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Sisal natural fiber reinforcement influenced with experimental and numerical investigation onto vibration and mechanical properties of composite plate

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Abstract
This study interested in preparation of composite material specimen by using natural fibers sisal and polyester resin. The specimens were pretreated in different of volume fraction of sisal and resins which are were (05-35) % sisal, respectively. Specimen model fabricated had plate shape, where, can be applying vibration test and tensile test. Specimens were tested by using tensile properties test. Results reveal that the best specimen had mechanical properties was (A) which are (35-65) % sisal-resin, where, specimen appeared best modulus elasticity in longitudinal fibers E1 (5.925) Gpa so lower value modulus elasticity in transverse fibers E2 (4.860) Gpa for same specimen. (A) specimen gives stronger material compared with at each of specimens, which indicates high toughness and strength of materials because reinforcement of sisal fibers use of a higher percentage of fiber 35%. Specimen were tested vibration test as types of fixations of specimen, result reveal the natural frequency high at clamped supported four edges (CCCC), (202.73) Hz compared at each of another specimens, because (CCCC) specimen had high volume fraction of plant fiber sisal and less volume fraction of polyester resin (35-65) % sisal-polyester. Natural frequency was obtained by using numerical analyzing at running ANSYS program (VER.14). the results finding, there are similarity between behavior of composite material samples from where, natural frequency and volume fraction , results reveal that numerical analyzing of plate composite materials was little better from experimental work but both of tests in simulation and experimental test appear same of final results which (CCCC) specimen was better at of each specimens to apply strength of materials and whenever increasing volume fraction of sisal obtained high strength of material.

Keywords: Sisal fiber; Volume fraction; Mechanical properties; Natural frequency and numerical analyzing.

1. Introduction

Natural fibers are classified into three categories (plant fibers, animal fibers and mineral fibers). The plant fibers many types: Seed fiber (Cotton), Bast fiber (Flax, Ramie, Hemp), stalk fiber (Rice), Leaf fiber (Sisal, pineapple), fruit fiber (Coir), stem (Wheat) and Tracheid (Wood (Softwood & Hardwood)). The natural fibers significant role in development of manufacturing and Contributed a big role in low cost of production especially of consumables, [1].

The industry considers a factors influence of environmental pollution types and was the main reason find for alternative materials of manufacture. Plant fibers Characterize low cost, light weight, testable and reduce pollution. Features of plant fiber deserve study from all ways. In this study select sisal fiber for find investigation experimental and numerical technique, [2].

Composite material of plant fibers pass in most mechanical tests gives amazing results, mechanical tests show improve mechanical properties have many variable can be controlled. Natural frequency analysis of composite material as plate-shell gives significant role in the part design of structure automotive, airplane, rocket, military equipment and aerospace applications, [2]

There are many studies are using sisal fibers reinforcement are blending with polyester for amelioration mechanical properties of composite materials which fabricate in different ration of many variables (polyester ratio, fiber ratio, dimensions are changing, ...etc.) for specimen, the studies as, S.Prabhakaran et.al. [3] found the free vibration absorbing and damping characteristics of specimens are making by natural material are mixing polyester and compare it over commonly used conventional composites. Fabrication of composite laminates by utilization vacuum assisted resin transfer moulding (VARTM), specimens were prepared, by different number of layers of reinforcement, samples selected two materials and polyester Glass/Flax/Epoxy (GFE) also the weight of samples dissimilar, Flax/Epoxy (FE), Glass/Epoxy (GE) and Glass/Flax/Epoxy (GFE) (25,38,29)grams. Style of samples were circular (100) mm diameter. Also utilization three samples have longitudinal which is dimensions (210x35) mm were Flax/Epoxy (FE), Glass/Epoxy (GE) and Glass/Flax/Epoxy (GFE). The strength and modulus flexural of flax fiber strengthening composite were equivalent of glass fiber reinforced composite.

C. Chaithanyan et.al [4] studied took care of investigation and preparation of hybrid of plant fibers in polyester resin. Fiber plant utilized were coir fiber and sisal fiber blending with polyester together as ratio controlled of variables, volume fraction (0.4 and 0.5). The hybrid specimens were mad of hand layup process. Mechanical properties of composite materials were fabricated form of samples like ASTM D790 for flexural test specimen, ASTM D256 for impact test and ASTM D638-03 for tensile test. The specimens of composite material consist Sisal-glass (40%-60%), Sisal-glass (50%-50%), Coir-glass (40%-60%), Coir-glass (50%-50%), Sisal-Coir-glass (40%-60%) and Sisal-Coir -glass (50%-50%).The results show the tensile strength of sisal-glass hybrid was better than the coir-glass hybrid. The flexural and impact strength for sisal-coir-glass composite were better than two combination hybrid residual.

U Ramirez-Barragán et.al [5] deals with the properties of the mechanical behavior for composite material make by polyester blend with orthogonal sisal fiber. Where, samples manufacture laminate. in order to limit dynamic characterization, plate dimensional (30X30)cm used 25 points net sketch on the surface of sample that's point are using in Dooper vibrometer PDV-100, by impact instrument hammer that's connected with the Dooper. Due to impact of hammer will be generated vibration waves, the signals analysis use MATLAB program to give the vibration data and obtain mode graphic of plant fiber use sisal.

On the other hand the study were presented show microstructure of sisal by optical microscopy, the results depend on vibration and tensile tests, the composite material obtained volume fraction 21.9%, resin 77.1%, voids 0.9% and elastic modulus 2.5GPa. The indicate determination quality of industrialization based on behavior of composite material.

