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REVIEW

Dynamic mechanical properties of natural fiber composites—a review

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Abstract

Natural fiber composites have become a new tradition as an alternative to conventional materials. To meet this new tradition material testing, newer techniques have been set up that are termed as dynamic mechanical analysis (DMA), which is an adaptable methodology that accompanies the more traditional techniques. Through these techniques, it is summarized that interconnected bonds between reinforced natural fibers within different matrix materials will affect the dynamic variables like storage modulus (E′), loss modulus (E″), and damping factor (tan δ), and also, it was stated that these are temperature dependent. The dynamic variables were unfavorably affected by the improvement in the length of fibers and fiber loading, but geometric changes (developments) were not considered. Frequent uncertainties in the dynamic loading in any structure are because of noises, shocks, winds, tides in the ocean and some of the live and imbalanced loads, etc. Much importance was given to vibration damping parameters for structural applications in order to have an improvement in the effectiveness, performance, and freeness in some of the building constraints. In this review, the employability of different natural fibers in forming composites with different matrix materials and the impact of fiber length, chemical treatment, and compositions on the dynamic mechanical characteristics were discussed in detail.

Keywords Natural fiber · Dynamic mechanical analysis (DMA) · Storage modulus (E′) · Loss modulus (E″) · Damping factor (tan δ) · Chemical treatment

1 Introduction

Natural fiber-reinforced composites have turned out to be well known for a diversity of uses due to their improved specific strength, specific modulus, bio-degradability, eco-friendly, and eco-efficiency natures [1–6]. Biodegradability is one of the important criteria which are gaining the concentration of all the sectors, and this special property of natural fibers/filaments plays an essential part in the increased future use of natural fiber composites [7]. With the utilization of a different variety of fibers used (artificial (man-made)/natural), life cycle of a composite component is shown in Fig. 1.

Also, natural fiber strengthened ecofriendly polymer composites materialized to have an extremely brilliant features for a wide scope in future applications [8]. Figure 2 demonstrates the type of biocomposites available with their biodegradability. Also, it shows the type of matrix and natural fiber available to prepare different combinations of bio-composites [8]. Many of the natural filaments, such as Sisal (*Agave sisalana*), Banana (Musa sepientum) and Roselle (*Hibiscus sabdariffa*), Sisal and banana (hybrid), Roselle and banana (hybrid), and Roselle and sisal (hybrid), were incorporated in the powder format along with the polymer(s) and are utilized in the fabrication of composites using molding method. And many more types of natural fibers and bio-polymers have benefits in the field of composites [9].

Usually, composites rely on the use of manmade fibers, but many of the researches showed us that natural fibers can be easily replaced with these manmade fibers and the use of naturally available fibers is of current interest.

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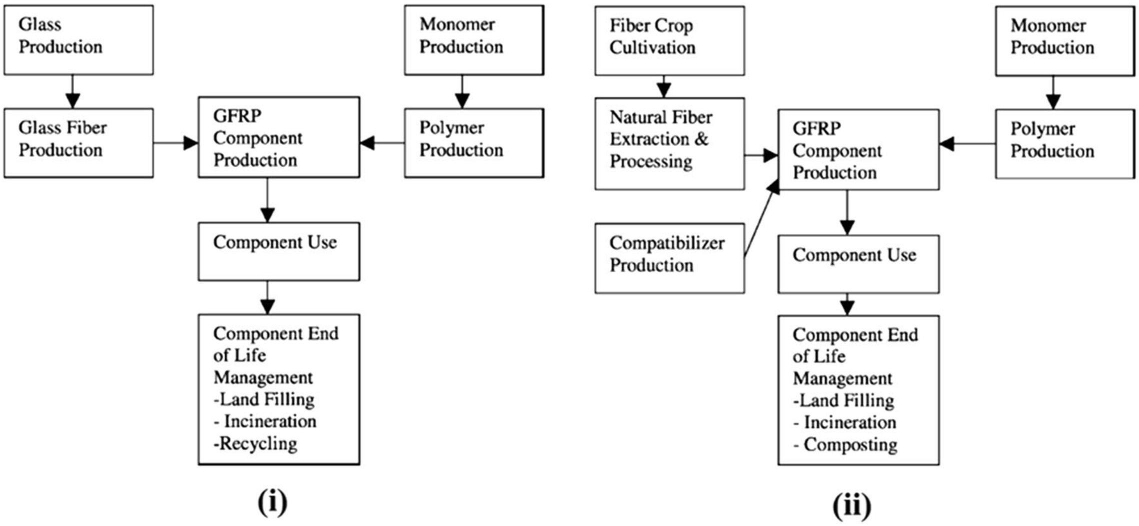


Fig. 1 Life cycle of (i) glass fiber-reinforced and (ii) natural fiber-reinforced composite component [7]

Natural fiber composites are (mainly) cost-effective products and they will impart negotiable structural characteristics at a comparatively affordable cost. These natural fibers have many superiorities such as being obtained from an inexhaustible resource, they need little energy inputs in their manufacture, and they can be effectively disposed in soil (generally known as composting) or by increasing the calorific value of these materials by treating them in furnace, which is preposterous with glass fibers. Presently, natural fibers as reinforcements in specialized applications are primarily utilized in the automotive, transportation, construction, and packaging industries, where high load-carrying capacity is not required

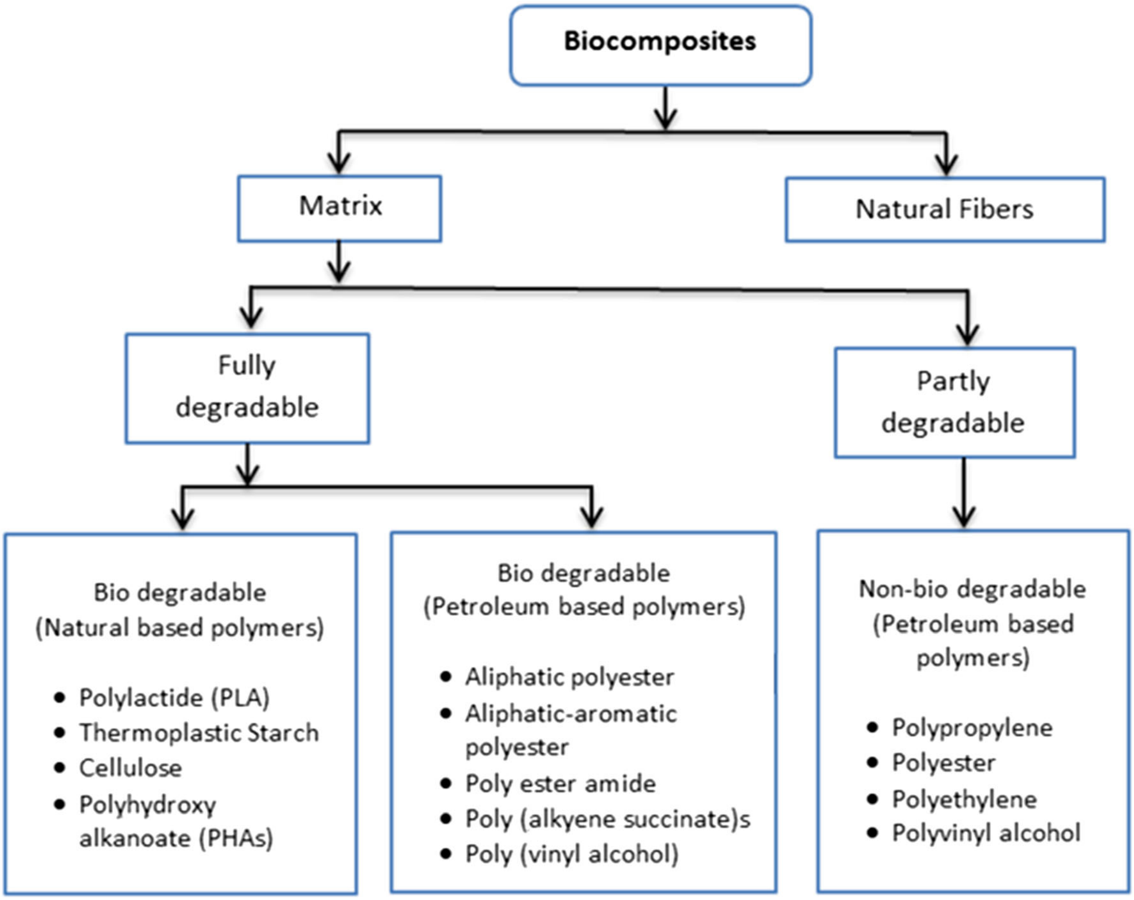


Fig. 2 Classifications of bio-composites [8]

[10]. Meanwhile, natural fiber-reinforced hybrid composites found applications in a variety of automobile accessories such as dashboard, roof panels of cars, door handles, door panels of cars, and many more [11].

The use of bio fibers became a good replacement for the conventional materials like metal, nonmetals, and artificial fibers, for example, glass and carbon fibers, etc. in the enhancement of fundamental natural frequencies [12].

For dynamic mechanical analysis, results were commonly expressed as E′, E″, and loss factor (tan $\delta = E''/E'$) by the several researchers and are presented in the present review paper.

The capacity of the material to withstand the applied load can be called as E′; thus, it describes the specimen's elastic constant. Viscous characteristics of samples were equivalent to lose modulus, and it is proportional to the scattered energy and damping capacity of the material will be summarized by the loss factor.

DMA helps in finding the phase metamorphosis and tranquility activities in different combination material behaviors. Also, it is a better and productive way to study the tranquilities in neat polymer and fiber-incorporated polymers. This technique is also used to find the pertinent tan δ and stiffness of neat and fiber-incorporated composites for a variety of uses [13, 14]. And variations in frequencies, chemical treatment of fibers, and hybridization also affected the dynamic mechanical (DM) properties of NFRPCs [14].

Mechanical responses of material in the dynamic mechanical analysis (DMA) will be examined through dynamic characteristics. Here in this context, as a result of frequency and time dynamic characteristics were evaluated. In DMA, as a function of time, sine waves of stress and strain curves were recorded during the application of vibrating force on to the sample (such response is shown in Fig. 3).

The modulus from DMA is not the same as of Young's modulus from the load-deformation graph or by Hook's law. The inclination of the linear region at the beginning of the load-deformation graph is Young's modulus, but here in DMA, the complex modulus is studied through the response of materials to sine wave loading. This modulus is the ratio of stress and strain of the material which is in the testing condition. The measure of complex modulus can be expressed as [14, 15]

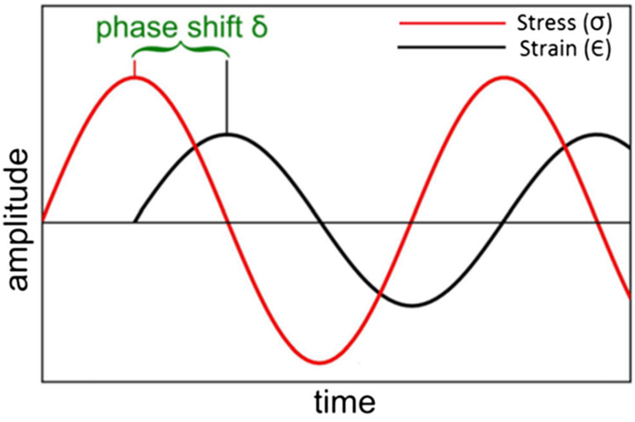


Fig. 3 Sinusoidal oscillation and its response [14]

$$\text{Complex (Young's) modulus (E)} = \sigma/\varepsilon \tag{1}$$

Further,

$$E = E' + i\,E'' \tag{2}$$

In eq. (2), real part of complex modulus is named as storage modulus (E′) and the imaginary part (E″) is called as loss modulus. From Fig. 4 also, it is possible to define E′ and E″ as response values for the dynamic properties. The following dynamic mechanical characteristics of materials can be obtained using DMA.

