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SANDWICH DAMPING TREATMENTS WITH MULTI-LAYER AND MULTI-MATERIAL VISCOELASTIC CORES

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Abstract. *The application of a viscoelastic core inside a sandwich plate provides an efficient dissipative mechanism able to introduce high levels of damping in light and flexible structures. Due to the decoupling effect produced by the soft viscoelastic core, the flexural stiffness of these sandwich panels can be significantly reduced and, therefore, can compromise the behavior of the damped structure. In this work, it is proposed a multi-layer core configuration which proved to be able to reduce the decoupling effect, maintaining though the treatment efficiency. A multi-material configuration is also proposed providing a good solution to enlarge the efficient temperature range of the damping treatment. A numerical simulation and an experimental study were performed on multi-layer and multi-material specimens. The achieved results verify and sustain the above assumptions and confirm that, under particular temperature conditions, a multi-layer configuration can be more advantageous than using a single layer. The overall flexural stiffness and damping efficiency increase of the sandwich structure are, thus, the most important benefits when adopting a multi-layer configuration.*

1 INTRODUCTION

The application of thin viscoelastic layers in the core of sandwich plates provides an effective passive damping mechanism broadly applied on light structures such as aeronautic fuselage panels and satellite panels. In fact, the viscoelastic core is cyclically shear deformed due to the relative motion of the external skins of the sandwich, leading to an important thermal dissipative effect and, thus, to a considerable reduction of the vibration energy of the structure.

Usually, very thin viscoelastic layers (0.02-0.10mm) are efficiently applied due to the high shear deformation that is imposed by the adjacent stiff layers. The application of thick viscoelastic layers, which increase the viscoelastic deformation energy, strongly reduces the overall flexural stiffness of the sandwich panel due to the reduced skin stiffness coupling provided by the soft and thick viscoelastic core. Moreover, the relative shear deformation developed within thin viscoelastic layers is significantly higher than the one developed within thick layers.

To solve these restrictions it is proposed to apply several thin viscoelastic layers separated by interlaminar constraining layers. With this configuration, it is possible to increase the amount of viscoelastic material maintaining the flexural stiffness of the sandwich plate. Moreover, by using a multi-layer scheme, it is possible to apply viscoelastic materials with different transition temperatures, which can be useful to enlarge the efficient temperature range of the damping treatment.

The aim of this work is to test and simulate several multi-layer and multi-material specimens in order to verify and validate the feasibility of the proposed treatment configurations.

2 MULTI-LAYER AND MULTI-MATERIAL CORE DAMPING TREATMENTS

The application of multiple viscoelastic layers in free or constrained surface treatments was initially proposed by Jones [1, 2] as a promising procedure to increase the treatment efficiency. This multi-layer configuration was also reported as a solution to enlarge the narrow efficient range of the viscoelastic treatments by employing layers of materials with different transition temperatures.

The application of this technique to the integrated layer configuration in sandwich structures, pursuing the same benefits, isn't, however, straightforward. In fact, the number of layers, the relative dimensions of the layers, the material properties and the layering sequence of multi-material configurations are important design parameters and play an important role in the structure behavior. The influence of these variables is considerably of extreme importance when compared to the multi-layer surface treatments, where the damping layer do not greatly modify the flexural stiffness of the structure. Contrary, the core of the integrated treatment is simultaneously responsible for the dissipative effect and the stiffness coupling between the outside layers, which defines the global flexural stiffness of the structure.

3 EXPERIMENTAL STUDY

The first step of this study was the experimental verification of the feasibility of the multi-layer concept. In this initial part of the study, an experimental work on a set of representative specimens was developed to evaluate the variation of the fundamental natural frequency and corresponding modal loss factor when adopting a multi-layer configuration.

The experimental results obtained were also used to validate the model adopted in the numerical analysis of this study.

3.1 Experimental specimens

To develop the experimental study several plate specimens with integrated viscoelastic treatments were produced. Two viscoelastic materials, both provided by the 3M company, were used to produce the viscoelastic layers applied in the core of the sandwich plates. The first material, 3M ISD112 [3], is designed for room temperature applications presenting an efficiency peak between 20 and 30°C. The other viscoelastic material, 3M ISD110, is designed for higher temperature applications, ranging from 40 to 100°C.

