Review Article

Dynamic Mechanical Performance of Natural Fiber Reinforced Composites: A Brief Review

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Abstract
Natural fiber reinforced polymer composite is a much focused area of study owing to its environmentally friendly nature and good mechanical properties. These composites offer comparable mechanical properties to that of steel and other composite materials. Dynamic mechanical analysis is a widely used technique to investigate the mechanical performance of fiber reinforced composites at a wide range of temperatures. Using this technique, the thermal transitions and damping properties of fiber reinforced composites can be studied. These natural fiber composites are widely employed in structural applications in many industries. Here, in this short review we have presented the recent works on the dynamic properties of natural fiber reinforced composite materials with an essence of the influencing factors

Keywords: Dynamic mechanical properties, Natural fibers, Polymer composites, Storage modulus

1 Introduction

With the advancement in polymer technology, more and more varieties of synthetic fibers are being developed for high end applications. Hence the waste associated with these fibrous materials has increased drastically and the process of degradation has become challenging [1]. As the degradation rate is very slow and burning of these fibers create toxic gases and environmentally hazardous materials, researchers are in the search of alternative green materials. Natural fibers are such green materials with good specific properties, low density, non-toxic and available in abundance [2]–[4].

Natural fiber composites are attractive materials having advanced properties with a wide range of applications, especially as structural materials. These natural fiber composites have good strength to weight ratio, specific properties and are very cheap and sustainable. These composites have gained lot of attention in many fields for structural applications. Especially, natural fibers like flax [5], jute [6], hemp [7], sisal [8], and coir [9] are found to have good reinforcing effect in thermoplastic and thermoset polymers and are investigated for construction, packing, marine and automotive applications. Natural hybrid fibers based composites are capable of nullifying the disadvantages of mono natural fiber based composites and are capable of enhancing the mechanical properties to a great extent [10]. Natural fiber based hybrid composites are renewable materials with comparatively less weight and increased recyclability [11].

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2 Natural Fibers and Properties

Natural fibers are the fibers obtained from renewable sources and are sustainable. Depending on the source of utilization, the plants that produce natural fibers can be classified as primary and secondary respectively. The plants that are grown for their fibers are called primary plants (ex: jute, sisal etc.). The plants in which the natural fibers are obtained as by products are called secondary plants (ex: pineapple, coir etc.) [12]. These fibers are of six types as presented in Table 1. Natural fibers are having few disadvantages like hydrophilicity, poor thermal stability, inconsistent properties, less wettability and compatibility. So, surface modifications are considered as efficient medication techniques to overcome these disadvantages and prepare enhanced natural fiber composites [13]. In Table 2, the list of few recent works on natural fiber composites is mentioned. Synthetic fibers are having enhanced mechanical properties over natural fibers but due to environmental aspects, low cost and light weight, these natural fibers are replacing synthetic fibers from various industries like automobile industries.

Table 1: Types of fibers

S.No	Fiber	Example
1	Bast fibers	flax, jute, kenaf, hemp and ramie
2	leaf fibers	sisal, abaca and pineapple
3	Seed fibers	cotton, coir and kapok
4	Grass and reed fibers	rice, corn and wheat
5	Core fibers	jute, kenaf and hemp
6	Others	wood and roots

3 Dynamic Mechanical Properties of Natural Fiber Reinforced Composites

Dynamic mechanical analysis (DMA) is an efficient tool to determine the morphology and visco-elastic properties of polymers and composites. The associated parameters like crosslinking, complex viscosity, dynamic fragility etc.can be determined by this technique [14]–[16].This technique helps in analyzing the properties of composite materials as a function of temperature, time and frequency or combination of all [17], [18]. The storage modulus (E'), loss modulus (E'') and mechanical damping factor (Tan δ) are the

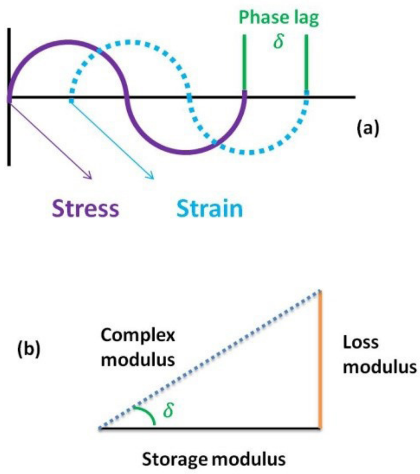

Figure 1: (a) Sinusoidal oscillation and response, (b) representation of complex modulus.

important properties of the materials that are evaluated by DMA. The storage modulus express the stiffness of the material, the loss modulus express the energy dissipation tendency of the material and the ratio of loss modulus to storage modulus is determined by tan δ. It is observed that tan δ is dependent on molecular motions, relaxations, transitions and other structural heterogeneities. It is also observed that the dynamic properties depends on arrangement of phases like interface, nature and morphology [19], [20]. The role of fibers, its content, orientation and testing mode on the dynamic performance was also elaborated. In Figure 1(a) the sinusoidal stress-strain curves related to DMA are presented and in Figure 1(b) the relation between the dynamic properties is presented.