In one cycle of oscillation, the material which sores the maximum energy is termed as E′ and also gives the stiffness behavior (temperature-dependent) and load-bearing ability of the composites. It could be expressed as given in eq. (3); [14, 15]

$$\text{Storage modulus } (E') = E \cos \delta \tag{3}$$

In one cycle of sinusoidal load, the rate of energy disseminated as heat by the materials is named as loss modulus; it also represents the viscous response of the composites. Through the E″ curve peak, it is possible to identify the dynamic transition temperature for the composites. Equation (4) gives the mathematical formula for the loss modulus. [14, 15]

$$\text{Loss modulus } (E'') = E \sin \delta \tag{4}$$

Molecular mobility of the composites could be related to damping and is characterized as a relationship between E′ and E″ of the material (eq. (5)). The larger estimation of tanδ is described through high non-flexible nature, but the low estimation of tan δ shows a highly versatile nature of the material. [14, 15]

$$\tan \delta = E'/E'' \tag{5}$$

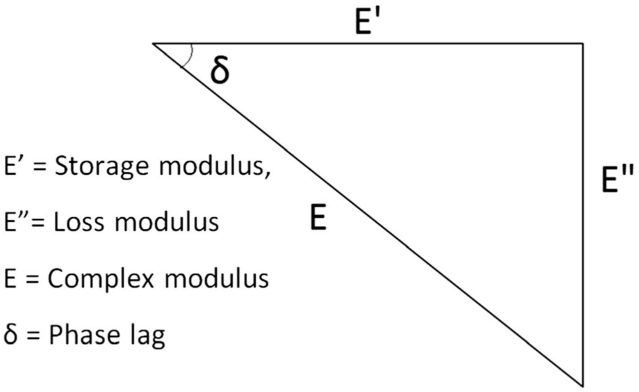


Fig. 4 Complex modulus of DMA [14]

To make use of natural fibers in our day-to-day life, a feasible arrangement of entire components of natural fibers must be combined with artificially available matrix materials (as shown in Fig. 5) which are derived from petroleum or renewable resources.

2 Dynamic mechanical properties

2.1 Laminated composites

Combination of the different number of fibrous mats/layers prepared with different orientation of fibers in it will be combined as one component by keeping these prepared mats/layer one over the other at different orientations will give us the laminated composites. These laminated composites will be having directional stability and strength as compared to normal composites. Figure 6 shows the typical laminate composite with inter-laminar damping layers. And Fig. 7 describes the fabrication process involved in the preparation of laminated composites for different applications in the engineering streams.

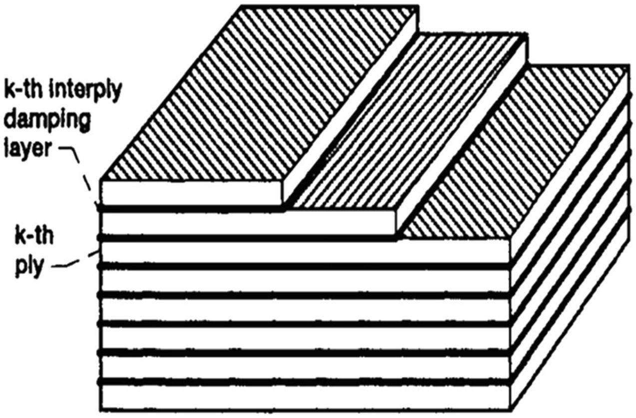


Fig. 6 Laminates with inter-laminar damping layers, typical laminate configuration [17]

Due to the wide usage of composites in many of the mechanical applications, several tests are important to identify the capacity of the composites prepared. Among several tests, the determination of mechanical and dynamic properties plays a key role in the different structures and applications. A few of the dynamic mechanical results were exhibited in this chapter. Some of the dynamic properties predicted as modal damping in laminated composite plates as simply supported sample

Fig. 5 Structure of natural fiber [16]

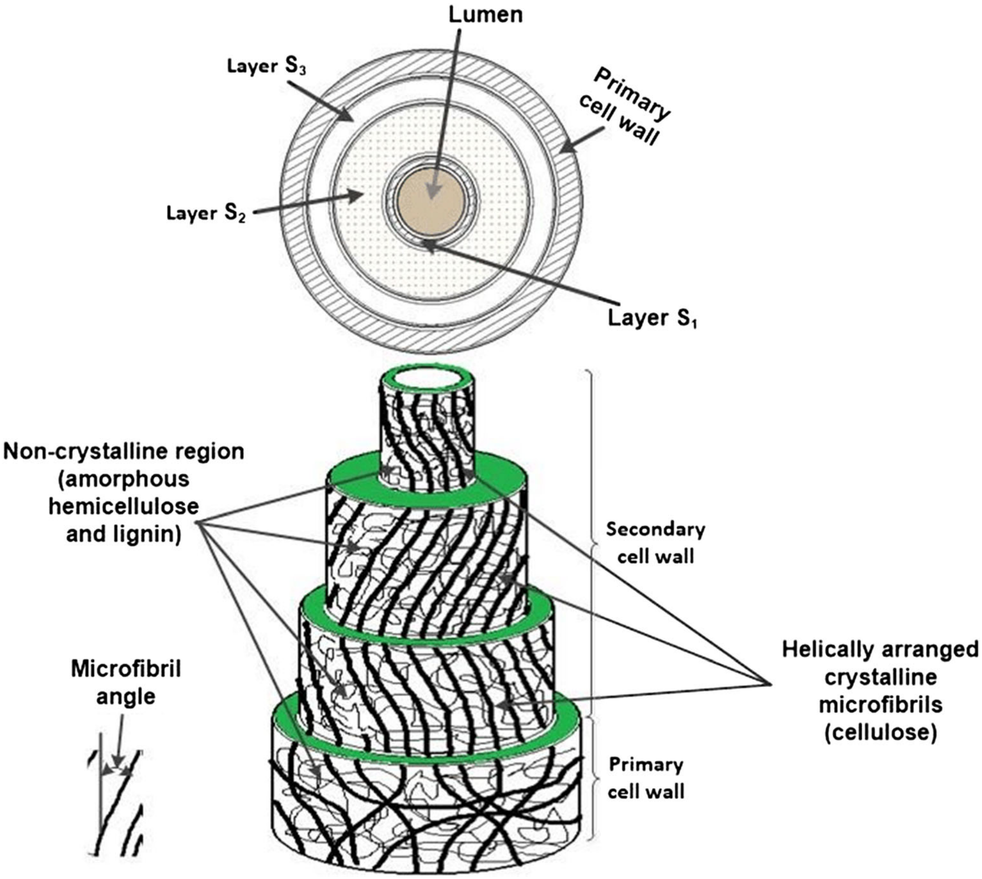
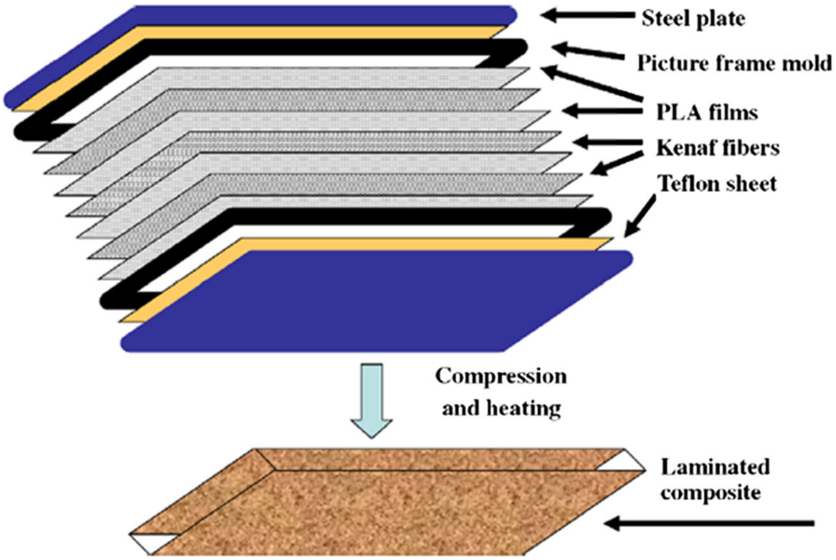


Fig. 7 Fabrication procedure of laminated composites [18]



with damping layers through separate sheet damping mechanics in connection with a semi mathematical method were presented [17].

Composite laminates made of jute fibers as a non-woven fabric (untreated and chemically treated with cyano-ethyl) and polyester were studied for dynamic mechanical thermal characteristics over a predominant range of temperature. The E′ of the prepared samples was found to increase extensively due to the cyano-ethylation of fibers. Also, increased stiffness and E′ were observed for composites fabricated with surface-modified fibers as measured to raw fiber-reinforced composites. And remarkable fall in the peak of the tan δ was noticed for composites with jute fiber (both chemically treated and untreated) and unsaturated resin [19].

With a special concentration on the variation of fiber volume fractions, sequencing in layers and architecture of the fabrication architecture for dynamic analysis of banana and glass woven fabric reinforced polyester composites have been studied. And from these reinforcements, it was demonstrated to be a useful consolidation in conferring high strength to polyester. The E′ and E″ curves showed the highest value (3.5 GPa and 0.19 MPa) for composites with four layers of the fabric and additional peaks with an increase in the number of layers, respectively. Improved fiber/matrix interaction was observed with the addition of maximum fabric layers [20].

As a function of temperature (20–100 °C), dynamic mechanical characteristics were analyzed for bio-composite laminates made of PLA and kenaf fibers with the help of DM Analyzer (TA 2980) arranged with dual-cantilever bending fixture at a frequency of 1 Hz and a constant heating rate of 5 °C/min. Through this, it is noticed that the chemically altered fiber-reinforced composites have enhanced E′ rate with higher flexural modulus.

An increment in the E′ value was noticed for the chemically treated fiber (silane-treated) (FIBNASI) composites as compared to others. Composite made with surface-modified fibers had shown better E′ of 8000 MPa which is double the value of unsaturated fiber composites (4000 MPa). This indicates the better bond between the surface-modified kenaf fibers and matrix. From these DMA results, improvement in thermal stability (0.2 tan δ at 68 °C) that is obtained by the addition of silane-treated fibers in composites was observed [18].

Wood fiber ply and PLA film-reinforced composites exhibited 63 to 66% of experimentally determined damping properties, meanwhile with these values, young's modulus of the wood-fiber mat (0.44 GPa for dry condition and 0.34 GPa for humid condition) and PLA (0.78 GPa for dry condition and 0.68 GPa for humid condition) film were determined [21].

With the new vibration-damping method, thermoplastic composites based on polypropylene/natural fibers (like kenaf, hemp, flax) and glass fiber composites had been studied to describe nature at higher frequencies. In this study, it was observed that NFC has damping characteristics that are greater than GFC at the elevated compression range (e.g., thickness 2 mm), decreased trends were reported for lower compaction. With these results, it was concluded that given potential replacements, NFCs could be used in place of GFCs in many engineering applications by the contrast of mechanical and dynamic characteristics [22]. And adaptability of natural fiber composites made of flax and Cordenka epoxy for high-performance structural applications were tested. Woven flax and reconstructed cellulose (Cordenka) textiles were soaked in commercially available resin to form laminated composites, and through them, dynamic properties were analyzed. These properties were analyzed through SEA (specific energy absorption), and in this test, SEA was found to be diverse between 21.2 and 34.2 kJ/kg [23]. Kenaf fiber/HDPE composites have shown increased storage and loss moduli with growth in the fiber loading when tested using the DMA model Q800 (Supplied by TA Instruments, USA) in the narrow film form. The increased value of E′ (16.15 GPa) and E″ (625 MPa) at HPT was achieved in these composites with a weight percentage of 17.5 fiber in the composites as compared to other combinations. And for higher values of fiber loading 17.5% intensified at LPT exhibited reduced value of E′ (4.05 GPa) and E″ (152 MPa) [24].

