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Hybrid Friction Stir Welding of Carbon Steel

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Abstract. A new welding technique called hybrid FSW was developed to decrease the tool load and the defects during the FSW of high melting point materials. This method consists of FSW and a laser for preheating ahead of the tool. The hybrid FSW enables the proper welding conditions to be significantly expanded, and the joint characteristics are similar to those obtained by the normal FSW at the same welding speeds.

Introduction

Friction stir welding (FSW) has been widely used for low melting point materials such as aluminum alloys. Recently, several studies on comparatively high melting point materials, such as steel [1-9], titanium and molybdenum [10], have also been reported. However, in the present situation, there are still many problems to be solved, such as the high tool load and equipment rigidity. In order to decrease the tool load and then defects in the weld, a hybrid FSW technique was developed, in which the FSW was performed after local heating using a laser heat source. By using this method, a carbon steel was welded and the joint properties were investigated in detail.

Experimental Procedure

The material used was a carbon steel plate (SS400) of 50mm^{W} x 300mm^{L} x 3.2mm^{T}. Table 1 shows the chemical compositions of the steel plate. Figure 1 shows a schematic illustration of the hybrid friction stir welding system. The preceding heat source was a 2.0kW YAG laser with a beam head angle of 45 degrees. The FSW was carried out at the rotation rate of 400rpm using a WC based tool in an argon atmosphere. The welding speed was varied between 100 and 800 mm/min. For comparison, a normal FSW was also carried out without any other heat sources at the welding speed of 50 to 700 mm/min. After the friction stir welding, the cross-sectional microstructure observation, and the hardness and tensile strength examinations were carried out.

Table1 Chemical compositions of material used.

	Chemical composition (mass%)					
	C	Si	Mn	P	S	Fe
SS400	0.16	0.01	0.49	0.015	0.006	Bal.

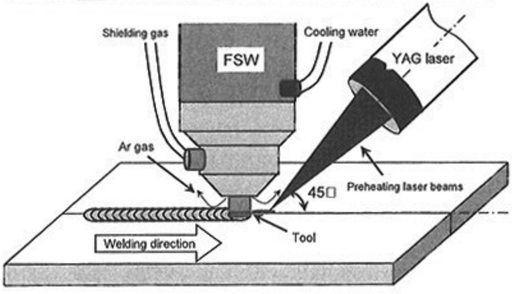

Fig.1 Schematic illustration of Hybrid FSW.

Results and discussion

Figure 2 shows the macrostructures of the joints which were friction-stir-welded at 400mm/min or hybrid-friction-stir-welded at 400 and 800 mm/min. For the normal FSW, no defects were formed at

50 to 300 mm/min, but a small defect was formed on the advancing side of the stir zone at 400 mm/min. The tool was fractured at higher welding speeds. For the hybrid FSW, on the other hand, defect free joints were obtained up to the welding speed of 700 mm/min. Thus, the hybrid FSW enables the defect formation to be reduced and the suitable welding conditions to be expanded.

Figures 3(a) and (b) show the microstructures of the stir zone obtained by the hybrid FSW at 400 mm/min. They are the microstructure before the FSW (after laser) and after the FSW, respectively. Figure 3(c) shows the microstructure which forms only when the FSW was carried out (normal FSW).

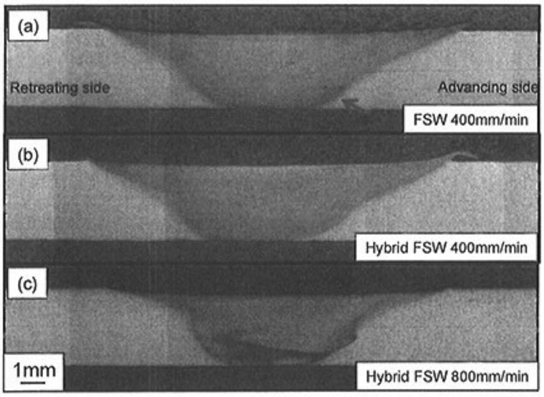

Fig.2 Macrostructures of (a) normal FSW joints and (b), (c) hybrid FSW joints.

For the microstructure of the hybrid FSW joint, a solidified microstructure is first formed by the laser which is the preceding heat source, as shown in Fig.3(a). The solidification microstructure then disappears by the stir action of the tool and a refined ferrite-bainite microstructure is formed, as shown in Fig.3(b). This microstructure is quite similar to that obtained by the normal FSW (Fig.3(c)).

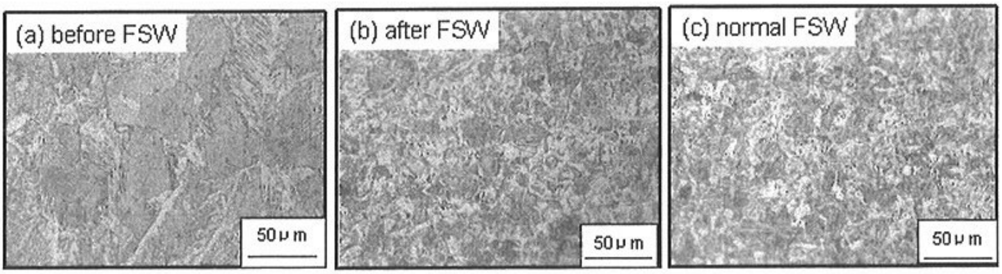

Fig.3 Microstructures of stir zone (a) before FSW (after laser) (b) after FSW in hybrid FSW joints and (c) in normal FSW. (400mm/min)

