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Synchronous improvement of loss factors and storage modulus of structural damping composite with functionalized polyamide nonwoven fabrics☆

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ABSTRACT

Conventional structural materials and damping materials both don't combine excellent mechanical and damping properties at the same time, which makes them unable to meet the practical demand. Study on structural damping composites that possess higher mechanical and damping properties is becoming a hot research direction. Meanwhile dynamic mechanical analysis (DMA) could provide information on the mechanical and damping properties via storage modulus and loss factor, respectively, which makes it one of the most convenient and effective research methods on structural damping composites. In this paper, composites with polyamide nonwoven fabrics (PNF) and functionalized PNF with crystalline thermoplastic polymer polyvinylidene fluoride (PVDF) and nanoscale carbon material vapor grown carbon fiber (VGCF) as interleaf materials are prepared firstly, then dynamic mechanical behaviors are measured and the microstructure is analyzed to study the effect of different interlayers on the mechanical and damping properties of the co-cured composites. The results indicate that PNF could improve the loss factors without significantly reducing the storage modulus, moreover, functionalized PNF with PVDF and VGCF are capable of further improving storage modulus and loss factors synchronously.

1. Introduction

Carbon fiber reinforced polymer (CFRP) was widely used in aircraft structures due to their high specific strength and high specific modulus [1]. Recently, the increasingly high requirement on vibration and noise reduction of aeronautical vehicles poses a challenge to conventional CFRP, so many efforts have been made by worldwide researchers on the improvement of the damping properties of CFRP [2–5]. Among them, co-cured viscoelastic materials method exhibits more advantages than others in improving damping properties [6–8]. However, because the present commonly used co-cured materials were viscoelastic rubbers, their poor heat resistance, aging-resistance and mechanical properties lead to the obvious decrease of mechanical properties and heat resistance of co-cured composite and restricted their application [9–15]. To solve the problem, other new co-cured materials like Nomex honeycomb, Kevlar honeycomb, piezoelectric ceramic, electro-rheological materials and natural fibers have also been studied [16–18]. Toshio [19] studied the effect of dispersed PZT particles on vibration damping and mechanical properties of the CFRP beams. Although the damping properties were improved and the mechanical properties did not decline sharply, big densities of PZT restricted its application in the aerospace field. James [20] studied the relationship between the interlayers such as Nomex honeycomb with different densities and shear modulus and the mechanical and damping properties of co-cured composites. One significant weakness of this kind of sandwich-like structures is the huge thickness due to the addition of thick interlayers, which generates the decrease of the composite mechanical properties and their poor interfacial connection with the polymer matrix. In addition, multi-walled carbon nanotubes and nanosilica were also reported to be able to improve the composite damping and mechanical properties simultaneously [21–25], however their poor dispersion and high cost greatly limit their large-scale application. Therefore, it is highly desired to integrate high damping properties into advanced CFRP composites without damaging their structural properties and heat resistance.

In this manuscript, some new structural damping composites were prepared by incorporating polyamide non-woven fabrics (PNF) and functionalized PNF with semi-crystallization thermoplastic PVDF and nanoscale carbon fiber VGCF as interleaved materials into the CFRP. The influences of PNF numbers and functional materials on the mechanical and damping properties were studied via storage modulus and loss factors of the co-cured composites. One of the main purposes of the manuscript is to obtain a feasible designing method and rapid assessment on the structural damping materials.

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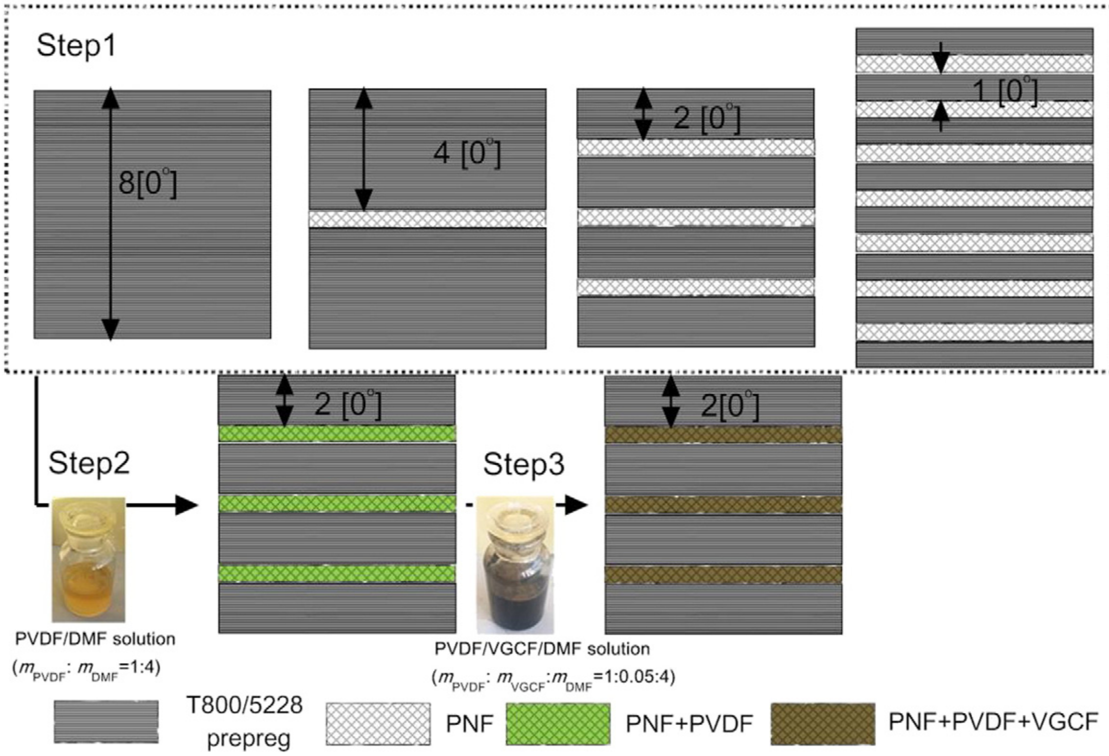

