Kissing-Bond Characteristics in a Friction Stir Welded Aluminum Alloy by Transmission Electron Microscopy

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ABSTRACT Initial oxide layer on the butt surface fragments during friction stir welding (FSW) and then often remains as a faint zigzag-line pattern on the cross section. When remnant of the oxide layer often adversely affects the mechanical properties in the weld, it is called as "kissing-bond". The present study systematically examines effect of oxide array on bend property in the root of friction stir (FS) welded Al alloy 1050 by transmission electron microscopy (TEM), and then clarifies identity of the kissing-bond.

1. Introduction

Friction stir welding (FSW) produces a finer recrystallized grain structure accompanying better mechanical properties than fusion welding without elimination of initial oxide layer on the butt surface. Sato et al. [1] suggested in a TEM study that the initial oxide layer on the butt surface fragmented during FSW and was locally distributed on a zigzag line on the cross section of a friction stir (FS) welded Al alloy. Some previous studies reported that the remnant of the oxide layer on the zigzag line did not affect the mechanical properties [1,2], but effect of oxide array on mechanical properties in the root of the weld has not been examined yet. The mechanical properties should depend on the size, density and connectivity of the oxides. Considering FSW process, a decrease in heat input would weaken the fragmentation of the oxide layer. The remnant of the oxide layer produced during low heat-input FSW often acts as a fracture site for the root-bending, which is generally called as "kissing-bond", but identity of the kissing-bond in the stir zone has not been well understood. To clarify the identity of the kissing-bond in the FS-welded Al alloy, the present study systematically examines effect of oxide array on bend property in the root of an FS-welded Al alloy 1050 by TEM.

2. Experimental Procedures

The base material used in this study was a 2mm-thick Al alloy 1050-H24. Two plates of this alloy were FS-welded at rotational speed of 600 to 2400 rpm and travel speed of 1.45 to 12.0 mm/s. A constant plunged depth of the pin (1.9mm) was used at all welding parameters during FSW. After FSW, the cross-sectional observation and the root-bend test were performed with all welds. The zigzag line existing in the root of the cracked weld was defined as the kissing-bond in this study. The kissing-bond was thinned by focused ion beam (FIB), and then the oxide distribution along the kissing-bond was observed by TEM.

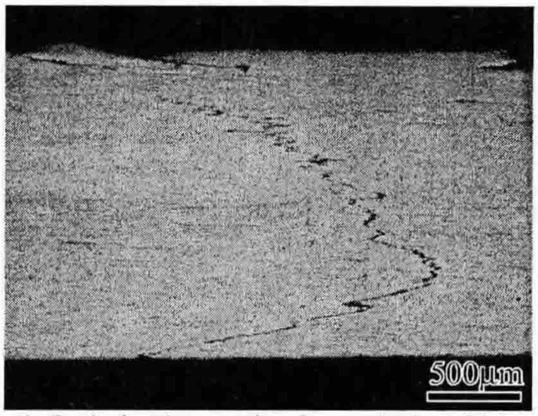

Fig. 1 Optical micrograph of a typical weld having zigzag line produced at travel of 8.45 mm/s and rotation of 2400 rpm.

3. Results and discussion

In all welds produced in the present study, there were no defects observed on the as-polished cross section. In addition, there were no defects detected by dye penetration test. Etching in an NaOH aqueous solution made the preferentially etched the zigzag oxide-line in the stir zone of the most welds, except for the welds produced at the high heat-input parameters, as shown in Fig. 1. The root tip of the zigzag line was identical to the position of the initial butt line on the bottom surface. Optical microscopy confirmed that the vicinity of the zigzag line had roughly the same grain structure as the center of the stir zone in all welds having the zigzag line.

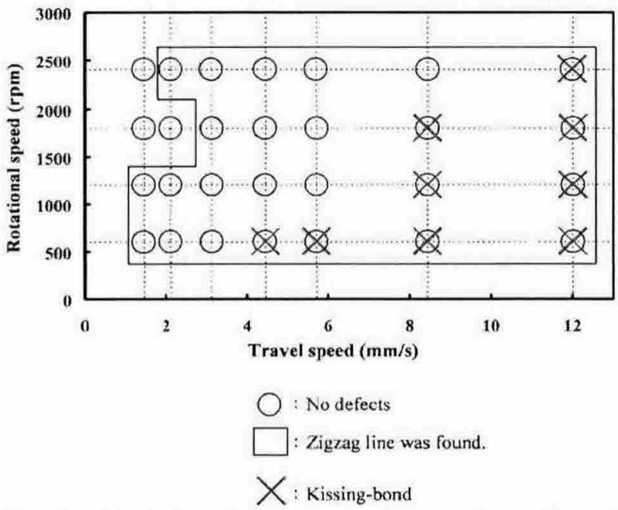

Fig. 2 Effect of welding parameters on formation of zigzag line and kissing-bond in friction stir welded Al alloy 1050.

The root-bend test revealed the presence of the kissing-bond in some welds produced at the lower heat-input parameters forming zigzag line. In the cracked weld, the fracture during root bending is initiated from the root tip of the zigzag line and propagates along the zigzag line. Effect of welding parameters on formation of zigzag line and kissing-bond in the weld was summarized in Fig. 2.

