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Multi-objective optimisation of viscoelastic damping inserts in honeycomb sandwich structures

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ABSTRACT

The Double-Shear Lap Joint (DSLJ) is a novel damping insert sited internally within a structure which is particularly well suited for lightweight sandwich structures with internal voids, such as honeycomb core sandwich panels. In high performance lightweight structures, the insertion of relatively more dense dampers of any type may increase the total mass substantially and alter the mass distribution significantly. The objective herein was to determine the optimum location, number and orientation of DSLJ inserts within a typical sandwich panel, and thereby to assess the efficacy of two different optimisation approaches to this problem; a parametric optimisation and the Adaptive Indicator-Based Evolutionary Algorithm (IBEA). Both approaches were used to maximise the damping while minimising the additional mass of the damping inserts applied to the structure. Although the parametric approach was faster and easier to implement, the Adaptive IBEA identified significantly better configurations in many cases, especially where veering occurred, in one case improving modal loss factors more than fourfold *vs* the parametric method. Solutions were identified with large increases in modal loss factors but only small increases in mass *vs* the empty structure.

1. Introduction

Sandwich structures are extensively used in the aerospace and other transport sectors for their low density and excellent mechanical properties [1,2]. They exhibit a high stiffness-to-mass and strength-to-mass ratios which make them ideal candidates for load-bearing applications where mass is a critical issue. However, structures used in transport are often deployed in vibration-rich environments which leads to high cycle fatigue (and thus more frequent service intervals) and passenger discomfort. Vibration damping in sandwich structures has therefore been the subject of multiple research projects [3]. Initial attempts at designing damped sandwich structures consisted of two rigid skins constraining a monolithic viscoelastic core, i.e. no honeycomb or other stiff core [4,5]. Although these structures were capable of damping flexural vibration significantly, they were not very weight efficient.

Subsequently, Nokes and Nelson [6] proposed a partial constrained layer damper arrangement which covered only a fraction of the vibrating host structure, and coincidently was more mass efficient. A later development of this concept was to combine viscoelastic materials with cellular solids in sandwich cores, in order to provide both significant energy dissipation and good mechanical integrity. Michon et al. [7] filled the cell of a honeycomb-cored sandwich beam with viscoelastic hollow particles which achieved a substantial damping with a moderate impact on the structure's mass and stiffness. Murray et al. [8] proposed filling the cells of a metallic honeycomb structure with a lossy polymer (with a low modulus typical of rubbers) which significantly increased the structural loss factor. Boucher et al. [9] showed that a partial filling of the honeycomb cell void can achieve an appreciable damping, and importantly with only a minimal increase in mass. Recently, the authors developed a new concept – the Double Shear Lap Joint (DSLJ) damper – a high weight-efficiency passive damper which can be located internally within structures, e.g. a honeycomb core [10]. It consists of a Double Shear Lap-Joint arrangement which can be inserted along three different orientations into the hexagonal cell of a honeycomb lattice and filled with viscoelastic damping polymer [11].

Development of dampers in general has required use of heuristic optimisation strategies for location, orientation and sizing of the dampers, so as to maximise the modal loss factor of the vibrating structures while minimising the additional mass. Minimising mass and maximising modal loss would normally be competing objectives. In particular, the optimal design of constrained layer dampers, including the number of plies, the ply thicknesses, composite fibre orientation and damper location, has been investigated with various methods including genetic algorithms [12],

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cellular automata [13] or the method of moving asymptotes [14,15]. Some of these optimised configurations for constrained layer dampers were investigated for honeycomb cored sandwich panels, and compared with solutions using DSLJ dampers. The DSLJ dampers were placed at locations with the highest strain energy in the first vibration mode [10]. The DSLJ damper was notable because it exhibited a better weight-efficient damping performance than the constrained layer dampers, i.e. the ratio of modal loss factor to mass was higher.

Implementation of heuristic optimisers to such problems can be a computationally expensive and difficult process. The question arises whether such methods are necessary or whether simpler approaches can yield similar quality results. In this paper, the location and orientation of DSLJ damper on a honeycomb-cored sandwich plate is optimised using two different approaches; (i) a quick and simple parametric optimisation based on the strain distribution of the mode shape of each structure considered, and (ii) a more complex and computationally demanding multi-objective evolutionary algorithm, namely the Adaptive Indicator-Based Evolutionary Algorithm (IBEA) [16]. The objective functions to be minimised are the negative of the modal loss factors and the total mass of the structure.

2. Methods

The approach taken here was to optimise the same structures with two approaches, a computationally simple and quick method and a more complex and computationally demanding method. As well as identifying new and highly weight-efficient damping configurations, this would identify whether the use of evolutionary optimisation methods would be required for similar problems. The structure chosen was a rectangular plate (aspect ratio of approximately 1.7), modelled in both cantilevered and free boundary conditions, and constructed as a sandwich panel with a honeycomb core.

