Proceedings of the 12th International Conference on
Aluminium Alloys, September 5-9, 2010, Yokohama, Japan

pp. 1763-1767

Instability of Microstructure in Friction Stir Welded 5083 Aluminum Alloy Sheets during Post-Weld Heat Treatment

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Present paper aims to clarify the condition and the mechanism of abnormal grain growth that proceeds during post weld heat treatment of friction stir welded joints of 5083 aluminum alloy. Friction stir welding of bead-on-plate type was performed on 3mm thick aluminum sheets using a welding tool composed of shoulder and M4-threaded probe of which the dimensions are 12mm in diameter and 4mm in length, respectively. The rotation speeds varied from 500 to 1500RPM with a fixed welding speed of 100mm/min. Grain refinement in the stir zone was effectively realized with decreasing rotational speed and a minimum grain size of 3 μm was achieved in the case of 500RPM. Annealing of the welded sheets at 773K brought about an abnormal grain growth in the stir zone, which was mostly observed in the vicinity of the surface contacted to the shoulder of welding tool during welding. This instability of microstructure at elevated temperature also appeared in the sheets welded using a welding tool without probe. EBSD measurements revealed a weak but locally strong texture in this region suggesting the onset of the coarsening is closely related to this local microstructural condition. Thus the shoulder of welding tool exerts a peculiar effect on the stir zone microstructure where a heterogeneous distribution of residual strain and a local texture can be developed due to the metal flow under the shoulder.

Keywords: *5083 Al alloy, FSW, abnormal grain growth, EBSD*

1. Introduction

Friction stir welding (FSW) is well known to be developed to join aluminum alloys [1, 2] and is now expanding its possibility of being applied to fabricate trains, aircrafts, ships, bridges and so on. Many intensive works reported that grain refinement was successfully achieved due to both dynamic and static recrystallization during welding. The refined grain structure is effective for improving mechanical properties of FSW joints, while the stability of such refined grain structure is not always made clear in terms of both practically and theoretically. Indeed some friction stir welded joints are known to show abnormal grain growth during the post-weld heat treatment [3, 4]. From the viewpoint of reliability and dependability of FSW joints, it is very important to clarify the stability of joint microstructure at elevated temperature in order to fabricate reliable FSW joints.

Regarding the metal flow of FSW and FSSW (Friction Stir Spot Welding) the material around the rotating tool experiences a complex deformation such as shear and compression that vary depending on the location [5]. Hence it should be noticed that heterogeneity of deformation may result in a variation of texture if the heavily strained region exist. Recently two major flows are proposed to possibly exist during FSW, and one of those flows is located in the region contacting to the shoulder of welding tool [6]. Since the shoulder gives a severe plastic deformation generating frictional heat, textural feature of the "shoulder contacted region" in the stir zone might show some peculiar microstructure that accounts for the instability of microstructure at elevated temperature.

The present study aims to clarify the post-weld heat treatment conditions where the stir zone microstructure becomes instable, and tries to explain the mechanism of the instability in terms of texture.

2. Experimental procedure

2.1 Specimen

The present study used plates of aluminum alloy A5083-O of which the dimension is 70mm in width, 300mm in length and 3mm in thickness. Chemical composition of the base metal is shown in Table 1.

Table 1 Chemical composition of materials. (mass%)

Material	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
A5083P	0.07	0.19	0.10	0.62	4.5	0.06	0.02	0.01	Bal.

2.2 Friction Stir Welding

Welding tool utilized for the seam welding tests consists of a probe and a shoulder, which is made of SKD61 tool steel. Probe has a profile of M4-tapered right screw of 2.2mm in length, which is at the center of the shoulder of 10mm in diameter. The stir-in-plate welding tests were performed at various tool rotation speeds from 300 to 2000rpm, and with rotation speeds ranging from 100 to 500mm/min. The tool was tilted 3° backward along the welding direction. Prior to the welding tests, the tool was preheated by carrying out the welding of an A1050 aluminum plate. The present work utilized a backing plate made of SUS304 stainless steel with 10 mm in thickness.

2.3 Heat Treatment and Evaluation of Microstructure

Thermal stability of the joints was investigated by an isothermal heat treatment at temperatures from 500K to 823K in a salt bath.

