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Effects of nano-particles concentration on dynamic response of laminated nanocomposite beam

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1. Introduction

The laminated composite beams are increasingly being used in the many advanced industries due to their excellent engineering properties including the weight to stiffness ratio. Recent advances in nano technology leads to manufacturing laminated composites reinforced with nano particles, resulting in hybrid composites, to improve the mechanical behavior of the structures. Hybrid compositesare usually used when a combination of properties of different types of fibers need to be achieved, or when the longitudinal as well as the lateral mechanical performance are required. Addition of fillers to polymer matrix is a common approach to reinforce the laminated structures. The fillers can be chosen between fibers or powders [1]. Filler particles are assumed to increase the toughness of the composite beams [2]. Gadakaree [3] used the microscale filler particles in glass matrix to improve the mechanical properties of composite structures. Kwak et al. [4] studied the effect of microscale fillers with respect to their vibrational behavior. Recently, fillers in the nanometer scale were used to improve the general performance of the composite structures [5]. Materials with nano particles introduce a new class of materials that is different from the individual components. They made a very high specific surface area to cause a fundamental change in the material properties like flexural modulus and impact energy [6, 7]. It is shown that the nano fillers, Epoxy / TiO_2, at very low filler volume fraction may significantly affect the mechanical properties of composite structure [8, 9]. Meguid et al. [10, 11] investigated the effect of carbon nanotubes and alumina nanotubes on mechanical behavior of composite structures. Laminated composites structures are highly being used in dynamic application, particularly, in aerospace application. Aerospace industries need laminated composite structures with higher stiffness and higher damping coefficients [11]. The damping of reinforced composite structures is investigated by many researchers [2]. They showed that continuous fiber has more effect in damping characteristics than other composite specifications. The effect of orientation and the length of fiber on damping are investigated by Suarez et al. [12]. Chandradass et al. [2] studied the effect of weight fraction of nanoclay on vibration properties of glass fiber reinforced with vinyl ester/coprod composite. The present work investigates the effect of adding nanoclay to Eglass/epoxy on the free and forced vibration of laminated composite beam. The material of nanoclayin the study is montmorillonite treated with methyl tallow bis-(2-hydroxyethyl) quaternary ammonium.

Experimental works have been performed to determine the free vibration response as well as damping coefficients of the fixed-free laminated beam reinforced with nanoclay particles. Numerical examples are provided to illustrate the effects of nanoclay weight ratio on forced vibration response of the sample beams.

2. Finite element modelling

The displacement fields for a laminated plate strip based on the layerwise theory are given by:

$$\left.\begin{aligned} u(x,y,t) &= \sum_{i=1}^{n}\sum_{j=1}^{m} U_{ij}(x,t)\theta_j(z)\varphi_j(x); \\ w(x,z,t) &= W_0(x,z), \end{aligned}\right\} \tag{1}$$

where u and w are the displacements along x and z axis, n and m are the total number of nodes through the thickness and along the length, respectively. Interpolations functions $\theta_j(z)$ and $\varphi_j(x)$ are defined along the z and directions, respectively. The finite element equation of motion for laminated composite plate based on layerwise theory is given by [13]:

$$[M]\{\ddot{d}\}+[C]\{\dot{d}\}+[K]\{d\}=\{F(t)\}, \tag{2}$$

where matrices M, C, and K are mass, damping, and stiffness respectively, d represents general nodal displacement defined as $\{d\}=\{u, w\}$ and $F(t)$ shows the external excitation.

For more details on finite element model one may consult [1]. Solution of Eq. (2) provides the vibration response of the structure under applied load $F(t)$.

3. Experimental works

The experimental works has been performed in three steps: 1) fabrication of the samples; 2) mechanical test; 3) vibration analysis. In the proceeding sections the details of the fabrication steps, materials preparation and vibration tests have been explained.

