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# Lamb waves generation on thin plates using piezocomposites

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**Abstract**

The mode selection of Lamb waves generated in thin aluminium plates by using 2-2 piezocomposites has been studied. In this paper, 2-2 piezocomposite square plates have been designed, made, and compared with standard piezoceramic plates to test the improvement on the generation and propagation of symmetric and antisymmetric Lamb modes. An optical interferometer was used to measure the out-of-plane displacement of the propagating Lamb wave modes generated with the piezoceramic plates. Different Finite Element Models, using a commercial simulation program (PZFlex) were also developed to calculate the displacement signals and to compare them with the experimental ones. Next, the same measurements were done with two different 2-2 piezocomposites to see the mode selection of the Lamb waves generated. Different excitation frequencies were used experimentally and implemented in PZFlex to calculate the displacement signals, verifying the mode cancellations. The experimental measurements show good agreement with the models.


*Keywords:* Composites; Non-destructive evaluation; Lamb waves

## 1. Introduction

Among the different transducers that can be used to excite Lamb waves, piezoelectric materials (piezoceramics) are particularly attractive because of their high force output at relatively low voltages, and their good response qualities at both low and high frequencies. Lamb waves can be efficiently excited in thin metallic plates by bonding these piezoceramics on the plate surface. The piezoceramic dimensions and the plate thickness and material properties are the parameters that define the most efficient excited modes.

Elastic waves, Lamb waves, are very useful in the Non Destructive Testing field for the detection of damage in metallic thin plates. In some practical applications as, for instance, phased array applications to detect structural defects, apart from the efficiency it is also necessary to have clean wave propagation (elastic diffraction). Moreover, the cross-coupling between the different piezoelectric array elements must be low to avoid the so called image “dead zone”.

This problem is quite cumbersome in the case of linear arrays formed by square piezoceramic plates bonded on metallic structures, because the transducers are two-dimensional with dimensions comparable with the wavelength. Moreover, the structure transmits very efficiently the elastic signal in-between the array elements producing inherently high cross-coupling. As consequence, the diffraction is not as simple as the one of piezoelectric array transducers in fluids. All these factors must be taken into account when designing a phased array system for thin metallic plates.

When using a conventional piezoceramic to excite a Lamb wave with these transducers several modes are generated. At the frequency excitation range used in this work two Lamb modes are at least present, the fundamental symmetric S0 and antisymmetric A0 modes. The analysis of the received signals when having a multimodal Lamb wave response is very complex, making difficult the defects identification. The use of 2-2 piezocomposites is proposed in this work as an effective method to carry out the Lamb wave mode selection, decreasing the inter-elements cross-coupling.

## 2. Experimental study

### 2.1. Experimental procedure

Experiments were conducted in two steps. First, Lamb waves were generated on an aluminium plate by bonding a conventional piezoceramic on its surface.[1] The presence of the two fundamental modes, A0 and S0, was then verified. In the second step, two

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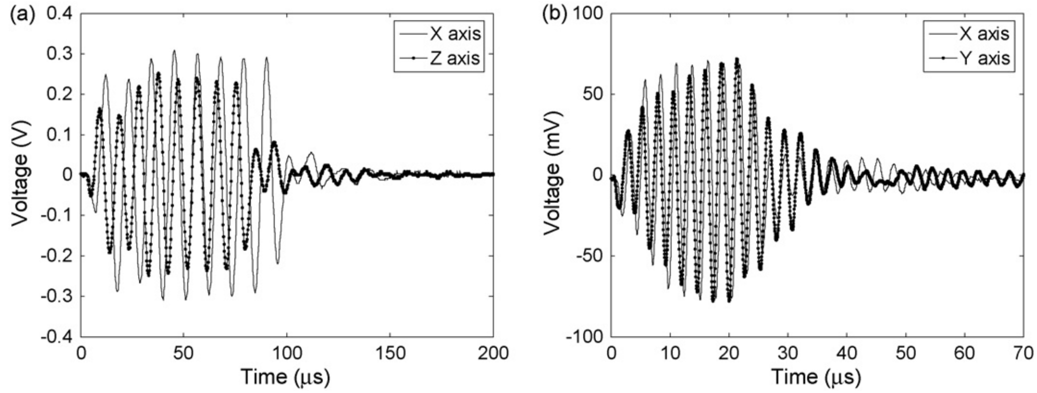


Fig. 1. Out-of-plane displacement amplitude signals at 1 mm from the piezoplate at (a) 90 kHz and (b) 373 kHz.

different piezocomposites were bonded on the same aluminium plate in order to achieve the Lamb wave mode selection.

