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Microstructures and mechanical properties of Gas Tungsten Arc Welded joints of new Al–Mg–Sc and Al–Mg–Er alloy plates

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ABSTRACT

The effect of microalloy element Sc and Er on Gas Tungsten Arc Welded (GTAW) joints of Al–Mg alloy was studied by comparative method. The microstructures and mechanical properties of Al–Mg–Sc and Al–Mg–Er alloy welded joint were examined by microhardness measurement, tensile test, optical microscopy and transmission electron microscope. The strength of Al–Mg–Sc welded joint is higher than that of Al–Mg–Er welded joint. The differences of the two welded joints can be attributed to the different thermal stability and the effect of $Al_3(Sc_{1-x},Zr_x)$ particles and $Al_3(Er_{1-x},Zr_x)$ particles. $Al_3(Sc_{1-x},Zr_x)$ particles, which have higher thermal stability, are still coherent with Al matrix in the HAZ, can strongly pin dislocations and subgrain boundaries of the HAZ. There are strain strengthening and precipitation strengthening in the HAZ of Al–Mg–Sc welded joints. Notable coarsening of $Al_3(Er_{1-x},Zr_x)$ particles and recrystallization in the HAZ of Al–Mg–Er welded joint lead to the reduction and disappearance of strain strengthening and precipitation strengthening.

1. Introduction

Al–Mg alloys have got wide attention in automobile and aeronautic industries due to their moderate strength, excellent corrosion resistance and weldability [1–3]. Because Al–Mg alloys belong to non-heat treatable alloy, working hardening and microalloy have been widely carried out to improve their mechanical properties [2,3]. Many research show that combined addition of Sc and Zr can greatly improve mechanical properties of Al–Mg alloys due to the formation of fine and dispersed $Al_3(Sc_{1-x},Zr_x)$ particles. $Al_3(Sc_{1-x},Zr_x)$ particles act as heterogeneous nuclei, and the grains of cast ingot can be refined greatly. In addition, $Al_3(Sc_{1-x},Zr_x)$ particles have good thermal stability, they are coherent or semi-coherent with the Al matrix, the dislocations and subgrain boundaries can be strongly pinned by $Al_3(Sc_{1-x},Zr_x)$ particles, which contribute to the improvement of microstructure and mechanical properties of Al–Mg alloys [3–7]. However, the high price of Sc impedes the extensive commercial application of Sc-containing aluminum alloys. Er, another microalloy element, has attracted attention today due to its lower price and similar positive effects like Sc on the aluminum alloys [8–11]. Some researchers think that Er can replace Sc to refine grain of cast ingot and enhance the strength of Al–Mg alloy. But up to now it is not clear whether the microalloy element Er has the same effect as the microalloy element Sc, and which of the two microalloy elements is better for the microstructure and mechanical properties of GTAW joints of Al–Mg alloys.

GTAW is a conventional and preferred technology for aluminum alloy welding because it is economical and applicable. And the weldments processed by GTAW bear higher strength, more ductility and higher reliability than those processed by Gas Metal Arc Welding (GMAW), there are no apparent microstructure defects in the weldments processed by GTAW [12].The efficient welding process can simplify product design and decrease the cost, it has important effect on the application of aluminum alloys. The microstructural characteristics of the welded joint are important in understanding the relation between welding process and properties of welded joint. Previous studies indicate that the fusion zone of GTAW joint exhibits typical coarse columnar grains after welding thermal cycle, which results in inferior weld mechanical properties and poor resistance to hot cracking [13]. At the same time, It is proved that the microalloy elements Sc, Er, Zr in Al–Mg alloy mainly exist in the form of $Al_3(Sc_{1-x},Zr_x)$ or $Al_3(Er_{1-x},Zr_x)$. These precipitates have significant impact on grain refining, eliminating hot cracking and strengthening of the fusion zone (FZ). They can also inhibit recrystallization in the HAZ by

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pinning dislocations and subgrain boundaries [13–17]. All these effects of $Al_3(Sc_{1-x},Zr_x)$ or $Al_3(Er_{1-x},Zr_x)$ particles contribute to improving the mechanical properties of GTAW joint.

Previous studies mainly focus on the comparison of welding process between GTAW and FSW of Al–Mg–Sc or Al–Mg–Er alloy. Few comparative investigations have been reported about the effect of minor Sc and Er on the microstructure and mechanical properties of Al–Mg–Mn alloy GTAW joint. In this study, the effects of Sc and Er on microstructure and mechanical properties of Al–Mg alloy GTAW joints are compared and evaluated.

2. Materials and methods

The chemical composition of base metals are Al–6.1Mg–0.4Mn–0.25Sc–0.12Zr (wt%) and Al–6.1Mg–0.4Mn–0.25Er–0.12Zr (wt%). The base metals are 2 mm-thick rolled plates annealed at 300 °C for one hour. The GTAW was conducted at China Aerospace Research Institute of Materials Processing & Technology, and the welding wire was Al–Mg–Mn–0.35 wt%(Sc+Zr) alloy. Fig. 1 shows the sampling locations of the tensile specimens for the base metal and welded joint. The voltage and current of Gas Tungsten Arc Welding was 14 V and 105 A, respectively. The welding speed was 120 mm/min, and the welding shield gas was argon (its flow rate was 12 L/min).

