Journal of Materials Processing Technology 214 (2014) 1806–1811

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Development of an 8090/3003 bimetal slab using a modified direct-chill casting process

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ARTICLE INFO

Article history:
Received 20 January 2014
Received in revised form 25 March 2014
Accepted 26 March 2014
Available online 4 April 2014

Keywords:
Al–Li alloy
Bimetal slab
Casting
Mechanical properties
Interface
Heat treatment

ABSTRACT

A modified direct-chill (DC) casting method was used to prepare an 8090/3003 bimetal slab of aluminum alloys with consistent mechanical properties. The interface of the as-cast bimetal material was free of detrimental intermetallic compounds, which indicated excellent metallurgical bonding. A diffusion layer with an average thickness of approximately 80 μm was obtained due to the interdiffusion of Li, Mg, Cu and Mn at the bimetal interface. The average ultimate tensile strength of the as-cast bimetal slab was 101 MPa, and all fractures occurred on the side of the softer 3003 alloy. T6 treatment was performed on the bimetal slab to investigate the response of the slab to heat treatment. The Vickers hardness of the 8090 side increased by 30% after T6 treatment, reaching 153 HV. The Vickers hardness of the interface layer also increased from 70 HV to 89 HV. The solution strengthening was considered to make the primary contributions on the hardness improvement of the bimetal slab at the interface after T6 treatment.

1. Introduction

As reviewed by Kim and Yu (1997), bimetal materials have been widely used in many industrial fields because they combine several promising properties that cannot be provided by monolithic materials. A number of approaches have been developed to fabricate bimetal materials. For instance, Eizadjou et al. (2008) investigated the roll bonding between commercial purity aluminum strips at warm and cold temperatures; Sato et al. (2004) produced a dissimilar friction stir weld of Al alloy 1050 and Mg alloy AZ31; Sexton et al. (2002) clad protective coating materials onto aerospace component substrates by laser cladding. In addition to these methods, DC casting is attracting increasing attention from a cost-effective perspective. Moreover, the DC casting process can yield superior metallurgical bonding between two different alloys. Gupta et al. (2007) prepared an Al–Si alloy and Al–Mn alloy clad ingot using the well-known Novelis Fusion process. Su et al. (2011) fabricated copper clad aluminum rods using horizontal core-filling continuous casting. Sun et al. (2012) investigated the microstructure and properties of an Al–Si alloy and Al–Mn alloy bimetal prepared by continuous casting. Fu et al. (2013) produced an Al–1 Mn and Al–10Si circular clad ingot via DC casting. Liu et al. (2014) prepared a clad hollow billet with an internal layer of 3003 and external layer of 4045 via horizontal continuous casting. However, most clad and core alloys mentioned above are ordinary commercial alloys. Bimetals that contain Al–Li alloys have not yet been reported to the best of our knowledge.

Al–Li alloys have been widely used in military, space and other commercial applications due to their low density, improved specific strength and high stiffness-to-weight ratio compared to other commercial 2XXX and 7XXX series aluminum alloys. According to a report by Lavernia and Grant (1987), the density of aluminum is reduced by approximately 3% for each weight percent addition of lithium, while the elastic modulus is increased by approximately 6%. However, as reported by Lavernia et al. (1990) and Lynch (1991), the application of Al–Li alloys is greatly restricted because they suffer from low ductility and fracture toughness and are susceptible to the damage of intercrystalline corrosion and exfoliation corrosion.

An 8090/3003 bimetal slab was designed in this work. The 8090 alloy, a typical Al–Li alloy, was designed to serve as the load-bearing part. The 3003 alloy, which shows excellent corrosion resistance

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http://dx.doi.org/10.1016/j.jmatprotec.2014.03.029

Table 1
Chemical composition of the experimental alloys in wt.%.

Alloy	Li	Cu	Mg	Zn	Zr	Mn	Al
8090	2.5	1.3	0.95	0.25	0.12	–	Balance
3003	–	–	–	–	–	1.0	Balance

and high ductility, was incorporated to improve the corrosion resistance of the bimetal material. In melting practice, the 8090 alloy is easily oxidized due to the presence of Li. The oxide layer impairs the bonding between the 8090 and 3003 alloys, which complicates the preparation of the bimetal. To solve this problem, a modified DC casting process was developed to prepare the 8090/3003 bimetal slab with superior interfacial bonding. Solution and aging treatments were also performed to investigate the response of this bimetal material to heat treatment.

