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Effect of overlapping friction stir welding passes in the quality of welds of aluminium alloys

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Abstract

The aim of this investigation is to study the effect of overlapping friction stir welding passes on the soundness and the change in the microstructure and mechanical properties of welds in two aluminium alloys. Overlapping passes were made in 3 mm thick plates of 5083-O and 6063-T6 alloys. Tunnel defects were detected in the first and second passes of welds in the 5083-O alloy but not in the 6063-T6 alloy. The first pass resulted in a small increase in hardness in welds in the 5083-O alloy. However, in the 6063-T6 alloy, there was a substantial decrease in hardness and strength. The subsequent overlapping passes produced a modest increase in hardness and strength in both alloys as well the elimination of tunnel defects in welds in 5083-O alloy. The mechanical efficiency of welds in alloy 5083-O is equal to one as opposed to welds in alloy 6063-T6 that show an efficiency around 0.47. An increase in efficiency of 15% was reached if tensile specimens were polished, in order to remove weld roughness.

Keywords: Friction stir welding; Aluminium alloys; Overlapping passes

1. Introduction

The friction stir welding process has several advantages when compared with fusion welding processes, mainly with regard to the welding of aluminium alloys. Difficulties related to the sensitivity to solidification cracking and the formation of porosity due to the absorption of hydrogen during welding and thermal distortion, which are very common in fusion welding processes [1,2], do not happen in friction stir welding because it is a solid-state process where the maximum process temperature does not reach the melting point of the welded materials [3].

This process was invented by The Welding Institute in 1991 [4] and has several benefits in welding difficult to weld materials such as 2xxx and 7xxx series aluminium alloys [5], the welding of dissimilar materials of the same family and even of different families [6,7], for example aluminium alloys to copper alloys. In addition, lower peak temperature results in lower residual stresses [8]. Other benefits of this process include the use of non-consumable tools, there is no need for filler metal or shielding gas, the process is very tolerant to joint fitting and the operators need not have special skills.

However, the friction stir welding process requires careful selection of welding parameters, mainly tool plunge force, tool rotation speed and longitudinal welding speed as well as tool geometry, in order to prevent defect formation [9]. Furthermore, some degradation in the mechanical properties of welds in aluminium alloys has been reported [10,11]. A question that can be raised is how a weld can be repaired if there is defect formation during manufacturing. A second or third overlapping pass can be easily performed but do these manage to solve the problem? Does this procedure produce any change in the microstructure and mechanical properties of the welds?

The aim of this investigation is to study the effect of overlapping friction stir welding passes on the weld sound-

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ness as well as on the change in the microstructure and mechanical properties of welds in a non-heat treatable aluminium alloy 5083-O and in a heat treatable alloy 6063-T6.

2. Experimental procedure

Single and overlapping welds were produced in 3 mm thick plates of aluminium alloys 5083-O and 6063-T6, using an ESAB Legio FSW 3 UT machine provided with a tool of 15 mm shoulder diameter and a threaded pin of 6 mm diameter and 2.8 mm length. The nominal chemical composition of the plates is shown in Table 1. The mechanical properties of the plates are indicated in the presentation and discussion of results.

The welding parameters applied in 5083-O plates were: travel speed – 400 mm/min; rotation speed – 800 rpm; axial (plunge) force – 8820 N (900 kg); initial tool penetration time – 6 s. Two series of 500 mm long coupon plates were prepared. In the plates of the first series, the first weld occupied the whole length and the overlapping weld occupied only half the length. In the plates of the second series, three overlapping passes were first made. A fourth overlapping pass was made along only half the length. This procedure is represented schematically in Fig. 1.

The following parameters were applied to the coupon plates of the 6063-T6 alloy: travel speed – 550 mm/min; rotation speed – 1000 rpm; axial (plunge) force – 4410 N (450 kg); initial tool penetration time – 6 s. Three overlapping passes were made in each coupon plate, leaving one third of each plate with a single pass, another third with two passes and the last piece with three passes, as illustrated in Fig. 2. The welding parameters for both materials were selected in previous tests.

Macroscopic examination of the welds was performed in order to detect superficial defects. X-ray and ultrasonic inspections were made of all plates using both Andrex CP533 equipment (60 kV, 2 mA) and a C-SCAN system from Physical Acoustics with a 10 MHz probe. Metallographic examination was performed in the cross section

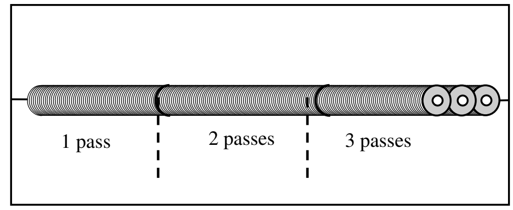

Fig. 2. Schematic representation of overlapping weld passes in 6063-T6 aluminium alloy.

of the welds etched with two different reagents: a modified Poulton's reagent was applied for 20 s to reveal the grain boundaries; a reagent composed of methanol (25 ml), hydrochloric acid (25 ml), nitric acid (25 ml) and a drop of hydrofluoric acid, placed on the specimen's surface at room temperature for 20 s was used to expose precipitates. 3 mm diameter discs prepared by electrolytic polishing at room temperature (12 V, 0.3 A) using an electrolyte composed of 25% nitric acid and 75% methanol were examined using transmission electron microscopy. Hardness and tensile tests were conducted on specimens removed transversely to the welding direction. Long tensile specimens with a gauge length of 50 mm were removed in order to test in sets the three zones of the welds – the thermo-mechanically affected zone (TMAZ), the heat-affected zone (HAZ) and the material (BM). Short specimens with a gauge length of 12.5 mm were used to test the TMAZ alone.

3. Results and discussion

3.1. Defects

The superficial appearance of the welds carried out on the alloy 5083-O using a single pass is illustrated in Fig. 3a. A continuous weld defect, indicated by an arrow in the figure, was observed on the advancing side, along almost the entire length of the welds. Similar results have been reported previously for the same alloy when using the same welding parameters [9]. In fact, the welding

Table 1
Nominal chemical composition of the plates, wt%

Alloy	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
AA 5083-O	94.8	0.05–0.25	0.1 max	0.4 max	4–4.9	0.4–1	0.4 max	0.15 max	0.25 max
AA 6063-T6	98.6	0.1 max	0.1 max	0.35 max	0.45–0.9	0.1 max	0.2–0.6	0.1 max	0.1 max

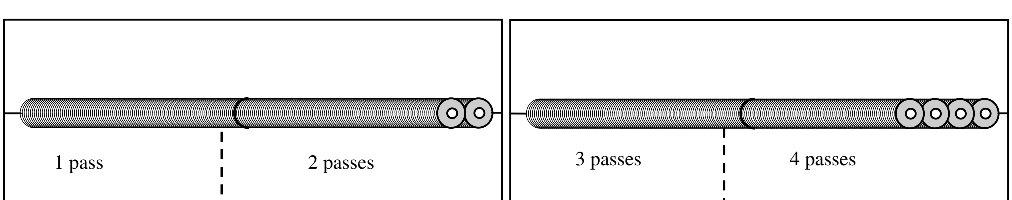

Fig. 1. Schematic representation of overlapping weld passes in 5083-O aluminium alloy.