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Experimental investigation of damping flexural vibrations in glass fibre composite plates containing one- and two-dimensional acoustic black holes

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ABSTRACT

In this paper, the results of the experimental investigation into the addition of indentations of power-law profile into composite plates and panels and their subsequent inclusion into composite honeycomb sandwich panels are reported. The composite plates in question are sheets of composite with visible indentations of power-law profile. A panel is a sheet of composite with the indentations encased within the sample. This makes a panel similar in surface texture to an un-machined composite sheet (reference plate) or conventional honeycomb sandwich panel. In the case of quadratic or higher-order profiles, the above-mentioned indentations act as two-dimensional acoustic black holes for flexural waves that can absorb a large proportion of the incident wave energy. For all the composite samples tested in this investigation, the addition of two-dimensional acoustic black holes resulted in further increase in damping of resonant vibrations, in addition to the already substantial inherent damping due to large values of the loss factor for composites. Due to large values of the loss factor for composite materials used, there was no need in adding small pieces of absorbing layers to the indentations to achieve desirable levels of damping.

1. Introduction

Composite materials and structures are found in an increasing variety of applications in aeronautical, automotive, and marine industries, where they replace many parts and components traditionally made of metals and metallic alloys. The main advantages of composite structures over their metallic counterparts are their higher stiffness-to-weight ratio and better resistance to corrosion. Another useful feature of composite materials is higher values of their intrinsic energy loss factors, which results in lower levels of undesirable structural vibrations under the same operational conditions. Nevertheless, structural vibrations in composite materials and structures do occur and are a key factor in delamination and crack propagation, therefore their reduction remains an important engineering problem that continues to be investigated (see e.g. [1–3]).

Usually, passive damping of structural vibrations is achieved by adding layers of highly absorbing materials to the structure in order to increase elastic energy dissipation of propagating (mostly flexural) waves [4–6]. The main disadvantage of this approach is the necessity to attach rather thick layers of absorbing materials to structural surfaces in order to achieve desirable levels of damping.

An alternative approach, which is applicable to damping of resonant structural vibrations, is based on reduction of reflections of structural waves from free edges of structures, rather than on increasing energy losses in the process of wave propagation (see e.g. [4]). To implement this approach in a more efficient way, a new method of damping flexural vibrations based on the so-called 'acoustic black hole effect' has been recently developed and investigated [7–9]. This method has been initially applied to one-dimensional metal plates of power-law profile (wedges) that had to be covered by narrow strips of absorbing layers near sharp edges [9]. Ideally, if the power-law exponent is equal or larger than two, the flexural wave never reaches the sharp edge and therefore never reflects back [7–10]. Thus, such a sharp edge of power-law profile materialises the 'acoustic black hole' (ABH) for flexural waves, with no reflection and with total energy absorption in the attached piece of absorbing layer. It has been established theoretically [7,8] and confirmed experimentally [9] that this method of damping structural vibrations is much more efficient than traditional damping methods.

In addition to the above-mentioned wedges of power-law profile, which materialise one-dimensional (1D) acoustic black holes, a serious attention has been paid also to circular indentations of

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power-law profile made inside plate-like structures [11–16]. Such circular indentations materialise two-dimensional (2D) acoustic black holes. Like 1D black holes, such 2D black holes have also proven to be efficient means of damping structural vibrations. The advantage of two-dimensional acoustic black holes over their one-dimensional equivalents is that such holes, as well as their combinations (arrays), can be situated inside plate-like structures, which eliminates sharp edges from constructions and thus makes them safer, while reducing the risk of damage to the indentation tips.

The main practical advantage of the method of vibration damping using the acoustic black hole effect is that it requires very small amounts of absorbing materials to be attaches at the sharp edges, which is especially important for light-weight structures. In the same time, the acoustic black hole effect is robust enough to remain effective even for structures with geometrical and material imperfections resulting from manufacturing [17].

The aim of the present paper is to investigate vibration damping in glass fibre composite plates and panels using 1D and 2D acoustic black holes. Note in this connection that a composite panel with smooth outer edges is one of the most commonly found composite structures. The construction of this type of a composite panel that can incorporate the damping abilities of an acoustic black hole forms the ultimate aim of this paper. Five types of composite structures containing acoustic black holes and their effect on vibration damping have been investigated. These structures are: a composite strip with a wedge of power-law profile (1D acoustic black hole), a composite plate with a circular indentation of power-law profile (2D acoustic black hole), combinations of composite plates containing circular indentations of power-law profile, smooth surface composite panel configurations with enclosed circular indentations of power-law profile, and a honeycomb structure with added plates containing circular indentations of power-law profile.