Evaluation of microstructure of the joints was performed on the cross section perpendicular to the welding direction. Each sample was cut from the joints with an elctro-discharging cutting machine followed by a seriese of mechanical and electrolytic polishing processes on the cross section, yielding the surface for microstructural observation as well as the determination of orientation distributions with SEM-EBSD(Electron Back-Scatter Diffraction) method. The electro-polishing was performed at -20^{o}C and DC 20.0V using a mixed solution of perchloric acid and ethanol with the volume ratio of 1 to 9

3. Results and discussion

Figure 1 shows an example of microstructure observed in the nugget after annealing at 823K for 30s. The joint was fabricated with the welding condition of 800rpm and 100mm/min. of the travelling speed. Abnormal grain growth occurred preferentially in the upper zone of the nugget where the shoulder of FSW tool was contacted. An isolated abnormal grain was also observed in the nugget far from the shoulder-contacted region. These coarsened grains were more than 50 times larger than the small grains. Additionally the base metals also showed little change in microstructure. This means

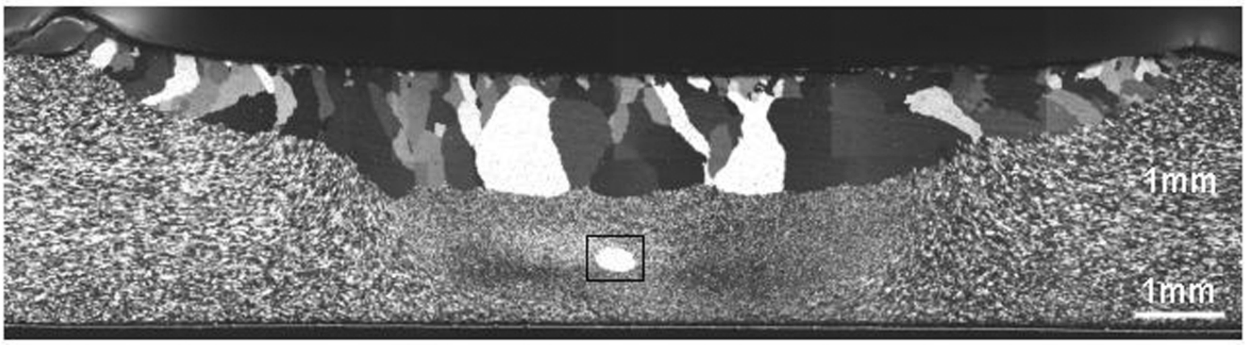

Fig.1 Abnormal grain growth observed at 823K in the joint of 5083 Al alloy friction stir processed at a rotation speed and a traveling speed of 800 rpm and 100mm/min., respectively.

Table 2 Relationship between rotation speeds and annealing conditions for the appearance of abnormal grain growth in 5083 Al alloy friction stir processed. X and circle mean the absence and appearance of abnormal grain growth, respectively.

		Rotation speed (rpm)									
		300	400	600	800	1000	1200	1400	1600	1800	2000
Annealing Temperature (℃)	250	×									
	300	○	×								
	350		○								
	400			×							
	450			○	×	×	×	×	×	×	×
	500				○	○	○	○	○	○	○
	550										

WS:100mm/min, Annealing time:10^3s

the joint microstructure became unstable when annealed at 823K.

The critical annealing temperature for the abnormal growth was then investigated for the joints fabricated under different rotation speed, and the result is summarized in Table 2. The critical temperature tended to increase as the rotation speed rose, suggesting that larger amount of heat input may raise the critical temperature.

The present study used a FSW tool having shoulders and pin with diameters of 12mm and 4mm, respectively. Thus role of shoulder seems to be important in the instability of microstructure, since the shoulder-contacted region should have affected by the frictional stress longer time than the pin, exerting its own peculiar plastic deformation on the region. Then the effect of shoulder on the instability of grain structure in the post-weld-heat treated samples was investigated. In this case the welding test was carried out with a tool without probe, so only the friction by shoulder generated the heat and softened material was plastically deformed by the rotation of shoulder. The rotation speed

