Ultrasonic guide wave inspection of fillet joints with bend

M.M. Narayanan¹,², A.Ravi Gopal¹, Anish Kumar¹ and B.Purnachandra Rao¹

Non-destructive Evaluation Division
Metallurgy and Materials Group,
Indira Gandhi Centre for Atomic Research¹, HBNI²,
Kalpakkam-603102, Tamil Nadu
Email ID: anish@igcar.gov.in

Abstract

The paper presents an ultrasonic guided wave methodology for inspection of a fillet joint with a bend. Owing to the complex shape of the geometry, it is not amenable for conventional techniques. The methodology developed utilizes through-transmission ultrasonic testing. Two 90° angle beam (surface wave) ultrasonic transducers of central frequency 2.25 MHz, acting as a transmitter and a receiver are used. A 2.0 mm thick fillet weld joint of SS 304 with rectangular notches, in the weld, of various depths viz. 20% - 50% wall thickness (WT) in the range of 0.4 mm – 0.8 mm with 10.0 mm length are considered. The amplitude drop for the notches is compared with that of defect-free locations to evaluate the sensitivity of the technique. The sensitivity of the technique is established to be 0.4 mm deep (20% WT).

Keywords: Fillet weld, ultrasonic guided wave, pitch-catch method

1. Introduction

Fillet welds are widely used in different storage components such as oil storage tanks, fuel tanks, aerospace applications, naval components etc. There are quite often hidden defects, in such welds, caused by service. A failure in the fillet weld may lead to heavy loss or wastage of the material contained by the structure that may be fatal in case of inflammable liquids. Hence, it is important to ascertain the integrity of the weld joints periodically for the early detection of such defects. Commonly used inspection technique for assessment of integrity of weld joints is the ultrasonic angle beam testing. This is time consuming as the inspection needs to be carried out point-by-point. Moreover, for complex joints, inspection becomes a real challenge. Besides, for thin fillet welds joints with curvature, ultrasonic angle beam testing cannot resolve defects in the weld and geometric features of the weld. To overcome the limitations of inspection by conventional ultrasonic inspection, an attempt has been made to utilize ultrasonic guided waves for the detection of defects in thin fillet welds. There is a very limited literature available in the area of defect detection in thin fillet welds using guided waves. However, literature shows that ultrasonic guided waves have tremendous potential in the detection of defects in plates, tubes, rods, multi-layer components and plate-like structures both in short range and long range [1]. Guided waves often propagate with many modes with different phase and group velocities leading to unavoidable problems of dispersion, mode conversion, etc. Despite the above problems, guided waves have good penetrating and propagating capability and controllability of sensitivity. The present study aims at detection of crack-like defects in thin fillet weld joints with bend using guided waves. In such scenarios, there is always scattering of guided waves from different acoustic interfaces and defects in the weld that can significantly alter the propagation...
properties (modes, frequency, amplitude etc.) of guided waves. Song et al. [2] have studied the scattering of guided wave modes A0, S0 and SH0 from a plate overlap of thick 12.7 mm, both experimentally and numerically and recommended the tuning of guided waves to achieve the maximum transmission and reflection across the overlap. Santos et al. [3] have studied the scattering from adhesively bonded lap joints using pulse-echo and pitch catch techniques and estimated the size of a dis-bond in the lap joint. In addition to the complications presented by the weld and the defect, there is a bend of 3 mm fillet radius that may lead to mode conversion of the incident modes. Abilasha et al. [4] have studied the effect of bend on the propagation of modes experimentally and numerically. Sun et al. [5] have studied variation of frequency, amplitude, time of flight of corresponding to various disbonds in aluminium lap joint slices of different transmitter-receiver distances across the lap joint.

The present study utilizes two fillet weld samples of 2 mm thickness each with a bend of radius 3 mm, as detailed below. Towards this, a pitch catch approach was used and the drop in amplitudes across the weld with defects was observed.

2. Fabrication of samples

AIST type 304 austenitic stainless steel (SS 304) plates of 2 mm thickness were chosen and fillet welds were designed. To simulate cracks in the weld of an actual sample, six EDM notches were machined in the center of the weld line. The notches were of depths: 10%, 20%, 30%, 40%, 50% and 100% (through and through notch) of 2 mm wall thickness. Each notch was of length 10 mm, width 0.5 mm and one was of through-and-through depth. Figures 1 shows the configuration of the defects.

