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Effect of friction welding condition on joining phenomena and mechanical properties of friction welded joint between 6063 aluminium alloy and AISI 304 stainless steel

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ABSTRACT

Dissimilar metal joints have some advantages such as high functionality characteristics for the industrial usage. This paper describes the effect of friction welding condition on joining phenomena, tensile strength, and bend ductility of friction welded joints between Al-Mg-Si alloy (AA6063) and austenitic stainless steel (AISI 304). When joints were made at a friction pressure of 30 MPa with a friction speed of 27.5 s^{-1}, the upsetting (deformation) occurred at the AA6063 side. The temperature on the weld interface increased with friction time, and it reached to 623 K or over at a friction time of 1.5 s or longer. When joints were made with a friction time of 1.5 s and a forge pressure of 240 MPa, all joints had the joint efficiency of approximately 100% and the fracture in the AA6063 base metal. Furthermore, those joints had the bend ductility of 90° in a single direction with no crack at the weld interface and did not have the intermetallic compound (IMC) interlayer on the weld interface. To obtain 100% joint efficiency with good joint, the joint should be made with the following conditions: a high forge pressure such as 240 MPa, the opportune friction time that the temperature on the weld interface reached to about 623 K or higher.

1. Introduction

Dissimilar metal joints (referred to as dissimilar joints) have some advantages such as high functionality characteristics for the industrial usage. Since an expansion in the use of dissimilar joints is expected and widely used in various component parts, easy welding method for dissimilar joints is strongly required. The joining between aluminium (Al) and its alloys (referred to as Al-system material) and other materials has some superior interest items, since the dissimilar joints have such advantages as the low cost solutions for the engineering requirements in the industrial usage. However, fusion welding between Al-system material and such other materials as steel [1–3], copper (Cu) [1,4], and titanium (Ti) [5] has poor mechanical properties because of the brittle intermetallic compound (IMC) interlayer produced at the joint interface [6]. In addition, fusion welds between Al-system material and various steels have severe problems, e.g. generating of blowhole and crack at the joint interface [1–3]. Therefore, a welding process for the joint between Al-system material and other material, which will result in less degradation of the mechanical and metallurgical properties, is urgently required. The solid state joining methods such as diffusion welding, friction welding, and so on, can be applied to join Al-system material and other metals [7]. In particular, a friction welding method is suitable for minimizing heat input in the welding.

In the preceding work [8], the authors clarified the joining mechanism during the friction welding process between commercially pure Al (CP-Al) and American Iron and Steel Institute (AISI) standard type 304 austenitic stainless steel. Furthermore, the friction welding condition for the joint, which had the bend ductility of 90° with no crack at the weld interface by bending test as well as the fracture on the CP-Al side by tensile test, was established. However, it can be considered that the range in application of pure Al will be narrow in comparison with Al alloy, since the strength such as ultimate tensile strength of Al alloy is higher than that of pure Al. If combinations of dissimilar materials such as Al alloy and stainless steels can be joined using the same method as that shown in the preceding report [8], the joining mechanism of its will be clarified. In particular, clarifications of the joining mechanism and the joint mechanical properties are strongly required concerning the weldability of Al alloy and other metals because an expansion in the use of Al alloy is expected. Then, it is especially useful for the joint of this combination as the structural applications in various engineering

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Table 1
Chemical compositions and mechanical properties of materials used.

(a) A6063

Chemical compositions, wt.%								Mechanical properties		
Si	Fe	Cu	Mn	Mg	Zn	Ti	Al	UTS, MPa	0.2% YS, MPa	El., %
0.43	0.18	0.00	0.03	0.49	0.00	0.01	bal.	197	166	19

(b) 304SS

Chemical compositions, wt.%								Mechanical properties		
C	Mn	Si	P	S	Ni	Cr	Fe	UTS, MPa	0.2% YS, MPa	El., %
0.05	1.54	0.46	0.03	0.02	8.10	18.22	bal.	680	475	47
0.07	1.50	0.49	0.03	0.03	8.18	18.48	bal.	670	435	57

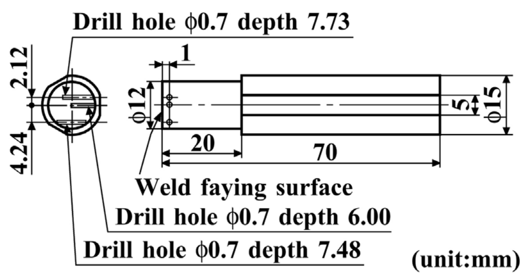

Fig. 1. Shape and dimensions of friction welding specimen of 304SS for measuring temperature change at weld interface.

fields such as automotive and aerospace industries because the use of steel materials which included stainless steels can be reduced.

