EVALUATION OF FRICTION WELDABILITY OF TYPE 5052 AL ALLOY/LOW CARBON STEEL JOINT.

By Kyung-Kyun.Kim[1*],Won-Bae Lee[2], Yun-Mo Yeon[3], Dae-Up Kim[4], Seung-Boo Jung[2]

[1]Asan Friction Welding Co.,

982-5 Keumsan-Ri, Waekwan, Chilgok-Gun, Kyongbuk, Korea, asan@asanfw.com

[2]Dep. of Advanced Materials Engineering, SungKyunKwan Univ.,

300 Chun-Chun Dong, Jang-An Gu, Suwon, Gyonggi-do, 440-746, Korea, saba38@hanmail.net,sbjung@skku.ac.kr

[3]Dep. of Automatic-Welding Engineering, Suwon-Science College,

Whasung, Gyonggi-do, 445-742, Korea, ymyeon@mail.suwon-sc.ac.kr

[4]Research Institute, Hyundai Mobis Co.,

Youngin, Gyonggi-do 449-910, korea, aeupkim@mobis.co.kr

ABSTRACT

The mechanical and metallurgical properties of friction welded joints type 5052 Al alloy/A36 steel have been studied in this paper. The joint strength increased with increasing upset pressure and friction time till it reached the crictical value. The joint strength was fixed at low strength compare to that of base metal in the case of increasing friction time.

Microstructure of 5052 Al alloy was greatly deformed near the weld interface. The very fine and equaxied grain structure was observed at the near interface. The elongated grain was formed outside dynamic recrystallizatoin region at the peripheral part, while the A36 steel' side was not deformed. The hardness of the near interface was slightly softer than that of 5052 Al alloy base metal. The maximun softening width was about 8mm from the interface. In the present work, the friction welding condition, t_1=0.5sec, P_2=137.5MPa, showed a maximum joint strength (202MPa) when friction pressure, upset time and rotation speed were fixed at 75Mpa, 5sec, 2000rev/min and these were the optimum friction welding condition of 5052 Al/A36 steel joints.

KEYWORDS

Friction welding, dynamic recrystallization, equaxied grain, optimum welding condition

1. Introduction

Friction welding is the solid state welding processes, which means that the joining is carried out below the melting temperature of the metals to be joined[1,2].

The practical structures are becoming more complicated every year, so it is difficult to manufacture them from only one material to satisfy the environmental and service requirement. Such structures should be manufactured from a combination of materials. It is necessary, therefore, to establish a bonding technique could be easily join the dissimilar metal[3,4].

In case of fusion welding of Fe-Al system, excess formation of brittle intermetallic compounds degrades the joint strength. Since friction welding is one of the solid-state bonding procedures, few intermetallic layers are formed at the welds interface[5]. However, in the Al-Fe system, the solid solubility is almost none, so some intermetallic compound will be formed in spite of friction welding. The major problems having the friction welding of aluminum to steel joints are the formation of intermetallic and oxides layer at the interface. Thickness of this layer must be controlled if sound welds are to be acquired.

It was still unknown how the welding parameters effect the formation of intermetallic layer and mechanical properties in Al alloys and steel joints. In order to make clear the relation between microstructure and mechanical properties, the microstructural change was observed from the interface to the unaffected part by OM(optical microscopy) and the variations of hardness were also measured. The intermetallic layer formed at interface was evaluated by SEM(scanning electron microscopy) and EDS(Energy Dispersive Spectrometry). The mechanical properties were measured by tensile and hardness test. The optimum condition of friction welded 5052Al/ A36 steel joints was finally established.

2. Experimental procedure

The materials used in the present work were commercially 5052 Al alloy and A36 steel (including about 0.2% carbon), which were machined to a rod shape 20mm in diameter and 120mm in length. The chemical compositions were shown in Table 1.

Table1 Chemical composition of the used materials.

	Si	S	Mg	Cr	Zn	C	Mn	P	Al	Fe
5052Al	0.094	0.113	2.51	0.006	-	-	-	-	Bal	-
A36	0.18	0.1	-	-	-	0.18	0.58	0.25	-	Bal.

