www.czasopisma.pan.pl PAN www.journals.pan.pl

Arch. Metall. Mater. **69** (2024), 1, 57-60

DOI: https://doi.org/10.24425/amm.2024.147785

YOUNGKYU KIM[1], KUKHYUN SONG[1]

EFFECT OF ENHANCED GRAIN REFINEMENT IN FRICTION WELDED SUS316L ALLOY

To investigate the solid state weldability on SUS316L alloy, this work was carried out. Friction welding as a solid state welding was introduced and conducted at a rotation speed of 2,000 rpm and a friction pressure of 25 MPa on tube typed specimens. After this work, the grain boundary characteristic distributions such a grain size, shape and misorientation angle of the welds were clarified by electron backscattering diffraction method. The application of friction welding on SUS316L resulted in a significant refinement of the grain size in the weld zone (6.03 μm) compared to that of the base material (57.55 μm). Despite the grain refinement, the mechanical properties of the welds indicate relatively low or similar to the base material. These mechanical properties are due to dislocation density in the initial material and grain refinement in the welds.

Keywords: SUS316L alloy; friction welding; electron backscattering diffraction; microstructures; mechanical properties

1. Introduction

Solid state welding (SSW) as a new concept welding and joining process, applicable to obtaining a high quality welds due to the non-melting which results in lower heat-input, is effective for the notable increase in mechanical properties such as microhardness, and yield, tensile strengths on the welds relative to the fusion welding processes [1-3]. Among them, friction welding (FW) is applicable to the rod and tube typed metals, which is good for the suppression of the weld defects such as void, crack, heat-distortion and so on, due to the significantly lower heat-input relative to the fusion welding [4,5]. In addition, this process is accompanying the friction heat and metallic plastic flow during the welding, which results in dynamic recrystallization in the welds [6,7]. Consequently, weld zone has notably refined grains relative to the base material, which leads to the enhanced mechanical properties of the welds. At several industries such as aerospace, power generation and shipbuilding, FW is applying and expanding to the new fields.

In this study, we investigate the application validity of FW on SUS316L alloy, mainly used at aerospace and shipbuilding industries, and the aspect of the microstructures and mechanical properties development during FW. Besides, the change of the grain boundary characteristic distribution (GBCD) such as grain size, shape and misorientation is systematically discussed with regard to the developed mechanical properties.

2. Experimental

The material used in this study is a tube typed SUS316L alloy, and its chemical details are shown in Table 1. To soundly weld the material, an initial material was prepared by a dimeter of 48.6 mm, thickness of 2 mm and length of 100 mm. For this material, FW was conducted at a rotation speed of 2,000 rpm, friction pressure of 25 MPa and upset pressure of 80 MPa under the constant welding burn-off length (5 mm). The welded materials were then machined to a size of 10 mm × 10 mm and mounted, in order to analyze their microstructure the specimen was mechanically ground and polished by sand paper and abrasive paper. After this work, the specimen was etched by the specific etchant and observed the macro and microstructure by optical microscopy. In particular, to clarify the development of GBCD such as grain size, shape, misorientation and so on through FW, electron backscattering diffraction (EBSD) method was introduced. In case of the mechanical properties, Vickers microhardness and tensile testes as a general method were introduced to the welds. Vickers microhardness was measured at cross-sectional direction to the welds with a load of 9.8 N and a dwell time of 10 s, and tensile test was carried out at a speed of 0.5 mm/min according to ASTM E8 to the parallel direction to the welds. At all conditions, tests were conducted for 3 times, and its values were adopted in average.

[1] S-WELDS INC., 27, EONJANG 1-GIL, SAMCHEOK-SI, GANGWON-DO 25913, REPUBLIC OF KOREA.

