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Mechanical properties of composite sandwich structures with core or face sheet discontinuities

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ABSTRACT

A combination of tensile tests, three-point bending tests, compressive tests, and low velocity impact tests was used to analyze the influence of face sheet modification and core discontinuities of composite sandwich panels. These modifications are the results of the effort to add new functionalities such as damping and/or to ease assembly of composite sandwich panels. This experimental analysis revealed that the tensile and flexural properties of sandwich structures remain unaltered when discontinuities of 2 mm are introduced in the core or small viscoelastic patches are inserted between face sheet plies. However, compressive properties are significantly reduced by the presence of such core or skin modifications. Finally, the energy absorbed during low velocity impact increases with increase interleaved viscoelastic film and increasing core discontinuity. Thus a special care must be taken at the early design stage to protect such vulnerable areas.

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1. Introduction

Recent research advancements on composite materials have focussed on enhancing properties or adding new functionalities to the materials. As a result, multifunctional composites can be designed for very specific applications such as acoustic and vibration damping, erosion resistance, and lightning strike protection. However, adding new functionalities must be done without affecting the composite material's inherent structural properties such as high specific stiffness. Therefore, analyzing the real impact of the design on the original mechanical properties of the structure is of great interest.

Composite sandwich structures are increasingly used in the aeronautic industry for airplane fuselage and floor panels, as well as helicopter ceilings and doors. The increased use of composite sandwich structures is motivated by the higher specific properties of these materials over metals, which results in important weight reduction. Further advantages include reduced manufacturing steps, smaller number of parts, reduced maintenance, and extended fatigue life. However, due to their lightness and stiffness, composite sandwiches are good transmitters both for mechanical vibration and acoustic waves. Therefore, damping functionality is promoted in the industry to prevent mechanical damage or discomfort due to vibration and noise. One solution consists of inserting a constrained viscoelastic layer between face sheet plies [1–5]. However, inserting viscoelastic layers can cause face sheet delamination [6,7], therefore weakening the sandwich structure. In order to obtain full damping capacity, viscoelastic inserts or damping devices can be placed in high shear zones of the structure. This can be achieved by implementing the devices within the core where the shearing stresses are maximal. However, the insertion process requires core cutting leading to discontinuities.

Also, metallic or foam inserts are often bonded inside the sandwich structures for assembly purposes [8–10]. As an example, the assembly and installation of airplane interior furniture made of composite sandwich panels is done using metallic inserts fixed within the core using appropriate adhesives [11]. Another example is the manufacturing of large parts made of many core pieces, where gaps can occur between pieces. In such cases, inserts or foam injections can be used in order to maintain the integrity of the core [12–14]. If the gaps are not filled, the real influence of these discontinuities on the core properties itself and on the mechanical properties of the whole sandwich structure must be assessed.

Any of the above described core or face sheet discontinuities can lead to structural weakness. One problem for many carbon reinforced laminates is their relatively low mechanical strength in the transversal direction. In fact, the mechanical properties in that

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direction is mainly determined by the strength of the polymer matrix [15,16], which could be depleted by the presence of inserts such as viscoelastic material layers. Such inserts can also degrade the in-plane properties of the laminates by spreading or crimping the fibers around resin-rich regions. The formation of such polymer-rich zones was found to reduce the in-plane tensile [17–19] and compressive [20,21] strength of the laminates. When used in helicopter or airplane floors, ship hulls, aircraft fuselages and wings, sandwich structures are mostly subjected to flexural and compressive loading [22]. Several investigations have been carried out on the flexural strength of composite sandwich structures, with a vast majority dealing with the fatigue and static modes [23–26]. However, researches dealing with the impact of core discontinuities or inserts in the facing plies on the flexural and compressive properties of sandwiches remain scarce.

Another concern with carbon reinforced laminates is the impact of foreign objects [27]. Such laminates are widely used as sandwich skins in aerospace applications. Low velocity impacts include tool drop, runway debris and hailstorms, whereas high velocity impacts can be bird strike during flight [28]. After impact, a significant reduction in compressive strength is generally observed, due to skin delamination and damage of the core and core/skin interface [29,30]. Damage initiation depends not only on the facings and core properties, but also on the nature of the functionalization integrated into the composite sandwich material. Recent publications dealing with this subject focussed on the failure mechanisms and the energy absorption for various materials and geometry configuration [31,32]. However, the behavior of sandwich structures with localized inserts in the skins or a discontinuity in the core under low velocity impact has seldom been investigated.

The purpose of this work is to study the influence of two types of discontinuities on the flexural and compressive properties of a composite sandwich structure. Interleaved viscoelastic layers between face sheet plies are evaluated through standard tensile testing of face sheets and three-point bending tests on sandwich beams. Gaps or breaks between core pieces are evaluated through three-point and four-point bending tests to provide shear modulus, ultimate strength of the sandwich structure with core discontinuities. The response to low velocity impact of sandwich panels with viscoelastic inserts and/or core discontinuities is also evaluated and discussed.

