MECHANICAL PROPERTIES OF FRICTION WELDED JOINTS BETWEEN DISSIMILAR ALUMINUM ALLOYS

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ABSTRACT 2017 aluminum alloy to 6061 aluminum alloy were welded using a brake type friction welding machine. Microstructures and mechanical properties of friction welded joints were investigated. The fine grain structures and mechanical mixed layer are observed closely near the weld interface. The softened area was observed on the heat affected zone of both alloy side at immediately after welding. The softened area on 2017 alloy side recovered to the same as 2017 alloy base metal after 14 days from welding. But the softened area on 6061 alloy side not recovered. The maximum joint efficiency as rate of the tensile strength is 78.4% that of the 6061 alloy base metal. And the maximum elongation is less than half value of the 2017 alloy base metal. The welded joints which the notch is put into the weld interface show the impact value higher than that of the both base metals.

Keywords : *Friction welding, Dissimilar metals, 2017 aluminum alloy, 6061 aluminum alloy, Microstructures, Mechanical properties*

1. INTRODUCTION

Today the light metals which are fit for various used for purpose of reduce the weight. The other hand, various propertied diversify required for industry products, then it is combined dissimilar metals. If dissimilar metals can be joining easily, then they can be used for various constructions. It can be used in the combination with dissimilar materials, it seems to be advantageous from the point of economy. Many reports were joining of dissimilar materials by friction welding which is one of the solid face bonding [1, 2]. Combination of dissimilar material are both same matrix alloys and different matrix alloys. The author reported that it is comparatively easy to obtain the friction welded joint in the combination of the wrought aluminum alloy to aluminum alloy castings [2]. But aluminum alloy castings are easily to manufacture the complex product, however, they are generally to show lower strength than wrought aluminum alloy. It seemed to be advantageous from the point of strength.

This paper deals applicability of friction welding to dissimilar aluminum alloys, which are 2017/6061 aluminum alloys, by examining the macro- and microstructures and mechanical properties of friction welded joints.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

Both 2017-T4 aluminum alloy and the 6061-T6 aluminum alloy bar of 20 mm in diameter was used after machining it down 80 mm in length and degreasing its welding surfaces with acetone just before welding. Chemical compositions and mechanical properties of the base metals are given in **Table 1** and **Table 2**, respectively.

Table 1 Chemical compositions of base metals. (mass%)

Materials	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
2017	0.45	0.38	4.40	0.56	0.59	0.03	0.07	0.02	bal.
6061	0.67	0.20	0.35	0.02	1.10	0.08	0.01	0.02	bal.

Table 2 Mechanical properties of base metals.

Materials	Tensile strength (MPa)	Elongation (%)	Impact value (kJ/m^2)	Hardness HV0.3
2017	557	16.4	349	132
6061	342	23.5	400	121

Friction welding was performed by using a braking type friction welding machine. The welding conditions are given in **Table 3**. JIS No.4 specimens were used for the tensile test. The impact strength was tested by the Charpy impact tester at room temperature, using the JIS No.3 specimens (U-notched, 2 mm) in which the notch placed at the weld interface. The hardness was measured by the micro Vickers hardness tester (load : 2.9N).

Table 3 Friction welding conditions.

Rotational speed	n (s^{-1})	58
Friction pressure	P_1 (MPa)	50, 60
Friction time	t_1 (s)	2, 3, 4, 5
Upset pressure	P_2 (MPa)	100
Upset time	t_2 (s)	5

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Observation of macro- and microstructures

The macro- and microstructures of the friction welded joint is shown in **Fig.1**. The heat affected zone clearly shows a weld interface taking the shape of a concave lens with its central part constricted. It is recognized clearly at the 6061 alloy side. The fibers structures are pressed forward along the flux of burr in the heat affected zone, and they disappear near the weld interface. They show as same as similar friction welded joints of each alloys [3, 4]. The burr of 6061 alloy side is larger than 2017 alloy side. It is due to the deformationability of 6061 alloy smaller than 2017 alloy. The structure of heat affected zone shown same as similar friction welded joints. On the welding layer, a fibers structure which was observed on the base metals disappears and non-directional fine grain structure appears where a deposit layer is observed along the boundary layer. The original fibrous structures were pressed forward to the outside along the flux of burr on the heat affected zone of outside of the welded joint. The portion where both alloys are mechanical mixed layer are clearly observed at intermediate section of welded joint. But the mechanical mixed layer are not observed on similar friction welded joints [3, 4, 5].