3.1. Fabrication of hybrid composite laminated beams

The laminated samples have been fabricated using Vacuum Resin Transfer Molding (VRTM) method. The structure is composed of 12 layers of plain woven E-glass fibers. Then, the resin mixture which is prepared using epoxy, hardener and nanoclay is induced at each layer. Fiber volume fraction of the structure is approximately 60%. Then, the epoxy/clay system is transferred to Vacuum Assisted Resin Transfer Molding. A at rectangular glass mold with dimensions of 900×600 mm, which was maintained at 40°C was used to prepare the glass/epoxy nanoclay plate (Fig. 1). Curing of the glass/epoxy nanoclay plate is performed for 150 min at 80°C followed by 150 min at 120°C. After curing process, a plate with average thickness of 2.5 mm ready to be cut into strips, hereafter, referred to sample beams. Mechanical properties of the structure have been improved by adding percentage of weight (1, 2, 3, 5, 7%) of organonanoclay, Closite 30B, to the resin at 40^{o}C. The mixture was sonicaed by ultrasound for 20 min. Finally, suspension was stirred with resin for 10 min at 80°C at the speed of 1000 rpm. Key materials used in the process are given in Table 1.

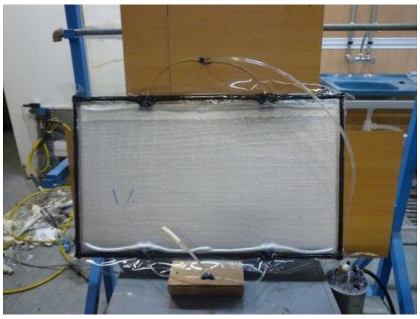

Fig. 1 Flat rectangular glass mold

Table 1
Materials for laminated nanocomposite beams

Components	**Materials**	**Commercial name**
Fibers	Plain woven E-glass, 200 g/m^3	
Resins	a diglycidyl ether of bisphenol A	Epon828, Shell Corp.
Hardener	amine-terminated polyoxypropylene diols 400 g/mol at weight ratio of 55:100	Jeffamine D-400, Huntsman Corp.
Nanoclay	montmorillonite treated with methyl tallowbis-(2-hydroxyethyl quaternary ammonium)	Cloisite 30B, Southern Clay Products

After sample fabrication, the mechanical properties of the samples were determined using regular tensile testing method and are provided in Table 2 Finally, the fabricated nanocomposite laminated plate has been cut into 150 mm long and 25 mm width strips (Fig. 2).

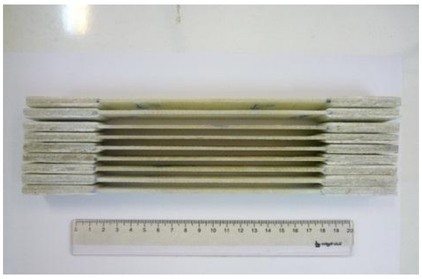

Fig. 2 Prepared samples with taps for tensile test

Table 2
Mechanical properties of hybrid laminated nanocomposite beam

Property	% of nano clay in resin					
	0	1	2	3	5	7
E11, GPa	40.56	40.60	40.67	40.80	41.17	41.15
E22, GPa	6.95	6.98	7.03	70.16	7.57	7.45

3.2. Characterization of the nanocomposites

The *d*-spacing of clay, the neat epoxy and its nanocomposite sites based on Closite 30B are illustrated by X-ray diffraction (XRD) method. As shown Fig. 3, the nanoparticles with in the epoxy resin are mostly in intercalated form rather than exfoliated that defined by individual layers separated with *d*-spacing more than 10 nm [14].

