Journal of Materials Processing Tech. 250 (2017) 65–72

Contents lists available at ScienceDirect

Journal of Materials Processing Tech.

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

Joining of 1060/6063 aluminum alloys based on porthole die extrusion process

Xiangkun Fan, Liang Chen*, Gaojin Chen, Guoqun Zhao, Cunsheng Zhang

Key Laboratory for Liquid-Solid Structural Evolution and Processing of Materials (Ministry of Education), Shandong University, Jinan, Shandong 250061, PR China

ARTICLE INFO

Keywords:
Joining
Porthole die extrusion
Microstructure
Texture

ABSTRACT

The microstructure and mechanical properties of 1060/6063 Al alloys joint fabricated by porthole die extrusion were investigated. A sound welding interface of 1060/6063 Al alloys was obtained, and the welding quality can be further improved using higher welding chamber. Complete dynamic recrystallization (DRX) occurred during porthole die extrusion, while the DRXed grain size of 6063 Al matrix was always much smaller than that of 1060 Al matrix. The height of welding chamber had an significant effects on the microtexture of the extruded profiles. The profiles extruded using welding chamber with a height of 10 mm exhibited highest tensile strength and elongation. On the contrary, the joining of 1060/6063 Al alloys using flat die is not acceptable, where many cracks appeared at the welding interface and only partial DRX occurred.

1. Introduction

Friction stir welding (FSW) can join materials without melting, and thus it significantly reduces the defects of air holes and large heat affected zone (Sharma et al., 2015). The welding residual stress and post deformation is slight after FSW, and the dynamic recrystallization (DRX) can occur to enhance the microstructure and mechanical properties of the joints (Sun et al., 2017). Many researchers have employed FSW to fabricate the joints of dissimilar materials. Ahmed et al. (2017) studied the microstructure and mechanical properties of 7075/5083 Al alloys using FSW under various traverse speeds. Yan et al. (2016) employed FSW to join Al-Mg-Si and Al-Zn-Mg alloys, and investigated the influences of sheet configuration on the quality of the joints. Luo et al. (2016) applied FSW to join dissimilar Mg alloys, and the relationships between microstructure, texture and mechanical properties of the joints were reported. Kimura et al. (2017) discussed the effects of friction welding condition on the joints of pure Al and austenitic stainless steel. FSW has been successfully applied in joining dissimilar materials. However, some shortcomings of FSW should be paid high attention, such as the abrasion and short lifetime of stir tools, inferior surface quality and high cost.

In recent years, some technologies were developed based on plastic forming processes, especially hot extrusion, to join dissimilar materials or produce composite plates. Tokunaga et al. (2014) fabricated a Mg alloy sheet with Al coating using hot extrusion and subsequent hot forging processes, and the sheet exhibited superplastic behavior due to the good bonding of Al/Mg interface. Wu et al. (2015) put Al alloy into a Mg hollow cup to make a bimodal billet for hot extrusion, and a well bonded Al/Mg laminate was fabricated. Similarly, using this kind of bimodal billet and hot extrusion, Al/Mg composite rod (Priel et al., 2016) and Al/Cu composite rod (Khosravifard and Ebrahimi, 2010) were produced. These previous studies proved that the sound joint or interface of dissimilar materials can be obtained using hot extrusion process. However, the preparation of bimodal billet for extrusion is usually complex and material wasting, which limits its application in practical production. Moreover, the oxidation and impurities existing on the initial interface of dissimilar materials cannot be well removed, which might affect the mechanical properties of the extruded joint.

In this study, it is attempted to develop a method based on porthole die extrusion to join dissimilar Al alloys. Porthole die extrusion is widely applied to produce hollow profiles due to its high efficiency and flexibility (Chen et al., 2015). Fig. 1 shows the material flow behaviors during porthole die extrusion process, where ED indicates the extrusion direction. The heated billet is split into several fresh streams by portbridge, and then these streams are solid bonded in welding chamber. Finally, the profile is extruded out from the die orifice. Although the longitudinal weld seams are formed along the whole length of the profile, the excellent welding quality can be obtained when the extrusion die and process parameters are well controlled (Liu et al., 2008). It is considered that the dissimilar materials might also be well joined using porthole die extrusion. The first reason is that the split metal streams are fresh without oxidation and impurities. Secondly, the materials inside welding chamber experience high temperature, high pressure and almost vacuum atmosphere, which is beneficial for solid

* Corresponding author.
E-mail address: chenliang@sdu.edu.cn (L. Chen).

http://dx.doi.org/10.1016/j.jmatprotec.2017.07.009
Received 5 May 2017; Received in revised form 29 June 2017; Accepted 7 July 2017
Available online 10 July 2017
0924-0136/

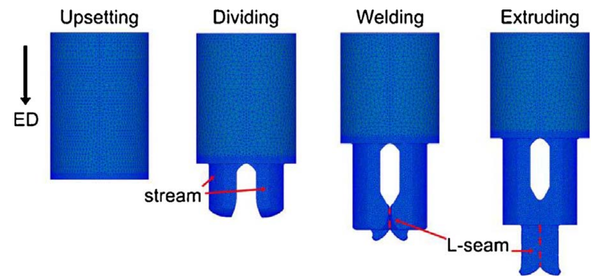

Fig. 1. Material flow behavior during traditional porthole die extrusion process.

bonding and microstructure improvement.