### 2.2. Experimental results

#### 2.2.1. Piezoceramics

A pristine aluminium plate of dimensions 1200 mm × 1200 mm × 1.1 mm was implemented with one piezoceramic Ferroperm PZ-27, 7 mm × 7 mm × 0.5 mm. The actuator, bonded to the centre of the plate with a stiff polymer, was driven with an 8-cycle sinusoidal tone-burst signal generated with an Agilent 33220A Function/Arbitrary waveform generator. An optical interferometer – Polytec OFV 5000 – measured the out-of-plane displacement (*Y*-axis) of the propagating Lamb modes at a distance of 1 mm from the edge of the piezoplate. Fig. 1 shows the measured signals for different frequency inputs. For each frequency, the out-of plane displacement was measured at both sides of the piezoceramic, *X*-axis and *Z*-axis. As it can be seen in Fig. 1(a), the displacement amplitude signals for the antisymmetric mode, A0-90 kHz, have practically the same amplitude. The same behaviour can be observed for the symmetric mode, S0-373 kHz (Fig. 1(b)).

#### 2.2.2. Piezocomposites

Piezoelectric composites are piezoelectrically active materials composed by a ceramic component and a passive, usually polymer, component.[2,3] Two different 2-2 piezocomposites, filled with soft and hard epoxy, respectively, were manufactured to test the mode selection (Fig. 2). The composites were fabricated following the well known dice-and-filling technique using a K&S dicing system.[4,5] Metallization was made by sputtering using a Baltzer SCD 050 station.

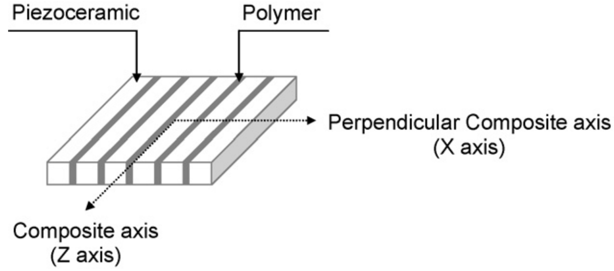


Fig. 2. Schematics of the 2-2 piezocomposites made.

- *Araldite*: A hard polymer, Araldite d-HY956, was used as the passive component to construct the first of the 2-2 piezocomposites. As before, the piezocomposite was bonded to the aluminium plate and the out-of plane displacement was measured with the laser vibrometer. The measurement point distance was 1 mm from the edge of the composite plate. The displacement was measured at both axis of the composite. That is on the composite axis (*Z*-axis) and perpendicular axis (*X*-axis) Fig. 3 shows the measured out-of-plane displacements when using the hard polymer composite. The propagation of the antisymmetric mode, A0-80 kHz, in the *X* direction was dramatically damped. The symmetric mode, S0-400 kHz, behaves as in the case of the piezoplate.
- *Eccogel*: The same measurements were made for a 2-2 piezocomposite filled with a soft polymer (Eccogel 1365). Fig. 4 shows the results.

To test the mode cancellation at distances of several wavelengths, the displacement amplitude was measured at 300 mm from the composite edge following the *Z* and *X* directions. Fig. 5 shows the results. The cancellations observed in the A0 mode close to the piezocomposites were also observed at the far field (Fig. 5(a)). No amplitude decay for the symmetric mode is observed (Fig. 5(b)).

## 3. Finite element study

### 3.1. Finite element simulation description

Several 3D models using the commercial simulation program PZFlex[6] (Weidlinger Associates Inc., Los Altos, CA, USA) were developed. The metallic plate dimensions were set large enough to avoid unwanted reflections from the edges of the plate. Two symmetry planes were also set to the models to minimize the simulation time. That is, only a quarter of the plate-ceramic set was modelled and then symmetry conditions were applied to obtain the full model. Mesh chosen was accurate enough that several elements per wavelength were present.

