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Characterization of wedge waves propagating along wedge tips with defects

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A B S T R A C T

Wedge waves are guided acoustic waves propagating along the tip of a wedge with the energy tightly confined near the wedge. Anti-symmetric flexural (ASF) modes are wedge waves with their particle motion anti-symmetric with the apex mid-plane. This study investigates the behaviors of ASF modes propagation along wedge tips with perfect and imperfect rectangular defects. Numerical finite element simulations and experimental measurements using a laser ultrasound technique are employed to explore the behaviors of ASF modes interacting with defects. Complex reflections and transmissions involved with direct reflections and transmissions as well as the newly discovered mode conversions will be explored and quantified in numerical as well as experimental ways.

1. Introduction

Wedge waves are discovered by Lagasse and coworkers in the early 1970s through a numerical study. Wedge waves are guided acoustic waves that propagate along the tip of a wedge, and their energy is tightly confined near the apex [1,2]. Like Lamb waves, wedge waves with displacement fields anti-symmetric about the mid-apex plane are called anti-symmetric flexural (ASF) modes. Fig. 1 shows motion patterns for the fundamental (A1) and the second (A2) ASF modes. While the apex truncation is small compared with wavelengths of the ASF modes, they exhibit no dispersion behavior [1].

So far attempts to find the elasticity-based exact solution for wedge waves are not successful. Alternatively, McKenna et al. assumed the wedge to be a thin plate of a variable thickness and obtained a theoretical approximation for the prediction of the dispersion relation of a truncated wedge [3]. Krylov and coworkers used geometric acoustic approximation to model phase velocities of the ASF modes [4]. In the area of experimental investigations, researchers employing piezoelectric transducers, miniature non-contact electromagnetic acoustic transducers (EMAT) [5] and laser ultrasound techniques [6–8] have been used to characterize ASF modes, including the influences of apex angles, apex truncation [7], circular geometry of wedge tips [9], wedge tips with coatings [10], and nonlinear phenomenon.

As a practical application of ASF modes, researchers reported a methodology to inspect the wear of machines blades based on the dispersion of truncated wedges [11]. Some blade-like structures, such as machine tool blades, are subject to the risk of having defect which may further cause a degradation of the structure's functions. It is therefore important to inspect the defect and better in a nondestructive way. Propagation behaviors of ASF modes along wedge tips render a possibility to inspect the existence and characteristics of defects in wedge-like structures.

ASF modes are wedge waves with their particle motion anti-symmetric about the mid-plane bisecting the apex angle. In this point of view, the ASF modes are treated as acoustic modes similar with the anti-symmetric Lamb modes [4]. Therefore, interactions of Lamb waves with defects can provide useful information and investigation direction for ASF modes interacting with a defect. Mode conversion (MC) phenomenon for Lamb waves propagating in plate structures has been extensively investigated [12,13] due to the importance in characterizing defects. For the Lamb wave case, the MC phenomenon is only reported for an incident anti-symmetric mode converted to a symmetric mode. No report is found for the reversed direction, neither for a MC to another anti-symmetric mode. The reflections of Lamb waves from notches in plates were studied by Lowe et al. [15,16] showing that, for both a0 and s0 modes, the width as well as the depth of the notch have significant influence on the reflections.

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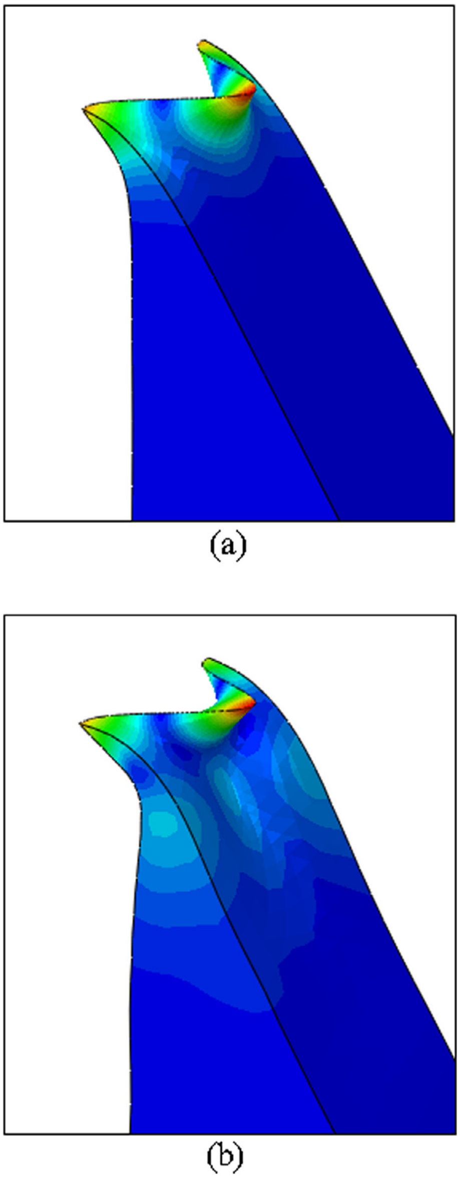

Fig. 1. Motions of (a) fundamental ASF (A1) mode (b) second ASF (A2) mode.