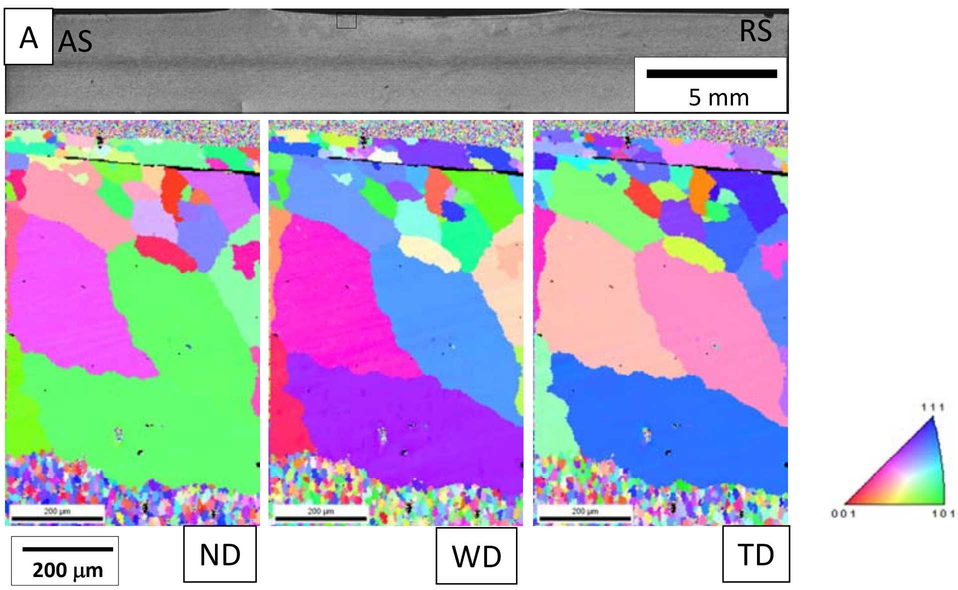

Fig.2 Cross sectional view and inverse pole figure maps of 5083Al alloy joint post-weld heat treated at 773K for 35s. The EBSD data was taken from the black rectangular shown in the Fig.2(A).

and welding speed were 1500RPM and 100mm/min, respectively. Post-weld heat treatment was conducted at 773K for 35s.

Figure 2 is a macroscopic view on the cross section of the sample(A), and the result of EBSD measurement conducted in the black rectangular region in Fig.2(A). The EBSD data is represented by a color-coded map called “inverse pole figure map (IPF map)“, and three maps are presented that show orientation distribution along the three directions such as welding direction(WD), normal direction(ND) and transverse direction(TD). In these maps each color uniquely corresponds to the orientaion in the unit triangle. The present IPF map gives a clear evidence of abnormal grain growth observed in the stir zone just close to the top surface of the plate where the shoulder contacted during the welding. In particular this phenomenon is also observed even when the probe-less tool is utilized. Abnormaly grown grains are surrounded by small grains but no significant feature is obtained in terms of texture from this data.

Grain growth proceeds by grain boundary migration, and grain boundary migration is driven by some microstructural factors such as a balance of grain boundary energy at triple junction, grain size distribution, difference of dislocation density and so on. Abnormal grain growth happens to occur when one or some of all of these factors effectively affect grain boundaries around one grain keeping the other grains in passive state. Texture factor is well known for the secondary grain growth phenomenon observed in silicon steels. In this material strong texture of {111}//ND in the primarily recrystallized structure containing extremely few Goss-oriented grains having the orientation of {110}//ND and {100}//RD. This orientaion has a great advantage for the preferential grain boundary migration since a coincidence orientation relationship is always realized during its growth while the other grains always have low angle boundaries because of almost same orientations in each other.

With this phenomenon in mind, the initial state i.e. as welded structure should be analyzed in

