MECHANICAL PROPERTIES IDENTIFICATION OF COMPOSITE MATERIAL USING FORCE ANALYSIS TECHNIQUE

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ABSTRACT

This study concerns the implementation and the validation of an experimental method leading to determine the complex elastic properties (modules and coefficient of absorption) of an orthotropic material by a non-destructive method on a range of frequencies. Based on an inverse vibratory method, it requires the measurement of a transverse displacement field and is independent from boundary conditions. It can then be used in situ on complex structures.Besides, as regards a method using a field of measures, it is possible to determine local properties. The first results show an interesting potential of the method since it gives good results in medium and high frequency ranges where the structure has not a modal behavior. The proposed approach can then be seen as a complementary method to modal analysis approaches

1 INTRODUCTION

With the massive introduction of composite component in the industrial products,it becomes necessary to predict exactly the mechanical behaviour of these structures in order to limit the costs and the mass of the whole product.During the conception step, an extensive use of finite element models is made to predict the static, dynamic and vibro-acoustic behaviour. To achieve predictions as accurate as possible, the key challenge is to enter the material characteristics into the model.

The simplest way to define the properties of a material is to measure the characteristic engineer parameter by classical mechanical testing in static condition. But in the some cases(for example polymer materials), the behaviour determined at lowstrain rates is not able to report the viscous aspect which modifies these parameters.

Then becausethestiffnessanddampingofcompositesmaystronglyvarywithfrequency,itisnecessaryto obtainmaterialpropertiesina widefrequencyrangeinsteadofextrapolatingresultsobtainedatlowfrequencies.

Then,itisnotpossibletocharacterizethematerialdirectlyonthetargetstructureitself:Experimentsaregenerallycarriedoutonspecifictestspecimens,apreciseknowledgeofboundaryconditionsbeingcrucial.

In consequence it is often necessary to measure theelastic and damping properties for the particular plateunder study, if vibration predictions of any accuracyare needed.

In this paper, an approach tomaking such measurements is described. It is based on observing damping factors of orthotropic plates with free boundaries with respect to frequency.

2 THEORETICAL BACKGROUND

Let us consider a thin orthotropic plate (h is the thickness and X and Y are principal directions of the material) supposed to be in free boundary condition as presented in figure 1.

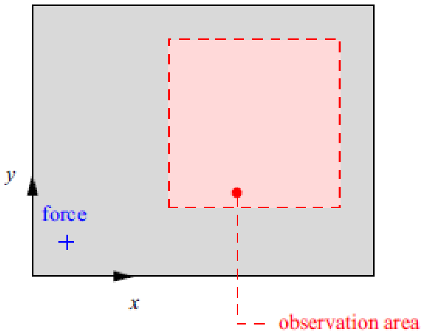

Figure 1. Geometry of the model and measurement set-up.

The general equation of motion of such orthotropic thin plate in the harmonic regime may be given by relation (1) considering an area on which no external force is applied [1]:

$$\mathrm{w(x,y)} = \frac{\mathrm{h}^2}{\rho\omega^2}\left[\mathrm{D1}\frac{\partial^4\mathrm{w}}{\partial\mathrm{x}^4} + (\mathrm{D2}+\mathrm{D4})\frac{\partial^4\mathrm{w}}{\partial\mathrm{x}^2\partial\mathrm{y}^2} + \mathrm{D3}\frac{\partial^4\mathrm{w}}{\partial\mathrm{y}^4}\right] \tag{1}$$

where D_1, D_2, D_3 and $D_4$are the flexural stiffness, ρ the density, h the thickness, ω the angular frequency, w(x,y)the transverse displacement.

The flexural stiffness are given by equation (2)wherethecomplexYoung’s moduli are considered to be complex E(1+jη), jbeingtheunitimaginarynumberand η denotingthestructural damping coefficient,which characterizesmaterialdamping.

$$\begin{aligned}
D_1 &= \frac{E_x}{12(1-\upsilon_{xy}\upsilon_{yx})}\\
D_3 &= \frac{E_y}{12(1-\upsilon_{xy}\upsilon_{yx})}\\
D_2 &= \frac{\upsilon_{xy}E_y}{6.\upsilon_{xy}\upsilon_{yx}} = \frac{\upsilon_{yx}E_x}{6.\upsilon_{xy}\upsilon_{yx}}\\
D_4 &= \frac{G_{xy}}{3}
\end{aligned} \tag{2}$$

Thetransversedisplacementatagivenlocationmaybeeasilyobtainedbyusingan accelerometeroralaservibrometer,itspartialderivativesarelessstraightforwardtoobtain.They are approximated by using finite difference schemes thanks to several measurements of displacement on a regular mesh grid.

