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Microstructural modification and ductility enhancement of surfaces modified by FSP in aluminium alloys

F. Nascimento [a], T. Santos [a,b], P. Vilaça [a,b], R.M. Miranda [b,c,*], L. Quintino [a,b]

[a] IST-UTL, Instituto Superior Técnico, Technical University of Lisbon, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
[b] IDMEC, Institute of Mechanical Engineering, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
[c] FCT-UNL, Faculty of Science and Technology, Universidade Nova de Lisboa Quinta da Torre, 2829-516 Monte de Caparica, Portugal

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ABSTRACT

Friction stir processing (FSP) is an emerging surface modification technology under exploitation, to evaluate its potentiality for improving both surface and bulk properties. Two types of material modification have been developed: the in-volume FSP (VFSP) consisting on the modification of the full thickness and the surface FSP (SFSP) consisting on the modification of the surface of processed materials up to 2 mm depth. This paper presents a comparative study of VFPS and SFSP for two aluminium alloys AA7072-T6 and AA5083-O with different tool geometries. A significant increase in materials formability was observed due to an increase in ductility resulting from grain size refinement, increasing the maximum bending angle by a factor of 12 for the VFSP treatment and of 4 for the SFSP treatment in the AA7022-T6 samples. In AA5083-O an increase of the maximum bending angle of about 2.5 times for VFSP treatment and of around 1.5 times for the SFSP treatment was observed.

1. Introduction

Friction stir processing (FSP) is a new solid-state technique that applies the basic principles of friction stir welding to shape materials structures and improve surface properties [1,2]. In FSP a non-consumable tool consisting of a pin and a shoulder provides mechanical mixing and visco-plastic deformation in the area processed by the tool. Heat is generated by internal energy dissipation during the visco-plastic material deformation and interfacial friction of the material.

The improvement of properties is related to grain size refinement and homogenization due to the large processing strains in the nugget. Four distinct zones can be distinguished in a FS processed domain: the nugget, in which occurs dynamic recrystallization due to the severe thermo-mechanical processing resulting in an homogeneous fine equiaxed recrystalized grain structure; the thermo-mechanically affected zone (TMAZ) where the grain is elongated as it was highly mechanically deformed; the heat affected zone (HAZ) that undergoes sub-grain rearrangements and grain coalescence and the base material (BM) which is the region unaffected by the process [2].

FSP has proven to be successful in the modification of various properties such as formability, hardness, yield strength, fatigue and corrosion resistance. It is also becoming very effective in the production of metal matrix composites and for the production of materials with superplastic behaviour [3–5]. Since the process eliminates surface microstructural defects, e.g., porosities and cracks, and refines and homogenises the grain size, the processed components become more tolerant to mechanical loading.

Improvements in the formability were investigated [6–8] and showed that ductility of the processed material significantly increases, being possible to bend thicker specimens without cracking.

Some materials after being friction stir processed can become superplastic [3] and, thus, be strained over 200% of their initial size before cracking. Materials with superplasticity at low temperatures are attractive for commercial formability, since this reduces energy costs, increases the lifetime of formable coatings improving the final surface quality. Charit and Mishra [9] observed superplasticity behaviours in an Al–Zn–Mg–Sn alloy with elongations of 1125 and 525% at 310 and 220 °C, respectively. The smaller the grain size, the better the superplastic behaviour [10,11], and it was also shown that there is an optimum point from which the material exhibits superplastic behaviour, that is different for each material.

The use of multiple passes to process a larger surface [12,13] showed that though the properties of the materials remain the same along all passes, there is a better superplastic behaviour in AA7075 alloy when it was processed with only one pass than with multiple passes. Kwon et al. [14] studied an aluminium alloy AA1050 and verified that the yield strength and hardness decreased with the

* Corresponding author. Fax: +351 21 2948531.
E-mail address: rmiranda@fct.unl.pt (R.M. Miranda).

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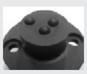
Table 1
Description of the tools used.

	Tool	Shoulder		Pin		
		Profile	$D_{shoulder}$ (mm)	Geometry	d_{pin} (mm)	l_{pin} (mm)
1		Smooth Concave	19	Conical threaded with 3 helicoidal longitudinal channels	8 (Max.) 5 (min.)	6
2		Smooth Concave	15	Threaded cylindrical	5	4.6
3		Scrolled profile	17	No pin, it has four discontinuous streaks 1.5 mm thick		
4		Smooth Concave	18	Semi-spherical	4	1.5

increase of the tool rotation. Chang et al. [15] conducted a similar study on the effects of FSP in a Mg–Al–Zn alloy, and were able to produce a processed zone with a grain size smaller than 500 nm increasing the hardness from 50 to 120 HV.

