EXPERIMENTAL ANALYSIS OF THE STRUCTURAL DAMPING FOR COMPOSITE PLATES WITH NANOCLAY ADDITION USING THE POWER INJECTION METHOD

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Abstract. *The aim of this work is to compare the structural damping coefficient introduced by nanoclay addition in the fiber glass laminated plates. The analysis of the structural damping is performed using the Power Injection Method (PIM) which can be performed measuring the force and the velocity at the driven point if no moment is introduced. Supposing free-free vibration of the structure, the power injected is the power consumed by damping vibration process. In order to perform the experimental analysis, a set of fiber glass laminated plates with 0%, 2%, 5% and 10% in weight of nanoclay dispersion in to the epoxy matrix were prepared. The comparison of the results shows that it is possible to identify which structure absorbs more power for all frequency range. Besides, it is possible to identify the optimum concentration of nanoclay dispersion to improve the damping.*

Keywords*: Composite plate, Power Injection Method, Structural Damping*

1. INTRODUCTION

High performance polymeric composites are a valuable alternative to conventional materials due to their high specific mechanical properties, i.e. stiffness-to-weight and strength-to-weight, tailor-ability, and damage tolerance. One interesting advantage of using composites is the possibility of adding nanoclay particles into the epoxy matrix, and consequently, changing the vibration behavior of the structure.

The main goal of this research is to investigate the nanoclay influence in damping loss factor of a fiber glassepoxy laminate composite using Power Injection Method, which is a method that turns possible to access the damping loss factor over all range of frequency instead of only the modal damping as performed by modal analysis.

To be able to perform such analysis, a series of composites were prepared where all manufacturing parameters were kept fixed, for details see Ávila et al. (2006a, and 2006b). The nanocomposite prepared for this investigation is a S2-glass/epoxy-clay. The resin system was chosen owing to its low viscosity and long gel time (60 minutes) at room temperature. The epoxy formulation is based on two parts, part A (diglycidyl ether of bisphenol A) and part B - hardener aliphatic amine- (triethylenetetramine). The weight mixing ratio suggested by the manufacturer is 100A:20B, and the average viscosity is around 900 cps. The nanoclay particles used in this study are organically modified montmorillonite in a platelet form, while the S-2glass fiber has a plain-weave woven fabric configuration with density of 180 g/m2 from Texiglass. The S2-glass/epoxy-nanoclay composite is a laminate with 16 layers and 65% fiber volume fraction. The nanocomposite synthesis followed the methodology proposed by Ávila *et. al.* (2006a, and 2006b). The amount of nanoclay dispersed into the epoxy system, in weight, is 0% (without nanoclay dispersion), 2%, 5% and 10%, respectively. The composite plates were prepared to be equally in size and shape, all of them having 136 mm × 116 mm × 2.4 mm, and mass 66,4 g, 66, 9 g, 67,5 g, and 67,9 g, respectively.

2. POWER INJETION METHOD

The power put into a system by a point excitation is equal to the time averaged product of the force F(t) and the velocity v(t), Lyon and DeJong (1995). The time average is easily evaluated in the frequency domain applying Fourier transform as,

$$\prod_{in} = \langle F(t)v(t)\rangle = \frac{1}{2}\Re\{F(\omega)V^{*}(\omega)\} = \frac{1}{2}\Re\{F(\omega)^{*}V(\omega)\} = 2\Re\{S_{FV}(\omega)\} \tag{1}$$

Were <> denotes the average, $\Re$ the real part, S the cross-spectrum, * the conjugate complex.

It is well know that the power flows out of a system through dissipation or by transmission to another system, Lyon and DeJong (1995). Supposing that the only dissipation mechanism is the internal damping, the dissipated power in the system can be evaluated by, Lyon and DeJong (1995),

$$\prod_{diss} = 2\pi f \eta E \tag{2}$$

Where f denotes the frequency vector, η the damping loss factor, and E the total dynamical energy of the system. The total energy E of the system is directly related to the measured response quantities. The total energy of a vibrating system of mass M as used in this study is given by,

$$E = M\left\langle v^2(t)\right\rangle = \frac{1}{2}M\left|V(\omega)\right|^2 = 2M\left|S_{VV}(\omega)\right|^2 \tag{3}$$

Where $<v^2(t)>$ denotes is the mean square vibration velocity averaged over the spatial extent of the system.

