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Interaction of the Shear Horizontal Bend Guided Mode (SHB) with Transverse Cracks

Prabhakaran Manogharan[a], Xudong Yu[b], Zheng Fan[b] and Prabhu Rajagopal[a,*]

[a]*Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600036, Tamil Nadu, India*

[b]*School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore*

Abstract

Recent research by the authors has revealed the presence of shear horizontal-type of feature-guided (SH_B) waves in plates with 90˚ transverse bends. The SH_B mode is non-dispersive and has low attenuation over a range of higher frequencies (500 kHz – 1 MHz). This mode is attractive for Non-destructive Evaluation (NDE) of bends in practical structures such as aerospace spar joints. Here the interaction of the SH_B mode with transverse small-width notches (cracks) running across bends in plates is studied using 3D finite element simulations and validated by experiments. For through-thickness cracks, the influence of transverse crack length on SH_B mode reflection is studied. For part-depth but long cracks (transverse length greater than operating wavelength), influence of crack depth on mode reflection is studied. The results demonstrate the potential of the SH_B mode for NDE of bent plate structures.

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1. Introduction

Feature guided waves confined or trapped in the vicinity of local features such as bends, corners, welds etc. have been investigated recently (Ramdhas *et al.* 2013,2015) and they are of interest to the Nondestructiive Evaluation (NDE) community for inspection of complex structures (Fan and Lowe 2012). More recently, research by the

* Corresponding author. Tel.: 04422574741
E-mail address: prajagopal@iitm.ac.in

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authors has revealed the presence of shear horizontal-type of feature-guided (SH_B) waves in plates with 90˚ transverse bends (Yu *et al* 2015). It was shown that the SH_B mode concentrates more energy in the bend and has low dispersion and attenuative properties in a specific high-frequency regime. More details on the properties of this mode can be found in Yu *et al.* (2015). Here we study the interaction of the SH_B mode with defects using 3D finite element (FE) simulations, validated by experiments, in order to gauge its potential for NDE of 90^0 plate bends.

2. Problem studied

We consider homogeneous linear isotropic plates bent at an angle $\theta_B = 90º$ as shown in Fig. 1 along with the coordinate axes. The bend region is provided a fillet with a radius of curvature R_B. For our studies we consider only tangential excitation (*x* direction) applied in the bend region as shown in Fig.1. Transverse cracks are considered for scattering studies, and the geometry (where *l* stands for the length of the crack and *b* is the crack depth) of the defects is shown in the Fig. 1 below.

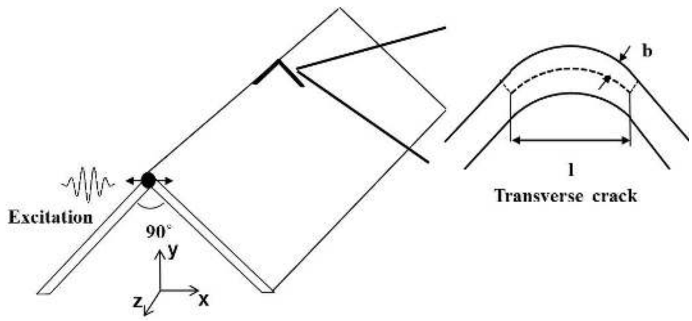

Fig.1. Illustration of the bent plate with crack geometry along with blow-up of the crack vicinity.

3. Methods

3.1. 3D finite element simulations

3D FE models of wave propagation in bent plates were implemented in a commercial FE package (ABAQUS V6.12). The geometry of the model is shown in the Fig. 1. The bend region was given a fillet radius of 4mm in order to obtain a smooth curvature. 8-noded cubic brick elements (C3D8R) were used to mesh the models. An integration time step of 1e-8 seconds was used based on the stability criteria. A 5 cycle tone burst signal was applied in the bend region as shown in the Fig. 1. Absorbing layers were used at the two sides of the adjacent plates to avoid edge reflections. Two types of defects were introduced in the FE model, located 50 λ_{SHB} (wavelength of the shear horizontal bend guided mode at the center frequency) away from the excitation. Zero-width cracks were introduced in the FE models, where the nodes on element of adjacent faces are disconnected (see for example, Rajagopal and Lowe 2007). A center-frequency of 650 kHz was used for simulations. The reflection ratio is calculated in the frequency domain by taking the ratio of displacement of the reflected signal to that of the incident signal.

