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Effect of chitosan/carbon nanotube fillers on vibration behaviors of drilled composite plates

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Abstract. The effect of Chitosan (CS), Carbon Nanotube (CNT) and hybrid (CS-CNT) fillers on the natural frequency of drilled composite plate is investigated by experimentally in this study. The numerical validation is also made with a program based on Finite Element Method (SolidWorks). Nine types filled and one neat composite plates are used in the study. The fillers ratios are 1% CS, 2% CS, 3% CS, 0.1% CNT, 0.2% CNT, 0.3% CNT, 1% CS+0.3% CNT, 2% CS+0.3% CNT, 3% CS+0.3% CNT. The specimens cut to certain sizes by water jet from the plates 400 mm x 400 mm in dimensions. Some of them are drilled in certain dimensions with drill. The natural frequency of each specimen is measured by the vibration test set up to determine the vibration characteristic. The vibration test set up includes an accelerometer, a current source power unit, a data acquisition card and a computer. A code is written in Matlab® program for the signal processing. The study are investigated and discussed in four main points to understand the effect of the fillers on the natural frequency of the composite plate. These are the effect of fillers contents and amounts, orientation angles of fibers, holes numbers and holes sizes. As results, the natural frequency of the plate with 1% CS and 0.1% CNT hybrid filler is lower than those of the plates with other fillers ratios for 45° orientation angle. Besides, in the composite plate with 0° orientation angle, the natural frequency increases with increasing the filler ratio. Moreover, the natural frequency increases until a certain hole number and then it decreases. Furthermore, the natural frequency is not affected until a certain hole diameter but then it decreases.

Keywords: composite plate; carbon nanotube; chitosan; filler; vibration

1. Introduction

For decades, the search for alternative materials against conventional metals has continued and usage of composite materials in especially aerospace, automobile, sporting goods, defense and construction fields is constantly increasing Wambua (2003). The composite materials are favorited due to their enhanced properties, which come from mixing different reinforcement and filler to a binding ambience Wambua (2003) and with the addition of additive materials in these days. Addition of nanofillers into the matrix forming the composite has been reported to enhance the mechanical properties and performance of composite materials Çallioğlu *et al.* (2011), Sridharan *et al.* (2016). The fillers are clays, hydroxyapatite, metal nanoparticles, and carbon nanotubes Wu *et al.* (2017). Moreover, the addition of nanofillers in interface of composite lamina can improve the bonding between fiber and matrix and called as nano-engineered composites (NECs) Garcia *et al.* (2008), Yamamoto *et al.* (2012).

Chitosan (CS) is extracted from crustaceous shells such as crabs, shrimp and prawns and in solid form, it is a crystalline polymer Wan *et al*. (2009). It is one of the most widely used structural polymers for biomedical applications because it has many favorable properties, including biocompatibility, biodegradability, antimicrobial activity, and a hemostatic characteristic Uragami and Tokura (2006), Dumitriu (2002). Some insect cuticles, squid beaks and shrimp shells have a higher modulus and hardness than most commercial plastics Vincent and Hillerton (1979), Miserez *et al.* (2008). Oh and Hwang (2013) examined the two mechanistic effects of L-3,4-dihydroxyphenylalanine, the catechol found in both insect cuticles and squid beaks, for improving the mechanical properties and the water absorption of a chitosan film in the presence of water and also adding Carbon Nanotubes (CNTs) to composite materials is one of the most promising routes to improvement multi-functionality to structures without significant weight impact Baur and Silverman (2007), Breuer and Sundararaj (2004). Liu *et al.* (2017) developed films from chitosan derivatives, grafted five kinds of hydroxybenzoic acids, by casting. They showed that hydroxybenzoic acid-g-CS films were better UV light and moisture barrier properties and higher tensile strength and elongation at break as compared with CS film. Gürkan and Cebeci (2016) presented a parametric study that the most significant parameters affecting the interlaminar shear strength results were type of epoxy, fabrication procedure and CNT loading. They have achieved an enhancement at the mechanical properties. Joshi and Dikshit (2011) investigated influence of the inter-ply characteristics of polymeric prepreg composites on their interlaminar fracture toughness and the overall performance. They observed that

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the addition of multi-walled carbon nanotubes (MWCNTs) in between carbon fiber reinforced polymer (CFRP) prepreg plies helps in strengthening the interface. Sridharan *et al.* (2016) investigated the machinability of jute fibre reinforced nanophased polymer composite and they reported the influences of matrix, fiber surface modification and nanofiller (graphene) on delamination. Kwon *et al*. (2016) fabricated nanocomposites utilizing the out-of-date prepreg coated with CNT nanofillers by a sheet molding method. They showed that the mechanical and interfacial properties of nanocomposites were improved according to neat carbon fiber/epoxy composites.

