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The effect of the strand diameter on the damping characteristics of fiber reinforced polymer matrix composites: Theoretical and experimental study

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ABSTRACT

The damping property of glass fiber reinforced polymer matrix composites with two different strand/fiber diameters, their different orientations and layups are investigated. It is found that the damping can be improved at the negligible expense of stiffness, by generating more number of interfaces, i.e., reducing the fiber diameter from 27.2 μm to 18.3 μm without compromising the dimensions of the composite specimen and the volume fraction of the fiber in the specimens. The natural frequencies and loss factors have been evaluated from experimental results, using the impulse technique. The same properties have also been evaluated theoretically by performing modal analysis, using Blevins' "Formulas for Natural Frequency and Mode Shape", and the three phase damping analysis using Ni and Adams's "the Specific Damping Capacity (SDC) model" and Gu et al. 's "the interfacial adhesion model" in the energy dissipation relationship. A good agreement exists between the experimental and theoretical values.

1. Introduction

In recent years, all the weighty metallic structures in certain applications, like the aerospace and automotive industries, are getting replaced by light weight polymer matrix composites (PMC) [1]. These materials possess superior properties, such as high specific strength and high energy dissipation, i.e. a high damping value at the negligible loss of stiffness [2]. The metallic structures possess inferior damping property. But, the use of a polymer matrix composite in structures improves the damping property considerably in several ways, and this has been reported in the recent past [3,4]. There are many types of damping/energy dissipation like material damping, aerodynamic damping, viscous damping [5] etc. This paper is confined only to the material damping. The energy can be dissipated from the materials by different ways such as: the fiber orientations, visco-elastic behavior of the polymer composites, temperatures, damages, interfaces, and flexible bonding at fiber-matrix interface. The following several reports have explained these possible ways of improving the damping properties of polymer matrix composites.

Adams and Bacon [6] have predicted the effect of different fiber orientations and laminate geometry, on the flexural and torsional damping and modulus of fiber reinforced composites. Their criterion was later used by Adams and Maheri [7] together with the basic plane stress relations, to predict the moduli and the specific damping capacity of the anisotropic beams with respect to fiber orientation. The results have shown that the longitudinal component (Ψ_x) of the SDC was the sole contributor in the 0° orientation and the major contributor in the 15° orientation of fibers in beams, while the shear component (Ψ_{xy}) of the SDC was the major contributor in the 45° orientations, and the transverse component (Ψ_y) of the SDC was the major contributor in the 60–75° orientations and the sole contributor in the 90° orientations of the fibers. They also showed that the damping values increased at a faster rate from 0° to 60°, and increased slightly from the 60° to 90° orientation of fibers. The effect of the beam aspect ratio was also considered in their predictions; i.e., the tests on different widths of beams showed no significant effect on the SDC or the modulus.

The dynamic properties of hybrid (carbon-glass fiber laminated) composites were estimated by Ni et al. [8]. They used an energy method and a finite element (FE) technique to demonstrate that the addition of a small amount of CFRP to the surface of the GFRP composite would improve the flexural modulus. Kishi et al. [9] studied the damping characteristics of fiber-reinforced

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interleaved epoxy composites with different arrangements of the reinforcing carbon fiber, but they used several types of thermoplastic-elastomer films as the interleaving materials. Hui and Ling [10] also investigated the damping behavior of laminated composites with integral visco-elastic layers, under the effect of the ply angle of the complaint layers and the location of the visco-elastic layers.

The modal strain energy method and FE technique were used by Mohan et al. [11] to study the modal parameters (resonance frequencies and modal loss factors) of the multi-damping layer of the anisotropic laminated composite beam under the effect of various temperatures. They found that the modal loss factor increased with an increase in temperatures, with little reduction in the stiffness and strength. Youssef and Berthelot [12] also predicted the damping behavior of the composite under the effect of temperatures and found that the material became highly soft and damped when close to the glass transition temperature of the polymer. Vijayakumar and Sundareswaran [13] have studied the dynamic properties of polymer (epoxy) matrix composite under different temperatures. They have found that the loss factor and the natural frequency of epoxy/glass fiber composite can be increased from 10% to 40% at 150 °C when the epoxy is modified with cyanate content. The vibrational behavior of fiber glass/epoxy specimen is also influenced by the temperature and moisture, i.e., the natural frequency of the specimen is reduced with the increase in the temperature and moisture content [14].

