Journal of the Research Institute of Industrial Technology, Vol. 25, 2008

Optimal Welding Parameters of 5083 Al Alloy by Friction Stir Welded

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ABSTRACT : *The objectives of this study were to evaluate the feasibility of Friction Stir Welding (FSW) for joining of Al 5083 alloy and to investigate the microstructure and mechanical properties of FSW on 5083 Al alloy. Weldability of Friction Stir Welding of hot extruded 5083 Al alloy sheet with 4-mm thickness was evaluated with various welding parameters, such as tool rotating speed and travel speed. The sound welding conditions mainly depended on welding heat input during the process. The lower heat inputs associated with FSW (relative to fusion welding process) are expected to produce less severe metallurgical changes in the HAZ and to minimize distortion and residual stresses in the Al 5083 alloy. Additionally, problem with hydrogen cracking in Al alloy should be eliminated due to the solid-state nature of the process. These advantages will make FSW attractive for joining of Al 5083 alloy in many applications. The microstructure of the welded zone was composed of 4 regions, Base Metal (BM), Heat Affected Zone (HAZ), Thermo-Mechanical Affected Zone (TMAZ), Stir Zone (SZ). The highest tensile strength was about 296 MPa in this experiment, which was 95% of the base metal value of 312 MPa. The fracture location was almost stir zone.*

KEY WORDS : FSW, Travel speed, Metallurgical change, Solid-state nature

1. Introduction

Al alloys were characterized by high strength to weight ratio, low density, corrosion resistance, relative ease of forming and machining, good cryogenic properties, ductility and non-magnetic[1][2]. There have been increased demands for the wider low distortion Al alloy sheet and plate in the fabrication industry, for example, the streamlined production of bridge decks, ship panels and other transportation application like train and airplane components. Larger extrusion process and rolling mills causing the production cost to be high are recently utilized in this field of part, but the problem associated with extrusion process is that they are limited in size and capacity. Friction stir welding is the viable method to overcome restriction of size and capacity on extrusion process[3].

Friction stir welding is a new solid-state welding technique, which was invented by The Welding Institute (TWI) in 1991[4]. It has enabled us to join the long butt Al alloys, which are often difficult to be joined by fusion welding without void, cracking, or distortion[5][6]. This process reduces manufacturing costs due to the elimination of some defects, filler materials, shielding gases and costly weld preparations[7][8]. Microstructural changes of friction stir weld zone have been the main subject of some recently published papers. Concerning age-hardnable aluminum alloys, there are some microstructural study in the welds of 7075-T651 Al by Rhodes et al[9] and of 6061-T6 by Murr et al[10][11] and of 6063-T5 by.Y.S Sato et al[12][13]. They have demonstrated that the weld zone consists of a fine, equaxied grain(SZ) and an elongated, recovered grain(TMAZ), the heat affected zone(HAZ) was formed beside the weld one. However concerning non-treatment aluminum alloy, such as Al 5083 alloy, the effects of friction stir welding parameters on microstructural change and mechanical properties have not been well known. The objective of the present study is to evaluate the microstructure of near weld zone and regarding the hardness profile and effects of the friction stir welding

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parameter on microstructural change and mechanical properties of friction stir welded Al 5083 alloy.

2. Experimental Procedures

The material used in this study was the 5083-H112 Al alloy with 140 mm in length 70 mm in width and 4mm in thickness. Its chemical composition is shown in Table 1. The details of the Friction Stir Welds parameters, such as tool tilting angle, tool rotation speed and travel speed, were shown in Table 2.

Table 1 Chemical composition of used material(wt%)

Element / Material	Zn	Mn	Mg	Cu	Si	Cr	Fe	Ti	Al
Al 5083 H112	0.003	0.516	4.130	0.001	0.131	0.115	0.154	0.022	bal

Table 2 Parameters of friction stir welds

Parameter	Selected point
Shoulder shape	Oval shape
Shoulder diameter	14mm
Pin diameter	4mm
Pin length	4mm
Tool angle	3 degree
Tool rotation	1600 rev/min
Welding velocity	87-342mm/min

Specimens were sectioned transversely in order to study the microstructural variations that exist from the center to the outside of the weld. Microstructural change of the welded specimens was examined with OM (Optical Microscopy) and SEM (Scanning Electron Microscopy). Chemical etching utilized Keller reagent (150 mL H_2O, 3mL HNO_3, 6mL HF, 6mL HCl) for 180sec. Vickers hardness was measured at the cross section perpendicular to the weld center and was used a microvickers hardness tester with 100g for 10sec. The tensile tests were conducted on an Instron test machine at room temperature at a crosshead speed of 1.67×10^{-5} m/sec.

