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Dynamic mechanical and thermo-gravimetric analysis of *Sansevieria cylindrica*/polyester composite: Effect of fiber length, fiber loading and chemical treatment

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ABSTRACT

The *Sansevieria cylindrica* (SC) fiber reinforced polyester matrix composites (SCFRPCs) were fabricated using compression molding machine. The influences of fiber length, fiber loading and chemical treatments of SCFRPCs over the mechanical and thermal stability were analyzed at different temperatures. The dynamic characteristics such as storage, loss modulus and damping were significantly influenced by the increase in fiber length and fiber loading but not in a geometric progression. Among various chemical treatments, the potassium permanganate treated SCFRPCs show the maximum increase in storage and loss modulus values. This result concluded that in addition to the reinforcing element (fiber length and wt% of fiber) the interfacial bonding between the fiber and the matrix plays a vital role in restricting the molecular mobility which was apparent from the storage modulus values. Efficient stress transfer at the interface is necessary to produce better dynamic properties rather than having more interfacial region. The change in morphology of cleaned and roughened SC fiber and the degree of interfacial adhesion between the fiber and matrix were studied using scanning electron microscope (SEM). The weight loss of SCFRPCs were also studied under varying temperatures with the help of thermo-gravimetric analysis (TGA).

1. Introduction

The momentum on the extraction and characterization of biodegradable fibers has notably increased for the development of fiber reinforced composites used in various applications ranging from automotive sector to packaging industries [1–3]. Subject to confirmation by life cycle assessment, natural fibers may provide a green environment for manufacturing the composite components providing comparable performance to the traditional composites in ecological aspects [4,5]. In addition to this, the selection of natural fibers as reinforcement in polymer matrix can justify its significance owing to their low cost, fairly good mechanical properties, high specific strength, non-abrasive, eco-friendly, bio-degradability, non-toxic and easy for processing and absorbing CO_2 during their growth characteristics [6–8]. The use of natural fibers in the place of conventional fibers, such as glass, aramid and carbon are studied in terms of effective ecofriendliness, ultimate disposability and best utilization of raw materials. Various natural fibers such as bagasse [9], flax [10], hemp [11], doum fruit [12], and date palm [13] are used as reinforcing material for polymer-based matrices.

In natural fiber reinforced composites (NFRCs), the parameters such as fiber length, fiber loading, addition of filler, chemical treatment of fiber, fiber orientation and the mode of testing were identified to have the most significant influence in affecting the mechanical, dielectric and transport properties [14–16]. In our previous work [17], the static mechanical properties of SCFRPCs were studied for fiber lengths of 10, 20, 30, and 40 mm and fiber loadings of 10, 20, 30, 40, and 50 wt%. The effective fiber volume fractions corresponding to each of fiber loadings are represented as 8%, 18%, 28%, 38%, and 48%. Higher mechanical properties were achieved at 30 mm fiber length with 40 wt% of fiber loading, whereas at 50 wt% of fiber loading the mechanical properties decreased – primarily due to insufficient binder in the system. In general, the natural fiber reinforcement gives poor compatibility with polymer matrix because of the hydrophilic nature of natural fibers. Hence, many researchers concentrated on surface modification of natural fibers to improve the compatibility and adhesion between the fiber and the matrix. The chemical treatments of the

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reinforcing fiber offer better interaction between the fiber and matrix. Leonard and Ansell [18] studied the alkalization of hemp, sisal, jute, and kapok fibers by using sodium hydroxide to improve adhesion between fiber and matrix and hence to enhance the mechanical strength of the composites. Some of the theoretical studies have also been performed to analyze interfacial behavior under dynamic loading conditions. Qian et al. [19] performed theoretical study on the effect of surface/interface stress on the dynamic stress around a spherical inhomogeneity subjected to asymmetric dynamic loads. The surface/interface stress effects are taken into account by introducing Gurtin–Murdoch surface/interface elasticity model. Tan and Lim [20] investigated the challenges involved in mechanical testing, current limitations and the possibility of predicting dynamic mechanical characterization of nanofibers. Idicula et al. [21] studied the dynamic and static mechanical properties of randomly oriented and intimately mixed short banana/sisal hybrid fiber reinforced polyester composites. They have also compared theoretical results from Einstein's and Nielsen equation for the storage modulus and damping factor, with experimental outcomes. Huang [22] carried out a micromechanical approach for examining the dynamic response of laminated composite plates composed of randomly oriented fibers in each layer.

