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Experimental and Numerical Investigation of Date Palm Fiber Effect on Natural Frequency of Composite Plate with Different B.Cs

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ABSTRACT: In this work, the numerical and experimental study of mechanical properties and natural frequency for composite materials reinforcement with natural fiber are presented. The experimental works included study of mechanical properties and vibration of composite materials are made of natural fiber, date Palme fiber, and polyester resin materials with different boundary conditions. And, the numerical study included evaluated the natural frequency of composite materials plate with various boundary condition and different reinforcement date Palme fiber volume fraction.The results shown the date Palme fiber causes increasing the modulus of elasticity of composite materials, then, it causes increasing the natural frequency of composite plate with increasing of fiber volume fraction. Also, the strength to weight ratio increase with using of natural fiber due to low density of natural fiber.
In addition to, the vibration study included valuated the natural frequency of composite plate with various boundary conditions as (CCCC, CCFF, CCSS, CFFF and CFFF). And compare the results of vibration plate evaluated between numerical method and experimental work, that is shown the good agreement results with maximum error about (7.5%).

KEYWORDS: Vibration of composite Plate, Mechanical Properties of Composite Materials, Composite Materials, Isotropic Composite Materials, Natural Fiber, Palm Reinforcement.

I. INTRODUCTION

Composites exist in nature, a piece of wood is a composite with long Fibers of cellulose (a very complex from a starch) held together by a much weaker substance called lignin. Cellulose is also found in cotton and linen, but it is the binding power of the lignin that makes apiece of timber much stronger than a bundle of cotton fibers. Other examples of natural composites are: spider silk is a biopolymer and a natural composite material. Its composition is a mix of an amorphous (which makes the fiber elastic), and the two simplest proteins(which give it toughness), in order words, it is simply a protein. The result is a good combination of strength and toughness. It is five times as strong as steel, twice as strong as Kevlar at same weight, twice as elastic as polyamide fibers (it can be stretched by 31% without breaking), more elastic than aramid fiber, finer than a human hair, and lighter than cotton, [1].

The analysis of natural frequency of composite plate/shell plays an important role in the design of structure in mechanical, civil, and aerospace engineering applications. Composite materials consist of two or more materials which together produce desirable properties that cannot be achieved with any of the components alone. The desirable characteristics of most fibers are high strength, high stiffness, and comparatively low density. Glass fibers are the mostly used ones in medium performance composites because of their high tensile strength and low cost, [2]. Many studies were performed to examine the Analysis of natural frequency and mechanical properties of composite plate, as, Mohd Z. M. Yusoff et. al. [3], this paper presented the studied of mechanical properties of short random oil palm fiber reinforced epoxy (OPF/epoxy) composites. Empty fruit bunch (EFB) was selected as the fiber and epoxy as the matrix. Composite plate with four different volume fractions of oil palm fiber was fabricated. The fabrication was made by hand-layup techniques. The tensile and flexural properties showed a decreasing trend as the fiber loading was increased.

D. Bachtiar, et. al. [4], a studied of the effect of alkaline treatment on the flexural properties of sugar palm fiber reinforced epoxy composites is presented in this paper. The composites were reinforced with 10% weight fraction of the fibers. The fibers were treated using sodium hydroxide (NaOH) with 0.25 M and 0.5 M concentration solution for 1 hour, 4 hours and 8 hours soaking time. The purpose of treating fibers with alkali was to enhance the interfacial bonding between matrix and fiber surfaces.

C. Chaithanyan et. al. [5], this paper deals with preparation and investigated of hybrid composites of natural fibers in isophthalic polyester resin. Natural fibers used here are sisal and coir fibers which are mixed with isophthalic polyester in volume fraction basis of 0.4 & 0.5. This composite is manufactured using hand layup process. Mechanical properties of each composite are determined through tensile, flexural, impact tests. The tensile strength of sisal-glass composite is found to be better than the coir-glass composite. The flexural strength and impact strength of sisal-coir-glass hybrid composite is found to be better than the remaining two combinations of composites.

Chandramohan D. and J. Bharanichandar [6], in this research, natural fibers like Sisal (Agave sisalana), Banana (Musa sepientum) and Roselle (Hibiscus sabdariffa), Sisal and banana (hybrid), Roselle and banana (hybrid) and Roselle and sisal (hybrid) are fabricated with bio epoxy resin using molding method. natural fibers are cheap and have a better stiffness per weight than glass, which results in lighter components, the grown interest in natural fibers is clear. Secondly, the environmental impact is smaller since the natural fiber can be thermally recycled and fibers come from a renewable resource. Their moderate mechanical properties restrain the fibers from using them in high-tech applications, but for many reasons they can compete with glass fibers. In this paper the optimum mixing of fiber and resin is achieved by using Taguchi method. In this work, tensile and hardness of Sisal and banana (hybrid), Roselle and banana (hybrid and Roselle and sisal (hybrid) composite at dry and wet conditions were studied. Hardness test were conducted using Brinell hardness testing machine. In this work micro structure of the specimens are scanned by the Scanning Electron Microscope.