3. Results and Discussion

Fig. 1 shows the schematic illustration of the friction stir welding. Basically, FSW process is that a non-consumable tool with a specially designed rotating pin is inserted into the abutting edges of plate to be welded. Once entered, the rotating tool produces the frictional heat and plastic deformation in the weld zone. The tool is then translated along the joint to complete the joining process[14].

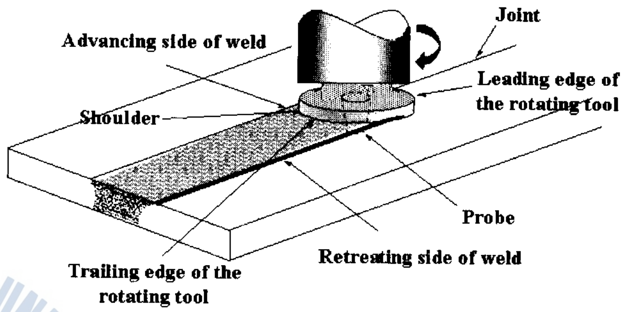

Fig. 1 Schematic of friction stir welding

As shown in Fig. 2, the surfaces of FSW joint were very smooth relative to the surfaces of GMAW joint. Also, FSW joint hardly had reinforcement comparing with GMAW joint. Namely, FSW hardly needs additional processing such as removing reinforcement after welding. Defects including void and crack were not visible at the both surfaces of FSW joint. These advantages will make FSW attractive for joining of Al 5083 alloy in many applications.

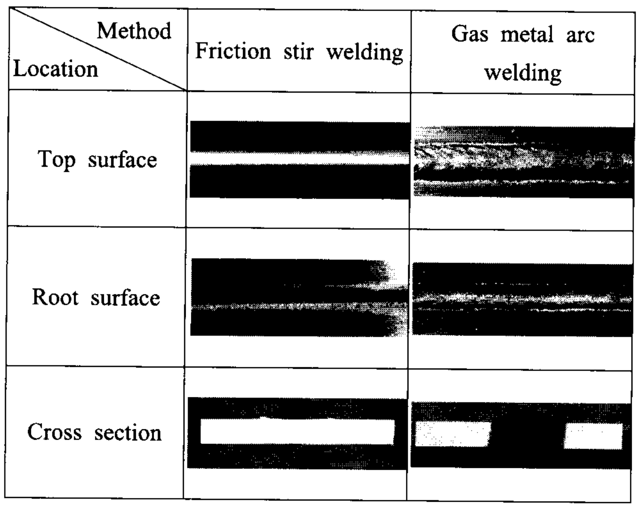

Fig. 2 Macro-view of weld joint

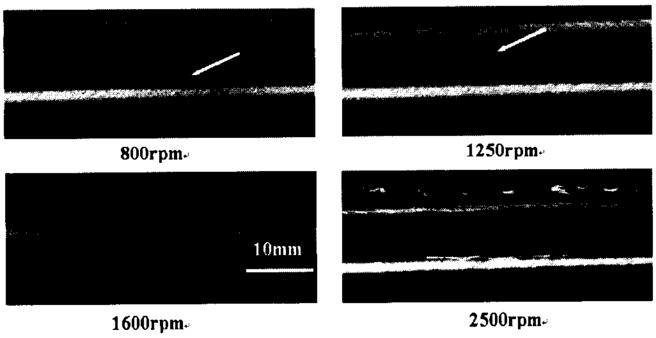

Fig. 3 Top surfaces of FSW joint at each tool rotating speed

The top surfaces of FSW joints at each tool rotating speed is shown in Fig. 3. All specimens have defects or excessive reinforcement except for 1600rpm. So, this experiment fixed tool rotating speed by 1600 rpm.