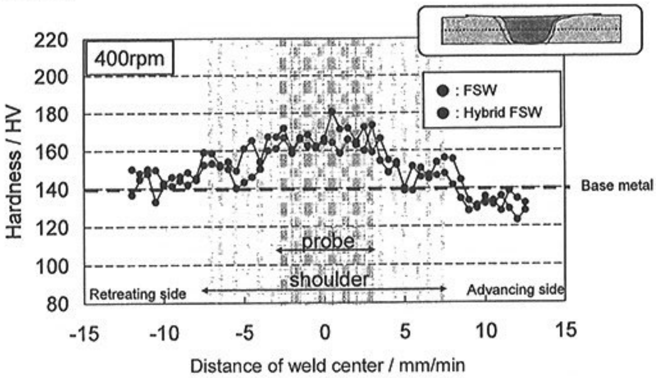

Fig.4 Comparison of hardness distributions of hybrid FSW and normal FSW joints. (400mm/min)

Figure 4 shows the hardness distributions of the cross sections perpendicular to the welding direction of the hybrid and normal FSW joints obtained at 400mm/min. The hardness distributions are similar to each other, which corresponds with the microstructure shown in Figs.3(b) and (c).

Figure 5(a) shows the tensile strength of the joints obtained by the hybrid FSW or the normal FSW. All joints formed at 50 to 400 mm/min by the normal FSW were fractured at the base metal, as shown in Fig.6(a). However, friction stir welding was impossible at 500 mm/min or higher. For the hybrid FSW, on the other hand, all joints were fractured at the base metal at the welding speed of 400 and 800 mm/min, as shown in Fig.6(b). Because all the tensile specimens referenced to JIS Z2201, which involve the entire joint, fractured in the base metals, small tensile specimens of which the gauge length was covered by the weld nugget were used to characterize the tensile properties of the stir zone. Figure 5(b) shows the tensile strength of the stir zone using these small specimens. The strength of the stir zone is higher than that of the entire joint. Note that there is no significant difference in the tensile strength between the two processes.

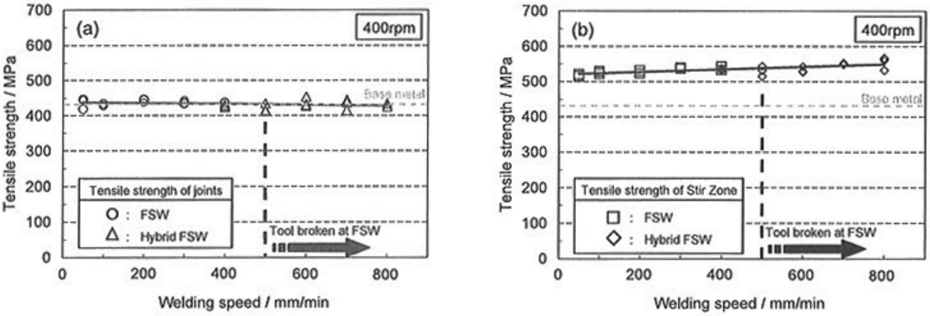

Fig.5 Tensile strength of (a) joints and (b) Stir Zone

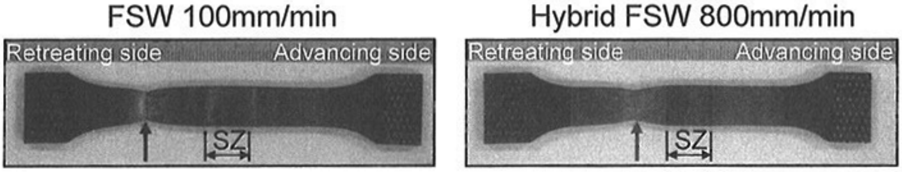

Fig.6 Appearance of fractured tensile specimens.

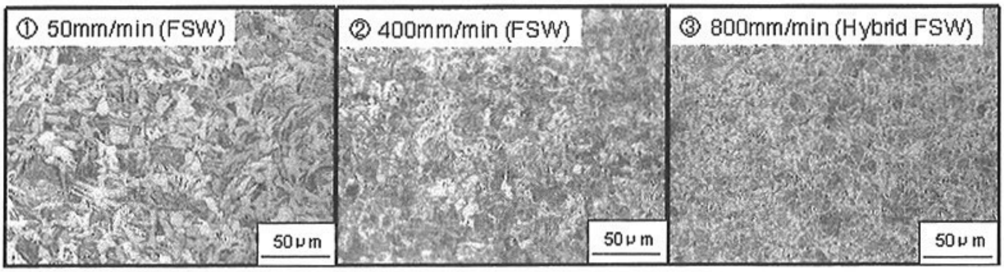

Fig.7 Effect of welding speed on microstructures of stir zone (a) (b) normal FSW and (c) hybrid FSW.

Figure 7 shows the change in the microstructure of the stir zone versus the welding speed. Figures 7(a) and (b) are obtained by the normal FSW and Fig.7 (c) is obtained by the hybrid FSW. The microstructure is independent of the process, but significantly dependent on the welding speed. The tensile strength monotonically increases with the increasing welding speed for both processes due to the change in the microstructure. However, as mentioned before, the hybrid FSW enables the welding speed to be increased. Consequently, the strength of the hybrid FSW joints can be higher than that of the normal FSW joints.

Summary

Hybrid FSW enables the defect formation to be reduced and the proper welding conditions to be significantly expanded by local heating ahead of the tool by a laser heat source. The microstructure in the joint is quite similar to the joint obtained using normal friction stir welding. All joints were fractured at the base metal during the tensile test. The tensile strength of the stir zone monotonically increases with the increasing welding speed due to the refined microstructure, independent of the process. However, because the hybrid FSW enables the welding speed to be increased, the strength of the hybrid FSW joints can be higher than that of the normal FSW joints.

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