Mechanical, Dynamic Mechanical and Vibration Behavior of Nanoclay Dispersed Natural Fiber Hybrid Intra-ply Woven Fabric Composite

M. Rajesh, P. Jeyaraj and N. Rajini

Abstract Influence of nanoclay dispersion on mechanical, dynamic mechanical and free vibration characteristics of basket type intra-ply woven banana/jute (banana yarn-weft direction, jute yarn-warp direction) hybrid polyester composite has been investigated. Results revealed that loading of nanoclay enhances the mechanical properties of the composite significantly as it improves the adhesion between fiber and matrix. Dynamic mechanical analysis result reveals that nanoclay addition significantly increases the storage modulus and glass transition temperature of the intra-ply hybrid composite. From free vibration studies, carried out on laminated beam like structures, it is found that the natural frequency of the composite laminate increases till 2 wt% of nanoclay while the modal damping increases when the wt% of nanoclay is more than 2. However, due to the agglomeration effect of nanoclay the properties are not improved for nanoclay loading beyond 2 wt%.

Keywords Nanoclay · Weaving · Dynamic mechanical analysis · Mechanical properties

---

M. Rajesh · P. Jeyaraj
Department of Mechanical Engineering, National Institute of Technology
Karnataka, Surathkal, Mangalore 575 025, India

N. Rajini (✉)
Department of Mechanical Engineering, Kalasalingam University,
Krishnankoil, Virudhunagar 626 126, Tamilnadu, India
e-mail: rajiniklu@gmail.com

N. Rajini
Laboratory of Biocomposite Technology, Institute of Tropical Forestry
and Forest Products, Universiti Putra Malaysia, 43400 Serdang,
Selangor, Malaysia

M. Jawaid et al. (eds.), *Nanoclay Reinforced Polymer Composites*,
Engineering Materials, DOI 10.1007/978-981-10-0950-1_12

1 Introduction

Natural fibers can be used an alternative material to conventional synthetic fibers such as glass, carbon, boron and kevlar fibers. Natural fibers such as banana, jute, sisal and hemp have advantages such as low cost, less weight, easy to process and bio-degradable compared to the synthetic fibers (Joshi et al. 2004; Venkateshwaran et al. 2011). Several researchers have investigated mechanical properties of several natural fiber hybrid composites and demonstrated that hybrid composites have better mechanical strength. Jacob et al. (2004) investigated the effect of sisal/oil palm fiber in natural rubber composite on mechanical properties. They concluded that increasing the concentration of fiber in matrix reduces the tensile strength. Venkateshwaran et al. (2011) analyzed the banana/sisal/epoxy hybrid composite with different fiber length and weight percentage. They achieved better mechanical properties for 50 wt% of sisal fiber in banana/epoxy composite. Jawaid et al. (2011) hybridized the oil palm empty fruit bunch fiber mat with woven jute composite and found that hybridized composite got maximum tensile and flexural result.

Several researchers demonstrated that based nanoclay added composites increases mechanical and dynamic properties such as tensile strength, modulus and glass transition temperature of composites compared to same filler reinforced in micron scale level in petroleum based resins such as unsaturated polyester, epoxy, vinyl ester etc. and natural resins such as vegetable oil, animal facts etc. (Wang et al. 2006; Haq et al. 2009). Chan et al. (2011) found that uniform distribution of nanoclay into polymer matrix increases the mechanical property as nanoclay added in small amount increases mechanical interlocking inside the composite and reduces the crack propagation while loading. Huang and Netravali (2009) found that micro/nano-sized bamboo fibrils in soy protein resin increases the fracture stress and Young's modulus of material. Fu et al. (2008) proved that particle size, particle/matrix interface adhesion and particle loading are important parameters to define the strength of composite materials. Yasmin et al. (2006) investigated the dynamic mechanical properties of epoxy based composite with 1–10 wt% of nanoclay content. They concluded that higher concentration (10 wt%) of nanoclay composite gives better property than lower and neat resin in all types of nanoclay composite. Huang and Netravali (2007) added nano particle in yarn and woven type flax/soy protein resin biodegradable composites. Their results revealed that nanoclay added woven composite has higher mechanical property than yarn type composite. Bozkurt et al. (2007) found that the addition of nanoclay in glass/epoxy composite up to 6 % increases the flexural modulus and dynamic mechanical properties such as storage modulus and loss modulus of composite. They also found that addition of nanoclay is not showing any significant improvement in the glass transition temperature. Haq et al. (2008) analyzed reinforcement of nanoclay in polyester/soybean oil/hemp composite and found that nanoclay addition increases stiffness, ultimate tensile stress and toughness of the composite. Jo et al. (2008) analyzed addition of montmorillonite (MMT) nanoclay into polyester composite and found that the nanoclay improves mechanical properties and also enhances the internal damping of composite material (Chandradass et al. 2007; Barick and Tripathy 2011). They concluded that organically modified silicate nanoclayenhances the viscous properties of composite material. In general, the addition of nanoclay in a composite increases the storage and loss modulus in both the glassy and rubbery region as the addition of nanoclay increases the resistance of molecular movement (Liu et al. 2013; Galooyak et al. 2011; Kostopoulos et al. 1993; Haddad and Yehia 2013; Gracida et al. 2005).