![Fig. 1: Configuration of defects normal to the horizontal plate of the specimen](image-url)
3. Experimental set-up

The methodology developed utilizes through-transmission ultrasonic testing. Two 90 deg angle beam surface wave ultrasonic transducers of central frequency 2.25 MHz were used, with one transducer acting as a transmitter and the other as a receiver. The incident angle at the acrylic glass- stainless steel interface was 70 degrees. This incident angle leads to the generation of guided ultrasonic waves in the thin SS plates. The pulser-receiver used for the excitation of the transducer and receiving of ultrasonic surface waves was a USB-based pulser-receiver from M/s. Lecoeur Electronique, France. The pulser-receiver was powered by a laptop computer via USB. The pulser-receiver was controlled by a LabVIEW program loaded in the laptop computer. The parameters such as the emission voltage of 170 V, centre frequency of 2.25 MHz, pulse repetition frequency of 1 kHz, gain of 45 dB, averaging of 5 and the digitization rate of 80 MHz were used. The ultrasonic transducers were placed across the weld, as shown in Fig. 2.

![Experimental set-up for ultrasonic inspection of weld joints in the fuel tank](image)

Fig. 2: Experimental set-up for ultrasonic inspection of weld joints in the fuel tank

With the above parameters, A-scans were obtained with the two ultrasonic transducers placed across the weld with either transducer placed at a distance of about 60 mm from the weld, as shown in Fig. 2 and the distance was chosen to provide good sensitivity.

4. Results and discussion

It was observed that ultrasonic guided waves(S0/A0) mode with the group velocity of 2900 m/s propagate in the specimen, travel all through the weld, turn on the edge and go down to
the receiver. Hence, for the defect free region of the weld, the receiver receives the signals, while for the region of through-and-through defect; there is an absence of signals on the receiver side due to the complete reflection resulting from through-and-through crack. Therefore, the region of the through-and-through defect will show up zero amplitude on reception. For the case of defects of intermediate depths, a part of the ultrasonic energy goes through the remaining ligament, leading to partial reflection and transmission of the signals. The partially transmitted signals across the weld will show up as non-zero received amplitudes.

Figures 3a and 3b show a typical A-scan obtained across the region of the weld with 30% WT defect and the positive envelope of the A-scan, respectively. The maximum of the envelope was chosen to represent the overall response of a particular defective region/non-defective region. This was done to avoid the difficulty in the interpretation of multi-modal guided wave resulting from the bandwidth of the transducer and the mode conversions at weld interfaces and the defects. Using the maxima of envelopes of various A-scans, the plot of response versus depths of the defects has been made, as shown in Fig. 4.

As mentioned above, each point on the plot corresponds to the maximum of the envelope of an A-scan. It can be seen from the plot that the transmitted amplitudes decrease as the depths of the defects increase due to partial transmission and eventually become zero due to complete loss of transmission for the through and through defect. It is observed that there is a scatter of amplitudes (0.45-0.65) from non-defective regions (marked 0% WT defect on the plot) of the weld, due to surface conditions, weld itself and couplant variation. The scatter of data, as shown in Fig. 4, is present in all the responses of the defects and hence, its influence on the data cannot be ignored. Given the scatter of data, it can be said that the technique is sensitive to 20% WT defects and greater. It can be inferred that regardless of the opening of defects in the weld from inside or outside, the developed technique can pick them up due to the complete in-sonification of the volume of the weld by guided waves.

![Fig. 3: (a) A-scan obtained across the weld with 30% WT notch and (b) the positive envelope of (a)](image)
5. Conclusions

An ultrasonic methodology has been developed for inspection fillet welds with a bend, based on reading drop in amplitudes and ignoring mode conversions due to weld interfaces, defects and the bend. The technique demonstrates the detectability of cracks with part-depths, initiating from the weld outside surface, during service. However, it holds a promise for detecting a crack initiated from the inside of the weld also. The sensitivity of the present technique has been established to be 20%WT defect.

References