3.2. Experiment

Mild steel plates of dimensions 500 mm×600 mm×2 mm with a fillet radius of 4 mm, cold-bent symmetrically along the plate central line at an angle of 90˚ were used for experimental validation. Transverse defects were introduced using electrical discharge machining. A commercially available PZT crystal (www.sparklerceramics.com/) was used for excitation by utilizing the input control level setting of a RITEC RPR

4000 pulser-receiver. The location of defect and excitation was similar to FE simulations. Polytec OFV 552 Laser Interferometer was used to monitor the signals. The interferometer reads the displacement of interest and the output was read by an Agilent DSO 7012B digital oscilloscope.

4. Results

4.1. SH_B mode interaction with transverse defects

Fig.2 shows typical time snapshots of the contour of the total displacement magnitude obtained from 3D FE simulation. Fig. 2(a) shows an instant soon after the excitation. We observe SH_B mode travels principally perpendicular to the direction of excitation and those of the fundamental symmetric Lamb mode S0 across the bend plate as shown in the Fig. 2(a). Here S0 wave tends to decay cylindrically away from the bend and has no interaction with the defect as shown in the Fig. 2(b). SH_B mode interaction with a $5\lambda_{SHB}$ long through-thickness transverse crack is shown in the Fig. 2(b). The scattered field consists of reflected SH_B waves from the crack face and diffracted SH_B waves from the crack tips or edges as shown in the Fig. 2(b).The monitoring point was located 200mm away from the excitation to pick the displacement of the back-scattered SH_B mode.

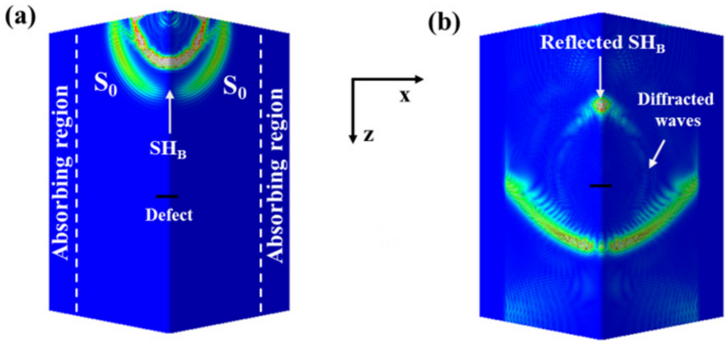

Fig.2. Time snapshots of the contour of the total displacement magnitude obtained from 3D FE simulation (a) show the incident wave; (b) show the reflected and diffracted SH_B waves for transverse crack of length $5\lambda_{SHB}$

4.1.1. Through-thickness cracks

A number of 3D FE simulation runs with crack lengths up to 10 λ_{SHB} were performed at a center frequency of 650 kHz to understand the effect of the length of through-thickness cracks on SH_B mode reflection. Fig. 3(a) shows the reflection ratio obtained from 3D FE simulations, plotted with increasing crack length. The crack length is expressed in terms of λ_{SHB}. From the Fig. 3(a) we see the reflection ratio starts from a low value and rises linearly with the crack length until about $3\lambda_{SHB}$. Beyond this point the reflection ratio attains an asymptotic value *en-route* through an oscillatory regime. The interference between the reflected and diffracted SH_B waves arriving together causes the oscillations in the reflected signal (this is for example, explained for the case of SH0 mode scattering from cracks in flat plates by Rajagopal and Lowe (2007, 2008). Experiments were carried out with different cracks lengths to validate the FE results. The reflected wave signals were monitored along the bend using the same method as for FE simulation. The reflection ratio was calculated and results obtained are shown in the Fig. 3(a) along with the FE results, which are in good agreement.

