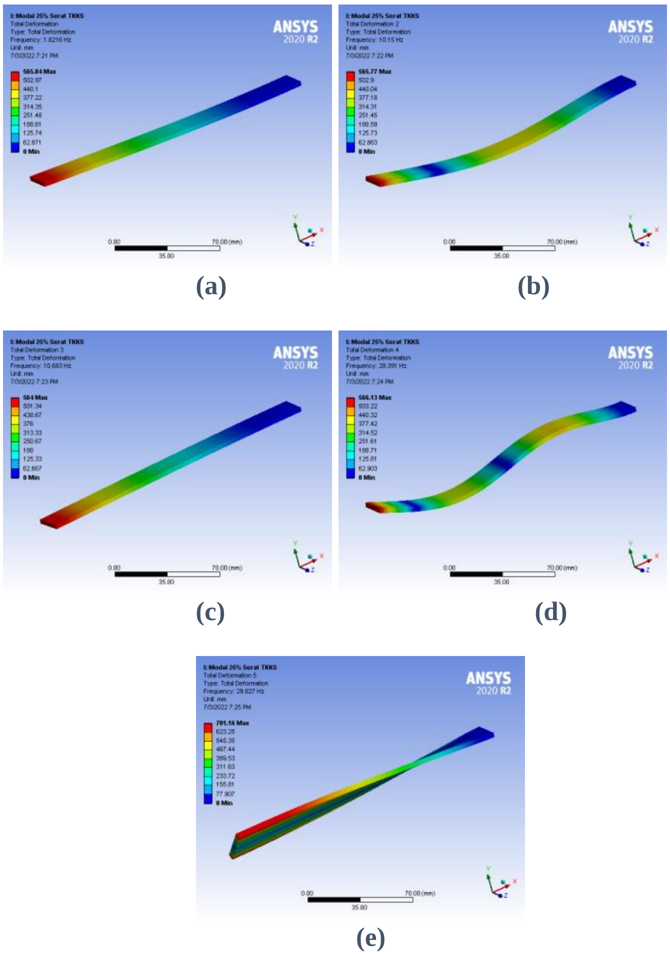


Fig 17. The results of the modal simulation of composite analysis of 25% OPEFB fiber, mode 1(a), mode 2(b), mode 3(c), mode 4(d), and mode 5(e).

The dynamic character of a material or structure, one of which can be expressed by the natural frequency along with the vibrating mode possessed by the material or structure. Modal analysis is used in determining the natural frequency and also the vibration form of the TKKS fiber composite material as seen in, Fig 14. The results of the modal simulation of composite analysis of 5% OPEFB fiber, mode 1(a), mode 2(b), mode 3(c), mode 4(d), and mode 5(e), where the composite material is simulated by providing fixed support at the end of one part of the composite (Clamp Free) and then a simulation is run to see the system's response to vibration, which is in the form of the natural frequency of the composite material. In Mode 1 to shape mode 4, bending and torsional loads are given in shape 5 mode. In Fig 15**.** it can be seen that in composites with 5% fiber volume, natural frequency values are obtained from the simulation results, namely, in mode 1 of 2.1095 (Hz), in mode 2 which is 13,205 (Hz), and in mode 3 the natural frequency value of the composite is at 13,898 (Hz), and mode 4 is worth 36,934 (Hz) And in mode 5 it is at 38,802 (Hz).

Composites with a reinforcing 15% OPEFB fiber have a natural frequency value as seen in Fig 16. namely, in mode 1 the composite natural frequency value is at 2.2183(Hz), and in mode 2 it is worth 13,885(Hz), as well as for mode 3 the composite natural frequency value with 15% OPEFB fiber is at 14,615(Hz) and also in modes 4 and 5 is at 38,838(Hz) and 40,803 (Hz).

In composites with a composition of 25% OPEFB fibers, natural frequency values were found as seen in Fig 17. that the natural frequency value of the OPEFB fiber composite in mode one is at 1.6216(Hz) and for mode 2 it is 10.15(Hz) while in mode 3 it is worth 10,683(Hz) and also in mode 4 the natural frequency value of the composite with 25% fiber reinforcement of OPEFB fiber is 28,391(Hz), and in mode 5 the natural frequency value of the composite material is 29, 827(Hz).