Wu *et al*. (2017) proposed an alternative way to produce graphene nanosheet/chitosan composites. They demonstrated that the mechanical properties (modulus and hardness) and electrochemical behavior (redox peak current) of these composites were significantly improved. Wang *et al*. (2005) showed significantly an improvement in mechanical properties of the CS/CNTs nanocomposites. Zhang and Huang (2016) declared that the CNT–CS assembly can be opened the way to the preparation of nanocomposites. So, they prepared nanocomposites with high mechanical properties by incorporating chitosan-grafted carbon nanotubes (CS–CNTs) in the epoxy resin. They mentioned that the chitosan played a very important role as connectors between the CNTs and epoxy resin. Al-Sagheer and Muslim (2010) fabricated Chitosan-Silica (CS-Si) hybrid films by sol-gel process using tetraethoxysilane as precursor. They showed that there was an increase in the glass transition temperature and the storage modulus by increasing silica content. Ahmed *et al.* (2017) prepared chitosan-based nanocomposite films by blending crab shell chitosan and graphene oxide (GO) nanosheets in solution at certain concentrations to enhance the thermo-mechanical properties of food packaging materials. They found that the addition of GO to CS was improved tensile properties and glass transition temperature and significantly influenced the dielectric properties as it did not influence the mechanical rigidity of the nanocomposite film blend.

Chakrapani *et al*. (2016) developed a nonlinear forced vibration model for carbon fiber reinforced composite beams by varying fiber orientations and laminate sequences. They observed that it was good agreement for 45° and 90° fiber orientations, but not for 0° fiber orientation as analytical results compared with the experimental results. Demir (2016) investigated the free vibration and damping characteristics of composite beams with holes. He found that the natural frequency decreases with increasing hole diameter but increases very little with the distance of the hole away from the clamped end. Al-Waily and Ntayeesh (2017) investigated an effect of adding multi-walled carbon nanotubes (MWCNTs) on the vibration characteristic, such as the natural frequency, mode shape, the response and mechanical properties of composite plate. They showed that the increase in nano particle addition was increased the natural frequency and elasticity modulus of composite plates. Chang (2017) dealt with the statistical dynamic behaviors of nonlinear vibration of the single-walled carbon nanotubes (SWCNTs) with nonlinear damping and random material properties under longitudinal magnetic field. In that study, the dynamic responses of nanotubes, such as the mean values and standard deviations of the midpoint deflection were computed. Chaudhari *et al.* (2017) studied non-linear free vibration behavior of elastically supported carbon nanotube reinforced composite beam subjected to thermal loading with random system properties. They compared the results of the present approach with the results in the literature. Rafiee *et al.* (2018) investigated experimentally the vibration and damping characteristics of epoxy composites reinforced by pristine and functionalized MWCNTs for potential use as integral passive damping elements in structural composite applications. Their results indicated that the damped natural frequencies of filled composites increased by adding MWCNTs up to a certain value, and decreased at higher MWCNTs content. Albooyeh (2019) investigated the effect of addition of MWCNTs on the vibration of Short Glass Fiber reinforced polypropylene and the polypropylene foam composites. He indicated that the damping factor and natural frequencies of the reinforced polypropylene and Short Glass Fiber / reinforced polypropylene composites increase with addition of MWCNTs to the samples.

In this study, vibration behaviors of the composite plates with adding CS, multi-walled carbon nanotubes (MWCNTs) and CS-CNT hybrid are investigated. The studies of the vibration behaviors on the composite plates with fillers, especially CS and CNT, are few in the open literature. Further, the effects of the fiber orientation, numbers of holes, diameters of holes (hole sizes), filler contents and filler ratios on vibration behaviors of the composite plates with nano fillers are investigated. It is found that the natural frequencies values obtained from experimental data and numerical solutions are in a good agreement. Similar to the above mentioned literature survey, it is found that the natural frequency increases with the increase in the filler ratios. However, it is not encountered study on the vibration behaviors of the filled composite plates with cut-out, in the open literature.

2. Materials and models

2.1 Production of the filled composite plates

The filled composite plates are produced by using F-RES 21 epoxy resin, Unidirectirional Glass Fabric and CS and CNT filler materials in different ratios by weight. As the filler ratios for CS are range from 1% to 3% in increments 1%, they for CNT are range from 0.1% to 0.3% in increments 0.1%. Hybrid filler ratios are taken as 1% CS-0.3% CNT, 2% CS-0.3% CNT, 3% CS-0.3% CNT. To compare the material properties of the neat composite with that of the filled composites, neat composite plate is also produced. The properties of the materials used and composite plate production are described below.