In recent years, the growing interest in NFRCs have led to creation of composites with better properties not only on static mechanical but also on visco-elastic behavior in polymer matrix. Several works [23–25] have been reported on the dynamic mechanical analysis (DMA) of synthetic fiber reinforced polymer composites. All these authors have mainly focused the importance of fiber loading (wt%) on polymer composites using the output of dynamic mechanical analyzer. More recently, Etaati et al. [26] studied static and visco-elastic properties of short hemp fiber polypropylene composites manufactured by injection molding method. They showed that increase in storage modulus was found to be negligible in the composites reinforced with more than 40 wt% of hemp fibers. They also confirmed that addition of coupling agent can improve interfacial bonding between hemp fiber and polypropylene matrix. Jawaid et al. [27] analyzed interfacial bonding on tensile fractured oil palm–epoxy composites using scanning electron microscopy. They also identified that static and dynamic mechanical properties of oil palm–epoxy composites improve due to good interfacial bonding between fiber and matrix. Karaduman et al. [28] reported visco-elastic properties of nonwoven jute reinforced polypropylene composites using dynamic mechanical analysis. They revealed that alkali treated jute fibers improve the adhesion between fiber and matrix in the resultant composites. The effect of silane and NaOH treatments on thermal and thermo-mechanical properties of hemp/polyethylene composites was investigated by Lu and Oza [29]. They observed that storage modulus of treated composites is greater than that of untreated ones. Gassan and Bledzki [30] have performed the dynamic mechanical analysis for jute/epoxy composites in different conditions and also observed an enhancement in storage modulus by the inclusion of treated jute fiber in epoxy matrix. Saha et al. [31] carried out comparative studies on the damping of untreated and chemically treated jute fiber reinforced polyester composite. Pothan et al. [32] investigated the influence of chemical modification on dynamic mechanical properties of banana fiber reinforced polyester composites. Various silane coupling agents were used to modify the banana fibers. The authors have reported that the shifting of damping peaks also depends on the nature of chemical treatment. And also, both storage modulus and damping values were found to be consistent and indicated the effectiveness of silane A174 as a coupling agent (*c*-methacryloxypropyl trimethoxy silane) for improving fiber–matrix adhesion. Bozaci et al. [33] studied the effect of chemical treatments on mechanical properties of flax/high density polyethylene (HDPE) and flax/unsaturated polyester composites to predict the interfacial adhesion between fiber and matrix. They concluded that chemical composition, functional groups and surface roughness of fiber vary with nature of chemical treatment.

Hitherto, preliminary investigations [17,34,35] have been carried out using *Sansevieria cylindrica*/polyester resin based composites only by our research group. The aim of this proposed work is to develop the partially biodegradable SCFRPCs with the combination of natural (SC) fiber and synthetic (polyester) resin. Towards this, dynamic mechanical analyses were performed on SCFRPCs to study storage modulus, loss modulus and damping factor. Additionally, the effect of fiber length, fiber loading and chemical treatments were also analyzed under transient temperature condition.

2. Experimental details

2.1. Materials

S. cylindrica leaves, were collected from farms around the city of Tirunelveli, Tamil Nadu, India, and the fibers were separated by a mechanical process called "decortication". Sreenivasan et al. [34] described the decortication method used for extracting SCF from its leaves. The chemicals used for the modification of SCF surface such as sodium hydroxide, potassium permanganate, benzoyl peroxide, acetone, stearic acid and ethyl alcohol were of commercial grade. The matrix used for the investigation was commercially available unsaturated polyester, with the trade name Satyan (Surat, India) polymer. Methyl ethyl ketone peroxide (MEKP) and cobalt naphthenate were used as curing catalyst and accelerator respectively. The chemicals, matrix, catalyst and accelerator were procured from Vasavibala resins (P) Ltd., Chennai, India. The properties of raw SCFs [34] and unsaturated polyester resin [17] have already been reported elsewhere as shown in Tables 1 and 2.

2.2. Fiber surface treatments

The raw SCFs were subjected to different surface treatments with alkali, benzoyl peroxide, potassium permanganate and stearic acid. SCFs were chopped into 30 mm long bits (critical fiber length) [17] before the chemical treatments.

2.2.1. Alkali-treated SCF (ASCF)

The SCFs were soaked in a stainless steel vessel containing 10% sodium hydroxide solution for 1 h. The fibers were washed thoroughly with water to remove the excess of sodium hydroxide

Table 1
Characteristics of raw SCFs [34].

Physical characteristics	
Length	1000–2000 mm
Shape of fiber cross-section	Irregular
Cross-sectional area	0.0245 ± 0.003 mm^2
Porosity fraction	32–37%
Density	0.915 ± 0.005 g/cm^3
Fineness	8.95 ± 0.028 Tex
Chemical characteristics	
Cellulose	79.7%
Hemicellulose	10.13%
Lignin	3.8%
Wax	0.09%
Moisture	6.08%
Mechanical characteristics	
Tensile strength	658 MPa
Young's modulus	6.69 GPa
Strain to failure	10–12%