Akash.D.A, et.al [6] investigated the composite material consist of jute-sisal laminate prepare by using woven jute-sisal. The hybrid is blending plant fibers (jute & sisal) together with resin of polyester types. The composite material becomes matrix material. The sample make a cantilevered rectangular plate of hybrid reinforced resin have (300X300X4.8) mm, aspect ratio of 0.83, five layers, so the fiber direction orientation at [+90°/+45°/0°/-45°/-90°] laminate is prepared. The rate damping factor found for frequency of hybrid laminate (3.681%) is 1.15 times bigger than that of jute laminate (3.19%). The difference in damping factor perhaps inasmuch difference in flexural strength of hybrid and jute and using orientation angle to variation dynamic behavior of composite. The Hybrid jute-sisal have good damping factor as compared to another composites material. Become these composites apply as vibration reduction materials as cars manufacturing, roofing material and interior applications.

In this paper were estimated mechanical properties of sisal fibers with changeable volume fraction of sisal and polyester, also found natural frequency of sisal plate via running two ways, reveal natural frequency in apply experimental methods and found natural frequency by using simulation methods which was used ANSYS program (VER 14) then comparison between them with different boundary conditions.

2. Experimental works

2.1 Materials and methods

In this part will be presenting experimental work. In begin select the specimen model which dimensional (300 X 300 X 5) mm, specimen prepare mineral mould consist (upper cover, vessel, lower cover, hydraulic jack and another support). The dimensions of specimen as shown in Figure 1 below, thickness of specimen control in hydraulic jack, as shown in Figure 2.

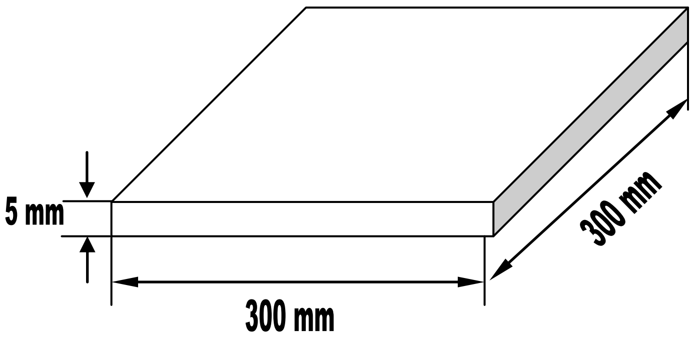


Figure 1. Specimen dimensional.

2.2 Preparation of specimens

Samples were classified into seven types according to the volume fraction, (95%, 90%, 85%, 80%, 75%, 70%, 65%) polyester material and (5%, 10%, 15%, 20%, 25%, 30%, 35%) sisal fiber respectively, also find another variables, density of resin is 1100 Kg/m^3 and density of sisal 1400 Kg/m^3 will be finding from Archimedes rule by using the weight of displaced water inside the glass beaker as,

Density = mass/volume $_{\text{water added}}$ ………………. Archimedes rules

$\rho_{sisal} = 1400\ Kg/m^3$

So, resin density is finds $\rho_{\text{Resin}} = 1100\ Kg/m^3$

$$\rho_{sisal} = \frac{mass}{V_{(Water+\ Sisal)} - V_{(Water)}} \quad (1)$$

The variables are to find them such as (weight and volume desired) to create of samples, depending on the density of composite materials for polyester (resin) and plant fiber (sisal). The samples classified into four Categories (A, B, C, D, E, F and G) each samples have changing of volume fraction to appear diverse results, which are help in the interpretation of results. Table 1 shown guess of specify of samples from where volume and weight before fabrication of specimens.

$$m_{composite\ materila} = (\rho \times V \times \forall)_{sisal} + (\rho \times V \times \forall)_{polyester} \quad (2)$$

where, m: mass, ρ: density, V: volume, $\forall$: volume fraction.

Table 1. Estimation of final weight of composite materials of samples before preparation.

Samples	Volume Fraction	Resin Mass(g)	Volume Fraction	Sisal Mass(g)	Composite Material(g)
A	65%	321.75	35%	220.5	542.25
B	70%	346.5	30%	189	535.5
C	75%	371.25	25%	157.5	528.75
D	80%	396	20%	126	522
E	85%	420.75	15%	94.5	515.25
F	90%	445.5	10%	63	508.5
G	95%	470.25	5%	31.5	501.75

The quantities of total mass of samples (A, B, C, D, E, F and G) are calculate by depending to the volume fraction of samples and by base on specification of materials (resin and fibres sisal) and dimensional of mould are (length, width, thickness) (300x300x5) mm, in additional of another properties were density of sisal and polyester (resin), as shown in Table 1.

2.3 Methods of specimens fabrication

Materials bring preparation were final weight each samples as shown in table (1), Previously, in the begin put fibres sisal and resin of limited inside the mineral base and then put the mineral cover as shown in Figure 1 and compressed by using hydraulic jack as shown in Figure 2 then, hydraulic jack will be compressing of mix composite material inside of mould to arrive to limited thickness (5) mm.
The composite materials will be remaining under the hydraulic jack pressure as shown in Figure 3 until the composite materials are merging with each other, this processing take few hours to get final product. For this reason, one sample takes several hours to produce. After that carry out mechanical properties include tensile tests and vibration tests.

Figure 2. Part of mineral mould using of preparation of specimens.