Friction welding was carried out by a brake type friction welding machine (Nitto Seike Co. Ltd). In this present work, t_2, P_1 and N were fixed at 5sec, 70MPa, 2000 rpm, respectively. The friction time was varied from 0.1 sec to 3.0 sec and the upset pressure was changed from 70 MPa to 150MPa. The 5052 Al alloy was located at rotating part, the A36 steel was at stationary part which pressed the force.

The cross-section was sliced by a diamond cutting wheel to avoid thermal degradation and grinded with SiC paper (#100-#2000), and micro polishing was carried out by using 0.05μm Al_2O_3 powder. The 5052 Aluminum alloys side for metallograph was etched with keller's reagent[6] (150mL water, 3mL nitric acid, 6mL hydrofluoric acid, 6mL hydrochloric acid) for 0.18ks and the A36 steel side was etched with nital's reagent (3% nitric acid in methyl alcohol) for 15sec, respectively. The microstructure of friction welded interface was observed by OM and SEM.

The hardness and tensile test were carried out to evaluate the mechanical properties of the joints. The Vickers hardness distribution of the each material in the vicinity of the weld interface was measured with a load of 0.98N, during 10sec.

3. Results

(1). Microstructure evolution

The macro images of the cross section are shown in figure 1. The released burrs from interface were formed symmetrically around the weld circumference at 5052Al alloy' part. The amount of burr was increased with the increasing friction time and upset pressure, while the A36 steel part was not deformed

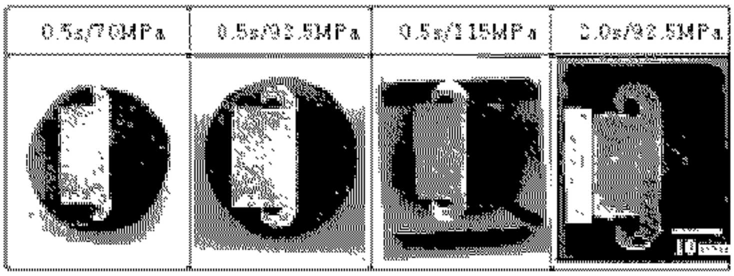

Figure 1 The cross-sectional macrostructure of friction welded joints for various welding conditions

Microstructures of 5052Al alloy which was shown in figure 2 were divided into four regions: (a) DRX[7,8](Dynamic recrystallization region) was fine and equaxied grain caused by strong plastic deformation and heat generated during the friction welding process. The grain size was ten times smaller than that of the base metal (b) HDZ (heat and deformation affected zone) had a flowed grain structure from the central part to the peripheral part (c) HAZ(heat affected zone) was located outside the HDZ, there was no difference in the grain structure with respect to optical appearance of the base metal and only distinguished from hardness test, and (D) base metal. The deformed range was increased with the increasing of friction time and decreased with increasing of the upset pressure.

