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Oberst and aging tests of damped CFRP materials: New fitting procedure and experimental results

Alessandro Fasana, Alessandro Ferraris*, Andrea Giancarlo Airale, Davide Berti Polato, Massimiliana Carello

Politecnico di Torino, Italy

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ABSTRACT

Materials play a fundamental role in defining the vibrational and acoustic characteristics of structures and their importance is even increasing because of the continuing demand for lightweight products. Carbon Fibre Reinforced Plastics (CRFP) components are becoming more and more popular because of their excellent mechanical properties but are unfortunately almost unable to dissipate energy. This is one of the reasons why their usage is limited to structural components and does not directly affect acoustic and vibrational response, which are among the factors responsible for harshness and comfort. In vehicles, for example, large panels of CFRP are as noisy as metallic panels so that this kind of lightweight structures is only used when a limited mass is of paramount importance, e.g. in racing cars. The chance of incorporating a damping material in the stacking sequence of CF layers that define a composite seems to be a viable solution to ameliorate the vibrational behaviour of composite materials. This configuration permits to cure the damping layers together with the resins, in order to obtain both free and constrained layer solutions.

In this paper, the Oberst beam method has been chosen to determine the elastic modulus and loss factor of such materials, as a function of both frequency and temperature. Three nominally identical samples for each configuration have been tested in a temperature controlled environment, according to the Oberst beam test method. The effects of aging have been simulated by an accelerated standard procedure, with cyclically varying temperature and humidity for a total of 792 h (3 cycles x 264 h). The analysis of experimental data has been performed in the frequency domain by a least square fitting procedure, aimed at outperforming the simple half-power point method. An open source version of the fitting technique has also been implemented and can be obtained from the authors under the CC-by license.

1. Introduction

Lightweight design and noise reduction are two of the hot spots of vehicle manufacturers as explained in Refs. [1,2]. These two critical topics are treated in this article starting with the analysis of CFRP mechanical behaviour and continuing with the integration of rubber-based compound to obtain a lightweight damped composite. The proposed target is the integration of damping material between CFRP layers, maintaining as constant as possible the mechanical and weight characteristics of composite while improving the NVH property. Nowadays the integration of the damping material in the stacking sequence is performed in two ways:

- external application on the surfaces of produced components (free layer formulation);
- integration between layers of CFRP (constrained layer formulation).

A noticeable characteristic of damping material used in this research is the possibility of integration in the CFRP, before the cure procedure, whose effects can be analyzed in deep as performed by Ref. [3]. This characteristic is interesting because their application can be integrated into the production process maintaining under control the technology and final product costs.

Material characterization is performed using Oberst test standard (following [4]), avoiding the use of destructive test as in Refs. [5,6]. The use of non-destructive Oberst test, to define Young modulus and loss factor of damping and structural materials, is preferred because of its capability to test exactly the same specimens at different environmental conditions. The use of vibrational and non-destructive test permits the repeatability and the immediate evaluation of damping

* Corresponding author.
E-mail addresses: alessandro.fasana@polito.it (A. Fasana), alessandro.ferraris@polito.it (A. Ferraris), andrea.airale@polito.it (A.G. Airale), davide.bertipolato@polito.it (D. Berti Polato), massimiliana.carello@polito.it (M. Carello).

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characteristics as in Ref. [7].

The effect of temperature and aging effect must be considered to verify if any unwanted damping decrement occurs, which could increase the vibration criticalities. In fact, the final use of these materials is on road vehicles where a vibration and noise increment gives the perception of quality decrement to the customer. For this reason, the aging tests have been integrated to the thermal Oberst tests taking under control the material performance degradation. Nowadays, the acoustic comfort is achieved by applying massive sound and vibration deadening materials on critical areas, such as the bonnet, door panel, roof and floor. Considering the new target of automotive weight reduction those solutions are not suitable for new applications, therefore innovative solutions and materials are analyzed in this article.

2. Test methodology

The aim of the study is the characterization of a CFRP sandwich, with and without a damping layer, at different temperatures, and also the documentation of its variations (if any) under an accelerated aging cycle. The damping material is basically a rubber based compound which can be produced in thin, flexible, large and light sheets. It can very simply be included in the stacking sequence of any CFRP component, beams in the present examples but also in more complicated structures, and can undergo the same curing process as the resins. These qualities make it particularly suited to fulfill the current standard production process of multi-layered sandwiches, and also to drastically limit the detachment of layers in sandwiches.