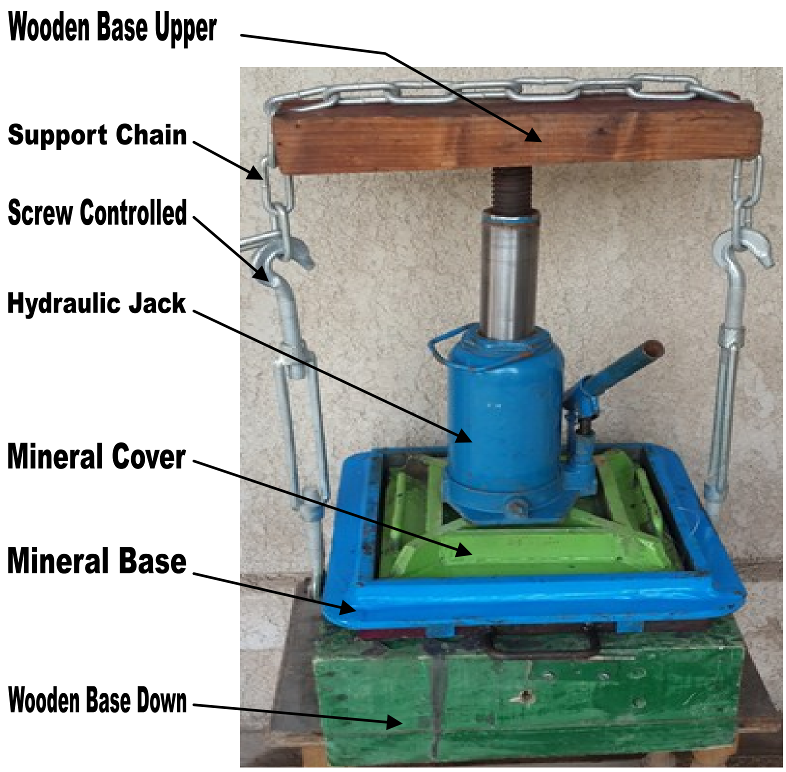


Figure 3. Show part of mineral mould with hydraulic jack using of preparation of specimens.

The samples of composite material make like plate shape as shown in Figure 4 depend on volume fraction in Table 1 with each kind (A, B, C, D, E, F and G) consist volume fraction of sisal-resin (35%-65%), (30%-70%), (25%-75%), (20%-80%), (15%-85%), (10%-90%) and (05%-95%) respectively. Figure 4 shows the specimens after fabrication by using hydraulic jack and mineral mould.

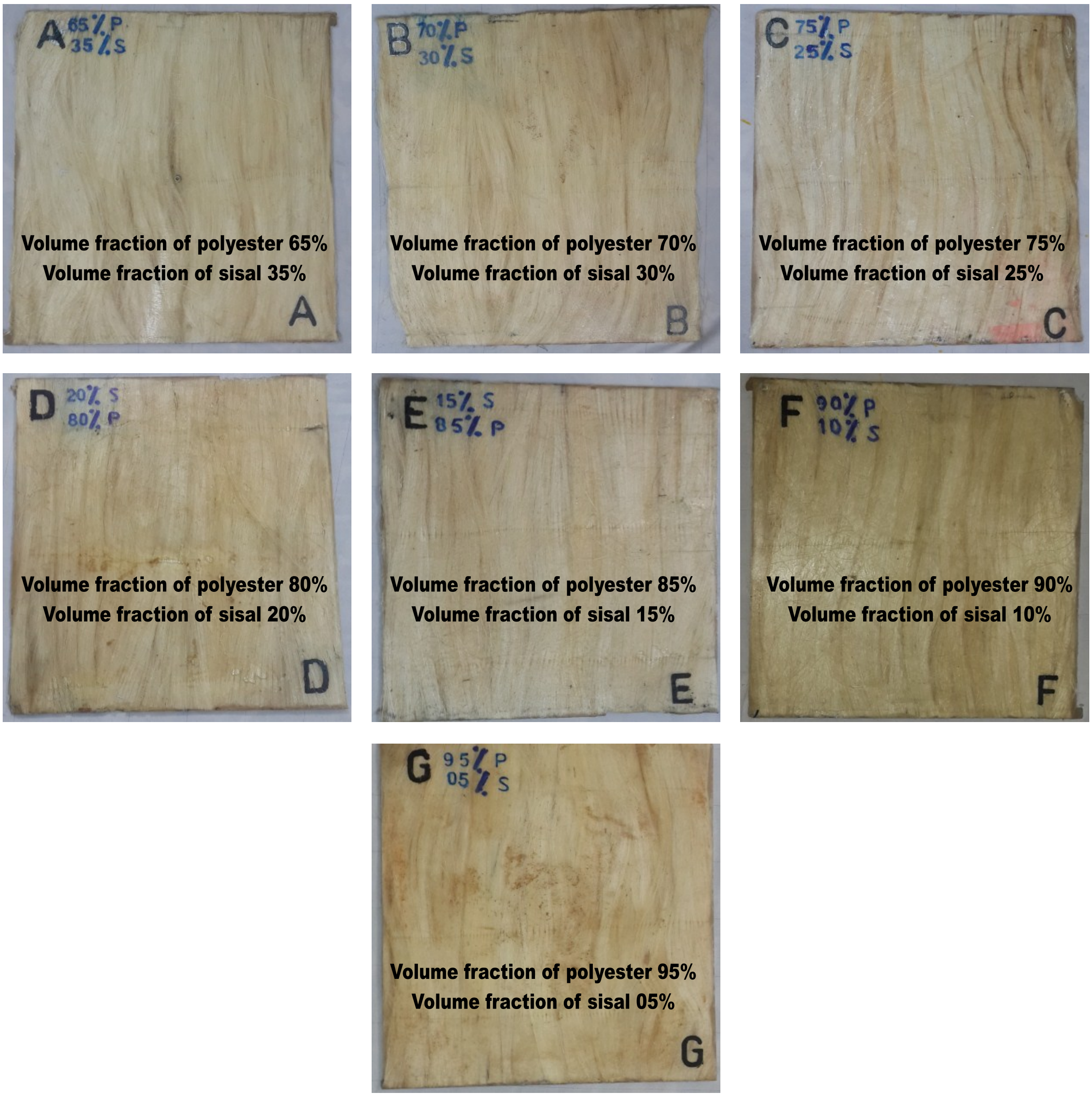


Figure 4. Kinds of samples make by using mineral mould and hydraulic jack.

