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A reflection coefficient analysis in flawed laminated plates immersed in acoustic fluids

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Abstract: The present work consists on computing the reflection coefficient for laminated plates immersed in acoustic fluid, making a comparison between bonding interfaces with imperfections and flawless ones. The QSA (Quasi Static Approximation), which adopts continuous distribution of normal and transversal springs as a boundary condition between layers, is used to describe these interfaces and the flaws are modeled by reducing the stiffness constants of the springs. The elastic layers are isotropic and the solution algorithm was developed with the aid of invariant embedding technique, ensuring numerical stability for the method.

Keywords: QSA, Laminated Plates, Reflection Coefficient, Interface Flaws

INTRODUCTION

Propagating a Gaussian pulse in a laminated plate immersed in acoustic fluids, it is possible to determine the reflection coefficient, and then analyse how it changes depending on the flaw level of the bonding interfaces. In the mathematical formulation, we assume that the wave fields are time harmonic, satisfying the next equations for stress ? and displacement u in solid layers:

$$\nabla.\sigma + \rho\,\omega^2 \mathbf{u} = 0 \tag{1}$$

$$\sigma = \mathbf{C} : \nabla \mathbf{u} \tag{2}$$

Where, C is the elastic tensor, ? is the density and ? is the angular frequency. With each layer having its own C and ?. We can decompose the displacement u and the traction t into upgoing and downgoing fields:

$$\mathbf{u} = \mathbf{u_1} + \mathbf{u_2} \tag{3}$$

$$\mathbf{t} = \mathbf{t_1} + \mathbf{t_2} \tag{4}$$

Where the subscript 1 is associated to upgoing fields and subscript 2 to downgoing fields, in relation to the vertical direction (z). The bonding interfaces are modelled with QSA, approximating these interfaces with continuous distribution of normal and transversal springs, giving us the following boundary conditions:

$$\mathbf{K}[\mathbf{u}^+ - \mathbf{u}^-] = \mathbf{t}^+ \tag{5}$$

$$\mathbf{t}^- = \mathbf{t}^+ \tag{6}$$

Where K is the stiffness matrix for the springs, and the superscript ?+? indicates the values of displacement and traction variables immediately above the interface and the superscript ?-? indicates those immediately below.

COMPUTATIONAL PROCEDURE

For the computational procedure, we use a recursive algorithm to estimate the reflection coefficient at the top of a laminated plate immersed in acoustic fluid, sweeping the laminate from the bottom up to compute the surface impedance tensor for each layer. Then we use it to calculate the reflection at the laminate?s top and make a comparison between plates with imperfections and flawless ones, by reducing the stiffness constants of the springs.

RESULTS AND DISCUSSION

It was analysed a three-layer isotropic plate, made of a aluminium layer with 2 cm thickness, an copper layer with 1 cm thickness, and a stainless steel layer with 3 cm thickness (from the bottom up), with an epoxy layer between each pair of constituent layers with 100 m nominal thickness, immersed in water. Table 1 gives the wave speeds and density for each constituent layer.

Table 1 – Experimental results for flexural properties of CFRC-4HS and CFRC-TWILL composites. Span/depth ratio = 35:1. Average results of 7 specimens.

Material	Density (kg/m^3)	P-Wave speed (m/s)	S-Wave speed (m/s)
Aluminium	2700	6320	3130
Copper	8930	4660	2660
Epoxy	1200	2150	1030
Stainless Steel	7900	5790	3100
Water	1000	1480	0

Figure 1 shows the reflection coefficient as function of the angle of incidence. The continuous line represents the flawless laminated plate, while the dashed line represents the model with reduced stiffness in the z direction.