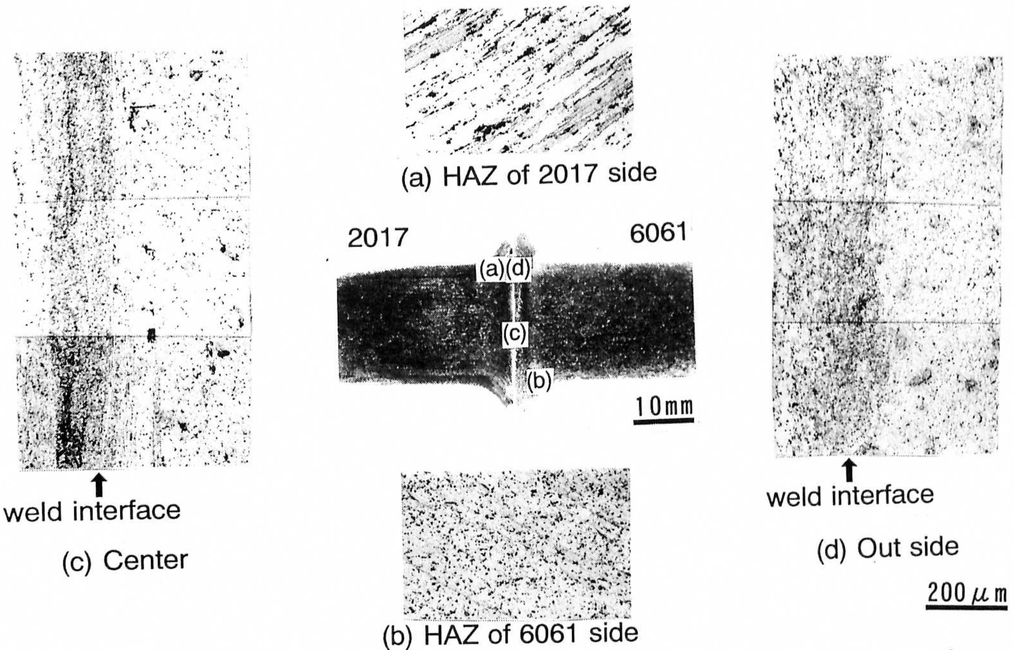

Fig.1 Macro- and microstructures of friction welded joint under conditions of friction pressure of 50MPa and friction time of 2 seconds.

Fig.2 shows the relation between the friction time and total loss. The total loss (difference of the total length of the work piece before welding and length of the welded joint) increased almost lineally with the increase of both friction pressure and friction time. Amount of axial shortening of 6061 alloy side are larger than 2017 alloy side, which is about 65 - 70% of total loss. It was larger than similar joint of 6061 alloy with the same welding conditions as in this test [3].

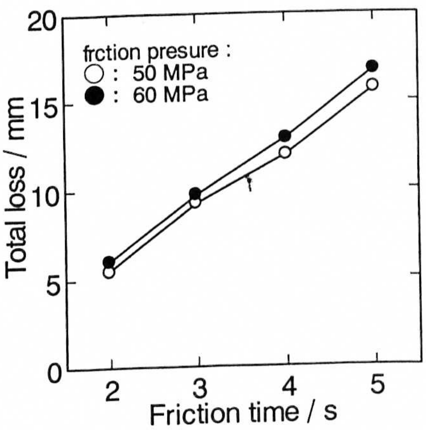

Fig.2 Relation between friction time and total loss.

