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FINITE ELEMENT ANALYSIS AND EXPERIMENTAL VALIDATION OF DYNAMIC BEHAVIOR OF CORNER JOINTED STRUCUTRES

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ABSTRACT: The simulation of joints in structures of sandwich panels is very important in order to obtain values of the analytical natural frequencies and mode shapes that are in accordance with the experimental values. By means of a FEM program and an experimental set for modal analysis, different assemblies of sandwich plates in aluminium, fit together with corner joints, are tested. The FEM simulation of the corner joints is made in different ways and the comparison between analytical and experimental results shows that different methodologies of simulation can be applied. Interesting results on the influence of the element set forming the joint are obtained. Moreover the non-linear behavior of the structures due to the thickness of the adhesive in the joint is analyzed.

Keywords: *FEA, dynamic behavior, corner joined structures*

1. INTRODUCTION

To predict the dynamic behavior of box-frames made of sandwich panels, it is important to determinate the natural frequencies and mode shapes. The study can be made by means of FEM codes that are capable of predicting with good accuracy the dynamical parameters of almost all practical components, no matter how complex their form [1-5]. However, when such components are assembled by means of joints to form a typical box frame, the same component models yield a greatly reduced quality of prediction [6]. The complex mechanical characteristics of sandwich plates (viz: anisotropy, non-homogeneity, and non-linear effects due to the core and the adhesive between different layers) involves greater difficulty in the analytical simulation of the dynamical behavior of the structure. The simulation of jointed zones, where different materials are present, can be made with good accuracy, but it is not always possible to generalize the results. Therefore the complexity of analytical models is not often justified by the accuracy of results.

The aim of this work is to check, by means of comparison with experimental tests, the possibility to make simplified analytical simulations to use in the dynamical analysis of jointed structures when the complexity of the analytical model can cause numerical and calculation time problems. The natural frequencies and mode shapes of two sandwich plates assembled with corner joint in 4 different manners were determined using an experimental set for modal analysis. The experimental data are compared with analytical results obtained by using a FE code for modal analysis. Four different FE models are employed to simulate the plates and the joint.

2. MATERIAL AND JOINTS DESCRIPTION

The structural joints can be made with different methods using adhesive and angular profiles of various materials. The joints used to connect the various components introduce a degree of influence that is often omitted by the coupled structure analysis methods used. The sandwich panel fabrication technology, as known, provides various types of joints such as: flat joints, corner joints and T joints. The tests included in this paper relate to plates assembled together by means of corner joints. Various methods are used to make the corner joints.

The tests were carried out on a simple structure of two jointed sandwich plates with aluminium skins 0.56 mm thick and a core of an aluminium hexagonal honeycomb cell 25.4 mm thick. The corner joints were made using three different kinds of bonding aluminium angular profiles and two thickness of adhesive (Table 1) checked by means of steel wires as shown in Fig-1. Shape and dimensions are the same for all specimens. They are made with two panels whose dimensions are 400x300 mm and 175x300 mm.

The manufacturer gives the core mass density as equal to 83 kg/m^3 with a + 10% tolerance and values of shear modulus as equal to 4.4E8 N/m^2 and 2.95E8 N/m^2 respectively in the longitudinal transverse direction. The aluminium of the skins has the following mechanical characteristics:

- Young modulus: E = 6.9E10 N/m^2
- Shear modulus: G = 2.62E9 N/m^2
- Mass density: ρ = 3180 kg/m^3

Table-1: The dimensions of tested joints

Type	Internal profile	External profile	Adhesive thickness
Joint-1	L20x20	L20x40	1 mm
Joint-2	L30x30	L30x60	1 mm
Joint-3	L30x30	L30x60	3 mm
Joint-4	L50x50	L50x50	1mm

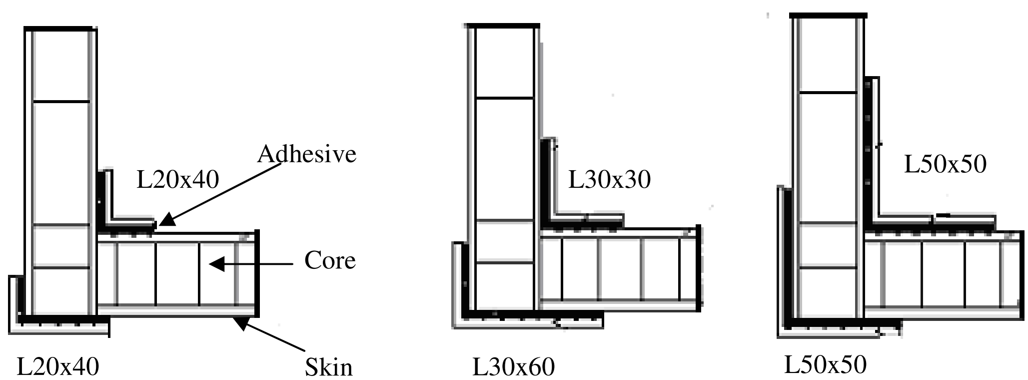


Fig-1 Types of tested joints

3. EXPERIMENTAL PROCEDURE

Dynamical analysis consists of the frequencies and mode shapes of the structure using modal analysis technique. The results of different analytical simulations and experimental tests are compared. A MIMO technique has been used by exciting the panels in different mesh-points using a hammer equipped with a force transducer. The transient signals of the accelerometers were acquired in the time domain with rectangular weighting. The length of the acquisition window has been selected in order to the signal has effectively died away to zero by the end of the record. The time record was converted in the frequency domain by means of a four channel FFT analyzer, with software to obtain the FRF; this technique can be expressed as the sum of the responses of n single degree-of-freedom system [7]:

$$FRF = \Sigma H_{ij}(w) = \Sigma X_{ij}/\mathbf{F}_j$$

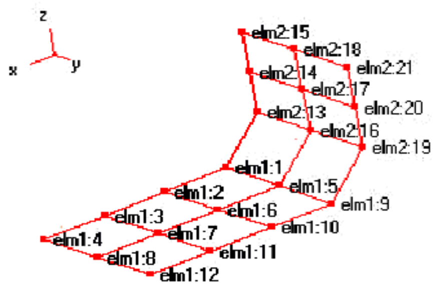


Fig-2 Experimental mesh

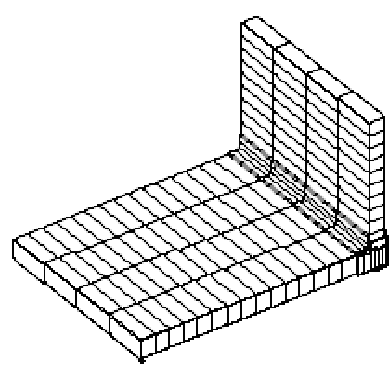


Fig-3 Finite element mesh

The experimental mesh is composed by 21 nodes (12 located on the horizontal panel and 9 on the vertical panel) as shown in Fig-2. In order to avoid recording double modes or placing the accelerometer on a nodal point two accelerometers were used. The constraint used in the tests was free-free in order to avoid the influence of the constrain realization which can introduce some factor of uncertainty as observed by other AA. [8]. In every case the FRF was recorded in a single test discarding the signals that were unclear.

4. FINITE ELEMENT ANALYSIS (FEA)

A pre and post-processor (FEMAP) and a finite element code (NASTRAN), were used for the FEA. In the finite element code analysis, the core simulation with two different shear module was fundamental to obtain the exact correspondence of vibration mode shapes at various frequencies; contrary to what literature shows in studies on static analysis on sandwich panels, whose cores are simulated with an average value of shear modulus G, in the present study the core anisotropy was not neglected to confirm the analytical mode shapes.
In the plane simulations the resistance sections are considered like a laminate composed by different layers:

- Aluminium angular profile 0.002 m thick
- Adhesive 0.001 or 0.003 m thick
- Skins 0.00056 m thick
- Core 0.0254 m thick.

Four simulations (i.e.S-1, S-2, S-3, S-4) were made using bi-dimensional laminate FE for plates and joints; they differ in the modeling of the joints. The third simulation (S-3) is different from the previous because the adhesive is considered by adding other layers. In the fourth simulation (S-4) the corner zone is simulated by the three layers sandwich adding, on the external surface, the adhesive and the angular profile, without considering the real discontinuity. Finally, the last simulation (S-5) is made with volume elements for all materials to reproduce the real geometry as shown in Fig-3.

5. RESULTS AND DISCUSSION

The results of modal analysis obtained with the five different simulations and from the experimental tests are compared in the first four natural frequencies (Table 2). The pattern of deviation from analytical and experimental values (Fig-4) concludes an almost analogous behavior of the simulations S-2 and S-3, as predictable, since only the adhesive layers differentiate the FE used in the pattern of plates and corner joint. In all simulations the best convergence is found in the values of the 2nd natural frequency (torsional mode). In all analytical simulations an inversion between the third and fourth mode shape with respect to experimental tests was detected (Fig-5). The percent deviations for the joint-3 (3 mm of adhesive) are slightly higher than the ones of the joint-2 (1 mm of adhesive). It is probably due to the non-linear behavior of the stiffness of the joint caused by the variation in the thickness of the adhesive. The more accurate simulation was obtained with volume elements (S-5). When using profiles that are either too small (joint-1) or badly arranged (joint-4), no advantage in the use of more complex model is recorded. The simplest model (S-1) without joint schematization shows a good accuracy on average. The results of this work lead to the rejection of the S-4 simulation that appears as the most intuitive to simulate technically the presence of the adhesive and the angular profiles in the joint.

6. CONCLUSIONS

Using a system of acquisition and analysis of signals for the modal analysis, the natural frequencies and mode shapes of the jointed sandwich are pointed out. The experimental values were compared to the analytical results carried out by a FE commercial calculation code. Different simulations of the joints, using plane elements and volume elements, were carried out to obtain a better simulation, introducing or not the adhesive layer, or neglecting the presence of the angular profiles in the joint zone. The comparison shows that a more accurate simulation, with greater complexity of analytical model and numerical problems, does not always produce more accurate results. Certainly stiffer joints are better simulated with volume elements. When the manufacturing is not very accurate and the joints are more flexible, a simplified simulation produces good results with less numerical problems. The effect of the adhesive thickness is better simulated with volume elements. Moreover, when the adhesive thickness increases a non linear behaviour of the joints occurs.