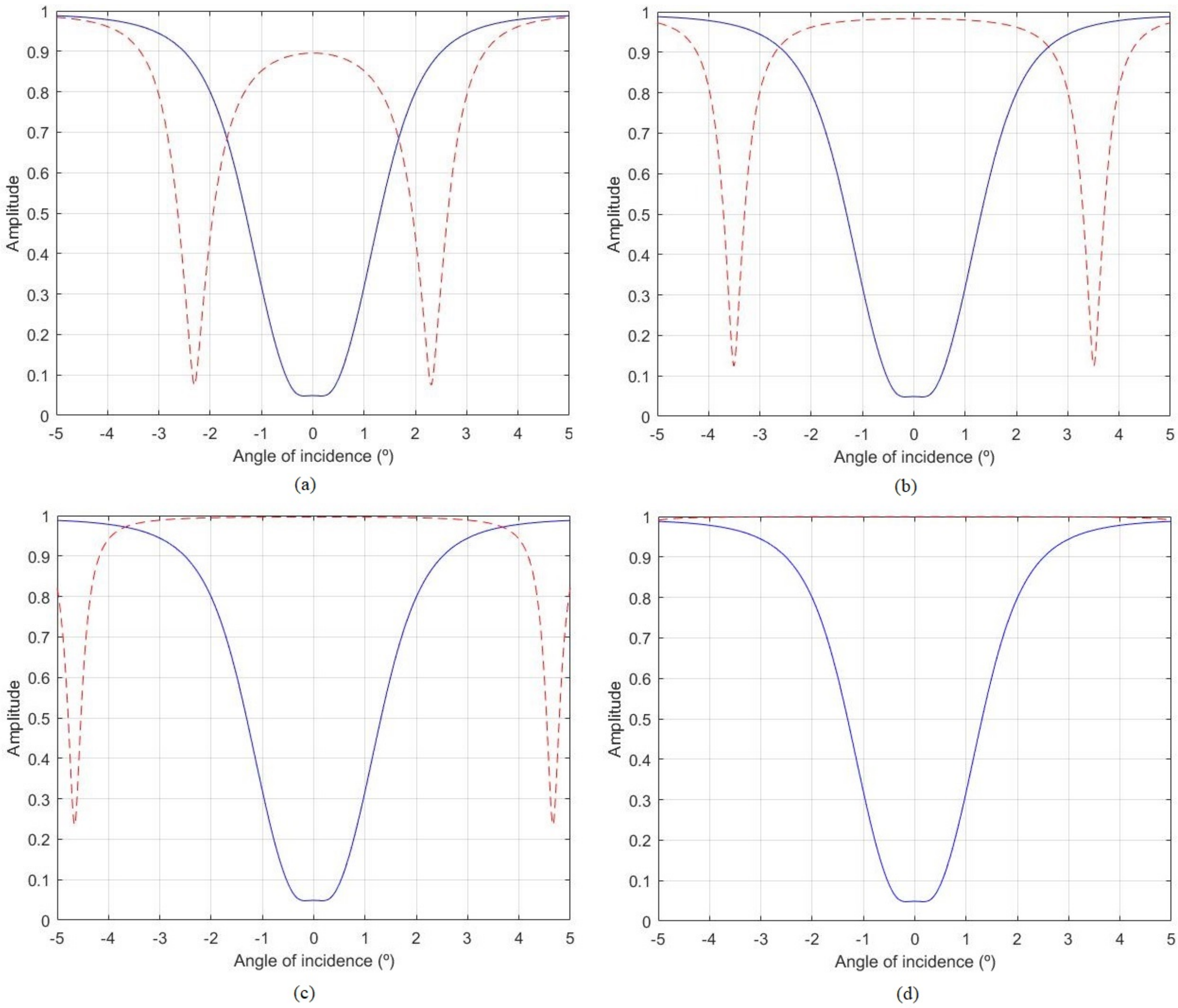

Figure 1 – Reflection coefficient as function of the angle of incidence for a frequency of 128.4 kHz. (a) 80% of original stiffness. (b) 60% of original stiffness. (c) 40% of original stiffness. (d) 20% of original stiffness.

CONCLUSIONS

It is possible to conclude that the optimum pair of angle of incidence and frequency, in order to identify bonding interfaces flaws in laminated plates immersed in acoustic fluids, can be determined by analysing the reflection coefficient when a wave is propagated in the structure.

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