Journal of Materials Science & Technology 32 (2016) 298–304

Contents lists available at ScienceDirect

Journal of Materials Science & Technology

journal homepage: www.jmst.org

# Microstructure and Mechanical Properties of Overcast 6101–6101 Wrought Al Alloy Joint by Squeeze Casting

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ARTICLE INFO

*Article history:*
Received 11 March 2015
Received in revised form
25 March 2015
Accepted 10 April 2015
Available online 25 November 2015

*Key words:*
Aluminum alloy
Overcasting
Squeeze casting
Interface
Microstructure
Mechanical properties

The wrought Al alloy–wrought Al alloy overcast joint was fabricated by casting liquid 6101 Al alloy onto 6101 Al extrusion bars and solidifying under applied pressure. The joint interfacial microstructure was investigated; the effect of applied pressure on the microstructure and mechanical properties was evaluated. The mechanism of joint formation and mechanical behaviors of both squeeze cast 6101 and 6101–6101 overcast joint material were analyzed. The results show that with the application of pressure during solidification process, wrought Al alloy 6101 could be cast directly into shape successfully. Excellent metallurgical bonding was then formed in the overcast joint by electro-plating 6101 solid insert with a layer of zinc coating, and a transition zone formed in the joint region. During the tensile test, the fracture occurs in the 6101 solid insert part with the ultimate tensile strength (UTS) of 200 MPa, indicating that the strength of the overcast joint is higher than 200 MPa, and the tensile strength of overcast joint material is independent on the magnitude of applied pressure. For Al–Al overcast joint material, if a clean and high strength joint is formed, the UTS and yield strength (YS) are determined by the material with the lower value, while for EL, the value is determined by the length proportion and the stress–strain behavior of both components.



## 1. Introduction

Aluminum materials are widely used to take advantage of their low density, corrosion resistance and combination of strength and formability, especially in the automotive and aerospace industries for lightweight applications[1]. Consequently, there is increasingly joining involved situations[2]. Several methods have been reported in fabricating Al–Al metal joints. These methods can be mainly divided into three categories: (i) solid–solid bonding, such as explosive welding[3,4], laser welding[5], friction stir welding[6,7], rolling[8,9], and surface activated bonding[10]; (ii) solid–liquid bonding, like overcasting[11–13]; and (iii) liquid–liquid bonding, like continuous casting bonding[14,15].

Overcasting is defined as a production technology where two metals, one in solid state while the other in liquid state, are brought into contact with each other, then a continuous metallic transition occurs from one metal to the other[16], which is also known as compound casting or solid–liquid casting. Due to its design flexibility, mass saving, manufacturing efficiency and low production cost, it has drawn great attention in a variety of systems recently. Hajjari et al.[17] prepared lightweight Al/Mg couples with compound casting method. The interfacial microstructure was well characterized, and the relationship between the interfacial structure and shear strength was analyzed. Durrant et al.[18] produced Al–steel bimetal with squeeze casting method. A sound interface was obtained by interaction of the two metals, the interface region was well characterized and the mechanical properties were evaluated. Compound cast Mg–Mg joints were fabricated by Papis et al.[19]. A continuously metallurgic, defect-free and well-defined transition between AZ31 substrate and AJ62 magnesium cast alloy was achieved. However, overcast liquid metal onto Al substrate to make metal joints is difficult to prepare because solid aluminum is always naturally covered with an oxide film, which is thermodynamically stable and not easily wettable by metallic melts. The oxide film cannot be dissolved during the process and prevents the formation of a metallic bonding. Current overcasting structures rely on the "shrink-fit" between the casting layer and the substrate due to the large solidification shrinkage during overcasting, resulting in a relatively strong mechanical bond or interlock at the interface[20].

A lot of attention has been paid on exploring new surface treatment to prepare Al solid insert involved in overcast joint. Zhang et al.[20] developed an "electropolishing + anodizing" surface treatment

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http://dx.doi.org/10.1016/j.jmst.2015.11.020