From the literature survey, it is found that the addition of nanoclay improves the mechanical properties, natural frequency and dynamic behavior of the polymer composites. Different kinds of natural fibers are available abundant in nature are becoming waste material as they are not being utilized effectively. Hybrid natural composites are fabricated by orienting different fibers layer by layer or keeping them in chapped form in the polymer matrix. Some researchers demonstrated that natural fiber reinforced in woven form gives better results compared to short natural fiber in random orientation. From the previous study it is found that the basket type woven composites have better mechanical properties compared to plain, twill, stain, huckaback woven composites. So the intra-ply hybrid woven natural fiber mats are prepared in basket weaving pattern. Additionally, MMT nanoclay has been added as a secondary reinforcement in the intra-ply natural/natural fiber hybrid composite to enhance the properties without affecting mass of the composite significantly.

The present work investigates the effect of nanoclay addition in a basket type intra-ply hybrid woven banana/jute natural fiber on the mechanical properties, free vibration behavior and dynamic mechanical properties such as storage modulus, loss modulus and damping factor.

2 Experimental Details

2.1 Woven Natural Fiber Mat and Polymer Preparation

In the present work, jute/banana natural fibers intra-ply hybrid woven mat is used as primary reinforcement while montmorillonite (MMT) nanoclay is used as secondary reinforcement in a polyester resin. Initially, these natural fibers are spurned into yarn, which contains around 100–150 numbers of loose fibers. From these yarns intra-ply hybrid basket type woven natural fiber mat is prepared manually. From the previous study it is found that basket type weaving pattern has higher mechanical properties than other type of weaving pattern. So intra-ply hybrid woven mats are prepared with basket type weaving pattern in the present work.

Figure 1 shows the schematic diagram of intra-ply hybrid woven natural fiber mats used in the present work. In intra-ply hybrid woven mat, one natural fiber yarn is oriented along warp direction while the other fiber is oriented along weft direction. Initially the secondary reinforcement MMT nanoclay is added with the unsaturated polyester resin then the mixer is stirred using high speed mechanical

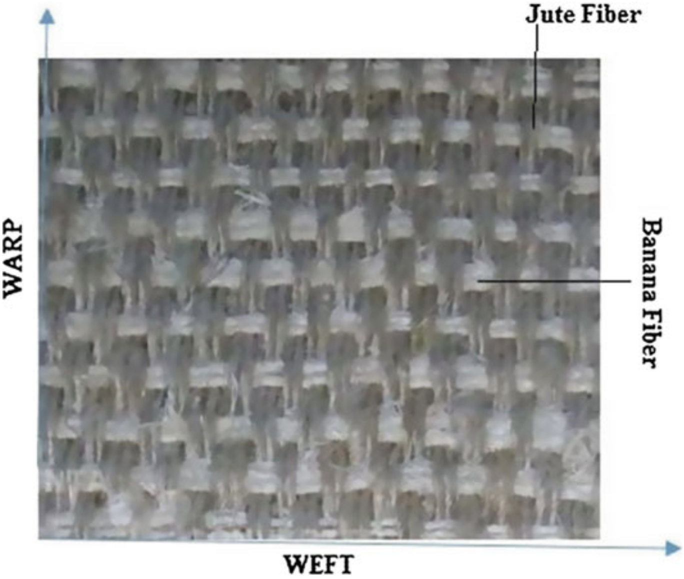

Fig. 1 Intra-ply hybrid basket type woven natural fiber mat

shear mixer at 900 rpm for 4 h for the reinforcement of nanoclay in resin with uniform dispersion. Then one wt% Methyl Ethyl Ketone Peroxide (MEKP) and cobalt naphthenate are used as catalyst and accelerator respectively and mixed with MMT nanoclay added unsaturated polyester resin in the ratio of 10:1. Weight percentage of the nanoclay is varied as 1–5 % in steps of 1 % and corresponding variations in different properties are analyzed.

2.2 *Fabrication of Composites*

Intra-ply hybrid woven composite laminates used in the present work are prepared using compression moulding technique, for that a mouldis prepared using steel of a dimension of 300 mm × 300 mm × 3 mm. The top and bottom parts are covered by stiff parallel plates made of EN steel. Firsta known amount of the prepared unsaturated, nanoclay mixture is poured then basket type intra-ply hybrid woven natural fiber mat is kept over the poured resin. In order to remove voids content from this laminate it is rolled using steel roller several times. After this mould is covered by two parallel plates and applying 20 bar pressure on the compression moulding machine. After 24 h room temperature curing, laminate is removed from the mould. Then according to ASTM standards for different test, the specimens are cut from the laminate.

2.3 Testing Standards

Tensile and flexural tests (three-point bending) are carried out using a universal testing machine while impact test is carried out using an izod impact test set-up. Tensile test is carried out as per ASTM standard D-638 with a loading speed of 2 mm/min. Three-point bending test is carried out using ASTM standard D-790. Impact test is carried out according to ASTM standard D-256 without notch. Each test is carried out on three samples and the average value is taken. For dynamic mechanical analysis, intra-ply hybrid composite specimen size of 50 mm × 50 mm × 3 mm is used and a test is carried out by the dual cantilever method using a dynamic mechanical analyzer (MODEL DMS 6100). Free vibration characteristics such as first three lowest frequencies and associated modal damping values are obtained using the impulse hammer method. The size of test specimen used for the free vibration test is 170 mm × 17 mm × 3 mm.