The specimens were produced with aluminum plates (aluminum alloy 1050A H24) with 1mm thickness, 200mm length and 100mm width. A thin aluminum sheet (aluminum alloy 8050 H24) provided the inner constraining layers for the multi-layer and multi-material specimens. Table 1 presents the properties of the materials applied in the study.

Material	Young's modulus [Pa]	Poisson's ratio	Density [Kg/m^3]
AA 1050A H24	70E9	0.32	2708
AA 8050 H24	70E9	0.32	2708
3M ISD112	see [3]	0.49	1140
3M ISD110	see [3]	0.49	1140

Table 1. Material properties

The viscoelastic layers were applied on the aluminum plates following the manufacturer instructions. While the 3M ISD112 can be easily bounded to the metallic substrate at room temperature, the application of the 3M ISD110 material requires the application of specific temperature and pressure conditions [3].

3.1.1 Single-layer specimens

The single-layer specimens, designated by S1 and S2 (Figure 1), were produced by applying a single core layer of 3M ISD112 and 3M ISD110, respectively, with 0.127mm thickness. These specimens provided the reference to evaluate the multi-layer and multi-material benefits/drawbacks.

3.1.2 Multi-layer specimens

Two multi-layer specimens, designated by M1 e M2 (Figure 1), were also produced applying, respectively, 2 and 3 thin layers (0.0508mm) of 3M ISD112 intercalated with thin (0.05mm) aluminum sheets that provided the constraining effect.

3.1.3 Multi-material specimens

The specimens M3 and M4 (Figure 1) represent the multi-material configurations. These specimens are dimensionally identical to the multi-layer ones where some 3M ISD112 layers were replaced by identical 3M ISD110 layers, as depicted in Figure 1.

The Figure 2 illustrates the experimental specimens produced and tested in this study.