Therefore, the power injected in the system can only be dissipated by internal damping. In this case, the damping loss factor can be evaluated in the frequency domain equaling Eq. (1) to Eq. (2) as,

$$\eta = \frac{\prod_{in}}{2\pi f E} \tag{4}$$

3. MUNERICAL EXAMPLE

In order to verify the Power Injection Method it was performed a numerical example using as a base a plate made of steel, whose material properties are Elasticity Modulus E = 210 GPa, density ρ = 780 kg/m^3, Poison υ = 0,3, and the geometry is 0,35×0,45×0,0021 m, under free-free-free condition. The simulation was performed using Finite Element Method (FEM), where the displacements were evaluated using rectangular thin plate classical theory, the stiffness and mass matrices following the expressions given by Przemieniecki (1985) for noncompatible displacements.

The FEM was performed using 1575 elements meaning that each element has 0,01×0,01 m^2. The simulation was performed for 3 plates using 3 different modal damping loss factor 0.001, 0.005, and 0.01, respectively. The input was considered as unit point force located at position (0.04, 0.01), and the results are obtained for the receptances, Ewins (1984).

The evaluation of the Power Injection Method (PIM) for the plates using Eq. (1), were it was assumed that the point force is equal to the unit. The results can be seen in Fig. (1), were the peaks are exactly the natural frequencies. It is possible to conclude that the most damped plate is the one that absorbed more power, represented by higher values of PIM. Obviously, as the structures are not connected to other structures, the only mechanism to dissipate energy is due to the internal damping.

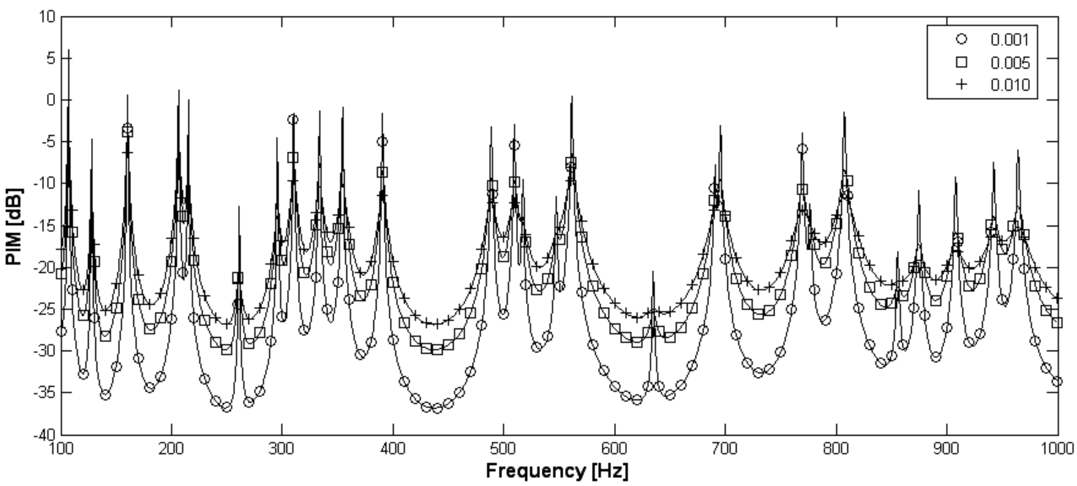

Figure 1. Power Injection Method for the plates

The kinetic energy was evaluated first transforming the displacement into velocity using the Fourier property, second, calculating the kinetic energy density, which is the kinetic energy at each measuring point, and finally, the kinetic energy is the sum of the kinetic energy density over the plate. The result can be seen in Fig. (2), where it is observed that there is practically no changes over the frequencies except for the natural frequencies, where the less damped case produced the highest peaks.

