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Evolution of microstructure and mechanical properties of a dissimilar aluminium alloy weldment

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ABSTRACT

This paper reports a study on the effect of heat input on the microstructure and mechanical properties of dissimilar aluminium alloys joint by MIG welding. The two alloys used are 6N01S-T5 and 7N01P-T4. The 6N01S-T5 alloy exhibited two distinctive sub-zones within its heat affected zone, with the one adjacent to the unaffected parent alloy being the weakest during tensile deformation. The remarkable reduction in the mechanical properties in the weakest region is attributed to the transformation of the precipitates upon welding from smaller sized β″ and β′ precipitates with strong strengthening effect to larger sized β precipitate. The 7N01P-T4 alloy exhibited nucleation of new grains, dissolution of precipitate, and loss of strength in the heat affect zone.

1. Introduction

Aluminium alloys are common structural materials used in the transport industry [1–3] for their light weight for fuel efficiency, such as high-speed trains, automobiles, ferries and recreational yachts and airplanes, to meet the growing demand of reducing energy consumption and air pollution. In the construction of such structures, different Al alloys are often joined by welding. Among the various welding techniques, metal inert gas (MIG) welding is commonly used for welding curved and large structures [4–6], because of its comparatively easy operation and better economy. However, the MIG welding are challenged by many weldability problems, e.g., over-ageing in the heat affected zone (HAZ), loss of strength [7–9], hot cracking [10], formation of porosity [11,12], liquation cracking [13,14], and formation of coarse columnar grains in the fusion zone [15]. Porosity, hot cracking and incomplete fusion can be prevented or reduced by proper control of the welding process, but HAZ is difficult to be avoided in industrial production, even in MIG welding [16], friction-stir-welding (FSW) [17], and laser welding [18]. For non-heat-treatable Al alloys, the loss of strength in HAZ is mainly due to the annealing effect of cold-worked microstructure [19]. For heat-treatable alloys, the loss the strength is often due to overageing [20].

Despite the common knowledge of HAZ for Al alloys, technical challenges remain for practical industrial fabrication, for example when dissimilar Al alloys are joined by welding. Owing to the different strengthening mechanisms, different aluminium alloys have different responses to the effect of heat input from welding. That implies strategies suitable for mitigating the effect of HAZ for one alloy may not be the most effective for another, imposing additional complexity for design of welded aluminium alloy structures. This study is motivated by the need to weld 6XXX and 7XXX alloys together for high speed train applications. In this case a 6N01S-T5 alloy, used for its better formability as upper body structures of a high speed train carriage, and a 7N01P-T4 alloy, used for its better strength as a chassis material, are welded together by MIG welding. For reliable design and for optimal fabrication, the impact of welding heat on the microstructure and the mechanical properties of the two alloys in different zones adjacent to the joint needs to be characterized and understood.

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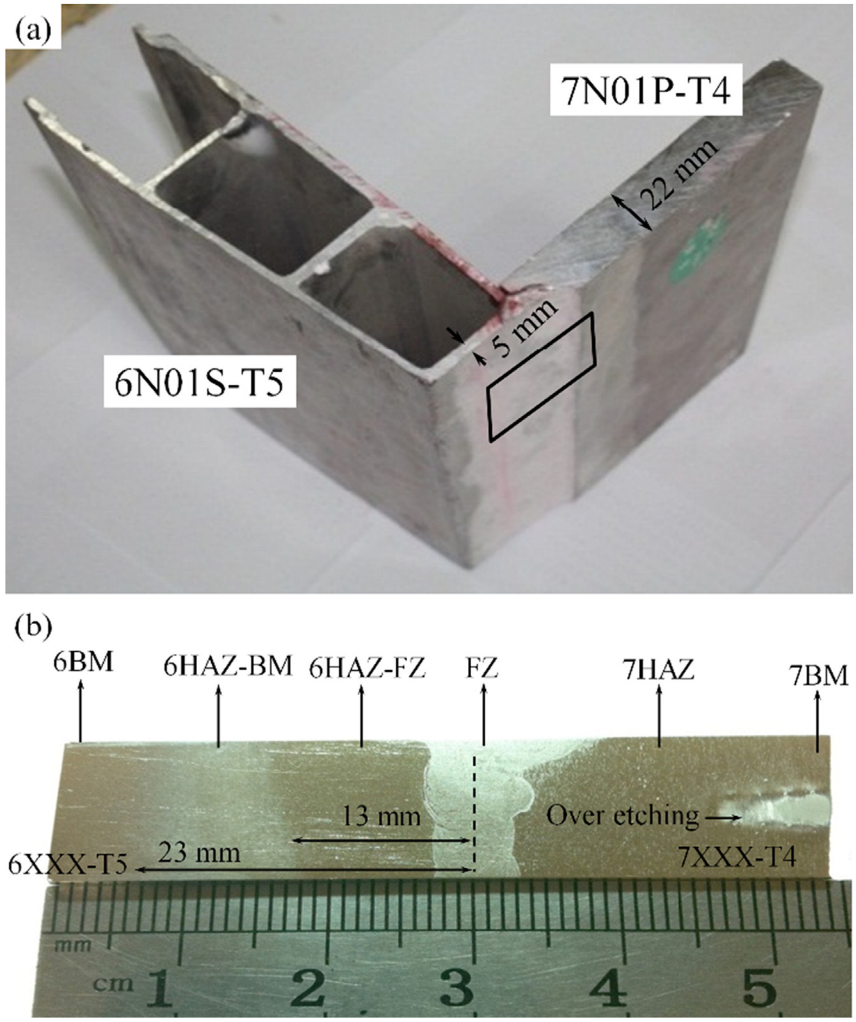