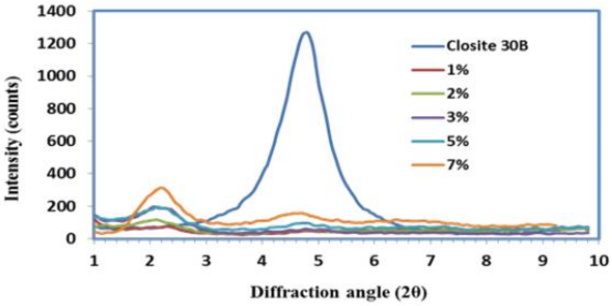

Fig. 3 X-ray diffraction curves for Closite 30B and epoxy/Closite 30B nanocomposites in different clay content

The *d*-spacing data calculated are summarized in Table 3. In all the nanocomposite samples, the clay layer separation is more than twice as large as in the originalCloiste 30B. As seen in Fig. 3, the Closite 30B shows a single, intense reflection at diffraction angle $2\theta = 4.75°$. The *d*-spacing associated with this peak is 18.61.

Table 3
Diffraction angle and d-spacing of epoxy/Closite 30B nanocomposites in different wt

Item	% of nano clay in resin				
	1%	2%	3%	5%	7%
2θ, °	2.16	2.02	2.19	2.09	2.17
d, Å	40.76	43.63	40.36	42.23	40.69

3.3. Free vibration test (FVT)

To determine the vibration response of the sample beams, a fixed-free beams has been considered.

A tiny velocity sensor has been mounted at the free end of the beam and the signals have been transmitted to a vibration data analyzer model STD-3300 (Technoken) (Fig. 4). The collected signals, then, are used to extract the time-displacement signals. Fig. 5 shows the free vibration response of the beam for different weight ratio of nanoclay. As it is observed, increasing the weight percent of nanoclay in the resin up to 5% increases the natural frequency of the structure. However, when the weight percent of nanoclay reaches to 7%, the natural frequency begins to decline. This phenomenon is as the results of decreasing the stiffness of the structure at this weight ratio of nanoclay as given in Table 4.

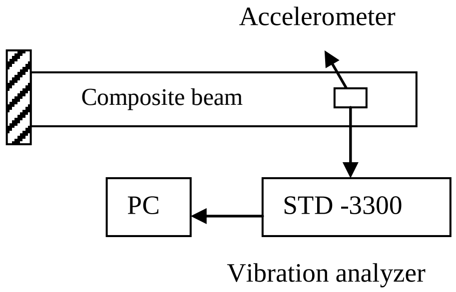

Fig. 4 Experimental set up for free vibration

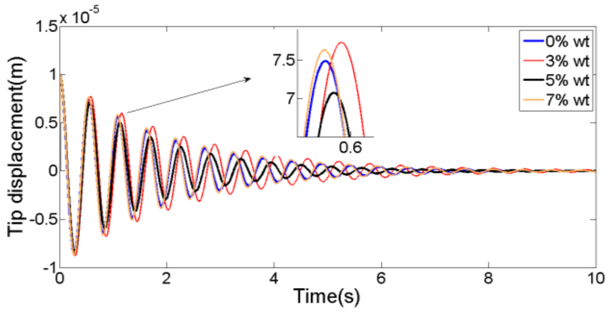

Fig. 5 Free vibration of uniform composite beam without/with nanoclay

Table 4

The dynamic characteristics of hybrid composite reinforced with nanoclay

Property	% of nano clay in resin			
	0%	3%	5%	7%
Damping coefficients, ζ	0.041	0.043	0.046	0.055
Natural frequency, Hz	10.88	11.17	11.66	11.60

Time-displacement response of the structure is also plotted in Fig. 6, where one may realize that increasing the weight ratio of nanoclay, reduces the amplitude of the vibration and increases the damping coefficients of the structure.