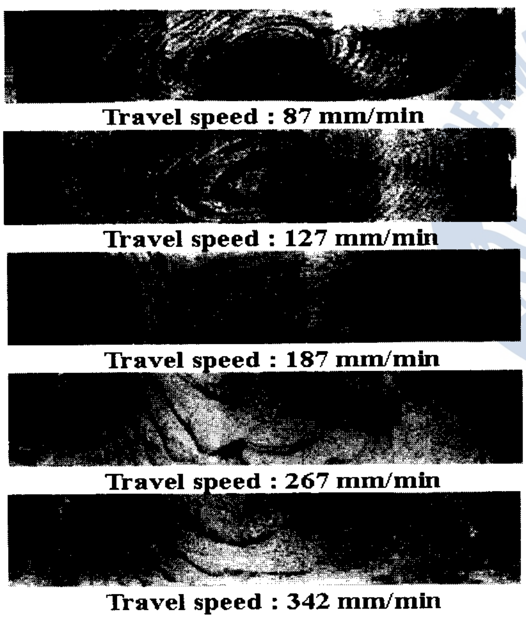

Fig. 4 Optical-micrographs of Al 5083-H112(FSW) with various travel speeds

Fig. 4 shows the transverse macroscopic change of FSW joint with travel speed. Macroscopic examination of the weld revealing a relative non-symmetric stir zone was mainly associated with the tilt angle of tool and difference between rotation direction and welding direction. It was apparent that the weld exhibited a high degree of continuity and no porosity. The area of the stir zone decreased with increasing travel speed because slower travel speed generated more frictional heat. The feature called 'onion ring or flow pattern' was visible in the stir zone and corresponded to the variation in the friction stir welding parameters[9]. Onion rings were tied to the tread of the tool and these were a sign of good quality. This ring pattern apparently represented the plastic deformation increments as the pin of the rotating tool moved through the joints. The number of onion rings decreased as the travel speed increased. However, the gap of onion rings increased with increasing travel speed.

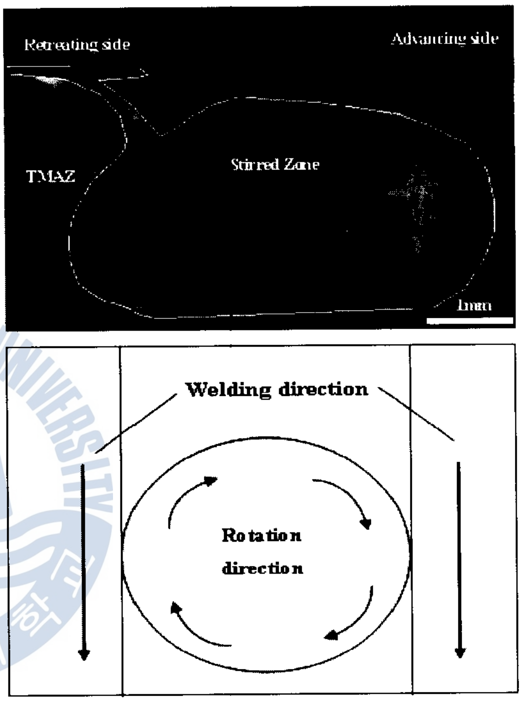

Fig. 5 Optical-micrographs of the cross section of FSW joint

The optical microstructure of the cross section of FSW joint are shown in Fig. 5. The FSW process generated heat by contacting cylindrical rotating tool with the weld specimens. The weld zone showed wider near the upper surface than lower surface because the upper surface experienced extreme deformation and frictional heat caused by contacting with a cylindrical tool shoulder during the welding. Sato et al. represented that the shape of the weld zone may depend on the welding parameters and thermal conductivity of the material[15]. Each weld zone exhibited a sharp (retreating side) and diffused (advancing side) transition region between the TMAZ and the SZ. These regions were formed as a result of the relation between rotation of the tool and the welding direction. The edge of the weld, where the direction of the tool's rotation moves opposite the travel (antiparallel), would be referred to as the retreating side. The opposite case, where direction of the tool rotation was parallel to travel, would be referred to as the advancing side. The difference of two regions was confirmed by slight difference of optical microstructure and hardness test. Ring pattern apparently represented the plastic deformation increments as the pin of the rotating tool moved through the joints. The number of onion rings decreased as the travel speed increased. However, the gap of onion rings increased with increasing travel speed.