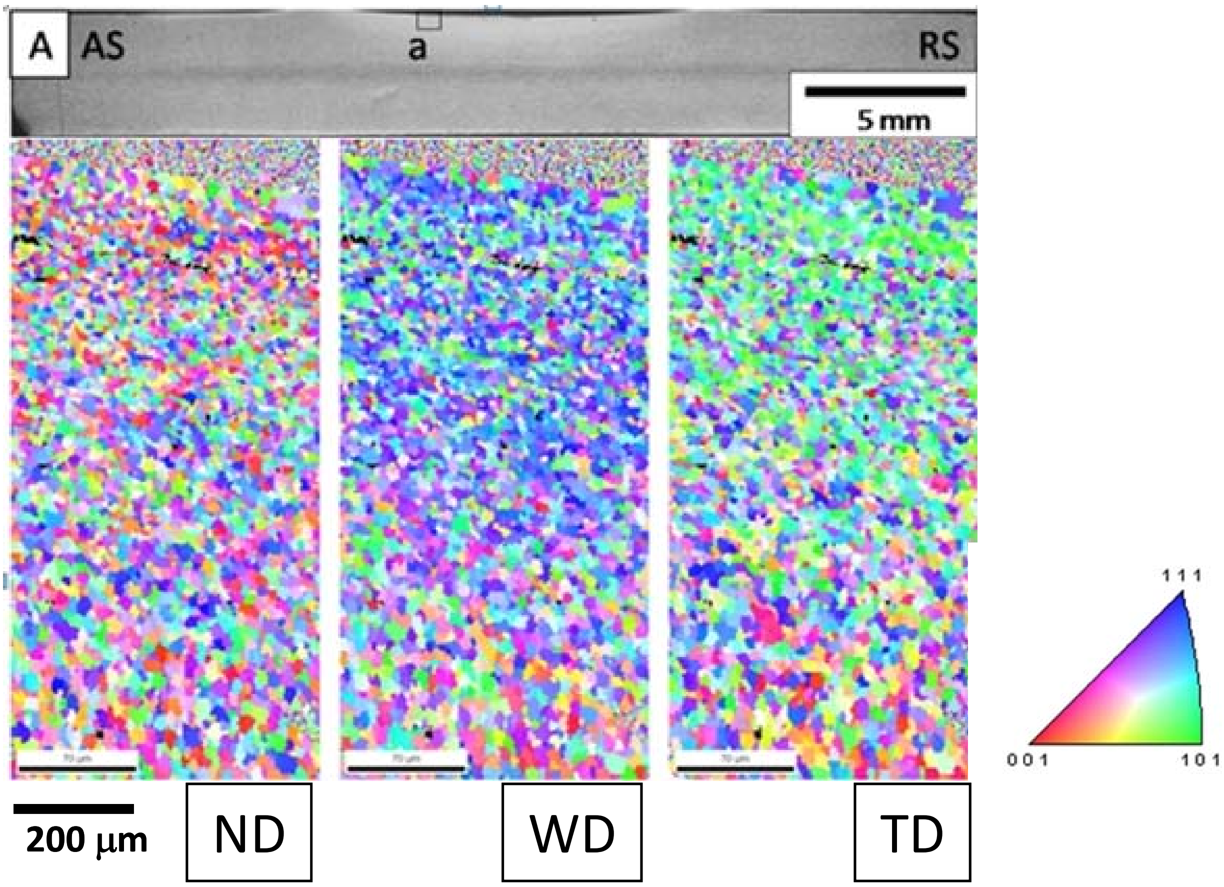

Fig. 3 Cross sectional view and inverse pole figure maps of friction stir welded 5083Al alloy joint. The EBSD data was taken from the black rectangular shown in the Fig.3(A).

terms of texture in order to consider if the texture effect is applicable to the present case. Thus EBSD analysis was carried out for the friction stir welded sample, and the result is shown in Fig.3. In this figure IPF maps of WD and TD orientations show textured areas which are recognized as many blue grains and green grains, respectively. This locally textured area should offer the chance of abnormal growth to some grains which happen to have a preferred orientation to start growing dominantly resulting in the instability of microstructure. Once the grains gains suitable size larger than their surrounding small grains, they can keep on growing since large grain can grow faster than small grains, and this mechanism is known as “grain size effect“.

Another possibe mechanism of abnormal grain growth is residual strain. Since a similar grain growth process was observed for the alloy annealed after tensile deformation of 20% [3], a residual strain caused by FSW may be a key factor for the abnormal grain growth in the friction stirred zone of the alloy. Therefore the instability of joint microstructure produced by FSW is caused by some mechanisms such as local texture and residual stress, or some others.

Summary

Friction stir welding by stir-in-plate was performed on Al alloy A5083-O focusing on the thermal stability of microstructure. Abnormal grain growth occurred in the stir zone when annealed at temperatures above 573K. This instability of microstructure initiated particularly shoulder-contacted region in the nugget. Friction stir welding using the welding tool without probe also brought about the abnormal grain growth in the stir zone during the post-weld heat treatment. Thus the shoulder plays an important role in producing the peculiar microstructure to become instable at elevated temperature. The texture effect was mainly considered in the present study regarding the similarity of secondary grain growth phenomenon in silicon steels. There was no significant relationship of orientations between the anomalously grown grains and their surrounding small grains, but a strongly textured region was found in the stir zone close to the top surface. This evidence suggests the locally textured region offers preferable conditions to some grains to grow preferentially in the early stage of heat treatment, followed by successive growth driven by the mechanism of grain size effect.

References

[1] C.J.Dawes: Welding Met. Fabrication, 63(1995), 13-16.
[2] R.S.Mishra and Z.Y.Ma: Metall. Mater. Sci. Eng., R50 (2005), 1-78.
[3] T.Shibayanagi et al: J. Japan Insititute of Light Metals 56 (2006),.347-353. (in Japanese).
[4] I.Charit and R.S.Mishra: Scripta Mater. 58(2008), 367-371.
[5] T.Shibayanagi et al: Metall. Mater. Trans. 40A (2009), 920-931.
[6] S.Muthukumaran and S.K.Mukherjee: Science and Technology of Welding & Joining, 11(2006), 337-340.