2. Manufacturing of experimental samples

Fifteen glass fibre composite samples were manufactured for this investigation; three strips of dimensions 250 × 50 mm and a thickness of 6 mm; the additional wedge being 50 mm long and of power-law profile with $m = 2.2$. A wedge of power-law profile with $m = 2.2$ was also produced in order to be attached to a steel strip, dimensions being the same as for the composite strip. The eleven glass fibre composite plates were of dimensions 310 × 185 mm and consisted of two 3 mm thick plates and nine 6 mm thick plates. The circular indentations of power-law profile with $m = 4$ had a diameter of 110 mm with a central hole of 10 mm, leaving a profile length of 50 mm.

The glass fibre composite used for these samples was SE84LV-Low Temperature Cure Epoxy Prepreg System. This composite has a high compressive strength and it is widely used in large heavily loaded components, such as yacht hulls, spars, aviation panels, and also in non-structural applications. SE 84LV is also widely used in sandwich structures with honeycombs. Each sheet had a thickness of 0.2 mm. The composite plates and strips were layed-up to the required thickness and then cured using the vacuum bagging process.

Fourteen of the profiles were created in the traditional way: A CNC (Computer Numerically Controlled) milling machine operating at a cutter speed of 1200 rpm with a carbide cutter was used to produce the wedges and circular indentations. The main problem encountered when utilizing this method of manufacturing was that it is not possible to construct directly a panel with internal cavities while utilizing a ‘vacuum only processing’ method. The outer layer needs to be cured separately and attached using epoxy resin. This can lead to a more lengthy manufacturing time.

These fourteen samples consisted of a reference strip and strip with an additional wedge (Fig. 1(a)); examples of the other three types of plates can be seen in Fig. 1(b–d). Fig. 2 displays the cross-sectional view of the plate samples when viewed from the narrow end. The average profile tip thickness for each of the samples is given in Table 1.

Two types of glass fibre composite honeycomb sandwich panels were created for this investigation, see Fig. 3: a reference composite honeycomb sandwich panel and a composite honeycomb sandwich panel containing two acoustic black holes in each of the composite plates.

There are several methods that could have been employed in the manufacture of these honeycomb sandwich structures: For this investigation, a method that was specific to composites and that would allow the integration of acoustic black holes into the structure was required. The standard method has four stages, the first being the curing of the outer composite plates. This was done using the same vacuum curing technique described above. The composite plates, aluminium honeycomb and the adhesive sheets are then cut to size. Each composite plate is then cured in turn onto the aluminium honeycomb, Fig. 4(a).

In addition to the method used above, two further stages were added for the construction of the sandwich panel incorporating the acoustic black holes (ABHs). The first being the manufacture of the ABHs, a CNC (Computer Numerically Controlled) milling machine operating at a cutter speed of 1200 rpm with a carbide cutter

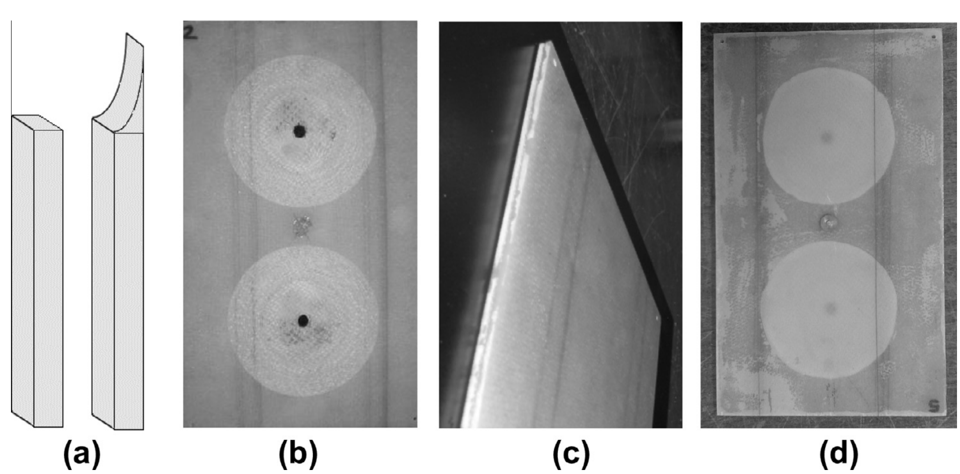

Fig. 1. (a) Strip with and without a wedge, (b) plate (6 mm) containing two 2D acoustic black holes, (c) combined composite plate (6 mm), and (d) composite panel (6 mm).