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A STUDY ON THERMOELASTIC GENERATION OF NARROWBAND ULTRASONIC LAMB WAVES USING A PATTERN SOURCE

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ABSTRACT

Guided ultrasonic waves are attractive for inspection of plate-like components that are produced by additive manufacturing. Recently, research has been focused on techniques that can perform non-contact testing and carry out an online inspection layer by layer while the component is being fabricated. We demonstrate a non-contact technique for generation of narrowband ultrasonic waves in an additively manufactured component using a spatial array illumination source that can be integrated onto the component. The wavelength-matched method enables the generation of specific Lamb wave modes which are detected using a two-wave mixing based interferometric technique.

Keywords: additive manufacturing, non-contact, ultrasonic waves, spatial array illumination, thermoelastic

NOMENCLATURE

T	absolute temperature
k	thermal conductivity of the material
ρ	density of the material
C_p	constant pressure specific heat
Q_{in}	power density of the heat source
u	displacement vector
S	stress tensor
F_v	volume force vector
R_c	reflection coefficient
A_c	absorption coefficient
σ_t	standard deviation of the temporal Gaussian signal

1. INTRODUCTION

Non-destructive testing (NDT) methods have much to offer in terms of ensuring the quality of components during development. Laser ultrasonics has emerged as an attractive technique due to the possibility of non-contact transduction [1].

The original method of ultrasound generation using a laser made use of a beam that had a circular profile at the point of incidence. Furthermore, attempts were made to create multiple laser line sources to create an array of sources. One such method made use of pattern sources (more commonly known as shadow masks or slit masks) to create an array of line sources that generated elastic waves with characteristics different than that of a single line source [2]. One such characteristic was the control over the wavelength generated. In this paper, we demonstrate a non-contact technique for generation of narrowband ultrasonic waves in an additively manufactured component using a slit mask that can be integrated onto the component. The wavelength-matched method enables the generation of specific Lamb wave modes in plate-like components.

2. MATERIALS AND METHODS

The sample consists of a rolled Aluminium plate with a thickness of 0.6 mm. A slit mask with seven slits is fabricated using the Selective Laser Melting (SLM) additive manufacturing process (Fig. 1). The material used for the fabrication of mask is AlSi12, an Aluminium alloy. In the current study, the element width (slit width) implemented in the slit mask is 0.40 mm.

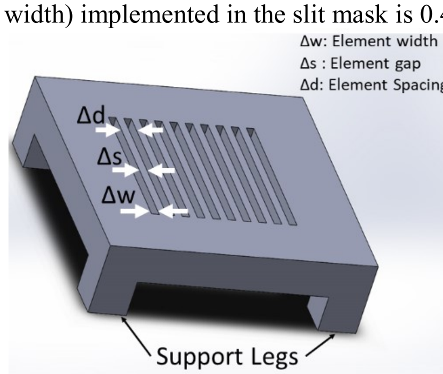

FIGURE 1: SCHEMATIC OF THE CAD MODEL OF THE SLIT MASK (ADDITIVELY MANUFACTURED).

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The experimental arrangement consists of a 10 mJ pulsed Nd:YAG laser with 1064 nm wavelength and a pulse width of 4ns. The pulsed beam is expanded, collimated and is incident on the additively manufactured slit mask. The generated ultrasonic signals are detected by a laser interferometer which has a bandwidth of 125 MHz.

3. FINITE ELEMENT MODELING

Finite element models serve to understand the underlying physics of the problem studied. For this purpose, a 2D plane strain model was developed using COMSOL™ Multiphysics v5.3 (Fig. 2). Linear elastic material model was chosen with dimensions 42 mm x 0.6 mm. The out-of-plane displacements were recorded at 32 mm from the centre of the slit mask (source).

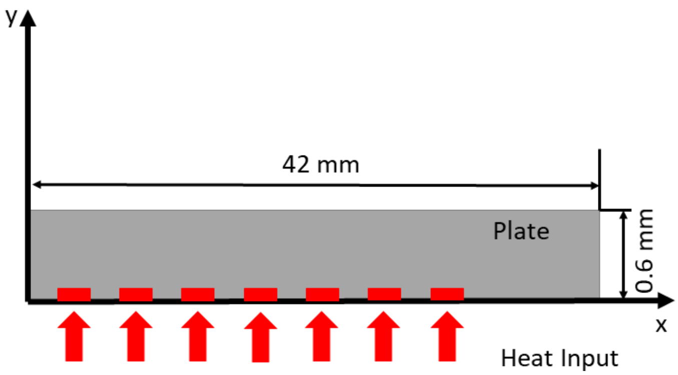

FIGURE 2: SCHEMATIC VIEW OF THE NUMERICAL MODEL.