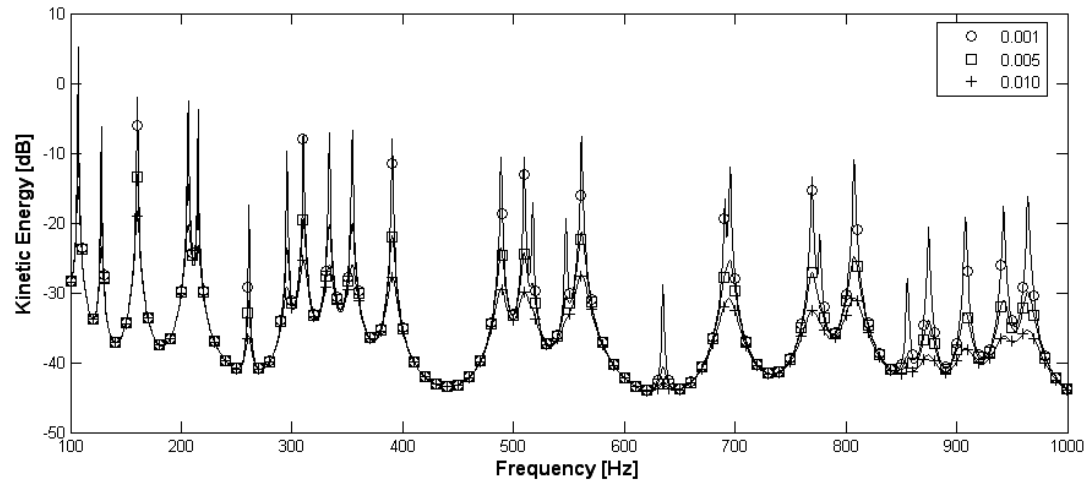

Figure 2. Kinetic Energy for the plates

Now, the power dissipated, Eq. (2), is equal to the power injected, Eq. (1), evaluating these equations for the damping loss factor, η, the result can be observed in Fig. (3), where it is observed that the method can reasonable predicted the damping loss factor.

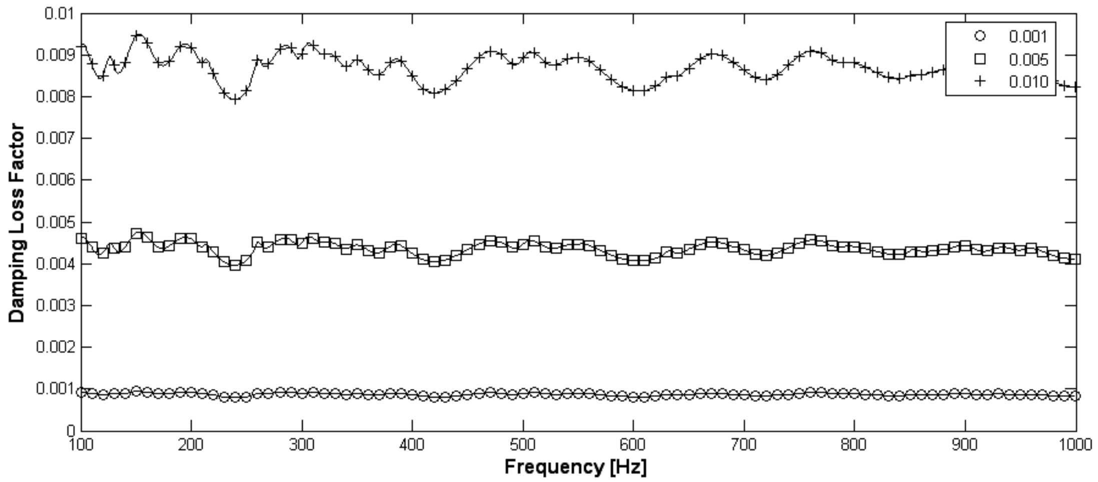

Figure 3. Damping loss factor for the plates

4. EXPERIMENTAL INVESTIGATION

The measurements were performed using a data acquisition from LDS model LDS Dactron, Fhoton II, a power amplifier from Brüel & Kyjaer model 2718, shaker Brüel & Kyjaer model 4810, a force transducer from PCB model 209C12, and an accelerometer from PCB model 352A71 weighting 0.65 g. The test plates were hanged by a fine nylon wire and excited by a white noise. In order minimize the introduction of momentum, it was used a stinger connecting the shaker to the force transducer.