The present study examines the effect of in-surface and in-volume friction stir processing of AA5083 and AA7022 aluminium alloys in single and multiple passes. The in-volume FSP (VFSP) consists on the modification of the full thickness of the processed materials and the surface FSP (SFSP) consists in the modification of the surface of the material up to 2 mm depth. An increase in the formability was observed in VFSP due to the grain refinement and homogenization, increasing the maximum bending angle of a factor of about 12 for the heat-treatable alloy at room temperature.

2. Experimental procedure

Two aluminium alloys were studied: a heat-treatable AA7022-T6 used in aeronautic applications and a non-heat-treatable alloy AA5083-O used in chemical and shipbuilding industries. Plates of both materials had an initial thickness of 10 mm.

Two tool geometries were selected for the SFSP and two tools for the VFSP with distinct geometries. Table 1 shows the tool and pin geometries used, the first two for VFSP and the others for SFSP.

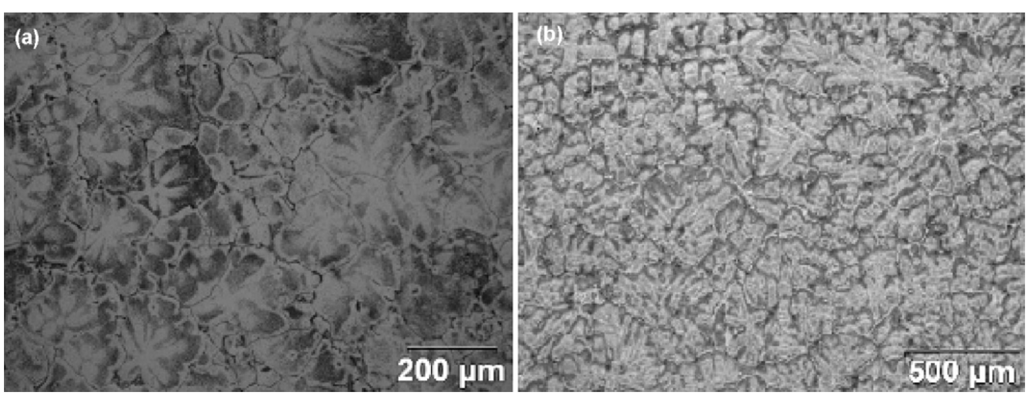


Fig. 1. Base material samples polished and etched with Poulton modified reagent: (a) AA5083-O e (b) AA7022-T6.

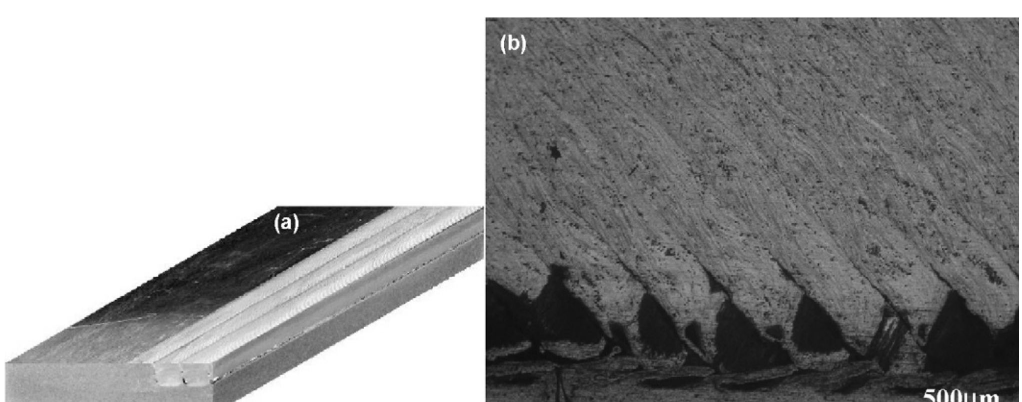


Fig. 2. Void defects observed in the AA5083-O alloy VFSP with tool 2: (a) 3-D visualization of the defect; (b) Micrography of the defects in the longitudinal section.