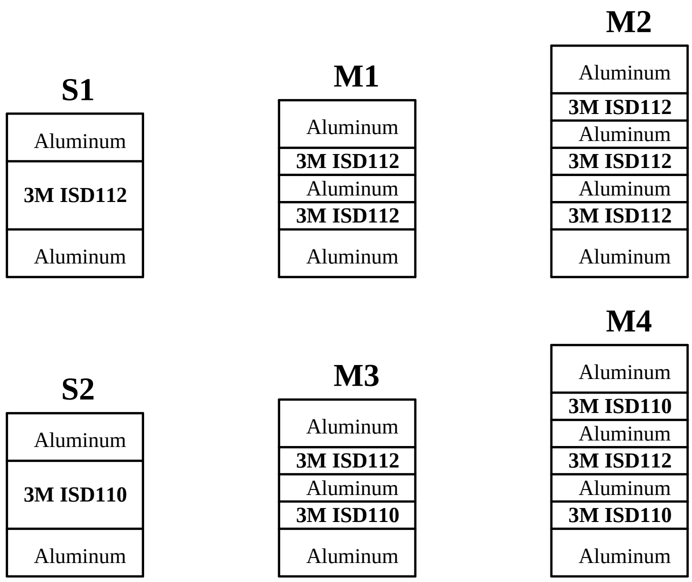

Figure 1. Specimens configuration

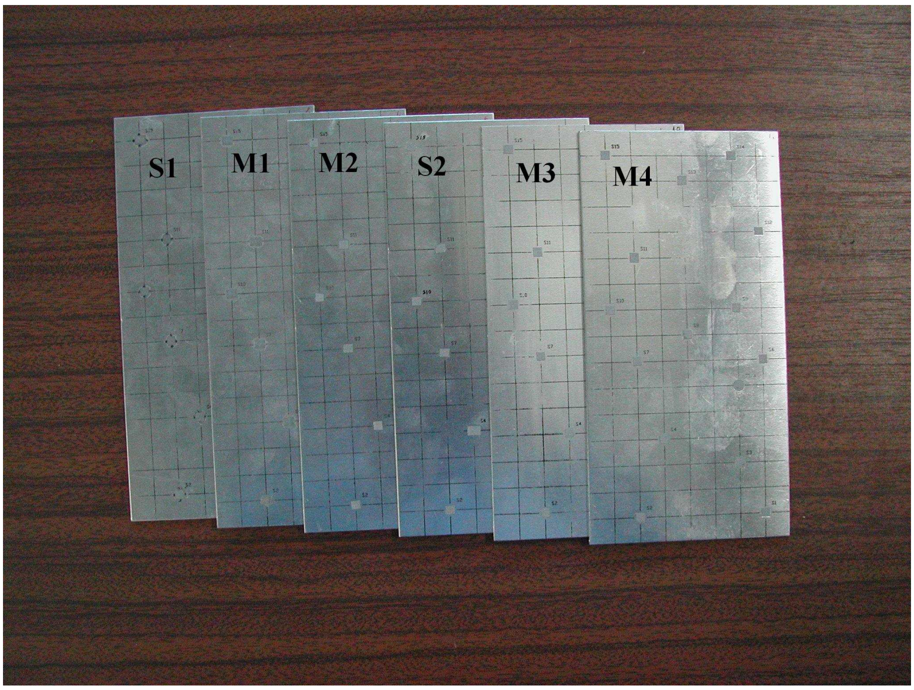

Figure 2. Specimens analyzed

3.2 Experimental setup

As stated above, the experimental study developed in this work had two distinct purposes: to provide a comparison analysis between the damping efficiency and the flexural stiffness achieved for each treatment, and to validate the model adopted for the numerical analysis presented in the following section. For both purposes, the aim of the experimental study was the determination of a representative set of frequency response functions providing the input data for a modal parameter identification process and, on the other hand, a reliable basis for the numerical layerwise model [5, 6] validation for a direct frequency analysis using the complex modulus approach [4].

To obtain free boundary conditions, which minimize the boundary error effects, the experimental specimens were suspended by a thin nylon wire from a rigid frame. A mesh with 15 measuring points, as depicted in Figure 3, was defined for all the tested specimens.

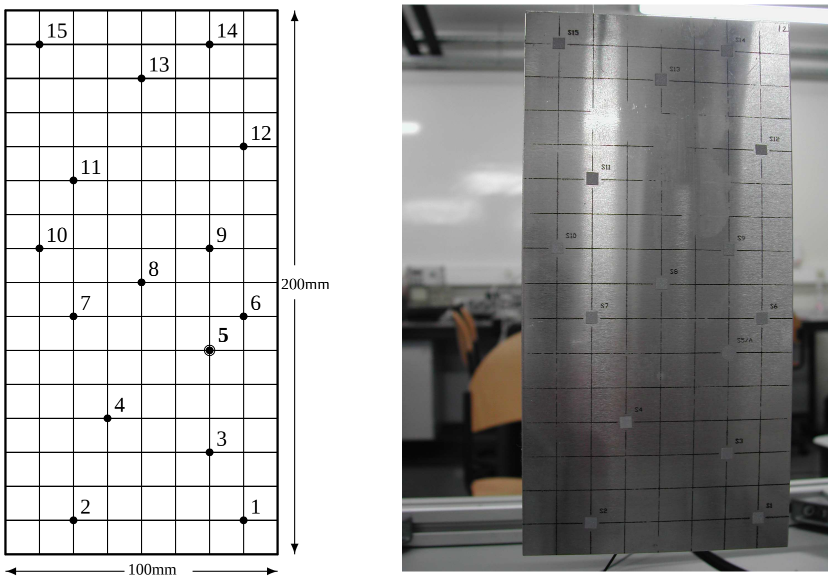

Figure 3. Measuring mesh and specimen boundary conditions

An electrodynamic shaker (Ling Dynamic Systems - model 201), suspended from an independent rigid frame, was utilized to generate a random ([0-800]Hz) excitation in point 5 of each specimen. A thin and flexible stinger was used to link the shaker to the miniature force transducer (Brüel & Kjær - model 8203) attached to the plate surface, which provided the measurement of the applied dynamic force (Figure 4). The specimens responses were evaluated by using a laser vibrometer (Polytec - model OFV303) to measure the velocity of each point of the measuring mesh (Figure 5). The temperature of the measurement was evaluated by a thermocouple located near the specimens.