Some researches on friction welding between Al alloy and stainless steel have been also studied [9–15], as well as many researchers have reported that the mechanical and metallurgical properties of the friction welded joints of pure Al and stainless steels [16–19]. For example, Fukumoto et al. [9] investigated the relationship between the joined area at the weld interface and the joint strength of the joint between AA5052 Al alloy and 304 stainless steel. Reddy et al. [10] and Ashfaq et al. [11] explained the joint strength and the characteristics of the IMC interlayer of the joint between AA6061 Al alloy and 304 stainless steel. Yokoyama [12] investigated the impact tensile properties of the joint with this combination. Sammaiah et al. [13] investigated the tensile strength of the joint between AA6063 Al alloy and stainless steel. Paventhan et al. [14] and Shubhavardhan et al. [15] tried for the establish of the optimum friction welding condition for the joint between AA6082 Al alloy and 304 stainless steel. Nevertheless, the joining mechanism of friction welding between Al alloy and stainless steel has not been fully clarified, so that the friction welding conditions for material combinations are determined by trial and error. Hence, it can be considered that the IMC interlayer can be easily generated at the weld interface between Al alloy and stainless steel as it is also pointed out to the combination between Al-system materials and other material [20]. Furthermore, the friction welding condition of the joint without the fracture from the weld interface will be considered different of between the combination of CP-Al on stainless steel [8] and the combination of Al alloy on stainless steel, so that the condition differs between CP-Al on low carbon steel [21] and the combination of AA5052 Al alloy on low carbon steel [22]. Hence, to weld Al alloy and stainless steels by the experiment is necessary for clarification of the joining mechanism and making good joint without the IMC interlayer.

Based on the above background, the authors have been carrying out research to clarify the joining mechanism during the friction process of dissimilar joints. The authors investigate the joining phenomena during the friction process of friction welds between AA6063 of a typical Al alloy and type 304 stainless steel of a typical austenitic stainless steel in the present work. The authors also show the tensile strength of the friction welded joints under various friction welding conditions, especially the effects of friction time and forge pressure on those. Furthermore, the authors show the friction welding condition for joints that had the bend ductility of 90° with no crack at the weld interface by bending test as well as the fracture on the AA6063 base metal by tensile test.

2. Experimental procedure

2.1. Materials and specimen shapes

The materials used were AA6063 Al-Mg-Si alloy (type JIS A6063BE-T5, referred to as A6063) and AISI 304 austenitic stainless steel (JIS SUS304, referred to as 304SS) in 16 mm diameter rods. The chemical compositions and the ultimate tensile strength (UTS), the 0.2% yield strength (YS), and the elongation (El.) for materials used were shown in Table 1. In this case, two kinds of 304SS having slightly different tensile properties were used for this experiment since they were purchased at different times. All rods were used for this experiment as-received condition. Those rods were machined to 12 mm in a diameter of the weld faying (contacting) surface. The temperature changes at the centreline, half radius, and periphery locations of 1.0 mm longitudinal direction from the weld faying surface were measured using the 304SS specimen for clarification of the temperature during the friction process, which was shown in Fig. 1. In this connection, the sufficient data could be obtained in order to understand the temperature distribution of the radius direction in the weld interface, although the temperature on the weld interface was able to estimate as those or higher. The details of the specimen shape for measuring temperature changes have been described in the preceding report [8]. All weld faying surfaces of the specimens were polished by a surface grinding machine before joining to eliminate the effect of surface roughness on the joint mechanical properties [23].

2.2. Friction welding method

A continuous (direct) drive friction welding machine was used for the joining. A6063 specimen was set to the fixed side and 304SS specimen was set to the rotating side, respectively. During the friction welding operations, the friction welding condition was set to the following combinations: a friction speed of 27.5 s^{-1} (1650 rpm), a friction pressure of 30 MPa, a range of friction times from 0.04 to 5.0 s, a range of forge pressures from 30 to 240 MPa, and a forge time of 6.0 s. To observe the joining phenomena during the friction process and to obtain the joint without the braking deformation, the authors carried out three experimental methods as follows.