2.4 Material Characterization

Interfacial bonding between the fiber and matrix and morphology of fractured surface are investigated using scanning electron microscope images.

3 Results and Discussion

Several researchers investigated the natural fiber reinforced composites and reported that the mechanical properties of these composites are significantly influenced several factors such as orientation of the fiber, fiber/matrix adhesion, hybridization of natural fibers and type of the natural fiber. Some researchers found that the addition of nanoclay act as secondary reinforcement material in the polymer composite enhances the mechanical properties. The present work proposes intra-ply hybrid woven natural fiber polyester composite with different wt% of nanoclay as secondary reinforcement. Influence of basket type woven intra-ply hybrid mat and nanoclay loading on mechanical properties (tensile, flexural and impact strength), dynamic mechanical and free vibration characteristics of the intra-ply hybrid woven nano composite has been analyzed in detail.

3.1 Mechanical Properties

Influence on nanoclay loading on tensile, flexural and impact properties of the intra-ply hybrid woven mat composite is shown in Table 1. From Table 1, it is clear

Table 1 Influence of nanoclay loading on mechanical properties of the intra-ply hybrid composite (Values in bracket indicates percentage increase compared to the hybrid composite without nanoclay)

wt%	Tensile properties		Flexural properties		Impact properties
	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)	Impact strength (J/m)
0	15.9	1.00	34.2	1.31	102
1	21.0 (24 %)	1.27 (26 %)	37.8 (11 %)	1.55 (18 %)	190 (86 %)
2	23.7 (33 %)	1.35 (35 %)	48.3 (41 %)	1.72 (31 %)	290 (184 %)
3	22.2 (28 %)	1.29 (29 %)	39.9 (17 %)	1.36 (4 %)	246 (114 %)
4	19.2 (21 %)	1.08 (8 %)	37.8 (10 %)	1.16 (−11 %)	134 (31 %)
5	18.5 (14 %)	1.02 (2 %)	36.7 (7 %)	1.02 (−22 %)	116 (14 %)

that the addition of nanoclay improves the mechanical properties such as tensile, flexural and impact strength of intra-ply hybrid composites. Rough surface on the fiber mat due to the addition of nanoclay increases the fiber-matrix adhesion. This enhanced fiber-matrix adhesion decreases the crack propagation rate while loading and hence increases the mechanical properties. This rough surface formed on the fiber increases the contact ratio between the fiber and matrix also. This results in increase in the mechanical interlocking capability between fiber and matrix. The nanoclay will act as small micro-pin between fiber and matrix. So it can carry high loads and transfer stress uniformly. It is evident from the SEM image. Figure 3a shows the presence of rough surface on the natural fiber after the addition of nanoclay.

Nanoclay loading in matrix always improves the mechanical properties of the hybrid composite as seen in Fig. 2 while beyond 2 wt% of nanoclay addition these properties reduce with increase in nanoclay loading. This can be attributed to the

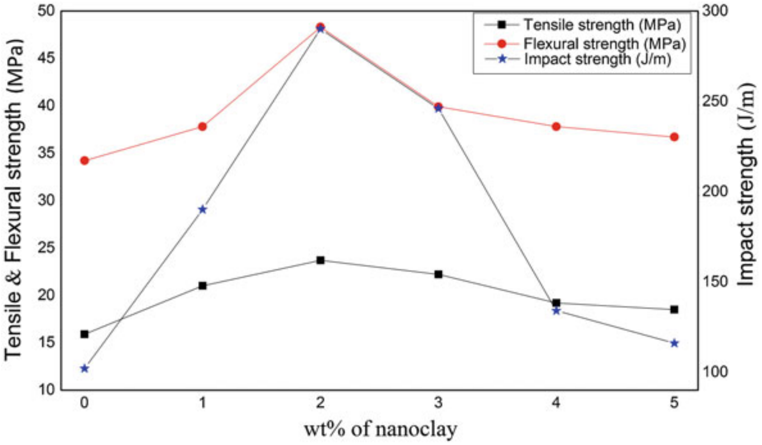

Fig. 2 Influence of nanoclay loading on mechanical properties of intra-ply hybrid composite