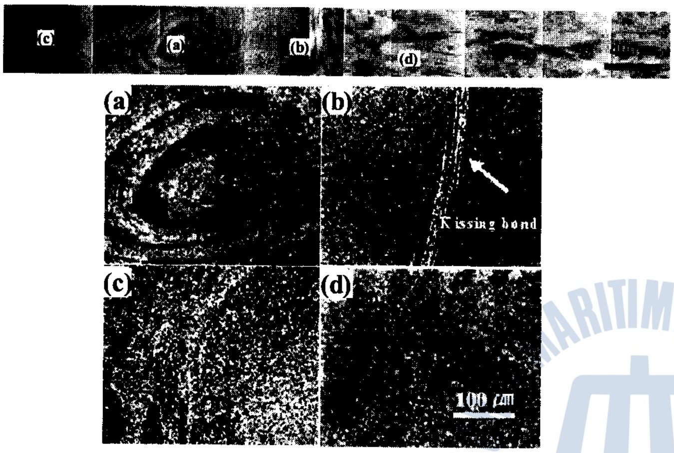

Fig. 6 Optical-microstructure of FSW joint in each location

The optical microstructures of FSW joint in each location are shown in Fig. 6. Unlike that of the base metal, the SZ had a fine, equiaxed grain structure and its diameter could not be measured by optical examination. This structure was mainly produced by dynamic recrystallization, which was caused by the frictional heat and deformation. SZ included the onion ring and the kissing bond concerning the trace of pin contacted with welded specimens. The formation mechanism of the kissing bond and onion ring had been studied in recent researches[17]. According to the recently published paper from Okamura et al[18], kissing bond contained Al, Mg and Si based oxides detected by EDS analysis and they had no significant effect on the tensile strength of the joint and onion rings pattern was performed by the process of friction heat due to the rotation of the tool and the forward movement extrudes the metal around to the retreating side of the tool[16]. The TMAZ was evident where the original grain structure was microscopically upsetting. The elongated and recovered grain structure was characterized in the TMAZ. The HAZ was only identified by hardness results, because the HAZ was no different in grain structure as compared with that of the base metal. The mechanical and temperature conditions in the HAZ were not sufficient to promote grain growth or macroscopically deform the metal.

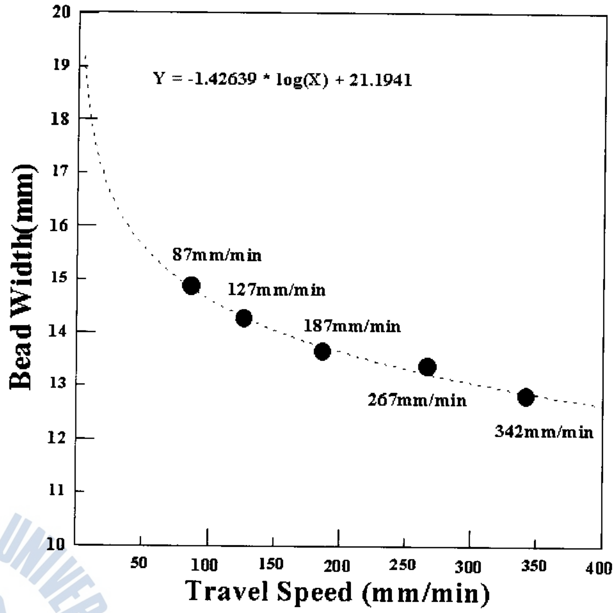

Fig. 7 Variation of bead width with travel speed

As shown in Fig. 7, the width of the weld bead had a special relation with the travel speed. Bead width decreased logarithmically with increasing travel speed. Namely, Bead width is more sensitive in case of the travel speed is slow than that of the travel speed is fast.

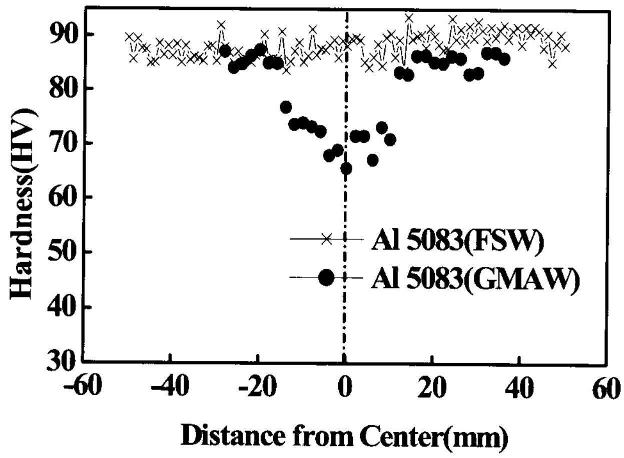

Fig. 8 Hardness distributions across a weld line

Fig. 8 shows the hardness distributions in the direction perpendicular to the weld interface of the FSW joint, which had a scattered hardness a range of 85-90Hv. This being solid state welding, it is because microstructure became fine by the press of shoulder and the rotation of pin. However, the hardness of the retreating side is found to be slightly lower than that of the advancing side.