Filler materials are chitosan from shrimp shells, 88% deacetylated (Sigma-Aldrich, USA) and small multi walled carbon nanotubes (S-MWCNT-OH) (Ege nanotek, Turkey), which has 98% purity, wt 1.76% -OH content:, 10-20 nm external diameter, 5-10 nm internal diameter, 0.5-2.0 μm

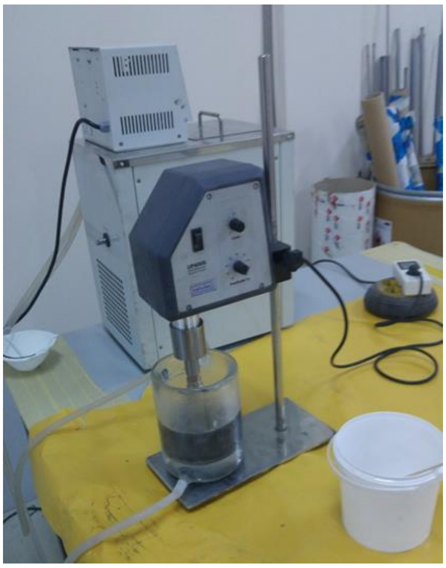


Fig. 1 Ultrasonic mixer with cooled water circulator

Fig. 2 Cut out from the composite plate of the specimens by water jet

length.

Unidirectional Glass Fabric are 330 gr/m^2 areal weight (1200 tex Glass Fiber in 0° direction, 68 tex Glass Fiber in 90° direction, 76 dtex Stich fiber).

A solvent type prepreg resin system is used as a matrix, F-RES 21 (Fibermak Composites, Turkey). It has low viscosity and high fiber wetting properties. Moreover, it has a wide curing range from 90°C to 150°C. Hardener is F-

HARD 22 (Fibermak Composites, Turkey). Weight mix ratio for resin and hardener are 21/100. Gelation time is 30-60 minute at 80°C.

Fillers added to the epoxy resin were distributed homogeneously in the epoxy resin by means of an ultrasonic mixer (Hielscher Ultrasound Technology UP400S, Germany) because fillers structurally tend to coexist in the ultrasonic mixing process. The fillers agglomerated were separated and dispersed in the epoxy resin by the sound waves. Heat generated during mixing prevents the homogeneous distribution of fillers in the resin. Therefore, heat in the mixture was prevented by using a cooled water circulator (Labo SM3, Turkey) and so, a homogenous distribution of the fillers has been achieved. During mixing process, the temperatures of the resins with fillers were kept under control so that it did not exceed 45 °C. Therefore, the mixing process was in the form of mixing for 15 minutes, then 5 minutes resting and then mixing again for 15 minutes, and is shown in Fig. 1 (Kavla, 2019).

Glass fiber fabrics were impregnated with resin by hand lay-up method and so, prepregs were formed. Prepregs were kept at room temperature for 5 days and cut to desired sizes. The silicon papers on the upper and lower surfaces of the cut prepreg fabrics were separated. Fabrics of the same size and fiber orientation were superimposed to obtain the desired thickness of mm Prepreg plates covered with silicone paper were placed under the press. The plates were cured under 6 bar pressure at 120°C for 1 hour. The heating system was then turned off and the plates were allowed to cool to the room temperature until almost 1 hour to avoid distortion of the composite plates under the press. In this way, composite plates of 9 layers, 400 mm x 400 mm in dimensions, about 2.6±0.1 mm thickness were produced at different filler ratios. The volumetric ratio of fiber varies between 75% (for neat) and 64% (for 1% CS + 0.3% CNT). The edges of the composite plates were properly trimmed by a circular saw. And then, to exactly the same and correct of the specimen dimensions, specimens of 180 mm x 24 mm were cut out from the composite plate by water jet, as shown in Fig. 2.

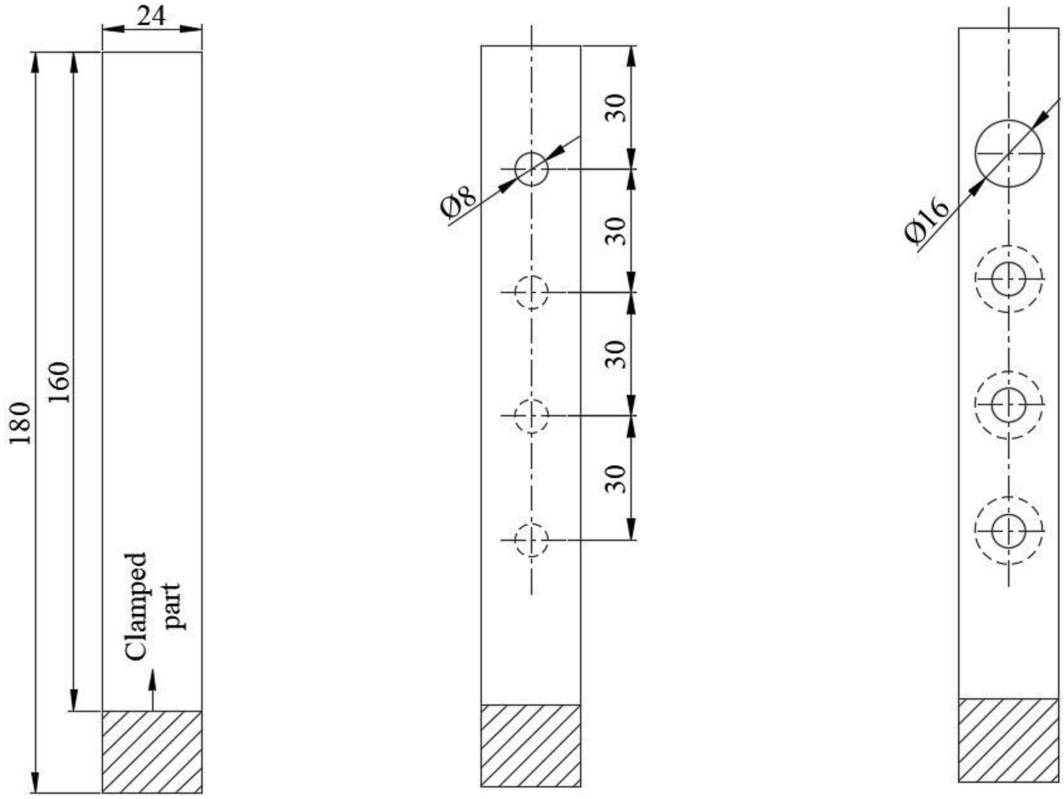
The material properties of the composite plates with/without fillers are given in Kavla (2019).