* Corresponding author: swelds@swelds.com

TABLE 1

Chemical details of SUS316L alloy used in this study

Chemical composition	C	Si	Mn	P	S	Ni	Cr	Mo
wt.%	0.03	1.00	2.00	0.045	0.03	12.00-15.00	16.00-18.00	2.00-3.00

3. Results and discussion

GBCD such as grain shape, size and misorientation angle of the initial material is shown in Fig. 1. At inverse pole figure map and grain size distribution, the grains with a comparatively elongated shape were composed of the size from 5 to 70 μm, and its average size was 57.55 μm, as shown in Fig. 1(a) and (b), respectively. In case of misorientation angle distribution, high angle grain boundaries are occupied over than 61% in fraction of whole grain boundaries, as shown in Fig. 1(c).

Top view and macrostructure of friction welded material is shown in Fig. 2. Welded specimen showed a sound welds without any defects such as crack, distortion, blow holes and so on mainly occurred at fusion welding, as shown in Fig. 2(a). However, the weld flash with a size of 4 mm was formed at the interface of the welds, due to the friction pressure during FW. In cross-sectional macrostructure, weld zone was narrow relative to fusion welded material, and there is also shown a sound welds without any defects at inner side, as shown in Fig. 2(b). In addition, the heat-affected-zone (HAZ) through FW was not formed at the welds, just existing thermo-mechanically-affected-zone (TMAZ) due to its lower heat-input.

GBCD of welded zone is shown in Fig. 3. Welded material consists on the grains ranging from 0.5 to 15 μm in size, comparatively equiaxed grains with an average size of 6.03 μm, as shown in Fig. 3(a) and (b). Among them, micron sized grains, from 4 to 12 μm, are occupied over than 70% in fraction, as shown in Fig. 3(b). In case of misorientation angle distribution,

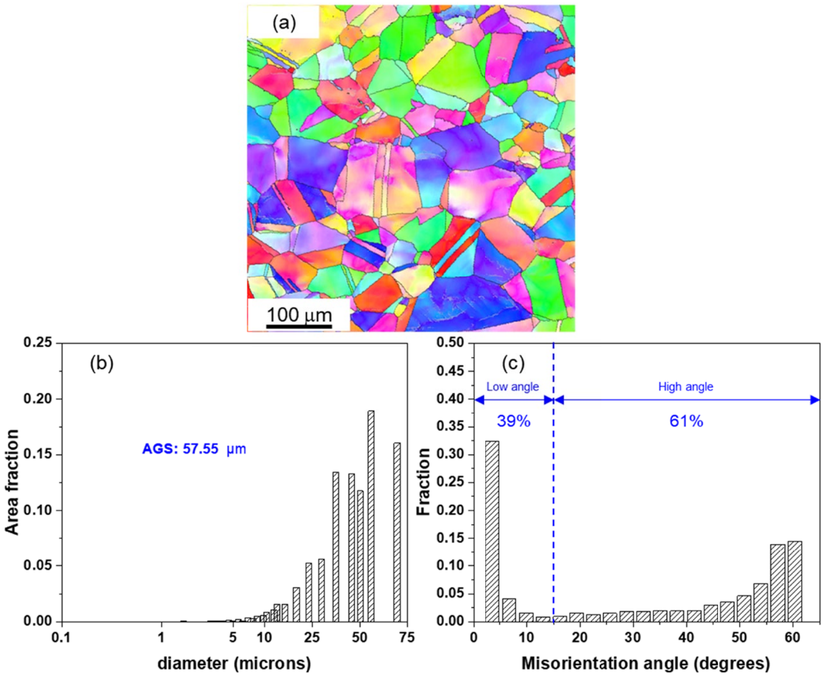

Fig. 1. (a) Inverse pole figure map, (b) grain size distribution and (c) misorientation angle distribution of initial material