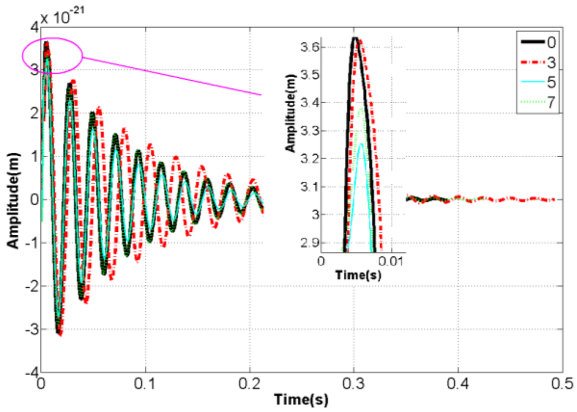

Fig. 6 Tip displacement of hybrid uniform composite beams with and without nano fillers

4. Numerical illustrations on forced vibration

In order to study the effects of nanoclay on forced vibration response, the beams with geometrical and mechanical properties of the experimental works has been considered. Various kinds of loading, namely, impulse, sinusoidal and random (white noise) loadings have been taken into consideration (Fig. 7). In the following subsections, the dynamic response of the beam for forced vibration has been explained.

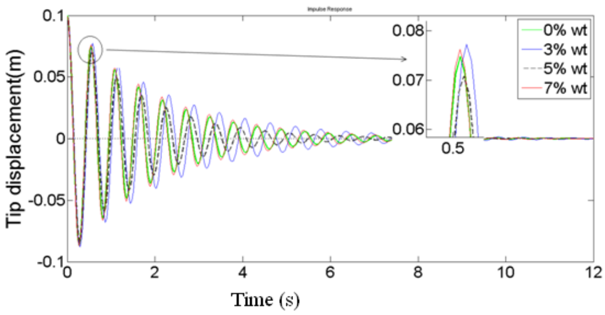

Fig. 7 Effect of nanoclay weight ratio on impulse loading

4.1. Impulse loading

The nanocomposite laminated beam given in section 3 is subjected to an impulse loading. Fig. 8 shows the response of the beams when weight ratio of nanoclay in resin changes from 0 to 7%. It is observed that increasing nanoclay up to 5% results in improvement of all dynamic characteristics, namely overshot, rise time and damping of the beams.

4.2. Sinusoidal loading

The nanocomposite laminated beam given in given in section 3 is subjected to a sinus loading with frequency of 10 Hz and amplitude of 10 N. Fig. 8 shows the response of the beams when weight ratio of nanoclay in resin changes from 0 to 7%.

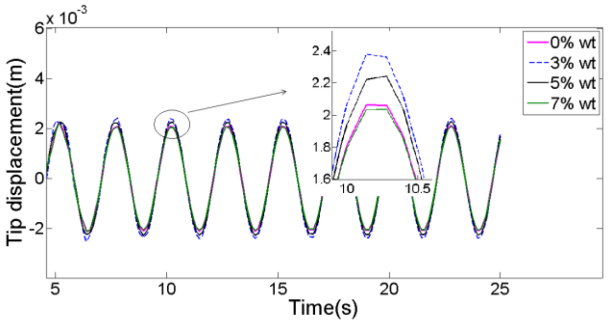

Fig. 8 Effect of nanoclay weight ratio on impulse loading

4.3. Random loading

Composite structures are being used in many applications such as aerospace applications, where the applied loadings are commonly sort of random loadings. In this section the effect of addition of nanoclay in composite on vibration response of the structure subject to a common random loading is studied. The nanocomposite laminated beam given in given in section 3 is subjected to a white noise with spectral density of 5 dB. Fig. 9 shows the response of the beams when weight ratio of nanoclay in resin changes from 0 to 7%. Fig. 10 shows the frequency response of the structure subject to white noise.

