ON THE INFLUENCE OF MECHANICAL AND PROCESSING CHARACTERIZATION ON THE VIBRO-ACOUSTIC RESPONSE OF LCM AND PREIMPREGNATED COMPOSITE LAMINATES

M.Ibáñez[1], E.Muñoz[2], L.Domenech[1], E.Cortés[3], F.Sánchez[1*], and J.A.Garcia-Manrique[2]

[1]Department of Building and Industrial Production Engineering, University CEU Cardenal Herrera
Avda.Seminario s/n, 46113, Moncada, Valencia, Spain
Email: m.ibanez@raschdrums.com, manuel.ibanez@uchceu.es, luis.domenech@uch.ceu.es, fernando.sanchez@uch.ceu.es (*corresponding author), web page: http://www.uchceu.es
[4]Departamento de Ingeniería Mecánica y de Materiales, Universidad Politécnica de Valencia, Spain
Email: emudom@mcm.upv.es, jugarcia@mcm.upv.es, web page: http://www.upv.es
[3]Aerox Advanced Polymers
Pol. Ind. La Pobla, La Eliana C/ Ausias March, Parcela nº 13 46185, Pobla Vallbona, Valencia, Spain
Email: ecortes@aerox.es, web page: http://www.aerox.es

Keywords: Vibro-Acoustic, Liquid Composite Molding, Prepreg, Resin Impregnation, Porosity

Introduction

Composite materials are presented as a viable alternative to traditional materials such as wood and metal in the music industry, [1] This is due to the inherent properties of material, such as its stability against environmental conditions, lightness and a high degree of acoustic configurability. Characterization of instrument material composite, and therefore modifying its mechanical properties, allows modulation frequencies generated by its vibrational modes. This fact gives us the possibility of intervening in the frequencies produced. In a previous work [2], the experimental and simulated data with Finite Element Analysis allowed one to correlate the vibro-acoustic response of the preimpregnated composite laminate of a drumshell with the mechanical and material characterization. The great variability of composite processing makes essential also a comprehensive study of the relationship between the material processing on the vibro-acoustic response.

Mechanical modelling. Acoustic response due to material characterization

The frequencies produced by a rectangular plate [3] can be expressed in terms of its geometry and its elastic and material properties as:

$$f(m,n) = 0{,}453 C_L t \left[\left(\frac{m+1}{a} \right)^2 + \left(\frac{n+1}{b} \right)^2 \right] \quad where \quad C_L = \sqrt{E/\rho(1-\upsilon^2)} \tag{1}$$

where ρ is the density, t the thickness, (m y n) factors that define a particular vibration mode, and (a, b) the measures of the plate. This equation is defined in terms of its longitudinal waves speed through the material of the plate C_L

The elastic properties of the composite laminate can be obtained experimentaly by two different approaches. The first, according to ISO 527-4:1997 standard for tensile test [6] and the second, using a dynamic method using acoustic resonance [7], where its Young Modulus has been obtained as:

$$E = \frac{48}{\pi^2} \left(\frac{f}{\lambda(\nu)} \right)^2 \frac{m a^3 (1-\nu^2)}{b t^3} \tag{2}$$

Where λ (ν) is a non-dimensional factor depending on the Poisson Ratio [3] calculated as $\lambda = (2fa^2/\pi)/\sqrt{D/\rho t})$ and D is the flexural stiffness of the plate D = $Eh^3/12\,(1-\upsilon^2)$. And f is the resonance frequency obtained experimentally for a particular vibration mode of the plate. The remainder being common to equation (1) variables. The theoretical composite values of E, ρ are also calculated from the matrix and fiber data as:

$$E_c = E_f V_f + E_m(1 - V_f)\ ;\ \ \rho_c = \rho_f V_f + \rho_m(1 - V_f) \tag{3}$$

