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Ultrafine-Grained Surface Layer Formation of Aluminum Alloy 5083 by Friction Stir Processing

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Abstract

Friction stir processing experiments are conducted on aluminum alloy 5083 plates to enhance the surface integrity by introducing an ultrafine-grained surface layer. Microstructural analyses are carried out using optical microscopy to characterize the grain structures under various conditions. Within the produced surface layer, equiaxed ultra-fine grains are observed due to dynamic recrystallized during FSP. The grain size is reduced from 40 μm to a submicron level for the FSP rotational speed of 800 rpm. The hardness is increased to a peak value of 151 HV, which is higher than that of the unprocessed area by 50%.

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1. Introduction

Aluminum alloy 5083 (AA 5083) is generally known for its outstanding corrosion resistance, particularly in marine environments. It is used in naval welded structures such as hulls, deck, and bulkheads, as well as in equipment items such as ladders, gratings, windows, and doors [1]. It is also the choice for superplastic aerospace and automotive parts materials.

Recently, there has been a significant research interest in generating ultra-fine grained (UFG) microstructure for aluminum alloys to enhance their strength and hardness. Severe plastic deformation (SPD) processes have been developed to obtain fine-grained microstructures for the whole workpiece of AA 5083 [2]. The UFG microstructure has been reported to be beneficial on improving ductility, formability, and mechanical strength for AA 5086 [3].

Friction stir processing (FSP) has been developed based on the principle of friction stir welding (FSW). During FSP, the rotating tool is inserted in the solid workpiece and mechanically mixes the treated surface material at elevated temperatures from

the friction heat. The large process strain results in the microstructural refinement and homogenization. Thus, FSP can be implemented to locally modify the mechanical component surface for strength enhancement of AA 5083.

FSP creates an area called the “stirred zone” (SZ) or nugget zone (NZ), which corresponds to the location of the tool stirring with the heavily deformed material. Under properly controlled conditions, the microstructure of the stir zone can be refined to have equiaxed ultra-fine grains with high angle grain boundaries, which can present the ideal conditions for superplasticity in some materials [4]. The selection of process parameters is critical to optimize the process for preferable microstructure and control the amount of heat generation. Abdi Behnagh et al. [5] developed a numerical modeling framework to capture the metallo-thermo-mechanical coupling effect during a friction stirring process and predict the microstructure evolution under various process conditions. The microstructural evolution by dynamic recrystallization (DRX) was found to be dominated by the process heat generation and thermal history of the workpiece. Process parameters such as

tool rotational speed and feed rate were found to play important roles in determining the frictional heat generation, process temperature, final material mechanical properties, and microstructure.

For considering reliability and repeatability for the FSP process, it is essential to conduct a thorough experimental analysis for industrial applications. Practically, no adequate information is available in the open literature on FSP of 5083 aluminum, particularly on the effect of multi-pass FSP on the grain size achieved after the process.

In this study, the multi-pass FSP experiments are performed to investigate the process capability of microstructure refinement and strength enhancement for rolled AA 5083 plates. The microstructural characteristics of the original and processed specimens are evaluated and compared.

2. Experiments

The material used in this study was 5mm thick AA5083-H111 sheet. The chemical composition of this material is given in Table 1. The bulk material (BM) of the as-received AA5083-H111 sheet as shown in Fig. 1 **Error! Reference source not found. Error! Reference source not found.** was characterized by a typical hot-rolled structure, which mostly consisted of large elongated pancake-shaped grains with length in tens of microns. The average grain size of BM was about 40 μm . The as-received rolled plates were cut into specimens of $30 \times 10 \times 5 \text{ mm}^3$ in length, width and thickness. The FSP experiments were performed on a modified vertical mill. The FSP tool made of DIN1.2436 tool steel as shown in Fig. 2 was employed in these experiments. A 3 mm tall 3.5-by-3.5 mm^2 tool tip was machined out of a concave shoulder with a diameter of 18 mm.

Table 1 Chemical composition of the experimental plates (wt. %)

Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Balance	0.1	0.31	0.04	0.61	4.27	0.1	0.02	0.026



Fig. 1. Microstructure of BM.

The FSP experiment procedure is illustrated in Fig. 3. The rotating FSP tool was plunged into the AA5083-H111 sheet until the shoulder contacted the top surface of the plate; the tool was then traversed along the sheet surface. The material around the tool became softened and highly plasticized from the frictional heat generated during the process and was carried around the tool. In this study, the tool was rotated in clockwise direction with a constant tilt angle (defined as the angle between spindle and workpiece normal) of 3° , which assisted

the forging action at the trailing edge of the shoulder. The tool rotational speed was varied from 600 to 1000 rpm, while its traverse speed was kept fixed at 50 mm/min. The FSP experiments were carried out at room temperature and each experimental condition was repeated three times to assure the repeatability.



Fig. 2. FSP tool used in the experiment.

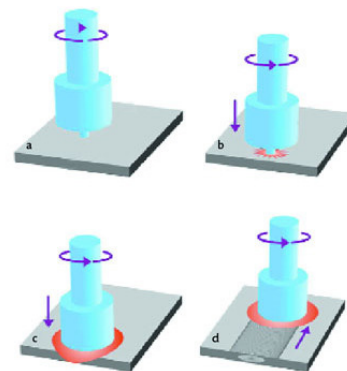


Fig. 3. The schematic of FSP.

The macro- and microstructural characteristics of the processed plate were investigated on the transverse section along the feed direction by optical microscopy (OM) under polarized light. The transverse section was polished and etched. Chemical etching was performed for one min by a modified Polltun's reagent containing 12 ml HCl, 16 ml HNO₃, 1 ml H₂O, 1 ml HF, and 12 ml of a solution consisting of 3g chromic acid per 10 ml H₂O at 25°C. Grain size measurement was carried out using the line intercept method. The hardness profile was obtained along the cross section of samples by a Vickers microhardness tester using a load of 100 gf for a dwell time of 5 seconds.

3. Results and Discussions

Fig. 4 shows the surface appearance of one of the FSPed 5083 alloy of 300 mm in length. AS and RS are referred to the advancing side and retreating side of the tool rotation, respectively. The top surface is very flat and smooth in spite of the tool's stirring. The surface was free of cracks or any other visible defects with only feed marks from the tool feeding motion.

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