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Performance of a graphite wafer-reinforced viscoelastic composite layer for active-passive damping of plate vibration

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ABSTRACT

In this work, an actively constrained viscoelastic layer over the surface of a substrate plate is supposed to be reinforced with a rectangular array of thin graphite-wafers, and the effects of the inclusions on the active-passive damping characteristics of the overall plate are investigated. The inclusions of graphite-wafers in the viscoelastic layer result in a 0–3 viscoelastic composite (VEC) layer. Its (VEC) stiffness and damping properties are distributed in a predefined manner for improved active-passive damping through all the transverse and in-plane strains of the viscoelastic phase. A finite element (FE) model of the overall plate is developed for its static and dynamic analyses. The static analysis reveals the mechanisms of active-passive damping. In the dynamic analysis, first, the damping in the plate is quantified for different sets of values of dimensions in the arrangement of graphite-wafers. These results suggest appropriate geometric configuration of the graphite-wafers for maximum enhancement of active-passive damping. So, the geometric configuration of 0–3 VEC layer is optimized, and finally the controlled frequency responses of the overall plate are presented. The results reveal significantly improved active-passive damping in the overall plate for the inclusions of graphite-wafers within the actively constrained viscoelastic layer in an optimal manner.

1. Introduction

Viscoelastic materials are capable of dissipating energy under the time-varying deformation, and this property has long been exploited for the suppression of structural vibration. Generally, these materials are used in the form of a layer that is freely attached to the substrate structure-surface or constrained between a constraining layer and the base structure-surface. These two kinds of arrangements of the viscoelastic layer for passive damping treatments of structural vibration are commonly known as the unconstrained layer damping (UCLD) and passive constrained layer damping (PCLD) treatments. A substantial number of studies on these UCLD and PCLD treatments of structural vibration have been reported in the literature [1–10]. These studies reveal that the damping in the UCLD treatment arises mainly due to the in-plane extensional/compressional strains of the freely attached viscoelastic layer, while the damping in the PCLD treatment appears because of the transverse shear deformation of the constrained viscoelastic layer. The PCLD treatment provides superior damping than that in the UCLD treatment [11,12], and thus the PCLD treatment has gained credential to become an efficient means of exploiting the viscoelastic materials for passive control of vibration of flexible structures. In the quest for further advancement of the constrained layer damping treatment, the active materials are utilised for the constraining layer along with a suitable controller. According to an appropriate control strategy, the active constraining layer acts as an actuator for controlling the deformation of the constrained viscoelastic layer so that the damping treatment not only becomes adaptive to the changes in the structural vibration characteristics but also appears with augmented energy dissipation capability. This advancement of the constrained layer damping treatment was first introduced by Baz and Ro [13] through the proposition of the active constrained layer damping (ACLD) treatment. In this proposition of ACLD treatment [13], a viscoelastic layer is sandwiched between two piezoelectric layers. The piezoelectric layers are utilised as the sensor and actuator layers through a controller to control the transverse shear deformation of the constrained viscoelastic layer for having enhanced damping in the overall structure. Instead of using two piezoelectric layers, Shen [14,15] utilised one piezoelectric layer to constrain the viscoelastic layer, while the control activities of the piezoelectric constraining layer were regulated by a controller and a point-sensor. In this early stage of development of ACLD treatment, Veley and Rao [16] and Tomlinson [17] carried out a comparison study of active damping, passive damping and hybrid damping (ACLD) for