2.4 Vibration test

In a few applications, vibration measurements are done through accustomed operations of a structure specimen in a current search suggestion of excitation method. The current research suggested excitation method, in actually been applied in the experimental aspect to measure vibration, the excitation method use a hammer impact hit the samples to generation of single pass via accelerometer another meaning an impact hammer considered measurement part which produces vibration levels from striking the sample structure at some point. The hammer includes a sensor (accelerometer) fix on surface of specimen, which creates a signal commensurate to the force of impact. Excitation force of impact hammer is some often used for modal analysis of structures of mechanical vibrator are convenient frequency measurements, a composite materials concentrates the excitation energy in a frequency rang as shown Figure 5 vibration device of main part of equipment.

There are multi positions of kinds of fixation composite materials plate using in vibration test, this research focused study four of fixed cases (CCCC), (CCFF), (CFFF) and (SSSS), and this cases can be shown in below:

1. Clamped supported four edges (CCCC)
2. Clamped supported two edges and free supported two edges (CCFF)
3. Clamped supported one edge and free supported three edges (CFFF)

4. Simply supported four edges (SSSS)

The composite material specimens are exam of each fixation cases and registered of data vibration test by applying equipment of vibration test in the lab of applied composite materials, device of oscilloscope measure natural frequency of composite material plate each of supported study in this paper which are (CCCC), (CCFF), (CFFF) and (SSSS) as shown in Figure 5 appear device of vibration test and type of supported for specimens, the boundary conditions of vibration test were kinds of supported apply on specimen fabricated as appeared in figure-6 types of supported samples which are boundary conditions for vibration test, (CCCC), (CCFF), (CFFF) and (SSSS).

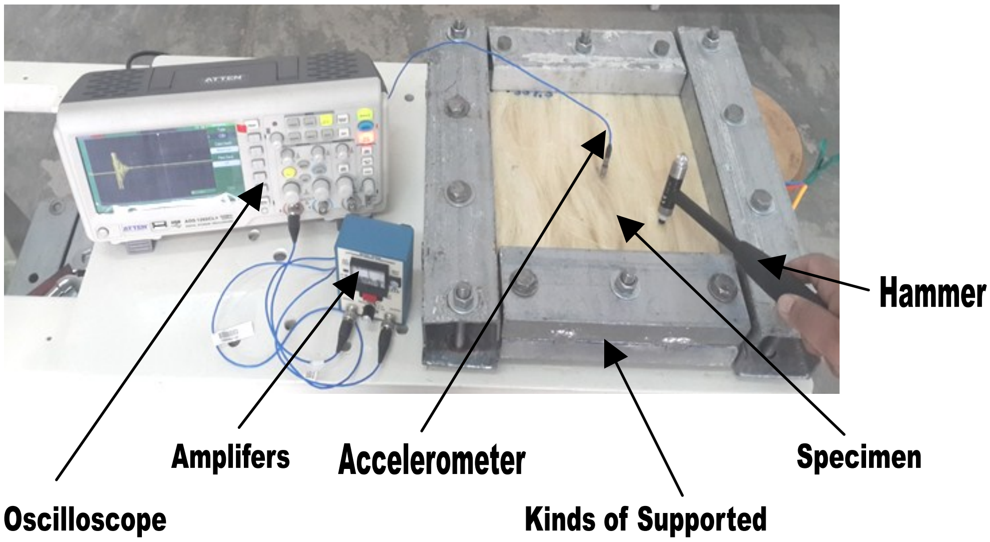
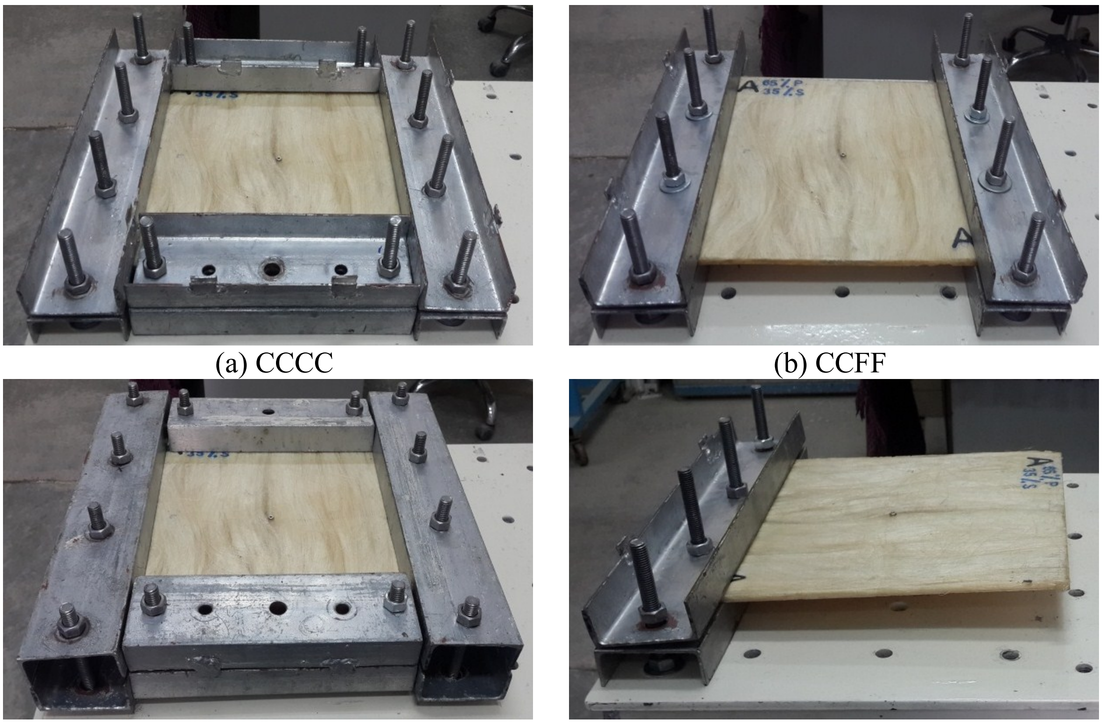


Figure 5. Device of oscilloscope measure of the vibration test.