Fig. 1. Schematic illustration of the co-cured composite.

2. Experimental details

2.1. Materials

The polyamide non-woven fabrics were with areal density 20 g/m^2 and a diameter 16 μm. The fiber-reinforced composite laminates were made of unidirectional prepreg tape (T800/5228, BIAM), and the carbon fiber volume fraction of the prepreg was 55%. PVDF particles labeled FR904 were purchased from 3F New Material Co., Ltd. and the VGCF with 30–200 nm in diameter and 2–5 μm in length was purchased from the Showa Denko K.K.

2.2. Specimen preparation

The co-cured composites were prepared by interleaving different numbers of PNF (1, 3, 7) between the carbon fiber reinforced epoxy matrix composites, and cured in an autoclave at 180 °C for 120 min under an applied pressure of 0.6 MPa. The heating rate was 1–1.5 °C/min. Schematic illustration of lay ups of the co-cured composites was shown in the “step1” in Fig. 1. Then different quantities of PVDF (10 g/m^2, 25 g/m^2, 50 g/m^2) were loaded on the PNF via dissolving some quantities of PVDF with DMF (mass ratio m_{PVDF}:m_{DMF} = 1:4) firstly and then brush painting directly on PNF. It needed to dry the loaded PNF in an oven at least 120 min at 120 °C before use. According to the same preparation method mentioned above, the co-cured composites with PNF/PVDF were made in the “second step”. Thirdly, VGCF was added into the PVDF/DMF solution in advance and the mass ratio m_{PVDF}:m_{VGCF} was 1:0.05, Next, the PVDF/VGCF/DMF solutions were loaded on the PNF (50 g/m^2) and dried at least 120 min at 120 °C. In the same way, the co-cured composite with PNF/VGCF/PVDF was prepared. Information on all specimens prepared in the manuscript has been listed in Table 1.

2.3. Property characterization

Measurements of dynamic mechanical properties of composites were carried out using dynamic mechanical analyzer (equipment type: DMA Q800). The dimensions of MA test were nominally 60.0 mm × 10.0 mm. The test was under 3-point bending testing mode and the strain amplitudes used were 0.008%. As for the functionalized PNF, the DMA test was under tensile mode and the strain amplitudes used were 0.005%. In addition, the scanning was performed over a temperature range from 30 to 250 °C with a heating rate of 5.0 °C/min and an excited frequency of 1 Hz. Optical microscopy and scanning electron microscopy (equipment type: QUNATA600) were used to

Table 1
The names of the specimen configurations, fiber volume and thickness of the specimen.

Specimen	Specimen configurations	Fiber volume/%	Thickness/mm
Control	T800/5228, $[0°]_8$	55	0.90
1PNF	$[0°_4/d/0°_4]$	53.2	0.93
3PNF	$[0°_2/d/0°_2/d/0°_2/d/0°_2]$	48.5	1.02
7PNF	[0°/d/0°/d/0°/d/0°/d/0°/d/0°/d/0°/d/0°]	41.6	1.19
3(PNF + 10 g/m^2 PVDF)	$[0°_2/d_1/0°_2/d_1/0°_2/d_1/0°_2]$	47.1	1.05
3(PNF + 25 g/m^2 PVDF)	$[0°_2/d_2/0°_2/d_2/0°_2/d_2/0°_2]$	45.8	1.08
3(PNF + 50 g/m^2 PVDF)	$[0°_2/d_3/0°_2/d_3/0°_2/d_3/0°_2]$	44.2	1.12
3(PNF + 50 g/m^2 PVDF/VGCF)	$[0°_2/d_4/0°_2/d_4/0°_2/d_4/0°_2]$	43.8	1.13
PNF + 50 g/m^2 PVDF	Cloth	–	–
PNF + 50 g/m^2 PVDF/VGCF	Cloth	–	–

Note: d means PNF, d_1 means PNF with 10 g/m^2 PVDF, d_2 means PNF with 25 g/m^2 PVDF, d_3 means PNF with 50 g/m^2 PVDF, and d_4 means PNF with 50 g/m^2 PVDF/VGCF.