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Review

A review on dynamic mechanical properties of natural fibre reinforced polymer composites

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HIGHLIGHTS

- DMA is one of the most powerful tools to study behaviour of polymer composites.
- DMA study will help utilisation of natural fibre composites in construction field.
- Natural fibre composites can be used for replacing steel, wood and concrete.

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ABSTRACT

Dynamic mechanical analysis (DMA) is a versatile technique that complements the information provided by the more traditional thermal analysis techniques such as differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and thermal mechanical analysis (TMA). The dynamic parameters such as storage modulus (E'), loss modulus (E''), and damping factor (Tan δ) are temperature dependent and provide information about interfacial bonding between the reinforced fibre and polymer matrix of composite material. The dynamic parameters were ominously influenced by the increase in fibre length and loading but not in a geometric progression. Dynamic loading conditions are frequently stumble in civil infrastructure systems due to sound, winds, earthquakes, ocean waves and live loads. Vibration damping parameters shows prime importance for structural applications in order to enhance the reliability, performance, buildings comfort and in the alleviation of bridges hazards. DMA also predicts the effects of time and temperature on polymer sealants viscoelastic performance under different environments. Present review article designed to be a comprehensive source of reported literature involving dynamic mechanical properties of natural fibre reinforced polymer composites, hybrid and nano composites and its applications. This review article will provides a perfect data to explore its industrial application primarily as cheaper construction and building materials for doing further research in this topic.

Contents

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1. Introduction

The growing interest in proper utilisation of natural fibres, paralleled to glass and carbon fibres are chiefly due to their low cost, high specific modulus, light weight, lower energy requirements-less wear and tear in processing, wide availability, biodegradability, resistance to deforestation along with other usual advantages. The incorporation of natural fibres as reinforcing agent in both thermoset and thermoplastic polymer composites has gained increasing applications both in many areas of Engineering and Technology [1]. A variety of natural fibres based polymer composite materials have been developed using modified synthetic strategies to extend its application from automotive to biomedical fields [2]. Natural fibres such as coconut, sisal, jute, ramie bast, eucalyptus pulp, malva, banana, hemp, kenaf bast, flax, pineapple leaf, sansevieria leaf, abaca leaf, bamboo, date, palm, sugarcane fibre and cotton are being commonly reinforced in the polymer system to complement the certain specific properties in the final products [3,2]. These cellulosic natural fibres have a wide range of physical and mechanical properties that is related to the original source such as diameter, length, specific gravity, methods of processing, treatment etc. governing its wider applications [4]. Among different natural fibres, hibiscus sabdariffa, henequen, pines, esparto, sabai grass and banana fibres are still some of the unexplored high potential fibres having similar chemical constituents (cellulose, hemicellulose and lignin), mechanical properties and thermal resistance to other natural fibres such as jute, sisal, hemp, bamboo, oil palm [5].

Construction and building materials are the most interesting application area, which relates to enhancing the functional properties of concrete, steel, wood, and glass, as the primary construction materials [6]. They are used as a structural component (construction material), for improving the properties of the polymer composites, and shows costs effectiveness, when compared to the total cost of the composites especially when high percentage of fibres involved compared to steel fibre [3]. The reuse and recycling for a sustainable development are the major issues of government policy around the globe. In response to this the use of natural fibres will ensure more greener, sustainable and smart construction development as compared to polymer/steel/synthetic fibres [7]. Thus a huge possibility of replacing the traditional structural component with natural fibres, currently get highlighted and inveterate by the many researchers [8].

Natural fibre (such as kenaf, jute, hemp) reinforced polymer composite reflects outstanding and comparable mechanical and dynamic mechanical properties to steel and aluminum, leading to extend its applications for special engineering materials such as automotive, aerospace industry and construction structures [6]. Currently cellulosic or natural fibres as reinforcements for cement mortar composites and Portland cement masonry blocks reinforced with lechuguilla natural fibres constitute a very interesting option for the construction industry in ecofriendly manner [9,7]. However, before their applications in structural fields, some testing techniques are required to prompt to investigate the composite structure and performance under periodic stress such as damping behaviour.

DMA technique which is useful in characterising composite structure and damping as a function of frequency, temperature, time, stress, atmosphere or a combination of these parameters [10]. The dynamic mechanical response of the multi-component systems like composites is highly complex and involves the theories of constitutive equations and micromechanics. DMA also depends on the physical or structural arrangement of phases such as interface, morphology and the nature of constituents [11,12]. Researchers elaborated that the presence of the compatibilizer, additives like filler, fibre content, fibre orientation and the mode of testing governed the dynamic mechanical properties of a composite material [13].

2. Dynamic mechanical analysis (DMA)

Dynamic mechanical analysis is an indispensable and effective tool for determining the morphology and viscoelastic properties of crystalline polymer and composite materials related to primary relaxations and other valuable parameters, such as crosslinking density [14], dynamic fragility [15], dynamic/complex viscosity, storage/loss compliance, creep compliance/stress–relaxation modulus and the non-Arrhenius variation of relation times with temperature [16]. The storage modulus (E') or dynamic modulus typically related to the Young's modulus. It often associated with "stiffness" of a material and determine how stiff or flimsy a sample. E' regarded as a material tendency/ability to store energy applied to it for future purpose [17]. Loss modulus (E'') or dynamic loss modulus, is a viscous response of the materials and regarded as materials tendency to dissipate energy applied to it [17]. The dynamic loss modulus is often associated with "internal friction" and is sensitive to different kinds of molecular motions, transitions, relaxation processes, morphology and other structural heterogeneities. Thus, when ball is allowed to bounced, it results some energy to be dissipated and some energy save for future as illustrated in Fig. 1.

Tan δ is expressed as a dimensionless number and regarded as the mechanical damping factor defined as the ratio of loss and storage modulus (Tan $\delta = E''/E'$) shown in Fig. 2. The relationship between loss, storage modulus and Tan δ in the DMA graph versus temperature are shown in Fig. 3. The resultant component obtained from the plot are called as complex modulus (shear modulus), denoted by (E^*). A high Tan δ value is indicative of a material having high, non-elastic strain component while a low value indicates high elasticity. Increase in the fibre/matrix interface bonding results reduction in damping factor since mobility of the molecular chains at the fibre/matrix interface decreases. Thus, lower the energy loss in relation to its storage capacity greater the Tan δ

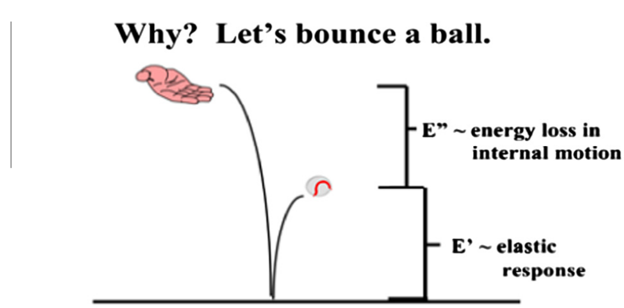

Fig. 1. Illustrations of the loss modulus and storage modulus.