The specimen fix by using types of supported mentioned in this study which are fixed cases (CCCC), (CCFF), (CFFF) and (SSSS) as illustrated in Figure 6, vibration test finds natural frequency in of each fixation cases of specimens with various volume fraction for polyester (resin) and plant fibres (sisal).



(a) CCCC (b) CCFF

(c) SSSS (d) CFFF

Figure 6. Types of supported samples depend on vibration test.

Natural frequency of response signal were recorded through oscilloscope to FFT by running SIG-VIEW program to convert from T-domain into ω-domain then give natural frequency of specimen as shown in Figure 7.

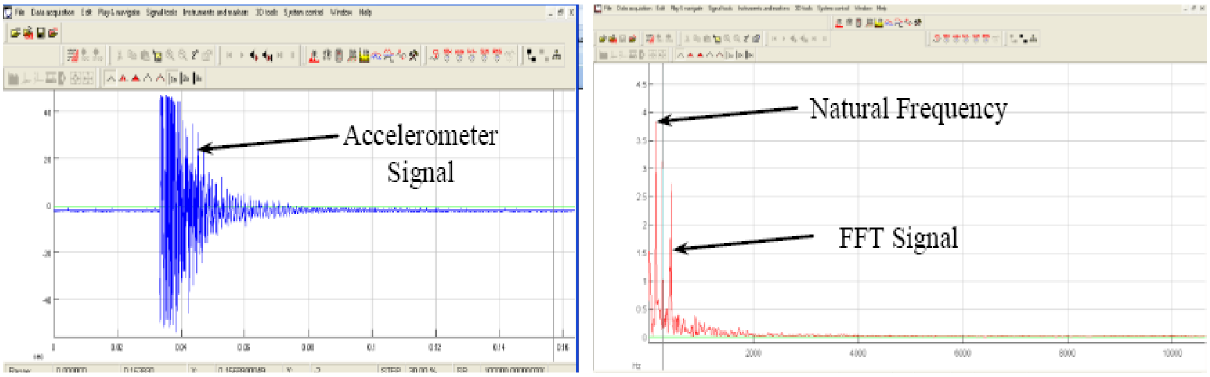


Figure 7. Sig-view program.

2.5 Tensile test

The dimensional of composite material plate of each samples were (30x30x0.5) cm, the composite material prototype operated to make shape of samples like that ASTM (D 3039 M-E122), [7] this shape using for tensile test as shown in Figure 8. The composite materials model will be cutting as ASTM (D 3039 M-E122) by two types (longitude and transverse), therefore, the tensile samples exam two cases as position of plant fibre (sisal) (longitude and transverse) as shown in Figures 9, 10.

Tensile test gives indicator about modulus elasticity for specimens in both cases, the first case be longitudinal fibres and the other cases was transverse fibres, where, the trend fibres have influence of strength of composite material duration of tensile test, so direction of fibres effect most of mechanical properties for samples, output data get from tensile device via connection with computer has program control of type of test so kind of specimen used for test, in additional input data as boundary condition before applying of test (see Figure 11).

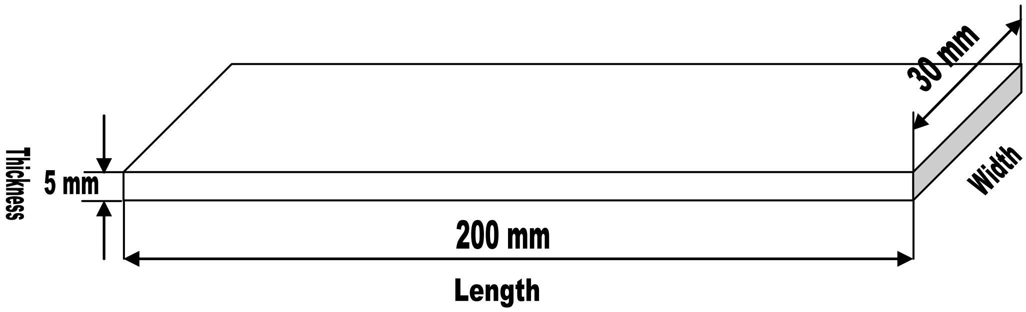


Figure 8. Illustrate shape and dimensions of specimen using of tensile test.

Figure 9. Longitude fibres prototypes of composite materials.

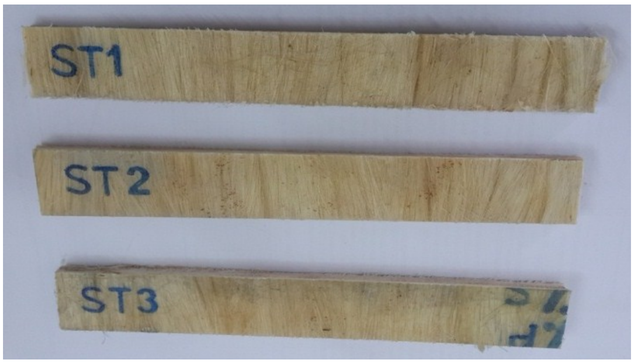


Figure 10. Transverse fibres prototypes of composite materials.