4.1.2. Part-thickness long cracks

Next we study the effect of mode reflection for long cracks (transverse crack length greater than wavelength) with increasing depth. The depth of the crack is varied form 10% of the thickness to 100%.The reflection ratio was calculated at monitoring position 200 mm away from the excitation. Experiments were carried out on cracks with depths 25%, 50%, 75% and 100% of the plate thickness with the required center frequency values. Settings for and calculations from the measurements were similar to those in the FE simulations. Fig. 3(b) shows the plot of reflection ratio obtained from experiments which are in good agreement with and validating our FE results. It can be seen to be an approximately higher order polynomial function of crack depth, and this increased sensitivity distinguishes its behavior from the flat plate SH0 mode (see Rajagopal and Lowe, 2008)

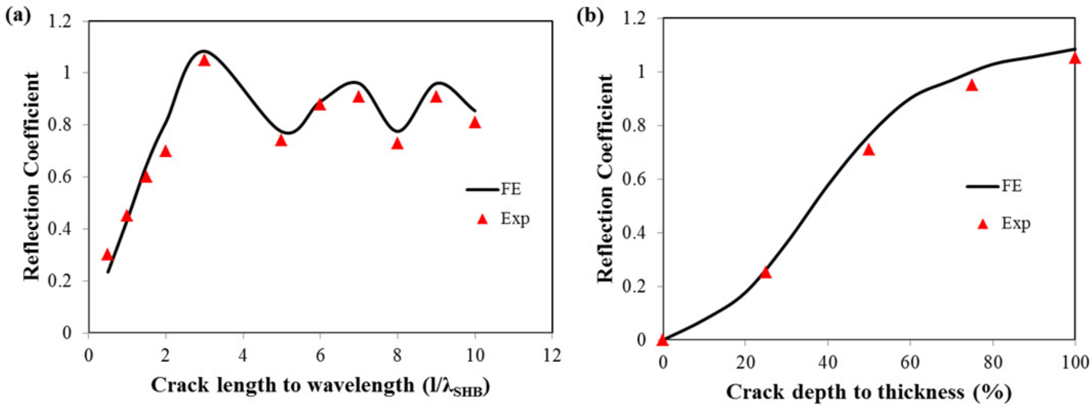

Fig.3. Reflection ratio of SH_B mode for transverse crack (a) varying length expressed in term of wavelength (b) varying depths obtained from 3D FE simulation and experiments

5. Conclusion

The interaction of Shear horizontal bend guided mode with transverse defects in the 90˚ bent plates was studied. 3D FE simulations were used for visualization of SH_B wave scattering and experiments were performed for validating the results. Both FE and experiments are in good agreement. The trends demonstrate the potential of SH_B mode for NDE of transverse bends in plates. Further work is ongoing to understand the physics of the observed trends, and also to understand the interaction of the SH_B mode with longitudinal or axially oriented defects.

References

Ramdhas, A., Pattanayak, R., Balasubramaniam, K., and Rajagopal, P., 2013. Antisymmetric feature-guided ultrasonic waves in thin plates with small radius transverse bends subjected to low-frequency symmetric axial excitation. J. Acoust. Soc. Am., 134(3),1886-98.

Ramdhas, A., Pattanayak, R., Balasubramaniam, K., and Rajagopal, P., 2014. Symmetric low-frequency feature-guided ultrasonic waves in thin plates with transverse bends. Ultrasonics. 56,232-242

Fan, Z., and Lowe, MJS., 2012. Interaction of weld-guided waves with defects. NDT&E International,14,124-133

Yu X, Manogharan P, Fan Z and Rajagopal P. Feature-guided waves (FGW) in plate structures with 90˚ transverse bends. In: D. O. Thompson, D. E. Chimenti, L. Bond, editors. Review of Progress in Quantitative NDE, Vol. 1650. New York, American Institute of Physics; 2015, p. 713-720.

ABAQUS 6.12 user's manual (2013), http://abaqusdoc.ucalgary.ca/v6.12/ (date last viewed: 21/04/ 2015).

Rajagopal, P., and Lowe, MJS., 2007. Short range scattering of the fundamental shear horizontal guided wave mode normally incident at a through-thickness crack in an isotropic plate. J. Acoust. Soc. Am., 122,1527–38.

Rajagopal P.,and Lowe, MJS., 2008. Scattering of the fundamental shear horizontal guided wave by a part-thickness crack in an isotropic plate. J. Acoust. Soc. Am.,. 124, 2895–2904.