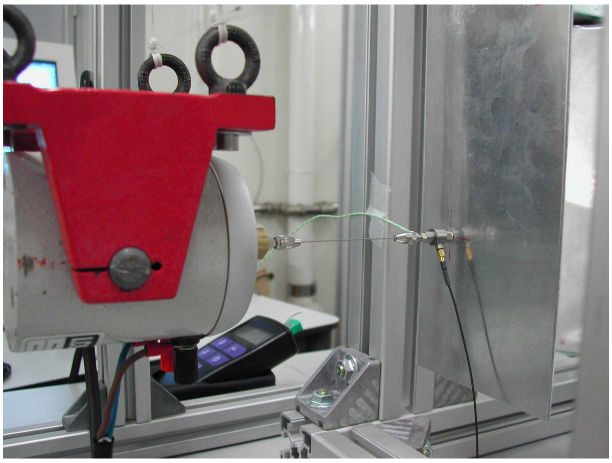

Figure 4. Experimental setup - specimen excitation

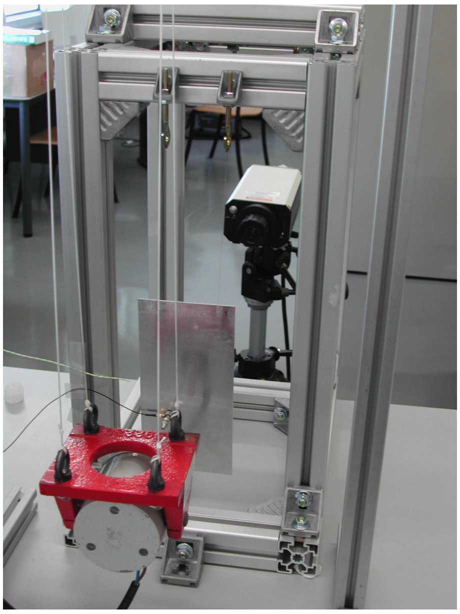

Figure 5. Experimental setup - response measurement

3.3 Experimental validation of the numerical model

Fifteen frequency response functions (mobility functions) were determined for each specimen. These experimental frequency response functions were compared to the numerical ones generated by using the finite element model adopted in this study [5], which allowed the validation of the finite element model as well as the complex modulus approach to characterize the viscoelastic material. This model assessment was performed by simple visual comparison of the experimental and numerical frequency response functions, as presented in Figures 6-11, and by using frequency response functions correlation indicators [7].

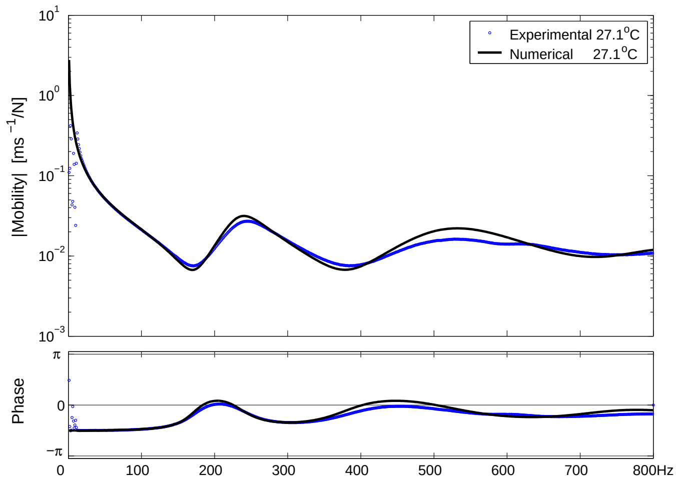

Figure 6. Direct mobility function for specimen S1 (27.11ºC)

