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Static and dynamic analysis of bonded sandwich plates

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ABSTRACT

Bonded joint technique provides several advantages in comparison with traditional approaches such as welded, bolted and riveted techniques. The main goal consists in obtaining mechanical performances as good as, or even better than, a system without discontinuity or linked in a traditional way. In this paper, the static and dynamic behaviour of bonded joints has been investigated by means of various techniques. For the bonded materials, we focus on an epoxy resin and two different adhesive tapes; we performed experimental modal analysis (EMA) to validate finite element (FE) models which will be used for further finite element analysis. We also applied a damage detection methodology to locate and detect damage.

1. Introduction

In recent years, the use of sandwich panels has proven to be functional in lightweight structures mainly in aeronautic and naval fields.

The studies and the manufacturing technology of these materials have solved a lot of problems due to corrosion resistance in seal environment, to thermal stresses generated essentially by different thermal expansion coefficients and to the high damping factor. A cold joining technique that makes use of adhesive tapes may improve the mechanical performances and restore the local damage replacing the traditional techniques like welded, bolted and riveted.

The decision to choose adhesive tape to connect materials with or without comparable characteristics (thermal expansion coefficients, elasticity and so on) as an alternative to the classical techniques is a crucial point in designing innovative systems. In order to have a large amount of applications, the mechanical characteristics of bonded joints must be as good as, if not better than, a system without discontinuity or linked in a traditional way.

In this work, we compared different techniques to investigate static and dynamic parameters of aluminium sandwich panels jointed by L-section extrusion aluminium profiles. We used an epoxy resin and two different adhesive tapes as bonded materials.

One of the benefits of these materials is the remarkably easy assemblage compared with traditional techniques (welded and bolted). Moreover, the non-presence of thermo-affected zones (resulting from welded processes) gives an additional advantage because supplementary treatments that often cannot be carried out in situ are not required. Finally, we do not take into account the geometrical discontinuities (such as the holes for the bolts). But the most important point consists in the possibility of modifying and improving some features of the structure (acoustic and vibration parameters) without losing the other mechanical properties. Many parameters need to be taken into account. Usually, thermal expansion coefficients of the adhesives and materials used in the bonded zone are very dissimilar. Thermal stress could be generated in this zone if the materials work in hard environments at a critical temperature (like under the sea or in the high atmosphere) [1,2].

Using energy approach [3], it is possible to have a good concordance between experimental, theoretical and finite element results mainly for composite material used in space applications and tested in a vacuum.

Using strain gage measurement associated with conversion techniques, we can determine the shear moduli of the adhesive used in bonded joints in load-bearing structures. The methodology can be used to determine accurately the adhesive shear stress–strain response in the linear–elastic range. No indications for different environmental factors such as temperature and moisture are considered [4].

Several studies are focused on validating FE procedure by a comparison between theoretical and experimental eigenvalues and eigenvectors.

For this aim [5], CFRP (Carbon Fibre Reinforced Polymer) composite plates with different ply orientations and aluminium plates with the same dimensions and the same boundary conditions (free–free) are tested. Some authors have developed two and three-dimensional finite element models to investigate the static behaviour of single or double overlap joints for automotive industry [6–8].

Most of them are focused on the evaluation of the forces in the adhesive interface and on the comparison with experimental and theoretical data.

Bonded joint systems made with different material characteristics are suitable for studying, locating, detecting and quantifying damage using various methodologies. In this frame, a common

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approach consists in sending and receiving vibration signals. To this purpose several sensors like traditional piezoceramic (PZT) actuators and optical fibres are usually used [9]. Finally, it is well known that one of the most common and the most complicated modes in which damage occurs is due to fatigue [10].

To allow a typical numerical error function to detect, locate and quantify damage [11], frequency changes in one or more pairs of mode shapes are taken into account. For this purpose, it is useful to apply a non-destructive test mainly when light materials, like fibre composite structures, are tested. In another work [12] on bi-dimensional structure, a sensitivity (perturbation) analysis was applied to localise damage. The comparison in the changes in stiffness between the damaged system and the un-damaged system highlights, with a good rough calculation, the possible damage site.