4.1. Calibration of the sensors

In order to perform correctly the power injection measurement, the most important parameter to be considered is the phase between the sensors, the accelerometer and the force transducer. For example, supposing that the force in Eq. (1) is a real quantity and the velocity is an imaginary quantity, than no power is injected into the system, on the other hand, if both are real quantities, maximum power is obtained. A simply experiment can be done to verify the relative phase between the sensors, know as relative correction, because one of then is considered correct while the other is the one which is been corrected.

The experiment can be implemented using a system with the first natural frequency very far from the frequency range used in the power injection method, with can be achieved using a large block of steel, Fig. (4). In this case, the relative phase $\phi(\omega)$ is evaluated calculating the angle of the transfer function defined as,

$$\phi(\omega) = \text{angle}(H(\omega)) = \text{angle}\left(\frac{A(\omega)}{F(\omega)}\right) \tag{5}$$

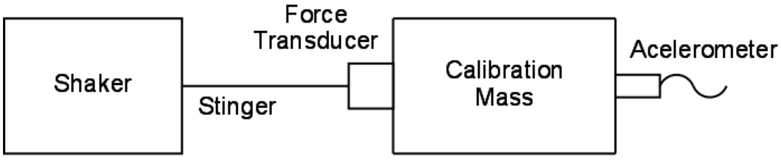

Figure 4. Phase relation between the accelerometer and the force transducer

The result can be seen in Fig. (5), where it is noticed that the relative angle between the force and acceleration measured by the sensors is approximately equal to -10°, which means that the acceleration measured by the accelerometer must be forwarded in 10°. It is easily accomplished multiplying the accelerometer signal by a complex exponential following,

$$A_C(\omega) = e^{i\phi(\omega)} A_I(\omega) \tag{6}$$

Where $A_C(\omega)$ is the acceleration with the phase shift, and $A_I(\omega)$ is the acceleration measured by the sensor.

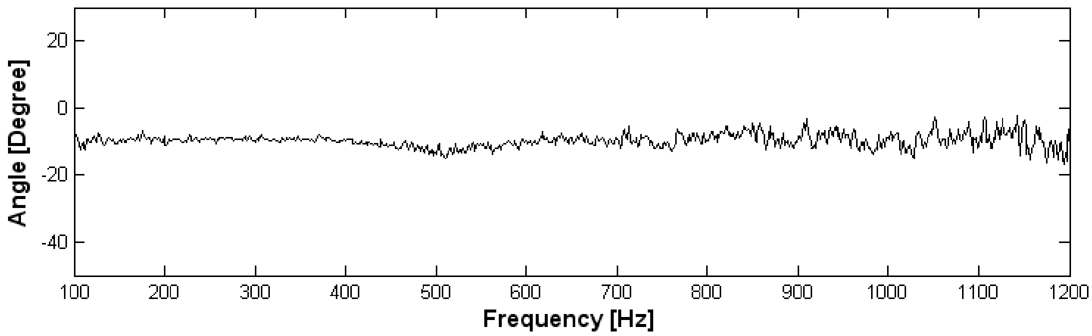

Figure 5. Phase relation between the force transducer and the accelerometer

4.2. Evaluation of the damping loss factor

In order to perform the analysis, in each composite plate was made a grid containing 35 points to perform the acceleration measurements, and the point force was fixed at position (0.01, 0.07). The accelerometer was moved to the other positions to complete the measurement. Every measurement was performed using a frequency range of 0 to 1317 Hz, with a spacing frequency of 0.732 Hz, white noise excitation, hanning windows with 30 averages, and it was used the H1 estimator to estimate the accelerance transfer functions.

The evaluation of the power injection method is performed following Eq. (1), and applying the correction in the accelerometer as described in the preceding section. The results can be seen in Fig (6), where the peaks are related to the natural frequencies of the composite plates. Besides, the peaks are not at the same frequency, which means that the plates does not have the same natural frequencies.

According to the present methodology, at the first natural frequency the addition of nanoclay particles decreased the power absorption, while for the others natural frequencies increased the power absorption. Besides, it seems that the best power absorption is reached by the 5%, and the worst power absorption by the 2%.

The Kinetic energy evaluated using Eq. (3) can be seen in Fig. (7), where it is noticed that the energy levels are dependent of frequency and the quantity of nanoclay particles. In general, there is no conclusion about which quantity presented more kinetic energy. This conclusion may be associated with few measurements of acceleration, only 35.