Results and Discussion

In this research, four sets of laminates with different processing technologies have been used in order to analyze the effect of the variability of impregnation, void content and porosity on the elastic properties and density of the composite and hence on its acoustic response. First, a comparison of prepreg laminates from Carbon Fiber / Epoxy obtained by processing in Autoclave (4 bar), and by vacuum bag (1 atm) was carried out. It is a 4x4 Twill fabric with 280gsqm. Laminates are formed by three collinear layers with orientation (0 ° / 90 °). Secondly a comparison of laminates with different volume fractions of Green-Composite from Fiber Flax / Bio-Epoxy obtained from processing by Resin Infusion, and also obtained by Resin Transfer Moulding. For each process were carried out respective laminates of 3 to 5 layers oriented collinear (0 °/90 °). In Table 1 is shown for each set of laminate samples, the experimental elastic properties obtained from the ISO 527-4:1997 tensile test (E_{iso}) compared with the dynamic young modulus (E_{dyn}) obtained from eq (2), and the theoretical value (E_{th}) obtained from eq. (3). The results are also referenced as a desviation in % of the theoretical value giving us an indicator of the processing capabilities in terms of obtaining the optimal material mechanical performance. The acoustic response is also evaluated by means of the comparison of theoretical value of frequency response *(f_{th})* for a given mode in eq (1) and the resonance frequency *(f_e)* for each process obtained experimentally. For future work, it is necessary, the study of the influence of processing in other acoustic properties as the damping or the acoustic impedance values of the laminates.

Table 1: *Results*

	E_{th} (Gpa)	E_{ISO} (Gpa)	$\frac{E_{Iso}}{E_{th}}$ %	E_{dyn} (Gpa)	$\frac{E_{dyn}}{E_{th}}$ %	ρ_{th} (kg/m^3)	ρ_e (kg/m^3)	$\frac{\rho_e}{\rho_{th}}$ %	f_{th} (Hz)	f_e (Hz)	$\frac{f_e}{f_{th}}$ %
Prepeg Auto.	55,75	55,9	0,27%	56,6	1,60%	1480,00	1450	-2,03%	366,9	370,0	0,85%
Prepeg. Vac.	53,66	41	-23,59%	42,4	-20,92%	1469,20	1350	-8,11%	373,8	354,0	-5,30%
RTM 3 plies	7,44	5,56	-25,24%	6,08	-18,25%	1207,37	1121,1	-7,15%	448,54	412,73	-7,98%
RTM 5 plies	9,55	7,18	-24,81%	8,24	-13,71%	1232,29	1234,4	0,17%	490,92	438,68	-10,64%
RI 3 plies	8,95	4,76	-46,79%	4,98	-44,33%	1225,17	988,2	-19,34%	357,06	308,78	-13,52%
RI 5 plies	9,55	4,38	-54,13%	5,02	-47,43%	1232,29	951,6	-22,78%	514,11	417,57	-18,78%

Acknowledgements

This work has been partially funded by the Projects with reference INDI1526 of the University CEU Cardenal Herrera and DPI2013-44903-R-AR of the Universitat Politecnica de Valencia.

References

[1] http://www.luisandclark.com

[2] M. Ibáñez, A.Giménez, F. Sanchez, *Material Characterization and Vibro-Acoustic analysis of a preinpregnate Carbon Fiber reinforced epoxy drumshell,* ICCM20, Copenhagen, 2015.

[3] A.W. Leissa, *Vibration of Plates* (NASA SP-160), US Government Printing Office, Washington, DC, 1969

[4] T.D. Rossing, N.H. Fletcher, *The Physics of Musical Instruments*, Springer, NY, 2010.

[5] ASTM Standard E1876-01. *Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio by Impulse Excitation of Vibration*, Book of Standards Vol. 03.01.

[6] EN ISO 527-4:1997. *Plastics -- Determination of tensile properties -- Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites*.

[7] M. Alfano, L. Pagnotta, *Determining the elastic constants of isotropic materials by modal vibration testing of rectangular thin plates*, Journal of Sound and Vibration 293 (2006) 426–439.