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Short Note

Experimental Natural Frequency Analysis of Moderately Thick Plates Made of Glass/Polyester Composite and Carbon

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Abstract: The experimental verification for the computational method sometimes varies due to numerous factors such as the manufacturing process and the materials' property change due to environmental aspects. In this work, we performed verification of experimental and computational evaluation of a hybrid composite moderate thick plate. The experiment was performed with simplistic approaches and without the advanced tools of preparing composite materials. This is due to the fact that most of the students in many developing countries around the world cannot have access to such equipment. As such, in this research, we are presenting cheap and easy preparation methods, with some details, for even equipment calibration and some tricks to attain a reliable composite structure for educational purposes. Moreover, the software and solvers used in this study are freely provided by the supplier for educational purposes. This study examined two methods for producing carbon and glass/polyester composite plates and discussed which one was best based on mechanical properties for different volume fractions, random stacking sequences, and ply angles (using OCTAVE's random estimation program). It also determined the three natural frequencies experimentally and with the aid of ANSYS. Less than 6% separated the experimentally determined natural frequencies from the calculated results.

Keywords: composite preparation; random fiber design; natural frequency; moderate thick plates

1. Introduction

During the last four decades, computer simulations of physical processes of composite materials have been expanded to very close values to real experimental results.[1][2][3][4][5][6][7][8] However, the manufacturing method may exert a variation in the verification of the results due to manufacturing process conditions and environments. This brief is aimed at examining manufacturing environmental effect on plate characteristics and evaluating the natural frequency for the application in hand (i.e., moderate thick composite plate). Fiber-reinforced composite materials are continuing to replace the conventional metals in primary and secondary aerospace structural elements owing to their best mechanical properties

Currently not just aerospace companies use composite in most of their work, cars companies, civil construction companies, sport equipment companies, etc. use composite in most of its works and its use efficient and face significant problems. Fiber-reinforced composite materials are continuing to replace the conventional metals in primary and secondary aerospace structural elements owing to their best mechanical properties

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The moderate thick plates are widely used in many things such as cars, aircrafts, civil constructions and the use of first-order shear plate theory give very good result in the design and optimization of moderate thick plates and commonly use in all over the world because of the behave of the moderate thick plates that make the neglecting of the effect of normal stress that perpendicular to the plate possible. There were several research covered the composite materials optimization and simulation/ experimental verification challenges. For example, Zafer Gurdal et al. [9], developed a programming solution using Fortran77 based on linear programming to find the optimal design for composite laminates for buckling constraints. Their work was based on a few cases to pike one of them as the best solution, and they noticed that the linear programming alone and with its simple form was not enough for the complex design of composite plates. Seung Jo Kim and Nam Seo Goo, [10] studied the use of a fuzzy environment to find the optimal design of laminated composite plates. Their goal was to minimize the weight design for composite laminate plates. For them, the fuzzy environment was satisfied for predesigned plates but with more lamina, the process gets more challenging and needs more time.

In 1993 T. Y. Kam et al. [11] published their paper that deals with dynamic programming with finite element method to find the optimum aspect ratio for laminated moderate thick composite plates that give maximum stiffness and low weight and find the natural frequencies for the plates. The FEM analysis gave an optimization process good tool for numerical analysis but the need for matrices made time not a dependent factor in their design. Dynamic programming is more powerful than linear programming but it is still an ordinary and classic method of optimization and not efficient as other evolutionary methods of optimization. Young Shin Lee et al [12], published their paper in 1994 on the optimal design of hybrid laminated composite plates with static and dynamic constraints and took ply angle and ply thickness as design variables. They use a linear programming method and nonlinear optimization problem for various hybrid rectangular composite plates with arbitrary boundary condition. C. Huang and B. Kroplin, [13] presented their research that deals with multi-objective function to minimize while satisfying constraints such as the structural deformation and the limits on design variables, and they performed the stiffness analysis by the finite element method for the optimal design of a rectangular thick and moderate thick laminated plate. For the multiobjective function, it was needed to ignore and cancel terms and not necessary (according to the researcher's viewpoint), and that makes the accuracy approaching optimum, not easy to achieve. Pavel Y. Tabakov [14] used to improve the genetic algorithm for multi-dimensional design optimization combined with the finite element method to find the best analysis for stacking laminates and show that the stability of evaluation in direct coding was less than for binary coding but the first coding was much fast in find solution.

