第Ⅰ部門

Fatigue Performance of FSW Joints in High Strength Weathering Steel

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1. Introduction

Weathering steel has been developed and widely used to improve the anti-corrosion performance of steel structures. However, cracks are more likely to occur in weathering steel during the conventional welding process due to the increasing contents of alloy elements such as P, Cu, etc.

Friction stir welding (FSW) offers the great capability to join weathering steel at a lower heat input. Wang[1)] studied the mechanical properties of weathering steel. The results indicate that FSW exhibits excellent welding performance. But the application of FSW to the weathering steel with higher strength remains to be investigated and verified. Aluminum and phosphorus can enhance the weather resistance of metals. At the same time, they can also effectively increase the strength of weathering steel.

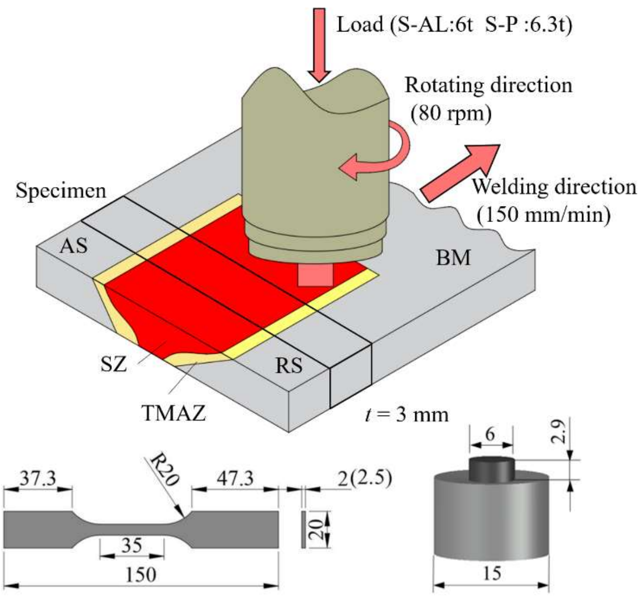

Fig.1 Welding procedure.

The purpose of this paper is to evaluate the fatigue performance of high strength weathering steels with high aluminum and high phosphorus joined by FSW.

2. Experimental procedure

Two kinds of steel with high aluminum (S-AL) and high phosphorus (S-P) were newly developed to evaluate the mechanical properties produced by FSW. The butt weld was performed by the FSW machine below the A1 temperature. The welding tool rotated clockwise and travelled at a constant welding speed of 150 mm/min and rotational speed of 80 rpm. The initial downward force was controlled at 6t and 6.3t for S-AL and S-P, respectively.

Welding procedure and the geometry of specimens are shown in Fig.1. The thickness of the welded steel plate was shaved to 2 mm (2.5 mm for BM plate) to reduce the influence of angular distortion.

The fatigue experiment was carried out by a servo 4830 hydraulic testing machine. The stress ratio R was equal to 0.1 and the loading frequency was constant at 16 Hz.

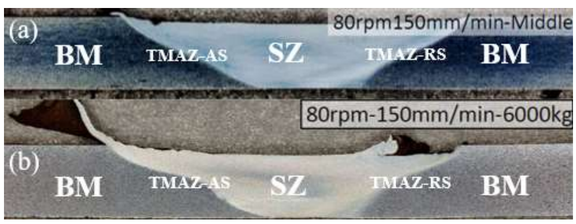

Fig.2 Transverse section (a) S-AL (b) S-P.

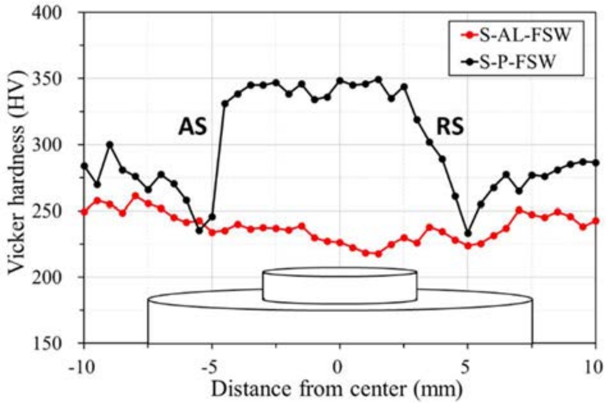

Fig.3 The micro-hardness of welded joints.

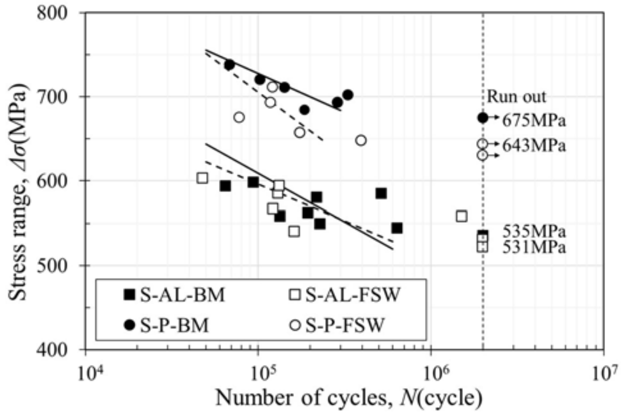

Fig.4 Stress range Δσ-fatigue life N relationship.

3. Results and discussion

Fig.2 shows overviews of the transverse cross sections of FSW samples. In each case, the joints can be split into regions including the base metal (BM), stir zone (SZ), and thermo-mechanically affected zone at the advancing and retreating sides (TMAZ-AS, TMAZ-RS). The weldment profiles appear "basin-shaped", which is consistent with the size of the tool probe.

The micro-hardness of S-AL-FSW and S-P-FSW is summarized in Fig.3. Slightly softening at SZ and no softening at TMAZ can be observed for S-AL-FSW. As for S-P-FSW, obvious hardening at SZ and softening at TMAZ can be observed. It can be observed that both the micro-hardness distributions are not perfectly symmetrical especially for S-P-FSW.

The fatigue experiment was carried out on a total of 36 BM and FSW specimens of S-AL and S-P. The specimens were defined to be running out when loading cycle $N > 2 \times 10^6$. Fatigue specimen of S-AL fractured at BM region, indicating a favorable fatigue strength of welded joints. However, the specimen of S-P fractured at TMAZ due to the softening.

Fig.4 shows the stress range $\Delta\sigma$ and fatigue life N relationship of the specimens. It is observed that the data points of FSW and BM specimens of S-AL are scattered together and illustrate similar fatigue strength. While for S-P, the fatigue strength of FSW is a little bit lower than BM because of the softening at TMAZ, but the affect is not significant. It is concluded that the fatigue strength of FSW joints of the studied steels in this research are generally higher than the conventional method.

4. Conclusion

In this study, the mechanical properties of high-strength weathering steel with elevated aluminum and phosphorus content joined by FSW below the A1 temperature were investigated. The primary conclusions are summarized as follows:

(1) An increase in aluminum and phosphorus content enhances the strength of the steel. The microhardness of two materials indicates that in the case of S-AL, there is slight softening in the SZ. Conversely, for S-P, there is noticeable softening in the TMAZ and hardening in the SZ.

(2) The fatigue strengths of S-AL-BM and S-AL-FSW are nearly identical. Although fatigue strengths of S-P-FSW is slightly lower than that of S-P-BM due to softening, the affect is not significant, which indicating good welding performance.

References

1) Y. Wang, S. Tsutsumi, T. Kawakubo, H. Fujii, Microstructure and mechanical properties of weathering mild steel joined by friction stir welding, Materials Science and Engineering: A 823 (2021) 141715.