2.2 Vibration test

In order to see the effects of fillers, orientation angles of fibers, number and size of the hole, the specimens shown in Fig. 3 are prepared. It can be seen from Fig. 3(a) that width and the length of the specimen are 24 mm and 180 mm, respectively. But, below section of 20 mm in the longitudinal direction of the test specimen is clamped during the vibration test. So, the specimen length is actually 160 mm. The thickness of the specimen is about 2.6 mm. Effects of filler's contents and ratios and orientation angles on vibration behaviors of the composite specimens are obtained by using those specimens.

To see the effect of the number of the hole, a hole with 8 mm diameter is drilled at a distance of 30 mm from the free edge of specimen as shown in Fig. 3(b). Then, the second, third and fourth holes are drilled respectively at intervals of 30 mm. The diameters of all holes drilled are 8 mm. As for the effect of hole size, the diameters of the 4 holes drilled previously are expanded from 8 mm to 16 mm. This process is shown in Fig. 3(c).

Experimental set up is shown in below. It can be seen form Fig. 4 that one edge of the specimen is clamped with a fixture. The specimen is clamped to the fixture as perpendicular to the surface due to get rid of the effect of gravity. The accelerometer (3035A1G, Dytran Instruments, USA) is connected to near the clamped end of the specimen. As a result, the weight effect of the accelerometer is minimized. The weight of accelerometer is 2.3 g. A rigid



(a) Non-drilled specimen (b) Increasing in the number of hole (c) Expansion the hole diameter

Fig. 3 Mixing process

metal profile is attached to the fixture to give the same initial amplitude to the specimen for vibration. The free end of the specimen bends towards the metal profile, and then the specimen is released. So, the composite specimen vibrates freely. Signals transmitted from the accelerometer are amplified via a current source power unit (4102C, Dytran Instruments, USA). Then the signal is taken to the computer by means of data acquisition card (NI USB 6008, National Instruments, USA).

In order to process the signal, a code is written in MATLAB program (MathWorks, USA). The code converts the signal from the time domain to the frequency domain using the Fast Fourier Transform Method. The peak value of the curve in the frequency domain corresponds to the natural frequency.

The vibration test was repeated three times for each specimen to obtain accurate data. Then arithmetic mean of these three values is taken.

3. Results and discussion

Four types of effects are taken into account in the preparation of specimen and performing the experiments. These are the effects of the filler's contents and ratios, the orientation angles of the fibers, the hole numbers and the hole sizes.

Fig. 4 Experimental set up

3.1 Effects of Fillers

In this study, three kinds of fillers are added into the resin. These are CS, CNT and hybrid mixture obtained by mixing these two fillers in a certain ratio.

3.1.1 Chitosan filler

In order to see the effect of CS filler on the natural frequency of the composite plates, the amount of CS into the resin is increased from 1% to 3% by increment 1%. In addition, the natural frequency of the neat composite plate is also obtained for comparison.