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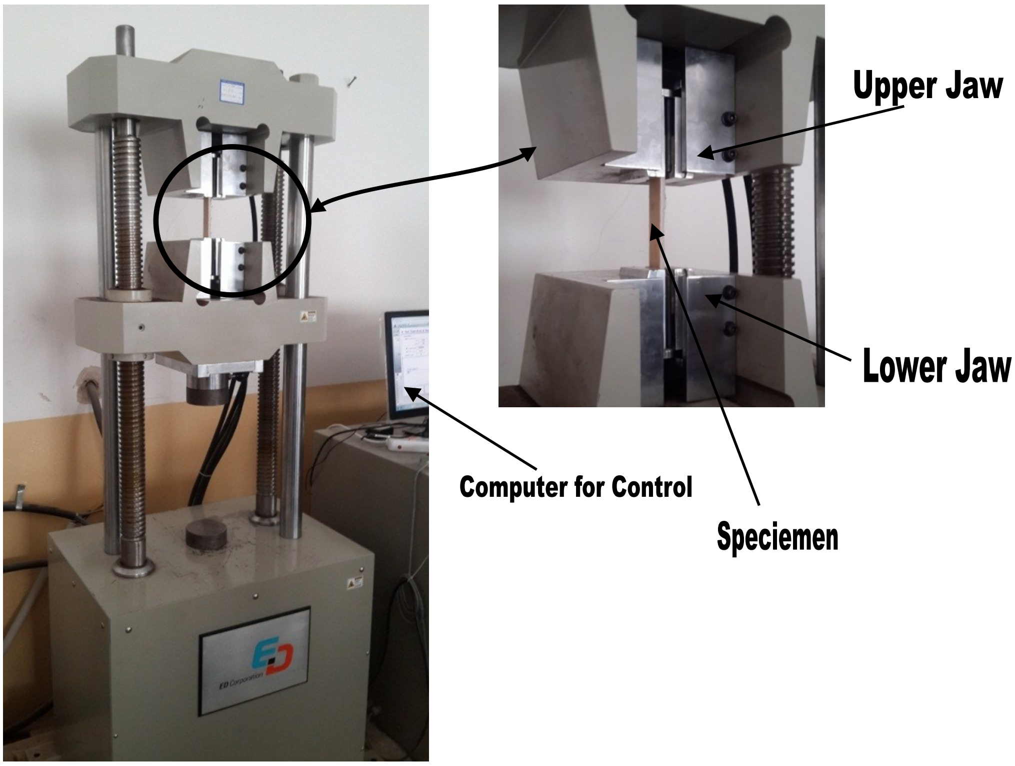

Figure 11. Illustrate device of tensile property test for metal and composite materials.

3. Numerical analysis

Numerical research of various composite materials orthotropic composite plate with force of lamina evaluated by using the finite elements way was applied via ANSYS Program (VER.14), 3D model were create and the element (SOLID 10 node 187) were applyied.it is appropriate for analysing, reasonably-thick solid structures. Analysing model need boundary conditions should be available to solve of simulation model, there are many information extract from tensile test which be available for fill out the required fields in ANSYS14 program were include orthotropic structure of elastic model as define material model behaviour toolbar in ANSYS14 program that information explain in Table 4.

4. Results and discussion

The specimen were tested by using vibration test so get data of natural frequency applying for multi cases of fixations of samples which were (CCCC), (CCFF), (CFFF) and (SSSS) as illustrated in Figure 6, the data of natural frequency data were obtained as volume fraction resin and sisal for composite materials, volume fraction were (0-100)%, (05-95)%, (10-90)%, (15-85)%, (20-80)%, (25-75)%, (30-70)% and (35-65)% sisal-resin, respectively. Tensile test finds E1 and E2 which mean modulus elasticity of longitudinal and transverse fibres. Tables 2, 3 explain average E1 and E2 were used in numerical analysing by using ANSYS Program (VER.14) as primary data fill out program field.

Table 2. Explain average modulus elasticity E_1.

Volume Fraction Sisal	Volume Fraction Resin	Sample 1 E_1 (Gpa)	Sample 2 E_1 (Gpa)	Sample 3 E_1 (Gpa)	Average E_1 (Gpa)
0%	100%	3.830	3.830	3.830	3.830
5%	95%	4.21	4.25	4.125	4.195
10%	90%	4.4	4.395	4.5767	4.457
15%	85%	4.883	4.67	4.723	4.632
20%	80%	5.156	5.145	5.012	5.104
25%	75%	5.325	5.438	5.395	5.386
30%	70%	5.78	5.59	5.68	5.683
35%	65%	5.98	6.035	5.76	5.925

Table 3. Explain average modulus elasticity E_2.

Volume Fraction Sisal	Volume Fraction Resin	Sample 1 E_2 (Gpa)	Sample 2 E_2 (Gpa)	Sample 3 E_2 (Gpa)	Average E_2(Gpa)
0%	100%	3.830	3.830	3.830	3.830
5%	95%	3.9	4.11	3.91	3.973
10%	90%	3.95	3.99	4.105	4.015
15%	85%	4.21	4.25	4.35	4.270
20%	80%	4.41	4.31	4.415	4.378
25%	75%	4.56	4.67	4.52	4.583
30%	70%	4.77	4.58	4.69	4.680
35%	65%	4.86	4.97	4.75	4.860

Data were required for fill out field ANSYS can be extract from tensile test and other data from theoretical way, available variables were E1 and E2 from tensile test were inserted in Tables 2, 3 another information, shear modulus and Poisson's ratio estimate by theoretical equations. Poisson's ratio of Sisal fibres= 0.32 [8] and Poisson's ratio of Resin polyester = 0.4 [9]. So,

$$G = \frac{E}{2(1+\nu)}, G_{sisal}=3.9773\text{Gpa}, G_{resin}=1.4286\text{Gpa} \tag{3}$$

where, G: Shear modulus, E: Modulus elasticity, ν: Poisson ratio, this equation applies on sisal fibers and resin polyester to find shear modulus for sisal and resin, also Poisson ratio and density of composite material specimen find by equations below [10],

$$\nu_{12} = \forall_{Fibre} \times \nu_{Fibre} + \forall_{Polyester} \times \nu_{Polyester} \tag{4}$$

where, $\forall_{Fibre}$: Volume fraction of fibres, ν_{Fibre}: Poison's ratio of fibres, $\forall_{Polyester}$: Volume fraction of polyester, $\nu_{Polyester}$: Poisson's ratio of polyester.
Shear modulus of composite material were found by using equation below: [10],

$$G_{12} = \frac{G_r + G_f}{\forall_r \times G_f + \forall_f \times G_r} \tag{5}$$

where, G_{12}: Shear modulus of composite, G_f: Shear modulus of fibre, G_r: Shear modulus of polyester, $\forall_r$: Volume fraction of polyester, $\forall_f$: Volume fraction of fibre.
Shear modulus and Poisson ratio were found as insert in Table 4, that's used to apply numerical analysis via ANSYS program. The results of tensile test gives indicators about modulus elasticity, whenever increase of volume fraction of sisal fibres, was high result of modulus elasticity, because of plant fibres give the reinforcement of composite materials, this results lead to increase of strength of materials with high toughness of composite materials. Also there are indicators were the modulus elasticity (E_2) less than modulus elasticity (E_1) because the longitudes fibres give strength of material high than transverse fibres.

