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Flow patterns in friction stir welds of AA5083 and AA6082 alloys

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ABSTRACT

The flow patterns in dissimilar friction stir welds of AA5083-O and AA6082-T6 alloys have been studied. It was observed that material flows (pushes but does not mix) more from the advancing side into the retreating side. Material flow from the retreating side to the advancing side only occurs in the tool shoulder domain, and the pull is greatest at the transition region between the tool shoulder domain and the tool pin domain. It was also observed that materials tend to extrude out only in the thermomechanically affected zone of the retreating side, which was influenced by rotation of both the tool shoulder and the tool pin. The finest grains were present in the regions closest to the tool edge in the retreating side. The volume fraction of recrystallized grains increases down into the deeper part of the nugget from the flow arm region. Microhardness measurements revealed that regions of lowest hardness values were the nugget and the heat affected zone of the AA6082-T6 alloy side. The welding speeds had no influence on the microhardness values per se, but affected the mixing proportions in the flow arm and in the nugget stem.

1. Introduction

Understanding of material flow in friction stir welding has attracted significant interest in recent times. This is because thorough understanding of the flow will help to predict the performance of friction stir welds in service. Researchers have employed different techniques and models in attempting to establish the flow patterns, as well as material positioning in dissimilar friction stir welds with consideration of different welding parameters [1–13]. However, all of these are far from being fully understood and established. Moreover, detailed microscopy has not been employed to support the existing theories reported in the literature.

The existing theories are highlighted below:

- the bulk of material transport occurs only from the retreating side (RS) to the advancing side (AS) in the tool shoulder domain [14];
- there is a region or line of mismatch [15] in the thermomechanically affected zone (TMAZ), showing distinct boundaries between the two alloys (a "border" of concern because it may have serious influence on the galvanic interactions of the alloys);
- materials only attempt to flow upward in the extrusion zone (EZ) in the TMAZ of the RS [16] and inward in the flow arm (FA) region of the AS, with the flow being created by both the tool shoulder and tool pin motion, and not only by the tool pin motion [17];
- materials only flow into the nugget from the AS [7]. Materials from the RS stirred in the nugget are firstly transported in regions near the top surface (in the tool shoulder domain) through torsional flow and radial flow from the rear to the AS. The transported materials are then pushed downward along with mixed materials in the AS to the nugget [16] where the interspersed materials swirl (in the tool pin domain); and
- in regions just outside the swirl/vortex movement of the materials, in the direction of the RS, there is an outward push of materials (some of which are still part of the nugget or dynamically recrystallized zone). Immediately after this outward push of materials comes the zone of upward flow of materials (the EZ), just before the heat affected zone (HAZ) [3,16,17].

In this work, microstructural examination of different zones of dissimilar friction stir welds of AA5083-O and AA6082-T6 alloys has been employed to determine material flow in the friction stir welds. As revealed, a careful study of the bulk flow directions of materials from zone to zone at the microscopic scale has been undertaken to confirm and also to add to the existing theories on flow patterns in friction stir welds. For a further appreciation of the zonal variations in the weld, microhardness measurements

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Table 1
Major alloying elements (in weight%) in the AA5083-O and AA6082-T6 alloys used in this study.

	Mg	Si	Fe	Mn	Zn
AA5083-O	3.92	0.03	0.23	0.44	0.01
AA6082-T6	0.74	0.44	0.33	0.40	0.05

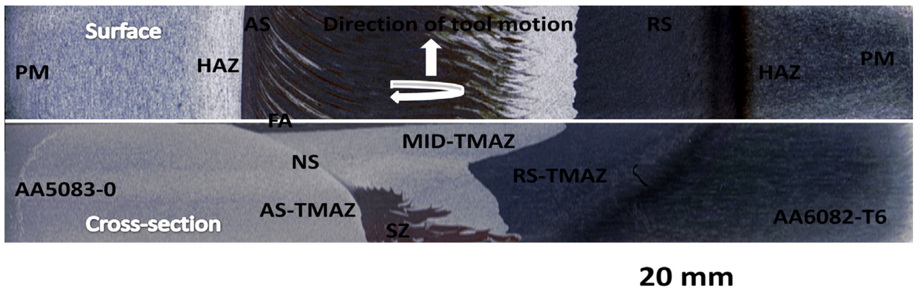

Fig. 1. Optical images of the friction stir weld of AA5083-O and AA6082-T6 alloys displaying the different zones in friction stir welding. The images were obtained after etching in 10% NaOH solution at 60 °C for 30 s. The description of the zones are as follows: **AS** represents the advancing side; **AS-TMAZ** represents the TMAZ of the AS present between the HAZ of AA5083 and the NS/SZ; **FA** represents the flow arm; **HAZ** represents the heat affected zone; the **MID-TMAZ** represents the TMAZ present after the NS and SZ (comprising mainly of AA5083, the AS material); **NS** represents the Nugget stem (the flow pathway from the FA to the SZ or nugget); **PM** represents the parent material/metal; **RS** represents the retreating side; **RS-TMAZ** represents the TMAZ of the RS comprising of AA6082 (the RS material) only; **SZ** represents the stir zone (the nugget also referred to as the dynamically recrystallised zone); and **TMAZ** represents the thermomechanically affected zone.