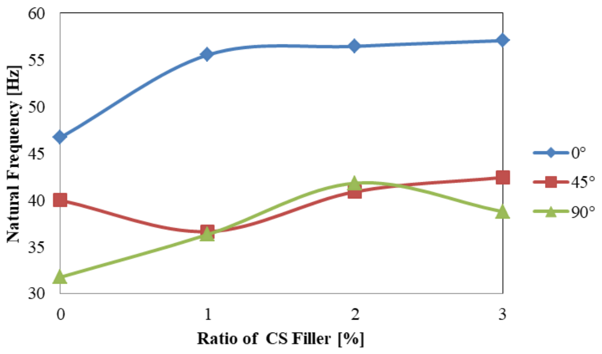


Fig. 5 Effect of CS filler on natural frequency

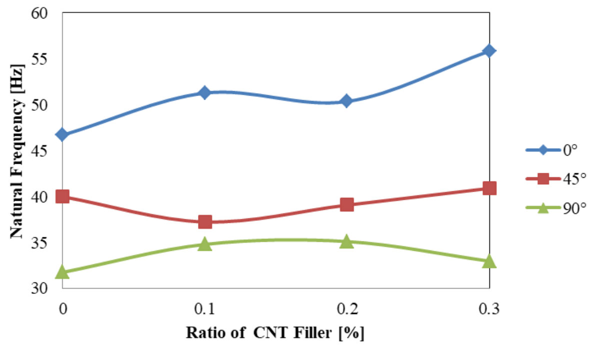


Fig. 6 Effect of CNT filler on natural frequency

The variation in the natural frequency according to the ratio of CS filler is shown in Fig. 5. The curves are given in the figure for different orientation angles of fibers. It can be seen from the figure that the natural frequency increases with increase in the amount of CS for the plate with 0° fiber orientation angle. But this increase is particularly significant in the range of 0-1% of the CS filler ratio. In the figure, the increase in the ratio of CS filler up to 3% does not affect the natural frequency too much for the plate with 0° fiber orientation angle.

The curve characteristic is changed for the plate with 45° fiber orientation angle. Unlike the plate with 0° fiber orientation angle, the natural frequency decreases in the range of 0-1% of the CS filler ratio, then it increases by the increase from 1% to 3% of CS filler ratio.

The curve characteristic is also changed for the plate with 90° fiber orientation angle. The natural frequency increases with increasing CS filler ratio up to 2%. Then it decreases a little value.

When three of the curves are examined, it is observed that the plate with 45° fiber orientation angle is not affected much by the increase in the ratio of CS filler. For the composite plate with 45° orientation angle, the natural frequencies of the neat plate and 2% CS filled composite plate are almost the same. However, in the composite plates with 0° and 90° fiber orientation angle, it is seen that this case is not the same.

3.1.2 Carbon nanotube filler

The effect of the CNT filler on the natural frequency is represented in Fig. 6. To see the effect of CNT filler on the natural frequency, the ratio of CNT is increased from 0.1% to 0.3% by increment 0.1%. The natural frequencies are obtained for the plates with 0°, 45° and 90° fiber orientation angles and they are compared with their corresponding neat plates (0% CNT filler ratio).

Although the curves characteristics obtained for CNT filler are similar to those for CS filler, small differences are observed. The natural frequency increases by increasing the ratio of CNT filler in the plate with 0° fiber orientation angle. Comparing the effects of CS and CNT fillers on natural frequency, the natural frequency remains almost constant after 1% CS filler ratio, but it continues to increase by increasing CNT filler ratio for the plate with 0° fiber orientation angle. The natural frequency obtained for the 0.3% CNT filler is almost equal to the one obtained for 1% CS filler.

When the curve characteristic of the plate with 45° fiber orientation angle in Fig. 6 is examined, it is almost the same as that of the plate with CS filler. The natural frequency first decrease in the range of 0-1% of the CNT filler ratio, and then it increase.

As for the natural frequency of the plate with 90°, firstly it increases and then decreases with the increase in the ratio of CNT filler. Unlike the CS filler, there is not much increase in the natural frequency.

3.1.3 Chitosan/carbon nanotube filler

The following natural frequency variation is obtained as a result of the addition of both CS and CNT fillers to the plate at certain ratios. The ratios are given on the x-axis of the graph shown in Fig. 7. The resulting filler is called as Hybrid filler. Fig. 7 shows the effect of both the CS and CNT fillers on the natural frequency of the composite plate. When the curves obtained from the plate with 0°, 45° and 90° fiber orientation angle are examined and compared with those given in Figs. 5 and 6, the curves obtained for the hybrid filler are almost among of those obtained for the CS and CNT fillers.

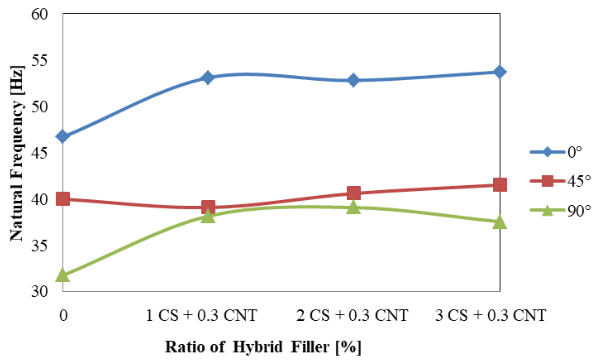


Fig. 7 Effect of hybrid filler on natural frequency

3.2 Effect of orientation angle of fiber

In order to see the effect of orientation angle of fiber on the natural frequency, three different orientation angels, such as 0°, 45° and 90°, are taken into consideration. The effect of the fiber orientation angle on natural frequencies of the composite plates with CS, CNT and hybrid fillers are discussed, respectively, in the below.