In this study, the porthole die extrusion was employed to join 1060/6063 Al alloys. The welding chambers with different heights (h) of 10 and 5 mm were attempted, and a flat die extrusion was conducted for comparison. The welding interface was observed by scanning electron microscope (SEM). The grain morphology and texture of the initial alloy and extruded profiles were examined using electron backscatter diffraction (EBSD). The tensile tests and fracture observation were carried out to evaluate the mechanical properties of the joints. The results showed that a sound joint of 1060/6063 Al alloys with excellent surface quality was obtained using porthole die extrusion, and the microstructure was greatly improved due to the occurrence of complete DRX. The present study provide a new point of view on the joining of dissimilar materials.

2. Experimental procedure

The designed experimental setup is shown in Fig. 2(a). The setup mainly consists of stem, ram, container, upper die, bridge, and lower die. The container was designed to have two cavities with the inner diameter of 24 mm. The diameter and height of upper/lower dies are 90 and 30 mm, respectively. An even bearing length of 4 mm was utilized. The welding chambers with the heights of 10 and 5 mm were attempted to investigate its effects on the welding quality of the extruded profiles. According to the method previously reported by He et al. (2016), a flat die extrusion setup was designed to make a comparison, where two half dissimilar billets were placed into the container, as shown in Fig. 2(b).

The chemical compositions of two Al alloys for extrusion experiment are listed in Table 1. The as-cast 6063 billet was received, and the homogenization treatment was carried out at 480 °C for 12 h. The 1060 alloy was received in extruded state. In order to achieve a comparable initial grain size of two alloys, the extruded 1060 alloy was held at 500 °C for 6 h and then quenched into iced water. After preparation of two alloys, the cylindrical billets with a diameter of 24 mm and height of 45 mm were machined for porthole die extrusion. The extrusion were conducted using a pressuring machine of 200 t. A heating coil was used to heat the container, billet and dies, and a thermocouple was inserted into the container for temperature measurement. The experimental temperature was set to be 480 °C, and the ram velocity was kept at 0.1 mm/s during the whole extrusion process. After experiment, the extruded profile was cooled to room temperature in the air.

Table 1
Chemical compositions of the as-received 1060 and 6063 Al alloys.

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
1060 Al (wt.%)	0.09	0.04	0.04	0.05	0.05	0.02	0.02	Bal.
6063 Al (wt.%)	0.45	0.35	0.10	0.10	0.80	0.10	0.10	Bal.

The plate-shaped profiles with a cross section of 18 × 5 mm were obtained from extrusion, and the welding interface was formed in the mid-plane of the profile parallel to ED direction, as schematically shown in Fig. 3. The profiles extruded using welding chamber of h = 10 mm and h = 5 mm are named as profile A and profile B, respectively. Similarly, the profile extruded using flat die is named as profile C. The positions of specimens for microstructure observation and tensile test are marked in Fig. 3. The specimen at the position of 100 mm away from profile front was prepared for SEM and EBSD analysis. For SEM observation, the specimen was etched by a solution of 5 ml HF and 95 ml H_2O after grinding and polishing. In case of EBSD analysis, the specimens were processed by electro polishing in the solution of 30 ml nitric acid and 70 ml methanol at 12 V for 20 s. The tensile specimen was machined perpendicular to ED direction, and the welding interface was located in the gauge of the specimen. It should be noted that the dimension of tensile specimen is not compliant with the standard due to the limited size of the extruded profile, while the results of the tensile tests should be suitable for comparison between different cases. The tensile tests were carried out at a constant stretching rate of 0.45 mm/min at room temperature, and the tensile fracture surface was observed by SEM.

3. Results and discussion

3.1. Initial microstructure

Fig. 4 presents the EBSD inverse pole figure maps and relative frequency of misorientation angles of initial 1060 and 6063 Al alloys. The grey lines indicate low angle grain boundary (LAB) with misorientation angle between 2 and 15°, and the black lines indicate high angle grain boundary (HAB) with misorientation angle higher than 15°. The fraction of LABs is defined by f and the misorientation angle smaller than 2° is excluded. It can be seen that the majority of both alloys consists of coarse equiaxed grains, and the average grain size of 1060 and 6063 Al alloys is around 36 and 77 μm, respectively. It is noted that the grain

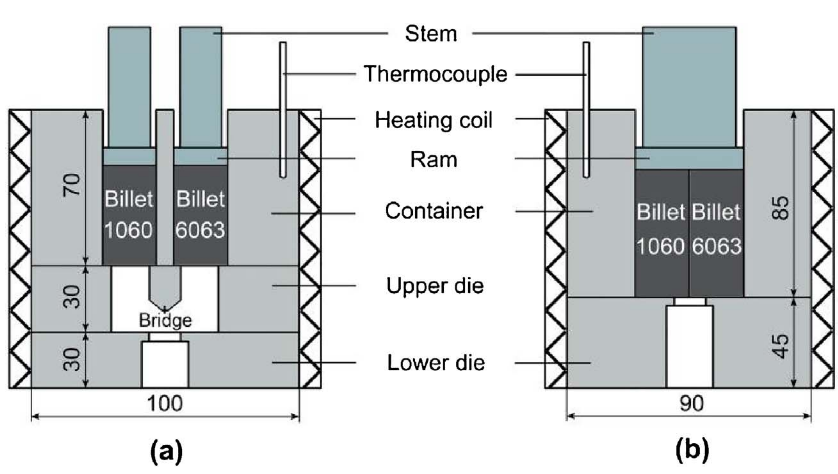

Fig. 2. Schematic diagram of the experimental setup: (a) porthole die extrusion, and (b) flat die extrusion. (Unit: mm).