3.2 Temperature-time histories of the welding process

An example of temperature-time histories of a welding process with friction pressure of 50MPa and friction time of 2 seconds is shown in **Fig.3.** It is measured at 6061 alloy side. It shows the highest value of the tensile strength and elongation in the tensile test to be mentioned later. As show in the figure, in the positions closer to the friction surface the temperature rises rapidly. That is, in the position of 1 mm, the temperature rise suddenly just after the start of welding, then, rises further at a slower constant speed, and reaches the highest value (783K) about 2.3 seconds after the start of the welding slightly before it stops rotation. In the position of 5 mm, the temperature rises sharply in less time than in the position of 1 mm and reaches the highest

value immediately before it stop rotation, through the nearly same process as that in the position of 1 mm. In the position of 20 mm distant from the friction surface, the initial temperature rises slowly where such a behavior as seen in the position of 1, 5 mm is not found. The speeds at which the temperatures rise in the positions of 1 to 5 mm which are close to the weld interface show a similar process. It is considered that the temperature grade moves at a constant speed according to the movement of the friction surface.
It is presumed that the temperature reaches the highest value after suspension of rotation because the position of 20 mm is not close to the friction surface where the temperature grade is low.

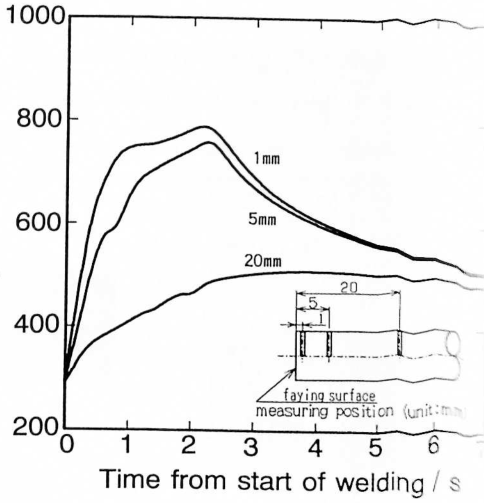

Fig.3 Temperature-time histories of friction welded process under condition of friction pressure of 50MPa and friction time of 2 seconds.

The temperature-time history in the welding process displays the same tendency regardless of the welding conditions, however, in a short friction time and low friction pressure the highest temperature is somewhat low. The temperature- time histories of 2017 alloy side shown as same tendency of 6061 alloy side. This result indicates that highest temperature is shown low values comparison of similar friction welded joint of 6061 and 2017 alloy which are 809K and 800K respectively [3, 4].

3.3 Results of hardness test

The hardness distribution of the center of the axial joint both after 4 hours and 14 days from welding is shown in **Fig.4**. After 4 hours from welding, the hardness at the weld interface shows a little higher value than heat affected zone and it reached higher value than both base metals after 14 days form welding. The softened area can be seen at both alloy side. This is the common phenomenon generally found in all the joints which are used hardened materials by heat treatment or work hardening. The softened area of 2017 alloy side can be noticed at the location of about 23 mm away from the weld

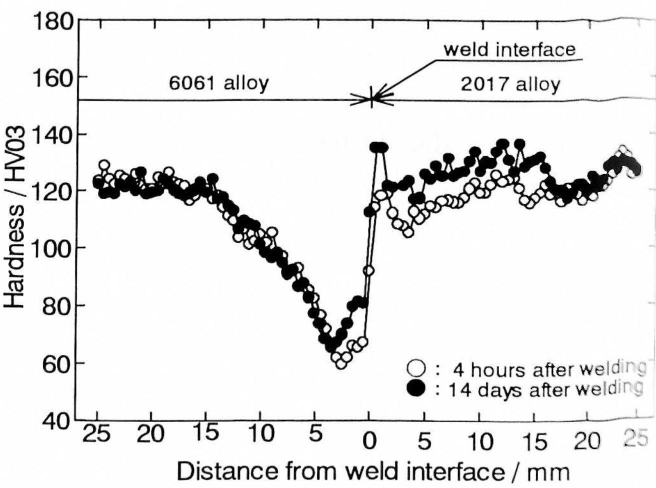

Fig.4 Hardness distributions of friction welded joint with friction pressure of 50MPa and friction time 2 seconds.

interface. The softened area of the 2017 alloy side after 14 days from welding is recovered to that of the 2017 alloy base metal . The change of hardness according to the passage of time is never found at the 6061 alloy side. Because 6061 alloy do not indicated age hardening at room temperature.