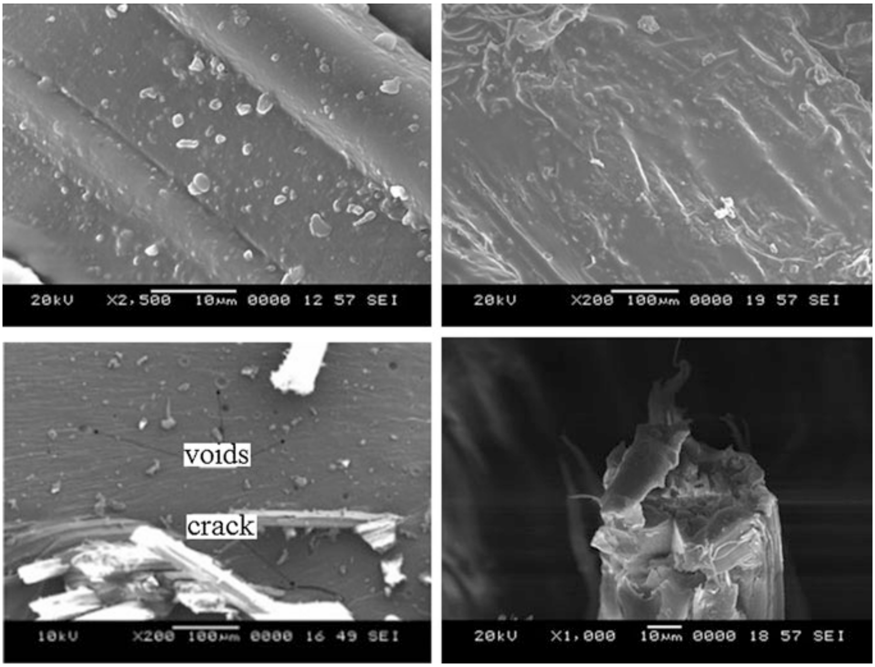

Fig. 3 SEM images to analyze influence of nanoclay loading on fractured surfaces. **a** Fiber surface after 2 wt% nanoclay addition, **b** 2 wt% nanoclay added composite under tensile load, **c** composite without nanoclay addition under tensile load, **d** fiber cross section

agglomeration of nanoclay in the matrix for the nanoclay loading beyond 2 wt%. Due to the agglomeration there will not be a uniform dispersion of nanoclay in the matrix which results in non-uniform stress distribution across the laminate and exhibits poor mechanical properties even though the amount of nanoclay loading is more than 2 wt%.

Figure 3b shows the tensile fractured surface of the intra-ply hybrid composite with 2 wt% nanoclay. Figure 3b reveals that the addition of nanoclay in the matrix increases the resistance to crack propagation while loading the specimen. But composite without nanoclay in the polymer matrix shows lowest tensile and flexural strength as they are poor in carrying high load and distribute stress uniformly between fiber and matrix while loading. This results in creation of multiple crack and propagation in all the direction under the action tensile and flexural load. It is evident from Fig. 3c shows the multiple cracks propagate, void formation and week fiber/matrix interaction while loading. Figure 3d shows the cross section of a fiber in the nanoclay reinforced matrix. It is confirmed by the appearance of the fiber shown in Fig. 3d, that the nanoclay addition in the matrix increases the resistances against the fiber pull out as the nanoclay also provides a strong interface between fiber and matrix.

Figure 2 also shows the effect of nanoclay loading on the impact strength of intra-ply hybrid composites. A trend similar to tensile and flexural strength has been observed for the impact strength also for different wt% of nanoclay addition. Toughness is an important property for a newly developed material. As it is a measure of energy stored in a material during the impact loading. Impact strength of the intra-ply hybrid woven composite also reduces beyond 2 wt% of nanoclay loading. Physical behavior of the composite with the addition of nanoclay and increasing wt% of nanoclay discussed for the tensile and flexural properties may be attributed for the variation of impact strength also. Behera et al. (2013), Kumar et al. (2015) also observed same behavior.

Another main possible reason for poor mechanical properties of the intra-ply woven hybrid composite with more than 2 wt% nanoclay is poor bonding between particle and heterogeneity property of composite material due to density variation of nanoclay and polyester resin. However, tensile strength of nanoclay composite increases by 32, 49, 39, 20, and 16 % respectively in 1–5 wt% nanoclay composites compared to composite without nanoclay. A similar trend is observed in flexural and impact strength also. The flexural strength of nanoclay added composite increases by 11, 41, 17, 11, 8 % respectively and 86, 184, 141, 31, 14 % respectively for impact strength in 1–5 wt% compared to nanoclay free composite.

3.2 Dynamic Mechanical Analysis

3.2.1 Storage Modulus

Effect of temperature and nanoclay loading on the storage modulus of intra-ply hybrid composite is shown in Fig. 4a. Results reveal that the addition of nanoclay improves the energy storing capacity of the intra-ply hybrid composite than the nanoclay free composite. Storage modulus of nanoclay free intra-ply hybrid composite decreases with increasing the temperature as the material losses the stiffness. So internal molecules will move freely without any restriction. Another observation found from Fig. 4a is extreme drops in the storage modulus near the glass transition temperature (T_g). This sudden dropping trend in storage modulus is distinctive of the viscoelastic actions associated with polymer based composites. In order to increase the load carrying capability of composite material, researchers proposed to incorporate the nanoclay in composites (Boumbimba et al. 2011; Abenojar et al. 2012). From Fig. 4a it is found that addition of nanoclay enriched the storage modulus substantively because of better interaction between polyester, nanoclay and fiber. So it is permissible stress between fiber and matrix is high. Nevertheless, as shown in Fig. 4a storage modulus of nanoclay composite is higher than nanoclay free composite. Higher storage modulus is observed in both glassy and rubbery regions and the nanoclay addition also increases the T_g value of composite material. This significant increment of storage modulus of the intra-ply hybrid composite