Abdulkareem A. Alhumdany et al [7], the reinforcement of the resin materials was made with two types of powder and short fiber to produce an isotropic hyper composite material presented. So it is composed of three materials, polyester resin material and two reinforcements: short glass fiber and powder in the form of glass or date palm nuts. The composite structure was studied to estimate the mechanical properties (modulus of elasticity E, yield stress y) experimentally and analytically, whereas the natural frequencies were estimated theoretically, experimentally and numerically. The results show that, when using the date palm nuts powder, the yield stresses and the fundamental natural frequency are increased. This encourage using this type of hyper composite plate safely in the engineering applications where high loads are encountered in a wide range of operating frequencies.

The main purpose of this research studding the effect of natural fiber palm on mechanical properties and dynamic properties (natural frequency) of composite plate with various volume fraction of reinforcement fiber and different boundary conditions of plate.

II. NUMERICALWORK

The numerical study of natural frequency of hyper composite plate evaluated by using the finite elements method was applied by using the ANSYS program (ver.14). The three dimensional model were built and the element (Solid Tet 10 node 187) were used. Solid 187 elements is a higher order 3-D, 10-node element. Solid 187 has a quadratic displacement behaviour and is well suited to modelling irregular meshes. The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper-elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper-elastic materials. In addition to the nodes, the element input data includes the orthotropic or anisotropic material properties. Orthotropic and anisotropic material directions correspond to the element coordinate directions. The geometry, node locations, and the coordinate system for this element are shown in Fig. 1.

The boundary conditions are another significant attribute that define the circumferential effects influenced on the structures. In the current study five different boundary conditions are used (SSSS, CCSS, CCFF, CFFF, and CCCC) to support the composite plate. The plates boundary conditions where the edges with U_X, U_Y, U_Z, ROT_X, ROT_Y and ROT_Z not equal to zero needed to be evaluated. ROT_X, ROT_Y and ROT_Z are presented by θ_x, θ_y, and θ_z.

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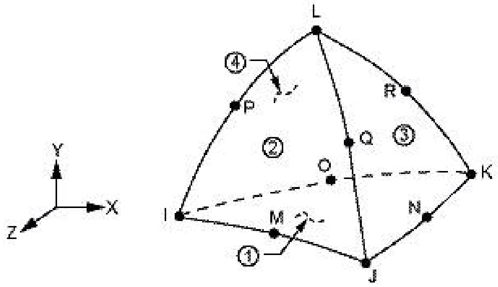

Fig. 1. geometry of Solid 187 Element.

III. EXPERIMENTAL WORK

The experimental part included the experimental test of the spacemen, with tensile and vibration test, which is manufactured in the laboratory. Where the tensile test can be done to calculate the tensile strength of the spacemen's and to find the young's modulus of elasticity which gives an indication to the toughness of the composite material with various fiber volume fraction of date palms reinforcement fiber.
The experimental test of the spacemen included the test of many spacemen to compare the toughness of the composite material with various properties which can be changed to get the most appropriate values of the fiber and matrix fraction. Where this study take into account the following property:

1. Changing the weight with respect to the fiber (palm tree fibers) with maintain the matrix weight constant.
2. The material used to manufacturing the samples:

The material used to manufacturing the samples is polyester as a matrix and palm tree fibers as a strengthen part where a different weight of palm tree fibers used and finding each volume for theses fractions. After that the mounds manufactured of metal and lubricated with isolated material to prevent the adhesion of the sample with mounds.
The samples of tensile test are manufactured with the following dimensions,(18cm width, 20cm length, 5mm thickness), as shows in Fig. 2., and divided to five samples with dimensions, as ASTM Number (D 3039 M-E122), (3 cm width, 20 cm length, 5 mm thickness), as shows in Fig. 3. The fiber using of experimental working is date palm fiber as shown in Fig. 4.

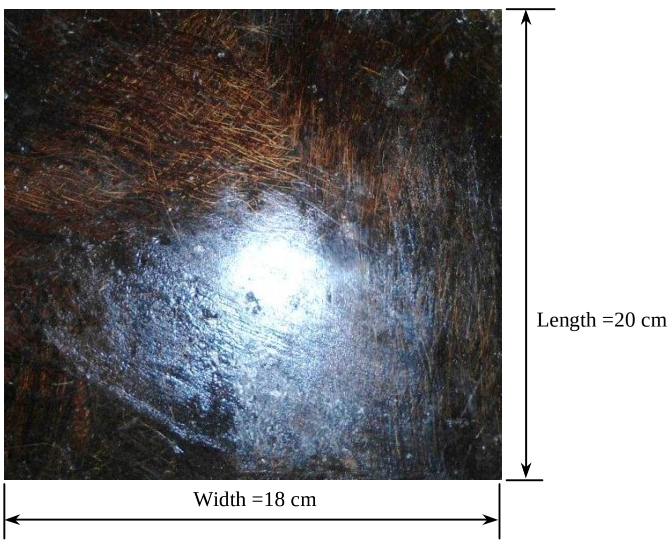

Fig. 2. Shape and Dimensions of Tensile Samples.

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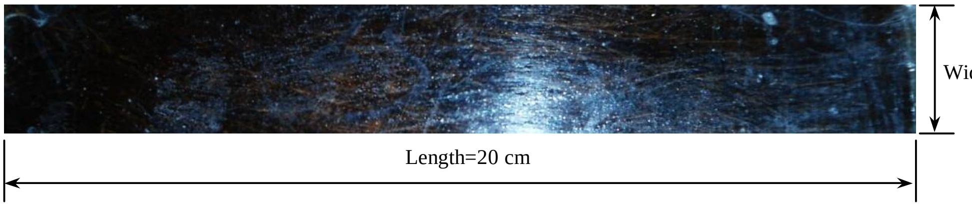

Fig. 3. Shape Dimensions of Tensile Test Sample

Fig. 4. Date Palm Fibers.

