Experimental Investigation on Fatigue Performance Improvement of Repaired Patch Plate Joint by Post-Weld Heat Treatment with Induction Heating

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1. Introduction

Fatigue has become a critical concern which should be taken into account for civil engineering structures under cyclic loadings particularly in steel bridges. It is well known that local stress concentration and high tensile residual stresses at the welded parts are two predominant factors to cause fatigue cracks. Generally, fatigue cracks initiate and propagate at the welded parts when the high tensile residual stresses combine with the externally applied load, leading to fatigue failure. Post-weld treatment (PWT) methods such as grinding, TIG dressing, and ultrasonic impact treatment (UIT) methods reduce the stress concentration at the weld toe by improving the weld toe geometry, enhancing the fatigue strength of the welded joints [1-2]. Unlikely to PWT, post-weld heat treatment (PWHT) methods alleviate the high tensile residual stress at the weld toe by stress release annealing, consequently, fatigue life of the structures is prolonged [3]. This study aims to propose a PWHT method with induction heating (IH) for fatigue performance improvement of the welded patch plate joints by means of stress relaxation of the tensile residual stresses at the weld toe. A series of experimental investigation was conducted on the patch plate welded joints. Furthermore, a four-point bending fatigue test was conducted under two loading conditions to examine the effect of PWHT on the fatigue life of the patch plate joints.

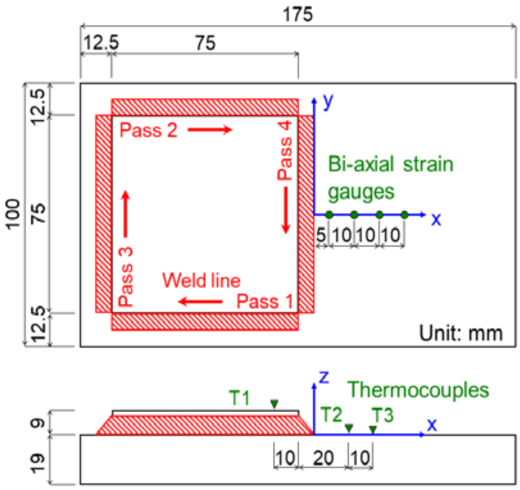


Fig. 1: Dimension and shape of patch plate joint

2. Experiment

2.1. Fabrication of test specimens

In this study, the patch plate joints were fabricated from SM400A steel plates. In Fig. 1, 19 mm thick base plate was connected with 9 mm thick patch plate by a leg length of 6 mm fillet weld. CO_2 semi-automatic welding was performed with the current of 100 A, the voltage of 20 V and the average welding speed of 4.5 to 5.0 mm/s. Besides, the As-welded specimens were used as control specimens to make a comparison with the PWHT specimens in order to evaluate the effect of PWHT on the residual stresses and fatigue life of the patch plate joints.

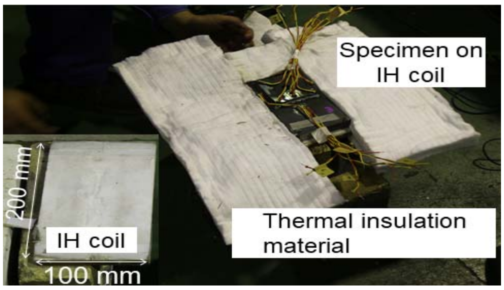
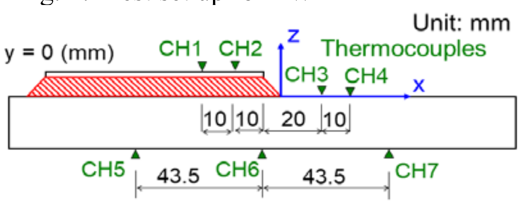


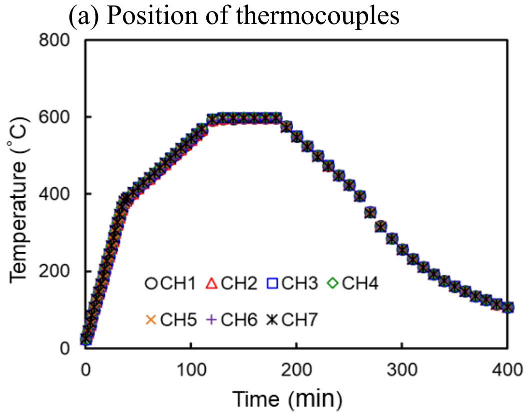
Fig. 2: Test set up for PWHT

2.2. Post-weld heat treatment (PWHT) with induction heating

Fig. 2 shows the setting position of the specimen for PWHT with IH. 200 mm long and 100 mm wide IH coil was set under the specimen. The specimen and IH coil were covered by a thermal insulation material for keeping the heat during PWHT process. Thermocouples were attached on the upper and lower surfaces of the specimen to control the temperature during PWHT as shown in Fig. 3(a). PWHT was performed according to JIS Z 3700 [4]. The soaking temperature is 600 ˚C and the holding time is over 30 minutes.



(a) Position of thermocouples



(b) Temperature histories

Fig. 3: Temperature histories during PWHT

2.3. Residual stress measurement

As shown in Fig. 1, biaxial strain gauges were mounted on the base plates of the As-welded and PWHT specimens to measure the residual stress by a stress relaxation method. The specimen was cut a 10 mm cube around the strain gauges. The residual stress was calculated from the released strain by cutting.

3. Results and discussions

3.1. Temperature history

Fig. 3(b) shows the temperature histories during PWHT process. The temperatures from all thermocouples were almost the same. It meant that PWHT with IH could control accurately the desired temperature.