For a semi-infinite isotropic material, with a laser beam incident normally on the free surface y=0, the temperature and the displacement in the material in the thermoelastic regime can be described by the thermal diffusion equation and the elastic wave equation respectively:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u.\nabla T + \nabla.(-k\nabla T) = Q_{in} \qquad (1)$$

$$\rho \frac{\partial^2 u}{\partial t^2} = \nabla \cdot S + F_v \qquad (2)$$

The body heat load Q_{in} within the model can be written as [3]:

$$= Q\,(1 - R_c)\; e^{-A_c y}\; e^{-\left(\frac{(t-t_0)^2}{2\sigma_t^2}\right)} \qquad (3)$$

4. RESULTS AND DISCUSSION

Figure 3 (a) shows the dispersion curves of phase velocity versus frequency and figure 3(b) shows the plot of group velocity vs. frequency (plotted in terms of time of flight) for an Aluminium plate. In the phase velocity vs. frequency plot, wavelengths can be represented as straight lines passing through the origin with a slope equal to the wavelength. The wave modes and their frequencies are pre-determined by the intercession points of the constant-wavelength line and the phase velocity dispersion curves.

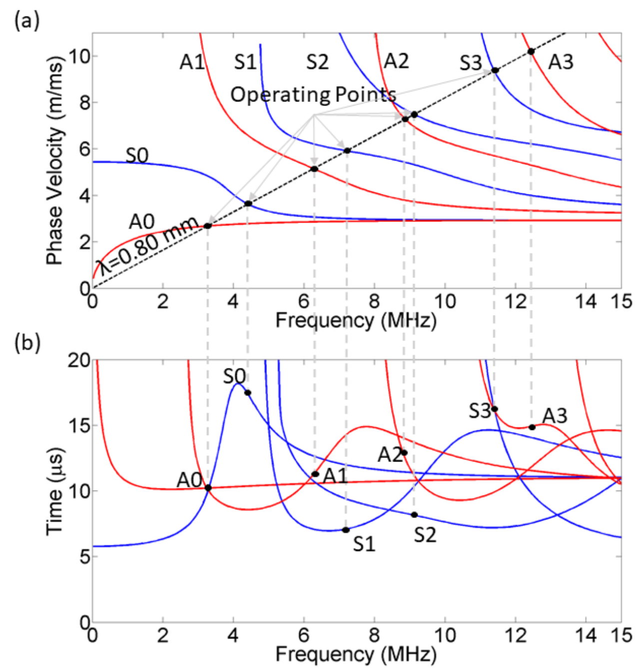

FIGURE 3: DISPERSION CURVES OBTAINED FOR A 0.6 MM THICK ALUMINIUM PLATE SHOWING THE OPERATING POINTS FOR THE LAMB WAVE MODES. (a) PHASE VELOCITY VS. FREQUENCY (b) TIME (GROUP VELOCITY) VS. FREQUENCY.

4.1 Experimental Results

An additively fabricated slit mask was glued on to the sample, and an expanded, collimated laser beam was incident on the slit mask. The signals proportional to the out-of-plane displacements from the specimen surface at a distance (32 mm) from the slit mask were received using a detection laser. The signal obtained was averaged and filtered to obtain a clean signal as shown in figure 4.

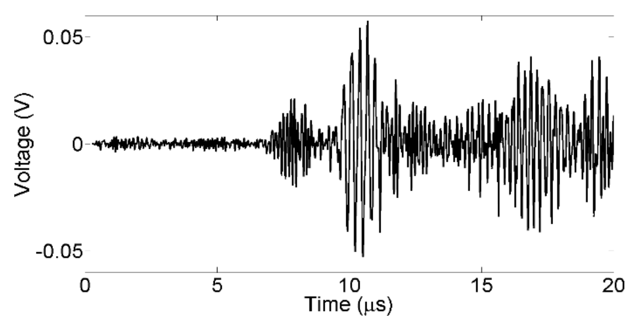

FIGURE 4: TIME TRACE OF SIGNAL RECORDED FROM THE SAMPLE.

A Short Time Fourier Transform (STFT) was carried out on the signal to obtain a Time-Frequency Response (TFR) of the signal. The group velocity dispersion plot obtained (in Fig. 3) was overlaid on the TFR to identify the predicted wave modes and their frequencies (Fig. 5). The fundamental modes (A0 and S0) are strongly excited. The higher order modes, though weak, are visible and are as predicted using the dispersion curves.