But the noise in the displacement field w(x,y)is considerably amplified by the finite difference scheme and a regularization step must be conducted [2-4]. In order to eliminate high wavenumbers components, a low-pass filter in the wavenumber domain is applied to the displacement field and the partial derivatives.

First, each field is windowed by a bidimensionalTukey window. This preliminary step replaces the truncation of the field at the edges by a smooth variation from zero amplitude. Then, the windowed field is convolved by the finite spatial response of a low-pass filter with cut-off wavenumber k_c.

At this point, a cut-off wavenumber $k_c$should be chosen low enough to diminish the noise level in the partial derivatives of the transverse displacement field, but not too low in order to keep as much information as possible.

3 EXPERIMENTAL DEVICE

3.1 Material

The material ofthe study is a composite made up of UD glassfiberimpregnated by a vinylester resin. Panel’s size is 600 mm longand 400mm width. A stacking of 8 layers(300g/m ^{2} each)oriented at 0 ° compared to the length of the plate is impregnated by the resin using a LRI process. The fibervolume ratio is 60 %.

Figure 2. LRI process.

After manufacturing, the total thickness of the plate is 2mm which is constant on its surface. Any default such as bubbles or delamination has been identified. According to the direction of the higher length (i.e. direction of fibers), the Young modulus is estimated using the classical laminate's theory to be E_1=20-25GPa.In the lower length, it is of E_2=5-10GPa.

3.2 Experimental device

The test plate is suspended to a frame in order to be close to free boundary (see figure 3).

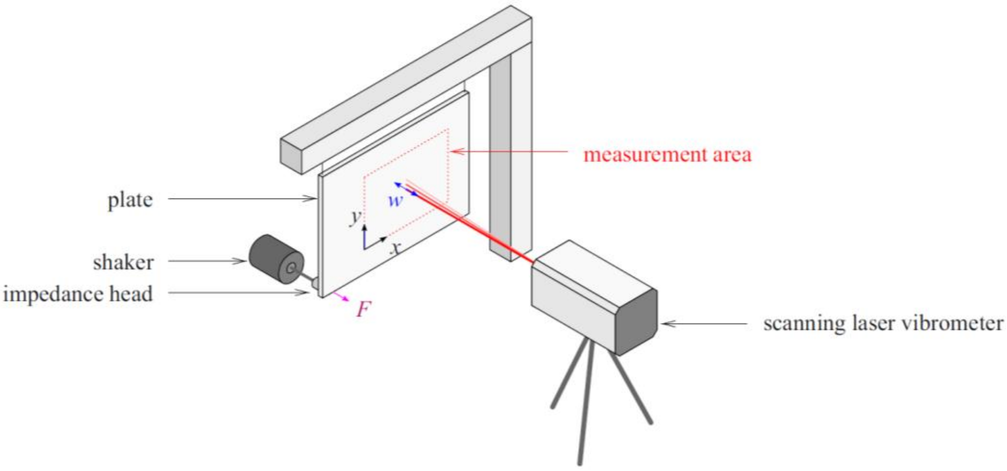

Figure 3. Global scheme of experimental device

A Polytec Scanning Vibrometer PSV 300 is used to measure the displacement field. The excitation is provided by a Brüel&Kjær 4810 shaker, supplied in power by a B&K 2718 amplifier. The excitation signal was a periodic chirp in the frequency range [8, 3200] Hz.Although no knowledge of excitation level is required by the method, a B&K 8001 impedance head is used to provide both phase reference and input force measurement, in conjunction with a B&K NEXUS conditioning amplifier.

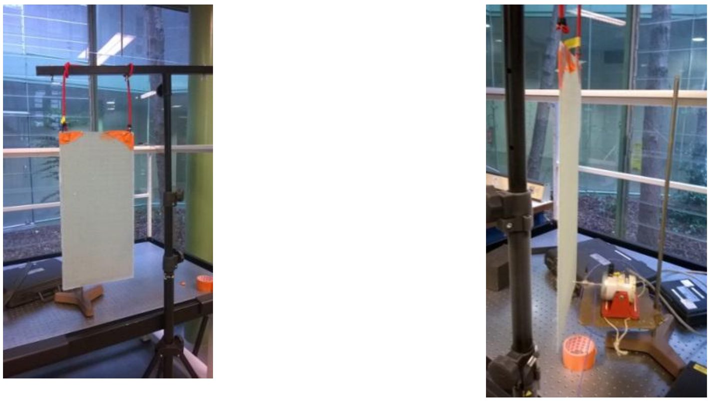

Figure 4. Specimen of the experimental device

Datacollected from this experiment consists of out-of plane displacementsof the specimen in its complex form for each frequency of the study (in our case between 8Hz and 3200Hz). The measurements(1000 points in a 200mmx400mm surface) are made on a regular meshgrid where the numerical treatment will be applied to determine the elastic performances of the material. The point of application of the mechanical excitation is outside of this zone.