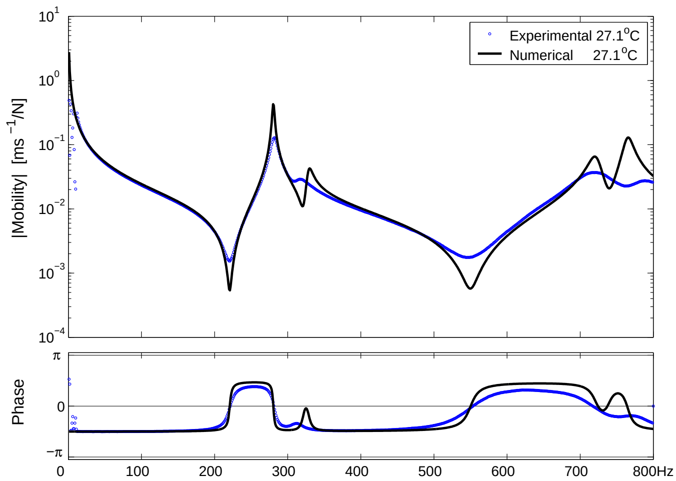

Figure 7. Direct mobility function for specimen S2 (27.11ºC)

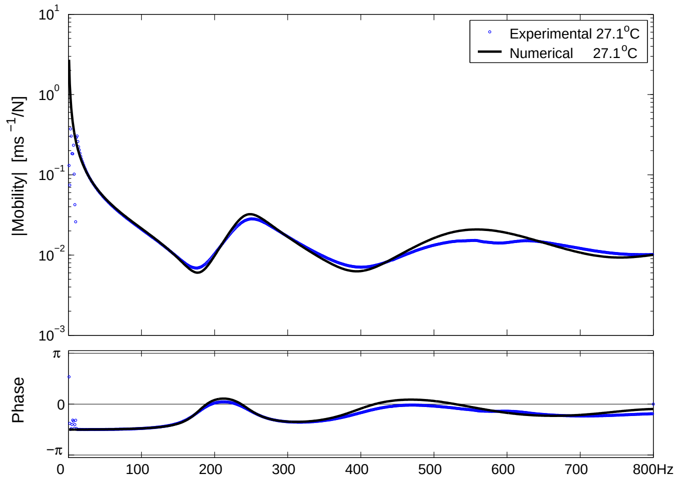

Figure 8. Experimental setup - response measurement

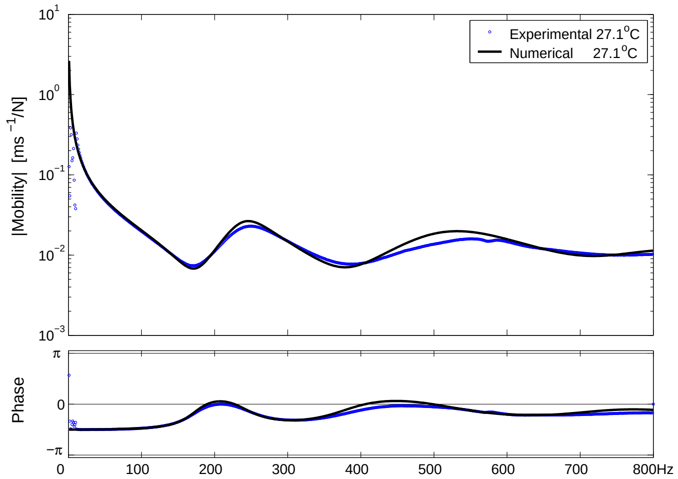

Figure 9. Experimental setup - response measurement

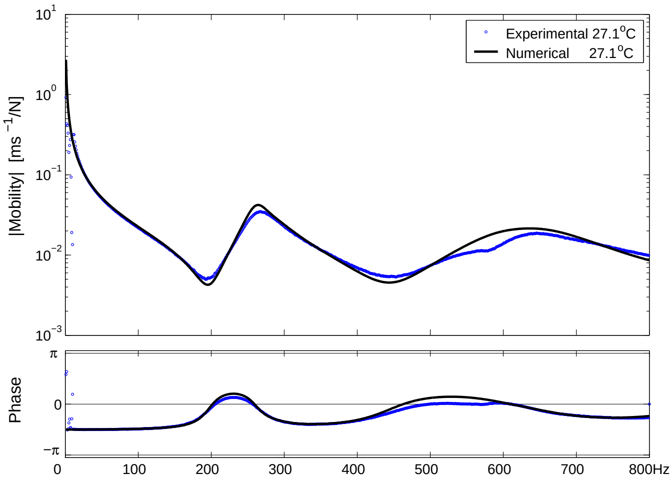

Figure 10. Experimental setup - response measurement

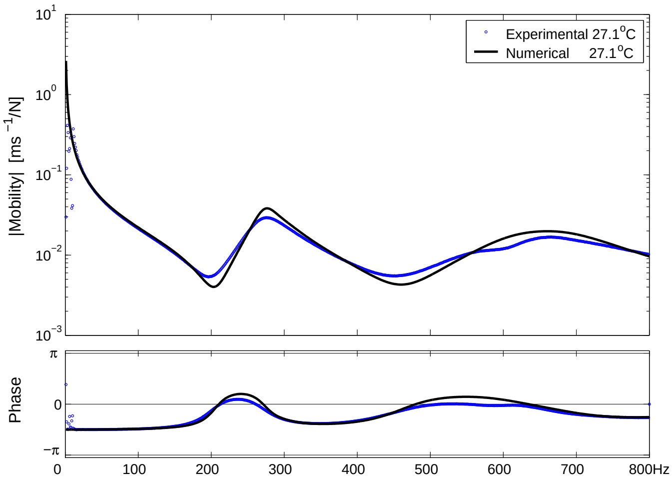

Figure 11. Experimental setup - response measurement

3.4 Experimental results - modal identification

Using a circle fit modal parameter identification procedure, the fundamental natural frequency and the corresponding modal loss factor were identified for the entire set of specimens. The identified values are presented in Table 2.

Specimen	Natural frequency [Hz]	Modal loss factor
S1	238.58	0.270
S2	281.42	0.032
M1	245.32	0.244
M2	250.54	0.299
M3	261.57	0.163
M4	267.21	0.193

Table 2. Fundamental natural frequencies and modal loss factors

While the modal loss factor provides an indicator for the damping efficiency achieved by each configuration, the fundamental natural frequency is useful to evaluate the flexural stiffness variation for each treatment configuration.

Since the inner constraining layer is made of aluminum, the additional mass of the multi-layer treatment is higher than the mass added by the single layer treatment. This observation, along with the higher values for the fundamental natural frequency achieved with the multi-layer and multi-material specimens, supports the assumed benefit of the integrated treatments with multiple layers in the core: the attenuation of the decoupling effect promoted by the soft core.