Vickers microhardness measurements were carried out under 0.1 kg load force and 10 s load time on the transverse cross-section of the welded joints by using HVS-1000 digital Vickers microhardness tester. The tensile properties were tested at room temperature on a MTS810 universal testing machine with a tensile velocity of 2 mm/min. All test data were got by at least three parallel samples (or three microhardness points). The specification of the tensile specimens is shown in Fig. 2. Optical observation was conducted on POLYVER-MET metallographic microscope, and the measurement of mean grain size was carried out by the line intercept method. The thin foils for transmission electron microscopy (TEM) were prepared by MTP-II twin-jet polishing with an electrolyte consisting of 30% HNO_3 and 70% methanol. The foils were observed on a TECNAI G^2 20 transmission electron microscope.

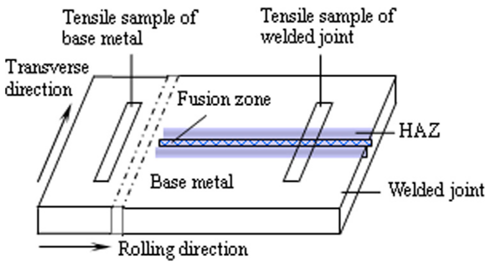

Fig. 1. Schematic illustration of the specimen sampling.

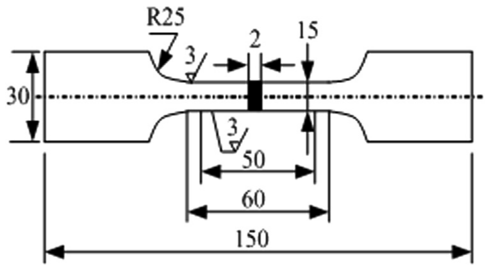

Fig. 2. Specification of the tensile specimen (mm).

3. Results

3.1. Tensile property

The true stress–strain curves of base metal and GTAW joint are shown in Fig. 3 and the tensile properties of base metals and welded joints (with reinforcement) are presented in Table 1. The ultimate strength and yield strength of Al–Mg–Er alloy welded joint are 320 MPa and 183 MPa, respectively. The ultimate strength and yield strength of Al–Mg–Sc alloy welded joint are 338 MPa and 238 MPa, respectively, which are higher than those of Al–Mg–Er alloy welded joint. However, the elongation of Al–Mg–Er alloy welded joint is higher than that of Al–Mg–Sc alloy welded joint. Welding coefficient is defined as the ratio of the ultimate strength of welded joint to that of base metal. The welding coefficients of Al–Mg–Sc and Al–Mg–Er alloy welded joints are 70.4% and 76.3%, respectively. The fracture positions of the two welded joints are in the HAZ.

3.2. Microhardness distribution of welded joints

The Vickers microhardness of the two alloys welded joints are shown in Fig. 4. For the two welded joints, the distribution of microhardness is symmetrical about the weld center line. The welded joint is made up of fusion zone (FZ) and heat-affected zone (HAZ). The microhardnesses of base metal of Al–Mg–Sc and Al–Mg–Er alloy are 136 HV and 119 HV, respectively; the microhardness of their fusion zones is the lowest, which is about 85 HV. From the welding center towards the base metal, the microhardness of the two welded joints gradually increases and finally reaches the same value as that of base metal. HAZ lies between

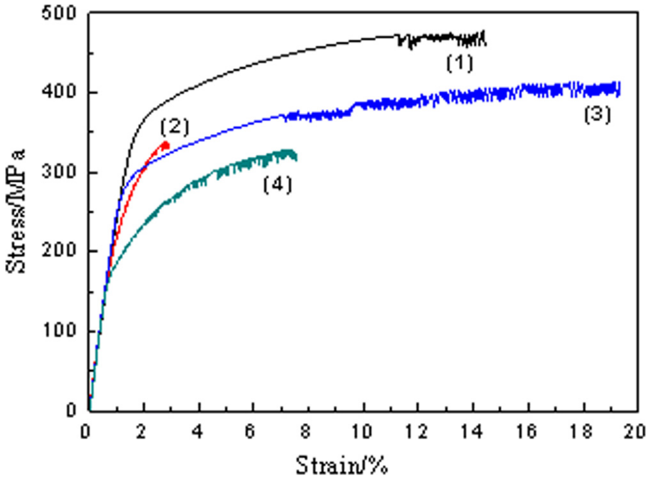

Fig. 3. True stress–strain curves of base metals and welded joints: (1) Al–Mg–Sc base metal; (2) Al–Mg–Sc welded joint; (3) Al–Mg–Er base metal; and (4) Al–Mg–Er welded joint.

Table 1
Tensile mechanical properties of base metals and welded joints with reinforcement (error bars are standard deviation about the mean value of three samples).

Sample		Ultimate strength (MPa)	Yield strength (MPa)	Elongation (%)	Welding coefficient (%)
Al–Mg–Sc	Base metal	480 ± 3	343 ± 1	14.5	–
	GTAW joint	338 ± 2	238 ± 2	3.8	70.4
Al–Mg–Er	Base metal	419 ± 5	284 ± 4	19.0	–
	GTAW joint	320 ± 7	183 ± 5	7.9	76.3