Natural fibers are used as reinforcement in thermoplastic, thermosetting as well as bio polymer matrices [14]. They are also used in nanocomposites and hybrid composites. Earlier researchers focused on evaluating properties of natural fiber composites using a single fiber. Later chemical treatments were conducted in fibers to enhance the fiber matrix interface and composites were developed. Nowadays, the trend is to prepared hybrid composites with use of different fibers and nanoparticles to develop multi functional composites. These nanoparticles along with natural fibers are expected to improve the mechanical performance and conducting performance of fibers based on type of nanoparticles employed.

Joseph *et al.* [21], prepared sustainable conducting polyvinyl alcohol (PVA) composites reinforced with natural fibers and carbon nanofillers. For the study they used ball milled jute fiber, multi layer graphene (MLG) and polyvinyl alcohol and prepared composites by solvent casting method. The visco-elastic modulus and electrical conducting properties of the composites are analyzed in detail. Alongside, another sample set with the sample materials and multiwalled carbon nanotubes (MWCNT) was prepared for comparison. The multilayered structures of these materials (2 mm and 4 mm) were made by hot pressing and the electromagnetic shielding effectiveness was also studied. They observed that the EMI shielding effectiveness decreased with increase in jute content and the wear resistance of these composites increased with increase in jute content (upto 10 w%) and later decreased. They also observed that the jute content increases the electrical content of graphene/PVA composites and samples loaded with CNT at 2.5% gave the highest electrical conductivity. Importantly, the storage modulus of the graphene/PVA composites increased with jute content and was maximum for PVA/20 wt%MLG/5 wt%JF composite.

The woven natural fibers are also capable of enhancing the dynamic properties of the composites to a greater extent. Generally, due to the enhanced modulus of the basket and intra-ply hybridized composites, the dynamic mechanical properties show enhancement [22]. Hybrid fiber reinforced epoxy composites are capable of showing a balance between glassy and rubbery state at higher temperatures [23].

Tajviji *et al.* [24] studied the effect of different natural fibers on the mechanical and thermal properties of polypropylene matrix composites. They prepared composites of polypropylene with kenaf, rice hulls, wood flour and newsprint fibers at 25 w% and 50 w% loading. Maleic anhydride grafted polypropylene is used as compatibilizer. Samples are made by injection moulding and tested for dynamic mechanical properties at a temperature range of –60°C to +120°C at a frequency of 1 Hz and strain amplitude is kept at 0.1% at a heating rate of 2°C. The storage modulus, loss modulus and tan δ of these composites were plotted as a function of temperature and compared with neat polypropylene. For all the fiber loaded samples, the storage modulus and loss modulus are observed to increase while there was a decrease in the tan δ value. It can be noticed that the prepared composites are having more elastic nature than the virgin samples. The composites with kenaf are having highest storage modulus while the rice hull samples are having low storage modulus. The effect of fiber content was noteworthy for increase in thickness and decrease in damping. It is also observed that glass transition temperature was shifted to low temperature but the α-transition temperature got increased. They concluded that further work is needed to understand the reason in a more detailed manner.

Prasad *et al.* [25] investigated the effect of TiO_2 on the performance of flax fiber/epoxy composite at different nano titania loadings. They concluded that there is good enhancement in the Mode I and Mode II interlaminar fracture toughness of the nano modified samples. The diffusion of nanoparticles into the fiber surface made the fiber matrix interface stronger and thus it showed an improvement in the toughness of the matrix. They concluded nano modification as an excellent method to enhance the composite performance. In Table 3, a list of few works where dynamic properties is investigated is presented.