The following stepping shown the method using to evaluated the density of date palm reinforcement fiber, [7],

1. Density of fiber, $\text{density} = \rho = \frac{\text{Weight}}{\Delta\forall}$ (1)

The weight using = 200 g, and, Origin volume of water= 2000 mL, Final volume of water with fiber= 365 mL. Then,

$$\text{density} = \rho_f = \frac{200*10^{-3}}{0.365*10^{-3}} = 548\ \text{kg/m}^3 \approx 550\ \text{kg/m}^3 \quad (2)$$

2. Density of resin, The weight of resin =500 g, and, Volume of resin = 460 mL. Then,

$$\text{density} = \rho_m = \frac{500*10^{-3}}{460*10^{-3}} = 1087\ \text{kg/m}^3 \approx 1100\ \text{kg/m}^3 \quad (3)$$

And the Fig. 5. shows the stepping to manufacturing the tensile test samples.

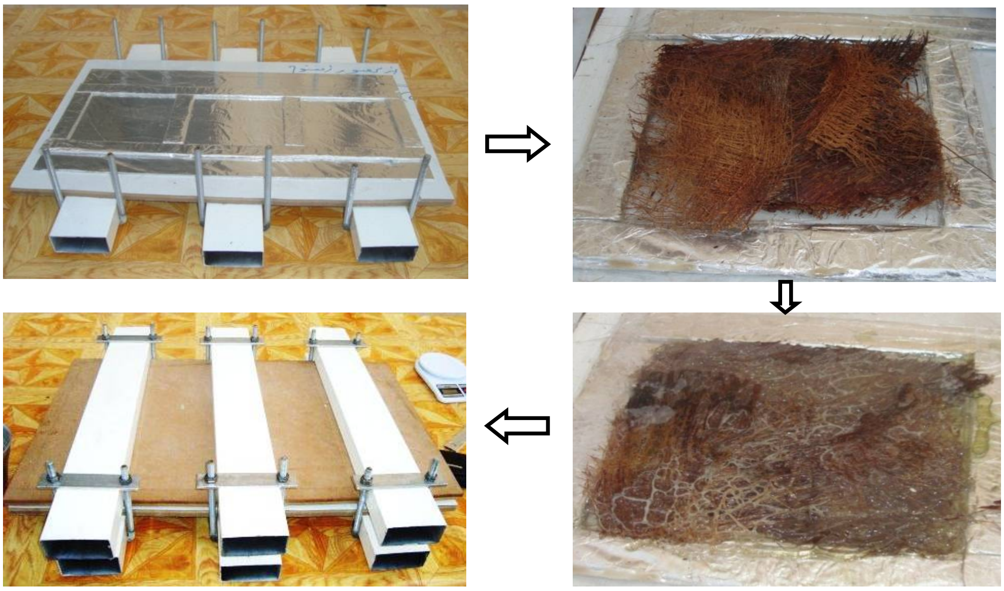

Fig. 5. Manufacturing Stepping of Tensile and Vibration Samples.

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The weight of each sample can be selected depended on the volume fraction of fiber and resin matrix materials as, [7],

$$\text{Weight of Fiber} = \rho_f * \forall_t * \forall_f$$

$$\text{Weight of Resin} = \rho_m * \forall_t * \forall_m \qquad (4)$$

$$\forall_t = 0.2 * 0.18 * 0.005 = 180\ cm^3 \qquad (5)$$

Then, the volume fraction using of tensile test sample and weight of sample shown in table 1, and, the tensile test samples with various fiber volume fraction are shown in Fig. 6. Also, the each sample dividing to five tensile test sample as shown in Fig. 7. And then, the tensile samples testing by tensile test machine shown in Fig. 8.

Table 1. Weight of Tensile Test Sample

Sample	$\forall_m$	$\forall_f$	Weight of date palm Fiber Materials (g)	Weight of Polyester Resin Materials (g)	Density (kg/m^3)
S_o	1.0	0.0	0.0	198	1100
S_1	0.9	0.1	9.9	178.2	1045
S_2	0.8	0.2	19.8	158.4	990
S_3	0.7	0.3	29.7	138.6	935
S_4	0.6	0.4	39.6	118.8	880
S_5	0.5	0.5	49.5	99	825

