



Investigation of the coupled Lamb waves propagation in viscoelastic and anisotropic multilayer composites by Legendre polynomial method



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ABSTRACT

In this paper, the attenuation of guided waves in damped multilayered arbitrary anisotropic composite laminates is investigated using a Legendre orthogonal polynomial approach. The laminate is made of the graphite–epoxy composite material with the layering sequence $[0/\phi/0]$. The validity of the polynomial approach is illustrated through a comparison with exact solution obtained from the Stiffness matrix method and a comparison with earlier known Lamb wave solution of pure elastic multilayered plate. The dispersion and attenuation of coupled Lamb waves with different layering sequences are investigated. The viscous effect on dispersion curves is shown. The combination of frequencies and modes with minimum attenuation in high and low frequencies are determined. These frequencies and modes are of great importance for NDT applications since they play a critical role in the selection of the optimal inspection frequencies.

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1. Introduction

Guided ultrasonic waves are commonly used for ultrasonic, nondestructive testing NDT of industrial structures since they allow fast and efficient control to be achieved [1,2]. The effective use of Lamb wave technology for such purpose largely depends on developing a good understanding of the mechanics of wave propagation in composite laminates. Many appropriate theoretical models are desired to investigate the behaviors of wave propagation in various media such as plates or pipes made of either single or stratified, isotropic or anisotropic, elastic or viscoelastic material layers [2–10]. There have been many methods to modeling this problem, such as the finite element method [11,12], the Transfer matrix method [13–15], the global matrix method [16–18], the WKB method [19,20], and the orthogonal polynomial series method [21]. Later on, Lefebvre et al. developed a Legendre polynomial with position-dependent elastic constants to study the propagation of Lamb waves in continuous functionally graded plates [22]. This approach is extended to investigate the influence of piezoelectricity, piezomagnetism and viscoelasticity on the dispersion properties of wave propagation in continuous functionally graded plates [23–25].

As discussed in some previous works [26,27], we can mention a few benefits of this polynomial method. Primarily, this method directly incorporates the boundary conditions into the equations of motion by the rectangular window function. Moreover compared to other methods it does not require an iterative search for the solutions, the displacement components are expressed by a linear combination of orthonormal functions, so the mathematical problem transforms into an eigenvalue equation. When convergence is achieved, stable eigenvalues yield the guided wave velocities, similarly the eigenvectors become accessible and the computation of profiles becomes easy [28]. Recently, the Legendre polynomial has been extended to examine the propagation of coupled Lamb waves in multilayered arbitrary anisotropic pure elastic laminates [28]. However, it can deal with the multilayered plate only when the material properties of two adjacent layers do not change significantly; otherwise the approach would not converge satisfactorily.

Despite the efforts devoted to study the acoustic wave propagation in the elastic media, those studies remain more and less worthwhile in the case of real materials [26], which are viscous. In this context, the Lamb waves have applications in nondestructive inspection of elastic–viscoelastic multilayer joints and plates [18,26,29,30]. Some modes of these waves have frequencies with minimum attenuation and they are recognizable in inspection by transducer, and they can also detect the defects in the structures [25]. However, before a NDT process gets set up, it is necessary to fully understand the propagation of Lamb-type modes in

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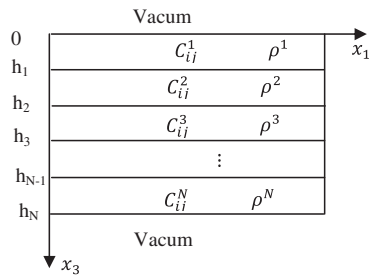


Fig. 1. A schematic diagram of a multilayered anisotropic plate, showing the coordinate system.

damping multilayered plates [1]. In this paper, an extended approach of the Legendre polynomial technique is promoted to solve wave propagation in viscoelastic multilayered plate. This study is a review of the coupled Lamb wave propagation in

Table 1
Elastic constants in GPa for a carbon/epoxy medium from Ref. [34] if the sixth-order symmetry A6 axis parallel to the (x_1) axis.

C11	C12	C13	C33	C44	P (kg m ⁻³)
13.7 + 0.13j	7.1 + 0.04j	6.7 + 0.04j	126 + 0.73j	5.8 + 0.1j	1577

multilayered arbitrary anisotropic composite laminates dealt with previously by He et al. [28]. The laminate is made of the graphite–epoxy composite material with the layering sequence [0/φ/0]. In the first section, the convergence of the complex solutions obtained from the polynomial approach were studied and compared with those calculated from stiffness matrix method. Subsequently, in order to find a combination of frequencies and modes with minimum attenuation in high and low frequencies, the dispersion curves and attenuation curves are illustrated. The effects of the viscoelasticity and the fiber orientation on the characteristics of the coupled Lamb waves are also discussed.