Table 2: List of recently available literature where natural fibers are used as reinforcement

S.No	Fiber	Matrix	Reference
1.	Aloevera/hemp	Epoxy	[26]
2.	Flax, hemp, kenaf and glass	Polypropylene	[27]
3.	areca/kenaf	Epoxy	[23]
4.	Coccinia Indica fiber	Polyester	[28]
5.	Cellulose fiber/ nanoclay/kenaf	Epoxy	[29]
6.	Nanoclay/bamboo/ kenaf	Epoxy	[30]
7.	Banana fiber	Epoxy	[31]
8.	Abaca fiber	Epoxy	[32]
9.	Coir fiber/TiC/ basalt fiber	Epoxy	[33]
10.	Flax fiber	Epoxy	[34]
11.	Flax fiber	Epoxy	[35]
12.	Fly ash/sisal fiber	polypropylene	[36]
13.	Jute/E glass	Epoxy	[37]
14.	Jute/kenaf/E glass	Epoxy	[38]
15.	Date palm fibers	Epoxy	[39]
16.	Roystonea regia and glass fibres	Epoxy	[40]
17.	Jute/kenaf/E glass	Epoxy	[41]

Table 3: List of dynamic mechanical properties of natural fibers reinforced polymer composites

S.No	Fiber	Matrix	Reference
1.	Bast fiber	Poly (butylene succinate)	[42]
2.	Pineapple fiber	polyethylene	[43]
3.	Henequen fiber	polyethylene	[44]
4.	Kenaf fiber	High density polyethylene	[45]
5.	Jute fiber	High density polyethylene	[46]
6.	Pine/agave fiber	High density polyethylene	[47]
7.	Sisal fiber	Epoxy	[48]
8.	Ramie fiber	Epoxy	[49]
9.	Agave fiber	Epoxy	[50]
10.	Flax fiber	Epoxy	[51]
11.	E glass/N glass/ woven jute	Epoxy	[52]
12.	Oil palm/glass fiber	Phenol formaldehyde	[20]
13.	Ramie fiber	Poly lactic acid	[53]
14.	Kenaf fiber	Poly lactic acid	[54]
15.	Cellulose fiber	Poly lactic acid	[55]
16.	Coir fiber	Natural rubber	[56]
17.	Oil palm	Natural rubber	[57]
18.	Carbon fiber/ kenaf fiber	Natural rubber	[58]
19.	Pineapple fiber	polypropylene	[59]
20.	Jute fiber	polypropylene	[60]
21.	Hemp fiber	polypropylene	[61]
22.	Wood flour	polypropylene	[62]
23.	Bamboo/glass fiber	polypropylene	[63]
24.	Glass/sisal fiber	polypropylene	[64]
25.	Banana fiber	polyester	[65]
26.	Piassava fiber	polyester	[66]
27.	Jute and kenaf fiber	Unsaturated polyester	[67]
28.	Short banana/ sisal fiber	polyester	[68]
29.	Glass/sisal fiber	Unsaturated polyester	[69]
30.	Flax/hemp fiber	polypropylene	[70]
31.	Jute fiber	polypropylene	[71]

In another work, 2-hydroxy ethyl acrylate treated oil palm and jute fibers were used for making reinforced epoxy composites. These chemically modified fiber loaded composites displayed a higher storage modulus when compared to untreated fiber composites. It can be understood that the chemical modification of fibers lead to reduction in the hydrophilic nature of fibers and hence exhibit better wettability and good fiber/matrix interface. The loss modulus of chemically treated composites got improved and Tg showed a higher value than the unmodified samples. The damping performance of these modified samples is observed to decrease with fiber modification. The TGA of these samples were done and it is observed that the chemically modified samples are stable than the functionalized samples [72].

Gupta *et al.* [73] studied the dynamic mechanical characteristics of hybrid jute/sisal /epoxy composites at different frequencies. He prepared hybrid composites by hand lay-up technique at 30 wt% of total fiber content. Dynamic mechanical properties were investigated in the temperature range of 30–200°C and the results revealed that storage modulus, loss modulus and glass transition temperature of the samples increased with increase in the applied frequency. Palm leaf stem stalk/Palm/epoxy composites were prepared and dynamic properties are evaluated [74]. They observed an increase of 75, 95, and 47% in storage modulus, loss modulus and damping factor of resultant composites. They also observed that the filler loaded composites are having better swelling and degradation resistance.

The dynamic property evaluation of randomly oriented short snake grass fiber/polyester composites was conducted by varying fiber weight fraction, length, frequency, and temperature [75]. It was found that the storage modulus of the fiber incorporated polyester composites was increased compared to neat polyester composite. Pothen *et al.* [65], studied the dynamic mechanical properties of banana fiber loaded polyester composites. They noted that the composite with 40 vol% fiber loading had the maximum storage modulus, and lower loss modulus and damping properties. Mohanty *et al.* [46] investigated the dynamic mechanical property of jute fiber/high density polyethylene composites. They observed that the storage modulus of the composites increased and reached maximum at 30% fiber loading.