Roberto Brighenti [15] used a genetic algorithm with a finite element method to perform the distribution and orientation of the laminates in the composite plates to have the best distribution for the desired bending load.

Erik Lund et al. [16], used discrete material optimization for laminate hybrid composite to find the optimal design for desired buckling loads.

A. N. Bambole and Y. M. Desai [17] published their paper that dealt with using a novel 27-node three-dimensional hexahedral hybrid-interface finite element model to analyze composite sandwich hybrid moderate thick and thick plates using minimum potential energy principle and optimize the thickness and orientation of laminates for bending in plates with multi-supporting conditions. B.

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Pluch et al. [18], combined the finite element method with a genetic algorithm to optimize composite hybrid moderate thick and thick structures with variable thickness.

M. Kemal Apalak et al. [19], studied the layer optimization and stacking sequence using a model of hybrid artificial intelligence method based on a genetic algorithm foundation and accelerated by using an artificial neural network with the use of finite element method as an evaluation technique to find the maximum fundamental frequency. They also made a numerical sequence to optimize layer sequences for maximum fundamental frequency using a genetic algorithm with an evaluation technique that Ritz-based layer wise. In this work, the author is addressing the manufacturing factor on the behavior of moderately thick hybrid composite plates and chosen the natural frequency characteristics and the verification factor.

2. Composite Plate Components

2-1 The Matrix

There is one type of resin used in this research to construct the models of hybrid composite plates that is; Polyester Resin (NCS 942), which is made by SRBS Company. The mixture needs 24 hours or more (according to environmental conditions) to solidify, and the mixture is done by 1 unit volume of hardener to 100-unit volume of resin.

2-2 The Reinforcement

The reinforcement of hybrid laminated composite plates has two different types of reinforcements which are: Fiberglass and carbon fiber. Fiberglass has many advantages, such as good physical properties, a high strength-to-weight ratio, and good resistance to chemical agents and it is relatively not costly. Using carbon fibers as other reinforcement associated with glass fibers to make hybrid composite plates, will increase the stiffness-to-weight ratio as well as improve the overall characteristics, but it will increase the overall cost.

2-3 Specimen Preparations

For composite plate making, there are many ways to do that, and each method or way is specified to a specific purpose, so mass production manufacturing differs from laboratory specimen made. Hand lay-up is the method used in this study to make laboratory specimens.

First, we need to find the exact density of the fibers by utillizing Eq. 1

$$D = {}^{w}\!/_{vol.} \qquad (1)$$

Where d is density, w and $vol.$ are weight and volume respectively (the densities which have been used in this work are shown in **Table (1)**), and that be by first determine of weight to amount of fibers then emerge if in distill water contained in beaker and find out the change in volume before and after fibers emerging and do that to matrix after solidification too.

Table (1) Densities of reinforcement that used

Material	Density (Kg/m^3)
Carbon Fiber	1509

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Glass Fiber	2340

It is worth to mention that the sensitive balance used was reevaluated using the measurement of 100 milliliter distal water as predetermine control test.

A suitable mold is one of the important items to do to make composite plates, it should be chemically stable for composite materials (no chemical reaction between mold and composite materials) and have good shape (and that depended on the method of making composites). To proceed with preparation, first, it should heat the mold to remove moisture the appropriate temperature used is about 100oC using the domestic oven for two minutes, and then (after it was cold) coat the inner sides of the mold and edges with an insulator material and waits for it to dry. The dray may take 25 to 55 minutes, so the use of a air heater (of temperature 70 degrees and speed of 0.1 m^3/sec.) to dry the molds is saving time.

Another method used to prevent sticking of made plates with molds that using wax. The mold heated and put wax on its warm surface, the wax melted and spread out all over the mold surface. The heating is done using the oven. The second step is to cut fibers bands within the range of the wanted length, and the third step is to mix the resin's components (monomer and polymer). The mixing must be good and fast to assure the full distribution of hardener all over the resin material to result in a good and homogeneous polymer. Then paint the first layer of resin inside the mold then spread the fibers carefully and press them gently, then put the second layer of resin and then fibers until having the desired composite, that is the fourth step. The next step was made by two ways:

-The first used way

The cast of laid composite layers was covered by a 6 mm glass sheet the weight of the glass sheet is and pressed by using 50 kilograms of athletics weights and after 72 hours in an open atmosphere (the made of samples done in a ranged of temperatures between (60-140) ^{o}C at January the thirteen so the range of preparing time changed according to temperature and environmental conditions).

-The second used way

Use the experimental device to precede the solidification of the composite plate.