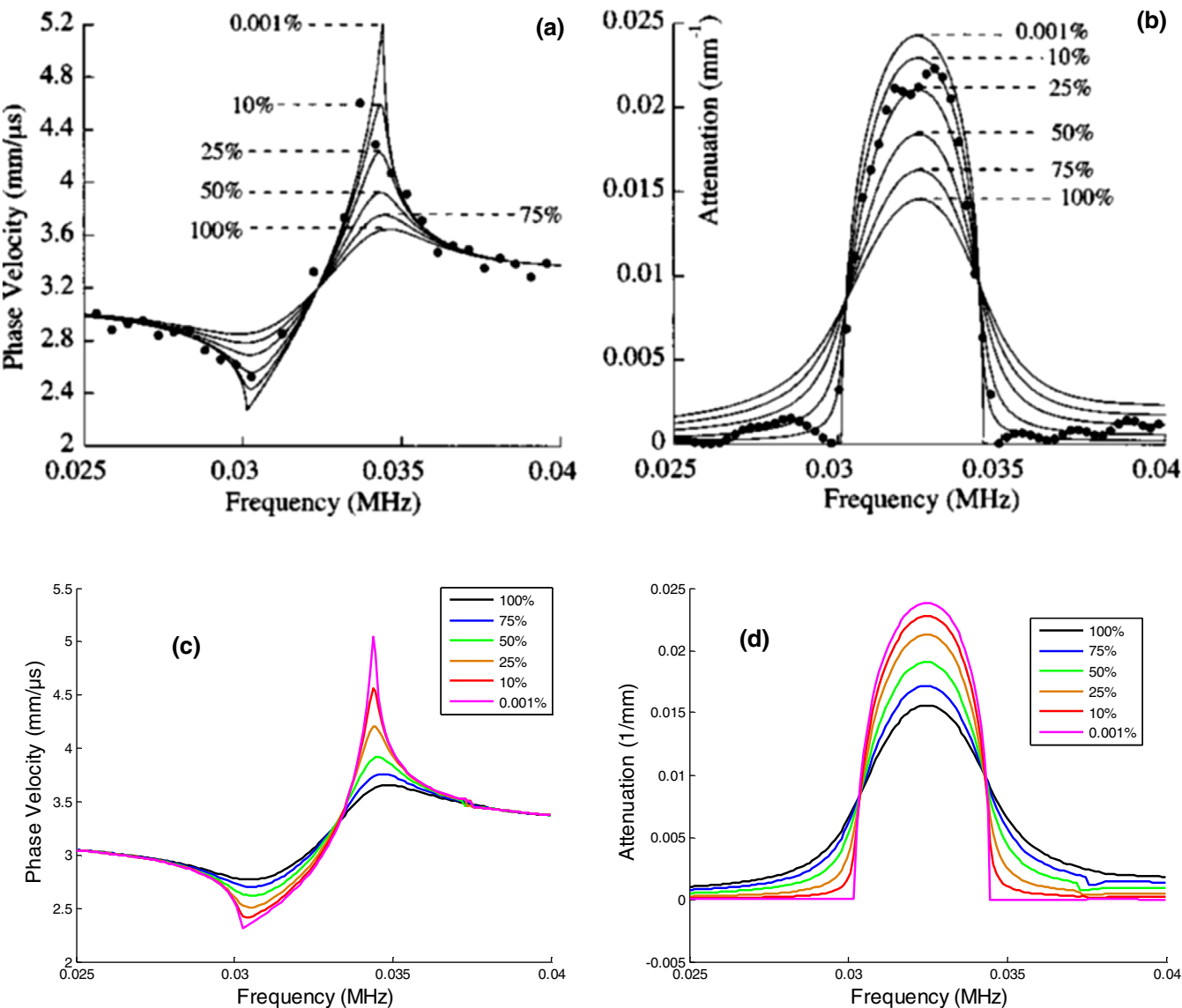


Fig. 2. Comparison of the complex solutions for sandwich plate calculated by: (c, d) the author's programs by using the Stiffness matrix method and (a, b) the Castaings's results calculated by Transfer matrix method.

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