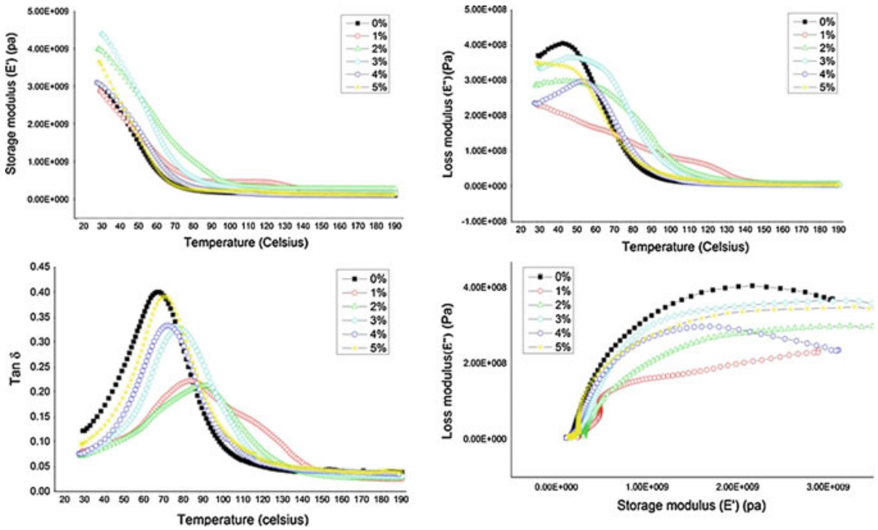

Fig. 4 Dynamic mechanical behavior of nanoclay added intra-ply hybrid composite. **a** Storage modulus, **b** loss modulus, **c** loss factor, **d** damping factor

material is due to the incorporation of nanoclay in a polymer which enhances the stress transfer by acting as a secondary reinforcement in the composite.

Another observation observed from Fig. 4a is, nanoclayupto 2 % increases the storage modulus extremely than other weight percentage but it is higher than composite without nanoclay. This is because increasing nanoclay content in the composite form cluster formation. Due to this it forms heterogeneity property and creates weak bonding between matrix and fiber, which is already discussed in Sect. 3.1. Results in Fig. 4a revealed that addition of nanoclay increases the storage modulus in both glassy and rubbery regions. This indicates that addition of nanoclay increase the thermal stability of the hybrid composite and gives better restriction to free molecular moment even at higher temperature.

3.2.2 Loss Modulus

Loss modulus is used to define the viscous nature of polymer composite. It is a measure of energy dissipation ofa material under deformation. From Fig. 4b, one can observe that variation of the loss modulus of the intra-ply hybrid woven composite with temperature and nanoclay loading is similar to the variation of storage modulus as discussed in Sect. 3.2.1. Addition of nanoclay increases the loss modulus and T_g value of intra-ply hybrid composites than composite without nanoclay. But nanoclay free composite and composite with 4 and 5 wt% has higher loss modulus in glassy region. After 45–55 °C temperature, sudden drop is observed in loss modulus peak. Lowering the loss modulus near T_g is due to the micro Brownian movement of polymer chain (Pothan et al. 2006). Normally loss modulus is dependent on frictional resistance between fiber and matrix. But due to molecule moment it reduces the frictional resistance. So it could reduce the heat loss and also it is due to poor interfacial bonding between clay/matrix/fiber. Composite with 1–2 wt% in the glassy region has less value compared to remaining wt% but composite with lower wt% shows good adhesion between fiber and matrix. Because temperatures range between 45 and 55 °C composite with lower wt% does not show sudden drop. This indicates addition of nanoclay increases the adhesion between fiber and matrix and reduces the molecular free moment and increases the frictional resistance. Due to this it increases the heat loss during deformation of materials.

3.2.3 Material Loss Factor or Tan δ

Material loss factor is a ratio of loss modulus to storage modulus and defines the material damping and it is a dimensionless property. It measures how the material dissipates energy. The variation of Tan δ peak is associated with molecule moment and amount of energy dissipation. In composite material, energy dissipation is dependent on fiber/matrix interaction, a molecule moment in the polymer chain, strength of fiber, fiber breakage and crack propagation in composite material. Peak height of the loss factor indicates the material's damping nature. From Fig. 4c it is found that composite with 1 and 2 wt% nanoclay have lower Tan δ peak, which indicates better fiber/matrix adhesion, decreases the molecular mobility and increasing load carrying capacity. This is because addition of nanoclay will act as secondary reinforcement material and also it carries more load and observe a large amount of energy. So it will increase the performance of composite material. Because the addition of nanoclay allows a small amount of energy at the interface. That means, stronger interface will dissipate less energy. So it will increase the stiffness of the material also increase the T_g value of composite material.

