The Possibility of Friction Stir Welding of High Nitrogen-containing Austenitic Stainless Steel

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To develop the practical use of high nitrogen-containing austenitic stainless steels (HNS), the possibility of using friction stir welding (FSW) of HNS was examined. In this report, butt-welding of 2 mm thick HNS steel plates was performed using a load-controlled FSW machine. Two types of welding tool materials were used in this study, namely, a Si_3N_4 -based material and a WC-Co-based material. For FSW with Si_3N_4 , full-penetrated and defect-free butt welding joints were successfully produced. On the other hand, for FSW with WC-Co, the tool was deformed and the stir zone did not completely reach the bottom. The stir zone produced by the Si_3N_4 tool showed a Vicker's hardness higher than the base metal and displayed a fine microstructure due to recrystallization. The yield strength and the tensile strength of the welds produced by the Si_3N_4 tool exceeded that of the base metal.

Key Words : Electro-slag remelting methods, Friction stir welding, Butt-welding, Austenite, α formation

1. INTRODUCTION

Although high nitrogen-containing austenitic stainless steel (HNS) is known as a superior material, having high strength, high toughness, and high corrosion resistance, there are some problems to be solved. These include blowhole generation or nitride precipitation, caused by heat input during the welding process due to the high nitrogen content [1-6]. Thus, the application of a solid state joining process for HNS, which can be performed below its melting points, is significantly demanded [7, 8].

Friction stir welding (FSW), a new solid state welding process developed by TWI (The Welding Institute, England) in 1991 [9], is considered as an effective technique. However, reliable FSW HNS butt-welding joints have not yet been successfully obtained [8].

In this study, FSW was applied to HNS under various welding conditions. To examine the effect of the FSW tool on HNS steels, the performances of two types of welding tool materials, a WC-Co-based material and a Si_3N_4 -based material, were investigated. To determine the optimum conditions to create reliable HNS FSW joints, the effect of welding parameters, i.e., the tool rotation speed, welding speed and the welding load on joint quality, were examined.

2. EXPERIMENTAL PROCEDURE

2.1. Test materials

The material used in this study was 1 mass% nitrogen-containing austenitic stainless steel (HNS) produced by pressurized electro-slag remelting methods (ESR) [10]. Its chemical composition was

Table 1 FSW conditions applied in this experiment.

	Tool Materials	Rotation Speed (rpm)	Welding Speed (mm/min)
Condition A	Si_3N_4	400	200
Condition B	WC-Co	400	100

Fe-23Cr-0Ni-1Mo-1N (mass%). The plates were 2 mm thick, 30 mm wide and 300 mm long.

2.2. Welding conditions

Butt-welding experiments were performed using a load controlled FSW machine. Two types of welding tools, Si_3N_4 and WC-Co based materials were used. A water-cooled holder was installed and argon gas was employed to prevent oxidation of the plates. The conditions utilized in this study are listed in Table 1.

2.3. Metallurgical inspections

The joints were evaluated on the basis of surface appearance,

Figure 1 Configuration of transverse tensile specimen used in this study.
(a) Specifications (b) Appearance

macrostructure and microstructure observation. The metallurgical inspections were performed on a cross section of the joint after polishing and etching with aqua regia.

2.4. Evaluation of joints properties

The mechanical properties were evaluated using the Vicker's hardness test and transverse tensile test. The hardness profiles of the transverse section of the joints were measured in the middle section of the welded plates with a load of 4.9 N for 15 s. The transverse tensile specimens were cut perpendicular to the welding directions, as shown in Figure 1 (a). Configuration of a tensile specimen is shown in Figure 1 (b). Before the test, the specimen was thoroughly mechanically treated to remove any ripples and flash. The tensile tests were carried out at room temperature at a crosshead speed of 1 mm/s. After the test, the fracture surfaces were examined using a scanning electron microscopy (SEM). The crystal structures of the base metal and the stir zone were identified by XRD.