Table-2: Natural frequencies

Joint	Modes	FEA frequencies, Hz					Experimental frequencies, Hz
		S-1	S-2	S-3	S-4	S-5	
Joint-1	1^0	467	396	406	496	469	384
	2^0	562	534	539	548	537	510
	3^0	968	912	924	994	1025	861
	4^0	1122	967	979	1105	1045	975
Joint-2	1^0	467	401	408	519	480	474
	2^0	562	516	519	548	553	545
	3^0	968	909	908	1012	1090	1046
	4^0	1122	913	922	1142	1102	1088
Joint-3	1^0	467	405	405	517	542	470
	2^0	562	522	518	549	548	542
	3^0	968	909	903	1014	1084	1043
	4^0	1122	920	927	1141	1100	1081
Joint-4	1^0	467	416	419	526	494	432
	2^0	562	544	552	559	562	524
	3^0	968	956	954	1042	1103	926
	4^0	1122	978	980	1141	1132	1006

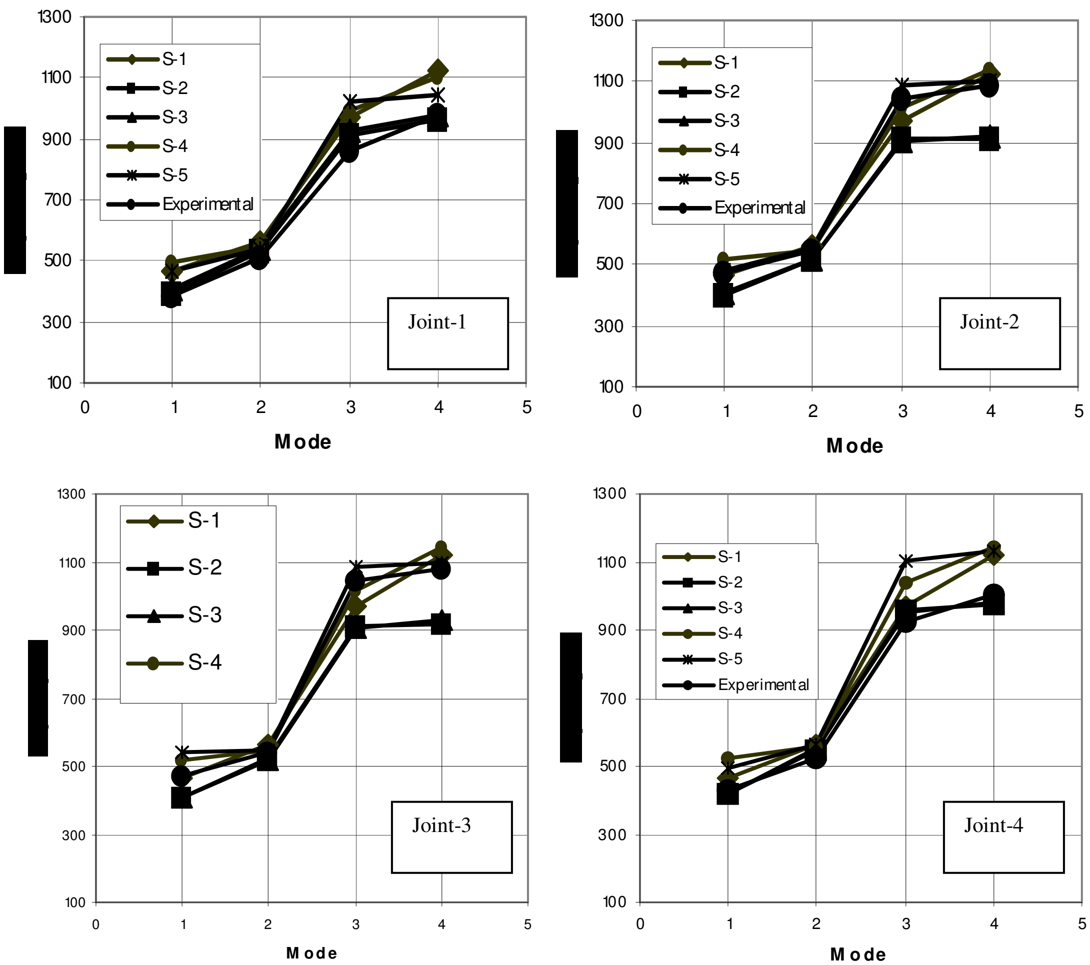


Fig-4 Natural frequencies of joints

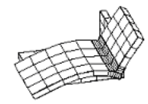
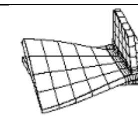
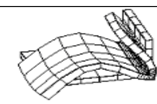
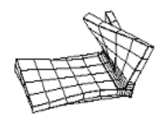
Modes	**Frequency, Hz**	**FEA simulation**
1	467	
2	562	
3	968	
4	1122	

Fig-5 Natural frequencies and mode shapes of the joint -2

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