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Enhancing damping features of advanced polymer composites by micromechanical hybridization

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ABSTRACT

A hybrid configuration at the micromechanical level is presented and described as a suitable approach to enhance the damping features of advanced polymer composites. A micro-level hybridization was achieved on dry preform reinforcements by embedding visco-elastic fibres within standard carbon tows. Unidirectional composites with two viscoelastic volume fractions (2.5% and 5% vol/vol) were manufactured by a vacuum infusion process and later tested by dynamic mechanical analysis along the principal directions. Final results reveal a significant enhancement (+80% and +56%) of the damping properties, respectively, for the longitudinal and the transverse directions in the case of the highest viscoelastic fibre content.

In turn, the elastic properties of the final composite were greatly reduced (−37% and −35%) with respect to the standard composite. Final results support further work in the direction of micromechanical hybridization looking at the potential exploitation of standard textile configurations with different visco-elastic fibre content to enhance damping properties.

1. Introduction

Due to their high specific strength and high modulus, advanced fibre-reinforced plastic composites have been increasingly used in weight sensitive applications. Especially for the aerospace and automotive sectors, the damping behaviour of composites represents a major requirement. Although damping mechanisms have been elucidated and experimentally investigated at various levels and a variety of applications are widely used in order to reduce noise and vibration, still many questions arise. The possibility to control vibration and noise, in a dynamic system, has been exploited by many others and a number of different methodologies have been proposed [1–7].

Currently, among the different methods to enhance damping behaviour of composite elements or structures, three main categories are recognised, according to the specific mechanisms of dissipation energy, namely: active, semi-active and passive methods.

Active methods are characterised by a feedback controlling signal which act "out-of-phase" for the vibration and noise energy dissipation; *semi-active applications* adopt the particular damping behaviour of passive element such as magneto-rheological or electro-rheological fluids, or active smart material embedded as a constrained layer within the structure [8,9].

Passive approaches have been driven by the possibility to integrate damping materials within structures or final elements. Conventional damping treatments exploit shear deformation mechanisms to increase the dissipation, i.e. in the case of bending structures the addition of bonded viscoelastic material sheets represents a valid approach (*Constrained Layer Treatment*) [9,10]. Nowadays, the possibility to access new materials accompanied by more sophisticated technological processes may allow the development of more effective passive systems to enhance damping features.

Passive control methods to improve damping properties of advanced composite materials, can be implemented on different dimensional levels. On the *macro-mechanical level*, researchers have utilised various approaches by changing geometry, material properties, lamina orientation, coupling effects, surface co-cured attachments, hybridization of the lamina and geometric fibre wave patterns. In all cases, materials were not altered and significant improvements were attained in damping characteristics.

Conventional macro-mechanical damping treatments are based on the addition of viscoelastic inter-ply layers [11–16]. These layers increase energy dissipation in the structure by transforming the time-dependent shear strain into heat. Location and material behaviour play a major rule for this technique. These approaches involve either additional layers within the composite system or

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co-cured laminae/patches on the outer surfaces of the composite elements. Although, the efficiency of these approaches have been demonstrated experimentally, the addition of interleaved laminae influences the failure mechanisms of the final element by increasing the magnitude of interlaminar shear stresses, at the viscoelastic material/lamina interface. On the other side co-cured layers certainly lead to undesirable weight and extra processing costs.

For all these reasons, researchers and technologists are still searching for innovative passive solutions by implementing both new damping materials and more effective configurations [6].

Hybridization of the laminates was studied and developed by Gibson and Mantena [6] particularly. These authors, revisiting previous work by Adams and Zimmerman [7], have manufactured hybrid composite laminates consisting of alternating layers of polyethylene SPECTRA fibre-reinforced laminae and graphite fibre-reinforced laminae. The rationale of this approach is mainly based on the combination of excellent damping properties and low stiffness characterising the SPECTRA fibres and the high stiffness of the graphite laminae with low performances in damping and impact resistance behaviour. Final results have reported that the through-thickness location of the SPECTRA laminae is the most important factor which influences the loss factor of the overall flexible composite materials. In fact, positioning the polyethylene layer near the outer surfaces represents the most optimised configuration due to the high loss factor value for the SPECTRA and the higher strain energy generated in the outer surface under flexural vibration.

