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ULTRASOUND METHODOLOGIES FOR DEFECTS DETECTION AND STRUCTURAL INTEGRITY VALIDATION OF FSW JOINTS

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ABSTRACT

This work deals with the detection and evaluation of the defects that occur in the friction stir welding (FSW) process. The analysis was carried out by the C-Scan and A-Scan ultrasound methods using a high frequency focussed transducer having high lateral and axial resolutions, which increases greatly the detectability of the defects. Twenty seven aluminium samples welded for different tool rotation, welding speeds, tool depth, axial force, tool tilt angle, and tool design were analysed in order to evaluate their influence in the defects formation. It was observed that parameters like tool depth and tool tilt angle have great influence in the structural integrity of the weldings.

Keywords: Friction Stir Welding, Ultrasounds, C-scan, A-scan.

INTRODUCTION

FSW is one of the major advances in welding technology in recent years. It emerged as a joining technique to weld aluminium alloys that were difficult to join with the existing techniques. A non-consumable rotating tool with a probe and shoulder is inserted into the parts to be joined and traversed along the joint. The tool is forced down into the joint line under conditions where the frictional heating is sufficient to raise the temperature of the material to the range where it is plastically deformed. As the tool moves along the joint, the material is forced to flow from the leading edge to the trailing edge of the tool, and the material that flows around the tool undergoes high levels of plastic deformation. The shape of the tool promotes high hydrostatic pressure along the joint line, causing consolidation of the material plasticized due to heat generation (Midling, 1998).

A great advantage for using FSW is related to the low flaw incidence, such as weld porosity, solidification cracking and distortion, when compared with the conventional fusion welding process. However, FSW leads to characteristic defects that occur in response to variations of some parameters as the tool rotation speed, welding travel speed, tool depth, axial force, tool tilt angle, and tool design (D/d ratio of tool, probe length, tool shoulder diameter, and probe diameter), among others. They have significant effect on the material flow and temperature distribution, thereby influencing the weld microstructure, the defects formation, and the joint mechanic properties. In particular, for not optimized parameters some defects can occur, for instance oxides entrapment, excessive flash, surface galling, tunnel, and root flaws. The last three ones are easy to identify by using ultrasounds (Lohwasser, 2010).

In this work some Non Destructive Testing (NDT) methodologies by ultrasounds, namely C-scan and A-scan have been used to evaluate the friction stir welded components.Tensile tests and welds transversal section metallography were performed.

MATERIAL AND METHODS

A. Friction Stir Welding process

FSW is a Solid-State joining technique. A Special tool in rotation is inserted into the workpieces and transversed along the line of the joint. The tool generates heat by friction and induces strong plastic deformation in the material, promoting its complex mixing across the joint. Figure 1 illustrates a schematic diagram of the FSW process (ESAB, 2010). The probe height is generally slightly smaller than the workpiece thickness, and its vertical penetration into the workpiece is halted when the shoulder makes contact with the workpiece surface. A downward forcing pressure from the shoulder helps to prevent the expulsion of softened material, in addition to providing supplementary frictional heating, (Moreira, 2008).

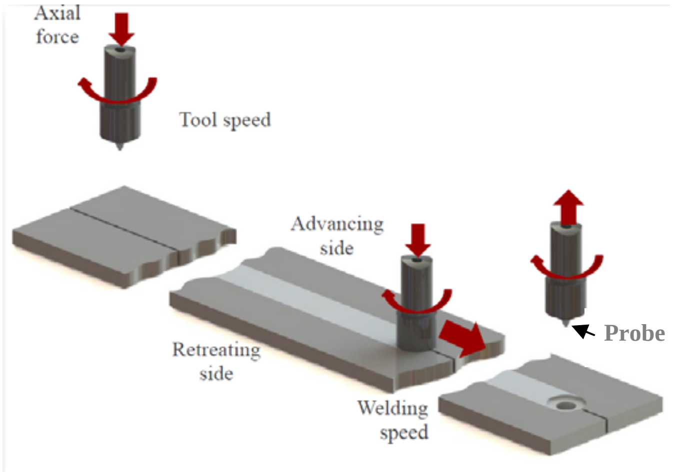


Figure 1. Schematic diagram of the FSW process.

B. Aluminium plates and FSW parameters

The welded test specimens were produced on aluminum alloys AA6082-T6, 380x150x3mm, in a butt-joint configuration. The aluminium plates were welded varying five parameters as tool rotation, welding speed, tool depth, tool tilt angle, and tool design in order to evaluate their influence in the defects formation. The used values are shown in Table 1.