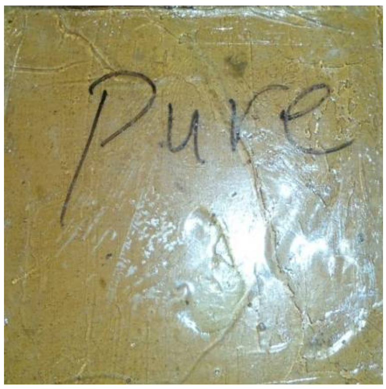
S_1, $\forall_f = 10\%$

S_2, $\forall_f = 20\%$

S_3, $\forall_f = 30\%$

S_4, $\forall_f = 40\%$

S_5, $\forall_f = 50\%$



S_o, $\forall_f = 0.0\%$

Fig. 6. Tensile Test Sample

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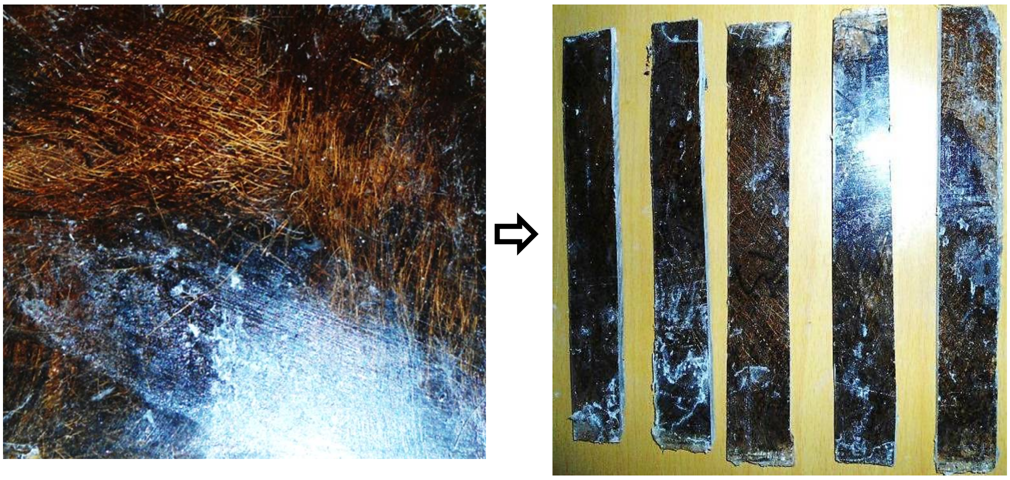

Origen Sample

Divided Five Sample of Test

Fig. 7. Dividing of Tensile Test Sample

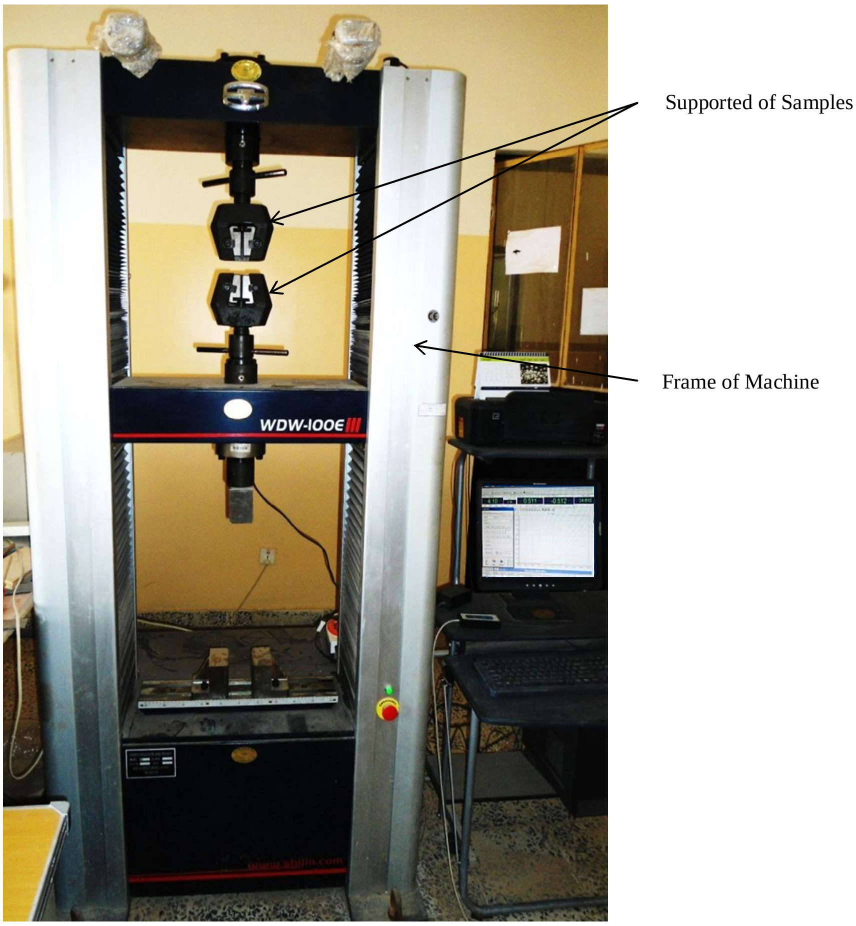

Fig. 8. Tensile Test Machine

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The vibration test involves studying the fundamental natural frequency for composite plate with different natural fiber volume fraction. The samples of vibration plate are made with dimensions as shown in Fig. 9, and the samples of vibration with supported dimensions are shown in sketch Fig. 10, as,

$a_t = a + 5\,\text{cm (edges)}, b_t = b + 5\,\text{cm (edges)}$ (6)

For, $a = 20$, $a_t = 20 + 5\text{cm (supported)} = 25\,\text{cm}$

$$h = 5\,\text{mm}$$

$b = 20, b_t = b + 5\,\text{cm (supported)} = 20 + 5\,\text{cm (supported)} = 25\,\text{cm}$ (7)

Where, a, b, h are length and width, thickness of plate, respectively.

And, a_t, b_t are the total experimental length, width of plate respectively.

