Composite Structures 119 (2015) 322–332

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

A novel viscoelastic damping treatment for honeycomb sandwich structures

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ARTICLE INFO

Article history:
Available online 15 September 2014

Keywords:
Honeycomb
Damping
Viscoelastic
Double shear lap-joint damper

ABSTRACT

Constrained layer dampers (CLD) are in widespread use for passive vibration damping, in applications including aerospace structures which are often lightweight. The location and dimensions of CLD devices on structures has been the target of several optimisation studies using a variety of techniques such as genetic algorithms, cellular automata, and gradient techniques. The recently developed double shear lap-joint (DSLJ) damper is an alternative method for vibration damping, and can be placed internally within structures. The performance of the DSLJ damper is compared in a parametric study with that of CLD dampers on beam and plate structures under both cantilever and simply supported boundary conditions, using finite element analysis. The objective was to determine which damper and in which configuration produced the highest modal loss factor and amplitude reduction for least added mass, as would be important for lightweight applications. The DSLJ tend to be more mass efficient in terms of loss factor and amplitude reduction for cantilevered beam and plate structure, and are competitive with CLD dampers in simply supported beam and plate structures. The DSLJ works well because it has the potential to magnify global flexural deformation into shear deformation in the viscoelastic more effectively than traditional CLD dampers.

1. Introduction

Sandwich structures are widely used in the aerospace, aeronautical and automotive industries for their high strength and stiffness-to-mass ratio [1]. These environments are often vibration rich, which can make fatigue problematic, reduce fuel efficiency, and adversely affect passenger comfort. A common mitigation technique is to damp vibrations via methods such as constrained layer dampers (CLD), which consist of a thin layer of viscoelastic material adhered to the vibrating structure and a constraining stiff layer on its surface. This arrangement constrains the viscoelastic layer to deform in shear and at relatively higher strain thereby efficiently dissipating vibration energy as heat [2]. Recently, the damping properties of load bearing structures have been enhanced by inserting viscoelastic material in constructs that constrain it in shear and therefore maximise the loss mechanism. Star-shaped inclusions filled with viscoelastic material [3], elastomer inserts at the acute vertices of a auxetic honeycomb cell [4] and viscoelastic ligament between opposite vertex of a honeycomb cell [5,6] have all proven their efficacy for vibration damping. A new type of viscoelastic damping device termed the double shear lap joint (DSLJ) has been developed which may offer an alternative to the CLD [5,7]. All such devices add mass to their host structures, and in very lightweight structures this might be expected to reduce natural frequencies, which may be adverse where structures have been tuned to avoid resonance in normal operation.

The design of a CLD was first proposed by Kerwin [8] in 1959 who examined the damping of flexural vibrations of a stiff simply supported beam structure with a continuous viscoelastic layer. The contiguous layer CLDs are effective in damping vibrations but may add significant extra mass to lightweight structures. To tackle this problem discrete CLD patches were developed where the host structure was only partially covered with dampers, proving to be more mass efficient designs than complete coverage. Nokes and Nelson [9] were among the first to investigate partial coverage with CLDs and showed both theoretically and experimentally that more efficient damping was possible for partially covered beams.

A number of studies optimising CLD location and dimensions have sought to maximise damping while minimising added mass. There are several parameters one could consider when attempting to quantify 'damping' in such optimisation studies, such as vibration amplitude, vibrational energy, and shift in natural frequency, depending on the nature of the application in question. Lifshitz

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http://dx.doi.org/10.1016/j.compstruct.2014.09.005
0263-8223/

and Leibowitz [10] were the first to apply optimisation techniques to damping of structures, and they used an equality constrained minimisation technique to identify optimal thicknesses, and therefore minimum additional mass, of CLDs on a cantilever beam under a range of constraints on mass and flexural stiffness of the host structure. Both a global criterion method and a genetic algorithm were used by Hajela and Lin [11] to optimise CLDs on a cantilever beam, with the objective being highest modal loss factor and minimal increase in mass. Marcelin et al. [12] used the method of moving asymptotes to find the highest modal loss factor and best location of CLD of a cantilever beam. Zheng and co-workers proposed optimal layouts of CLDs on simply supported beams minimised for amplitude of vibration [13] and for vibrational energy [14], while minimising the damping material volume. Chen and Huang [15] considered the shift of the resonance frequency due to the addition of the damper as a constraint for their optimisation. They proposed an optimised solution for the position of CLD on simply supported plates thanks to a topographical optimisation method. The cellular automaton method is particularly well suited to this problem, and has been implemented by Chia et al. [16,17] to identify optimal weight-efficient CLD configurations for plates with free boundary conditions using the loss factor as objective function. Kim also used a topology optimisation in order to find the best configuration of CLD on a fully clamped and cantilevered plate [18] that give the highest modal loss factor for a minimal increase in mass. A Genetic Algorithm was used by Hou et al. in order to minimise the vibrational energy of a simply supported beam [19] and plate [20] damped with CLD. The location of the CLDs was determined with a restriction on the mass added. Ling et al. [21] used the method of the moving asymptotes to determine the optimal layout of CLD on a cantilever and simply supported plate in order to maximise the damping ratio while minimising the added mass. Finally, Zheng et al. [22] had a similar approach considering the maximisation of the modal loss factor. Several studies on damping have used the Modal Strain Energy method developed by Johnson and Kienholtz [23] to calculate the modal loss factor of a structure under harmonic excitation. An alternative and potentially more accurate method to calculate the modal loss factor is the Half-Power Bandwidth approach [24].