3.2.1 The effect of orientation angle of the plate with chitosan filler

Fig. 5 shows also the variation of natural frequency with orientation angle for the plate with CS filler. For comparison, the result of neat plate is also added to the figure (0%). As previously mentioned, the CS ratio is increased by 1% intervals. It can be seen from the figure that the effect of CS filler on natural frequency is particularly high at the orientation angles of 0° and 90°. This effect is relatively little in the plate with 45° orientation angle. It is observed that the results obtained from the filled composite plates approach nearly the results of the neat plate for a 45° orientation angle.

As expected, it is seen from the figure that the natural frequency decreases as the orientation angle changes from 0° to 90° for the neat plate. But, addition of CS filler increases the natural frequency especially for 0° and 90° orientation angles. Furthermore, the increase in the contribution ratio of CS filler for the 0° orientation angle does not affect the natural frequency much. Namely, the natural frequencies of the plates with 1%, 2% and 3% CS fillers are almost the same in the 0° orientation angle. The increase in the natural frequency of the plate with 90° orientation angle according to the increase in CS filler ratio is observed clearly.

3.2.2 The effect of orientation angle of the plate with carbon nanotube filler

The variation of natural frequency with orientation angle for the plate with CNT filler is also shown in Fig. 6. It can be seen from the figure that the natural frequency decreases by increasing the orientation angle. It is seen that the CNT contribution increases the natural frequency of the plate with 0° orientation angle. This increase in the plate with 90° orientation angle is less than one with 0° orientation angle. The natural frequency of CNT filled composite plate with 45° orientation angle is close to the one of the neat plate.

3.2.3 The effect of orientation angle of the plate with chitosan/carbon nanotube filler

Fig. 7 depicts also the variation of natural frequency with orientation angle for the composite plate with both CS and CNT fillers (hybrid filler). The natural frequencies of all of the plates with fillers are almost the same for the same orientation angles. But the natural frequency of the neat plate is different from them. Nevertheless, the natural frequency of the filled composite plates with 45° orientation angle is approach the natural frequency of the neat plate. As seen in this figure, the natural frequency decreases with increasing the orientation angle. But this decrease is quite small between 45° and 90° orientation angle for the plates with fillers. As for the neat plate, it decreases gradually.

3.3. Effect of hole number

In order to see the effect of hole number, holes of 8 mm diameter are drilled respectively with distances of 30 mm interval from the free edge. The effect of increase in the hole number on the natural frequency is examined for different fillers in the following subheads. Due to the fact that the natural frequency almost the same for all of the filled plate with 45 orientation angel, the effect of the hole number is only investigated for these plates.

3.3.1 The effect of hole number of the plate with chitosan filler

The effect of the hole number on natural frequency of CS filled plate is depicted in Fig. 8. The figure also depicts the effect of the hole number on natural frequency of the neat plate.

It can be seen from the figure that the natural frequency increase until three holes for the plate with 3% and 2% CS filler. Then it decreases as fourth hole added to the plate. As for the neat plate and plate with 1% CS filler, it increases until two holes, then it also decreases. In the other words, the increase in the number of holes in plates with low filler ratio or no filler increases the natural frequency until 2. However, natural frequency decreases at the number of holes after 2. This threshold value is equal to 3 for the composite plate with high filler ratio.

Furthermore, it can also be seen from the figure that increases in the CS filler ratio of the plate increase the natural frequency of the plate. But interestingly, the curve of the neat plate is obtained between the plate with 1% and 2% CS filler.

3.3.2 The effect of hole number of the plate with carbon nanotube filler

The effect of the hole number on the natural frequency of the plate with CNT filler is similar to one with CS filler as seen in Fig. 9.