And, the weight required of vibration samples, where dimension of vibration sample are $25 * 25 * 0.5\,\text{cm}$, as in table 2.

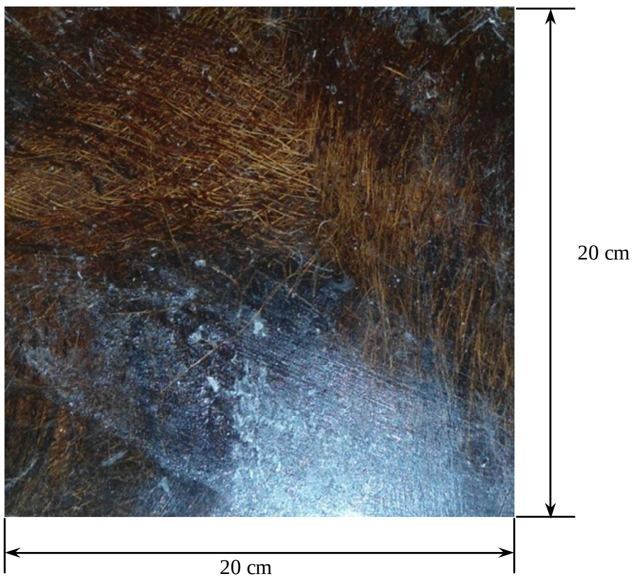

Fig. 9. Vibration Sample.

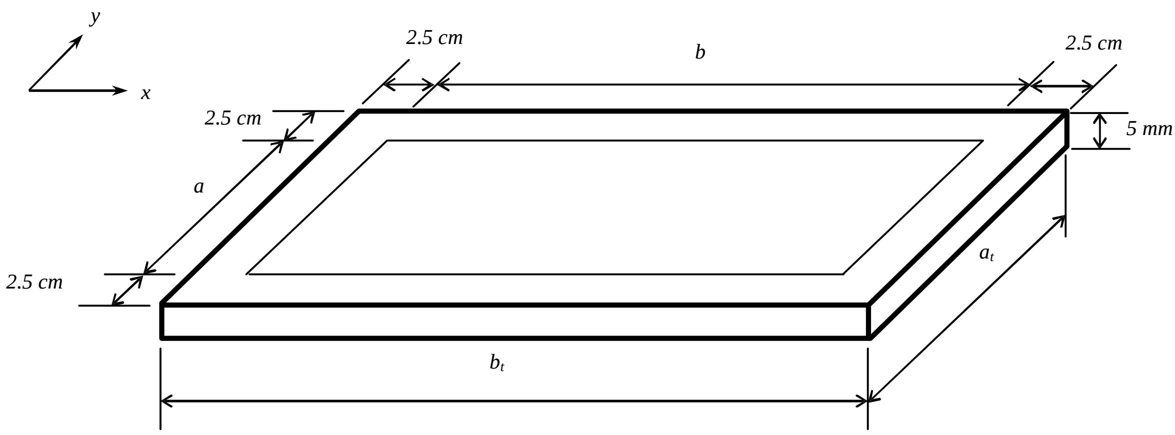

Fig. 10. Shape and dimensions of vibration test sample.

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Table 2. Required Weight of Vibration Samples.

Sample	$\forall_m$	$\forall_f$	Weight of date palm Fiber Materials (g)	Weight of Polyester Resin Materials (g)	Density (kg/m^3)
S_o	1.0	0.0	0.0	343.75	1100
S_1	0.9	0.1	17.2	309.375	1045
S_2	0.8	0.2	34.375	275	990
S_3	0.7	0.3	51.56	240.625	935
S_4	0.6	0.4	68.75	206.25	880
S_5	0.5	0.5	85.94	171.875	825

The vibration plate samples studied are supported with different boundary conditions as SSSS, SSCC, CCFF, SFFF,CCCC, as,

1- Simply supported along all edges (SSSS)
2- Simply-Free Support Edges (SSFF)
3- Clamped-Free Support Three Edges (CFFF)
4- Simply-Clamped Supported Edges (SSCC)
5- Clamped-Free Supported Edges (CCFF)
6- Clamped supported along all edges (CCCC)

The vibration structure rig shown in Fig. 11, is used to evaluate the fundamental natural frequency with different parameters and boundary condition. The machine and other parts used in the vibration structure rig are shows in Fig. 12 (a,b,c,d,e).The vibration test machine and rig involved the following parts:

1. Structure to support the plate sample, made of steel plate with (10 mm) thickness, and other dimensions as shown in Fig. 12 (a).
2. Digital storage oscilloscope, model (ADS 1202CL+) and serial No.01020200300012 as shown in Fig. 12 (b), with the information; maximum frequency (200 MHz), maximum read of sample per second (500 MSa/s), FFT spectrum analysis and two input channels.
3. Amplifier, type (480E09), as shown in Fig. 12 (c). The amplifier measures the response signal from accelerometer and gives output signal to the digital storage oscilloscope.
4. Impact hammer tool, model (086C03) (PCB Piezotronics vibration division), as shown in Fig. 12 (d), with the information about measurement range (2224 N), resonant frequency (≥ 22 KHz), excitation voltage (20 to 30 VDC), constant current excitation (2 to 20 mA), output bias voltage (8 to 14 VDC), discharge time constant (2000 sec), hammer mass (0.16 kg), head diameter (1.57cm), tip diameter (0.63 cm), and hammer length (21.6 cm).
5. Accelerometer, model (352C68), as shown in Fig. 12 (e), with The information regarding this accelerometer are: sensitivity (10.2 mV/(m/s2)), measurement range (491 m/s2), mounted resonant frequency (≥ 35 kHz), non-linearity (≤ 1%).