Untreated and chemical treated coconut sheath incorporated in epoxy composites were tested to determine the DM properties like E′ and damping parameters. From the dynamic mechanical tests, a higher value of E′ (3.2 GPa) was noticed for treated coconut sheath epoxy (TCSE) composites because of better intermolecular bonds in hydroxyl groups. And also the higher amount of stiffness was achieved from this as compared to untreated coconut sheath epoxy (UTCSE) composites. Loss factor for untreated fiber composites (0.3248) has been found elevated than that of treated fiber composites (0.2692) at a temperature of 84.1 °C and 82.4 °C, respectively. This is because of restrictions on the polymeric molecule movements, and this raises the E′ of the chemically treated fiber composites [25]. Figure 8 shows the categorized, organically fabricated coconut sheath and the construction of fiber in coconut sheath.

Experimental and numerical analysis was made of sandwich fascia embraced of 3-thin layer composite including a reusable, pre-peg consistent foam core and two face sheets made of flax-PE for the panel A, glass-PP for the panel B to identify the dynamic behavior. Lower natural frequencies were noticed because of lower elastic moduli of Flax-PE face sheets ($E_1 = 12.3$ GPa, $E_2 = 1.1$ GPa, $G_{12} = 0.85$ GPa, $\upsilon_{12} = 0.1$) and the glass-PP ($E_1 = 29.0$ GPa, $E_2 = 5.0$ GPa, $G_{12} = 2.70$ GPa, $\upsilon_{12} = 0.24$). The main concern in this work was about the damping values of sandwich panels, which were found to be doubled (in all ranges of frequencies) than the other panels investigated in this work. And numerical values were quite relevant to the experimental results; it was highlighted that a numerical model with a congruent core is sufficient to understand the global dynamic behavior of a configuration for the few of the basic modes [28].

Cotton waste from textile industries and unsaturated polyester were fabricated to make laminates and the performance of glass (G)/cotton (C) fiber is evaluated by dynamic mechanical properties. And it was found that at low temperature, the E′ of these laminates with distinct stacking sequences increases with glass fiber content. Decrement in loss factor values (443 MPa and 275 MPa) and higher T_g (transition temperature) (112 °C and 114.3 °C) qualities were accounted for the $[C/G/\bar{G}]$s and the [G/C/C]s test specimens, respectively, which jointly with the $[G/C/\bar{G}]$s test samples exhibited more prominent reinforcement adequacy and lower loss modulus peak height (0.12 at T_g 113.5 °C) [29]. In the jute/carbon fabric-reinforced laminate composite, laminates were prepared by varying the position of layers of two plies of jute fabric and two plies of carbon fabrics and are tested for dynamic mechanical properties with increasing temperature. Obtained results indicated that composites with carbon fabric outer layer had shown the highest storage (14 GPa) and E″ (2 GPa) [30].

2.2 Hybrid composites

As hybrid laminates with E-glass or N-glass chopped filament mats (CSMs) and jute (J) fabrics as fibers and amine-cured epoxy resin were arranged and examined for DMA at a steady frequency of 1 Hz, jute-reinforced composites resulted in slightly lower E′ as compared to glass-reinforced composites. And also, E′ values of hybrid composites (glass–jute) fall between 6 and 4 GPa, and for glass-reinforced composites, it was 7 GPa and 3.8 GPa for jute-reinforced composites [31]. Similarly, flax and hemp-fiber-reinforced polypropylenes (PPs) revealed that the properties like stiffness and E′ of the composite material will purely depend on the type of coupling agents (such as AR504 and HC 5) used in the fabrication of the composites [32].

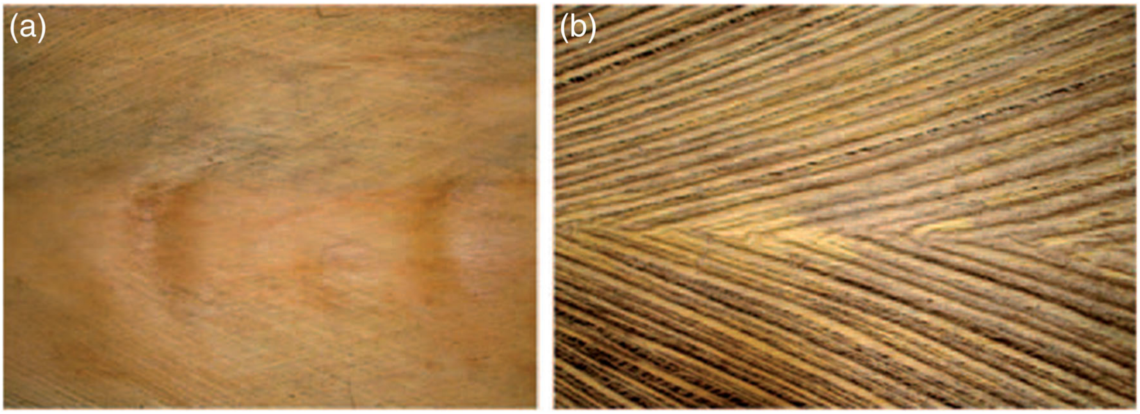


Fig. 8 **a** Sized naturally woven coconut sheath, **b** architecture of fibers in coconut sheath [26, 27]

Oil palm fiber-reinforced phenol-formaldehyde (PF) composites, oil palm/glass hybrid fiber-reinforced PF composites, and neat PF composites demonstrated the fall in the dynamic modulus properties as well as natural frequencies. After adding fibers, enhanced tan δ values and E′ were observed and these values are found to be growing with fiber percentage. The E″ demonstrates a reverse nature with an improvement in fiber loading percentage. Hybrid composites had revealed that the highest mechanical damping and reduced E′ values than the hybridized oil palm fiber/PF composite and also, the same tendency was noticed for E″ [33]. Banana–glass woven fabric-reinforced polyester composites have been fabricated and special attention was given to study the E′ [20]. These composites have shown improvements in the rubbery plateau, which indicates reinforcing effects due to the incorporation of fabrics. And higher E′ (3.5 GPa) was found for the composites with four layers. A slight difference was observed for E″ in gum (neat polyester), 3-layered and 4-layered composites (0.2, 0.198, 0.19 MPa, respectively).

Hybrid composite consisting of equal amount of kenaf fibers (KFs) and wood flour (dust) (WF) as the reinforcements in polypropylene (PP) to form PMCs and they were studied for dynamic mechanical properties, and it was noted that, at the transformation temperature (10 °C), the KF composite exhibited an impressive growth in the tan δ (0.07) value, WF composite and the hybrid composite showcased greater damping values at elevated temperatures. Enhancement in E′ (5.6 GPa) and E″ (0.27 GPa) values was observed for only KF-reinforced polymer composites as the temperature increases, whereas WF and hybrid composites exhibited poor results [34]. Concerning an enhancement in the weight fraction of the sisal and oil palm fibers in the natural rubber improved E′ (755.4 MPa) and low tan δ (0.899) was achieved. This is because of expansion in the stiffness, which is communicated through a higher amount of natural fiber content. Also, the effect of surface treatment by studying through alkali treatment with different proportions such as 0.5, 1, 2, and 4%. Fibers imparted through chemical treatment have shown increased E′ (3.5 MPa) and E″ (2.5 to 3 MPa). Damping characteristics were found to be decreasing for loading condition but E″ was found to be increasing [35].

Hybridized thermoplastic natural rubber (TPNR) with carbon fiber (CF) and kenaf fibers (KF) has been studied for dynamic mechanical characteristics. The actual performance of TPNR-reinforced chopped CF and KF hybrid composites was revealed in DMA. In this work, it was observed that the raw hybrid composites showed improved E′ and E″ values and higher tan δ values in comparison with the surface-modified composites. Poor properties were recorded in DMA due to a decreased fiber aspect ratio, and irregular orientation of fibers [36].

Maleic anhydride grafted polypropylene (MAPP) reinforced with bamboo and glass fiber (BGRP) hybrid composites were studied for DMA and obtained results exhibited that an improvement in the E′ (15 kPa) which indicates the improved stiffness in hybrid composites (PP + 15% bamboo fiber + 15% glass fiber + 2% MAPP) when matched with raw fiber-reinforced composites, and E″ of 0.8 kPa. Also, tan δ spectra exhibited firm control (0.92) of fiber content and coupling agent on α and γ relaxation process of polypropylene [37]. Using DMA, measurement of viscoelastic parameters has been determined and obtained results reveal the growth in the E′ (15 kPa) for the increase in the fiber content by 15% and MAPP (2%) also hybridization with artificial fibers (glass) [38]. Similarly, polypropylene (PP) reinforced with short sisal and glass fiber hybrid composites (15% sisal and 15% glass fiber loading in the presence of 2% MAPP) with and without a coupling agent (maleic anhydride grafted PP (MAPP)) have exhibited improved results after treatment of fibers with MAPP. And tests have revealed that the addition of fibers and MAPP had shown extension in the measure of E′ (17.1 kPa); this was considered for hybridization with glass also. And damping properties found to be decreasing with the incorporation of the fibers and MAPP (PP + 15% SF + 15% GF) [39].

Ramie and short jute fiber-reinforced polylactic acid composites have exhibited greater E′ for plain PLA composites. Because of the existence of ramie/jute fibers in the PLA composites, E′ of all samples decreases (ranging from 4000 to 1800 to 100 MPa) with increasing temperature (30° to 60 °C), where the E″ is high (ranging from 800 to 400 MPa between 40° and 60 °C), the maximum heat dissipation occurs at that temperature. The transition temperature of all-fiber-reinforced composites will shift to higher values because of fiber presence. And the damping properties of PLA-based composites will reduce as compared to neat PLA [40].

Glass/sisal hybrid composites with various fiber loadings, distinctive volume proportions between the glass and sisal and impact of fiber length have shown considerable growth in E′ and E″, just as a shift to higher qualities for higher glass loading and comprehensive fiber volume. And also, it was identified that the E′ and E″ diminished with the increase in temperature [41].

Randomly situated informally blended hybrid composites fabricated with pineapple leaf filaments (PALF) and glass filaments (GF) in unsaturated polyester (PER) resin hybrid composites have shown good dynamic modulus with the addition of GF. The intimately mixed (IM) hybrid composites with PALF/GF, 80/20 (0.46 V_f GF) exhibited improved E′ (5350 MPa) values and least damping (0.1 at 95 °C). And also, hybrid composites with 0.46 V_f GF or PALF/GF (50/50) revealed the highest damping (0.15 at 150 °C) behavior as compared to other compositions [42]. Curaua/glass hybrid composites have also shown considerably higher E′ (1E9.6 Pa) as compared to neat polyester composite

(1E9.2 Pa). Also, it was seen that a little amount of glass fiber, also, will enhance the E′ and loss moduli [43].

Oil palm empty fruit branches (EFB)/jute fiber-reinforced epoxy hybrid composites were examined for DM properties like E′, E″, and tan δ. From several tests, it was found that E′ decreases as the temperature falls in all cases, and tan δ peak height was least for jute composites and greatest for epoxy matrix (effect of the layering pattern was 36 at 80 °C). And epoxy had lowest E′ (32.5 MPa), pure jute composites have shown the highest E′ (37.5 MPa). Joining of a little amount of jute fibers to oil palm EFB/epoxy composites enhanced the damping properties of the hybrid composite [44].

