ABSTRACT: Ultrasonic guided waves are interesting for Non-Destructive Testing (NDT) since they offer the potential for rapid and long range inspection of large structures. Many engineering structures are plates with bends and corners, which makes the inspection challenging. In order to inspect complex specimens effectively it is important to understand beam deviations that may arise due to such features. Here we investigate the effect and influence of transverse bends in plates on axially propagating ultrasonic guided waves. Three-dimensional Finite Element (FE) simulation of bent plates with various bend-angles shows that the bent region can concentrate and guide ultrasonic energy along the direction of propagation. Further, the mode of wave propagation is strongly influenced by the extent of the bend that varies with bend-angle. Different excitation types and guided wave modes are considered. The results are validated by means of analysis and experiments.

Key words: Guided Ultrasonic Waves, Finite Element Simulation, Plate Bends

INTRODUCTION

Ultrasonic guided waves are widely known to be attractive for large-area inspection as they offer the potential for rapid screening from a single transducer position and remote inspection of physically inaccessible areas of the structure. Since guided waves produce stresses throughout the thickness of structures it is possible to detect internal as well as surface defects. However, inspection using guided waves is challenging due to their multi-modal and generally dispersive nature. A major issue in inspecting real plate-like structures is that there always some features such as welds, ribs, and stiffeners which may cause extra coherent noise that interferes with the inspection signal. Moreover practical testing of plates shows that there are issues concerning the propagation of ultrasonic guided waves across features such as bends and cross-section changes. Thus understanding the properties of guided wave modes, such as the dispersion curves and through-thickness mode shapes is essential for choosing proper modes and frequencies for practical inspection.

A number of studies have reported on the subject of wave propagation in structures with constant curvature and structures with slowly varying geometry [1–3]. Most of the work on complex structures has been focused on the study of surface waves but in recent years Liu and Qu [2], Beard [4] and Fong [5] have investigated wave propagation across axial curvatures. It has recently been shown that trapped modes exist in elastic waveguides that have either axial curvature or axial width variations [6–7]. On the other hand, Sargent [8] reported experimental evidence of a mode trapped within a weld section, viewed as a transverse cross-sectional change. Juluri et al [9] followed this with three dimensional finite-element (FE) simulations on idealized welded plate geometry and argued for the existence of a ‘weld-guided’ compression mode similar to the Lamb S0 mode in the plate. More recently Fan [10] has demonstrated the existence of several other types of ‘weld-guided’ modes.

The motivation of the present work is to study the effect of transverse bends on guided wave propagation through plates and to our knowledge there is limited work in understanding this phenomenon. Finite Element (FE) simulation was the tool used for this purpose.
PROCEDURE FOR FINITE ELEMENT SIMULATION

Three-dimensional time-domain FE simulation was carried out in a 3 mm thick plate having bends ranging from 30° to 120° implemented in the commercial package ABAQUS/Explicit [11]. The model plate assumed the properties of aluminium. The mesh consisted of standard three-dimensional spatial discretization using linear cubic shaped 3D brick elements (C3D8R), where each node has three degrees of freedom. A schematic of the model is shown in Figure 1. Dispersion curves for a straight aluminium plate without any bends (traced using the DISPERSE [12] software) and shown in Figure 2 indicate that at the low frequencies used in our studies, only the fundamental symmetric (S0) and antisymmetric (A0) modes are present. The parameters used for the FE study are given as shown in Table 1.

![Figure 1: Snapshot from finite element model used for study.](image1)

![Figure 2: Phase velocity dispersion curve for a 3mm aluminum plate](image2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Model Length</td>
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<tr>
<td>Model Thickness</td>
<td>3mm</td>
</tr>
<tr>
<td>Center Frequency</td>
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<td>Element Size</td>
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<td>Material Density</td>
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<td>Young’s Modulus</td>
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<td>Poisson’s Ratio</td>
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</tbody>
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Table 1. Parameters used for the Finite Element Modeling
RESULTS AND DISCUSSION

The excitation is a 5-cycle pulse with a centre-frequency of 100 kHz applied as an in-plane force along the vertical line of nodes bisecting the bend. Figure 3 presents a snapshot of the contour of total displacement magnitude obtained from the simulations for plates with 30° and 90° bends. We can observe from Fig. 3(a) the presence of a mode travelling at an A0-like velocity and trapped in the bend region, although the A0 mode is not expected to be generated in a straight plate for this type of in-plane excitation. An SH0 mode is also not expected along the weld as it lines along its plane of symmetry [13]. For illustration, Figure 4 presents the contour of the total displacement magnitude from FE simulations of waves generated by an in-plane line excitation in flat plate.

Figure 3: Time snapshots of the contour of total displacement magnitude illustrating the bend guided mode propagation along the bend in plate bent at (a) 30° (b) 90°

Figure 4: Time snapshots of the contour of total displacement magnitude illustrating the wave propagation in a flat plate (180°)
Figure 5: Time plot (A Scan) obtained at a sample observation point for a plate with 30° bend

Figure 5 shows a typical monitored time trace of the signals of a 5-cycle tone burst at 100 KHz at a distance of 200mm from the point of excitation. Here the graph is plotted for amplitudes for various displacements at a particular point for a plate with 30° bend. We find that U2 (out of plane) displacement was found to be stronger compared to U3 (in-plane) displacement and the velocity of the trapped wave was found to be around 2667 m/s, close to the A0 mode velocity at this frequency-thickness.

Amplitude distribution along the cross section of the bend plate at a distance of 100mm for different angles from the point of excitation is shown in Figure 6. It can be seen that the axial displacement quickly decays with distance away from the center, which indicates the energy is concentrated in and around the bend. Perhaps a simple explanation of this phenomenon is that for some reason which needs further investigation, the bend angle causes slower propagation velocities along the bend region compared with the plate. Therefore a part of the energy is trapped in the bend and causes the bend to act as a waveguide.

Figure 6: Amplitude distribution along a line spanning 100mm across a 30° bend
Figure 7 above shows the variation of the amplitude of the mode trapped in the bend, for different angles. We find that plates with a small degree of bend had more energy trapped inside the bend. It was also found that the amplitude almost remains constant for plates with bend angles higher than 90°.

We do not have quantitative validation for these results yet, but these trends qualitatively agree with transverse weld studies by Fan [10] where energy is shown to be focused in the weld-region. Our results also perhaps exemplify the prediction in [7] that curvature has perhaps the same effect on guided waves as cross-sectional variation.

Simulations were also carried out with excitation applied along a nodal patch encompassing the cross-sectional region containing the bend, instead of just along the nodal line bisecting the bend. The results did not show much difference compared to the line excitation results expect for scaling changes in amplitude.

CONCLUSION

A series of plates with different bend angle were investigated using three-dimensional Finite Element (FE) simulation. The studies reveal that in bent plates subjected to extensional/compressional in-plane excitation, guided waves can be confined to the bend region. This phenomenon is quite strong a small bend-angles but quickly dissipates at angles above 90°. We need to further investigate this interesting phenomenon, through quantitative studies of the focusing of energy as a function of the bend angle and curvature. Currently, we are in the process of obtaining validation through experiments or results from literature.

REFERENCES