Impulse force test hammer is adapted for adapts FFT analysis of structure behavior testing. Impulse testing of the dynamic behavior of mechanical structure involves striking the test object with the force-instrumented hammer, and measuring the resultant motion with an accelerometer. Then analysis of response signal is read from digital storage oscilloscope to FFT function by using sig-view program to transform from t-domain into ω-domain and get the fundamental natural frequency of the plate Fig. 13.

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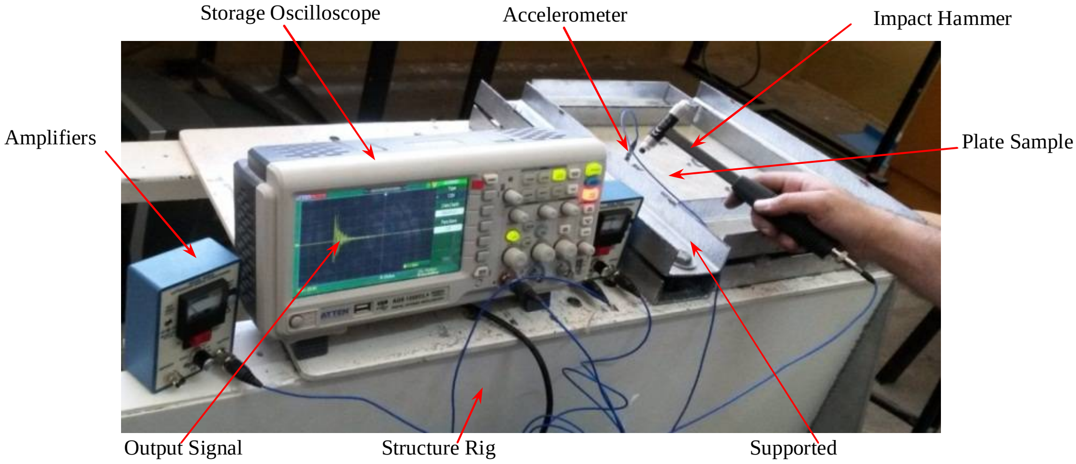

Fig. 11. Vibration Test Rig.

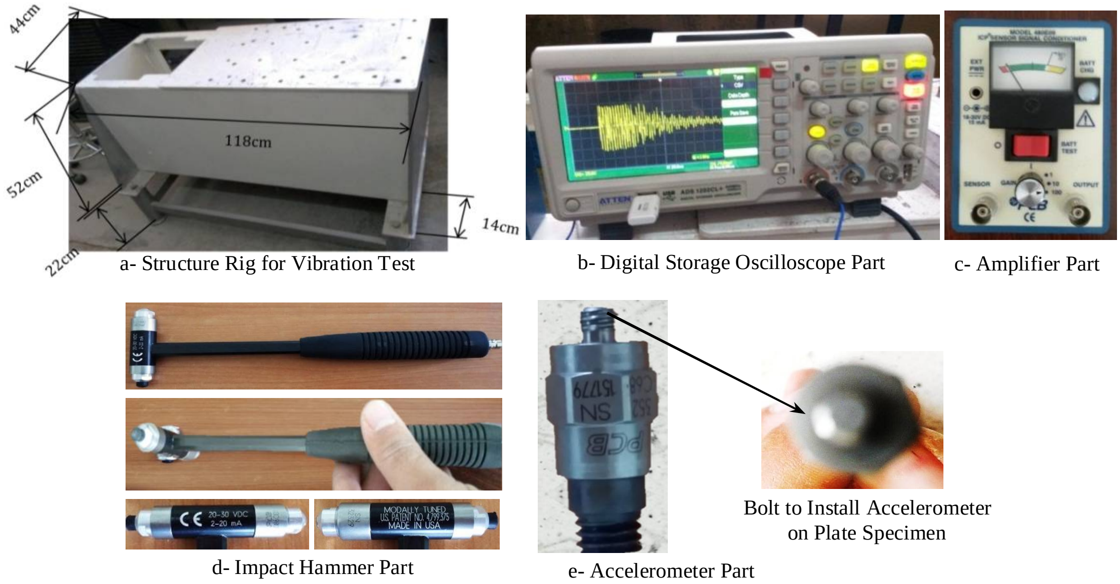

Fig. 12. Vibration Test Parts.

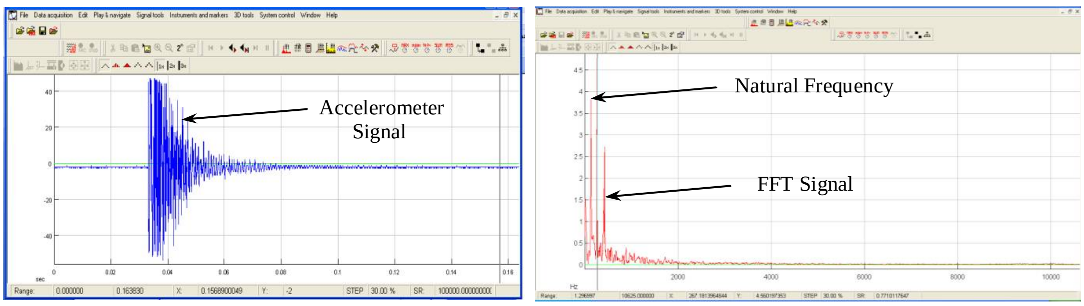

Fig. 13. Sig-View Program, Analysis of Accelerometer Signal.