2. Experimental

8090/3003 bimetal slabs were prepared using a laboratory version of the DC casting process. The chemical compositions of the 8090 and 3003 alloys are given in Table 1. Fig. 1 shows a schematic illustration of the experimental setup. A water-cooled dividing baffle, the elevating speed and water flow rate of which can be manipulated, was placed into the outer mold as an inner mold. A water passage was embedded in one side of the dividing baffle, and the other side was covered with a layer of refractory material to insulate the heat. The relative motion between the bimetal slab and the cooling dividing baffle during the DC casting process was simulated by pulling up the dividing baffle. The 3003 alloy melt was continuously poured into the left section of the mold that contained the water cooled side, as shown in Fig. 1. Once the dividing baffle was drawn upward, the 8090 alloy melt was poured into the right section of the mold under the protection of argon gas. The bimetal slab (150 mm × 120 mm × 100 mm) was finally prepared. Solution treatments were performed at 530 °C for 1 h under an argon atmosphere, followed by water-immersion quenching with a maximum delay of 5 s. Shortly thereafter, the specimens were subjected to an artificial aging treatment at 190 °C for 12 h under an argon atmosphere. This approach is a regular T6 treatment process for the 8090 aluminum alloy.

The specimens were ground, polished and etched using Keller's reagent (1% HF + 1.5% HCl + 2.5% HNO_3 + 95% distilled water) for 20 s. The microstructures of the bimetal slab at the interface were observed using an optical microscope. The chemical composition

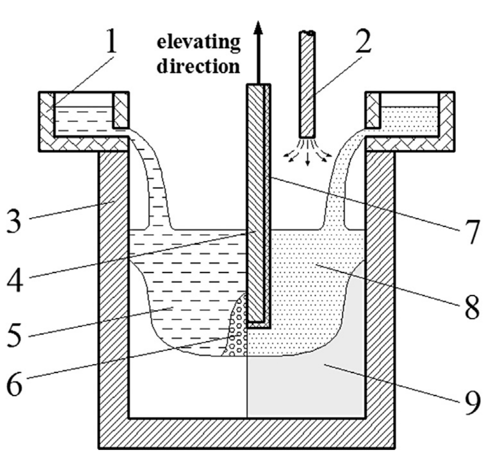

Fig. 1. Schematic diagram of the modified DC casting process: 1 – hot top, 2 – argon gas nozzle, 3 – mold, 4 – water cooled dividing baffle, 5 – 3003 alloy melt, 6 – 3003 alloy semisolid shell, 7 – heat insulation layer, 8 – 8090 alloy melt and 9 – bimetal slab.

variations were examined across the interface by EPMA. A Vickers hardness test was conducted with a load of 100 g for 15 s to examine the bonding strength of the interface. Tensile tests were performed using a ZwickBZ2.5/TS1S test machine with a strain rate of 1 mm min^{-1}. The test was repeated three times and average values were reported for each sample.

3. Results and discussion

3.1. Experimental casting parameters

The melting temperature of the 3003 alloy was slightly higher than that of the 8090 alloy. Therefore, the 3003 melt was designed to solidify with a layer of semisolid shell before being poured in the 8090 melt. This design was intended to prevent the semisolid shell from collapsing in the case with a reverse pouring order. The relatively narrow interval between the liquidus and solidus temperature of the 3003 alloy makes the solidification of a layer of semisolid shell rather difficult to manipulate, and the 8090 alloy is readily oxygenated when exposed to the atmosphere. Therefore, controlling the processing parameters and adopting anti-oxygen measures is necessary. A higher pouring temperature, increasing the speed of the dividing baffle and lowering the cooling water flow rate can result in mixed 3003 and 8090 melt flows. However, a lower pouring temperature, lowering the speed of the dividing baffle and increasing the cooling water flow rate can result in a failure of the metallurgical bonding. Therefore, optimized parameters are required. After a series of orthogonal experiments, the optimized parameters were obtained as listed in Table 2. The 8090/3003 bimetal slabs were successfully fabricated with the optimized parameters.

3.2. Microstructure and composition analysis

Fig. 2 shows the extrinsic feature and microstructure of the bimetal slab near the interface. The 8090 and 3003 materials are distinctly separated, and the interface is clearly identified due to the brightness contrast between the two metals after fine grinding (Fig. 2a). The interface is planar, clean and free from inclusions and porosities. Fig. 2b shows the microstructure of the bimetal slab at the interface. On the 8090 alloy side, the eutectic structure distributes at the grain boundary. According to the EPMA results, the composition of the eutectic structure (wt.%) was 23.7 Cu, 5.3 Mg and 65.4 Al, which was in accordance with the α-Al + Al_6CuLi_3 eutectic phase. On the 3003 alloy side, a few Al_6Mn particles distributed uniformly in the Al matrix.

When the 3003 melt contacted the water-cooled side of the clapboard, a layer of semisolid shell was formed that adhered to the cold surface of the clapboard. Once the 8090 melt was poured into the other side, α-Al started to grow on the surface of the 3003 semisolid shell. This process indicates that the 3003 alloy served as a heterogeneous nucleation substrate for the primary α-Al phase of

Table 2
Orthogonal experiments and the optimized parameters.

Parameters	Values	
	Experimental	Optimized
Pouring temperature of 3003 alloy (°C)	680, 690, 700, 710, 720	700
Pouring temperature of 8090 alloy (°C)	680, 690, 700, 710, 720	710
Dividing baffle elevating speed (mm min^{-1})	50, 60, 70, 80	70
Cooling water flow rate (L h^{-1})	120, 140, 160, 180	160