Surface Friction Welding of Thin Metal Sheets

Sung-Joon Kim\(^1,\,a\), Chang Gil Lee\(^1,\,b\),
Heung Nam Han\(^2,\,c\), Suk Hoon Kang\(^2,\,d\) and Kyu Hwan Oh\(^2,\,e\)

\(^1\)Korea Institute of Machinery & Materials, Changwon, Korea 641-010
\(^2\)School of Materials Science and Engineering, Seoul National University, Seoul, Korea 151-742
\(^a\)sjkim@kmail.kimm.re.kr, \(^b\)cglee@kmail.kimm.re.kr,
\(^c\)hnhan@snu.ac.kr, \(^d\)sangle77@snu.ac.kr, \(^e\)Kyuwan@snu.ac.kr

**Keywords:** Surface friction welding, Mechanical properties, Pole figure, EBSD

**Abstract.** A novel process for butt welding of thin metal sheets was developed and named as surface friction welding (SFW), which utilizes friction heat and severe plastic deformation like friction stir welding (FSW). The joining mechanism of the SFW is based on not stirring by the pin tool but surface friction between tool shoulder and joining metals. The developed method was successfully applied to butt welding of various metal sheets thinner than 1.5 mm thick. This paper deals with the principle of SFW, the difference between FSW and SFW, the effect of welding parameters, and the microstructure and mechanical properties of welded sheets.

**Introduction**

Friction stir welding (FSW) is a solid-state joining process using frictional and quasi-adiabatic heat generated by a rotating and traversing cylindrical tool with a profiled pin [1-4]. The FSW can produce a high-quality joint compared to the other conventional weld process, and also make it possible to join metals and non-metals which have been considered as non-weldable by conventional methods. With the development in FSW process, friction stir processing (FSP) employing FSW tooling is also being explored, and applied to refine microstructure in narrow regions [5].

In the present study, a new concept of friction welding is suggested and applied to various aluminum and other alloy sheets. Since the process utilizes only the surface friction between tool shoulder and parent material without stirring by tool pin, it was named as surface friction welding (SFW) by the present authors. Various light alloy sheets thinner than about 1.5 mm were successfully joined by the SFW process, and some of their microstructure and mechanical properties were evaluated.

**Description of Surface Friction Welding Process**

Surface Friction Welding (SFW) process also utilizes frictional heat between rotating tool and base material as well as severe plastic deformation like FSW. However, the SFW process does not employ stirring of tool pin, which is one of the most important steps of the FSW process. The only difference between FSW and SFW is the existence of pin, as shown in Fig. 1, so that the apparent view of the SFW process is almost same as the FSW process. Since the tool does not have a pin, the process can be applied to perfect closed loop of joining without key-hole, but can only be applied to thin materials. Fig. 2 shows the cross-sectional macroscopic views of various alloy sheets which are successfully SFWed, indicating that the SFW process can be applied to many kinds of metal sheets, although the soundness of welded area depends on many process parameters. Main process variables are alloy composition, tool rotating speed, welding speed, tool diameter, thickness of base material, and the kind of back plate material, etc. These process variables are mainly related with the heat generated and the material flow during the SFW.
process. The plate-normal direction (ND), welding direction (WD) and transverse direction (TD) are
indicated.

Fig. 1 Schematic drawings which show the typical difference between (a) FSW and (b) SFW
processes. The plate-normal direction (ND), welding direction (WD) and transverse direction (TD) are
indicated.

Fig. 2 Cross-sectional macrographs of SFWed (a) 1050 Al, (b) AZ31 Mg, and (c) pure Cu alloy sheets. The
thickness of all metal sheets is 1 mm.