The DSLJ damper developed by Boucher et al. [5,7] consists of a double shear lap-joint construct located internally in a structure so that flexure of the host structure results in deformation of the arms of the lap joint and thus shear in the viscoelastic. Boucher considered it within a hexagonal cell core sandwich panel. Both the deformed and undeformed CLD and DSLJ dampers are sketched in Fig. 1. The objective of the present work is to identify the most mass efficient configurations of the CLD and DSLJ devices via simulation using the finite element method. Specifically this is done within a simplified honeycomb sandwich host structure, under typical boundary conditions, utilising a 'lossy' material – in this case a viscoelastic elastomer. The efficiency of the CLD and the DSLJ damper is compared in beam and plate structures with simply supported and cantilever boundary conditions.

2. Methodology

The systems considered here were honeycomb-cored sandwich panels as illustrated in Fig. 2, being typical examples of lightweight high performance structures, and specifically beam and the plate structures, in this case composed of 18×2 and 20×10 cells respectively. For the cantilevered cases all nodes along the short edge were encastred (i.e. $u_1 = u_2 = u_3 = r_1 = r_2 = r_3 = 0$), and for the simply supported case nodes on the bottom surface along lines across the width (i.e. where the knife edge supports would contact) were constrained with no translational freedom but retaining rotational freedom, i.e. $u_1 = u_2 = u_3 = 0$, following Srinivas [25]. The honeycomb cells were regular hexagons, with depth and side lengths of 10 mm which is fairly typical of such honeycombs in use in the aerospace sector. The thickness of the honeycomb cell walls and the outer skins was 0.2 mm. The beam's length and width were 270 and 34.6 mm respectively (shown in Fig. 2), and the plate's length and width were 300 and 173 mm respectively. This gives length to depth aspect ratios of 27:1 for the beams 30:1 for the plates. The panel skins were considered to be thin (2% of the panel's depth), and made of the same material as the honeycomb cells (aluminium in this case). The DSLJ insert has a depth of 8 mm, and is positioned so as to stand 1 mm away from the upper and lower skins, as illustrated in Fig. 1, to prevent contact with the skins under flexure. The total thickness of the DSLJ damper is 3.2 mm, of which the central aluminium web is 0.2 mm. The viscoelastic material density was approximately a third of the aluminium density, its modulus 70000 times lower than aluminium, and had a material loss factor 200 times higher than aluminium. These values sits within the normal range of viscoelastic polymer material properties [16]. Material-dependant damping (ANSYS command MP, DMPR) was adopted to describe the damping ratio of each material. The material properties are given in Table 1. The Modal Strain Energy method [23] was used to estimate the modal loss factor of the structure. Although it is known this method may give an inaccurate estimation of the value of the modal loss factor, especially for material's with loss factors, it can efficiently provide a relative comparison of damping

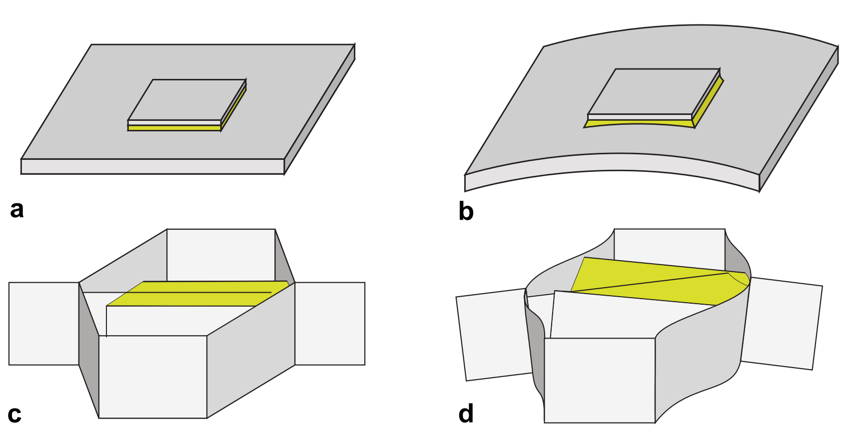

Fig. 1. A typical constrained layer damper, (a) and (b), and a double shear lap-joint damper inserted in a hexagonal honeycomb cell, (c) and (d). The structures shown in (b) and (d) are deformed under load.