Table 4. Variables use to solve numerical analysis.

Samples	$\forall_{Sisal}$	$\forall_{Resin}$	Density of Specimen (Sisal+Resin) (Kg/m^3)	E_1 (Gpa)	E_2 (Gpa)	ν_{12}	G_{12} (Gpa)
G	5%	95%	1115	4.195	3.973	0.396	1.4759
F	10%	90%	1130	4.457	4.015	0.392	1.5264
E	15%	85%	1145	4.632	4.270	0.388	1.5805
D	20%	80%	1160	5.104	4.378	0.384	1.6386
C	25%	75%	1175	5.386	4.583	0.38	1.7011
B	30%	70%	1190	5.683	4.680	0.376	1.7686
A	35%	65%	1205	5.925	4.860	0.372	1.8416

Results of natural frequency were obtained by run the ANSYS program (VER.14) depending on type of specimens fixation (CCCC), (CCFF), (CFFF) and (SSSS), the output data insert of Tables 5 to 8 shown natural frequency of specimens influence with volume fraction for resin and sisal in many ratio (0-100)%, (05-95)%, (10-90)%, (15-85)%, (20-80)%, (25-75)%, (30-70)% and (35-65)% sisal-resin, this result were considered numerical analyzing, also Tables 5 to 8 explain result of natural frequency were obtained by device of vibration test which are considered experimental work.

Table 5. Show natural frequency of numerical analyzing and experimental works for CCCC plate.

Samples	$\forall_{Sisal}$	$\forall_{Resin}$	Density (Kg/m^3)	ω (Hz) Num.	ω (Hz) Exp.	Error %
G	5%	95%	1115	194.37	183.22	6.09
F	10%	90%	1130	197.54	187.66	5.264
E	15%	85%	1145	199.62	191.28	4.36
D	20%	80%	1160	202.18	195.47	3.43
C	25%	75%	1175	204.84	198.35	3.27
B	30%	70%	1190	207.58	200.58	3.49
A	35%	65%	1205	210.43	202.73	3.80

Table 6. Show natural frequency of numerical analyzing and experimental works for CCFF plate.

Samples	$\forall_{Sisal}$	$\forall_{Resin}$	Density (Kg/m^3)	ω (Hz) Num.	ω (Hz) Exp.	Error %
G	5%	95%	1115	120.72	108.25	11.52
F	10%	90%	1130	123.73	112.598	9.89
E	15%	85%	1145	126.62	118.47	6.88
D	20%	80%	1160	129.4	120.58	7.31
C	25%	75%	1175	132.06	123.87	6.61
B	30%	70%	1190	134.63	128.47	4.79
A	35%	65%	1205	137.1	129.89	5.55

Table 7. Show natural frequency of numerical analyzing and experimental works for CFFF plate.

Samples	$\forall_{Sisal}$	$\forall_{Resin}$	Density (Kg/m^3)	ω (Hz) Num.	ω (Hz) Exp.	Error %
G	5%	95%	1115	18.82	16.87	11.56
F	10%	90%	1130	19.306	17.12	12.77
E	15%	85%	1145	19.771	17.89	10.51
D	20%	80%	1160	20.216	18.24	10.83
C	25%	75%	1175	20.642	18.77	9.97
B	30%	70%	1190	21.051	19.23	9.47
A	35%	65%	1205	21.444	19.98	7.33

Table 8. Show natural frequency of numerical analyzing and experimental works for SSSS plate.

Samples	$\forall_{Sisal}$	$\forall_{Resin}$	Density (Kg/m^3)	ω (Hz) Num.	ω (Hz) Exp.	Error %
G	5%	95%	1115	105.78	96.98	9.07
F	10%	90%	1130	106.88	98.24	8.79
E	15%	85%	1145	108.05	100.01	8.04
D	20%	80%	1160	109.3	103.558	5.54
C	25%	75%	1175	110.61	104.58	5.77
B	30%	70%	1190	111.99	105.89	5.76
A	35%	65%	1205	113.44	107.55	5.48

The comparison between experimental work and numerical analyzing were represented by using the graphs which were shown the relations between volume fraction of sisal with natural frequency for two cases (numerical analyzing and experimental work) also types of supported of specimens (CCCC), (CCFF), (CFFF) and (SSSS). Results reveal high natural frequency for specimen had supported kinds clamped supported four edges (CCCC) at volume fraction (35-65)% sisal-resin respectively, also the result reveal same sample (CCCC) had high strength of materials inasmuch fibers plant sisal until maximum volume fraction (35%) of sisal were used in creation of specimen.

The practical consequences were approached the numerical analysing results as such shown in Figure 12. so numerical results were reveal the best specimen composite material had high volume fraction sisal and high natural frequency, another meaning whenever fibres ratio high the results give best vibration test as shown in Figure 13. Also Figure 12 Demonstrated best type support with beset volume fraction and the lower natural frequency had (CFFF) specimen at (05-95) % sisal-resin volume fraction. Figure 14 appears comparison between natural frequency influence with volume fraction sisal at each type of supported used in vibration test in experimental work and numerical analysing.