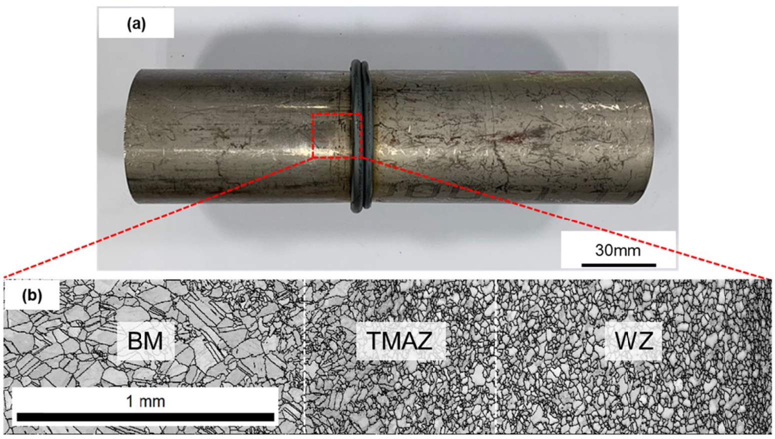

Fig. 2. (a) Top view and (b) macrostructure of friction welded material

high angle grain boundaries are occupied over than 88% in fraction at the whole grain boundaries, as shown in Fig. 3(c), which means that the dynamic recrystallization during FW was perfectly occurred.

Results of Vickers microhardness test of the welds, including the base material zone, is shown in Fig. 4. At the base material zone, microhardness values ranges from 250 to 265 Hv, as shown in Fig. 4(a). Despite the Application of FW, the weld zone showed values from 200 to 215 Hv, 25% lower relative to the base material in average. As the base material is partially recrystallized through hot rolling, it is judged that a residual deformed structure (high dislocation density) remains inside. To confirm this, we analyzed the kernel average misorientation (KAM) map. As a result, it was confirmed that the dislocation density of the base material (KAM_{avg}: 0.93) was higher than the weld zone (KAM_{avg}: 0.75), as shown in Figs. 4(b) and 4(c).

Top view and tensile properties of the tensile tested material are shown in Fig. 5. Yield and tensile strengths of the base material indicate 508 and 746 MPa with an elongation of 49%, respectively, as shown in Fig. 5(a). In case of the welded material, yield strength, tensile strength and elongation are 484, 678 MPa and 17%, which decreased compared to the base material, respectively. At the top view of the tensile tested welds, fracture occurred at the base material zone, as shown in Fig. 5(b).

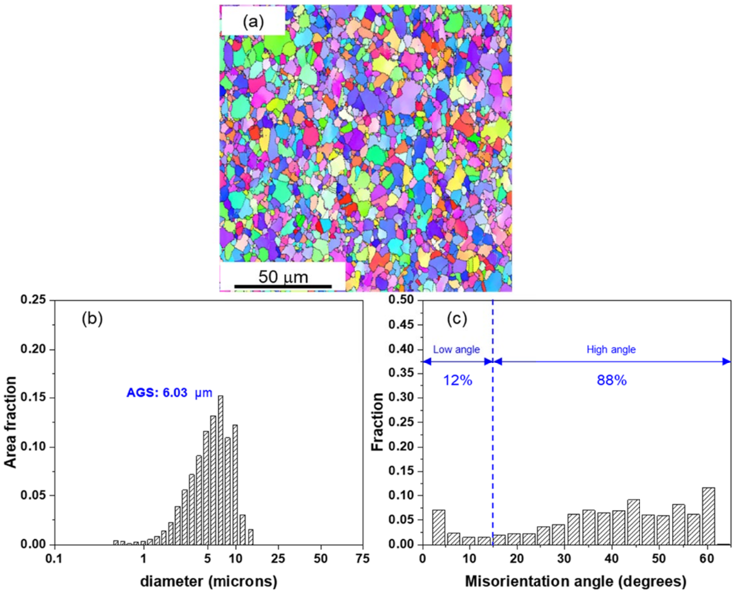

Fig. 3. (a) Inverse pole figure map, (b) grain size distribution and (c) misorientation angel distribution of friction welded material