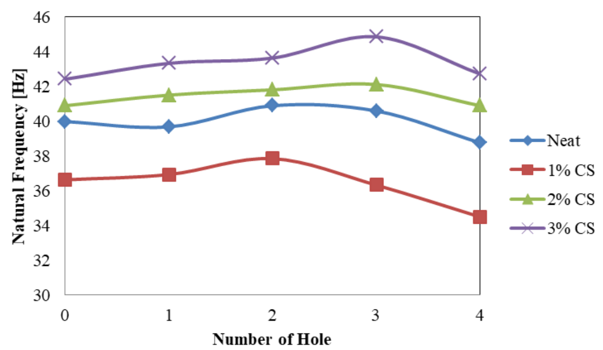


Fig. 8 Effect of the hole number on natural frequency of CS filled plate

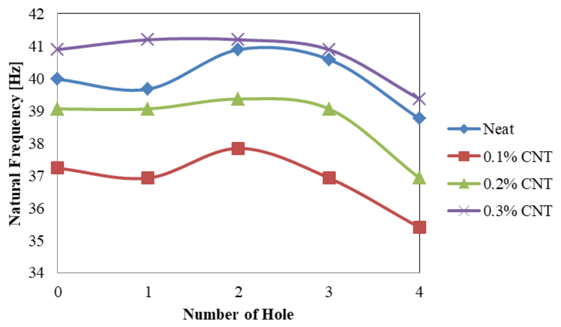


Fig. 9 Effect of the hole number on natural frequency of CNT filled plate

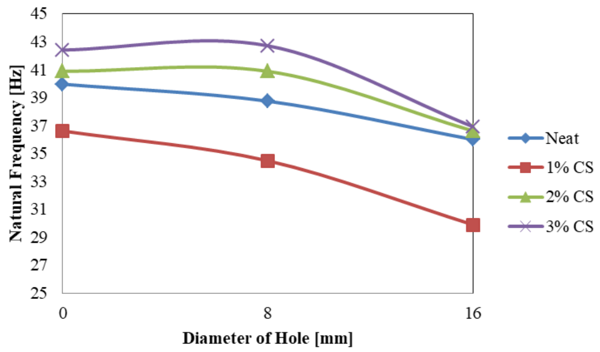


Fig. 11 Effect of the hole diameter on natural frequency of CS filled plate

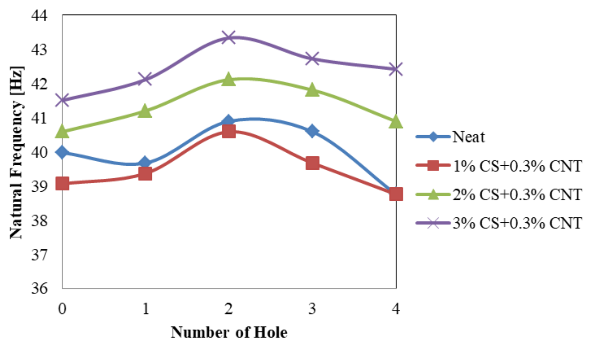


Fig. 10 Effect of the hole number on natural frequency of hybrid filled plate

But there are two major differences. The first one is that the natural frequencies of all the plates with and without filler decrease after the two holes. The second one is that the curve of the neat plate is obtained between the curves of the plates with 0.2% and 0.3% CNT filler. Here, the natural frequency is also increased by increasing the filler ratio as in the plate with CS filler.

3.3.3 The effect of hole number of the plate with chitosan/carbon nanotube filler

The effect of the number of holes on the natural frequency is given below when both CS and CNT fillers are present in the plate. It can be seen from the Fig. 10 that the natural frequency increases by increasing the CS fillers ratios. It is also seen from the figure that the number of 2 holes is the threshold value. The natural frequencies of the all plates with and without filler increase until the number of 2 holes and then they decrease. The curve of the neat plate is obtained between the plates with 1% CS + 0.3% CNT and 2% CS + 0.3% CNT fillers.

3.4 Effect of hole size

In order to see the effect of size of the hole, the diameters of the 4 holes previously drilled are expanded from 8 mm to 16 mm. The drilled specimens are compared with non-drilled specimen. This comparison for different is described below. The effect of the hole size is only investigated for the plates with 45° orientation angle.

3.4.1 The effect of hole size of the plate with chitosan filler

Fig. 11 depicts the variation of natural frequency with diameter of holes for the plate with CS filler. When the figure is examined, the natural frequency decreases with expanding the hole size. This decrease is gradual when the curves of neat plate and plate with 1% CS filler are examined. As for the curves of plates with 2% and 3% CS fillers and neat plate, the natural frequencies values of the undrilled and 8 mm drilled plates are close to each other. However, the natural frequencies of them decrease when the holes are expanded from 8 mm to 16 mm. Furthermore, it can be also seen form the figure that the decrease in the natural frequency caused by the holes is greater in the plate with 1% CS filler. The natural frequencies of the neat plate and the plates with 2% and 3% CS fillers are almost the same, especially in the hole diameter of 16 mm. As obtained from previously subsection, the curve of the neat plate is obtained between the plate with 1% and 2% CS fillers.

3.4.2 The effect of hole size of the plate with carbon nanotube filler

As for the plate with CNT filler, the natural frequency decreases gradually with expanding the hole size for the all the composite plate with or without filler. As can be seen from the Fig. 12, the curves are relatively close to each other. But the decrease in the natural frequency of the plate with 0.3% CNT filler is more than the others. Moreover, the curve of the neat plate is obtained between the curves of the plates with 0.2% and 0.3% CNT fillers.

3.4.3 The effect of hole size of the plate with chitosan/carbon nanotube filler

Fig. 13 shows the variation of the natural frequency of the plate without or with hybrid fillers. It can be seen from the figure that the natural frequency increases by increasing the hybrid filler ratio. But the natural frequency values of the neat plate are obtained between the natural frequency values of the plates with 1% CS + 0.3% CNT and 2% CS + 0.3% CNT fillers. When the curve of the neat plate is examined, the natural frequency of the neat plate decrease gradually with increasing the hole diameter. But the character of the curve is changed some for the plates with filler.