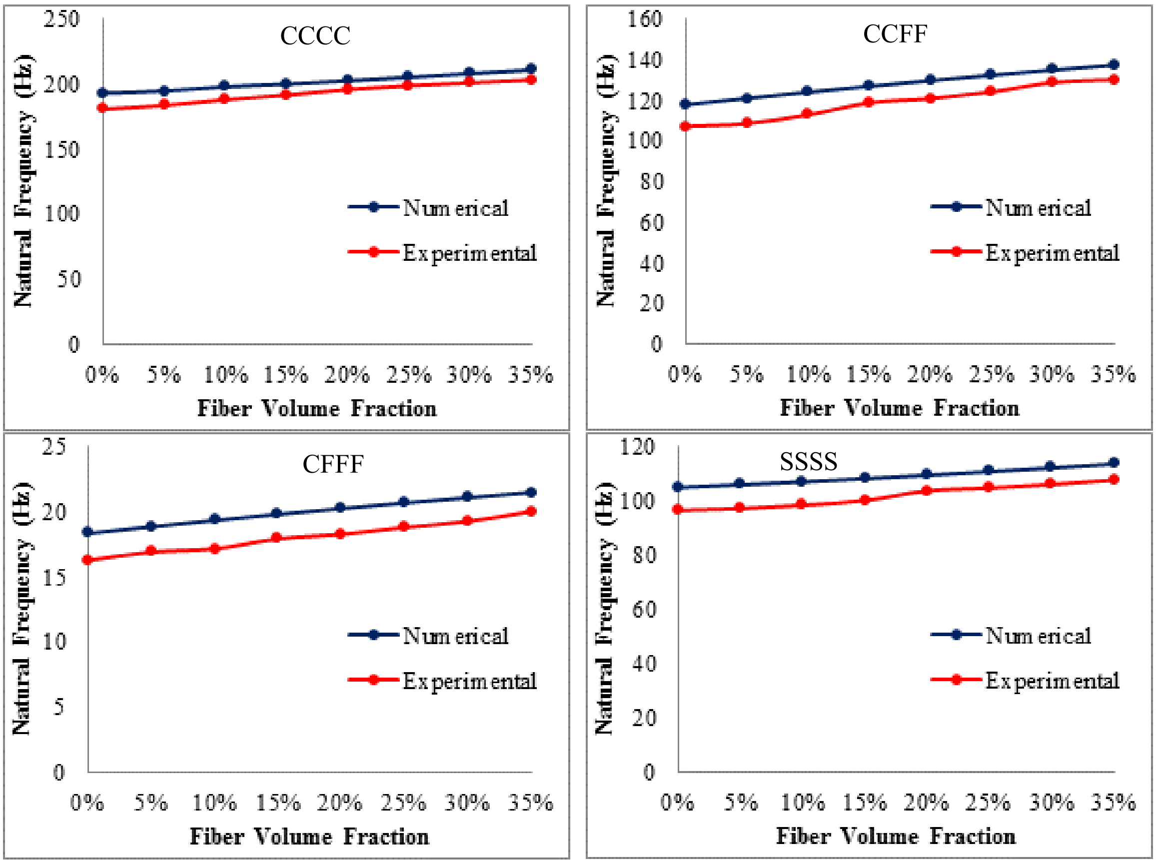

Figure 12. Relationship between volume fraction and natural frequency at each types of supported.

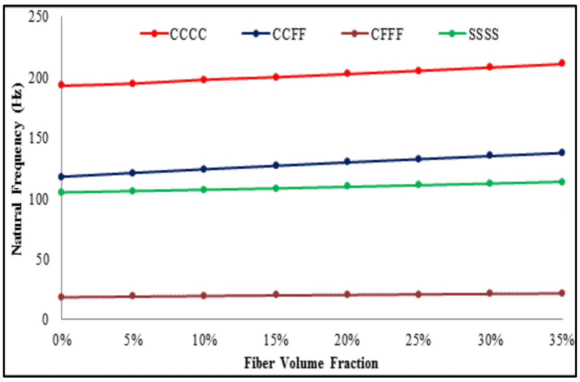

Figure 13. Type of supported for specimens influence volume fraction.

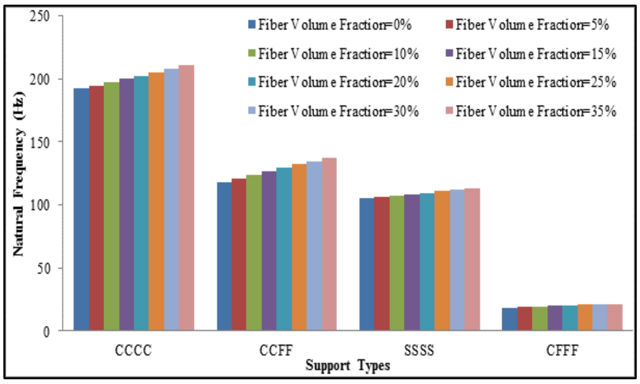

Figure 14. Type of supported for specimens with natural frequency at each volume fractions.

5. Conclusion

The significant conclusions in this study as:

1. The enforcement of composite materials by using sisal fibres can be presenting for many applications in the industry of plates or thin and results reveal prove this.
2. The best mechanical properties of specimens manufacture when high volume fraction sisal with less volume fraction of polyester, where give high modulus elasticity and maximum load, shown in tensile test. So there disparity between longitudinal modulus elasticity and transvers the last recorded reading less than the first.
3. Preferable natural frequency were appeared at specimens fixed kind clamped supported four edges (CCCC) she is same sample the best at trait tensile trait test.
4. When using of tensile test as boundary conditions to simulation analysing then obtain result was explained the better of specimen which was filled high volume fraction of fibre plant.
5. Comparison between simulation analysing and experimental work were conclusion the results of ANSYS program better than experimental work.
6. Specimen (CCCC) at volume fraction (35-65) % sisal - polyester was registered best results at practical aspect and numerical analysing can be considerate the ascendant specimen.

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