Microstructure and Mechanical Properties of SFWed Metal Sheets

As previously observed in every FSWed metals [2,3], typical dynamically recrystallized zone (DXZ),
thermomechanically affected zone (TMAZ), heat affected zone (HAZ), and base material (BM) are
also observed in the SFWed metals. However, the weld nugget which is very typical in the friction stir
welded area is not formed in the SFWed plates due to the absence of tool pin. Fig. 3 shows the
distribution of low angle grain boundary less than 5° within the welded area measured by an electron
backscattered diffraction (EBSD) for the Al 6061-T651 alloy plates which are FSWed and SFWed
under the same welding and tool rotating speed. These low angle boundaries seem to be related with
the appropriate plastic deformation without recrystallization. During SFW, the severe metal flow on
the interface between the tool and the welded metal gives rise to the plastic deformation even at
TMAZ adjacent to DXZ. As a consequence, the microstructure expected in TMAZ might become a
dislocation cell structure [6], and these cells metastably remain as subgrains when there is no
succeeding dynamic recrystallization. Then, the low angle boundaries become strongly developed in
TMAZ as shown in Fig. 3. From the distribution of the low angle boundaries, therefore, the shape of
DXZ and TMAZ can easily determined. It can be confirmed that, as shown in Fig. 3, the DXZ in the
SFWed plate is shallower than that of the FSWed one. This is caused by the fact that SFW process
does not employ stirring of tool pin.

Fig. 3 Shape of TMAZ in FSWed and SFWed Al 6061-T651 alloy plates recognized by the
distribution of low angle grain boundary less than 5°. The welding and tool rotating speed was 200
mm/sec, and 1600 rpm, respectively.
Fig. 4 shows a crystallographic texture observed at weld nugget in FSWed Al 6061-T651 alloy plate in the form of (111) pole figure. The exact measured position of this pole figure was just beside the track of pin tool after FSW. In case of rotating pin tool during FSW, welding direction (WD) and transverse direction (TD) are parallel to a horizontal shear direction (SD) and a vertical shear plane-normal (SPN), respectively. From the relationships between the principal directions of material and the deformation directions of simple shear, it can be confirmed that the texture shown in Fig. 4 closely resembles that of ideal simple shear texture in FCC metals [7].

Fig. 5 (a) shows another (111) pole figure observed at weld nugget in FSWed Al 6061-T651 alloy plate just below the track of tool shoulder. The texture in Fig. 5 (b) was calculated after 90° rotation about the normal direction (ND) assuming a shear plane tangential to the tool shoulder and a shear direction along the weld transverse direction (TD). The rotated texture is also fairly similar to that of ideal simple shear texture in FCC metals [7]. The results shown in Figs. 4 and 5 suggest that the predominant deformation in FSW is simple shear and two shear modes, which have different horizontal shear direction (SD) and vertical shear plane-normal (SPN), coexist at FSW process.

Fig. 6 shows an (111) pole figure typically observed at weld zone in SFWed Al 6061-T651 alloy plate below the track of tool shoulder. The {100}//ND texture was observed together with the fine-grained microstructure, as the welding material is swept around the welding tool. In SFW, the principal directions of shear deformation are equivalent to that caused by the tool shoulder during FSW, and thereby the crystallographic texture fairly resembles the pole figure shown in Fig. 5. This indicates that the predominant deformation in SFW is also simple shear.

Tensile strength of SFWed 5052 Al alloy sheets as functions of welding speed and tool rotating speed is given in Fig. 7. The dotted line in the figure is the tensile strength of parent alloy, and the value is 232 MPa. In any processing conditions of SFW, the tensile strength over 185 MPa is obtained. Thus, the tensile strength of welded plate was maintained at above 80% of parent alloy. As shown in Fig. 7, tensile strength decreases almost linearly with the increase of welding speed, whereas the tool rotating speed does not give significant change in tensile strength. Since the increase in welding speed reduces the exposure time of friction between the welded plate and tool, the heat generated during welding is reduced. This reduction of heat generation might affect the microstructure of welded area and change the tensile properties [8].
Conclusions

A new concept of process for butt welding of thin metal sheets, named as surface friction welding (SFW), was developed. In the SFW process, the soundness of welded area mainly depends on alloy composition, tool rotating speed, welding speed, tool diameter, and the kind of back plate material. The microstructure of welded area consists of dynamically recrystallized zone (DXZ), thermomechanically affected zone (TMAZ), and heat affected zone (HAZ). Tensile strengths at least 80% or more of the parent material can be obtained by the SFW process. The crystallographic texture observed at weld zone in a SFWed Al alloy sheet resembles that of ideal simple shear texture in FCC metals. This suggests that the predominant deformation in SFW is simple shear.

Acknowledgement

This research was supported by a grant from the Center for Advanced Materials Processing (CAMP) of the 21st Century Frontier R&D Program funded by the Ministry of Commerce, Industry and Energy (MOCIE), Republic of Korea

References