A variety of attempts have been made also *at the micromechanical level* by altering some geometric or material property parameters such as fibre aspect ratio and spacing, fibre orientation, fibre/matrix interphase, fibre coatings, woven configuration and constituent material hybridization. Suarez et al. [17] and Gibson et al. [18] have reported an increase in damping behaviour for unidirectional composite with a decreasing fibre aspect ratio. Experimental and numerical results have also shown that the fibre end gap induces variation of the damping behaviour in discontinuous, aligned fibre composite enhancing loss property due to shear mechanism at the fibre matrix interface near the fibre ends [19]. Numerical and experimental evidence of increasing damping behaviour by working on the fibre/matrix interface, fibre coatings [20–25] and woven fabrics effect on damping property [26,27] have been also published. A further consideration regarding passive methods is connected to the potential enhancement of the damping behaviour along different directions. Viscoelastic material co-cured or layered, added to the composite in order to enhance damping behaviour, commonly leads to an isotropic behaviour of the composite system, inducing a corresponding contribution to stiffness and damping properties in all directions. A few years ago, Biggerstaff and Kosmatka [28,29] presented an integrated composite configuration, characterised by copper strands embedded among viscoelastic lamina to develop novel damping applications. The strategy of adding directional elements within the composite in order to enhance orthotropic damping behaviour has attracted the attention of many industrial sectors, due to the great number of potential applications.

In this work, a micromechanical hybridization of reinforced polymer composite is presented and developed by integrating passive damping material in the form of intra-tow viscoelastic fibres within a single laminae (*micromechanical hybridization*). The proposed architecture enhances directionally the dissipation mechanism of the lamina, allowing the integration of the damping treatment directly within the weaving process of the dry preform. The possibility to integrate the viscoelastic material at micro-level within the raw fibre preform opens up the way for new multifunctional composites characterised by hybrid configuration with specific directional damping properties.

The present work is organised as follows: firstly, a discussion on the basic characteristic of hybrid dry preform is presented along with manufacturing features associated to the realisation of both dry preform and laminate composites. It is outside the scope of the present work to review all the technological issues emerging from the various textile stages occurring for the realisation of the dry UD reinforcement. Secondly, the manufacturing process of hybrid reinforced composite samples and preliminary tests on neat materials, by thermal analysis (DSC) and dynamic mechanical analyser (DMA), are presented and described. Two different viscoelastic material volume fractions were considered to manufacture the composite coupons. Finally, the two UD hybrid composites were tested in order to assess the effects of micromechanical hybridization on Young modulus and damping capacity presenting and discussing the obtained results.

2. Materials and methods

Three different typologies of long fibre reinforced composites were manufactured by Vacuum Infusion Processes (VIP) in our Processing Lab. The epoxy matrix was reinforced with a standard UD carbon fabric (*standard composite*), with a 5% w/w (*5Hybrid*) and a 10% w/w (*10Hybrid*) viscoelastic fibre hybrid carbon preforms. It is worth noticing that the cited percentages are referring to the total weight of the dry preform. The effective percentages of viscoelastic fibre volume fraction, computed to the total volume of the final composite, were $\sim$2.5% and $\sim$5% vol/vol respectively. The resin used was the RMT6 epoxy system supplied by Hexcel and certified for aerospace components. This matrix was specifically designed for RTM/infusion processes as the low viscosity level, reached around 100 °C [30], allows the complete impregnation of the dry preform. The G1157 UD fabric, characterized by a HR 12K carbon fibre tows and supplied by Hexcel Ltd. (UK) was used as the reinforcing system to manufacture the dry preforms. The specific viscoelastic fibre employed to enhance the damping behaviour of the final composite, was a polyurethane viscoelastic fibre supplied by Du Pont under the commercial name of Lycra (78.4 dtex). Preliminary tests of Lycra samples were performed by differential scanning calorimeter, type DSC 2920 from TA, equipped with a cooling system GCA able to achieve the lowest temperature of -100 °C and to control the heating/cooling segment with a programmed temperature rate. DSC sample weights ranged from 4 to 5 mg and all scans were performed at a standard heating ramp of 10 °C/min under a 30 mL/min nitrogen flow. Dynamic mechanical measurements were carried out using a TA DMTA 2980 under a three point bending test configuration, with a 50 mm span between supports. The temperature scans were performed over the temperature range -50 °C to 180 °C with a heating rate of 5.0 °C/min and a constant frequency of 1.0 Hz. Composite specimens with nominal dimensions of 60 mm $\times$ 10 mm $\times$ 1 mm (±0.1 mm) were accurately cut from the manufactured plates by a low speed cutting machine.

3. Micromechanical hybridization of dry perform

A micromechanical hybridized carbon fibre preform has been conceptualised to integrate viscoelastic material among carbon fibre tows as shown in Fig. 1.

The main advantage of such a configuration would be the possibility to overcome the problem of embedding a passive damping layer into the composite laminate, avoiding unwanted interlaminar stresses at the boundaries between the soft damping layer and high modulus carbon fibre lamina. However, the hybrid laminae concept (*micromechanical hybridization*), presented in this study, shows a further advantage which is the possibility to