The honeycomb core was composed of an array of 181 hexagonal cells, with 10 complete cells along its length and 10 complete cells across its width, plus 9×9 interleaving cells, see Fig. 1. The sandwich plate was 300 mm long, 173 mm wide and 10 mm thick. The size of the panel was chosen so as to provide the subsequent optimisation with a large enough search space, while keeping the computational cost within reason. The cells were regular hexagons, with cell walls 10 mm long and 0.2 mm thick. The two sandwich skins were 0.2 mm thick and considered to be perfectly bonded to the core. The DSLJ damping insert is shown in Fig. 2, and is formed by aluminium constraining layers sandwiching a viscoelastic lossy centre. There were three possible different orientations for the DSLJ within the honeycomb cell, see Fig. 3. The DSLJ insert was offset by 1 mm from the top and the bottom of the cell in order to prevent any contact between the insert and skin during flexure.

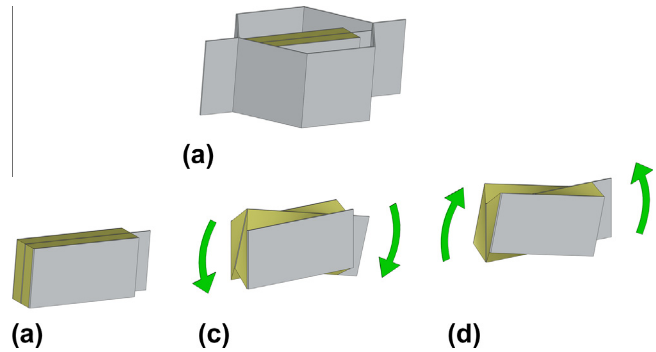

Fig. 2. A hexagonal honeycomb cell with a DSLJ insert (a), a DSLJ insert alone (b), a DSLJ insert under deformation as might occur in flexure of the sandwich panel (shown exaggerated for clarity) in both directions (c) and (d). The yellow solid represents the viscoelastic, and the grey the constituent array material. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The sandwich structure was modelled using commercial finite element software (ANSYS 14.0) [17]. Four-node structural shell elements with six degrees of freedom per node (SHELL181 in ANSYS) were used to mesh the honeycomb core and skins. The viscoelastic material within the DSLJ was meshed with an eight-node brick element with three degrees of freedom per nodes (SOLID185 in ANSYS). A total of approximately 33 000 elements were used to mesh the sandwich structure. The nodes at the interface between the solid and the shell elements were forced to be coincident and their degrees of freedom were coupled in order to enforce compatibility between shell and solid elements. The enhanced strain formulation was used to prevent shear locking of the brick elements. The honeycomb and the sandwich skins were considered to be made of aluminium and the damping material in the DSLJ of a viscoelastic silicone rubber. The properties of the viscoelastic material were taken from Chia et al. [13] and were typical for a silicone rubber at constant room temperature. The aluminium's intrinsic loss factor was considered to be 0.0001 [18], set out with other relevant properties in Table 1. The material-dependant damping model was adopted in ANSYS to describe the damping ratio of the materials [19]. The sandwich plates were subjected to both cantilever and free boundary conditions. Specifically, the cantilever boundary condition consisted in constraining all degrees of freedom of all nodes at $x = 0$, i.e. sitting on the short edge of the panel, with all other nodes free. The free boundary condition imposed no constraints on any nodes. The eigenvalue problem, described in Eq. (1), is solved by modal superposition using the Preconditioned Conjugate Gradient (PCG) iterative solver and the first two modes were extracted using the Lanczos PCG modal extraction method:

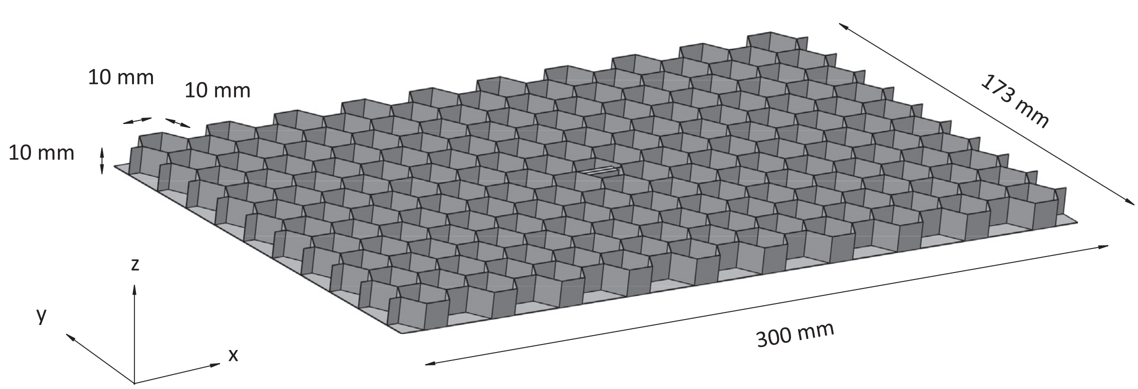

Fig. 1. The array of hexagonal cells in the honeycomb core and the lower skin, with upper skin removed for clarity. A single DSLJ insert is sketched in the centre.