Naturally available woven coconut sheath/clay strengthened hybrid polyester composites have been studied for the impact of organoclay expansion (1, 2, 3, and 5 wt.%), alkali (ATC), and silane treatment (STC) of the coconut sheath surface on free vibration qualities. From the studies, it was understandable that improved E′ was achieved for chemically surface-modified composites with silane (1.75E + 10 Pa) as compared to alkali (7.5E + 9) and untreated (5E + 9) conditions at room temperature. Also, the addition of nano clay to least filler content ($< 3\%$) in untreated, alkali-treated, and silane-treated conditions shows the improved natural frequency (34, 42, 44 Hz, respectively, for coconut sheath composites) and damping ratios. And the impact of surface preparation on E′ and E″ from DMA was noticed [26]. Hybrid composites made with the synthesis of naturally woven coconut sheath/E-glass/nano clay using unsaturated polyester matrix revealed that the addition of nano clay (2%) improves the damping attributes of the composite because of enhanced stiffness of the matrix by a proper and uniform distribution of clay. In addition, improved free vibration characteristics were noticed for alkali-treated fiber stacking sequence of coconut sheath/coconut sheath/glass composites (natural frequencies: mode 1: 34.18 Hz, mode 2: 230.71, and mode 3: 639.65 Hz and damping: mode 1: 0.08929, mode 2: 0.03439, mode 3: 0.03912) [45]. Glass/bamboo composites had shown a fall in the E′ value by enhancement in the bamboo weight fraction. And, it was seen that E″ will also diminish with loading, whereas damping was established to be barely increasing. Finally, it was concluded that the volume fraction of fiber and percentage of glass fiber supplanted by the bamboo fiber will affect the DM properties of glass/bamboo fiber-reinforced composites [46].

The effect of hybridization was studied for glass/ramie fiber-reinforced composites, a shortfall in the E′ was observed, and this drop is because of the reinforcement of much fiber in the composites. And E″ was found to be decreasing as the temperature increases for 75:25 composites (75% glass and 25% ramie fiber composites). Also, tan δ (mechanical loss factor) was found with diminishing values for the composites with ramie/glass fibers (below 0.4 for all hybrid composites), as compared with the neat resin (0.58) [47]. The same kind of shift was also seen for the case of the oil palm empty fruit bunch (EFB)/woven jute fiber (J_w)-reinforced epoxy hybrid composites, which is the embodiment of the oil palm EFB and woven jute fibers expanded the estimation of E′. It implies that the filaments will expand the epoxy matrix ability to help mechanical bounds with amendable deformation. Stiffness and greater stress transfer were observed in connection with the hybridization of oil palm EFB and woven jute fiber composites. The highest percentage of the E″ was noted for hybrid composites (3 MPa) as compared to pure J_w (2.8 MPa); this indicates that movements in the T_g of the polymer matrix with the expansion of fiber as reinforcing stage demonstrate that fiber is assumed to have the most significant role above T_g. The highest E_{max} (3.6 MPa) (T_g) is noticed for pure J_w, followed by EFB/J_w/EFB, pure EFB, and J_w/EFB/J_w composites. Tan δ found to be decreasing for pure J_w (0.24) and increasing for pure epoxy composites (0.34) [48]. In another study, the amount of E′ of EFB and jute (4:1) hybrid composite is diminishing (3.55 MPa) because as fiber loading increased, stress transfer rate was also expanded. Hybrid composites demonstrated an expanding pattern in E″ after expanding the jute fiber content; however, there is marginally diminishing pattern in the rubbery region in the case of EFB/jute (4:1) hybrid composite. The T_g evaluated from E″ is observed to bring down that of tan δ curves. Tan δ peak height is lower for jute composite (0.24), and hybrid composites contrasted with EFB composite (0.29), which exhibit reduced damping and improved fiber/matrix adhesion in it [49].

Variation in the fiber content of glass and ramie fibers have shown enhanced E′ for all fiber fractions studied (0:100, 25:75, 50:50, and 75:25). And E″ improved with fiber content (E″ for the composites 0:100 was 350 MPa and for 75:25 composite 550 MPa) over the complete temperature range investigated and for all glass–ramie proportions contemplated and reduced damping characteristics were found for all hybrid composites, maximum value was obtained for pure resin [0:100] (0.58) [50].

Alkali-treated PPLSF (palmyra palm leaf stalk fiber) and jute fiber-reinforced hybrid composites have demonstrated less E′ at a higher temperature. An improvement in E′ was obtained when jute fiber content increased in the hybrid composites. Because of effective stress transfer E″ found to be increasing as the jute fiber content increases [51], in this work, the estimation of E′ was observed to be higher for neat resin composite and only jute composites (4700 kPa) accompanied by different compositions have nearby values of E′ at a reduced temperature (for example in the plastic region). The value of E′ was found to be diminishing with the growth in the temperature but for neat resin composites E′ was found to be 2150 kPa at 170 °C after adding jute fibers, the value improved to 3390 kPa for the resin (25%) and jute (75%) composites. Composites completely fabricated with jute fibers showed the maximum value of E″ (3260 kPa) at reduced temperature. E″ for the hybrid (25% resin and 75% jute fibers) composite was observed to be diminishing (3000 kPa) at small temperature (20 °C) and it expanded with the expansion in temperature. E″ was most extreme for this composite at a temperature of 170 °C with 1880 kPa. The maximum value of tan δ (0.58) was noticed for pure resin composites, whereas a reduced value (0.28) for 25% resin and 75% jute fiber composites as compared to all other composites considered in the work.

Chemically modified jute and EFB fibers have shown higher E′ (3.8 MPa) and E″ (2.95 MPa) due to the reduced water-loving property of the fibers, which increased the wettability between fiber-matrix interface bonding. This had increased the stiffness of hybrid composite with high E′. Also, it was observed that the E′ of raw fiber composites has shown poor results (below 3.6 MPa (which is considerably reduced than the other two examples)). 2-HEA modification of EFB and jute fibers cause a reduction in the portability of molecular chain at the interface by a solid collaboration of fiber/matrix and diminished the damping attributes of the hybrid composites were found (less than 0.3) [52].

The fundamental frequency of hybrid sisal-bagasse composite (3.681%) is 1.15 times greater than that of the sisal composite (3.19%). The discrepancy in the tan δ might be because of differences in the flexural stiffness of hybrid sisal-bagasse composite and bagasse composite and changes in the fiber angle yields different dynamic characteristics of the composite. Hybrid sisal-bagasse fabric-reinforced epoxy composites have great tan δ as compared to conventional composites [53].

The impact of varying variables, for example, particle size (4, 6 and 13 μm) and percentage weight (2, 4, 6, 8, and 10 wt%) of red-mud in hybrid composite was established by adding red-mud as auxiliary reinforcing filler with banana fiber-reinforced polyester composites (BFRPCs). The addition of red-mud (with reduced particle size), the larger surface area of red-mud particles resulted in the highest modal damping and inherent modal characteristics of BFRPCs. In the BFRPCs with red-mud of 8 wt% and 6 μm particle sizes, the highest natural frequency (110 Hz) and tan δ (0.11308 for mode 1) were found as compared to other combinations. NaOH and silane-treated fiber with 8 wt% red-mud and particle size 4 μm had exhibited a decline in natural frequency (77.5 and 74.4 Hz) and tan δ (0.3544 and 0.21863 for mode I, respectively) [54].

The impact of inclusion of 1 wt% water absorbing nanoclay on polylactic acid (PLA)/polycaprolactone (PCL)/oil palm mesocarp fiber (OPMF) biocomposites have shown reduced E′ (71 kPa) of biocomposites, this indicates the reduced stiffness of biocomposites, meanwhile increment in the E′ (78 kPa) was observed when fiber percentage was increased. From the loss modulus, it was observed that the inclusion of nano-clay shift two T_g in composites and become close to one and other (7.5 kPa recorded for biocomposites at a T_g of 50 °C). This indicates that the joining of nano-clay shows somewhat similarity in the characteristics as of biocomposites. And, tan δ (2.2) highlighted about the less energy dispersion in hybrid composites as measured with biocomposites (2.8). This shows that the incorporation of clay to biocomposites enhances the fiber/matrix adhesion [55]. Similar results have been found for nano-clay dispersed natural fiber hybrid intra-ply woven banana/jute hybrid polyester composite; in particular, the natural frequency of the composite laminate improves (for fixed-free beam 44 Hz and for fixed-fixed beam 254 Hz) till 2 wt% of nano-clay while the modular damping improves when the wt% of nano-clay is higher than 2 [56].

A worthwhile stress communication (in terms of tensile strength and impact strength) from the matrix to pure and hybrid fibers is registered after the NaOH and trichloro-vinyl silane treatment to fibers. In this work, locating the sisal dominanted hybrids (sisal as main and adjacent layers) and sisal for coconut sheath predominant hybrids (i.e., CSC) by separating the coconut sheath layers exhibited effective stacking. And it was observed that the increment in the natural frequency for pure and hybrid composites with surface-modified fibers, independent of the hybrid fiber, coconut sheath, and sisal fiber composites. The natural frequency enhanced in the following order STC > ATC > UTC for the fiber composites. Different combinations of natural fiber layer orientations has been shown in Fig. 9 [57].

Swan timber beams reinforced with glass fiber-reinforced polymers (GFRP) demonstrated the higher stiffness (21.6%) for a higher amount of reinforcements and a decrease in the tan δ (25 to 40%). The dynamic properties of reinforced timber beams were favorable by the use of GFRP [58].

Dynamic mechanical and free vibration characteristics of jute and banana woven polyester composite with waving pattern and impact of intra-ply hybridization of filaments by arranging them in the warp and weft angles in various compositions were estimated in this work. Enhanced DM properties and good quality T_g values for both jute and banana woven composites were revealed, comparably in the intra-ply hybrid composites with jute fiber along wrap and banana fibers along weft direction (as shown in Figs. 10 and 11) had resulted in higher dynamic mechanical properties (E′ 3.5E + 09 Pa, E″ 2.5E+08 Pa at 80 °C, tan δ 2.4 (less among other combinations)) than other combinations. Also, it was noticed that hybridization by the reinforcement of natural fiber in woven form and intra-ply hybridization improves the E′ and E″ of composites as estimated to short and random fiber-oriented composites for the same quantity of fiber loading. Figure 12 shows the schematic outline of the experimental arrangement with the expectation of free vibration examination [59].

In the hybrid composites made of sisal and jute fiber-reinforced epoxy resin, E′ enhanced with an improvement in the weight fraction of sisal fibers. The highest and diminished

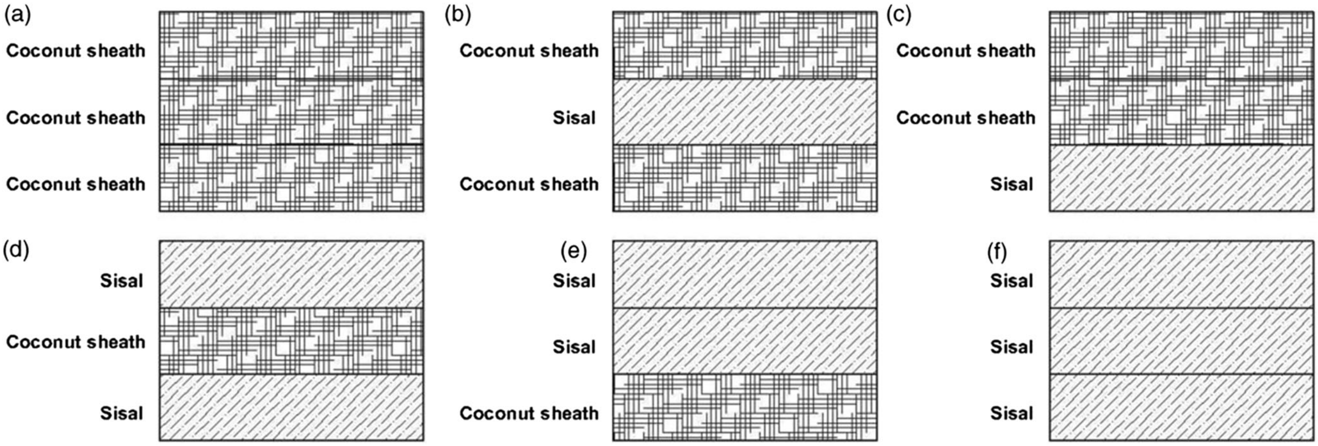


Fig. 9 Different stacking sequences for the coconut (C) or sisal (S) layers: **a** CCC, **b** CSC, **c** CCS, **d** SCS, **e** SSC, and **f** SSS polyester matrix composites [57]

value E′ was observed to be 3500 MPa and 2090 MPa for composite with 30 wt.% of jute fiber and sisal fiber-reinforced epoxy composite (H30) and 30 wt.% of sisal fiber-reinforced epoxy composite (S30), respectively in the glassy region. E″ of these composites (H30 and S30) was found to be increasing (0.525 GPa and 0.286 GPa) initially and then it decreases as the temperature increases; this is due to the mobility of matrix at higher temperatures. The incorporation of a higher amount of sisal fiber content will affect the decrease in the tan δ; lower tan δ (0.278) values corresponding with T_g indicate the good load-bearing capacity of the hybrid composites [61]. But jute/sisal fiber-reinforced epoxy composite was revealed higher E′ (5.10E + 08 Pa), E″ (6.6E + 07 Pa), and tan δ were found to be less (0.31). Epoxy had the highest value of tan δ (0.89) than all composites which show better damping [62].