To clarify the difference in oxide distribution at the root between the uncracked and cracked welds, the vicinity of the zigzag line in these welds was observed by TEM. TEM images of the root tip of the uncracked zigzag line and kissing-bond were shown in Figs. 3 and 4, respectively. Al_2O_3 oxides having an amorphous structure were observed both around the zigzag line and kissing-bond. The uncracked zigzag line contains the locally distributed oxide particles (Fig. 3), while the kissing-bond consists of a continuous oxide film (Fig. 4).

A previous study [1] suggested that the initial oxide layer on the butt surface fragmented during FSW and was locally distributed on a zigzag line on the cross section of a FS-welded Al alloy. In this study, a variation in the welding parameters shows that the lower heat-input FSW leaves a continuous oxide film in the root part due to weaker fragmentation of the initial oxide layer on the butt surface. FSW is achieved by shear deformation arising from rotation of the welding tool along the pin column surface [3], so that formation of the kissing-bond would be attributed to a decrease in shear strain introduced into unit volume of the material during FSW.

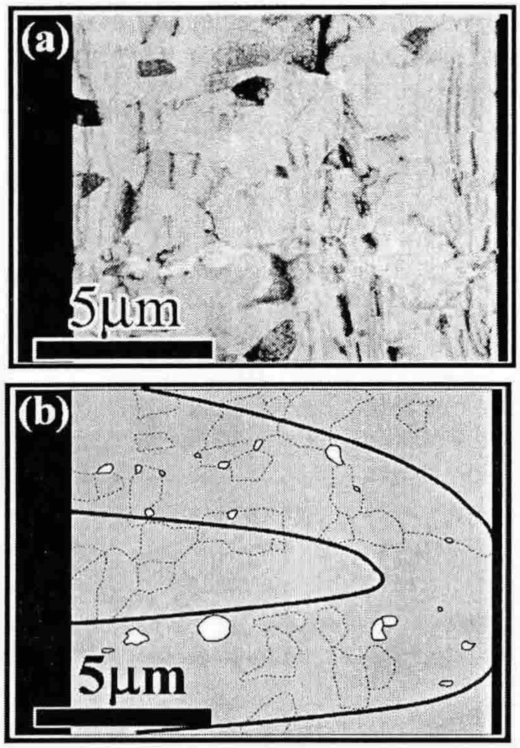

Fig. 3 TEM image (a) and schematic illustration (b) of the root tip of the zigzag line of the uncracked weld produced at travel of 8.45 mm/s and rotational speed of 2400 rpm.

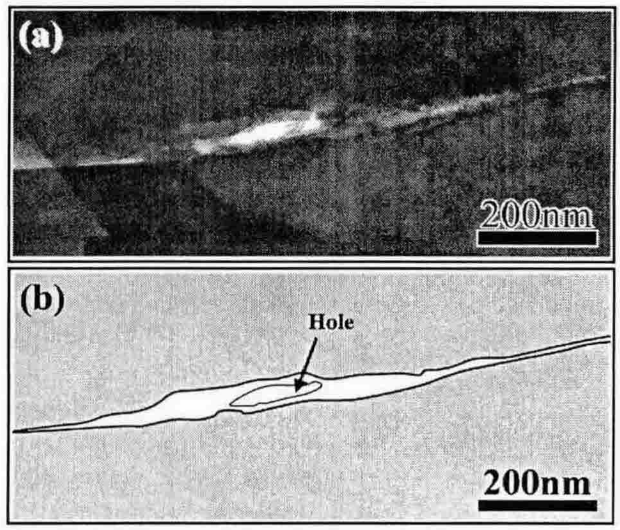

Fig. 4 TEM image (a) and schematic illustration (b) of the root tip of the zigzag line of the cracked weld produced at travel of 12.0 mm/s and rotational speed of 2400 rpm.

4. Conclusions

To clarify the identity of the kissing-bond, effect of oxide array on bend property was systematically examined in the FS welded Al alloy 1050 by TEM. An increase in heat input during FSW changed the oxide array from continuous film into particle distribution in the zigzag line in the stir zone. The bend property was adversely affected by only the continuous oxide film. The present study suggests that presence of the continuous oxide film is a feature of the kissing-bond.

Acknowledgements

The authors are grateful to Mr. A. Honda and Mr. Y. Kondo for technical assistance and acknowledge Prof. Ikeda, Prof. K. Maruyama and Prof. Z.J. Wang for their helpful discussions.

References

1. Y.S. Sato, F. Yamashita, Y. Sugiura, S.H.C. Park and H. Kokawa : FIB-assisted TEM study of an oxide array in the root of a friction stir welded aluminum alloy, Scripta Mater., 50 (2004), 365-369.
2. H. Okamura, K. Aota, M. Sakamoto, M. Ezumi and K. Ikeuchi : Behavior of oxide during friction stir welding of aluminum alloy and its influence on mechanical properties, Quart. J. Jpn Weld. Soc., 19 (2001), 446-456 (in Japanese).
3. Y.S. Sato, H. Kokawa, K. Ikeda, M. Enomoto, S. Jogan and T. Hashimoto : Microtexture in the friction-stir weld of an aluminum alloy, Metall. Mater. Trans. A, 32A (2001), 941-948.