2. Experimental procedures

2.1. Samples with core discontinuity

Square sandwich panels (400 mm × 400 mm × 14.3 mm) were manufactured for four-point bending tests. The panels are made of lightweight aramid honeycomb core and woven carbon/epoxy fabric face sheets stacked in a $[0/45]_s$ sequence. These panels were cured in an autoclave under controlled pressure and temperature. The edges of the honeycomb core were chamfered at 30° to prevent crushing due to compaction pressure. Chamfering also allows a better pressure distribution and prevents fiber shifting during curing. In order to assess the impact of core modifications, discontinuities were artificially created. Small pieces of honeycomb were obtained by carefully debonding core sheets along the glue line in the ribbon direction (L direction). The core pieces were then joined together with no adhesive, or placed with a gap of 2 mm between them; the samples are referred to as *cut modification* and *gap modification*, respectively. Cut and gap modifications were 350 mm long. Three panels with modified core and one baseline panel were made in order to understand the importance of core discontinuities in a closed edge panel. The first panel contains 15 *cut modifications* (3 of which are placed in each shearing zone) and the second panel has 2 *gap modifications* (one in each shearing zone). In order to assess the influence of multiple core discontinuities within the core, a third panel having 15 *gap modifications* in the core (3 of which were placed in each shearing zone) was also manufactured. A spacing of 22 mm between modifications was applied in the case of panels with 15 cut or gap modifications. The shearing zone refers to the zones of maximal shearing in four-point bending tests (discussed further down). Fig. 1 illustrates the panels investigated with modified honeycomb core.

Another set of panels was manufactured using the same manufacturing procedure presented above. From those panels, 300 × 60 mm^2 beams were cut using a diamond saw, providing three baseline beams and three beams with honeycomb discontinuities placed transversely to the axis of the beam. For beam samples, core modifications (*cut modification* or *gap modification*) were made in such a way that only one modification appears in the shearing zone in the four-point bending tests.

2.2. Samples with face sheet discontinuity

In order to assess the influence of interleaved viscoelastic layers, sandwich beams (core not modified) having face sheets with viscoelastic inserts were manufactured. The viscoelastic material inserted in the face sheets is a Smacwrap ST film from Smac having a thickness of 0.2 mm. Each beam is 250 mm long, 30 mm wide and has 2 inserts placed symmetrically under the outer layer of the top and bottom face sheets as seen on Fig. 2. Each insert pair was placed at different positions along the longitudinal axis of the beams. The size of each insert is 40 × 28 mm^2.

Finally, beams made solely of face sheet laminates were produced. Each beam sample was 0.8 mm thick (1.0 mm at the insert location), 30 mm wide and 254 mm long. The viscoelastic layers were inserted under the top layer of carbon/epoxy composite face sheets before curing. Viscoelastic inserts of 40 × 20 mm^2 and 40 × 28 mm^2 surface area were used, thus leaving 5 mm and 1 mm closed edges on each side of the insert, respectively.

2.3. Testing procedures

In order to assess the influence of inserted viscoelastic films, tensile tests were performed on carbon/epoxy laminate beams

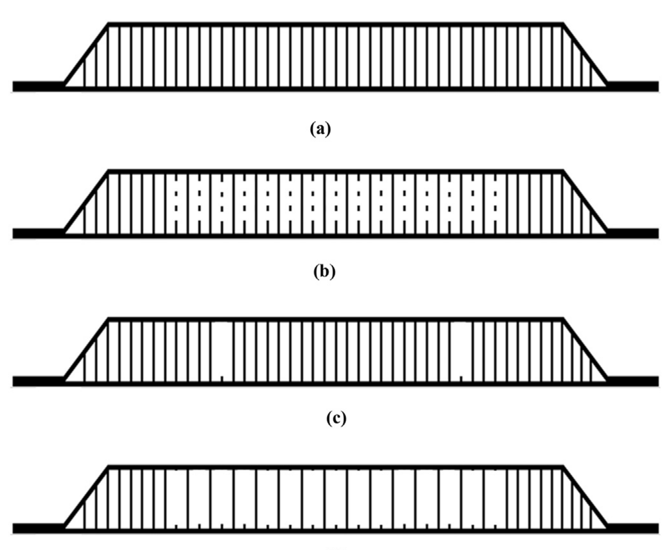

Fig. 1. Schematics of core modification in the composite sandwich panels; (a) reference panel, (b) Panel with 15 cut modifications, (c) panels with 2 gap modifications and (d) panel with 15 gap modifications.

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