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Microstructure and mechanical properties of overcast aluminum joints

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Abstract: The aluminum joints were prepared by overcasting liquid aluminum A356 onto 6101 aluminum extrusion bars. The microstructure, element distribution, hardness and tensile strength of the joint interface area were investigated, the mechanism of interface formation and fracture behavior were analyzed. The results show that good metallurgical bonding was formed in the joints by electro-plating the solid 6101 aluminum alloy with a layer of zinc coating and carefully controlling the overcasting process. There is a transition zone between the two bonded aluminum alloys, and the fine equiaxed grained structure in the transition zone is due to the high undercooling during solidification. The tensile strength of the joint interface is higher than that of the as-cast A356 aluminum alloy (about 145 MPa) and the final fracture is always located in the as-cast A356 material.

Key words: aluminum alloy; overcasting; interface; microstructure; mechanical properties

1 Introduction

Metal joining has been extensively used in industries to develop advanced functional and structural materials [1−4]. Materials possess combination of required characteristics can be produced by joining similar and dissimilar materials. Several methods have been reported in fabricating Al−Al metal joints. These methods can be mainly divided into three categories: 1) solid−solid bonding method, such as brazing [5], explosive bonding [6] and cold roll [7,8]; 2) Solid−liquid bonding method, like compound casting [9,10], overcastting [11]; 3) Liquid−liquid bonding method, such as continuous casting bonding [12,13].

Overcasting is defined as a process via which two metallic materials (one in solid state, the other in liquid state) are brought into contact with each other in such a manner that a reaction zone forms between the two materials and thus a continuous metallic transition occurs from one metal to the other [6]. Because of its high efficiency and low manufacturing cost, this method has drawn great attention in a variety of systems, such as aluminum and cast iron [14], aluminum and steel [15], aluminum and copper [16,17], cast iron and steel [18,19], magnesium alloy and aluminum alloy [11,20] , stainless steel and structural alloy steel [21]. However, the application of such method in aluminum alloys is still very limited since solid aluminum alloys are always naturally covered with an aluminum oxide film, which is thermodynamically stable and not easily wettable by metallic melts [9,10]. PAPIS et al [9] presented a promising approach of joining aluminum alloys by replacing the oxide layer with a zinc coating. Besides zinc coating can successfully inhibit the reoxidation, the low melting temperature (420 °C) and high solubility of zinc in aluminum at elevated temperature can also prevent it from aggregating around the interface. These are crucial properties to make zinc well suited as coating material. However, few studies have been reported so far on aluminum joining and joint interface characterization, mechanical properties of the overcast aluminum joints and bonding mechanism of solid−liquid bonding [10].

6101 aluminum alloy has high strength, excellent thermal and electrical conductivity, while A356 aluminum alloy has good castability. A356 aluminum alloy–6101 aluminum alloy bimetal can combine their advantages. Therefore, in this work, 6101 aluminum

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alloy and A356 aluminum alloy bimetal was fabricated by solid−liquid bonding (overcasting) method. The overcast joints were investigated by metallographic examination, chemical element analysis and mechanical tests. The mechanism of interface formation and fracture behavior were discussed.

2 Experimental

2.1 Materials and overcasting

A commercial 6101 aluminum alloy was used as the solid insert material, and a commercial A356 aluminum alloy was used as the casting material. The chemical compositions of the materials are tabulated in Table 1.

Table 1 Chemical compositions of materials (mass fraction, %)

Alloy	Si	Cu	Mg	Mn	Zn
A356	6.5−7.5	0.2	0.25−0.45	0.1	0.1
6101	0.49	0.23	0.92	0	0
Alloy	Fe	Ti	B	Other	Al
A356	0.2	0.2	0	0.15	Bal.
6101	0.45	0	0	0.1	Bal.

The 6101 aluminum alloy inserts were cut into bars with the dimensions of 60 mm × 10 mm × 2.5 mm, and the surfaces were polished with abrasive paper, then subjected to a series of chemical treatment procedures including degreasing, alkali erosion, acid pickling, the first zinc treatment, and the second zinc treatment. The main purpose of the surface treatment of the aluminum insert material was to remove the natural oxide layer from the surface and to simultaneously prevent the occurrence of reoxidation.

After chemical treatment, the 6101 aluminum alloy inserts were electro-plated in a zinc solution. After electro-plating, the 6101 aluminum alloy bars were pre-seated at the bottom of the mold, then A356 liquid metal was poured into the cylindrical mold (55 mm in diameter and 50 mm in height). The process is schematically presented in Fig. 1. The effect of thickness of the zinc layer, casting temperature and mold temperature on the interface formation between A356 aluminum alloy and 6101 aluminum alloy were evaluated, and it was found that with a 5 μm thick zinc layer and carefully controlling of the overcastting parameters, good metallurgical bonding was formed in the joints.

2.2 Metallographic examination

To investigate the microstructure of the interface region, the samples were subjected to standard metallographic preparation including grinding and polishing. To observe the grain structure, the polished samples were further anodized at 30 V for 30 s in a 2% solution of fluoroboric acid. The anodized samples were then observed with optical microscope and scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS) and electron back scattered diffraction (EBSD).

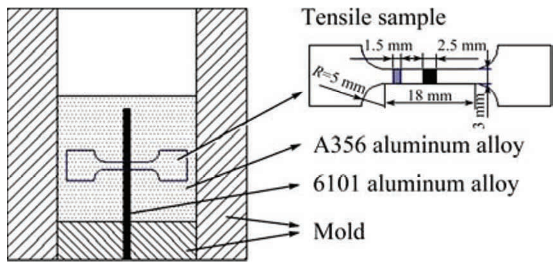

Fig. 1 Schematic illustration of mold and tensile sample

2.3 Mechanical testing

Tensile samples were prepared according to the GB/T228—2002 standard with sandwich structure (A356, interface region, 6101, interface region, A356) in the gauge section, which is shown schematically in Fig. 1. To ensure repeatability, at least three samples were tested in each testing condition. Micro-hardness of the samples was also measured across the joint interface region in the middle part of the bimetal at three different places.

3 Results and discussion

3.1 Coatings

The 6101 aluminum bars were received in rolled condition, which always leaves thick films containing oxides and lubricant remainders on the surface. An appropriate procedure was thus developed by combining several aluminum surface pre-treatments, including degreasing, alkali erosion, acid pickling, first zincate treatment, zinc retreatment and second zincate treatment. The lubricant containers, oxides and pickling layer were removed step by step. Then comes the most important step "zincate process" [22,23]. The use of this process has been widely reported for pre-treatments prior to electro-plating [24]. The process includes two parallel chemical reactions, the first is a etching process with the alkaline solution containing OH^- anions, which removes Al_2O_3 (Eq. (1)). The second is a redox reaction, where Al oxides dissolve and Zn anions reduce and deposite on the aluminum matrix (Eqs. (2)−(5)).

Dissolution of oxide film:

$$Al_2O_3+2OH^- \rightarrow 2AlO_2^- + H_2O \quad (1)$$

Dissolution of aluminum:

$$Al+4OH^- \rightarrow [Al(OH)_4]^- + 3e \quad (2)$$

$$[Al(OH)_4]^- \rightarrow AlO_2^- + 2H_2O \quad (3)$$