The Oberst beam test is a standard method to determine the elastic modulus and the loss factor of a damping material on the basis the frequency response of a multi-layered clamped-free beam (standardized by Refs. [4] and [8]). A summary of the procedure and some comments are given in this section, and the relevant expressions are reported in Appendix A.

A base beam of given dimensions (Table 1) and weight is vibrated by a non-contact exciter (Fig. 2) and the measured frequencies of the first few flexural modes, together with their analytical expression based on the Bernoulli-Euler model, allow to determine its Young's modulus – eq. (A.1). A layer (or two) of damping material is then bonded on the same beam, according to one of the configurations presented in Fig. 1. The composite beam is vibrated again, possibly at different temperatures, and from its dimensions, weight, resonant frequencies and damping ratios, the properties of the viscoelastic material (elastic modulus and loss factor) are inferred – eq. (A.2).

The base beam is supposed to be un-damped so that most often it is metallic but, in the present work, a CFRP material has been used as a support for the damping layer. The first aim was to measure the properties of the CFRP sandwich itself, and the second was to bond the damping layer on the same material as in the actual applications, in order to determine its effectiveness in terms of total damping. It is also worth noticing that in the Oberst model, the damping layer is required to be much more flexible than the supporting beam and this is one of the reasons why the damping layer thickness has to be limited.

The important issue of simulating the interfacial behaviour between different layers, which is addressed by a number of papers with both static and dynamic applications, e.g. Refs. [9–13], has not been investigated because of three main reasons. First of all, the procedure for manufacturing the composite beams does not require any additional adhesive layer, since the resins of the viscoelastic material and of the carbon fibre pre-preg undergo the same curing cycle and eventually form a unique component. Secondly, the accelerated aging process showed no detachment of the layers, as attested by both a visual check and the measured mechanical parameters, thus confirming the excellent junction of the layers. Finally, the fitting procedure described in Section 3 does not rely on any specific model aimed at describing neither a sandwich beam nor a CFRP material, but only on a generic multi-degree-of-freedom system.

Fig. 1. The Oberst beam configurations: single free layer (top), two free layers (centre), constrained layer (bottom). Grey colour indicates the damping material.

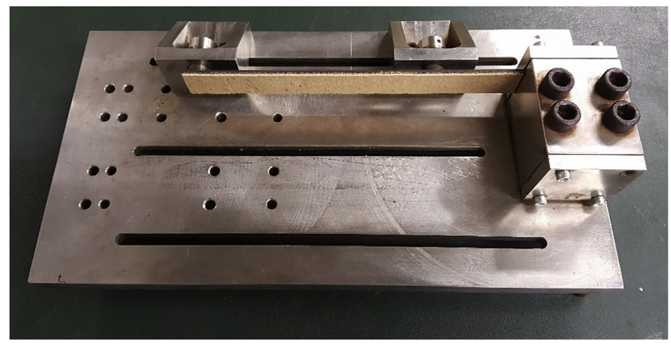

Fig. 2. Oberst test bench. Contactless magnetic exciter MM0002 on the right, near the clamping; contactless capacitive displacement sensor MM0004 on the left, near the free end.

The test rig used for the experiments is presented in Fig. 2 and Table 1 gives the relevant characteristics of the tested specimens. The free length of the beam was fixed to 200 mm and an electromagnetic contactless exciter MM002 was placed at about 42 mm from the clamping, on the right side in Fig. 2, so to avoid the nodes of the first five flexural modes. The magnetic transducer MM0002 is a device produced by Brüel & Kjær and can be used as either a tachometer or an electromagnetic vibration exciter. Both its sensitivity (when used as a velocity sensor) and the applied force (when used as vibration exciter) largely depend on the mean distance from the tested ferromagnetic specimen (the beam in the present case). The producer declares 0.45 N at 0.2 mm and less than 0.15 N at 1.0 mm. The output, proportional to the displacement, has been recorded by a contactless capacitive sensor MM004 placed at the tip of the beam, on the left side in Fig. 2. Also this capacitive transducer is produced by Brüel & Kjær and is a displacement sensitive pickup. The distance between the specimen and the transducer is again of great importance because the sensitivity is inversely proportional to the squared distance. The producer declares

Table 1
Characteristics of the beams (average of three specimens).

Material	Layers (CFRP + damping)	Thickness [mm]	Width [mm]	Length [mm]	Mass [g]	Density [kg/m^3]	Layout
CFRP	3	0,91	12,8	259,9	3,93	1305	Base beam
SUT 9609 **One side**	3 + 1	1,96	12,8	259,9	8,25	1260	One side
SUT9609 **Sandwich**	2 + 1 + 2	1,71	12,7	259,8	7,39	1307	Sandwich

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