3.4 Results of tensile test

The results of tensile test are shown in **Fig.5**. Tensile strength of welded joints decreases with increase of friction time regardless of friction pressure. Although it can hardly be noticed that the difference of friction pressure affects the tensile strength of joint, it shows a little higher value in the case of friction pressure of 50MPa. The maximum tensile strength of joints which is welded with friction pressure of 50MPa and friction time of 2 seconds such as 78.4% of that of the 6061 alloy base metal. Furthermore, the elongation is affected only a little by the difference of friction time and shows the low values such as less than half value of that of the 2017 alloy base metal. Appearance of tensile fractured specimen of welded joint is shown in **Fig.6.** The 2017 alloy side hardly deformed but 6061 alloy side contracted locally as same as similar joint of 6061 alloy. All the welded joints were fractured at heat affected zone of 6061 alloy side such as softened area.

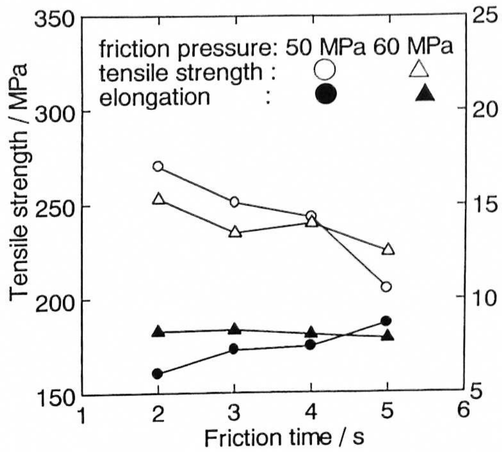

Fig.5 Results of tensile test.

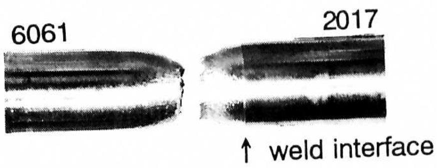

Fig.6 Appearance of tensile fractured specimen of welded joint.

3.5 Results of impact test

The results of Charpy impact test are shown in **Fig.7**. Regardless of friction pressure, the impact value of joints increases with increasing of friction time and reaches the maximum value in the friction time of 5 seconds. In general, the ductility of friction welded joint is said to decrease in the majority of case of wrought aluminum alloys, impact strength of the welded joints were inferior to the base metal. The other side, impact value of friction welded 6061 alloy joint is higher than that of the base

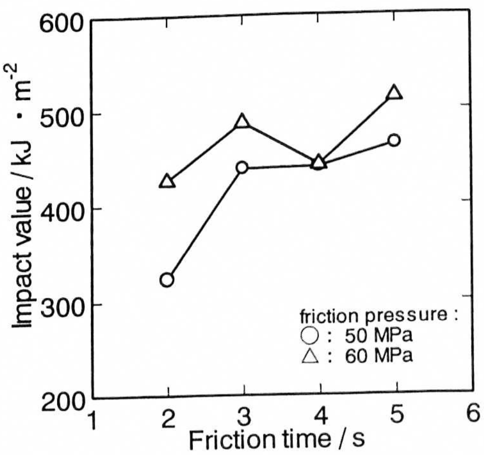

Fig.7 Results of impact test.

metal [3]. The impact value of all the welded joints without condition of friction pressure of 50MPa and friction time of 2 seconds show higher value than both 2017 and 6061 alloys base metal. Reason why, this combination observed mechanical mixed layer on the weld interface which is notch position. Therefor crack propagated zigzag along the mechanical mixed layer and softened area of 6061 alloy side is not recovered. So impact value of welded joints show higher value than that of the base metals.

4. CONCLUSIONS

As the results of the examination of structure and mechanical properties of the dissimilar friction welded joints of 6061 aluminum alloy to 2017 aluminum alloy, the following results are obtained.

(1) The structure in the welded joint nearby the weld interface is parallel to the weld interface at the both alloy side and observed to be partly finer than that of the base metal. Furthermore, the portions where both alloys are mechanical mixed layer are distinctly observed.

(2) As for the hardness distribution on the axis at the center part of joint, there is a softened area seen at the both alloy side. The softened area of 2017 alloy side are recovered to the same hardness so that of 2017 alloy base metal after 14 days from welding. But the softened area of 6061 alloy side dose not recovered.

(3) The maximum tensile strength of the welded joint is 78% of that of the 6061 alloy base metal and elongation of the welded joint is less than half value of the 2017 alloy base metal. All the welded joints fractured in the heat affected zone of 6061 alloy side.

(4) The impact value almost all the welded joints which notch is put into the weld interface show higher value than that of the every base metal.

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