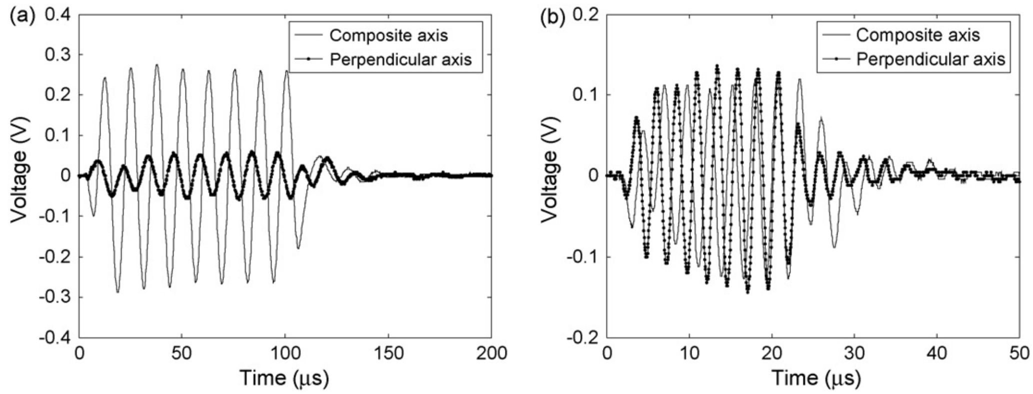


Fig. 3. Measured out-of-plane displacement close to the hard polymer piezocomposite. (a) A0 mode-80 kHz and (b) S0 mode-400 kHz.

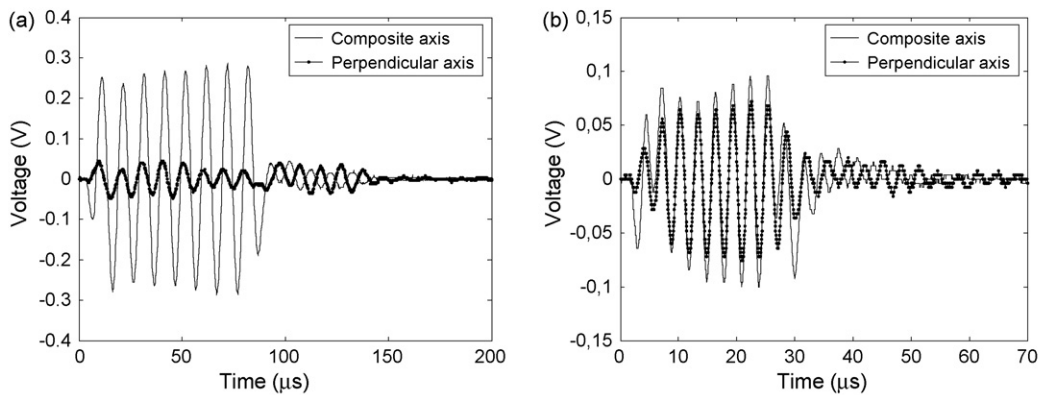


Fig. 4. Measured out-of-plane displacement close to the soft polymer piezocomposite. (a) A0 mode-100 kHz and (b) S0 mode-330 kHz.

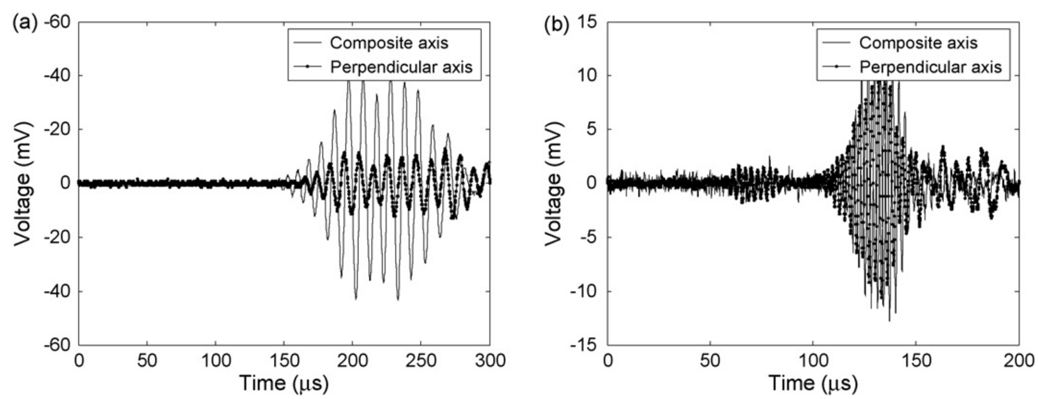


Fig. 5. Measured out-of-plane displacement at 300 mm from the soft polymer piezocomposite. (a) A0 mode-100 kHz and (b) S0 mode-330 kHz.