The mold press is to make the (Hardener) loss as minimum as possible and to force air bubbles to leave the pattern using an insulated plate of glass (6mm) that weighs about 10 kilograms and put inside the sucking chamber to ensure evacuation of air bubbles, as well as heating sucking chamber. The heating is done by using a secondary container with hot water flowing in it from the electric boiler (30 litter water capacity) to control temperature.

The sucking chamber is a pressure pot connected with a fitted 7.5 cm steel tube after removing the one-way valve of the pot and sealed with epoxy steel (manufactured by MJM Company), wrapped with rubber of a tube of Bike then wrapped by medical gypsum.

Use a medical sucker (manufactured by MEDAP, Model P820, West Germany) as a device to induce negative pressure in the pot using -0.2 bar according to its gage see Fig. (1).

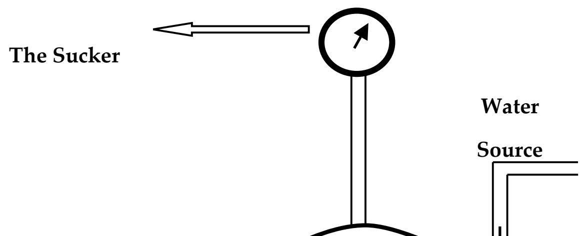

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Fig. (1) Schematic diagram for sucker device

The sucker operation is put on and off with a timer of 5 on and 5 off minutes alternatively to avoid damage to the sucker. The pressure pot is put in a plastic sink which is used as a hot bath to keep the pressure pot at a temperature (of 50-60) o C. Providing the sunk with two plastic taps one above and one below to provide a current of hot water flow 150 drops per minute to keep the path hot at (50-60) ^{o} C for 48 hours. The plastic sunk is covered by double layers of plastic sheets used in agricultural greenhouses and from around and below, the plastic sank wrapped with a wool blanket. Use room (2*2 square meter area *3-meter height) provided with a square window (45 cm side length) closed with a glass sheet and fitted with industrial cork used in packing fridges then sealed of peace of clothing. The room is warmed by domestic 1000-watt IR laps electric heater according to the availability of electricity. The lower space of the door and key opening is filled with ordinary domestic sponges. After 48 hours the specimen is ready to extract from the mold and that is by easy depending on a good coating of insulator and mold shape. The cutting of samples test was made using an angel grinder manufactured with the use cutting wheel (100 mm, A-30-S), and an available drill with a grinding head. The wasted material is difficult to be calculated because of -manual processing -shattering and spreading of the particles of the material.

3. Mechanical Properties Determination

The tensile test device used in this research was featured with drawing data. The strain gauge device used is associated with the tensile test apparatus. The strain gauge that was used manufactured by omega Company was made of Nickel foil and its resistance was 25 ohms with a tolerance of around 25 ohms, the calibration was done with specific known mechanical characteristics steel specimen at a temperature of woke and it was about 25^{o}C. The cleaning of the surface of the composite specimen is required with a special cleaner liquid. After cleaning the envelope of strain and gage was removed and stamped the gage slowly and takes a few hours to inshore good adhesion then the test began.

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The nine independent elastic material properties required for a 3D lamina-based analysis were listed as (E1, E2, E3, G12, G13, G23, υ12, υ13, and υ23). Preparing tensile test samples based on ASTM 2003 standard (D638) to evaluate young modulus for all three directions (E1, E2, E3). The first sample set was cut with the direction of fiber to calculate E1, and a second set was cut perpendicular to it to calculate E2.

For the tensile test the apparatus draws a relation between the calculated force and its action representing elongation, and the original area and length are known (Eq.2)

$$\sigma = \frac{P}{A_o} \tag{2}$$

Where

F=force in Newton and A_o area in m^2

$$\varepsilon = \frac{\Delta L}{L_o} \tag{3}$$

Where

ΔL= change in length and Lo is original length in m

So

$$\mathrm{E} = \frac{\sigma}{\varepsilon} \tag{4}$$

An assumption used to calculate E3 that E2 equal E3 , so they are both perpendicular to fibers direction. A strain gages used associated with tensile test by put it in 90o to tensile direction for calculating (ε2) to find out Poisson's ratio (υ12), (υ23)