Fig. 1. The 6N01S-T5 - 7N01P-T4 welded sample. (a): optical image of the weldment. (b): optical image of the cut-out sample after electrochemical polishing.

2. Experimental details

The Al alloys used are 6N01S-T5 and 7N01P-T4 (Japanese Industrial Standards H4100). The 6N01S-T5 alloy was in an extruded form as shown in Fig. 1. The T5 code refers to a condition involving cooling from hot working temperature and then artificially ageing at an elevated temperature. The 7N01P-T4 alloy used was a cold-rolled plate of 22 mm in thickness. The T4 code refers to solution heat treated and naturally aged condition. The chemical compositions of the two alloys were determined by means of X-ray fluorescence spectrometry and are given in Table 1. The two base alloys were joined using MIG welding with an ER5356 filler alloy (standard AWS/SFA A5.10) at a welding rate of 55 cm/min. The heat input of the welding was estimated to be 9327 J/cm along the weld line, using the equation of $H = 60\frac{UI}{V}$, where U is the voltage, I is the electric current and V is welding speed in cm/min. The welding parameters used were $U = 30$ V, $I = 285$ A and $V = 55$ cm/min.

Electron backscatter diffraction (EBSD) analysis was conducted on the weldment to characterize the microstructure of the various heat affected zones. A sample of 10×54 mm^2 were cut across the weld line, as shown in Fig. 1(a) and (b). Vickers hardness was also measured using the same sample. Mechanical properties of different zones were measured in tension with a strain rate of ~10^{-4}/s. Samples for transmission electron microscopy (TEM) analysis were prepared from small thin plates spark cut from the weld joint. The plates were first mechanically reduced to ~30 μm in thickness by grinding. The ~30 μm thin sheet was then punch cut into 3 mm diameter disc specimens and finally electrochemically polished using a twin jet polisher in a 30 vol.% nitric acid-methanol solution at −20 °C.

EBSD tests were conducted using a FEI Quanta 250 scanning electron microscope (SEM). Grain orientation distribution was registered using a TSL-EDAX EBSD system with an angular accuracy of 0.5° [21]. The beam size was ~10 nm. EBSD measurements were conducted at an accelerating voltage of 20 kV and a step size of 1 μm (i.e., with a pixel size of 1×1 μm^2 for spatial resolution). The more detailed description of the EBSD experiment can be found in reference [22]. TEM analysis was conducted using a JEOL 2010 microscope at an accelerating voltage of 200 kV.

Table 1
Chemical compositions (wt.%) of the 6N01S and 7N01P base metals.

Base metal	Mg	Si	Mn	Fe	Cr	Zn	Al
6N01S	0.47	1.2	–	0.39	–	–	Balance
7N01P	1.3	0.2	0.3	0.092	0.32	4.8	Balance

3. Results and discussion

3.1. Mechanical properties of the weldment

Fig. 1(a) shows the 6N01S-7N01P welded sample. A specimen for hardness and EBSD measurements was cut from the sample, as