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IV. RESULTS AND DISCUSSIONS

The results included evaluated the mechanical properties, experimentally, of composite materials combined from date Palme reinforcement fiber and polyester resin material with different fiber volume fraction. And, evaluated the natural frequency of composite plate, experimentally and numerically, with different fiber volume fraction and various boundary condition of plate.

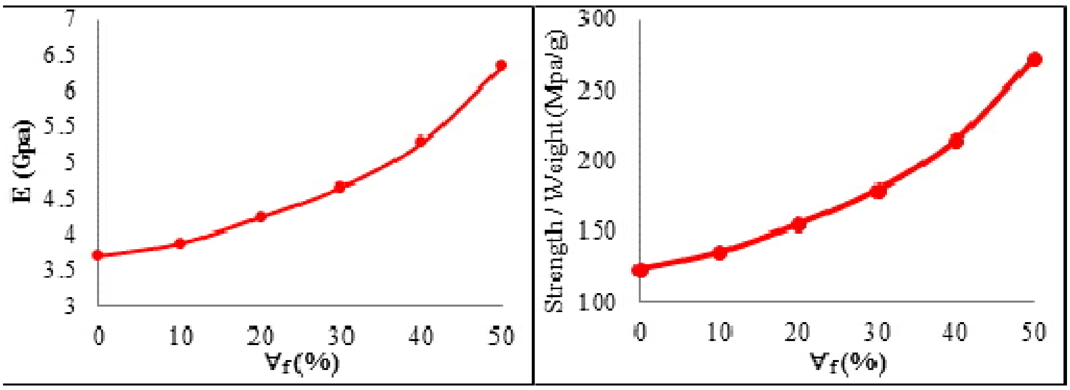
The mechanical properties of composite materials evaluated by tensile test, it's included testing of five sample for each volume fraction of fiber sample, then using the average for five sample to taking the true value of module of elasticity for each sample, as shown in table 3, for date Palme and pure polyester resin. And, the Relation between the modulus of elasticity and volume fraction of date Palme reinforcement fiber composite materials shown in Fig. 14.a. and, the figure shown the modulus of elasticity increasing with increasing of weight or volume fraction of date Palme fiber. In addition we can see the ratio of $(strength/weight)$ increasing with increasing of volume fraction of date Palme fiber as shown in Fig. 14.b.

The natural frequency results of composite plate with various fiber volume fraction ($\forall_f = 0 \rightarrow 50\%$) and different boundary condition (CCCC, CCSS, CCFF, SSSS, CFFF) with plate dimensions ($0.2 * 0.2 * 0.005\ m$) are shown in Fig. 15 and 16. Where, Fig. 15, shows the compassion between experimental and numerical results of natural frequency, from figure shown the good agreement between the results evaluated with maximum error about 7.5%.

Also, Fig. 16 shows the effect of fiber volume fraction of date Palme reinforcement fiber on the natural frequency of composite plate with effect of boundary condition of plate supported, and the figure shown that the increasing of volume for date Palme reinforcement increasing the natural frequency of plate due to increasing the ration between the stiffness to weight ratio. And, the figure shown that the natural frequency of plate supported as clamped around all edges more than the natural frequency of plate supported with other supported types. And the plate supported as cantilever have minimum natural frequency comparison with other plate supported.

Table 3. Modulus of Elasticity (Gpa) of Date Palme Fiber Reinforcement Composite Materials and Pure Polyester Materials, Evaluated by Experimental Study.

Number	Pure	S1	S2	S3	S4	S5
1	3.74	3.98	4.13	4.75	5.39	6.41
2	3.8	3.87	4.3	4.65	5.2	6.21
3	3.69	3.96	4.25	4.58	5.35	6.52
4	3.52	3.72	4.31	4.55	5.15	6.35
5	3.72	3.86	4.2	4.77	5.33	6.28
Average	3.7	3.878	4.24	4.66	5.28	6.35



a. Modulus of Elasticity b. Strength to Weight Ratio

Fig. 14. Modulus of Elasticity of and Strength to Weight Ratio with Date Palme Reinforcement Fiber with Various Volume Fraction.