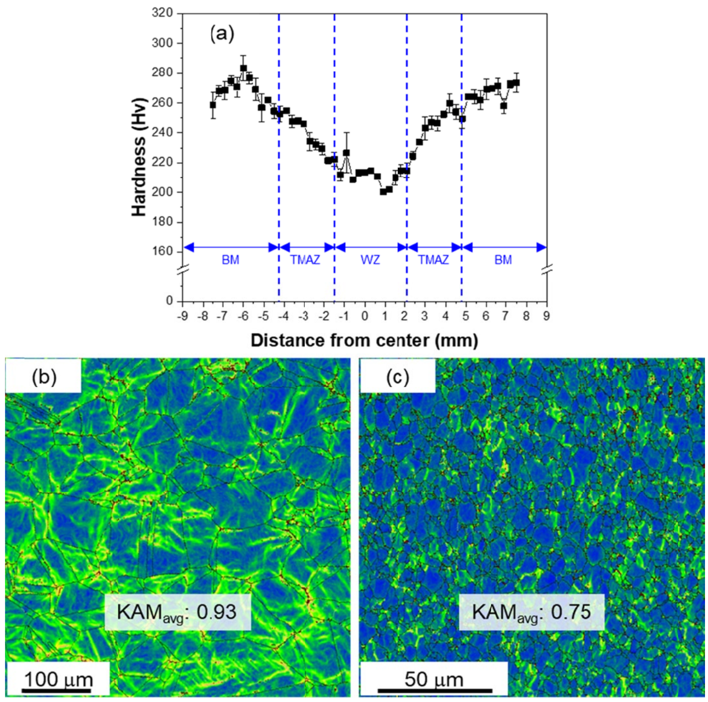

Fig. 4. (a) Distribution of cross-sectional Vickers microhardness in friction welded material, kernel average misorientation of base material zone (b) and welded zone (c)

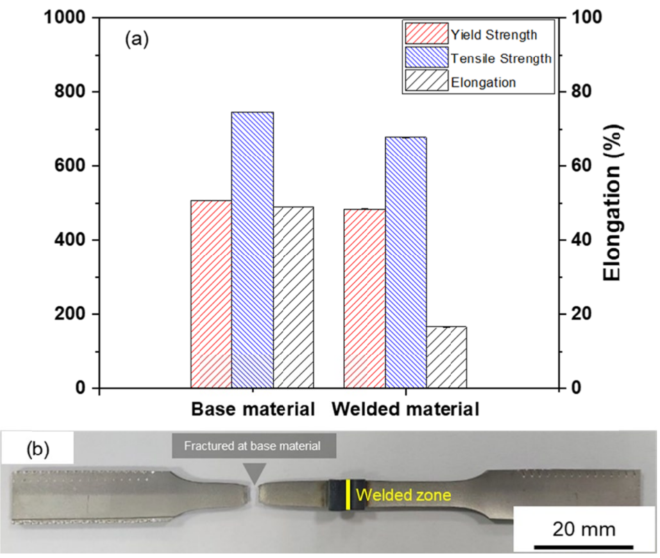

Fig. 5. (a) Tensile properties and (b) top view of tensile tested welds

SUS316L alloy was soundly welded without any defects such as distortion, cracks, voids and holes at weld surface and inner side, as shown in Fig. 2. FW has lower heat-input relative to the fusion welding such as gas tungsten arc welding, laser welding and electron beam welding, which can suppress the weld defects as mentioned above [8,9]. In addition, the friction and upset pressure are entailed during the welding so that the defects such as void and cracks are rarely formed at the joint, and oxides and carbides are seldom formed during the welding because of solid state welding process [10]. In particular, microstructure control is feasible by welding parameter such as rotation speed, friction and upset pressure so that the formation of heat affected zone (HAZ) can be suppressed at the joints, as shown in this study (Fig. 4). Therefore, the application of FW as a welding process on SUS316L alloy is effective to obtain the sound welds.