3. RESULT AND DISCUSSIONS

In FSW joints produced under Condition A (Table 1), defects, such as voids and cracks, were not observed on the surface. The top surfaces was very smooth and there were almost no protrusions or depressions. On the other hand, in joints under Condition B, tool deformation was observed during welding process, and the stir zone did not penetrate to the bottom.

The low magnification cross sections of a FSW joint under Condition A are shown in Photo. 1. The left and right sides of the weld are consistent with the advancing and retreating sides, respectively. The stir zone is clearly observed to have thoroughly penetrated to the backing side. The presence of a high degree of continuity and no defects in the weld interior indicate the production of a sound weld joint.

The optical micrographs of 3 regions (labeled A, B and C shown in Photo. 1) are presented in Photo. 2. Region A is located on the weld center, region B is on the border of the stir zone and the heat affected zone (HAZ), and region C is on the base metal. The average grain size of the base metal is estimated to be more than 100 μm . On the other hand, the size of grain is extremely fine in the stir zone. This was the result of dynamic recrystallization during

Photo 1 Cross section images of the friction stir welding joints of Condition A.

Photo 2 Optical microstructures of regions A, B and C shown in Figure 2.

FSW.

The hardness profiles across the stir zones of the welded joints are shown in Figure 2. The hardening of the stir zone in HNS during the FSW was also observed in this study [8]. The stir zone exhibits about a 1.5 times higher hardness than the base metal. No significant differences in hardness were observed for the two conditions. A good relationship between the increase in hardness and the refinement of the grain were observed in this study.

The stress and elongation relationship of weld samples are shown in Figure 3. Both weld samples show higher strength than the base metals. The tensile strength and the yield strength of joints of Condition A show the highest values. However, the elongation of joints of Condition A is inferior to that of Condition B.

SEM observations of the fracture surfaces of the weld joints and the base metal are shown in Photo 3. The base metal shows a clear dimple pattern over the entire viewing field. Although fractures occurred in the HAZ in both Conditions A and B, the fracture

Figure 2 Hardness distribution of friction stir welding joints.

Figure 3 The stress and elongation relationship of the HNS friction stir welding joints.

morphology is completely different. The fracture surface of the joints under Condition A shows a small dimple relating to the fine grain. On the other hands, fracture surface of Condition B shows the characteristic feature of brittle fracture failure. The difference in failure fracture shown here is probably due to the α phase formation identified in Figure 4.

Figure 5 shows typical changes in the temperatures of the work piece during the process. Thermocouples were embedded on the

Figure 4 XRD patterns of the base metal and the fractured surface of FSW joints.

Figure 5 Temperature cycles for thermocouples located on the bottom surface.

bottom surface at the center line [11], thus the temperature in the upper zone should be higher than the measured value. In this case, the peak temperatures under Condition B showed a higher value than that of Condition A. Although the difference recorded here is small, it was suspected that the FSW under Condition B was performed in α formation zone shown in Figure 6. This suggests that the temperature should exceed that of α formation zone to produce sound HNS joints..

4. CONCLUSION

Friction stir welding to obtain butt-welding joints of 1 mass% nitrogen-containing austenitic stainless steel was successfully performed without welding defects and tool deformation utilizing Si_3N_4 under the condition of the rotation speed at 400 rpm and the welding speed at 200 mm/min. The stir zones consist of very fine grain structures and show an increase in the Vicker's hardness. These joints also show higher tensile strength and yield strength than the base metals. The present study shows that FSW is an efficient joining process to join HNS with sound quality.

Figure 6 Thermo dynamics phase diagram of HNS(Fe-23Cr-1Mo-xN) depending on nitrogen contents, calculated by the multi-component phase diagram calculation software: Pandat, Materials Design Technology Co., Ltd..

Photo 3 SEM images of the fracture surfaces of the base metal and the FSW joints.

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