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demonstrating the fruitfulness of the concept of ACLD treatment. Later, various mathematical models of this hybrid damping treatment have been addressed by many researchers for investigating the damping mechanisms and also for quantification of damping in the treatment for different kinds of engineering structures [18–29]. In addition to the development of various mathematical models of the ACLD treatment, numerous configurations of ACLD treatment have been addressed by many researchers in the quest for its augmented damping capability. Yellin and Shen [30] and Shen [31] proposed a self-sensing active constrained layer (SACL) damping treatment where the piezoelectric constraining layer is used for both the sensor and actuator through the bridge circuit. Gao and Shen [32] presented a parametric study on this SACL treatment using its partial coverage over the host structure-surface. Lesieutre and Lee [33] implemented the concept of the segmented constraining layer in the ACLD treatment for effective active-passive damping in long wavelength modes of vibration. The effectiveness of this segmented ACLD treatment was also experimentally verified by Kapadia and Kawiecki [34]. Chattopadhyay et al. [35] proposed a hybrid displacement field to model the segmented ACLD treatment correctly. Cento and Kawiecki [36] developed a finite element (FE) model of the segmented ACLD to illustrate the effects of the adhesive layer on its (ACLD) damping capacity. The main advantage of the partial ACLD treatment is to achieve sufficient damping using the minimum mass of the treatment. So, several studies on the optimal size and location of the segmented ACLD treatment over the surface of the host structure-surface have been reported by many researchers. Among many others, Huang et al. [37] presented a study on the optimal sizes of active constrained layer, passive constrained layer and pure active control treatments, and compared their (treatments) capabilities in control of vibration of a beam element. Ray and Baz [38] presented an optimisation study to find the optimal size and control gain of the ACLD treatment of plates to maximise passive and active loss coefficients. Recently, Lu et al. [39] presented the optimal utility of the partial ACLD treatment for controlling vibration in the broad frequency range. Besides the partial ACLD treatment, Liao and Wang [40] proposed a new configuration of the damping treatment by the name of Enhanced Active Constrained Layer (EACL) damping treatment. The speciality of this design is the utilisation of edge elements which significantly improve the active action of the piezoelectric constraining layer as well as the damping capacity of the treatment. This kind of ACLD treatment is subsequently studied by few researchers [41–43] for further improvement of its damping capacity. Askari et al. [44] utilised EACL treatment for augmentation of aeromechanical stability of helicopters by applying the treatment on flex beams. Based on the concept of ACLD treatment, Liu and Wang [45] proposed a Hybrid Constraining Layer (HCl) damping treatment. In this concept of HCl damping, passive and active materials are used together in place of the pure piezoelectric constraining layer for achieving improved damping characteristics of the ACLD treatment. The same authors also integrated HCl and EACL damping treatments for achieving the advantages of both the treatments [46]. Kumar [47] utilised a pre-stressed damping layer within the ACLD arrangement and reported enhanced damping capacity of the treatment due to the initial stress within the constrained damping layer. Kumar [48] and Kumar et al. [49] presented an improved ACLD treatment of structural vibration using stand-off layer and edge anchors. Plattenburg et al. [50] proposed a configuration of ACLD treatment where the constraining layer is comprised of active and passive patches. Many other configurations of the ACLD treatment are also available in the literature towards the development of the active-passive damping treatment of structural vibration. Stanway et al. [51] carried out a comprehensive literature review on this development of ACLD treatment. Benjeddou [52] also carried out a literature review on the advancement of the hybrid damping treatments using piezoelectric and viscoelastic materials. This review report [52] illustrates different hybrid damping configurations, modelling techniques, response analysis methods, control strategies and optimization techniques. Trindade and Benjeddou [53] also presented a literature review and an assessment of active-passive damping treatments of beam elements using the piezoelectric and viscoelastic materials.

The literature shows a substantial number of studies on the ACLD treatment for vibration control of different kinds of engineering structures. Through these studies, ACLD treatment gains the credential as an eminent active-passive damping treatment of structural vibration. However, in all the available studies on the ACLD treatment of structural vibration, it is observed that the passive counterpart of the total active-passive damping appears mainly due to the transverse shear deformation of the actively constrained monolithic viscoelastic layer. Along with this transverse shear deformation of the constrained viscoelastic layer, if the in-plane strains appear with reasonable magnitudes, then the damping capacity of the treatment may improve. This occurrence of reasonable in-plane strains along with the transverse shear strains may be achieved by distributing the stiffness and damping properties within the constrained layer in an appropriate manner. In this concern, a foremost option is to tailor the stiffness and damping properties of the actively constrained viscoelastic layer by inserting passive inclusions within it in a predefined manner. But, a study on the ACLD treatment using passive inclusions within the actively constrained viscoelastic layer has not yet been reported in the literature. So, presently it is intended to carry out an analysis of the active-passive damping in plates using an actively constrained 0–3 viscoelastic composite (VEC) layer. The 0–3 VEC layer is constructed by inserting a rectangular array of thin graphite-wafers through the middle surface of a viscoelastic layer. Its (0–3 VEC) construction can be explained by two pure viscoelastic layers over the top and bottom surfaces of a middle

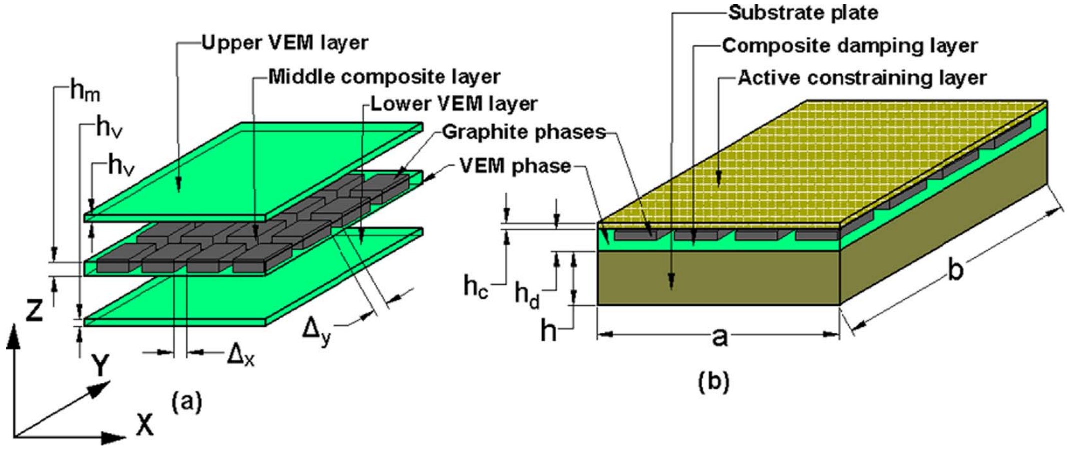

Fig. 1. Schematic diagrams of (a) the different layers within the 0–3 VEC layer and (b) a substrate plate integrated with the actively constrained 0–3 VEC layer.