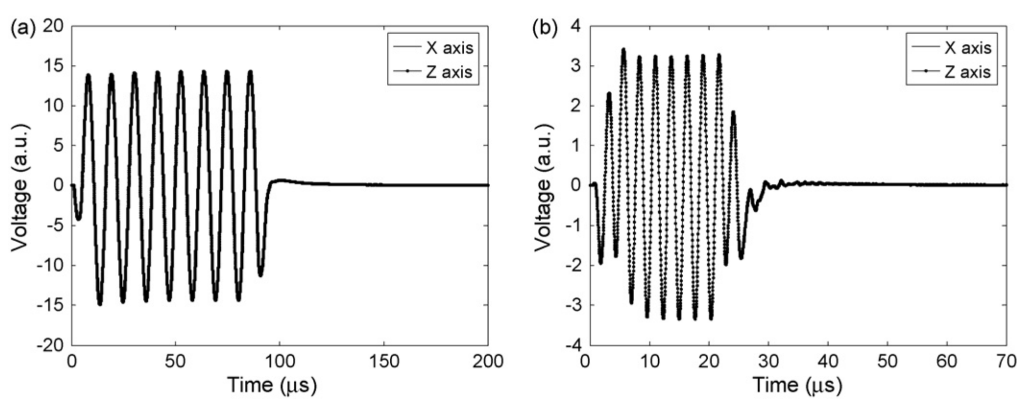


Fig. 6. FEM calculated out-of-plane displacement close to the piezoplate. (a) A0 mode-90 kHz and (b) S0 mode-373 kHz.

### 3.2. Finite element simulation results

#### 3.2.1. Piezoceramics

The aluminium plate was modelled as an isotropic plate, while the piezoelectric element considered the full anisotropic material properties. The simulated piezoelement was placed above the aluminium plate and excited by an 8-cycle sinusoid signal.

Fig. 6(a) and (b) shows the results of the out-of-plane amplitude displacements obtained with the simulations for the piezoceramic plates. As in the experimental results, the displacement amplitudes are the same in both axis (*X*-axis and *Z*-axis) either for the antisymmetric mode A0 as for the symmetric mode S0.

#### 3.2.2. Piezocomposites

Piezocomposites were modelled intercalating thin bars of ceramic with the epoxy component until reaching the ceramic dimensions. The piezocomposite electrode thickness was assumed to be negligible.

- *Araldite*: A hard epoxy material with the same material properties as the Araldite used in the experiments was used to fill the piezoceramic bars. Fig. 7(a) and (b) shows the

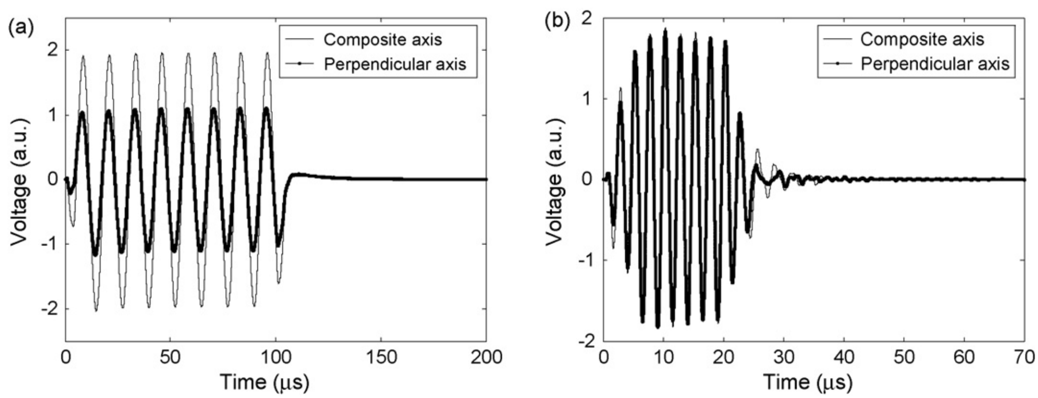


Fig. 7. FEM calculated out-of-plane displacement close to the hard polymer piezocomposite. (a) A0 mode-80 kHz and (b) S0 mode-400 kHz.