This indicates that addition of nanoclay provides better adhesion between the fiber and matrix due to the formation of rough surface on fiber as already discussed. Influence of nanoclay loading on the material loss factor is shown in Fig. 4c. From the results it is observed that composite with 1 and 2 wt% nanoclay has a low magnitude of loss factor compared to the nanoclay free composite. This indicates that addition of nanoclay in composite increases the restriction to molecular free moment. Because Tan δ peak height associated with molecular motion in the polymer chain and the amount of energy dissipation between fiber and matrix. But further addition of nanoclay increases the Tan δ peak high which indicates addition of nanoclay increases the interaction between fiber and matrix. Interesting result is observed from Table 2 is addition of nanoclay in intra-ply hybrid woven composite increases the glass transition temperature due to restriction of molecular free moment. From Table 2, it is found that T_g value from Tan δ is more realistic than loss modulus curve. But nanoclay free composite has the highest peak as nanoclay

Table 2 Peak height and glass transition temperature of nanoclay added composites

wt% (%)	Peak height of Tan δ	Temperature (°C)	
		T_g from Tan δ	T_g from loss modulus
0	0.4007	67.8	45.9
1	0.2219	84.3	60.5
2	0.2126	91.5	64.3
3	0.3273	77.8	58.4
4	0.3337	72.0	53.0
5	0.3916	70.9	50.0

added intra-ply woven composite has better fiber/matrix interaction. Due to this it dissipates more energy than nanoclay composites.

3.2.4 Cole-Cole Plot

Figure 4d shows the Cole-Cole plot of different weight percentage of nanoclay added intra-ply hybrid composites. Adding of nanoclay in the polymer changes the perfect semi-circle into imperfect semicircular shape. It indicates that, nanoclay changes the materiel behavior from homogeneous to heterogeneous. From the results, it can be seen that composite without nanoclay showing perfect semicircle, but composite with nanoclay shows an imperfect semi-circle. Because beginning of the curve is showing imperfect shapes. This is due to the influence of nanoclay addition in the composite. From this it is concluded that nanoclay influences the dynamic mechanical properties of material and affects the Cole-Cole plots shape and behavior of materials.

3.3 Free Vibration Analysis

Three important parameters such as storage modulus, loss modulus and the material loss factor of a material analyzed with the help of dynamic mechanical analyzer gives dynamic properties associated with a material at different temperatures. Any newly developed material will be used to develop structural members for several engineering applications. It is important to predict and analyze natural frequencies and associated modal damping of these structures for the sake of their undesirable behavior during resonance. Modal analysis performed on a structure will give these two basic and important inherent dynamic characteristics of the structure.

In the present work modal analysis is carried out on intra-ply hybrid woven nano composite beam like structure for Fixed-Free and Fixed-Fixed boundary condition. From the free vibration analysis, natural frequency and damping factor associated with the first three bending modes are obtained for different intra-ply hybrid nano composite in order to investigate the influence of nanoclay loading on the free vibration behavior. A rectangular specimen of size 170 mm × 17 mm × 3 mm is used for the free vibration analysis. The beam is excited with the help of turned impact hammer and vibration response is obtained using a less weight accelerometer. The less weight accelerometer is chosen particularly to avoid the added mass effect of the sensor on the light weight composite. The vibration response obtained for the impulse hammer excitation at five different chosen locations is given as an input to DEWETRON, modal analysis software, through DEWESoft data acquisition system. The modal analysis will give the mode shapes and its natural frequency and associated modal damping factor using circle fit method. Equation 1 used to calculate the damping ratio which is given below

$$\xi = \frac{\omega_2^2 - \omega_1^2}{2\omega_0\left[\omega_2 \tan\frac{\alpha_2}{2} + \omega_1 \tan\frac{\alpha_1}{2}\right]} \tag{1}$$

where, ω_0 refers angular frequency at resonance, ω_2, ω_1 are angular frequencies, α_1, α_2 are angle between angular frequencies.

Table 3 shows the influence of different wt% of nanoclay addition on free vibration characteristic of intra-ply hybrid woven nanocomposite for Fixed-Free and Fixed-Fixed boundary conditions. From Table 3, it is seen that the addition of nanoclay increases the natural frequencies up to 2 wt% of nanoclay for both the boundary conditions. Further addition of nanoclay in the composite decreases the frequency, but it always higher than the composite without nanoclay. Because nanoclay addition enhances the polymer composite while loading and nanoclay added polymer carry more amount of stress and allows a small amount of stress between the fiber and matrix interface. Due to this intra-ply hybrid woven composite with 2 wt% nanoclay gives lower damping value than the other combination. Because of this, energy dissipation in the nanoclay polymer composite and its strong interface is less than composite without nanoclay. Therefore, it is concluded that less energy dissipation decreases the inherent damping of the material. But higher wt% nanoclay composite increases the fiber/matrix interaction and provided the frictional resistance and mechanical interlocking due to large surface area. Because of this reason, higher wt% nanoclay composite gives better inherent damping property than composite with lower wt% (Rajini et al. 2013). In general addition of nanoclay increases the natural frequency of intra-ply hybrid composite compared to the composite without nanoclay. Because the addition of nanoclay increases the modulus of intra-ply hybrid composite than nanoclay free composite and further adding nanoclay results in decreasing natural frequency but always higher than composite without nanoclay. Because at higher wt% composite will lose their stiffness due to agglomeration and poor fiber/matrix interaction. Due to this large stiffness variance in fiber/matrix interface, higher wt% added polymer composite increases the internal damping. It is evident from Table 3.