Where

$$\upsilon = \frac{\varepsilon_{lateral}}{\varepsilon} \tag{5}$$

The value of (υ12) assumed equal to (υ13) . Equation (6) used to find G12

$$G_{12} = \frac{1}{4/E_{45^o} - 1/E_1 + 2\upsilon_{12}/E_2} \tag{6}$$

Where E45 is modulus of elasticity to sample cut with angle 45o from fibers direction. The assumption of equality of G12 and G13 used in this work, and G23 could be found from equation (7)

$$G_{23} = \frac{E_2}{2(1+\upsilon_{23})} \tag{7}$$

4. Vibrational Tests

A frame made to achieved simply supported case. The frame consist of two sharp knife edges jaws and hold together by four screws

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Using the results of optimizations programs, the hybrid laminated composite plates constructed, then using home made force vibration device to vibrate the plate with known frequencies and recording the response to find out first three natural frequencies. Use OCTAVE based wave generation system to generate controlled sin wave goes to the vibrator in addition to build recording system to record the respond wave induced in simply supported plate. The recording done by home made small micro phonic recording system stick on upper middle side of the plate

Test done by generate waves and record it to out put files as audio files. The generations raise in frequency by 100 Hz every step, and then comparing outputs using audio analyzer software to find out at what frequency the amplitude of recording files is the largest one, so the frequency is the natural frequency. The estimation of starting frequency and end frequency based on ANSYS results.

5. Model Formulation in ANSYS Program

Building a finite element model requires more of an ANSYS 5.4 use's time than any other part of the analysis. First, job name and analysis title are specified then preprocess is used to define the element types, element real constants, material properties, and the model geometry.

5-1 Defining Element Types

The ANSYS element library contains more than 100 element type. The element type determines among other thing:

1 - The degree of freedom set

2 - Weather the element lies in two dimensional or three dimensional space

The element type that used in this work was SHELL99 (see ***Fig. (2)*** and for more information see ANSYS help)

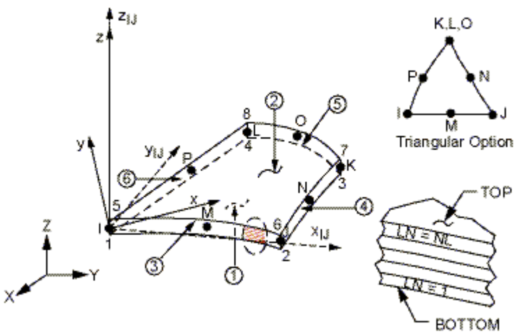

Fig. (2) ANSYS element type that used

5-2 Defining Element Real Constants

Element real constants are properties that depend on the element type, such as cross-sectional properties of a beam element, for example area, moment of inertia, initial strain, height, etc.

5-3 Defining Material Properties

Depending on the application, the material properties may be:

1. Linear or non-linear
2. Isotropic, orthotropic, or anisotropic

3. Constant temperature or temperature depended.

5-4 Creating the Model Geometric

Once the material properties have been defined, then generating a finite element model–nodes and elements that adequately describe the model geometry. With solid modeling, the geometric shape of model is described, and then instructs the ANSYS program to automatically mesh the geometry with nodes and elements, and then control the size and shape of the elements that the program creates.

5-5 Apply Loads and Obtain the Solution

In this step, the solution processor is used to define the analysis type and analysis options, apply loads, specify load step options, and initiate the finite element solution**.** The main goal of a finite element analysis is to examine how a structure or component responds to certain loading conditions. The element used SHELL99 (fore more descriptions see ANSYS help). The mathematical model was FSDT with Navier's solution

6. Results

This section deals with experimental and numerical results and discussion which are found out in this thesis as follows:

-Mechanical properties results of composite plates experimentally
-Optimal design results of composite plates numerically through three programs
-Natural frequencies results of composite plates experimentally and numerically with comparison.

Tensile strength in the fiber direction a unidirectional fiber-reinforced composite material deforms as the load increases in the following four stages, more or less, depending on the relative brittleness or ductility of the fibers and the matrix:

A) Both fibers and matrix deform elastically
B) The fibers continue to deform elastically, but the matrix deforms plastically
C) Both the fibers and the matrix deform plastically
D) The fibers fracture followed by fracture of the composite material

6-1 Mechanical Properties Results

As said before, two different ways used to prepare hybrid composite plates, and they discussed in chapter four. The test done to samples of plates made by the two mentioned ways and using testing apparatus.

In this research three volume fractions used to achieve best mechanical properties and they are 30%, 40%, 50%, and using the necessary methods.