C. Ultrasound experimental setup

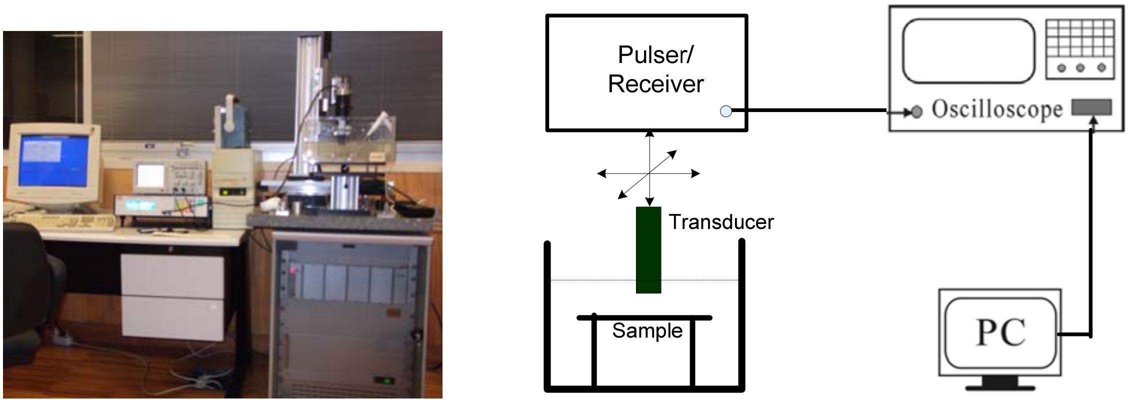
Figure 2a shows a picture of the ultrasonic immersion C-Scan. The equipment is composed by a XYZ axes system of high precision and resolution, a wide band pulser-receiver and the image software. The samples were immersed in a water tank supported by a sample holder as illustrated in the schematic A-Scan setup shown in figure 2b. A 6 mm-diameter 25 MHz focused broadband transducer (Kraukramer) was used in the experiment. The received signals were displayed by a digital oscilloscope (Tektronix TDS 3032) and transferred to the computer for processing.

Table 1. Friction Stir Welding parameters

Sample ID	Rotation speed (rpm)	Welding speed (mm/min)	Tool tilt angle (º)	Root tool distance	Ratio D/d
BJ1	735	216	2	0,2	3
BJ10	735	216	1	0,15	2,5
BJ19	735	216	0	0,1	2
BJ2	735	290	1	0,15	3
BJ11	735	290	0	0,1	2,5
BJ20	735	290	2	0,2	2
BJ3	735	360	0	0,1	3
BJ12	735	360	2	0,2	2,5
BJ21	735	360	1	0,15	2
BJ4	1000	216	0	0,15	3
BJ13	1000	216	2	0,1	2,5
BJ22	1000	216	1	0,2	2
BJ5	1000	290	2	0,1	3
BJ14	1000	290	1	0,2	2,5
BJ23	1000	290	0	0,15	2
BJ6	1000	360	1	0,2	3
BJ15	1000	360	0	0,15	2,5
BJ24	1000	360	2	0,1	2
BJ7	1500	216	1	0,1	3
BJ16	1500	216	0	0,2	2,5
BJ25	1500	216	2	0,15	2
BJ8	1500	290	0	0,2	3
BJ17	1500	290	2	0,15	2,5
BJ26	1500	290	1	0,1	2
BJ9	1500	360	2	0,15	3
BJ18	1500	360	1	0,1	2,5
BJ27	1500	360	0	0,2	2

RESULTS AND CONCLUSIONS

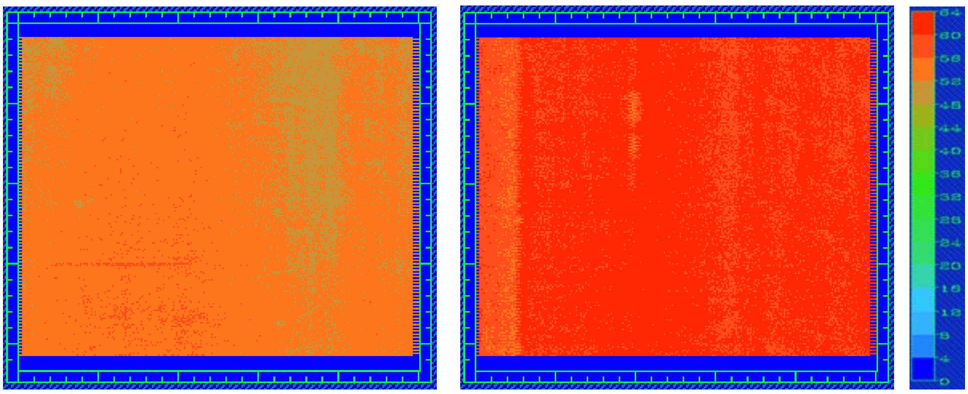
Twenty seven stir friction welded samples were tested by ultrasonic C-Scan imaging to evaluate the effect of the different parameters in defects formation. The A-scan approach was also used to prove the defects presence as well as to provide information about their depth and exact location.