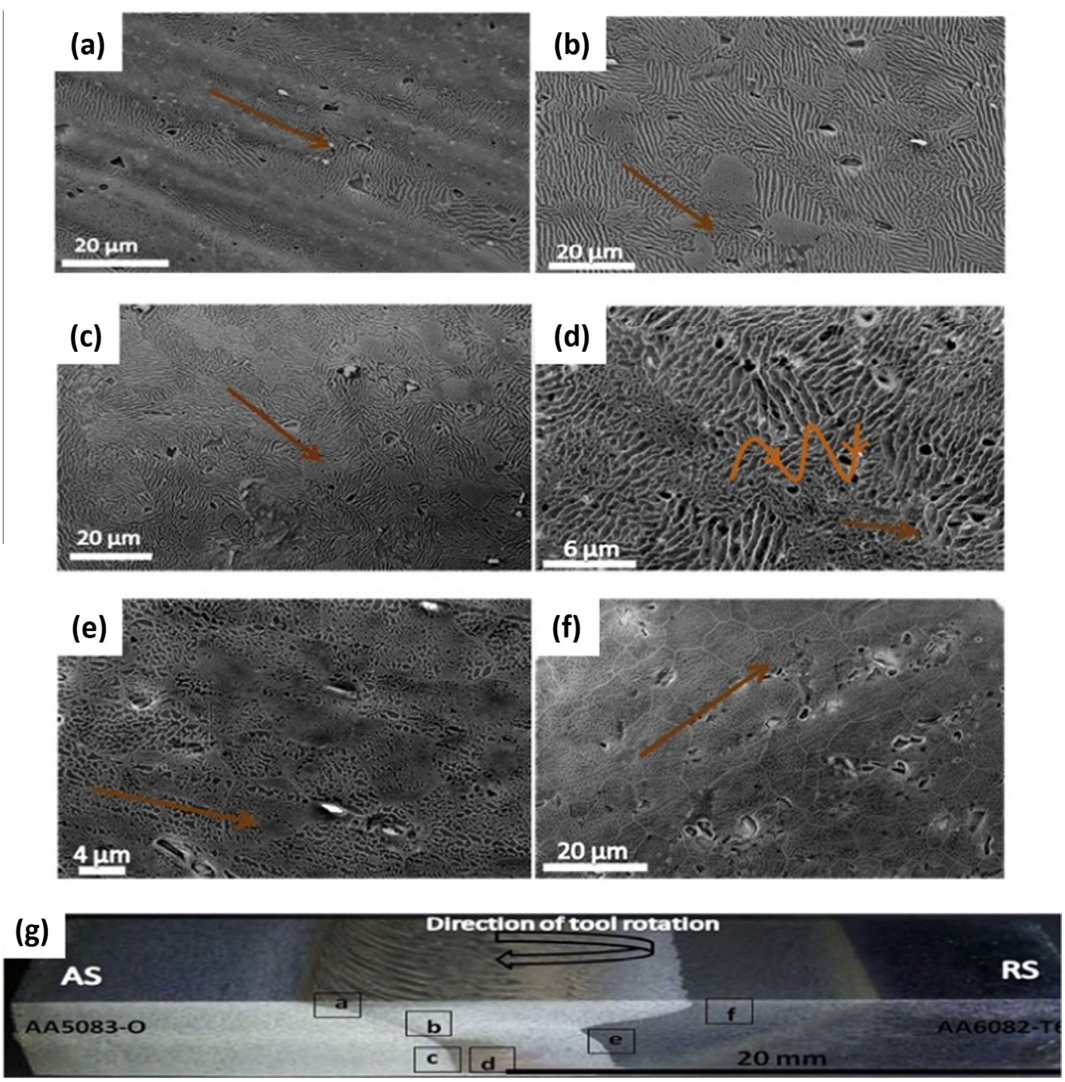

Fig. 2. Scanning electron micrographs (obtained after Barker's treatment), (a)–(f)) displaying directionalities in the various zones of the friction stir weld of AA5083-O and AA6082-T6 alloys: (a) FA; (b) MID-TMAZ adjacent to the FA; (c) AS-TMAZ adjacent to the SZ; (d) SZ; (e) RS-TMAZ adjacent to the MID-TMAZ in the tool pin domain; (f) RS-TMAZ adjacent to the MID-TMAZ in the tool shoulder domain; and (g) optical image (obtained after etching in 10% NaOH solution) indicating the zones from which SEM images were taken.