6-1-1 First Method of Preparing Group

Taking three volume fractions percentage, gave the following results

Table (2) Mechanical properties of first method of preparation for 30% volume fraction

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Glass Fibers\Polyester		Carbon Fibers\ Polyester	
E1(GPa)	23	E1(GPa)	109
E2(GPa)	7.2	E2(GPa)	2.74
E3(GPa)	7.2	E3(GPa)	2.74
υ12	.39	υ12	.32
υ23	.43	υ23	.44
υ13	.39	υ13	.32
G12(GPa)	2.93	G12(GPa)	.724
G23(GPa)	2.83	G23(GPa)	.916
G13(GPa)	2.93	G13(GPa)	.724

Table (3) Mechanical properties of first method of preparation for 40% volume fraction

Glass Fibers\Polyester		Carbon Fibers\ Polyester	
E1(GPa)	29.73	E1(GPa)	145.8
E2(GPa)	9.06	E2(GPa)	3.46
E3(GPa)	9.06	E3(GPa)	3.46
υ12	.35	υ12	.3
υ23	.4	υ23	.42
υ13	.35	υ13	.3
G12(GPa)	3.73	G12(GPa)	.96
G23(GPa)	3.62	G23(GPa)	1.213
G13(GPa)	3.73	G13(GPa)	.96

Table (4) Mechanical properties of first method of preparation for 50% volume fraction

Glass Fibers\Polyester		Carbon Fibers\ Polyester	
E1(GPa)	22.8	E1(GPa)	182.33
E2(GPa)	6.	E2(GPa)	4.33
E3(GPa)	7.1	E3(GPa)	4.33
υ12	.38	υ12	.31

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υ23	.42	υ23	.43
υ13	.38	υ13	.31
G12(GPa)	2.91	G12(GPa)	1.2
G23(GPa)	2.8	G23(GPa)	2.73
G13(GPa)	2.91	G13(GPa)	1.2

6-1-2 Second method of preparing

Table (5) Mechanical properties of second method of preparation for 30% Volume Fraction

Glass Fibers\Polyester		Carbon Fibers\ Polyester	
E1(GPa)	24.1	E1(GPa)	111.8
E2(GPa)	7.1	E2(GPa)	2.18
E3(GPa)	7.1	E3(GPa)	2.18
υ12	.32	υ12	.28
υ23	.38	υ23	.4
υ13	.32	υ13	.28
G12(GPa)	3.1	G12(GPa)	.896
G23(GPa)	2.72	G23(GPa)	.92
G13(GPa)	3.1	G13(GPa)	.896

Table (6) Mechanical properties of second method of preparation for 40% Volume Fraction

Glass Fibers\Polyester		Carbon Fibers\ Polyester	
E1(GPa)	32.133	E1(GPa)	149.06
E2(GPa)	9.46	E2(GPa)	2.906
E3(GPa)	9.46	E3(GPa)	2.906
υ12	.32	υ12	.28
υ23	.38	υ23	.4
υ13	.32	υ13	.28
G12(GPa)	4.13	G12(GPa)	1.19
G23(GPa)	3.62	G23(GPa)	1.22
G13(GPa)	4.13	G13(GPa)	1.19

Table (7) Mechanical properties of second method of preparation for 50% Volume Fraction

Glass Fibers\Polyester	Carbon Fibers\ Polyester

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E1(GPa)	40.16	**E1(GPa)**	186.33
E2(GPa)	11.83	**E2(GPa)**	3.633
E3(GPa)	11.83	**E3(GPa)**	3.633
υ12	.34	**υ12**	.31
υ23	.4	**υ23**	.43
υ13	.34	**υ13**	.31
G12(GPa)	5.16	**G12(GPa)**	1.493
G23(GPa)	4.55	**G23(GPa)**	1.533
G13(GPa)	5.16	**G13(GPa)**	1.493

6-2 Vibration Characteristics Results

ANSYS program used to find out the natural frequencies and modes for prepared plates and using the device that discussed in section three, and the results are:

Stacking sequence and Ply angles

Table (8) Three natural frequencies numerically and experimentally

Theoretical first three natural frequencies (Hz)			*Experimental first three natural frequencies (Hz)*		
6566.2	10333	10431	6400	10000	10300
7066.7	11165	11182	7000	11000	11300
6566.1	10378	10386	6500	10300	10300
6835.7	10744	10872	6700	10500	10700
6706.5	10527	10680	6400	10200	10300
6835	10746	10871	6400	10200	10300
6835.7	10799	10818	6600	10500	10700
6955.8	10927	11083	6800	11000	11100
6706	10571	10635	6700	10500	10800