From the modal loss factor values it was also possible to establish an efficiency relationship between multi-layer and single-layer treatment configurations. Despite the higher damping achieved with the specimen M2, having into consideration the viscoelastic material mass effectively introduced in the dissipative core, specimen M1 presents the highest damping configuration.

The multi-material specimens present higher natural frequencies and lower modal loss factors because the 3M ISD110 material has a higher storage modulus and a low loss factor at the testing temperature conditions (27.1°C).

4 NUMERICAL ANALYSIS

Using a layerwise finite element model proposed by the authors [5], a numerical analysis was performed on the proposed treatment configurations in order to verify their behavior along with the temperature. This study intends to verify the assumed benefits of the multi-material configuration, which is here proposed as a solution to enlarge the efficient range over the temperature.

4.1 Analysis method

To avoid the computational cost of a direct frequency analysis [4], and since the aim of this analysis is merely to compare the different multi-layer and multi-material configurations over a large range of temperature, it was used an approximate analysis procedure to determine directly the modal parameters of the specimens.

The Modal Strain Energy (MSE) method [8] was the selected analysis method due to its computational efficiency, providing with relatively low cost the modal model that can be used to compare the treatment configurations through its natural frequencies and corresponding modal loss factors. The MSE method assumes that the modal shapes of the undamped structure are representative of the structure with treatment. Therefore, the approximate loss factor of the damped structure can be easily determined through the ratio between the dissipated energy and the storage energy using the undamped mode shapes.

