Materials and Design 30 (2009) 101–108

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Mechanical behaviour of similar and dissimilar AA5182-H111 and AA6016-T4 thin friction stir welds

C. Leitao [a], R.M. Leal [a,b], D.M. Rodrigues [a,*], A. Loureiro [a], P. Vilaça [c]

[a] CEMUC, Department of Mechanical Engineering, University of Coimbra, Portugal
[b] ESAD.CR, Polytechnic Institute of Leiria, Caldas da Rainha, Portugal
[c] IST, Technical University of Lisbon, Lisbon, Portugal

ARTICLE INFO

Article history:
Received 18 December 2007
Accepted 16 April 2008
Available online 28 April 2008

Keywords:
Taylor welded blanks
Friction stir welding
Aluminium alloys
Thin sheets

ABSTRACT

The tensile behaviour of similar and dissimilar friction stir welds in 1 mm thick sheets of two aluminium alloys (AA5182-H111 and AA6016-T4) is analysed in this paper. The heterogeneity in properties across the welds was studied by performing microhardness tests and microstructural analysis. The tensile tests were performed in samples extracted longitudinal and transverse to the weld direction. It was found that the tensile behaviour of the welds depends mainly on the grain size in the TMAZ, for the AA5182-H111 alloy, and on precipitate distribution, for the AA6016-T4 alloy. In all types of welds, the HAZ preserves the same properties of the base materials. The global mechanical behaviour of the AA5182-H111 similar welds is very similar to that of the base material. However, for the AA6016-T4 similar welds and for the AA6016-T4-AA5182-H111 dissimilar welds a 10–20% strength reduction relative to the base materials and important losses in ductility were reported.

1. Introduction

Increasing industrial concern with ambience and energy is becoming notorious. In this context, friction stir welding (FSW) appeared as an easy, ecologic and promisingly productive weld method that enables to diminish material waste and to avoid radiation and harmful gas emissions, usually associated with the fusion welding processes. The FSW tools are mainly constituted by a small diameter entry probe and a concentric larger diameter shoulder, both usually made of high strength steel.

During the weld process, the FSW tool is rotated and the probe is plunged into the boundary of the adjoining plates. Penetration depth of the probe is controlled by its length and by the tool shoulder, which should be in intimate contact with the plates during welding. The heat generated by friction between the rotating tool and the plates promotes a local increase in temperature and softens the materials under the tool shoulder. At the same time, the plunged rotating probe moves and mixes the softened materials, by intense plastic deformation, joining both in a solid state weld.

According to the temperature attained and the volume of material which is plastically deformed during the welding process, it is usually possible to distinguish two main zones, with different characteristics, in the FS welds: the thermomechanically affected zone (TMAZ), that is constituted by the material plastically deformed during the welding process, and the heat affected zone (HAZ), comprising the material affected by the weld thermal cycle but not plastically deformed [1–4]. Frequently, part of the TMAZ presents a recrystallized fine-grained microstructure, resulting from the combination of extremely high plastic deformation and temperature, which is usually called as Nugget. The HAZ of the friction stir welds is of the same nature of the heat affected zone of welds resulting from the fusion welding processes [5].

Despite the large amount of published literature about the FSW process, systematic information does not exist on the influence of the tool and the process parameters on the weld quality for a large range of materials, thicknesses and joint configurations. Until now, FSW industrial application had mostly been restricted to the construction of large components in shipbuilding and aerospace and aeronautics industry [6,7]. The application of this process in the automotive industry is relatively recent and has one of its main fields of interest for the production of aluminium tailored welded blanks (TWB) from very thin sheets [8–13]. In fact, some difficulties continue to restrict the application of TWBs in industry [14–17] such as, the difficulty in welding some materials (Al alloys and HSS), the strength reduction in the weld line and the poor formability of the TWBs. The FSW process diminishes some of the weldability problems usually associated with fusion welding processes, due to its low heat input [6]. However, FSW process has limitations in butt-joining thin sheets. The thickness reduction resulting from the forging effect of the shoulder can significantly reduce the mechanical resistance in thin plates (1 mm or less). The presence of micro defects, usually acceptable in thick welds, also pose serious problems in thin plate sheet welds [11].

* Corresponding author. Tel.: +351 239 790 700; fax: +351 239 790 701.
E-mail address: dulce.rodrigues@dem.uc.pt (D.M. Rodrigues).

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doi:10.1016/j.matdes.2008.04.045

In this work the mechanical behaviour of similar and dissimilar welds obtained by FSW of 1 mm thick plates of two very popular automotive aluminium alloys, the AA5182-H111 and the AA6016-T4 alloys, are analysed. The AA5182 aluminium alloy, supplied annealed and slightly cold worked (H111), is characterised by its high content on Mg, exhibiting Portevin-Le Châtelier effect under plastic deformation. Due to its excellent formability, especially during deep drawing with a high amount of stretch forming, this material is ideally suited for intricate critical inner panel applications. The second aluminium alloy, the AA6016, was supplied as a solution alloy heat-treated and naturally aged to a stable condition (T4). This aluminium alloy, that presents stable formability in T4 condition, is usually used for car skin sheet applications and for some inner panels.