Sisal and banana fiber-reinforced (randomly) polymer composites exhibited maximum natural frequency as measure with other compositions such as different weight percentage on banana, sisal, and hybrid composite because wt% will

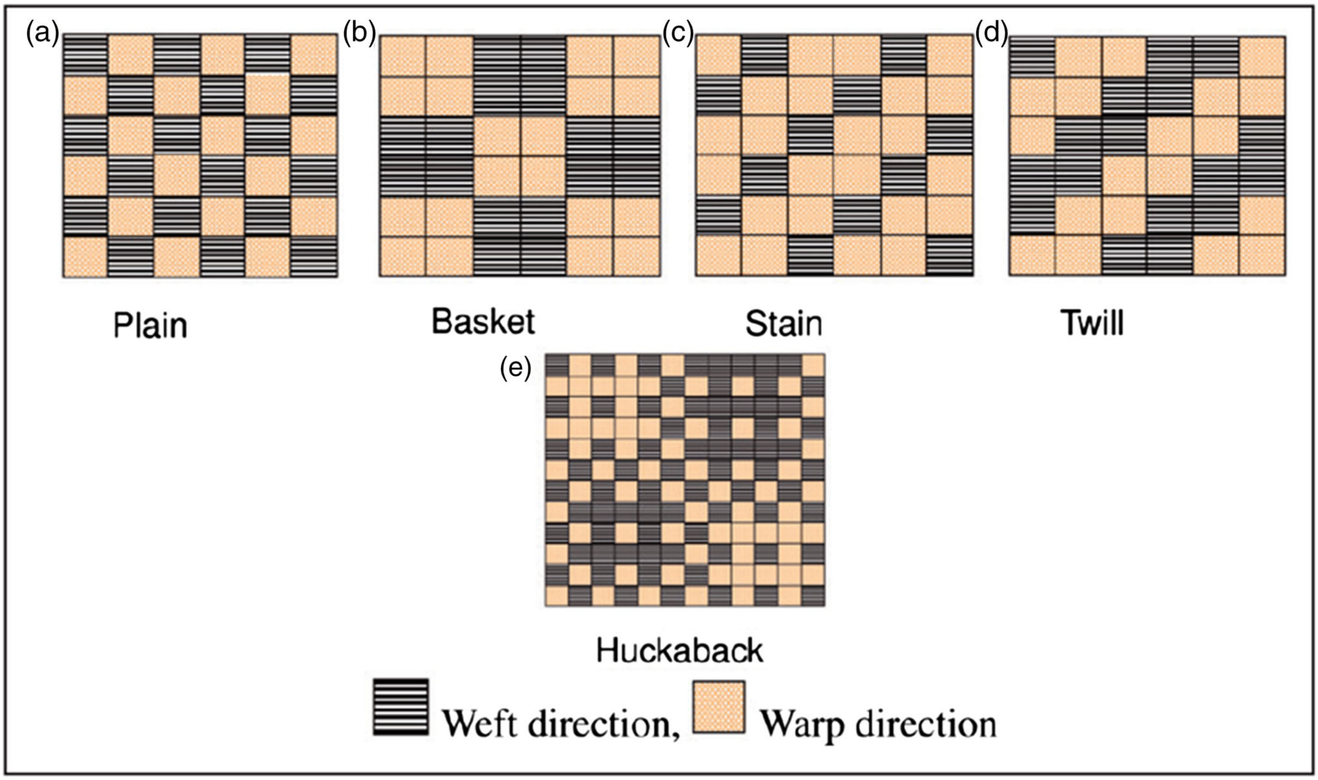


Fig. 10 Schematic diagram of different woven mats [59, 60]

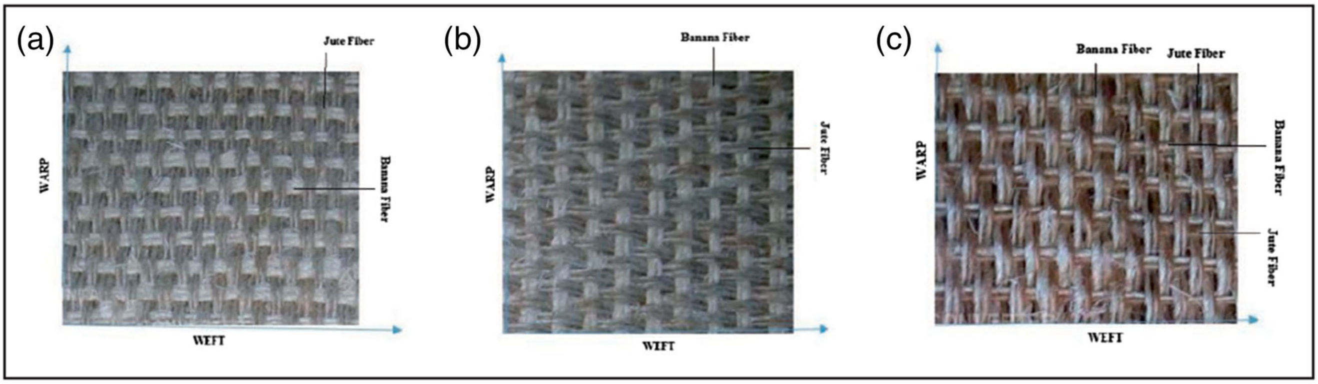


Fig. 11 Different orientation of hybrid banana/jute polyester composite: **a** type A, **b** type B, **c** type C [56, 59, 60]

improve the stiffness of the material. The outcome demonstrates that surface modification expands the modulus of the material and enhances the stiffness of the composite [63].

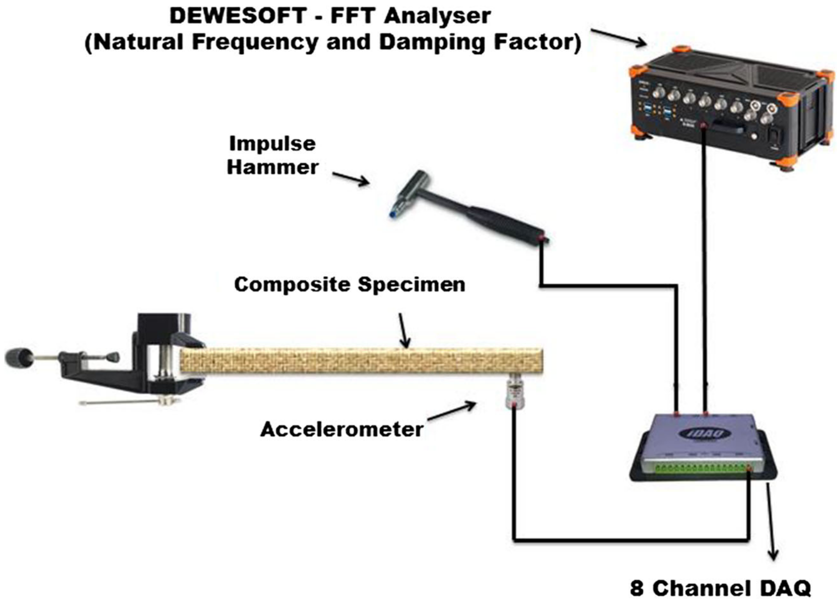
Untreated and alkali-treated *Pennisetum purpureum* grass fiber and glass fiber-reinforced hybrid composites were studied for DM characteristics. Among different combinations of these reinforcements, 5% alkali-treated *Pennisetum purpureum*/glass-reinforced composites have recorded higher E′ (4000 MPa), E″ (460 MPa), and tan δ 0.95. Neat epoxy composites recorded maximum tan δ (0.88) as compared to other combinations [64].

Effect of nanofiller (nano OPEFB, MMT, OMMT) loading on the E′ of kenaf/epoxy composites was observed to be diminished with temperature in all cases. And it was clear from the studies that considerable enhancement in the E′ (3700 MPa) values due to the inclusion of nanofiller in kenaf/epoxy into OMMT composites. Kenaf/epoxy composites show the diminishing E″ peak height (260 MPa). Although OMMT/kenaf/epoxy hybrid nano-composites display, the improved E″ peak height (370 MPa) because of the increase in internal friction. The kenaf/epoxy composites demonstrated the high tan δ (0.44) and the OMMT/kenaf/epoxy hybrid nano-composites exhibited poor (0.22) between all the combinations [65].

These hybrid composites have shown increased values in the E′ (480 MPa), E″ (61 MPa), and the least value of tan δ (0.28) at a T_g of 90 to 100 °C for composites made with equal proportions (50–50%) of jute and sisal fibers and are tested at 1 Hz frequency values. And the same trend was followed by 50–50% of jute and sisal fiber composites for 5 Hz and 10 Hz frequency range. Among all the frequency ranges, epoxy has shown the higher value of tan δ (0.88, 1.0, and 0.93 for 1 Hz, 5 Hz, and 10 Hz frequency range) and poor estimation of change temperature in all cases [15].

Intra-ply hybrid composites made of chemically treated banana yarn and jute yarn with alkali (NaOH), potassium permanganate ($KMnO_4$), benzoyl chloride (C_7H_5ClO), and saline (SiH_4) have been analyzed. From this study, it was noticed that C_7H_5ClO and NaOH treatment improve DM characteristics. Experimental modal analysis implemented on

Fig. 12 Schematic diagram of experimental setup for free vibration analysis [12, 57, 59]



intra-ply fabric composites reports that C_7H_5ClO treatment improves the natural frequency fundamentally compared with the raw composite [60].

2.3 Natural fiber-reinforced composites

In this context, discussions were made on the composites made of naturally available fibers reinforced with different combinations of matrix materials and also DMA of these natural fiber composites had been discussed in detail.

The DM properties of pure polystyrene and composites with short sisal fibers have been analyzed; due to the increase in segmental mobility, these composites had shown decreased E′ upon growing temperature. And also enhanced E′ (9.2 Pa) was observed for a 10% addition of sisal fiber to the PS matrix accompanied by a leveling off at peak loading. The impact of chemical modification of natural fiber (benzoylation) has resulted in improved fiber-matrix adhesion, which exhibits the higher E′ as of raw fiber composites. Matrix modification expands the activation energy for transition and the most extreme transition was seen with benzoylated fabric composites. The damping characteristics of the composites were diminished due to the incorporation of a higher percentage of fibers. The height of the damping peak of the composites were poor and width was better than that of perfect PS. Fiber alterations result in the fall of peak and expand the width of the damping top [66]. Also, enhancement of shear modulus (2400 MPa), frequency (20 Hz), and reduced log decrement (0.6) were observed with 43 vol% of fiber content in the jute fiber-reinforced epoxy foam composites. An enlargement in the jute fiber content had accompanied in a reasonable growth in the frequency of pure epoxy resin and jute fiber-based non-foamed composite materials [67].