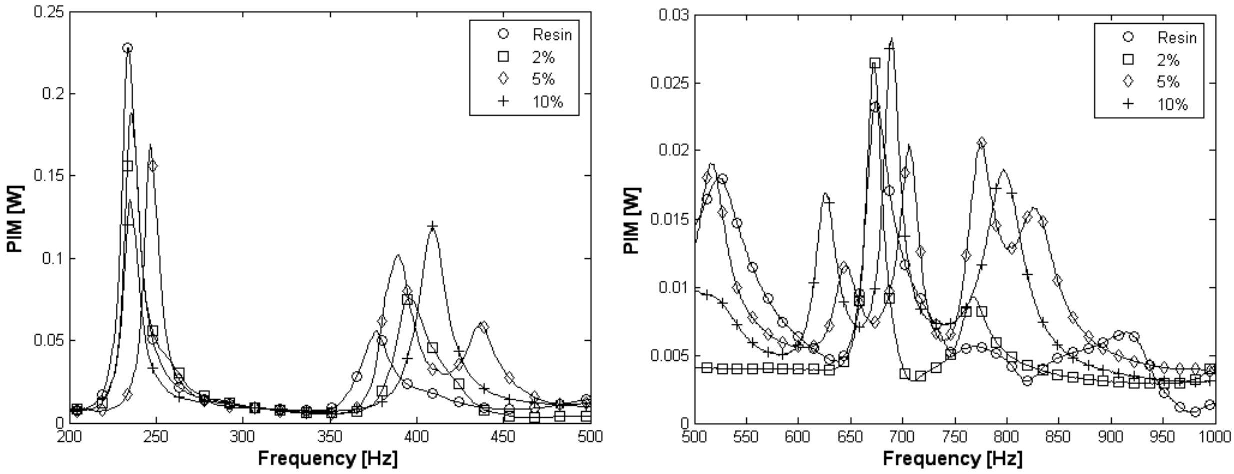

Figure 6. Power injected into the composite plates

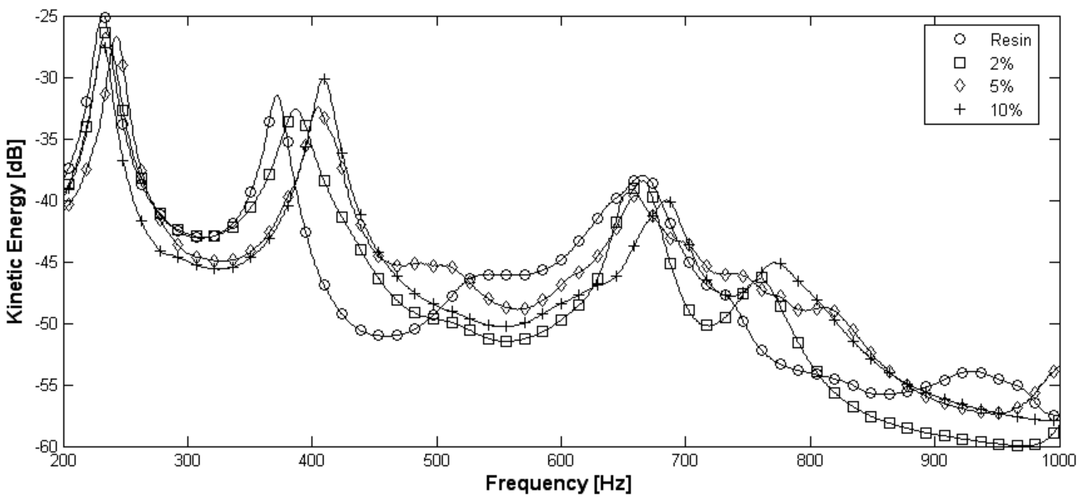

Figure 7. Phase relation between the force transducer and the accelerometer

The evaluation of the damping loss factor using Eq. (4) can be seen in Fig. (8), where can be seen that it is not possible to identify which quantity of nanoclay achieved the biggest damping loss factor. However, it is possible to observe that the 5% achieved in average the best damping loss factor.