In another work, the dynamic mechanical properties of randomly oriented kenaf fiber loaded poly lactic acid is reported [54]. They observed that composites with more than 50% kenaf fiber have less damping peak compared to neat polylactic acid. Sonia *et al.* [76], carried out investigations on the dynamic properties of cellulose microfibers in poly (ethylene-co-vinyl acetate) (EVA) composite. The result shows that the storage modulus increased with microfiber loadings. It increased upto 7.5%, but after that it started to decrease at showed a minimum at high fiber loading. Sreenivasan *et al.* [77], studied the influence of fiber content, length and chemical treatment on Sansevieria cylindrical (SC) fiber incorporated polyester matrix. They found a strong influence of the fiber loading and fiber length on the dynamic properties. They concluded that the fiber reinforced composites can improve the storage modulus because of the stiffening effect. The damping curve decreased and they reported that the damping performance of fiber reinforced composites depend on many parameters like fiber/matrix adhesion, fiber breakage interphase zone etc. A study on keratin fiber from chicken feathers reinforced poly (methyl methacrylate) matrix short fiber composites was reported [78]. In that study, the researchers observed an increase in storage modulus and decrease in tan delta peak indicating strong interfacial interaction.

Kumar *et al.* [79] prepared epoxy composites with chemically modified and unmodified coconut sheath fibers by hand layup technique followed by compression molding followed by compression molding technique. The dynamic mechanical testing of these treated fiber epoxy composites showed increase in storage modulus and decrease in damping parameter. They concluded that there is an improved adhesion between epoxy resin and the chemically modified coconut fiber than unmodified fiber and hence the mechanical performance of treated fiber composites is better. Singhal *et al.* [80] prepared chemically modified and unmodified Jute fiber/epoxy composites and investigated their dynamic performance. They found that all the surface treated samples (modified by benzoyl chloride, alkali, permanganate, silane and malic anhydride) are having better storage modulus than untreated samples. Huda *et al.* [81] prepared kenaf fiber/PLA composites by treating kenaf fibers with silane and alkali. They found that the treated fiber composites are having superior mechanical performance.

In a work, Ray *et al.* [82], reinforced vinyl ester matrix composites with untreated and NaOH treated jute fibers and investigated the dynamic properties with respect to temperature. They observed that the storage modulus increased with fiber content. The addition of fibers decreased the tan delta indicating the decrease in the damping property and the storage modulus showed a decreasing trend with respect to temperature. Essabir *et al.* [83] investigated the dynamic properties of doum fibers incorporated polypropylene binary and ternary composites. They observed improvement in the viscosity and glass transition temperature for ternary composites when compared to binary composites.

Due to rapidly increasing concern towards environment, bio polymers and degradable polymers have gained much importance [84]. Many researchers are focussing on electrospun biopolymer fibers for multi functional applications [85]. These fibers are having good surface area and are continuous, so these are optimal materials for reinforcements. If hybrid composites are made from electrospun bio-fibers and natural fibers, those composites are expected to have excellent dynamic properties and can be utilized for high end applications. Further, novel green composites with novel natural fibers and biopolymer matrices can be developed with enhanced modulus. These green composites are sustainable and environmentally friendly as well [86].

4 Conclusions

Natural fibers are renewable raw materials with recyclable characteristics. So, the employment of natural fibers for composite reinforcement is a green route to prepare biodegradable materials with less toxicity. Several natural fiber composites reach the mechanical performance of glass fiber composites and are available in the market. The dynamic mechanical performance of natural fiber composites is an interesting and much studied area. In this mini review, we have tried to bring together many studies done on natural fiber reinforced composites by researchers. The main takeaways from the review are that DMA is a very important technique to measure the storage modulus, loss modulus and mechanical damping factor. This technique will allow us to understand and investigate the phase transitions in the composite materials in a widespread range of temperature and frequencies. In the case of natural fiber composites, the DMA properties are being influenced by the fiber type, its content, length, size and the stacking arrangement. The DMA properties are also observed to be effected by the fiber functionalization. At present, lot of researchers are working on natural fiber/synthetic fiber hybrid composites for advanced applications. Preparing conducting bio composites by the incorporation of hybrid fibers containing conducting fillers is another emerging area of study. It is anticipated that a more focused study of the DMA of composites containing hybrid fillers will take place in recent years so as to stimulate the application arena of fiber reinforced composites.

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