7. Discussions

The experimental results taken for two kinds of plates were prepared in two different ways and tested by tensile test apparatus for each tensile test it took the average of five specimens, and other mechanical properties were calculated using the equations (5),(6). It can show from **Table (2)** to **(7)** that the brittleness increases with the increasing of the volume fraction and for more discretion, the relation between chosen characteristics for the first plate preparation method was taken as an example (see ***Figs. (4) and (5)***)

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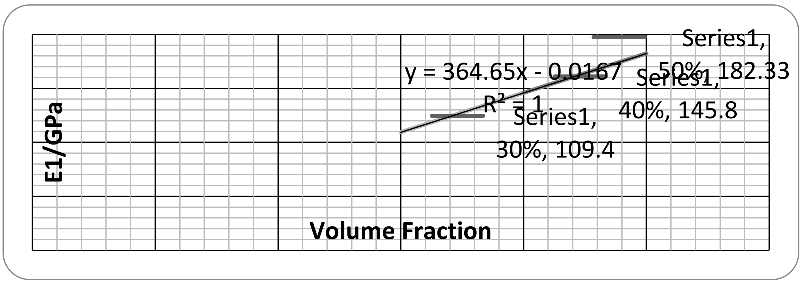

Fig. (4) Young modulus relation with volume fraction variation

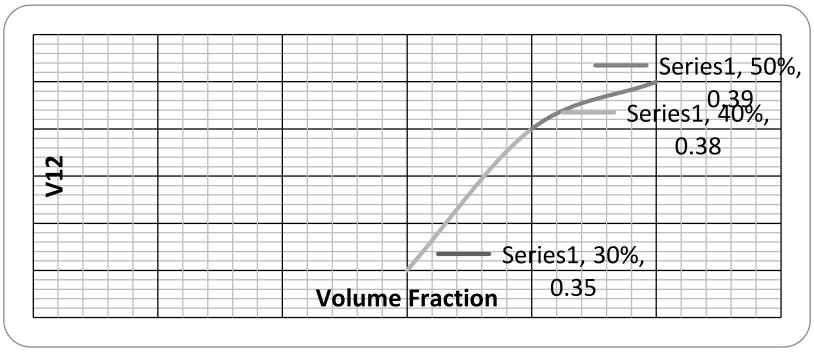

Fig. (5) Poisson's ratio relation with volume fraction variation

The second way of preparation gave better results than the first way, because of negative atmospheric pressure that help evacuate air from the lamina. The mechanical properties of the second plate preparation method (that has been noticeable in Tables ((2) to (7)) are better than the first method of preparation of plates, so the mechanical properties database was chosen in optimization programs of the second plate preparation method. The effect of volume fraction on mechanical properties is obvious from the results tables (Table (2) to (7)), the increase in volume fraction increases the value of strength and also increases Poisson's ratio. The program's database builds on a volume fraction of 30% so it was more ductile and that gives it more flexibility in response to loads compared with other volume fraction plates.

Exciting frequencies, (natural frequencies), are a property of the system. Amplified vibration, called resonance, occurs when a generated frequency is tuned to a natural frequency. An exciting natural frequency is a resonant condition. Resonance in rotating machinery is the same as an amplifier in electronics. Therefore, excessively high vibration amplitudes are often encountered. ANSYS program is used to identify and calculate natural frequencies, and mode shapes. A vibrator was used to induce natural frequencies in prepared plates that were analyzed using ANSYS as discussed in chapter four. The results showed high values of natural frequencies that agreed with ref. [20-27]. The difference in natural frequencies results between experimental and theoretical values of about 6%.

9. Conclusions

Following are the main summarized conclusions drawn from this paper:

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1- It could be seen that the second method of preparing of composite plates was more efficient from the first way, and that could be because of the effect of the negative atmospheric pressure that make lose of air bobbles more easy and efficient.
2- During putting loads on plates in the first method the layers and fibers moved clustering in places, so load distribution on all over plate been unequal and made it more weaken.
3- The difference between the experimental and numerical finding of natural frequencies were less than 6%. The high value of natural frequencies could be noticed, because of the complex composition of plates in the microstructure, so every fiber and even the chain of matrix materials give a special response in its direction and the wide verity of play angle gave its this specialty.
4- The mechanical properties of composite plates are used in this thesis which has been found out experimentally and compared with its relevant used in **ref. [28]**, found almost same behaviors.

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