In this study, improvement of the loss factor by the creation of a larger number of interface regions is demonstrated; i.e., the fiber diameter is reduced without change in the size of the laminate. Fibers with diameters of 18.3 μm (at the Standard Deviation (S.D.) of 0.64) and 27.2 μm (at the S.D. of 0.51) are considered for this study. If the fiber diameter decreases, the number of fiber-matrix interfaces increases, which leads to higher energy dissipation when the specimen is excited. The loss factor values have been found for two different diameters of the fiber in the two different strands with the same fiber-matrix proportions of the laminates. The frequencies obtained from the dynamic test have been compared with those obtained from the modal analysis performed by using Blevins' [15] “Formulas for Natural Frequency and Mode Shape”. Similarly, the loss factors obtained from the dynamic test have also been compared with those obtained theoretically. The loss factors obtained from the theoretical approach are in three phases, in which the loss factors of the first two phases or the system (fiber and matrix) have been found by Ni and Adam's [16] “Specific Damping Capacity (SDC) model” and the loss factor of the third phase or the damping between the interfaces by Gu [17] and Gu et al. 's [18], “interfacial adhesion model”.

2. Materials and properties

Low temperature curing epoxy resin, Rotex EP-207S with a specific gravity of 1.14 at 25 °C, a solvent based high temperature curing hardener, Rotex EH-210S, and the accelerator, Tertiary amine which were supplied by ROTO Polymers, Chennai, have been used for the fabrication of the composite. The unidirectional glass fiber of a density of 2.50 g/cm^3 supplied by SUNTECH Fibers, India, has been taken as reinforcement for the preparation of the composite laminate. The test specimens are made up of the unidirectional fiber mat, resin, accelerator and catalyst, using the simple hand lay-up technique followed by pressing at room temperature. The two different test specimens of the dimension 300 × 25 × 4 mm^3 with a stacking of 12 layers for the smaller and 4 layers for the larger strand diameter of the fiber category, were thus prepared from the laminate plates for the free vibration test. The test specimens, as mentioned above, have different stacking sequences, such as unidirectional and angle ply with 50% volume fraction of fiber at the S.D. of 1.3 for small diameter fiber and 1.37 for large diameter fiber.

3. Experimental work

3.1. Dynamic mechanical analysis (DMA)

Dynamic mechanical analysis (DMA) has been performed in the three point bending testing mode to check the effect of the visco-elastic properties like the loss factor, storage and loss modulus under the influence of different temperatures as shown in Figs. 1 and 2. These visco-elastic properties have been recorded from the specimens of the pure epoxy and FRP materials of dimension 35 mm × 12.5 mm × 3.3 mm using dual cantilever geometry. A constant strain amplitude of 1% and a frequency of 1 Hz have been imposed on to the test specimen. The viscoelastic properties have been monitored from 20 °C to 160 °C at a heating

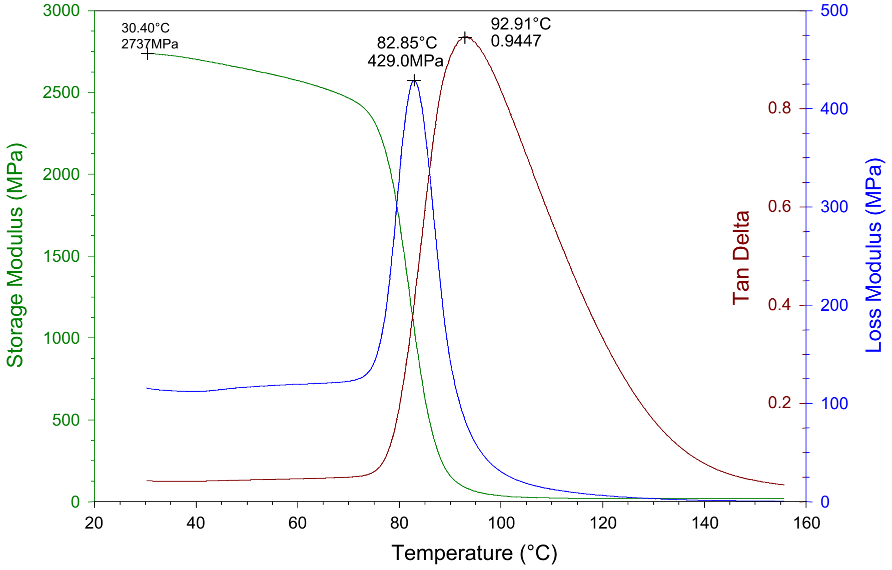

Fig. 1. DMA scan of the pure epoxy specimen showing the effect of storage modulus, loss modulus and tangent delta curves under the influence of various temperatures.