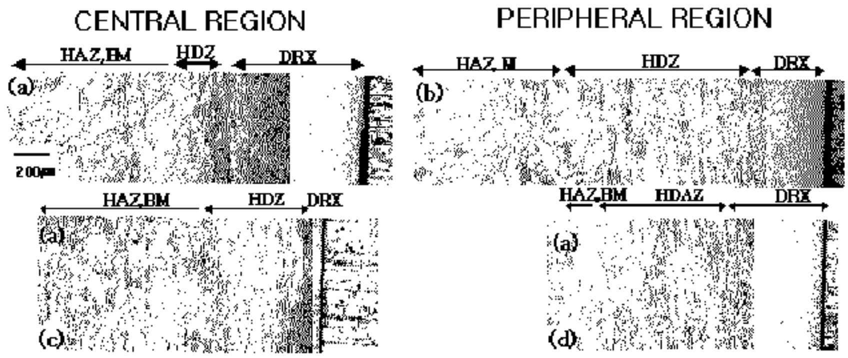

Figure 2 Microstructure of near weld interface of 5052 Al part

(a) and (b) :P1=70MPa, t1=0.5s, (c) and (d): P1=92.5MPa, t1=0.5s

Figure 3 shows the hardness profile of the weld interface at 5052Al alloy part. The softening area was formed at near interface. As the Al alloy used in the present study was cold drawn bar, it was already work hardened before the friction welding procedure. Therefore, the 5052 Al alloy recovered and recrystallized as a result of friction heat and deformation was slightly softened[9]. There was no difference of the hardness value among the measured locations (central, peripheral, R/2part). The softening area showed lower hardness about 60-70HV than base metal, which showed a scattered hardness value range from 85 and 90 HV. The softening area could be divided into region A, B and C as with different hardness values. The hardness of region A was slight higher relative to region B. The region A received plastic deformation and thermal components, so the microstructure has effectively been forged. But region B received thermal components only[4]. The Region C was the recovered region. The softening area became wider as friction time increased, and narrower with increasing upset pressure. So the maximum and minimum width of softening area from the weld interface was about 8mm and 5mm, respectively.

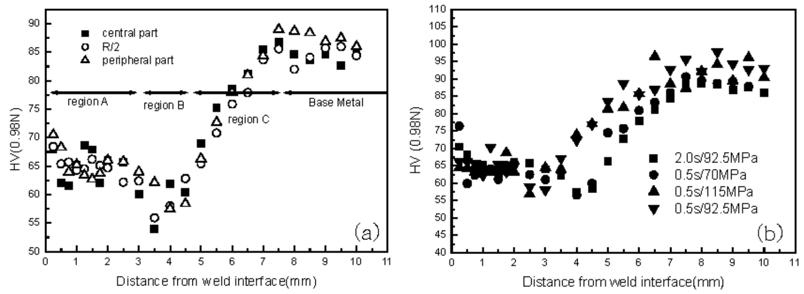

Figure 3. Vicker's hardness distribution of 5052 Al alloy at near weld interface:
(a) Hardness at various measured location (central, R/2, peripheral part) (b) central part at various welding conditions

Figure 4 shows the SEM image of the weld interface. The intermetallic reaction layer could be observed by SEM with t_1=0.1s and t_1 =1.5s. The thickness of the intermetallic reaction layer slightly increased with increasing friction time. Generally, a thicker reaction layer was observed at the peripheral part[9]. When friction time was 0.1sec, it was almost the same thickness at the central part and the peripheral part. An intermetallic layer was formed only in the 5052 Al alloy. At friction time 1.5 sec, the thickness of the reaction layer was increased and formed both the 5052 Al alloy and the A36 steel. Also many elements (Fe, Al, Mg, Si, O, C) were detected by EDS analysis. Probably this reaction layer was composed of mainly FeAl intermetallic and MgO oxide. XRD(X-ray Diffractometry) was used to estimate the phase of this layer. However, the intermetallic compound and oxides could not be detected because it was very thin layer within 1μm.

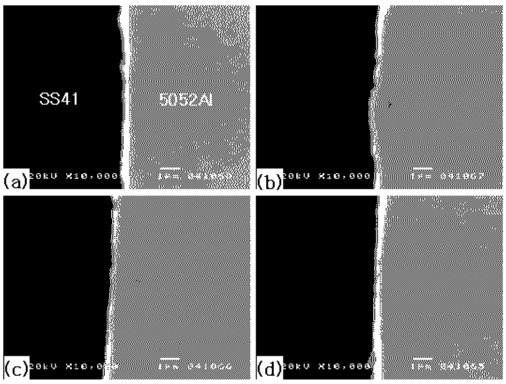

Figure 4 SEM image of weld interface: (a) central part and (b) peripheral part at 0.1sec, (c) central part and (d) peripheral part at 1.5sec.

(2). Joint strength of friction welded joints

The relation between upset pressure (P_2) and joint strength, amounts of burr are shown in figure 5(a). The tensile strength increased with increasing upset pressure and finally showed the fixed value, 202MPa which was about 98% of the joints efficiency compared to that of the 5052 Al alloy base metal. The joints strength fixed at the constant value over upset pressure 137.5MPa.