Table 3 Influence of nanoclay loading on natural frequency and damping factor for intra-ply hybrid composite

Beam	wt% (%)	Mode 1		Mode 2		Mode 3	
		Natural frequency (Hz)	Damping factor	Natural frequency (Hz)	Damping factor	Natural frequency (Hz)	Damping factor
Fixed-free	0	34	0.173	229	0.045	600	0.025
	1	39	0.159	239	0.038	644	0.024
	2	44	0.133	253	0.043	693	0.047
	3	39	0.102	250	0.045	688	0.032
	4	35	0.162	234	0.051	644	0.053
	5	34	0.179	200	0.063	590	0.058
Fixed-fixed	0	219	0.151	565	0.093	1137	0.055
	1	234	0.094	610	0.069	1171	0.043
	2	254	0.061	678	0.063	1298	0.041
	3	252	0.096	644	0.086	1206	0.058
	4	239	0.109	639	0.089	1220	0.066
	5	215	0.197	551	0.087	1137	0.099

Natural frequencies evaluated experimentally are compared with numerical and analytical solution by assuming the composite as quasi-isotropic material. Commercial available finite element software ANSYS is used for the numerical analysis and beam is modeled using four noded structural shell element SHELL 181 in ANSYS by giving the equivalent Young's modulus (based on the flexural modulus), density (based on mass) of the laminates and assuming a poison ratio of 0.3. The expression used for analytical method given by Thomson et al. (2008) for bending mode frequency of ith mode based on Euler-Bernoulli hypothesis is

$$\omega_i = \beta_i^2 \sqrt{\frac{EI}{\rho AL^4}} \text{ rad/s}$$

where, E = Young's modulus (N/m^2), A = Cross-section area of beam (m^2), ρ = Density of composite material (kg/m^3), I = Moment of inertia (m^4), L = Length of composite specimen (m), β value for first three modes of Fixed-Free condition is 1.875, 4.694, 7.854 and Fixed-Fixed condition is 4.73, 7.8532 and 10.995 (Thomson et al. 2008). Table 4 shows comparison of experimental results with the results of analytical and finite element methods for the intra-ply woven hybrid composite with 2 wt% of the nanoclay. Experimentally obtained natural frequencies are in good agreement with the natural frequencies evaluated based on analytical and finite element methods as seen in Table 4.

Similar to the mechanical properties and dynamic mechanical properties variation with nanoclay, free vibration frequencies and modal damping factors of the intra-ply hybrid woven composite beam also reduces when wt% of the nanoclay is above 2.

Table 4 Comparison of natural frequency (Hz) of nanoclay added intra-ply hybrid composite for first three mode with analytical and finite element methods

Boundary condition	Experimental			Analytical			FEM method		
	Mode			Mode			Mode		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Fixed-free	44	253	693	40	247	692	40	249	695
Fixed-fixed	254	678	1298	235	647	1268	236	632	1227

4 Conclusion and Future Work

Influence of addition of the small amount of nanoclay as secondary reinforcement in intra-ply woven natural fiber hybrid composite's mechanical properties, dynamic mechanical and free vibration characteristics are analyzed. Results revealed that, inclusion of nanoclay in the intra-ply hybrid polymer composite influences the material inherent properties and hence changes mechanical behavior significantly. Results also revealed that addition of nanoclay upto 2 wt% increases the mechanical properties. Further addition of nanoclay in the composite decreases the stiffness of the composite material, but higher than composite without nanoclay. From the dynamical mechanical analysis, it is found that addition of nanoclay increases the glass transition temperature however it reduces the material loss factor. Natural frequencies associated with beam like intra-ply woven hybrid composites increases nanoclay addition till 2 wt% then it reduces however, modal damping behavior is reverse to that of natural frequency variation.

- Exploring the possibilities of using natural fiber woven fabric reinforced polymer nano composite in consumer goods and structural applications.
- Improving the properties of the composite by sandwiching the natural fiber woven fabric polymer nano composite between composite facing layers.
- Improving the mechanical behavior of the composite by replacing the weak natural fiber with glass fiber in the intra-ply woven fabric.

Acknowledgments Authors wish to thank Department of Science and Technology-India for funding through SR/FTP/ETA-64/2012 and also wish to thank Material Characterization Lab, Department of Mechanical Engineering, NITK, Surathkal for allowing us to carry out tensile and flexural tests.

Compliance with Ethical Standards

Funding: This study was funded by SERB-Department of Science and Technology, India. (SR/FTP/ETA-64/2012).

Conflict of Interest: We declare that we have no conflict of interest.

References

Abenojar, J., Martnez, M., Pantoja, M., et al.: Epoxy composite reinforced with nano and micro sic particles: curing kinetics and mechanical properties. J. Adh **88**, 418–434 (2012)

Barick, A., Tripathy, D.: Effect of organically modified layered silicate nanoclay on the dynamic viscoelastic properties of thermoplastic polyurethane nanocomposites. App. Clay. Sci. **52**, 312–321 (2011)

Behera, A.K., Avancha, S., Sen, R., et al.: Development and characterization of nanoclay-modified soy resin-based jute composite as an eco-friendly/green product. Poly. Plas. Technol. Eng. **52**, 833–840 (2013)

Boumbimba, R.M., Ahzi, S., Bahlouli, N., et al.: Dynamic mechanical properties of pmma/organoclaynanocomposite: experiments and modeling. J. Eng. Mat. Tech. **133**, 030908 (2011)