The E′ was increased (14.5 GPa) with the increment in the fiber loading (35%) and chemical treatment (4- h alkali treatment) in the composites because of the reinforcement communicated by the filaments that permitted more stress transfer at the interface. However, on account of the chemically modified fiber composites, the rise in the rate of E′ (11.5 GPa and 14.5 GPa for 8 h alkali-treated and 4 h alkali-treated, respectively) with temperature was found to be directly related to the defect concentrations in the composites. Surface treatment of the natural fibers will encourage the fiber and resin bonding [68].

Short sisal fiber-reinforced propylene composites have been examined for dynamical mechanical properties by giving special care to the impact of loading, fiber length, chemical modification, frequency, and temperature. An increase in the E′ of these composites found to be increasing as sisal fiber percentage increases in the PP. This is because of the addition of fibers in the sisal-PP composites. E′ and E″ will increase as the fiber loading increases, for the fiber length of 2 mm higher dynamic modulus and E″ were found, also chemically modified sisal fiber-PP composites have shown improved values than the untreated ones because of a good bond among fiber and matrix [69]. Short banana fiber-reinforced polyester composites had shown great dependency on the volume fraction of reinforcements, the dynamic modulus was found to be decreasing due to the incorporation of fibers. Improved properties were developed for 40% fiber loading, and this was selected as basic fiber loading, at this loading E′ peak gets expanded highlighting the enhanced fiber/matrix attachment. And due to the interlayer (as shown in Fig. 13) effect, additional peaks were observed on the tan δ curves. Further addition of fibers will affect the δ peak height, which again adds the credits to enhanced fiber/matrix adhesion [70].

Individual study on DM properties of polypropylene and wood as fibers in composites reviewed with polybutadiene-styrene elastic rubber and maleated poly (propylene) as an effective intensifier and mixing operator. Maleated poly (propylene) produces the development of the changing temperature of plain (raw) and rubber-reinforced PP wood fiber composites. The vast majority of elastomer is likely situated around the fiber filament, and the impact of collaboration on the fiber surface rules over the plasticization of the matrix; however, as a result of better bond among the matrix and filaments in the agreeable PP wood fiber composites, the undefined macromolecules in the crystal phase is more limited. Maleated poly (propylene) significantly affects the capacity modulus of the composites and two transition points in the E′-T curves can be promptly isolated [71]. The addition of maleic acid anhydride-grafted PP in the flax- and hemp-fiber-reinforced polypropylenes (PPs) enhances the interfacial bonds among the filaments and matrix, these results in the higher loss of E′ at greater temperatures [32].

Composite panels were fabricated by using plant oil-based resin [acrylated epoxidized soybean oil (AESO)] and natural fiber mats made of flax, cellulose, pulp, and hemp. Depending upon the type of natural fiber mat used, an increment in the flexural modulus was observed in a range of 1.5 and 6 GPa (when natural fiber reinforcement of about 10–50 wt%). AESO (acrylated epoxidized soybean oil) resin was found to be good with recycled paper (cheap source of cellulose fiber)

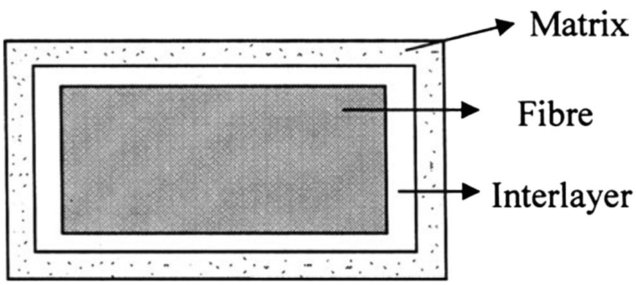


Fig. 13 Schematic representation showing the fiber, matrix, and the interlayer [42]

regarding flow, impregnation, and surface bonding, giving a modulus of over five times that of the neat resin [72]. Figure 14 shows the composite structure made out of 55.2 wt% reused paper reinforced AESO composite material with foam as cores.

Short, randomly arranged, intimately mixed banana/sisal fiber-reinforced polyester composites as shown in Fig. 15 were prepared with a 0.40 volume fraction, and these composites showed better results. The E′ above the transition temperature (T_g) was observed to be expanded with fiber volume division up to $0.40V_f$ and after that diminished. Hybridized and un-hybridized composites were prepared at $0.40V_f$ and properties were compared. For the relative volume fraction of banana and sisal 1:1, maximum E′ (4.07 MPa), moderately poor tan δ (0.13) at 20 Hz frequency were found [73].

Short coir fiber-reinforced natural rubber composites had shown, at the 10 Hz frequency of natural rubber compound maxima in tan δ (0.076), E″ (2.9×10^5 MPa) and the center of E′ (4.3×10^6 MPa) were found. Also, it was observed that tan δ (0.186) and E″ (2×10^6 MPa) and E′ (0.25×10^7 MPa) were found in the NR composite at 10 Hz.

An increase in the dynamic properties was identified on account of both plain resin and the composites, due to the fact that the addition of fibers will enhances E″ and tan δ. The impact of surface modification of coir fiber on damping of composites was considered; furthermore, it was discovered that composite with decreased interfacial bonding has a susceptibility to dissolve higher energy than that with great interfacial bonding [74].

Untreated and chemical treated banana fiber composites were tested for dynamic properties, and it was found that increased dynamic modulus values were determined for neat polyester composites (8.3 MPa), and low damping values for treated fiber composites (below 8.3 MPa). Similarly, higher E″ was observed for neat polyester (8 MPa) and other composites; it was within 7.54 to 7.78 MPa. This demonstrates the great bond between fiber and matrix material. Depending on the different chemical treatments (silane treatment, NaOH treatment, and acetylation), damping peaks have been found. Among different chemical modifications listed above, treatment with silane A174 and furthermore with NaOH has brought about the greatest increment of modulus values [75]. Composites prepared with 25–50% (by weight) various fibers (fibers include kenaf fibers, wood flour, rice hulls, and newsprint) with polypropylene (PP), and 1–2% of maleic anhydride grafted polypropylene were studied for dynamic characteristics. Among all the composites, pure PP had shown poor results (E′: 3 GPa at T_g, E″: 0.19 GPa, and tan δ: 0.086) as compared to other natural fiber-reinforced composites, but loss factor was found to be lower for the fibrous composites. With the different combinations of rice hulls and kenaf fiber respectively, composites exhibited the highest and lowest loss factors over the examined temperature range. Because of the fiber content, extraordinary increase and decrease in the stiffness and damping were found in the composites, respectively [76].

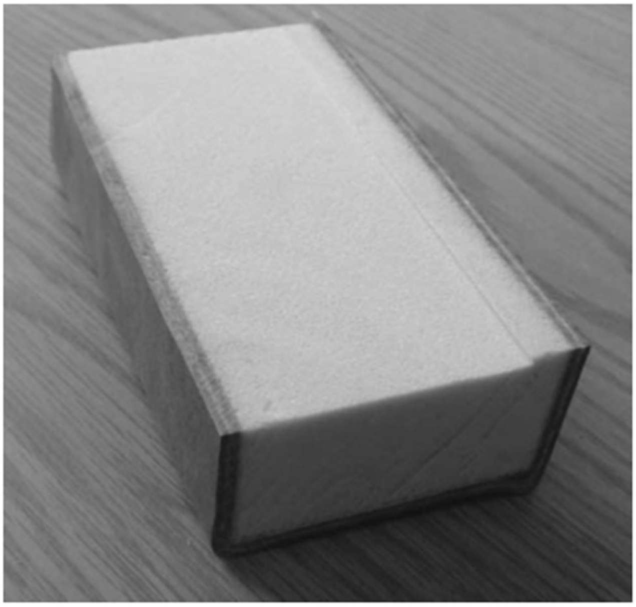


Fig. 14 Composite structure made out of 55.2% recycled paper reinforced AESO composite materials with foam cores. Composite skin thickness is 0.255 in., foam core

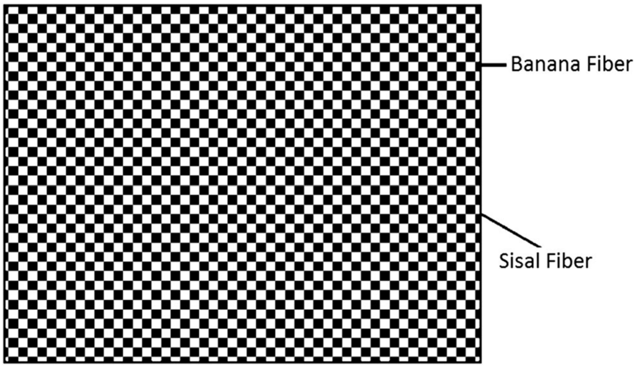


Fig. 15 Schematic representation of intimately mixed banana and sisal fiber [73]

In the jute fiber-reinforced, high-density polyethylene (HDPE) composites, variation of E′, E″ and tan δ with the addition of fibers and coupling agents was examined. Also, composites, treated with MAPE (maleated polyethylene), showed improved properties (E′: 1.59E + 09, E″: 1.62E + 08 at 91 °C, and tan δ: 0.19), in comparison to the untreated composites [77].

The DM properties of PP and jute/PP composites with surface alterations and without considering some of the surface altering techniques were estimated. As a function of temperature, E′ was studied. As the rise in the temperature, E′ values of PP and composites will decrease because of the softening of the matrix. And an improvement in the fiber content in the composites has shown greater E′ as temperature increases. A slight increase in the E′ was found in the modified PP with 2 wt% maleic anhydride grafted polypropylene (MAHgPP) as a coupling agent and jute composite. This effect was appreciated only in modified PP composites as compared to non-modified PP composites. The increase in E′ demonstrated improved filament and matrix adhesion due to the proper usage of suitable coupling agent and this leads in the proper stress communication from the matrix to the fiber. Also, in the case of chemically surface-modified fiber composites, due to the addition of fiber content enhancement in the E″ values were noticed. It is recommended that with expansion in fiber content, the losses in energy will increase with the interfacial bond among the matrix and the filaments due to the activity of external vibrating load [78].

In the composites made with re-usable high-density polyethylene (RHDPE) and regular natural fibers, for example, wood and bagasse, impacts of the fibers and the coupling agent type/concentration of the composite characteristics were contemplated. The utilization of maleated polyethylene (MAPE), carboxylated polyethylene (CAPE), and titanium-derived mixture (TDM) enhanced adherence among the bagasse fiber and RHDPE. Based on RHDPE/bagasse matrix, the E′, E″ properties were extreme with the MAPE content increment from 0 to 4.5%; 1.5–3.0% of MAPE had shown the best properties. At the point when 1.5%MAPE was included, the E′ of RHDPE/bagasse composite was expanded. The E′ of the RHDPE/pine composite was expanded by around 49%, 9%, and 11%, separately, by 1.8% MAPE. Also, when 0.3% TDM was included, the E′ of RHDPE/bagasse composite expanded around 9%; yet for RHDPE/pine composite, the expansion of TDM had little effect on E′ [79].

The ineffective stress transfer was found in the increased coconut fiber (volume)-reinforced composites, which led to a decrease in the strength also. Also, it was observed that decrease in the stiffness factor affects the natural frequency. But for 10% fiber content, maximum damping peak was achieved for all the frequency modes. Coconut fiber-reinforced polyester composites had shown more flexibility and easy deformation because of the high strain value and the decrease of high resonant amplitude [80].