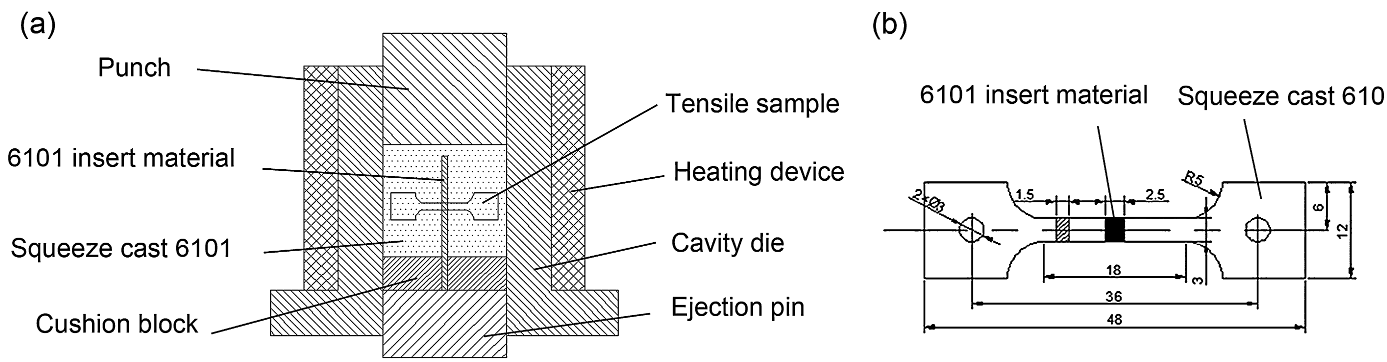


**Fig. 1.** Schematic illustration of the mold (a) and the tensile specimens in mm (b).

to disrupt the oxide film on the surface of Al–1 wt% Sn alloy, improving the wetting and metallurgical bonding between molten Mg and Al–1 wt% Sn substrate in bimetallic experiment. Another promising approach to prepare overcast Al joint was presented by Papis et al.[16] by replacing the oxide layer with a zinc layer. Joints of AlMg1 substrate and various Al alloys are produced on a laboratory scale in an Ar 6.0 atmosphere under controlled thermal conditions. Based on Papis's method, Rübner et al.[11] and Koerner et al.[21] focused on the realization of overcast Al–Al joint by high pressure die casting.

However, to our best knowledge, limited studies have focused on wrought Al alloy–wrought Al alloy overcast joint because when wrought Al alloy is subjected to casting process, a large number of shrinkage porosities will be produced within its microstructure due to its long solidification range[22]; besides, cracks will occur because of its high heat crack trend[23]. In recent researches, many wrought Al alloy compositions have successfully been cast directly to shape by squeeze casting process[24]. Squeeze casting is a manufacturing process, in which metal is solidified under pressure. Application of pressure on molten metal during solidification may cause a series of effects, such as reduction of gas and shrinkage porosities, reduction of the degree of micro-segregation, change of solidification rate and change of phase diagram[25]. So, in the present investigation, wrought Al alloy–wrought Al alloy overcast joint was prepared by squeeze casting method. The work was conducted on 6101 aluminum alloy, which is extensively used for its high strength and excellent thermal and electrical conductivity. The overcast joint was fabricated by casting liquid 6101 Al alloy onto 6101 Al extrusion bars and solidifying under applied pressure. The effect of applied pressure on microstructure and mechanical properties of the 6101–6101 overcast joint was investigated. The mechanism of interface formation and fracture behavior were discussed.

## 2. Material and Method

### 2.1. Material and surface treatment

Commercial 6101 aluminum alloy (Al–0.49 wt% Si–0.23 wt% Cu–0.92 wt% Mg–0.45 wt% Fe) was used to produce wrought Al alloy–wrought Al alloy overcast joint. The solid inserts were received in rolled condition, before the squeeze casting procedure; the inserts were cut into rectangular bars with a dimension of 60 mm × 10 mm × 2.5 mm. In order to remove the lubricant remainders and natural oxide films on the surface, the solid inserts were subjected to a series of mechanical and chemical pretreatments, including polishing with abrasive paper, degreasing, alkali erosion, acid pickling, first zinc treatment, zinc retreatment and second zinc treatment. Electro-plating method was then operated onto the insert material to develop a uniform zinc layer with a thickness of about 5 μm.

### 2.2. Overcasting

An 80-ton vertical hydraulic press was used for direct squeeze casting. The mold was preheated to 250 °C. Before squeeze casting procedure, the electro-plated 6101 aluminum alloy insert was pre-seated at the bottom of the mold; then liquid 6101 Al alloy melt was poured into the mold, and solidified under different applied pressures. The values of applied pressure varied from 0 to 90 MPa. The wrought Al alloy–wrought Al alloy overcast joint was thus produced by squeeze casting method. The samples were received with a dimension of Φ 55 mm × 50 mm. The process is schematically presented in Fig. 1(a).

### 2.3. Metallographic examination and mechanical testing

Tensile samples for both 6101–6101 overcast joint material and squeeze cast 6101 were took from the middle part of the cylindrical sample, then cut into rectangular tensile specimens according to the ISO 6892-1:2009 standard[26]. The tensile specimen of 6101–6101 overcast joint material has a sandwich structure (squeeze cast 6101–overcast joint–6101 solid insert-overcast joint–squeeze cast 6101) in the gauge section, which is shown schematically in Fig. 1(b). Tensile testing was carried out on a Zwick/Roell-20 kN material test machine at a strain rate of $8.33 \times 10^{-4}$ $s^{-1}$ at ambient temperature. To insure repeatability, at least three samples were tested in each testing condition. Hardness was also measured across the interface region. Microstructure samples were prepared with standard metallographic procedure and etched with Keller etchant (5 mL $HNO_3$, 3 mL HCl, 2 mL HF, and 190 mL distilled water) for 20 s. Average grain size is determined according to the ASTM E112-10 standard. Microstructure characterization was carried out with an optical microscope (OM) and a scanning electron microscope (SEM) equipped with an energy dispersive spectroscope (EDS).

## 3. Results and Discussion

### 3.1. Metallographic analysis

The microstructures of the 6101–6101 overcast joints, which were fabricated under different applied pressures, are shown in Fig. 2. It can be observed that there are no defects or discontinuities along the interface. The 6101 solid insert and the squeeze cast 6101 are distinctly separated. The microstructure of 6101 solid insert shows typical rolled structure consisting of fine elongated grains. The microstructure of squeeze cast 6101 shows rosette-like α-Al grains and uniformly dispersed eutectic phase in the intergranular spaces. The eutectic phase consists of α-Al, $Mg_2Si$ and AlFeSi[27,28].