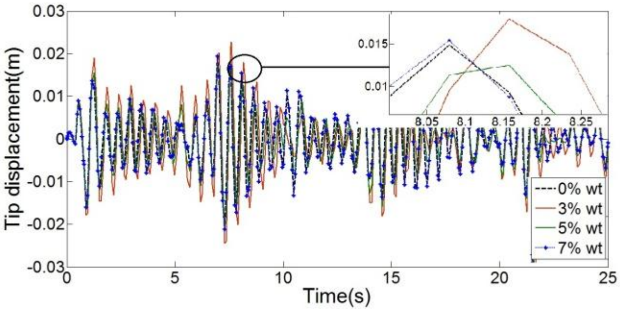

Fig. 9 Effect of weight ratio of on random loading

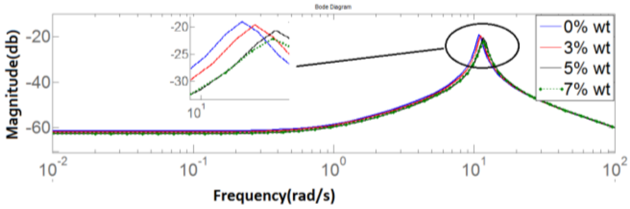

Fig. 10 Frequency response of the composite beam under random loading

5. Conclusions

The effects of adding nanoclay to the resin on dynamic response of nanocomposite structures has been investigated. Using hand-layup method, a laminated plate made of E-glass/fiber and epoxy resin has been fabricated. Weight ratio of 1-7% of organo nanoclay, Closite 30B, has been added to the base resin. The prepared plate has been cut into strips and subjected to tensile testing to determine the mechanical properties of the structure. The free vibration response of beams has been obtained using a tiny velocity sensor and a vibration analyzer. Increasing the percentage of nanoclay from 1 to5% increases the natural frequency and damping ratio of the beams, however, when the percentage of nanoclay reaches to 7% both the natural frequency and damping coefficients began to decline. Effects of adding nanoclay on forced vibration response of the nanocomposite laminated beam has also been investigated using numerical examples. The dynamic response of a fixed-free beam subjected to impulse, sinusoidal as well as random loading has been determined. Similar to free vibration response, increasing the percentage of nanoclay up to 5% improves the forced vibration behavior of the beams for all the applied loadings, however, when the weight ratio of nanoclay reaches to 7%, the rate of improvement of the dynamic characteristics of the beams began to decline.

6. Acknowledgements

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NANO DALELIŲ KONCENTRACIJOS ĮTAKA DINAMINEI NANOKOMPOZICINIO LAMINUOTO STRYPO REAKCIJAI

Reziume

Ištirti hibridinių nanokompozicinių nanodalelėmis sustiprintų laminatų virpesiai ir slopinimo charakteristikos. Virpesių analizei pasirinktas pastovaus skerspjūvio laminuotas E stiklo/epoksidinis strypas, praturtintas Cloizitu 30B, nanodalelių tūrinės frakcijos įtaka strypo virpesiams ir slopinimo koeficientui ištirta pritaikius sluoksnių poslinkio teoriją. Eksperimentinė iliustracija panaudota nanokompozitu laminuoto strypo laisvųjų virpesių ir slopinimo koeficientams skaičiuoti. Didinant nanodalelių tūrinę frakciją nuo 1 iki 5%, didėja ir įtvirtinto bei laisvo strypo bandinio savasis dažnis nuo 10.88 iki 11.66 Hz , o slopinimo koeficientas nuo 0.041 iki 0.055.

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EFFECTS OF NANO-PARTICLES CONCENTRATION ON DYNAMIC RESPONSE OFLAMINATED NANOCOMPOSITE BEAM

Summary

This paper investigates the vibration and damping characteristics of hybrid nanocomposite laminates reinforced with nono-particles. A uniform laminated beam made of E-glass/epoxy enriched with Cloisite 30B is considered for vibration analysis. Effects of the volume fraction of nano-particles on vibration response and damping coefficients of the beam have been studied using a layerwise displacement theory. Experimental illustration has been set up to compute the free vibration response and damping coefficients of the nano-composite laminated beam. Increasing the volume fraction of nano-particles from 1 to 5% increases the natural frequency of the sample fixed-free beam from10.88 to 11.66 Hz and its damping coefficients from 0.041 to 0.055.

Keywords: nanoparticles, fiber-glass, laminated composite, vibration, damping coefficients.

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