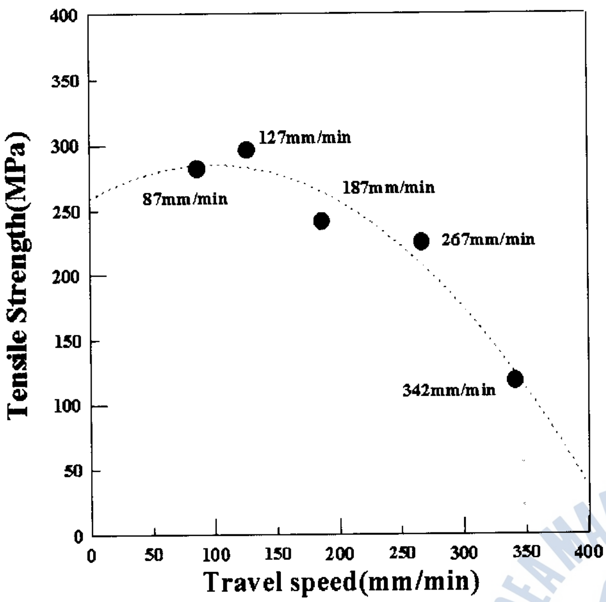

Fig. 9 Variation of tensile strength with travel speed

Fig. 9 shows the effect of travel speed on the tensile strength. The highest tensile strength was attained at the travel speed of 127 mm/min. Tensile strength is good in general in the whole travel speeds except the travel speed of 342 mm/min. The tensile strength of as welded 5083 Al alloy had no proportional relation with the travel speed. This result means that the sound weld quality was acquired over a wide range of FSW conditions. The highest tensile strength of as welded 5083 Al alloy was about 296 MPa at the travel speed of 127 mm/min, that was the 95% of the base metal(312MPa)

The microfractographs of tensile fracture surfaces in each travel speed are shown in Fig. 10. In the travel speed of 127 mm/min, the fracture surface displays a typical dimple a pattern. When the travel speed is 342 mm/min, which is the fastest speed in this experiment, fracture was begun in the unbounded region by micro-void coalescence [19]. The formation of micro-void coalescence was due to insufficient heat and time for plastic deformation by fast travel speed. The locations of failure were stir zone in the whole travel speed.

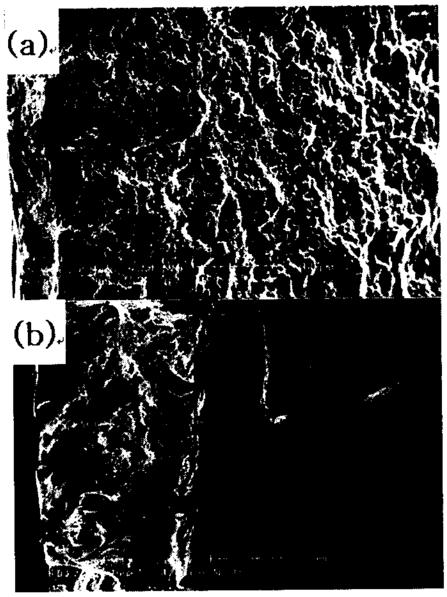

Fig. 10 SEM Fractographs of FSW joint in each travel speed
(a)travel speed-127 mm/min
(b)travel speed-342 mm/min

4. Conclusions

The present work examined the microstructure and mechanical properties of the Friction Stir Welded 5083 Al alloy as increasing travel speed. The result of this work was as followed:

1. The onion ring pattern in the weld had a special relation with friction stir welding speed. The number of onion rings was decreased and the gap of onion rings was increased with increasing travel speed.
2. The non-symmetric stir zone was mainly associated with the tilt angle of tool and difference between rotation direction and weld direction.
3. FSW joint was no considerable softened region. It was because microstructure became fine by the press of shoulder and the ratation of pim
4. There is no proportional relation between the tensile strength and travel speed. The highest tensile strength was obtained at the travel speed of 127 mm/min.

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Received : 10 December 2007
Accepted : 18 January 2008