The effect of chemical treatment (NaOH and acrylic acid) and fiber content on DM characteristics of bagasse fiber-reinforced diluted polyester resin (USP) was evaluated. From these tests, it was concluded that surface modifications of bagasse fibers will enhance the E′ (4000 MPa), poor tan δ (0.48) of the composites as contrasted with untreated/raw fiber composites (E′: 2700 MPa and tan δ: 0.82), and also, the increase in the fiber content (20 Vol%) will also help the composites to gain the E′ [81].

Impact of reinforcement of natural fibers in thermoplastic and thermosetting polymers was studied for natural fiber (kenaf and henequen) reinforced polypropylene (PP) and unsaturated polyester (UP) bio-composites. Electron beam treatment with 10 and 200 kGy doses, respectively, or with a 5 wt% NaOH solution on kenaf (KE) and henequen (HQ) fibers were selected for fabricating four types of bio-composites (KE/PP, HQ/PP, KE/UP, and HQ/UP). Out of all these combinations, reinforcement of kenaf fiber had exhibited a higher impact on DM characteristics of both PP and UP bio-composites than the henequen fiber. UP matrix and 200 kGy EB-treated kenaf fiber-reinforced composites had the highest E′ (6.76 GPa), higher E″ (0.47 GPa), and poor tan δ (0.16) [82].

Most promising methods to form covalent bonds between matrix and natural fiber are chemical modification/surface treatment methods. These modification methods will enhance the bonds between hydrophilic fibers and hydrophobic matrix. Some of the treated natural fiber-reinforced composites have shown good results in dynamic mechanical properties because of good communication between matrix and fibers [16].

A total of 0.06 M alkali-treated sisal fiber reinforced with polyester and epoxy resin matrices had exhibited better results for the E′ (24 GPa) at a T_g 110 °C whereas untreated fiber composites resulted in 16 GPa at a T_g of 80 °C for 70% fiber loading. E′ will be enhanced as fiber loading increases on account of treated fiber composites. A slight variation in the tan δ was observed between treated and untreated fiber composites, i.e., 0.088 and 0.085, respectively, for 75% fiber loading. composites with lower fiber loading exhibited higher tan δ value in both treated and untreated conditions [83]. Also, thermoplastic composites based on polypropylene (PP)/glass fibers and PP/natural fibers (i.e., kenaf, hemp, flax) had shown comparable and sometimes superior damping properties as compared to glass fiber composites [22].

Natural rubber (NR) reinforced with macro/micro-fibrils of oil palm fiber had been studied for dynamic properties and it was found that the E′ of the above said composites were found to increase (9.25 Pa) with fiber loading (30 phr), and as temperature increases, this is due to the reinforcement imparted by the fillers. Highest tan δ value (1.25 at a T_g of − 45 °C) and a large degree of mobility was observed for unfilled compound and hence good damping properties were achieved. Because of the addition of fibers (micro/macro), free movement of the macromolecular chain was disturbed and this will decrease the damping characteristics of composites. The addition of chemically (saline, benzoyl chloride, and resorcinol-silica bonding) treated micro-fibrils resulted in enhanced E′; this is because of the arrangement of strong fiber/matrix interface. Composites with micro-fibrils treated with silane as a coupling agent demonstrated the most extreme dynamic properties [84].

To some extent, dynamic properties are concerned, damping of CFRC specimens will be improved and natural frequency diminishes with the growth in the damage because of static loading in all the examples. With 3% of fiber content, the CFRC beam had demonstrated most astounding damping (17%) and diminished natural frequency (110 Hz) cracked and uncracked specimens as compared to CFRC beams with 1 and 2% fiber content variations [85]. The impact of 1% to 5% fiber proportions by mass of cement and fiber lengths of 25, 50, and 75 mm are examined to explore the impact of coconut fibers in enhancing the characteristics of concrete. The characteristics of plain concrete were utilized as a source of reference. With structural damage, the damping of coconut fiber-reinforced concrete (CFRC) beams increases but the fundamental frequency was found to be diminishing. An increment in the fiber content in CFRC exhibits quality damping, but poor dynamic and static modulus of elasticity. And it was observed that CFRC with a fiber length of 50 mm and a fiber content of 5% possesses suitable characteristics (for un-cracked beam ζ: 6.9%, f: 109.3 Hz, and cracked beam ζ: 14.1%, f: 84 Hz) as compared to other combinations [86].

Study on the impact of parameters like fiber length and weight percentage on free vibration aspects was analyzed on short sisal fiber (SFPC) and short banana fiber (BFPC) polyester composites. Fundamental frequencies and relevant modular damping values of the laminated composites were gathered by conducting some experimental modal analysis. Enhancement in the mechanical and damping properties was found due to the increment in the fiber content in these composites. Sisal fiber polyester composites with the length of the fiber 0.3 cm and 50 wt% of fiber content exhibited improved characteristics, out of which the best combination found for banana fiber polyester composites was 0.4 cm fiber length and 50 wt% fiber content. And 0.4 cm/50 wt% of BFPC and for SFPC at 0.5 cm/50 wt% have shown an enhancement in natural frequency in all the three modes of vibration [87]. A remarkable increase in the damping ratio of CFRC ($\zeta_{\text{transversal}}$: 3.65%, $\zeta_{\text{longitudinal}}$: 3.73%, $\zeta_{\text{torsional}}$: 3.27%) was observed in comparison with limited polymer composites. Maximum natural frequency was observed in plane concrete (PC: 202.3 Hz), then reduced natural frequency (CFRC: 196.4 Hz, FFRP-PC [2 layers: 193.1 Hz, 4 layers: 191.4 Hz], FFRP-CFRC [2 layers: 188.2 Hz, 4 layers: 182.5 Hz]) and dynamic modulus of elasticity and increased dynamic Poisson's ratio and damping ratio were observed for confined CFRF and FFRC as compared to unconfined PC and CFRC [88].

P. N. E. Naveen and Yasaswi (2013) proposed that dynamic properties could be in strong association with mechanical properties and both these properties incredibly depend on fiber volume percentage. Five percent of coconut coir fiber-reinforced composites had shown good tensile results (25 MPa) which are having a linear relationship with the natural frequency of the composites and also damping ratio was found to be increasing due to the incorporation of the coir fibers [89]. A maximum frequency of 1750 Hz was recorded for 5% fiber composites (for 1st mode) and a maximum of damping ratio was observed for 15% fiber composites (9.2% for 1st mode).

Banana fiber and sisal fiber-reinforced natural rubber composites were made as dampers for frequency analysis and obtained results indicate that sisal and banana fiber blended natural rubber composites had shown better (reduced) damping characteristics (amplitude of 2.5 mm at a frequency of 6 Hz) and Young's modulus (banana fiber composite: 34.28 N/mm^2 and Sisal fiber composites: 21.25 N/mm^2) as compared with other specimens [90].

Newly developed woven fabrics from Sansevieria (*Sansevieria trifasciata*) fibers and banana (*Musa sapientum*) fiber-reinforced composites have shown good stiffness against the temperature, and E′ decreases as temperature increases. The higher value of the E′ was attributed to the natural strength of banana fibers (5.4 GPa) and also tan δ of 0.48 at 122 °C [91]. Some interesting behaviors in the jute nano-fiber-reinforced composites reveal that E′ increased in the presence of the jute nano-fiber; maximum E′ (1.6E + 06 MPa) was identified for the composites with 3% fiber volume. Due to energy losses caused by the rearrangements of the molecules and jute nano-fiber as well as the internal friction among the jute nano-fiber and the epoxy polymer matrix, the E″ increases (1650 MPa for with composites with 3% fiber volume) with increase in the percentage of jute nano-fiber. Reduced tan δ (0.225) was observed for higher values of fiber volume (5%) and it was found that increment in fiber percentage resulted in a fall in tan δ values of all classifications [92].

The impact of chemicals like alkali, permanganate, benzoyl chloride, malic anhydride, and silane treatments on jute fibers was examined and it was noticed that improved E′ and lower tan δ values for the surface-modified fiber composites as compared to raw jute fiber composites. Among all different composites, maleic anhydride-treated jute fiber composite samples have shown good results with E′ (13.2 GPa at 28 °C), E″ (1.100E + 06 Pa at 60 °C), and reduced tan δ of 0.135 with the percentage change of 28.5%. This is because of enhanced fiber–matrix bonds in the case of surface-modified fiber composites [93]. Raw, NaOH and SiH_4-treated coconut sheath/polyester composites with varying weight percentage (1 to 5 wt%) of naturally modified montmorillonite (MMT) nano clay had exposed that E′ will diminish in nature with increment in the temperature and with the negligible drop in the temperature between 50 and 110 °C. Surface-modified coconut sheath has exhibited higher loss modulus (E″: 1E + 009 Pa) and damping peaks (tan δ: 0.174). Silane-treated composites found with the maximum increase in E′ (1.8E + 010 Pa) and E″ (1E + 009 Pa) values. Incorporation of nano clay resulted in an increase in the dynamic parameters of a wide range of composites and varying patterns were studied by varying wt%. Silane- and NaOH-treated composites resulted in a negligible growth during the transfer of temperature in the transition zone range that were identified concerning the E″ peaks as compared to untreated composites [27].

Sansevieria cylindrica (SC) is one kind of natural fiber and its fiber-reinforced polyester matrix composites (generally denoted as SCFRPCs), an increase in the immensity of stiffness and additionally the modulus of composites was observed. In SCPCs, the expanded stiffness of SCFRPCs resulted the abatement in damping proportions than the unadulterated polyester. Among the assortment of fiber length and fiber stacking, the SCFRPCs created with the basic length of 30 mm fiber and 40 wt% of fiber stacking were discovered the ideal estimation of the modulus. Because of progress in the degree of fiber, matrix adhesion, chemically surface-modified SCFRPCs exhibited better dynamic properties not just in the part of storage and E″ yet additionally in damping values also. Among different surface modification techniques, potassium permanganate-treated SCFRPCs exhibited predominant execution at the 40 wt% (ideal wt%) in all the dynamic characteristics like E′ (3E + 10 Pa), E″ (1.75E + 09), and tan δ (0.21) [94].

Luffa cylindrica fiber-reinforced epoxy composites had demonstrated the higher damping characteristics (for the frequency of 159, 419, and 862 Hz, damping value obtained are 0.8, 1.2, and 1.5, respectively) than the composites made of glass fiber reinforcements (for the frequency of 192, 303, and 792 Hz, damping value obtained are 0.4, 0.5, and 0.6, respectively). These outcomes proved that natural fiber materials can be utilized rather than man-made artificial materials, in retaining the vibration because of their high damping (damping value of 0.86 at 200 Hz) [95].

Half power bandwidth technique was used to estimate the dynamic properties of Himalayan Nettle (a natural plant fiber) reinforced polyester resin matrix composites. For cantilever composite, damping ratio was found to be in the range of 0.35 to 0.45 (order 10^{-1}), at a fundamental natural frequency of 20.507 Hz. At higher frequencies, the damping ratio was found to be in the (order 10^{-2}) range of 0.02 to 0.04 and the corresponding frequency was found to be 78.125 Hz. Similarly, for structural damping, the damping ratios were found to be in the (order 10^{-2}) range of 0.05 to 0.08. Also, improved damping properties were exhibited when these composites subjected to impulse forces and matrix part of polymer molecular chains could slide and rearrange to dissipate the energy [96].

Sugarcane bagasse fiber (SBF)-reinforced epoxy composites had shown higher resonant frequency for 20 wt% epoxy/SBF during transmissibility, and it was considered that these 20 wt% composites increase the damping ratio up to 7.2% as compared to other high-density bio-polymer foam composites and kenaf fiber-reinforced composites. Vibration abruption was found to be reduced for these composites when they tested with one, two, three and four absorbers [97]. Free vibration properties of sandwich panels were achieved by filling the foam in the unfilled space of core. The outcomes likewise demonstrated that the triangular core foam filled sandwich board deforms less as related to different core composites. From the free vibration investigation, the impact of filling foam is successful in cellular and trapezoidal core. This will enable the support to truss core sandwich board (as appeared in Fig. 16) filled up with foam normally utilized in aerospace/aviation applications [98].