In this numerical study, a modified version of the original MSE method [9] is applied in order to account for the effects of the viscoelastic core in the modal frequencies of the treated plates.

Modified MSE method algorithm

1. Starting condition:

   $\omega_r^i = \omega_0$

2. Iterative loop for calculation of undamped natural frequency:

   - eigenvalue problem statement

   $$[K_R(\omega_r^i)]\{\phi_r\}^i = (\lambda^2)^i[M]\{\phi_r\}^i$$

   - natural frequency determination

   $$\omega_r^{i+1} = \lambda_r^i$$

   - convergency assessment

   $$\Delta_\omega = |\omega_r^{i+1} - \omega_r^i|/\omega_r^{i+1} \quad \leq \Delta_{\text{max}}$$

3. Modal loss factor determination:

   $$\eta_r = \frac{\{\phi_r\}^T[K_I(\omega_r^{i+1})]\{\phi_r\}}{\{\phi_r\}^T[K_R(\omega_r^{i+1})]\{\phi_r\}}$$

This iterative procedure allows to get an approximate value to the damped natural frequency and, consequently, a better approximation to the real viscoelastic material properties.

4.2 Numerical results

The proposed modified version of the MSE method was applied to calculate the fundamental natural frequency and corresponding modal loss factor of the analyzed treatment configurations for a set of temperatures from 0°C to 100°C.

An additional multi-material configuration, M4*, was considered in this analysis. This configuration, based in the M4 treatment configuration, has the middle viscoelastic layer made of 3M ISD 110 and the two outside viscoelastic layers made of 3M ISD112.

The obtained fundamental natural frequency values are represented in Figure 12. The obtained results show that the treatment configurations with the viscoelastic material 3M ISD110 , S2, M3, M4 and M4*, present higher natural frequencies than those configurations with the material 3M ISD112. This observed effect is due to the higher transition temperature of the 3M ISD110 viscoelastic material. Additionally, it is also observed that the multi-layer configurations, M1 and M2, present higher natural frequencies than the single-layer configuration S1, sustaining the assumed major benefit of the multi-layer: the attenuation of the decoupling effect.

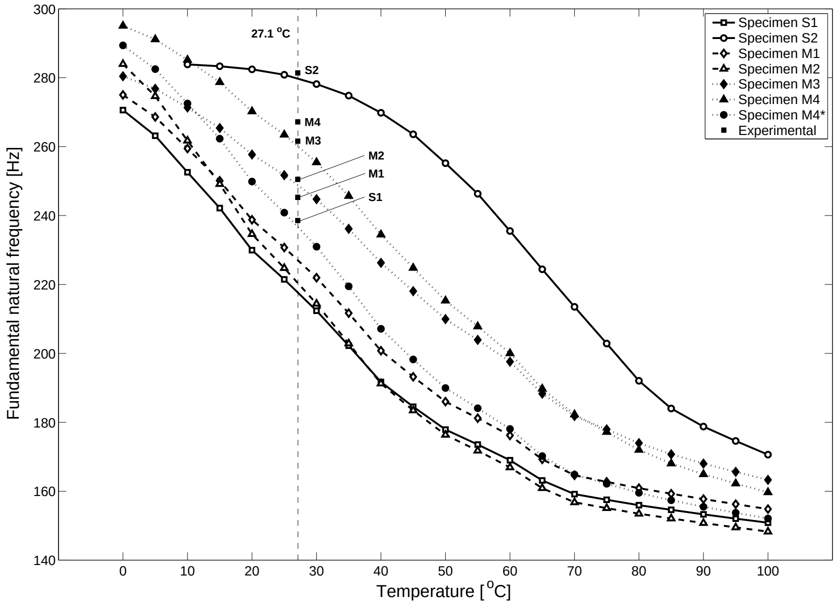

Figure 12. Fundamental natural frequency distribution

On the same graphic it is also represented the identified fundamental natural frequencies listed in Table 2, which present a good agreement with the numerical values.

The modal loss factor distribution, represented in Figure 13, provides the relationship between the temperature and the treatment configuration efficiency.

