Effect of Postweld Heat Treatment and Welding Residual Stress on Fatigue Behavior of Weldable Structural Carbon Steel

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1. Introduction

Welding is one of the most convenient and efficient joining methods for steel components or structures. Despite the many advantages of welding, it has also disadvantages such as welding residual stress, microstructural change, welding defects, etc. According to the literature [1], the magnitude of the residual stress may have a value near the yield stress of the base material, although it depends on the method and procedure of the welding, and other welding parameters. Post-weld heat treatment (PWHT) has been used to remove welding residual stresses. Despite much research on PWHT [2], there have been few studies on the effect of PWHT on fatigue strength. It has been believed that PWHT will increase the fatigue strength of the weldment. However, according to experimental results [3-5], PWHT generally reduces the fatigue strength of the weldment. Zhang et al. [3] studied PWHT effect on the crack propagation rate of a high-strength low-alloy steel (yield strength, 690 MPa, tensile strength, 790 MPa). Flux-cored arc welding was used. Annealing was carried out at 930 ℃ for one hour. PWHT specimens had 9.1 % shorter fatigue lifetime than as-welded specimens. Leitner et al. [4] investigated the fatigue behavior of a mild steel S355 (yield stress, 355 MPa, tensile strength 470~630) using load-carrying and non-load-carrying cruciform specimens. Annealing was conducted at 550 ℃ for 30 minutes. PWHT specimen had fewer cycles to failure than as-welded specimens. They insisted that the decrease of fatigue strength of the PWHT specimens was due to the relief of the compressive welding residual stress. Udo and Numakura [5] produced single V grooved butt welded specimens of a super duplex stainless steel (UNS S32750) by flux-cored arc welding. The specimens were solution-treated in a vacuum at 1050 ℃ for one hour. According to their experimental results, PWHT decreased the fatigue strength, which was caused by the σ phase formed during cooling.

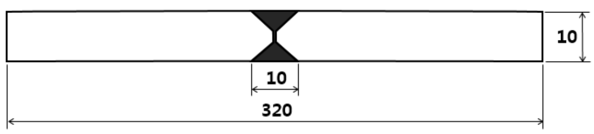
In this study, a medium-strength structural carbon steel, SM490A (equivalent to EN-S355J0, yield stress, 355 MPa, tensile strength, 490-610 MPa) was chosen for research. The SM490A sheet is widely used in various fields such as automobile, shipbuilding, railroad, etc. However, the effect of PWHT on the fatigue behavior has not been sufficiently studied. Mechanical properties, microstructures, welding residual stress, etc. will be comprehensively investigated using specimens with and without PWHT.

2. Material and Methods

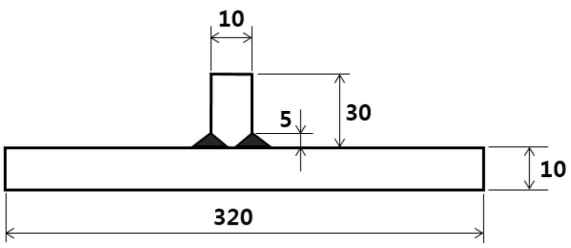
The composition of SM490A is C (≤0.20 wt. %), Si (≤0.55), Mn (≤1.6), P (≤0.035), S (≤0.035) and Fe(balance). Specimens for hardness measurement, tensile and fatigue tests were produced from SM490A plates. The gas metal arc welding (GMAW) parameters are shown in **Table 1**. **Fig. 1** shows the specimen shapes. Micro hardness of PWHTed and non-PWHTed specimen were measured and compared. Microstructures of weld metal, heat affected zone (HAZ) and base material were examined using scanning electronic microscope (SEM). Residual stresses were measured using an X-ray diffraction analyzer. Tensile fatigue tests were carried out for PWHTed and non-PWHTed specimens. In addition, welding residual stress was analyzed by the finite element analysis, and experimental and numerical results were compared. **Fig. 2** presents the finite element meshes for the T-shaped fillet welded specimen.

Table 1 GMAR welding parameters.