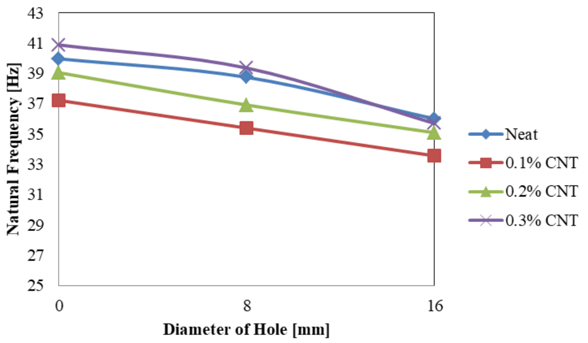


Fig. 12 Effect of the hole diameter on natural frequency of CNT filled plate

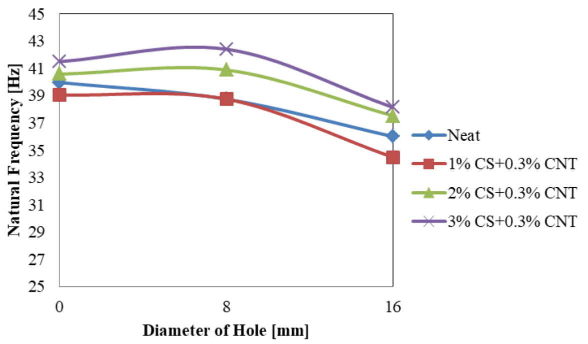


Fig. 13 Effect of the hole diameter on natural frequency of hybrid filled plate

Table 1 Comparison of experimental and numerical results

Number of Hole		Neat	1%CS	2%CS	3%CS
	Experimental value	39.978	36.6211	40.8936	42.4194
0	Numerical value	40.874	37.826	39.582	41.11
	Relative Error [%]	-2.241	-3.290	3.207	3.087
	Experimental value	39.6729	36.9263	41.5039	43.335
1	Numerical value	39.715	36.744	38.44	39.928
	Relative Error [%]	-0.106	0.494	7.382	7.862
	Experimental value	40.8936	37.8418	41.8091	43.6401
2	Numerical value	39.264	36.326	37.12	39.473
	Relative Error [%]	3.985	4.006	11.216	9.549
	Experimental value	40.5884	36.3159	42.1143	44.8608
3	Numerical value	39.288	36.347	38.023	39.498
	Relative Error [%]	3.204	-0.086	9.715	11.954
	Experimental value	38.7573	34.4849	40.8936	42.7246
4	Numerical value	39.724	36.75	38.445	39.936
	Relative Error [%]	-2.494	-6.568	5.988	6.527

The natural frequencies of the undrilled and the 8 mm drilled plates are almost the same for the plates with hybrid filler. Even the natural frequencies of the plate with 2% CS + 0.3% CNT and 3% CS + 0.3% CNT filler higher a little for hole diameter of 8 mm than undrilled plate. But the natural frequencies of them decrease when the holes are expanded from 8 mm to 16 mm.

3.5 Numerical validation

In order to compare the some results obtained from experiment, the SolidWorks® program (Dassault Systemes, USA) is used. The program is based on Finite Element Method. The program has the ability not only to draw a solid part but also to calculate engineering problems. The specimen models are drawn in drawing module of the program according to the Fig. 3. Then, the vibration simulation module of the program is run. The materials of the models are added as new materials to the program by entered the properties of the materials (Kavla 2019). The clamped fixture is applied to the model and the model is meshed. Then the program is run. The results obtained from the program are compared with the some results obtained from experiments, in Table 1.

It can be seen from the Table 1 that the numerical results are quite close in especially neat composite specimen and composite specimen with 1% CS filler. Although the % relative error is relatively high in some composites specimens with 2% CS and %3 CS filler, it is within acceptable limits.

Relative error (%) is calculated from follow equation.

$$\%\ relative\ error = \frac{experiment - numeric}{experiment} x\ 100 \qquad (1)$$

4. Conclusions

The effects of filler's contents and ratios, fiber orientation angles, hole numbers and hole sizes of the filled and drilled composite plates on the behavior of the vibration are investigated. The following results are obtained from this study.

- The natural frequency of the plate with 1% CS and 0.1 % CNT hybrid filler is lower than those of the plates with other fillers ratios for 45° orientation angle.
- In the composite plate with 0° orientation angle, the natural frequency increases with increasing the filler ratio. But the increase in the plate with CS and hybrid fillers is very little after 1 % filler ratio.
- The natural frequency increases with the increase in both CS and CNT filler ratios.
- The natural frequency of the plate with 0° orientation angle is always the highest.
- The natural frequencies of the plates with 45° and 90° orientation angles are almost the same for the plates of 1% CS + 0.3% CNT and 2% CS + 0.3% CNT fillers.
- The natural frequency increases until two or three

hole numbers for the filled plate. But it decreases in four holes.

- Expansion in the hole up to 8 mm diameter does not affect the natural frequency much, whereas expansion to 16 mm reduces the natural frequency, clearly.
- The natural frequencies values obtained from experimental data and numerical solutions are in a good agreement.

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