Globally, it can be observed that the treatment configurations based on the 3M ISD112 material, S1, M1 and M2, present an efficiency peak near the transition temperature of the viscoelastic material. On the other hand, the single-layer treatment made of 3M ISD110 viscoelastic material, is particularly efficient at higher temperatures, showing an efficiency peak at 70÷80°C. As predicted, the multi-material configurations can be regarded as a transition

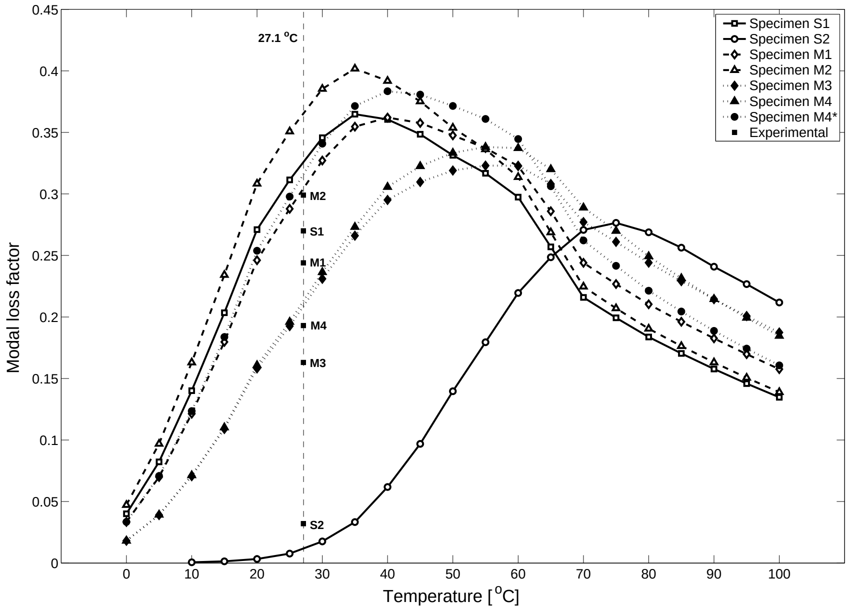

Figure 13. Modal loss factor distribution

configuration, showing an efficiency peak in the middle of the transition temperatures of both viscoelastic materials.

When comparing the multi-layer configuration M1 to the multi-material configuration M3, obtained by replacing one of the 3M ISD112 layers by a 3M ISD110 layer, it is possible to observe that the efficiency increase at the high temperature range is accompanied by a reduction of the efficiency at the lower temperatures. Contrary, the M4* configuration, obtained by adding a 3M ISD110 viscoelastic layer into the middle of the M1 core, is able to enlarge the efficient range without an efficiency reduction at the low temperature range. From the results, it is also possible to verify that the sequence of the layering scheme along the dissipative core of the multi-material configuration is of major importance in the flexural stiffness of the treated structure. The treatment efficiency is also highly dependent upon the layering scheme due to its effect onto the shear deformation transmissibility from the outside plates to the dissipative layers.

5 CONCLUSIONS

The present study allowed to evaluate the feasibility of the application of the multi-layer concept into the integrated viscoelastic damping layer configuration.

The application of multiple viscoelastic layers, separated by stiff constraining layers, provide a potential solution to overcome the decoupling effect produced by the soft core of the integrated damping treatments. Moreover, adopting a multi-layer configuration, is is possible to increase the shear deformation effect in the individual layers, increasing thus the treatment efficiency.

Despite the benefits of using a multi-layer configuration, it is necessary to give special attention to the mass density of the material used to produce the constraining layers. Low density polymers or composite materials should be thus regarded as a more interesting solution than the aluminum sheet applied in this study.

The multi-material configuration is also a promising solution to enlarge the efficiency range of the viscoelastic treatments by applying several layers made of viscoelastic materials with different transition temperatures. Nevertheless, the layering sequence of the layers dictates, not only the treatment efficiency but also the stiffness coupling capability developed by the damping core and the deformation pattern inside the sandwich structure. Special attention must be devoted to this issue when designing integrated multi-material treatments.

6 ACKNOWLEDGMENT

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