Bozkurt, E., Kaya, E., Tanoglu, M.: Mechanical and thermal behavior of non-crimp glass fiber reinforced layered clay/epoxy nanocomposites. Comput. Sci. Technol. **67**, 3394–3403 (2007)

Chan, M.I., Lau, K.T., Wong, T.T., et al.: Mechanism of reinforcement in a nanoclay/polymer composite. Compos. Part B Eng. **42**, 1708–1712 (2011)

Chandradass, J., Kumar, M.R., Velmurugan, R.: Effect of nanoclay addition on vibration properties of glass fibre reinforced vinyl ester composites. Mater. Lett. **61**, 4385–4388 (2007)

Fu, S.Y., Feng, X.Q., Lauke, B., et al.: Effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate polymer composites. Compos. Part B Eng. **39**, 933–961 (2008)

Galooyak, S.S., Dabir, B., Nazarbeygi, A., et al.: The effect of nanoclay on rheological properties and storage stability of sbs-modified bitumen. Petr. Sci. Technol. **29**, 850859 (2011)

Gracida, J., Perez-Guevara, F., Cardoso-MartNez, J.: Thermal and dynamic mechanical properties of binary blends of bacterial copolyester poly (hydroxybutyrate-co-hydroxyvalerate)(PHBHV) with poly (2-hydroxyethylmethacrylate)(PHEMA). J. Mater. Sci. **40**, 2565–2567 (2005)

Haddad, Y.M: Mechanical Behaviour of Engineering Materials: Volume 2: Dynamic Loading and Intelligent Material Systems. Springer Science & Business Media (2013)

Haq, M., Burgueno, R., Mohanty, A.K., et al.: Hybrid bio-based composites from blends of unsaturated polyester and soybean oil reinforced with nanoclay and natural fibers. Comput. Sci. Technol. **68**, 3344–3351 (2008)

Haq, M., Burgueno, R., Mohanty, A.K., et al.: Processing techniques for bio-based unsaturatedpolyester/clay nanocomposites: tensile properties, efficiency, and limits. Compos. A Appl. Sci. Manf. **40**, 394–403 (2009)

Huang, X., Netravali, A.: Characterization of flax fiber reinforced soy protein resin based green composites modified with nano-clay particles. Compos. Sci. Technol. **67**, 2005–2014 (2007)

Huang, X., Netravali, A.: Biodegradable green composites made using bamboo micro/nanofibrils and chemically modified soy protein resin. Compos. Sci. Technol. **69**, 1009–1015 (2009)

Jacob, M., Thomas, S., Varughese, K.T.: Mechanical properties of sisal/oil palm hybrid fiber reinforced natural rubber composites. Compos. Sci. Technol. **64**, 955–965 (2004)

Jawaid, M., Khalil, H.A., Bakar, A.A.: Woven hybrid composites: tensile and flexural properties of oil palm-woven jute fibres based epoxy composites. Mater. Sci. Eng. A **528**, 5190–5195 (2011)

Jo, B.W., Park, S.K., Kim, D.K.: Mechanical properties of nano-mmt reinforced polymer composite and polymer concrete. Constr. Build. Mater. **22**, 14–20 (2008)

Joshi, S., Drzal, L., Mohanty, A., Arora, S.: Are natural fiber composites environmentally superior to glass fiber reinforced composites? Compos. A Appl. Sci. Manf. **35**, 371–376 (2004)

Kostopoulos, V., Vellios, L., Philippidis, T.P., et al.: Dynamic mechanical analysis of a two-dimensional carbon-carbon composite. J. Mater. Sci. **28**, 5495–5499 (1993)

Kumar, M., Arun, S., Upadhyaya, P., et al.: Properties of pmma/clay nanocomposites prepared using various compatibilizers. Int. J. Mech. Mater. Eng. **10**, 1–9 (2015)

Liu, W., Liu, B., Wang, X.: Morphology, rheological properties, and crystallization behavior of polypropylene/clay nanocomposites. Int. J. Poly. Mater. **62**, 164–171 (2013)

Pothan, L.A., Thomas, S., Groeninckx, G.: The role of fibre/matrix interactions on the dynamic mechanical properties of chemically modified banana fibre/polyester composites. Compos. A Appl. Sci. Manf. **37**, 1260–1269 (2006)

Rajini, N., Jappes, J.W., Jeyaraj, P., et al.: Effect of montmorillonite nanoclay on temperature dependence mechanical properties of naturally woven coconut sheath/polyester composite. J. Rein. Pla. Com **32**, 811–822 (2013)

Thomson, W.T., Dahleh, M.D., Padmanabhan, C.: Theory of Vibrations with Applications, 5th edn. Pearson Education, India (2008)

Venkateshwaran, N., Elaya Perumal, A., Alavudeen, A., et al.: Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites. Mater. Des. **32**, 4017–4021 (2011)

Wang, L., Wang, K., Chen, L., et al.: Preparation, morphology and thermal/mechanical properties of epoxy/nanoclay composite. Compos. A Appl. Sci. Manf. **37**, 1890–1896 (2006)

Yasmin, A., Luo, J., Abot, J., et al.: Mechanical and thermal behavior of clay/epoxy nanocomposites. Comput. Sci. Technol. **66**, 2415–2422 (2006)