In a previous study [17], we have initiate a mythology and instrumentations for studying the propagation behaviors of ASF modes interacting with a defect along the wedge tip. In this study, the behaviors of ASF modes propagating along wedge tips with various types of defects and their parameters are investigated. Experimental measurements with a laser ultrasound technique and numerical simulations with finite element method are conducted to investigate the propagation behaviors of ASF modes travelling along defected wedge tips.

2. Samples

The investigated samples are edges of cutters (Makita Corp. Japan) for electric planner in fresh and defected conditions. Theses cutters are made of high speed steel (HSS) and have a wedge-shaped tip with an apex angle (θ) of 40°. In a fresh condition, the wedge tip has small apex truncations ranging from 6 to 12 μm. These truncations are small compared with wavelengths at mm level for the investigated ASF modes. For this 40° HSS wedge, velocities for the first two ASF modes are measured with a laser ultrasound-based B-scan method [9] as V_{A2} = 1980 m/s for the A1 (or fundamental) mode and V_{A2} = 2720 m/s for the A2 mode respectively.

Two types of defects are investigated in this study: perfect rectangular defects and imperfect (or modified) rectangular defects. The purpose for investigating the rectangular defects is to investigate the effect of defect size, particularly the depth, influencing the interaction behaviors of the ASF modes with the defect. Rectangular defects with a width of 1.0 mm and depths from 0.2 mm to 0.8 mm are introduced by using electric discharge machining (EDM). Although the width of a rectangular defect has been reported to play a significant role in the reflection behaviors of Lamb waves [15,16], this research focuses on the discussion of defect depth and leaves the width effect for further study. Modified rectangular defects as shown in Fig. 2 are investigated while the defects deviate from rectangular shape with geometrical modifications. This kind of defects are hypothetical and only studied with numerical simulations.

3. Laser ultrasound experiment

A laser ultrasound technique (LUT) is used for measuring the propagation behaviors of ASF modes propagating along the defected wedge tip. As shown in Fig. 3, the experimental configuration consists of a pulse laser for the generation of ASF modes and an interferometer for detection. The excitation source is a frequency-doubled Nd:YAG pulsed laser with a pulse energy of approximately 100 mJ, a 532 nm wavelength, and a pulse duration time of 6.6 ns (Quantel Corp., France). The optical ultrasound detector is a Doppler type heterodyne detector OFV 511 with a controller/decoder unit OFV 2700 (Polytec, Germany). The generation laser impinges point A on the wedge tip to generate ASF modes. With the defect located at point D, the pulsed laser impinges the wedge tip at point A. The detection probe beam is separated into two beams that enable receiving ASF signals at point B and point C simultaneously. At point B the optical probe detects the incident and reflected ASF modes, while it detects the transmitted ASF modes at point C. Distances between point A

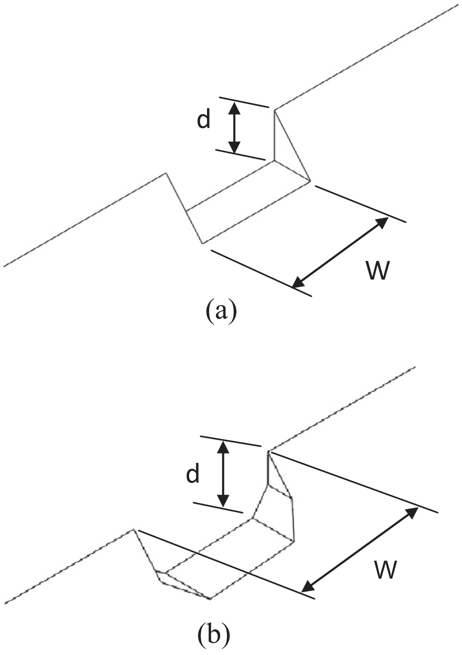

Fig. 2. (a) Rectangular defect and (b) modified rectangular defect along wedge tip.