Figure 5 (b) shows the relation between friction time (t_1) and joint strength , the amount of burrs. The joint strength was slightly increased with increasing friction time until friction time was 0.5 sec, At friction time over 0.5 sec, the joints strength was fixed at the constant value, 180 MPa. The location of fracture was almost near the weld interface. The possibility of intermetallic compound formation increased with increasing friction time because the temperature of the weld interface was higher. However, the friction welding process has an upsetting stage which operated repulsion of burrs containing the intermetallic compounds and oxides out of the interface. The layer of intermetallic compound and oxides were almost repulsive out of the weld interface so that a few layer existed at the weld interface (thickness less than 1μm, above described). The longer friction time, the more amounts of burr formed out of the interface. The joint strength showed costant value regadless of friction time. The intermetallic reaction layer, which had a great effects on joints strength in the case of fusion welding method, had slight effects on joints strength.

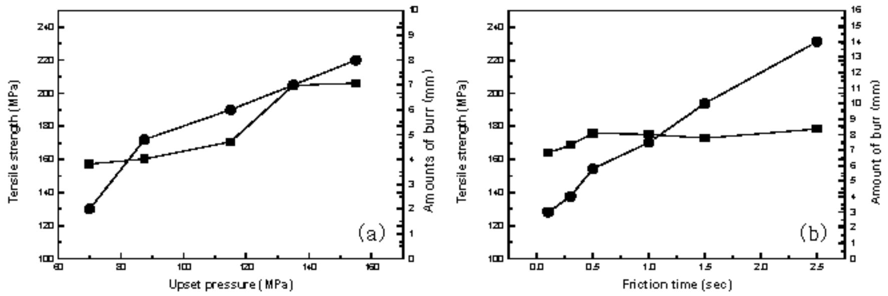

Figure 5 Relation between welding parameters and tensile strength, amount of burr:

(a)variable upset pressure (b) variable friction time.

(■ mark: joint strength ● mark : amounts of burr)

In this work, the condition of t_1=0.5sec, P_2=137.5MPa showed the maximum joint strength (202MPa) and this was the optimum friction welding condition of 5052 Al alloy/ A36 steel joint.

4. CONCLUSIONS

1). 5052 Al alloy was greatly deformed relative to base metal and divided into four regions : (a) DRX,(b)HDZ, (c) HAZ and (d)BM. However A36 steel was not deformed.

2). The softening area was formed near the weld interface. Increasing upset pressure minimized that area. However Increasing friction time widened that area.

3). The thickness of the intermetallic reaction layer increased with increasing friction time. It was thicker in the peripheral region than in the central region. This layers were identified as FeAl and MgO .

4). Joints strength increased and then fixed at a constant value after reaching a maximum value with increasing upset pressure and friction time.

References

[1] B. S. Yilbas, A. Z. Sahin, N. Kahraman, and A. Z. Al-Garni : Journal of Materials Processing Technology, 49(1995), 431-443

[2] J. Ruge, K. Thomas, C. Eckel and S. Sundaresan : Welding Journal, August (1986), 28-31

[3] S. Fukumoto, T. Inuki, H. Tsubakino, K. Okita, M. Aritosh and T. Tomita: Material Science and Technology, 13(1997), 697-686

[4] R .A. Bell, J. C. Lippod and D. R. Anolphson: Welding Research Supplement, 11(1984), 325-332

[5] S. Fukumoto, H. Tsubakino, K. Okita, M. Aritosh and T. Tomita : Scripta. Mater., 42(2000), 807-812

[6] G. Liu, L. E. Murr, C-S. Niou, J. C. McClure and F. R. Vega: Sctipta Materialia, 37(1997), 365-367

[7] B. Ren and J. G. Morris : Metallurgical and Materials Transactions, 26A(1995), 31-40

[8] W. Blum and H. J. McQueen : Material Science Forum., 217(1996), 31-42

[9] S. Fukumoto, H. Tsubakino, K. Okita, M. Aritosh and T. Tomita : Material Science and Technology, September 15(1999), 1080-1086