Mechanical structures could present a mix of welded and bonded joints; in this case it could be useful to find an optimal joints configuration to investigate linear elastic buckling and free vibration behaviour [13]. Some authors have established that it is more complicated to predict the damping values on composite materials. Experimental data [14], based on modal analysis using a non-contacting laser sensor, compared with FE results, showed that it is possible to predict eigenvalues and eigenvectors of CFRP rectangular plates in various carbon fibre configurations. Theoretical and experimental results proved that there is no linear correlation between eigenvalues, damping values and the geometrical shapes of composites. In another work [15] to identify non-linear damping of a solid composite beam, a pair of coil–magnets, mounted at the mid-span of the beam, was taken into account. The damping capacity and the ratio between the energy dissipation per cycle and the maximum strain energy were calculated.

The aim of our work consists in the investigation of the static and dynamic behaviour of systems bonded by L-section extrusion aluminium profiles in different configurations. Our intention is to understand the variations in the mechanical behaviour when two aluminium sandwich panels are jointed together using different materials. For this purpose, we focus on the bonded layer and we aim at finding out if it is possible to replace the traditional bonded material (epoxy) with the adhesive tape without decreasing the mechanical properties of the whole structure.

2. Material properties

As test samples, we used sandwich panels with aluminium skins (thickness = 0.0005 mm) and a core with hexagonal aluminium cells (thickness = 25.4 mm); the dimensions of the longitudinal panels are (200 × 300 × 26.4 mm). The vertical panels are (175 × 300 × 26.4 mm). Table 1 shows all the mechanical properties of all the materials used. These materials are made by Ciba Composite and 3-M Industry and the values showed in Table 1 are optimised from nominal values, written in the technical data sheets, using a comparison between experimental and analytical eigenvalues. In this work, the *supported by bonded L-section extrusion* method to link longitudinal and vertical panels has been employed.

For the bonding process, we followed the steps suggested by 3M Industry: we cleaned the surface using a commercial solvent to facilitate wetting of the surface by the adhesive (or the epoxy); we applied the adhesive (or the epoxy); we jointed all substrates (sandwich panels and L-profiles) and we applied pressure for the proper time to handling strength (a few hours for the adhesive, 24 h for the epoxy).

The two panels are connected together using two L-shaped aluminium profiles: the first in the internal zone (30 × 30 × 2 mm) and the second in the external part (30 × 60 × 2 mm) (see Fig. 1(a)).

For the bonded materials, we used three different materials: one epoxy resin and two adhesive tapes composed by acrylic foams with a closed cell structure suitable for low temperature applications (3 M-Scotch-VHB). Using these materials, we obtained and investigated four configurations (Fig. 1(b)).

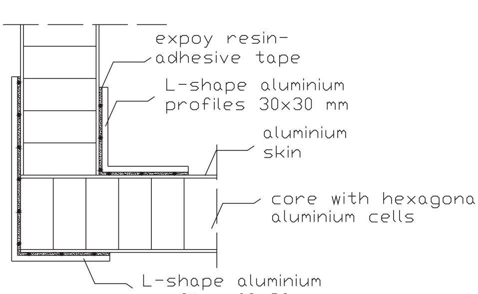
It is important to note that damping of a laminated structure, in this case (an aluminium profile, the adhesive and a thin aluminium sheet) not only depends on the shear modulus and density of materials, but is also a function of the way in which the laminate structure is made: adhesive material with a good damping property may provide a poor damping factor when it is used in an inappropriate way. In fact, the dissipation of the vibration energy assumes relevant levels only when the damping element is bound to the structure as a constraining layer.

For the experimental tests we had 21 mesh points and we used two accelerometers for a total of 42 FRF. The mesh in the FE models is finer in the corner zone (Fig. 2(a) and (b)).

Table 1

Material	Longitudinal and transverse modulus (Pa)	Shear modulus (Pa)	Density (kg/m3)	Thickness (mm)
Core	E11 = 1.00E+07 E22 = 1.00E+07 E33 = 4.40E+08	G12 = 1.00E+07 G13 = 2.95E+08 G23 = 2.95E+08	83	25.40
Skin	6.9 E+10	2.62 E+10	3180	0.56
L-shape profiles	6.9 E+10	2.62 E+10	3180	2
Epoxy	3.00E+09	1.15 E+9	1200	1–3
3M-4936	6.2E+06	6.2E+06	720	0.74
3M-4956	4.5E+06	4.5E+06	720	1.55

a



b

1. Epoxy thickness equal to 1mm;
2. Epoxy thickness equal to 3mm;
3. Acrylic adhesive tape name 3M-4936;
4. Acrylic adhesive tape name 3M-4956.

Fig. 1. (a) L-shaped sandwich panels and (b) materials and configurations used.