Dynamic mechanical and experimental modal analysis results of interlaced yarn woven fabric reinforced polyester composites and traditionally contorted yarn woven fabric and weaved woven fabric composites demonstrated that growing pattern for E′ over conventional woven, weaved, and interlaced woven fabric reinforcement fortification. Intra-ply hybridization resulted in enhancing E′ (braided: 4.5 E + 09 Pa, woven: 3.5 E + 09 Pa, knitted: 4.9 E + 09 Pa), E″ (braided: 4 E + 09 Pa, woven: 2.5 E + 09 Pa, knitted: 2.5 E + 09 Pa) and poor material loss factor (braided: 0.35, woven: 0.25, knitted: 0.35) as compared to the banana, jute, and neat resin composites [99].

Sandwich composites with a glass fiber fabric facing layer and natural fiber fabric as core layer have shown increased buckling strength (280 N) and a reduction in the free natural frequency with expansion in the axial compression load, but it is interesting that within the pre-buckling region tan δ increases. Figure 17 shows the schematic sketch of the exploratory arrangement for buckling and free vibration investigation [100].

With varying percentages (10, 20, 30, and 40) of jute fibers, epoxy composites were prepared to test the dynamic mechanical properties. At a frequency of 1 Hz, a higher value of E′ (550 MPa), E″ (69 MPa), and reduced tan δ (0.284) were found in the rubbery region for epoxy composite reinforced with 30 wt.% of jute fibers. An impressive amount of growth in the natural frequency, E′ of all other composite was found to be increasing. In the rubbery region, epoxy composite reinforced with 30 wt.% of jute fibers at 10 Hz frequency has exhibited the better E′ (600 MPa), E″ (88 MPa), and reduced loss factor (0.32) values [101].

Enhanced dynamic mechanical properties were observed for kenaf/epoxy, bamboo/epoxy, and bamboo charcoal/epoxy composites. Among these combinations, kenaf/epoxy composites shown better dynamic properties as highest complex modulus strength (E′: 3538 MPa) and lowest damping behavior (peak height of tan δ: 0.49) [102]. Date palm fibers (DPF) reinforced epoxy composites at various loading (40%, 50%, and 60% by wt.) that have been tested for three-point bending dynamic properties. From this test, it was observed that loading of 50% DPF improves the modulus of pure epoxy composites from 2.26 to 3.28 GPa, E″ (235 MPa) and reduced loss factor (0.2). Likewise, it was seen that consolidation of DPF into epoxy additionally enhances the E′ and E″; yet, 50%

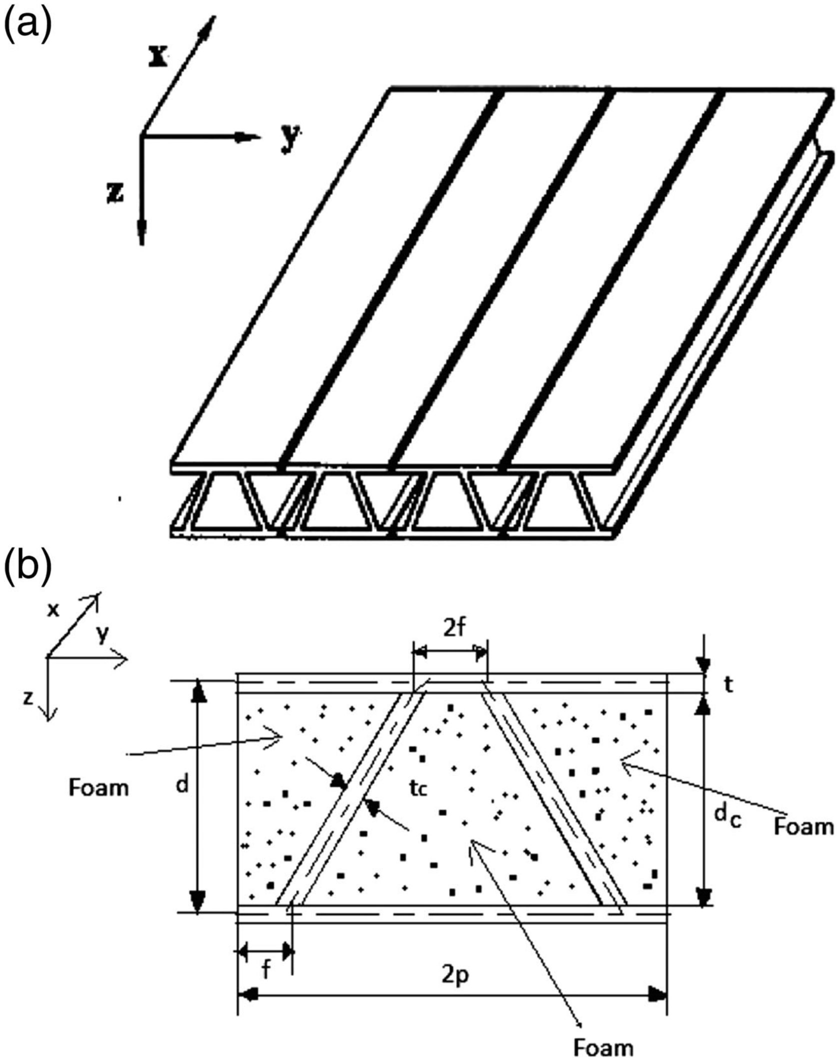


Fig. 16 Truss core sandwich panel [98]

DPF indicates a more surprising change contrasted with 40% and 60% DPF stacking. Additionally, tan δ diminishes extensively by the support of DPF and is discovered least for half DPF/epoxy composites as compared to all other composites available. It had been inferred that 50% of DPF stacking is the perfect stacking to improved powerful properties of epoxy composites [103].

Kevlar and carbon fiber-reinforced composites (KFRC and CFRC) containing SiC particles in epoxy resin have shown significant improvement for natural frequency of different content of SiC particles in the CFRE and KFRE samples (11.2% and 9.4% raise in natural frequency for CFRE and SiC particles incorporated KFRE specimens at filler content of 15 wt% was observed). Superior interfacial bonding quality among particle and matrix results in the betterment of damping properties. This shows that the substantiation of SiC particles in the epoxy resin at a specific measure of the weight content will maintain the stability and safety of kevlar fiber-reinforced composites. Also, the extra addition of SiC loading into epoxy resin will affect the dynamic properties by reducing them; this leads to diminishing load transfer connecting particle and matrix [104].

Similarly, jute and human hair-reinforced epoxy-based polymer composites with five various fiber percentage combinations were studied. For the combination of jute (12.5%), human hair (12.5%), and epoxy (75%) composite higher values of E′ (4900 MPa), E″ (440 MPa), and loss factor (0.58) were observed at a frequency of 1 Hz. Composites with jute and human hair as fiber composition of 25:0 and 0:25% separately display nearly a similar behavior and show poor E′ values when matched with hybrid composites at the frequency range between 0.2 and 5 Hz [105].

2.3.1 Summary

The present scenario is shifting towards the use of artistic composite materials over the conventional materials because of the scarcity in the availability, density, strength

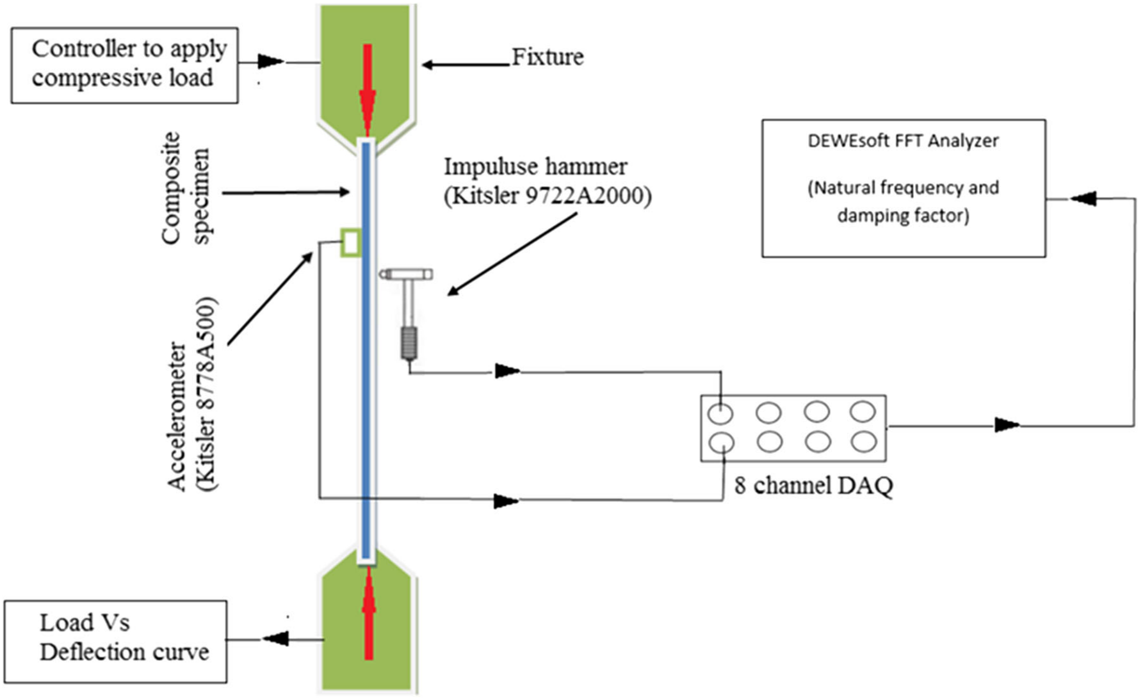


Fig. 17 Schematic diagram of experimental setup for buckling and free vibration analysis [100]

to weight ratio, chemical communications, and some of the matrix and traditional material relations in the composites. The best way to overcome these problems is composite materials in all the sectors of the engineering and they are proving all prerequisites for any applications and are presented in this article. Some of the key points have been listed as below in concerning with the some of the DM characteristics of the NFRCs (natural fiber-reinforced composites).

In this work, few studies on DM properties of natural fiber composites have been presented, and the main points are outlined as follows:

1. NFRCs could be formed in any of the formats (like laminated, hybrid, and usual NFC) and used for many of the applications were in which traditional materials could not be used.
2. Almost all the natural fibers like hemp, sisal, jute, pineapple leaf branches, coconut sheath, etc. could be used as reinforcement materials and they will be in good relation to the matrix materials used.
3. Another possibility of obtaining a new type of composites is with hybridization, in which the use of natural fibers and man-made fibers is considered to boost up the performance of the composites prepared.
4. DMA is one of the important techniques available to measure the phase variations of the NFRCs with the variable frequency and temperatures.
5. In almost all of the studies, DMA had a vital role in finding the DM properties like material behavior, E′, loss modulus, and damping and NFRCs, and it is concluded that DMA is one of the highly effective methods.
6. Dynamic mechanical properties observed to be influenced by some of the key factors like fiber contents, fiber shape and sizes, orientations, and stacking sequences in the NFCs.
7. Variations in the natural frequency and all other dynamic mechanical properties were also noted for the chemically treated fiber-reinforced composites. Hence, it was proven that DMA is a sensitive tool in generating the dynamic mechanical parameters related to NFRCs to ensure the safety, design, and replacement of the many automobile parts and other structural components in the future applications.

The mechanical and DM characteristics of natural fibers and natural fiber-reinforced composites were from time to time better than those of glass and other ordinary/man-made fiber composites. Hence, from these points, it is advisable that normal fiber composites can be the great substitutes for man-made fibers for dynamic mechanical applications.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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