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Experimental analysis of the vibrational response of an adhesively bonded beam

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ABSTRACT

This paper presents an experimental procedure for studying the influence that geometrical properties of adhesive joints have on the vibrational response of a metallic beam doubly supported on adhesive joints. A test bench has been developed for the experimental program. This procedure begins experimentally identifying the modal shapes. The beams are seismically excited and the influence of joint thickness and overlapping length on the beam motion is analyzed using the root mean square value of twenty-one transmissibility functions obtained along the length of the beam. The study is performed on resonance frequencies, peak amplitudes, and modal loss factors.

1. Introduction

Panel vibration has relevant influence on the structural noise involving human transportation systems and above all, flexural modes are the most significant ones [1]. In this context, joints have an important influence on the dynamic behavior of structures affecting damping [2–4]. Concretely, adhesive joints are used in structural noise control due to its capability to introduce effective modal damping below 1 kHz [5,6]. In fact, for any structure subjected to dynamic loads, joints are the responsible for the transmission of noise and vibration [7–11].

In this sense, this experimental procedure is focused on the investigation of the influence of adhesive joints (joint geometry) on the dynamic response of adhesively bonded beams. The analysis is performed over the low order flexural modes.

Relating adhesive joint configuration, there are many designs that are currently used in the industry. Concretely, lap joint configurations [12] are extensively used by car manufactures and other relevant industrial goods [13,14] and therefore, in this work, the single lap joint configuration is taken into account.

The mechanical behavior of adhesive materials can be classified in three different categories: rigid, tough and flexible. Flexible present low tensile or shear strength in comparison with rigid or tough adhesives. However, they present high resistance to peeling and to cleavage, as well as to dynamic and impact loads. Silicones, polyurethanes and modified silanes can be cited as examples. Thus, it can be concluded that flexible adhesives are candidates for vibration control applications [15,16].

Most adhesive materials show viscoelastic behavior [17–21]. Energy dissipation in viscoelastic materials arises when the material is strained. Due to this, they have to be highly strained in order to dissipate large amount of energy from the vibrating structure. So, for a given stress state distribution, the lower the adhesive modulus, the higher the strain, and therefore the higher the dissipated energy quantity.

Concluding, the object of the present paper is to develop an experimental procedure to study the influence that

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viscoelastic adhesive joints have on the vibrational response of a seismically excited doubly supported metallic beam. A test bench has been specifically developed in order to carry out a repetitive test procedure to analyze the influence of overlapping length and joint thickness. The experimental procedure consist on obtaining, for each combination of overlapping length and joint thickness, the root mean square (rms) value of transmissibility functions $T(f)$ between the adhesive base and twenty-one equally spaced beam locations. These rms functions are employed to study the variations in resonance frequencies, peak amplitudes, and modal loss factors. The article is structured as follows:

- Introduction of the experimental program and of the test bench whose components are individually described. The employed signal processing is explained and the materials and specimens are presented.
- Obtaining experimentally the modal shapes for one of the specimens.
- Presentation and discussion of the experimental results in frequency domain.
- Conclusions.

2. Experimental program

The objective of the experiments is to obtain sets of frequency f dependent transmissibility functions $T(f)$ to study the influence that overlapping length ℓ_o and joint thickness h have on the beam vibrational response.

2.1. Equipment

Fig. 1 shows a schematic diagram of the experimental set-up, whereas Table 1 gives the details about measuring equipment. Fig. 1 shows three groups of components: excitation of the system, data acquisition and processing, and the adhesively bonded beam itself.

The seismic motion used as excitation is imposed by a PPA40M piezoelectric actuator of CEDRAT Technologies [22]. This device is controlled by a DS1104 dSPACE real-time control card [23] installed on a personal computer. This card commands the piezoelectric actuator by a control

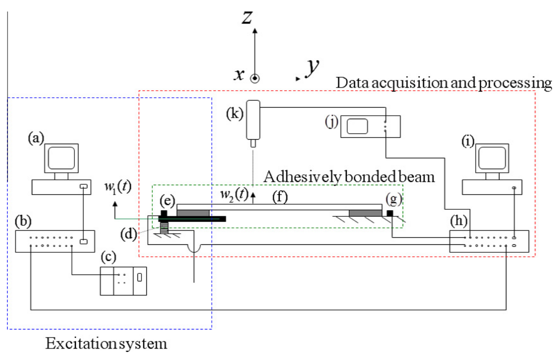

Fig. 1. Experimental set-up: (a) personal computer 1, (b) dSPACE card, (c) charge amplifier, (d) piezoelectric actuator, (e) tri-axial accelerometer ICP PCB 356A16 (1), (f) metallic beam, (g) tri-axial accelerometer ICP PCB 356A16 (2), (h) PULSE acquisition system, (i) personal computer 2, (j) laser signal amplifier, and (k) laser interferometer OFV-505.

program developed in Simulink® [24]. The digital control signal is converted into an analogical signal by the dSPACE card. Finally, it is amplified and sent to the piezoelectric actuator.

For data acquisition and processing system (see Fig. 1) another personal computer is devoted to control the B&K PULSE acquisition system [25]. Two response sensors are employed: a tri-axial accelerometer ICP 356A16 of PCB electronics [26] for measuring the adhesive base motion and a laser interferometer OFV-505 of POLYTEC [27] for measuring the beam response. Consequently, acceleration of the adhesive base is measured in three directions, whereas the velocity of a point of the vibrating beam is just transversally measured (see Fig. 1). This velocity signal $\dot{w}_2(t)$ is derived to obtain the corresponding acceleration $\ddot{w}_2(t)$.

The test bench was specifically designed in order to carry out a repetitive test procedure. Basically, it is composed by a moving support and a steady support assembled on a rigid base. Fig. 2(a) shows a general view of the test bench and Fig. 2(b) illustrates a detailed view of the moving support.

Fig. 2 shows a general view of the test bench and a particular view of the excitation system. Concerning the former, Fig. 2(a) illustrates (i) the test bench base placing, (ii) the moving support and (iii) the steady support, where (iv) an adhesively bonded beam can be appreciated. Relating the latter, Fig. 2(b) illustrates that the moving support was fabricated assembling several components; these are: (i) the actuator base, (ii) the excitation device actuator PPA40M of CEDRAT technologies, (iii) the adhesive base, and (iv) the car-guide set. From Fig. 2(b) it can be appreciated also that the piezoelectric actuator imposes the seismic motion directly to the adhesive base.

The overlapping length ℓ_o is determined for the moving and for the steady supports by two groups of metallic pieces with different slots that allow the placement of the beam with precision. Fig. 3 shows these pieces and it can be appreciated that each have five equally spaced slots to obtain five different overlapping lengths. The procedure for the right hand side (steady support) is exactly the same. Consequently, the left and right overlapping length are always nominally identical. For the experimental results presented, three different overlapping lengths are used, ℓ_o = 15 mm, 35 mm and 55 mm respectively.

The adhesive joint thickness h is controlled by a set of pieces that are assembled onto the previously mentioned ones. This procedure is repeated exactly and simultaneously in the steady support ensuring that both adhesive joints are nominally identical. Besides, these components sustain the beam during the adhesive curing. Fig. 4 illustrates one of them.

Fig. 4 shows that these parts are positioned through the two holes represented in the model. Five sets have been manufactured. Each set has a particular height and consequently, each of them ensures a particular joint thickness.

These two components controlling overlapping length and joint thickness are assembled together onto the adhesive bases before the adhesive material is applied. Thus, the hollow for the adhesive joint is formed among the set determining overlapping length and joint thickness, the