4 RESULTS

Figure 5 shows the displacement field measured on our sample at one frequency in the study range. The elastic wave propagation starting at the application point at lower left corner of the plate can be visualised.

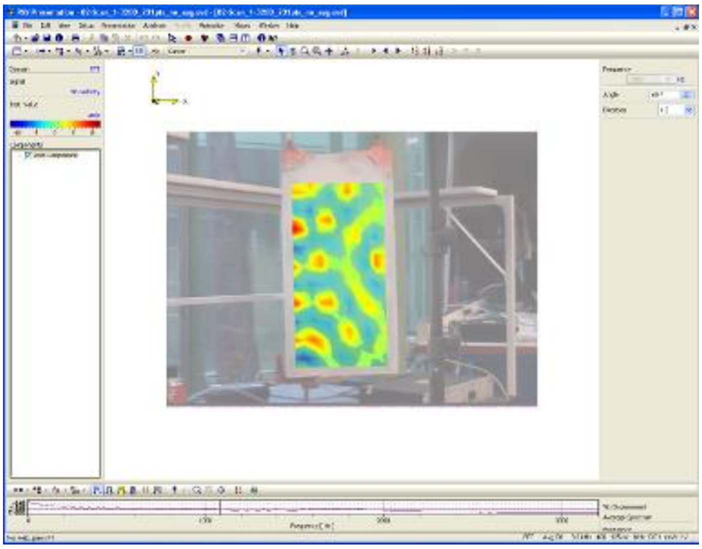

Figure 5. Experimental displacement field at 848Hz.

Using the analytical method as previously presented, the evolution of the rigidity in both directions according to the frequency can be determined as presented in the figure6. Note that the orientations of axes where D_3 gives information onto E_x and D_1 on E_y.

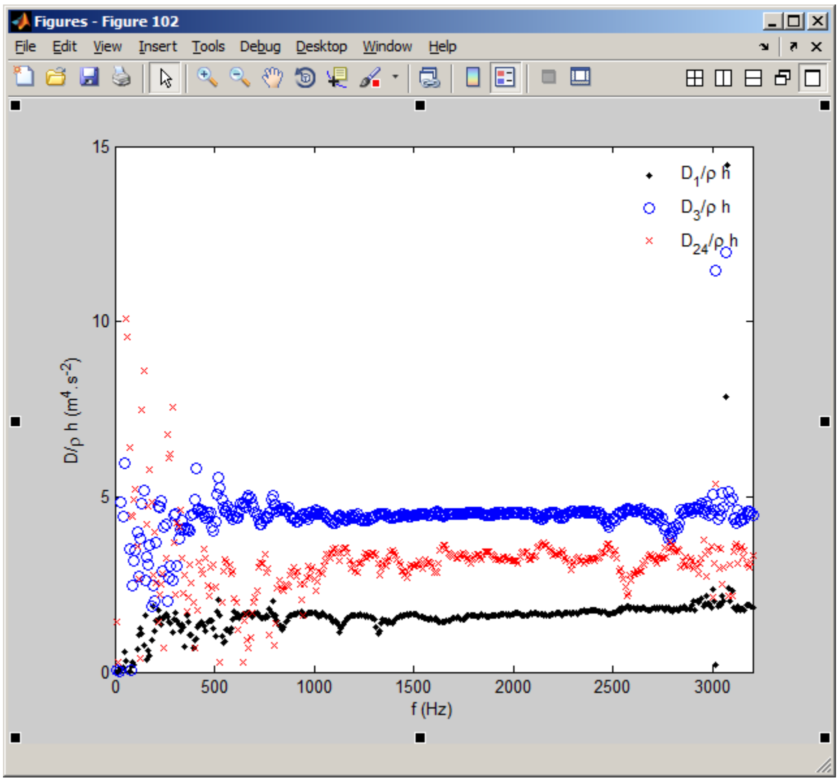

Figure 6. Evolution of elastic properties according to frequency.

Both rigidity of the main directions (D_1 and D_3) are in accordance with what can be deduce with the classical theory of laminate. Indeed using Poisson's ratio, the values of modulidetermined by the formulae 2 are in the range of the static value.

Globally, the evolution of the rigidity remains constant on the studied range of frequency of the study. The visco-elastic effects are so little marked as we could expect it with a thermosetting resin.

5 CONCLUSION

From a simple loadingin a zone of a structure to be estimated and without any boundary conditions, the method presented here allows the determination of the rigidity of anorthotropic thin plate in its main directions.

Actual improvements of the method deal with a reliability increase: the filtering and the windowing steps, the improvement of the quality of the results in low frequencies and study on typical more viscous materials (thermoplastic for example). Finally a comparison with results from DMA will validate the accuracy of the calculated values.

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