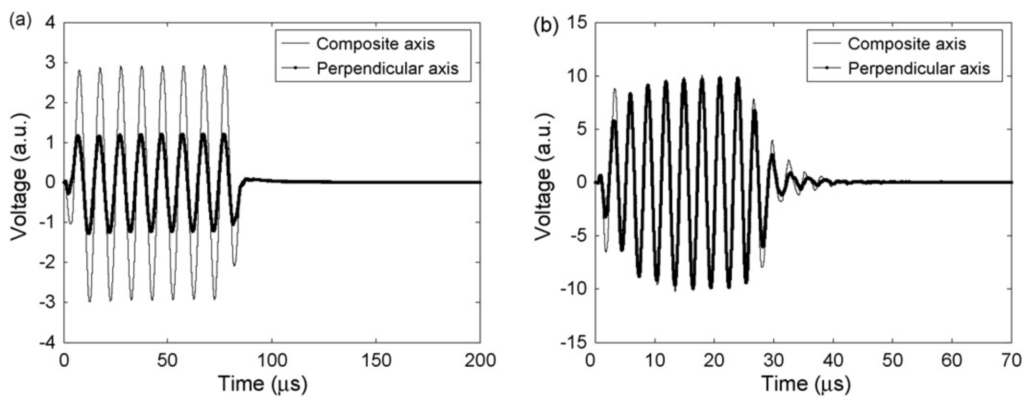


Fig. 8. Measured out-of-plane displacement close to the soft polymer piezocomposite. (a) A0 mode-100 kHz and (b) S0 mode-330 kHz.

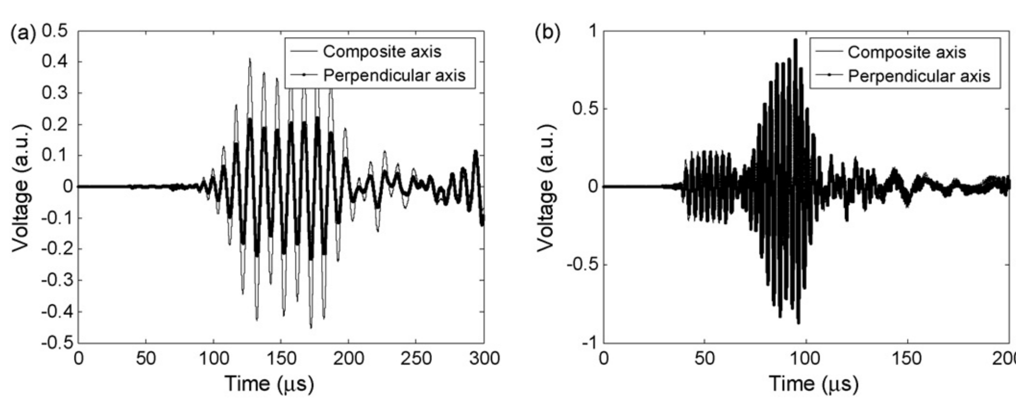


Fig. 9. FEM calculated out-of-plane displacement at far distance from the soft polymer piezocomposite. (a) A0 mode-100 kHz and (b) S0 mode-330 kHz.

same behaviour for the amplitude displacements that in the experimental results. That is, at the antisymmetric excitation frequency (Fig. 7(a)), an amplitude decay in the out of plane displacement in the perpendicular composite axis can be clearly appreciated. The displacement in the composite axis follow the same behaviour that in the case of the piezoceramic. The same occurs for the symmetric mode S0 (Fig. 7(b)).

- *Eccogel*: In this case, a soft epoxy materials library was used to construct the piezocomposite. The simulations were then re-run and the same behaviour as in the case of the hard epoxy was obtained (Fig. 8(a) and (b)).

Finally, simulations with soft polymer composite were done to test the mode cancellation at far distance from the composite (Fig. 9(a) and (b)). Once again, the simulations show good correlation with the experiments.

## 4. Conclusions

In this work, the Lamb wave generation in thin aluminium plates by using conventional piezoceramics and 2-2 piezocomposites has been studied. The use of these 2-2 piezocomposites instead of piezoplates has demonstrated to be an effective method to decrease the lateral propagation and then to diminish the cross-talk between neighbour elements in the case of linear arrays bonded on thin metallic plates.

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