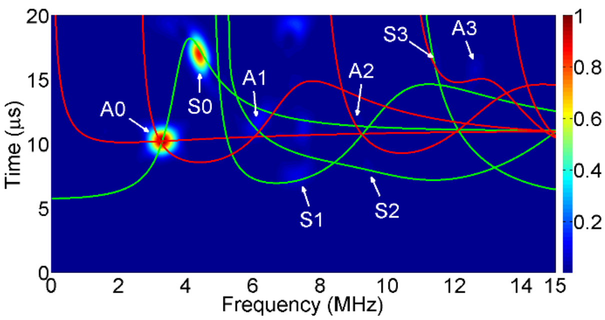

FIGURE 5: GROUP VELOCITY DISPERSION CURVES OVERLAID ON THE TIME-FREQUENCY RESPONSE PLOT OF THE OBTAINED SIGNAL IDENTIFY THE DIFFERENT MODES PREDICTED FOR THE EXPERIMENTAL SAMPLE.

4.2 Finite Element Results

Figure 6 shows the out-of-plane displacement recorded from the surface of the component at 32 mm from the source. The signal was processed using STFT and overlaid on the dispersion curve plot to identify the different modes generated (Fig. 7).

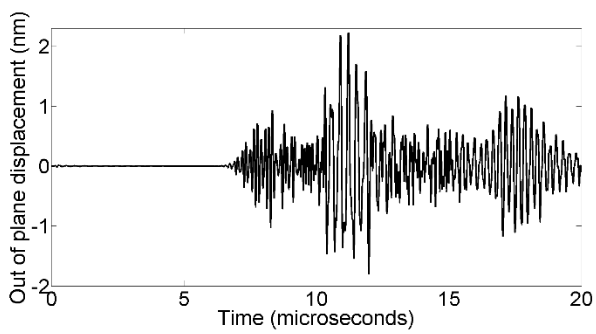

FIGURE 6: OUT-OF-PLANE DISPLACEMENT MEASURED ON THE COMPONENT SURFACE.

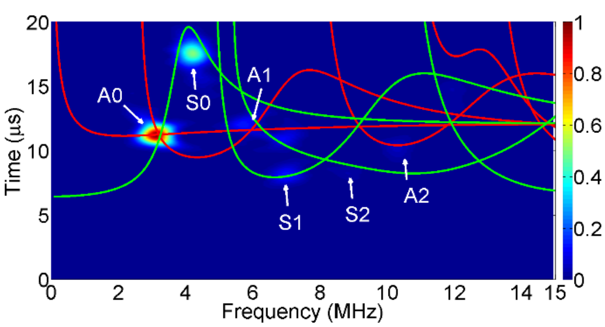

FIGURE 7: GROUP VELOCITY DISPERSION CURVES OVERLAID ON THE TIME-FREQUENCY RESPONSE PLOT OF THE SIGNAL OBTAINED FOR THE FINITE ELEMENT MODEL FOR A PULSE WIDTH OF 4 ns.

The pulse width of the temporal Gaussian laser beam was varied from 4 ns to 100 ns, and the out-of-plane displacements were recorded. It is observed that the higher order modes disappear and only the fundamental modes exist for a pulse width of 100 ns. This is primarily due to the distribution of energy across the spectrum. As the pulse width is increased, the energy distributed across the frequency band is concentrated on the lower frequency components. The TFR of the signal obtained using a pulse width of 100 ns is overlaid on the group velocity dispersion curve to confirm the prediction (Fig. 8).

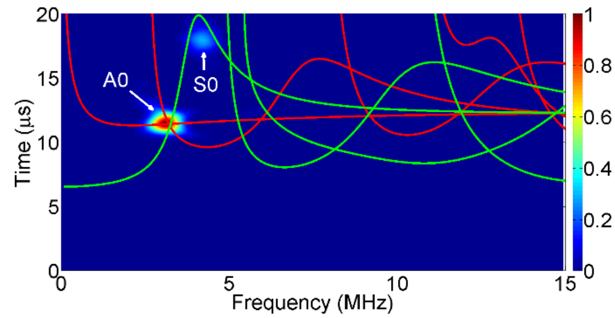

FIGURE 8: GROUP VELOCITY DISPERSION CURVES OVERLAID ON THE TIME-FREQUENCY RESPONSE PLOT OF THE SIGNAL OBTAINED FOR THE FINITE ELEMENT MODEL FOR A PULSE WIDTH OF 100 ns.

5. CONCLUSION

An additively manufactured slit mask that can also be integrated onto the component for generation of narrowband Lamb waves with a dominant wavelength according to the pitch of the slits was demonstrated, and the different modes were identified using dispersion curves. The wavelength-matched method enabled the generation of specific Lamb wave modes. This method can be used for non-destructive evaluation of any additively manufactured component.

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