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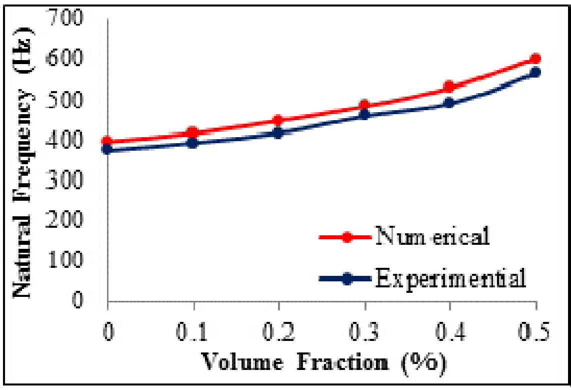
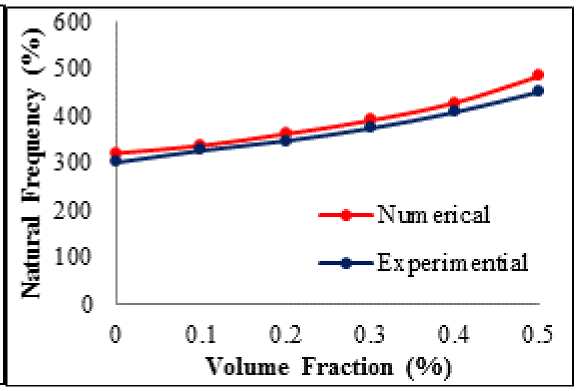
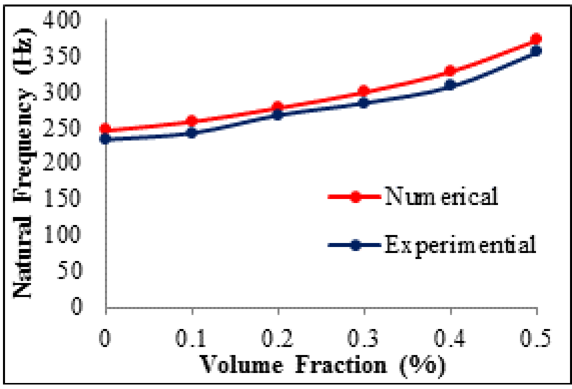


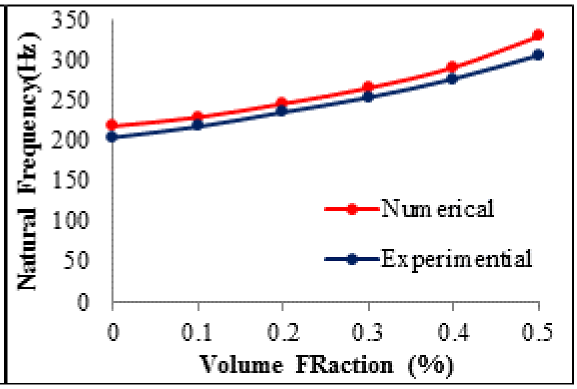
a. CCCC



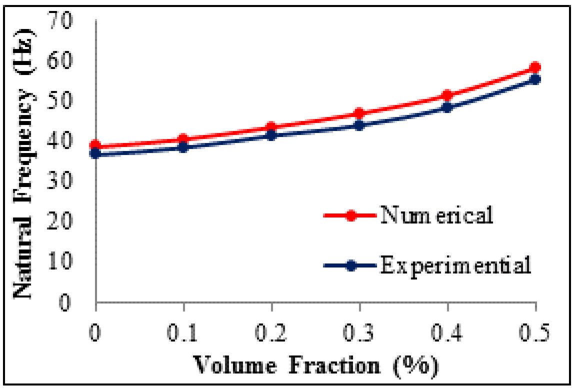
b. SSCC



c. CCFF



d. SSSS



e. CFFF

Fig. 15. Comparison Between Experimental and Numerical Results of Natural Frequency with Different Fiber Volume Fraction.

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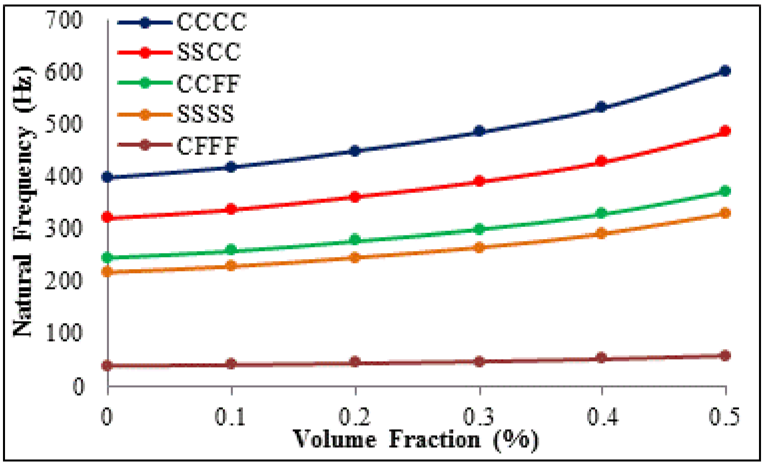

Fig. 16. Experimental Natural Frequency of Composite Plate with Different Fiber Volume Fraction and Various Boundary Condition of Plate.

V. CONCLUSION

When the natural fiber used, as date Palme fiber, we get good mechanical properties and strength to weight ratio in addition to good natural frequency of composite plate. The main conclusion of work are

1. The comparison between the experimental results of natural frequency with numerical results FEM by using Ansys program Ver.14, showed a good approximation with a maximum discrepancy of (7.5%).
2. The modulus of elasticity increasing with increasing the volume fraction of reinforcement fiber. And modulus of elasticity increasing with increase the strength of reinforcement fiber.
3. The natural reinforcement fiber given high strength to weight ratio and high modulus of elasticity.
4. The natural frequency of composite plate increasing with increasing the volume fraction of reinforcement fiber. And the natural frequency increasing with increase the strength of reinforcement fiber.

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