Now, comparing with the results from a modal analysis where the results are presented in Tab. (1). The modal analysis was performed using Ortogonal Chevbechev Polynomial Method (ORTPOLY), Arruda *et al.* (1997) and a survey was presented in Donadon *et al.* (2007). Comparing the Tab. (1) with Fig. (8), it is possible to verify that the both methods achieved practically the same results for damping loss factor. However, using the method presented here, it is possible to access at any frequency the damping loss factor.

It is necessary to mention that the method presented here have two main disadvantages. The first one is the necessity of performing the energy measurements if the final objective is to access the damping loss factor. The second it is the sensors used in the process must have matched phase.

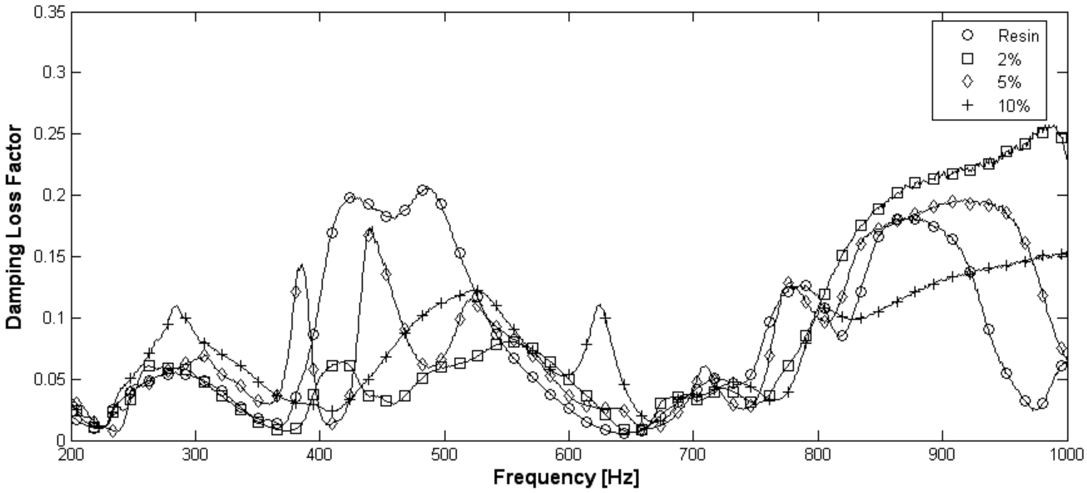

Figure 8. Phase relation between the force transducer and the accelerometer

Table 1: Results from Modal Analysis. The "----" means that it was impossible to identify the mode

Nanoclay composition		Results from Modal Analysis			
		1º mode	2º mode	3º mode	4º mode
0%	Damping factor	0,0235	0,0133	0,0266	-----
	Natural Frequency [Hz]	237,00	392,00	665,00	-----
	Peak amplitude [m/s^2 / N]	4,30	2,25	0,98	-----
2%	Damping factor	0,0252	0,0304	0,0146	0,0236
	Natural Frequency [Hz]	235,00	391,00	661,00	761,00
	Amplitude [m/s^2 / N]	3,60	1,75	0,95	-----
5%	Damping factor	0,0222	0,0217	0,0231	0,0181
	Natural Frequency [Hz]	243,00	408,00	609,00	678,00
	Peak amplitude [m/s^2 / N]	3,40	1,70	0,61	-----
10%	Damping factor	0,0237	0,0201	0,0249	0,0308
	Natural Frequency [Hz]	232,00	411,00	680,00	781,00
	Peak amplitude [m/s^2 / N]	3,25	2,50	0,84	-----

5. FINAL REMARKS

The mainly conclusion is that the addiction of nanocly in composite plates changes considerable the damping loss factor, and this fact can be used to increase the vibration performance of the composite.

Besides, the applicability of the methodology presented here is dependent of the evaluation of the energy, which can be difficult to be performed compared to other methods, however it is possible to access the damping loss factor not only in the natural frequencies but also in any other frequency range, which can be very interesting when working in high frequencies ranges.

The power injection method by itself showed that it is easy to be performed, since that the sensors used in the measurements have matched phases, and the result is quite good to identify which structure or system absorb more power, consequently which one is more damped.

6. ACKNOWLEDGEMENTS

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