	Double V-grooved butt weld	T-shaped fillet weld
Current	300 (A)	270 (A)
Voltage	30 (V)	28 (V)
Moving speed	4.1 (mm/s)	5.0 (mm/s)
Shield gas	Ar 80%+CO_2 20%	Same
Filler metal	AWS ER 70S-6, Φ1.2	Same



(a) Double V-grooved butt welding specimen.



(b) T-shaped fillet welding specimen

Fig. 1. Welding specimens, width =25 mm.

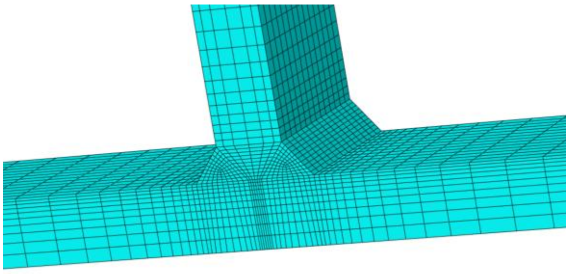


Fig.2 3-dimensional finite element meshes for T-shaped welding specimen.

3. Results and Discussion

Fig. 3 shows tensile curves tested with displacement control. It can be seen that PWHT slightly reduced the yield stress and slightly increased the tensile strength. The elongation was almost the same. **Fig. 4** presents the Vickers hardness measured from the left edge. It is interesting that the hardness value decreases in the order of HAZ, weld metal, and base metal. And PWHT lowered the hardness of the base, HAZ and weld metal. Microscopic observation showed that the crystal size of the heat affected zone was the smallest. In general, particle size and hardness are inversely related. According to the tensile fatigue test results, the effect of PWHT on the base metal and butt welded specimens was negligible. In case of T-shaped specimens, the fatigue strength of PWHTed was lower than that of non PWHTed specimens.

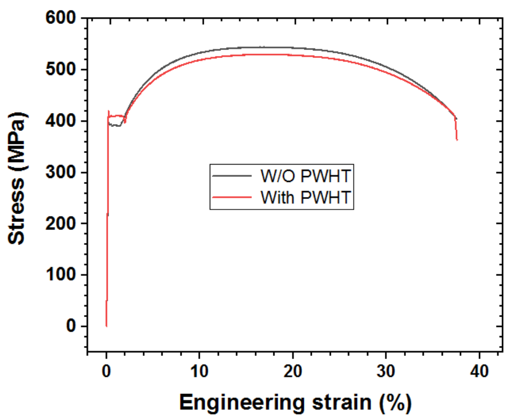
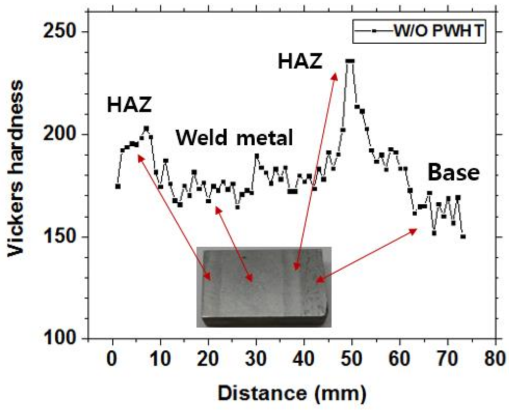
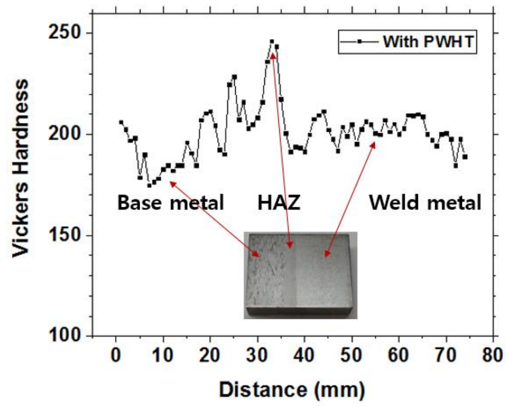


Fig. 3 Strain-stress curves of SM490A.



(a) Non PWHTed specimen



(b) PWHTed specimen

Fig. 4. Vickers hardness, distance is from left edge.

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