EVALUATION OF INTERFACIAL BEHAVIOR OF COMPOSITE MATERIALS ON ULTRASONIC WAVE PROPAGATION

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1 Introduction

In this paper, ultrasonic wave propagation in three phase (3P) composite materials was investigated. The simulation was conducted by *PZFlex* analysis code[1], a time domain finite element program. The reflection and transmission characteristics with different shapes of middle layer between glass fiber and epoxy resin are investigated in order to understand basic ultrasonic behavior of energy dispersion and transmission in the middle layer. The relationship between impedance in middle layer and ultrasonic propagation characteristics is discussed.

2 Ultrasonic Wave Equations of Motion

Consider a middle layer between fiber and matrix in a 3P composite material. Two dimensions analysis is conducted as shown in Fig. 1 for three types of middle layer. When an ultrasonic wave propagates in these models, from Hooke's law, the stress-strain relationship for two-dimensional plane strain in an isotropic media is written as follows [2]:

$$\sigma = c\varepsilon \tag{1}$$

$$c = \begin{bmatrix} \lambda+2\mu & \lambda & 0 \\ \lambda & \lambda+2\mu & 0 \\ 0 & 0 & \mu \end{bmatrix} \tag{2}$$

$$\sigma = [\sigma_{xx} \quad \sigma_{yy} \quad \sigma_{xy}]^T \tag{3}$$

$$\varepsilon = [\varepsilon_{xx} \quad \varepsilon_{yy} \quad \varepsilon_{xy}]^T \tag{4}$$

where λ and μ are lamé constants, and the T superscript denotes the transposition.

3 Analysis results

Three models as shown in Fig.1 are used to investigate the influence of middle layer shape on the characteristics of ultrasonic wave propagation in 3P composite materials. The interfaces between 3 phases of the material regions (epoxy resin, middle layer and glass fiber) are perfectly bonded, but their material properties are different. The model size used here is 20λ×10λ, where λ is wavelength, and the meshing is 60 elements per wavelength λ. The input data for the waveform and material properties are shown in Table I.

Table I. Material parameters used for analysis

Materials	Epoxy	Glass	Inter1	Inter2	Inter3	Inter4
Impedance	Z_1	Z_2	Z_{01}	Z_{02}	Z_{03}	Z_{04}
Density	1200	2400	1600	1400	1200	1100
Longitudinal velocity	3000 (m/s)	6000 (m/s)	4500 (m/s)	2570 (m/s)	2000 (m/s)	1500 (m/s)
Transverse velocity	1500 (m/s)	3000 (m/s)	2250 (m/s)	1280 (m/s)	1000 (m/s)	750 (m/s)
Loss	1.2	0	0	0	0	0

3.1. Detection of the thickness of middle layer

For a longitudinal incidence wave, Fig. 2 shows the transmission energy curves with the propagation time at the output edge (receiver side) in model 1 (see Fig.1) when the thickness of the middle layer changes with 0.5λ, 1λ, 2λ and 3λ. Four strong energy peaks correspond to the first transmitted wave, and four weak peaks are ascribed to the multi-reflection wave by the four different thicknesses of middle layer. The normalized peak energy is almost the same no matter of the change of the thickness of the middle layer since the attenuation of each phase of material is not taken into account in this model. As for the two energy peaks in the transmission energy curves, the first energy peak resulted directly from transmitted wave. The second energy peak is generated by the wave source of the multi-reflection within the middle layer.

3.2. Influence of the impedance in middle layer

The acoustic impedance Z defined by the product of wave velocity and the density is one of important parameters in materials. In 3P composite materials, there are three different values of impedances, Z_1, Z_0, Z_2, for matrix, middle layer and fiber, respectively. Figure 3 shows the relationship between the transmission energy loss and the parameter Z_0^2/Z_1Z_2, the dimensionless of the impedance Z_0 in the middle layer to the impedances Z_1, Z_2 in matrix and fiber phase. It indicated that the energy loss at the receiver side (glass region) has the minimum value when the dimensionless impedance $Z_0^2/Z_1Z_2 = 1$. This result agrees well with the result as shown in the reference [2], where in the reference the dimensionless impedance is defined by Z_0/Z_1 since the media only has two phases.