Vibration shape mode shows the character of the vibration shape in the composite, the first mode with the -Y direction bending shape, the 2nd bending mode in the middle of the composite and the composite end in the -Y direction, and in the 3 bending modes in the -z direction and in the fourth shape mode, the bending occurs in two directions -Y, and Y, and the fifth mode is the torsional mode.

The determination of natural frequency of the composite is determined by the root K (stiffness) divided by the mass of the composite. In this study, it was found that the natural frequency in the three types of composite materials with OPEFB fiber reinforcement has a difference between a fraction of 5% of fiber volume with 15% and also 25% of fiber volume as shown in table 4.7 and figure 4.12.

From the results of the modal simulation analysis that has been carried out, it can be seen that the highest natural frequency of OPEFB fiber-reinforced composites is found in a variation of 15% of the fiber volume fraction, this happens because it is influenced by the stiffness value obtained from the results of experimental test values in mechanical testing, namely in the form of a higher elasticity modulus value than two other types of composite material variations, this is in line with experimental and numerical studies by Nur Wahyuni et. all [17] studies conducted by them the modulus value of elasticity in composite materials will influence the value of natural frequencies.

The addition of fiber to the composite in this study shows an influence on the increase in the natural frequency value of the composite, but it is not linear so it can be seen that from the three variations in the volume fraction of OPEFB fibers studied the value of the natural frequency of the composite will increase at the fraction of 15% of the fiber compared to the variation of the fraction of 5% fiber but then fall back to the variation of the fraction of 25% of the OPEFB fiber.

The natural frequency value of the composite is also known to be directly proportional to the stiffness value of the composite itself [18] TKKS fiber composite material is represented by the modulus value of elasticity of each composite, the higher the modulus value of elasticity of the material, the stiffer the material [5].

The rigidity of a material becomes a value that can be set in a design because the rigidity of a material depends on the value of the modulus of elasticity and the Poisson number ratio that affects the elastic properties of a vibrated model. The rigidity of the material has a great influence on the dynamic character of the material, the assessment of the dynamic character needs to be carried out on the material if it is to be applied to a structure that gets not only static but also dynamic loading. Determination of the natural frequency of the OPEFB fiber composite material using the finite element method can provide resonant frequency information if later the OPEFB fiber composite is used in structures where there is an electric motor.

Determining the natural frequency of composite materials is something that must be done to select materials for application to a structure that has vibrations so that there will be no large vibrations due to resonant phenomena.

4 Conclusions

Composite manufacturing using OPEFB fiber reinforcement has been successfully carried out, Composites are made by varying the fiber volume fractions of 5%, 15%, and 25%.

The fiber volume fraction affects the tensile stress value and the composite elasticity modulus value, but it is not linear to the addition of fiber volume. Where the highest tensile stress value is obtained at the 15% fiber volume fraction, which is 37.50MPa fiber, the highest modulus of elasticity of OPEFB fiber composites is also found in OPEFB fiber composites with a fraction of 15% fiber volume, which is 40.32MPa, this value is higher than the other two fiber fractions, namely in the 5% variation of tensile stress OPEFB fibers of 28,635MPa and the elasticity modulus value of 38.95MPa and in the 25% variation of fiber tensile stress value of 28. 929MPa and elasticity modulus of 18,309MPa. From this research, it can also be concluded that not always the addition of a larger volume of fibers to the composite manufacturing process will have a greater strength iMPact, this is evidenced by the increasing number of fibers added making the tensile stress value and modulus of composite elasticity decrease, as a result of the imperfection of the bond between the fiber and the matrix, so that when given a loading, the fiber will be easily detached from its bond with the matrix.

The dynamic character of OPEFB composites from the results of modal simulation analysis using the Finite element method in ANSYS software found that the highest natural frequency value of OPEFB fiber composites is in the 15% fiber volume fraction, this is influenced by the rigidity properties of composite materials, which is in the form of a higher elasticity modulus value compared to the other two fraction variations.

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