Due to the different applicability and formability characteristics of these two aluminium alloys, their joining in dissimilar TWBs is very interesting. However, it is well known that the AA5xxx (Al–Mg–Mn) and the AA6xxx (Al–Mg–Si) alloys present different characteristics when joined in homogeneous welds by FSW. In fact, for the AA6xxx aluminium alloys, it was already found that the mechanical properties of the FS welds depend mainly on the size, volume fraction and distribution of precipitates in the TMAZ and HAZ. These welds usually experience softening in the TMAZ due to the dissolution and coarsening of the precipitates during welding [3,4,18–24]. Friction stir welding of the AA5xxx aluminium alloys is much less studied than for the precipitation-hardenable alloys, such as the AA2xxx, AA6xxx and AA7xxx alloys. However, it was already found that the mechanical properties of the TMAZ zone of the welds produced from AA5xxx alloys depend mainly on the grain size and on the density of the dislocations after plastic deformation and recrystallisation occurring during welding. When the AA5xxx alloy series are used in the annealed condition the microstructure is stable and usually no softening occurs in the TMAZ and HAZ. In contrast, when these alloys are used in the strain hardened condition, the work hardened structure will readily recover and/or recrystallize during welding, and softening may occur [9,10,25–27].

Due to its remarkably different welding behaviour and its potential industrial interest, the joining of AA5xxx and AA6xxx alloys in dissimilar TWBs, with 2 and 3 mm plates, was already investigated by several authors [10,25,26,28,29]. Giera et al. [12] performed a statistical investigation on FSW of the AA5182 and AA6016 alloys in similar TWBs. They established window process parameters for joining 1 mm thick plates of both alloys. Present authors also published a study on the effect of friction stir welding parameters on the microstructure and hardening properties of similar friction stir welds in AA5182-H111 and AA6016-T4 aluminium alloys in 1 mm thick plates [30]. A comparative analysis of the plastic behaviour of similar and dissimilar welds in these same materials is presented in present paper.

2. Experimental procedure

2.1. Materials and welding

The chemical nominal composition of the AA5182-H111 and AA6016-T4 base materials used in this investigation is presented in Table 1. The welds were produced in 1 mm thick plates of both base materials by using a steel tool with a scrolled shoulder (Fig. 1a) at a 0° tilt angle. The threaded probe was 3 mm in diameter and 0.9 mm long and the scrolled shoulder had 14 mm in diameter. The welds were performed under position control by moving the tool at 320 mm/min travelling speed and 1120 rpm rotational speed. Similar (AA5182–AA5182 and AA6016–AA6016) and dissimilar (AA5182-AA6016) TWB's were made by welding the base material plates parallel to the rolling direction of the plates. On the dissimilar blanks, the AA5182 plates were always positioned at the advancing side of the welding tool and the AA6016 on the opposite side. In the next, the samples extracted from the similar welds (AA5182/AA5182 and AA6016/AA6016) will be labelled as S55 and S66, respectively, and the dissimilar weld samples (AA5182/AA6016) as D56.

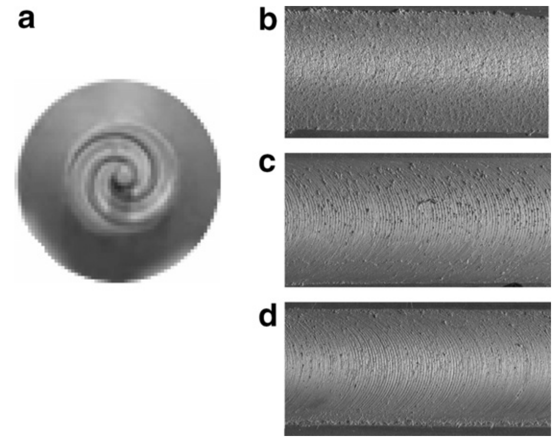

Fig. 1. FSW tool (a) and weld crown appearance for the S55 (b), S66 (c) and D56 (d) welds.

Before testing, a qualitative analysis of the welds has been performed and no defects were found in the weld roots. The surface appearance of the weld crowns is shown in Fig. 1b (S55), c (S66) and d (D56). As it can be seen in the figure, no flash was produced during the weld process but the weld surfaces are deeply rough. Small depth striations are observable for the S66 and D56 welds. Thickness reduction in the stirred zone was almost inexistent for all the welds.

2.2. Hardness testing and microstructural analysis

The heterogeneity in mechanical properties across the welds was evaluated by performing several microhardness measurements transversely to the weld direction (see Fig. 2). Hardness tests were performed after several weeks of natural aging at room temperature of the welds. Since the hardness measurements can present some scatter even for homogeneous materials, an analysis concerning the sensitivity of the hardness measurements to the hardness testing load was previously performed for both base materials. Based in this study, the test loads used in this work were: 50 g for the AA5182 base material and S55 similar welds, 100 g for the AA6016 base material and S66 similar welds and 75 g for the D56 dissimilar welds. The load holding time was 30 s in all cases. For each type of sample, the hardness variation across the weld was verified by performing hardness measurements in several positions along the welding directions. In each testing line the hardness measurements were spaced by intervals of 0.25 mm.

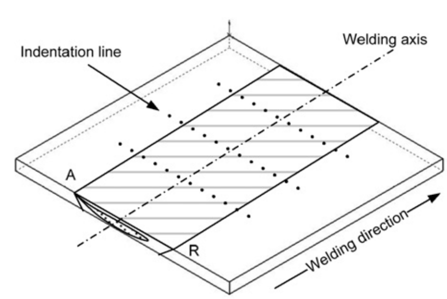

Fig. 2. Specimens were cut from the welds, ground to a suitable surface finishing and microhardness tests performed across the weld.

Table 1
Nominal chemical composition of the base materials (wt%)

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
AA5182-H111	<0.2	<0.35	<0.15	0.2–05	4.0–5.0	<0.1	<0.25	<0.1
AA6016-T4	1.0–1.5	<0.5	<0.2	<0.2	0.25–0.6	<0.1	<0.2	<0.15