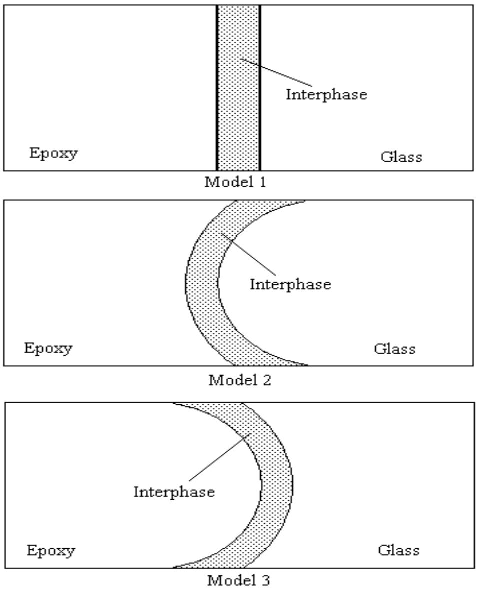

Fig. 1. Three models with different shapes of middle layer.

3.3. Influence of the shape of middle layer

Figure 4 shows the transmission energy of the ultrasonic wave for the three models with different shapes of the meddle layer as shown in Fig.1. The transmission energy is defined by normalization. For model 1, the incident ultrasonic wave is perpendicular to the plane of the middle layer, and the transmitted wave and reflected wave occur along the entire plane, so that the normalized transmission energy is much larger than that in the other models. The full-reflection takes place in the part of the middle layer in both models 2 and 3 where the incidence angle is larger than the critical angle because the ultrasonic wave radiates obliquely on a convex or concave interface.

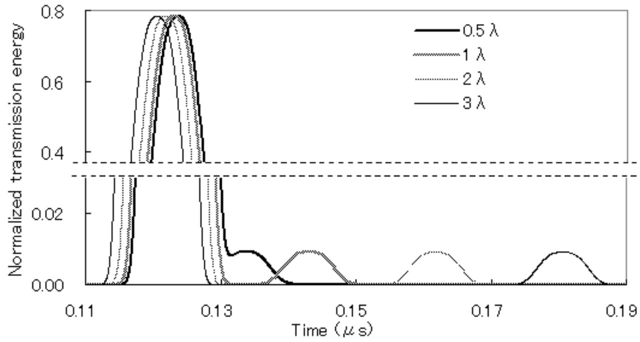

Fig. 2. Transmission energy at the output edge.

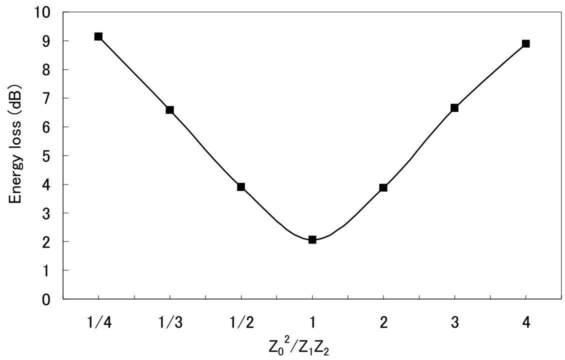

Fig. 3. Energy loss with different dimensionless impedance.

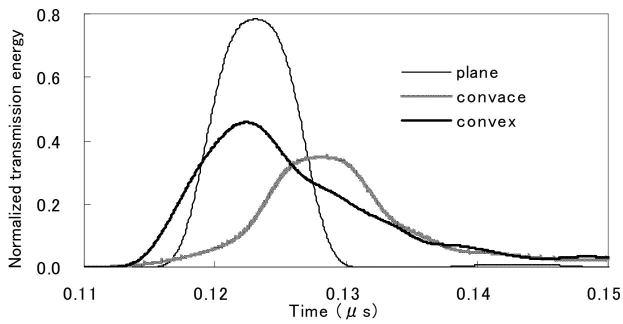

Fig. 4. Normalized transmission energy for three different shapes of middle layer.

References

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