Keywords: residual stress, post-weld heat treatment, induction heating, fatigue performance
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3.2. Residual Stresses

The residual stresses after welding and PWHT calculated from the stress relaxation method were plotted in Fig. 4. Only the residual stress in x-direction is focused in this study since the stress component σ_x along the orthogonal direction of the weld line mainly contributes to the initiation and propagation of fatigue crack at the weld toe. This experiment showed that the tensile residual stress at 5 mm away from the weld toe was reduced by 50% after PWHT. However, it was predicted that at the weld toe, a larger percentage of the tensile residual stress would be reduced by PWHT and this would improve the fatigue life of the patch plate joints.

4. Fatigue test on patch plate joints

The dimensions of the fatigue test specimens were 540 mm long and 100 mm wide for the base plate and 75 mm x 75 mm for the patch plate. Four-point bending test was conducted to evaluate the effect of PWHT on the fatigue life improvement. The support span was 440 mm while the loading span was 240 mm. Two types of loading conditions; namely a positive loading pattern to produce tensile stress at the weld toe and a negative loading pattern to produce compressive stress at the weld toe were examined. Fig. 5 shows the relationship between the applied stress range and fatigue life. The fatigue cracks were observed at the weld toe in the As-welded and PWHT specimens under both loading conditions. The fatigue life of the PWHT specimens applied by the positive loading pattern was increased twice that of the As-welded specimens under the applied stress ranges of 50 MPa and 60 MPa. In the case of the stress range of over 80 MPa, the effect of fatigue life improvement by PWHT was not confirmed. In contrast, over from 8 to 10 times of the fatigue life improvement effect was confirmed in the stress range over 80 MPa under the negative loading pattern. The results indicated that the fatigue life improvement effect was different with the applied stress condition and the magnitude of stress around the weld toe.

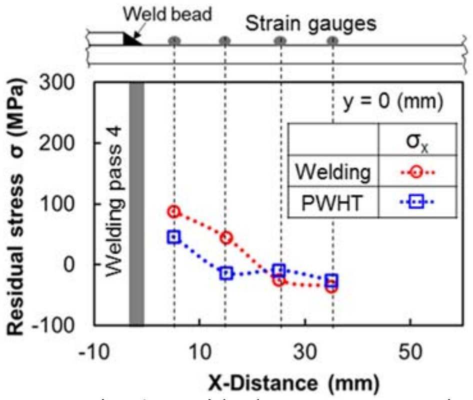
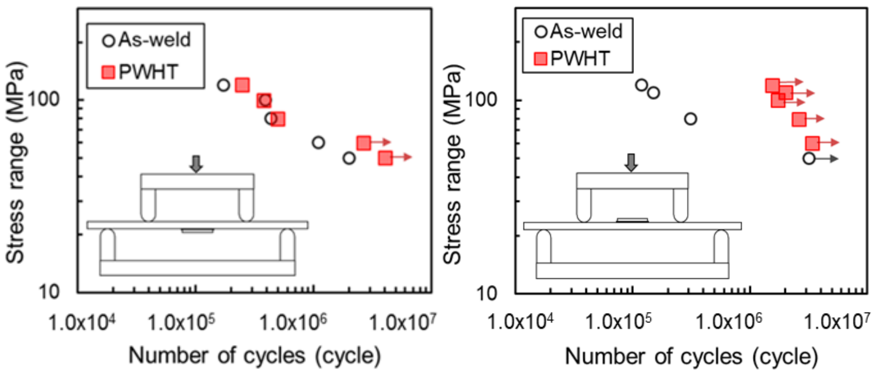


Fig. 4: Residual stresses comparison



(a) Positive loading pattern (b) Negative loading pattern

Fig. 5: Results of fatigue test experiment

5. Conclusion

A series of experiment on the patch plate welded joints was conducted to examine the effect of the PWHT with IH on the residual stress control and the fatigue performance improvement. The following conclusions can be drawn:

1) IH device had a high controllability of temperature for patch plate joints.
2) Tensile residual stress at the distance of 5mm away from the weld toe were reduced by 50% after PWHT.
3) In the loading pattern by which the tensile stress was applied on the weld toe, the fatigue life of the PWHT specimens became twice as long as that of the As-welded specimens under the stress ranges of 50 MPa and 60 MPa whereas over 8 to 10 times of fatigue life improvement effect was confirmed under the stress ranges of over 80 MPa in the loading pattern by which the compressive stress was applied on the weld toe.

The fatigue life improvement affected by the residual stress release with PWHT is limited by the applied stress pattern (tension or compression) and magnitude around the weld toe. It should be noted that the PWHT not only on the patch plate welded joints but also any other joint types should be considered based on the applied stress conditions on the joints.

Acknowledgement

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References

[1] Pedersen, M.M., Mouritsen, O.Ø., Hansen, M.R., Andersen, J.G., Wenderby, J. Comparison of post weld treatment of high strength steel welded joints in medium cycle fatigue. *Welding in the World,* 54, 2010, pp. R208-R217.

[2] Roy, S.; Fisher, J.W.; Yen, B.T. Fatigue resistance of welded details enhanced by ultrasonic impact treatment (UIT). *International Journal of Fatigue, 25,* 2003, pp. 1239-1247.

[3] Hirohata, M., Itoh, Y. Residual Stress Relaxation of Box Welded Joints by Portable Heat Source, *Journal of Japan Society of Civil Engineers*, Ser. A1 (SE/EE) 71(2), 2015, pp. 208-220. (In Japanese)

[4] Japan Industrial Standard. The post-weld heat treatment method JIS Z 3700, 2009.