The grain size of the welds was significantly decreased through FW. At initial state, an average grain size was 57.55 μm in base material, which was notably decreased to 6.03 μm in welded zone, as shown in Figs. 1 and 3, respectively. In addition, the distribution of grain size was notably homogenized through FW, as shown in Fig. 3. These are explained by dynamic recrystallization occurred during FW. In general, FW process accompanies the metallic plastic flow during the welding so that the material can be accumulated a stored energy, which act as the simultaneous recrystallization nuclei sites [11-13]. Also, the friction heat, generally 0.5-0.6 T_m, occurred during the welding is enough to be recrystallized the welded material. Consequently, the grains of the welded zone were wholly changed from elongated to equiaxed shape, which brings about the multiple simultaneous grains nuclei during the welding.

Despite grain refinement by FW, the Vickers microhardness of welded zone was 25% lower values relative to the base material zone due to the relatively high dislocation density of the base material compared to the welded zone, as shown in Fig. 4. However, grain refining was effective to sustain the yield and tensile strength of the welded material, though elongation was significantly decreased relative to initial material, as shown in Fig. 5. As a result, the tensile specimen was firstly deformed and fractured at base material zone, as shown in Fig. 5(b). Therefore, grain refining during FW is effective to retain the mechanical properties such as yield and tensile strength, as directly shown in this study.

4. Conclusions

SUS316L alloy was soundly welded without any defects such as voids, cracks, distortion and so on in the welds. Application of FW led to the grain refinement of the welds due to the dynamic recrystallization, as a result, yield and tensile strength were similar to the base material. Moreover, the absence of HAZ and refined grain size in the welds was contributed to the fracture aspect at the base material zone, not at the welded zone. Therefore, FW process on SUS316L alloy joining could be obtained the developed microstructures and mechanical properties of the welds relative to the fusion welding.

Acknowledgments

This work was supported by the Establishment of Demonstration Infrastructure for Regulation-Free Special Zones funded by the Ministry of SMEs and Startups (MSS, Korea)

REFERENCES

[1] J.W. Choi, Y. Aoki, K. Ushioda, H. Fujii, Scr. Mater. **191**, 12-16 (2021).
[2] S. Karami, H. Jafarian, A.R. Eivani, S. Kheirandish, Mater. Sci. Eng. A. **670**, 68-74 (2016).
[3] T.J. Yoon, S.W. Park, M.C. Kang, J.S. Noh, S.W. Chung, C.Y. Kang, J. Powder. Mater. **22**, 181-186 (2015)
[4] M.B. Uday, M.N.A. Fauzi, H. Zuhailawati, A.B. Ismail, Sci. Technol. Weld. Join. **15**, 534-558 (2010).
[5] R. Palanivel, R.F. Laubscher, I. Dinaharan, D.G. Hattingh, Int. J. Press. Vessel. Pip. **154**, 17-28 (2017).
[6] M. Stütz, R. Buzolin, F. Pixner, C. Poletti, N. Enzinger, Mater. Charact. **151**, 506-518 (2019).
[7] Y.H. Liu, Z.B. Zhao, C.B. Zhang, Q.J. Wang, H. Sun, N. Li, Mater. Lett. **277**, 128329 (2020).
[8] M. Maalekian, Sci. Technol. Weld. Join. **12**, 738-759 (2007).
[9] Z. Liang, G. Qin, P. Geng, F. Yang, X. Meng, J. Manuf. Process. **25**, 153-162 (2017).
[10] W. Li, A. Vairis, M. Preuss, T. Ma, Int. Mater. Rev. **61**, 71-100 (2016).
[11] T.R. McNelley, S. Swaminathan, J.Q. Su, Scr. Mater. **58**, 349-354 (2008).
[12] F.C. Liu, T.W. Nelson, Mater. Charact. **140**, 39-44 (2018).
[13] A. Rollett, F. Humphreys, G.S. Rohrer, M. Hatherly, Recrystallization and Related Annealing Phenomena, Elsevier 2004.