(a) (b)

Fig. 2. (a) Ultrasonic immersion C-Scan system; (b) Schematic A-Scan setup.

Most of the samples seem to be in good condition as far as the resolution the C-Scan system can provide (lateral resolution of 1 mm). Figure 3 illustrate two images of those samples, namely BJ7 and BJ11, welded using rotation speeds of 1500 and 735 rpm, and welding speeds of 216 and 290 mm/min, respectively. The root tool distance was the same for both and the tool tilt angle was 1 and 0, respectively. In spite of they represent weldings made with different parameters they do not show defect evidences.



(a) (b)

Fig. 3. C-Scan images (20x20 mm in size) without apparent defects: (a) sample BJ7; (b) sample BJ11.

Thus, it was concluded the used tool rotation speeds (735, 1000 and 1500 rpm) and welding speeds (216, 290 and 360 mm/min) have no visible contribution for defects formation. Unlike, as the root tool distance increases more pronounced is the gap between the two welded specimens. Also it is clear that the tool tilt angle has great influence in the defects formation. It was observed serious defects for a 0º tool angle and a clear decreasing of them for higher angles. Such is illustrated in Figure 4 for images of two samples with tool tilt angles of 0º and 2º (BJ3 and BJ12). The A-Scan pulse echo method was also used to prove the defects presence in such samples. As illustration, Figure 5 shows the echoes diagram found through the thickness of the sample BJ3, corresponding to a line in the image of Fig. 4(a), proving the defects presence.

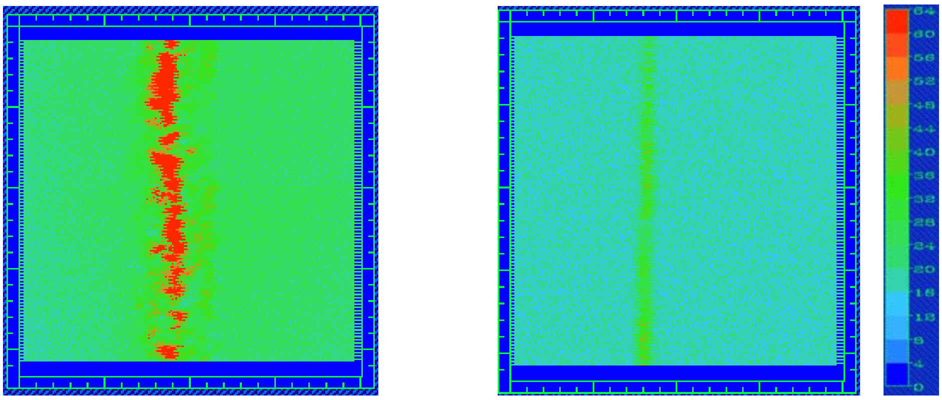


Fig. 4. C-Scan images (20x20 mm in size) with tunnel defects: (a) sample BJ3; (b) sample BJ12.

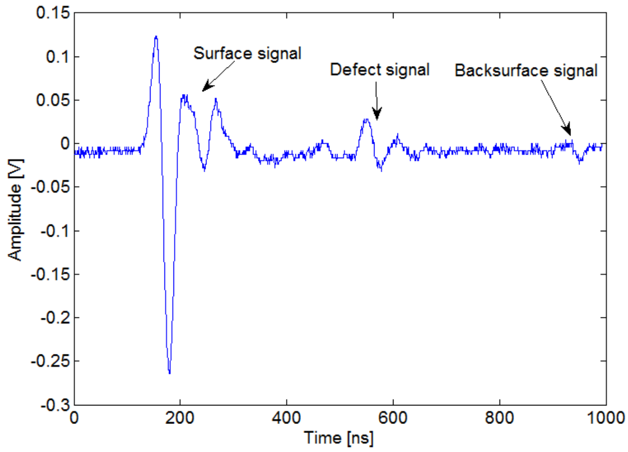


Fig.5. A-Scan signal showing a defect located at half depth in the BJ3 sample

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