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Effect of Heat Treatment on the Grooving Corrosion Resistance of ERW Pipes

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The v-sharp grooving corrosion of ERW(electrical resistance welding) steel pipes limited their wide application in the industry in spite of their high productivity and efficiency. The grooving corrosion is caused mainly by the different microstructures between the matrix and weld that is formed during the rapid heating and cooling cycle in welding. By this localized corrosion reaction of pipes, it evolves economic problems such as the early damage of industrial facilities and pipe lines of apartment, and water pollution. Even though the diminishing of sulfur content is most effective to decrease the susceptibility of grooving corrosion, it requires costly process.

In this study, improvement of grooving corrosion resistance was pursuited by post weld heat treatment in the temperature range between 650℃ and 950℃. Also, the effect of heat input in the welding was investigated. By employing chromnoamperometry and potentiodynamic experiment, the corrosion rate and grooving corrosion index(α) were obtained. It was found that heat treatment could improve the grooving corrosion resistance. Among them, the heat treated at 900℃ and 950℃ had excellent grooving corrosion resistance. The index of heat treated specimen at 900℃ and 950℃ were 1.0, 1.2, respectively, which are almost immune to the grooving corrosion. Potential difference after the heat treatment between base and weld metal was decreased considerably. While the as-received one measured 61 ~ 71 mV, that of the 900℃ heat treated steel pipe measured only 10mV. The results were explained and discussed.

Keywords : *grooving corrosion, electrical resistance welding, galvanic corrosion, post weld heat treatment*

1. Introduction

In general, the steel pipe manufacture by the electric resistance welding process, which represents almost 70% of domestic pipe production can be attributed to the productivity and efficiency. But the v-sharp grooving corrosion of ERW steel pipes, caused mainly by the microstructural differences between the matrix and weld that is formed in the rapid heating and cooling cycle of welding. The susceptibility of grooving corrosion could be affected by the environmental conditions, i.e., temperature, dissolved oxygen content, pH and aggressive ions.[1] The sulfur content in the steel(over 0.005wt%) has the highest effect among those detrimental factors on the grooving corrosion susceptibility; the less the sulfur content in steel, the higher the resistance of the grooving corrosion.[2),3)] But it requires costly process. The resistance of grooving corrosion could be improved by post-weld heat treatment, which modify the abnormal microstructures. However, few experimental result about post-weld heat treatment has been reported.

Therefore, in this study, improvement of grooving corrosion resistance was pursued by post weld heat treatment in the temperature range between 650℃ and 950℃. The work was focused on the obtaining optimal temperature for post-weld heat treatment. Also, the effect of heat input in the welding process on the grooving corrosion susceptibility were investigated.

2. Experimental procedures

2.1 Specimen preparation and post-weld heat treatment

Table 1 shows the chemical compositions of the carbon steel used to manufacture the pipes, which meets the specifications in the KS D 3507. Nine specimens with various welding heat input, which can be classified as under-heat(A,B,C), optimal-heat(D,E,F), over-heat(G,H,I), were prepared and the welding conditions are shown in Table 2. The microstructures and macrostructures of both

Table 1. Chemical compositions of ERW steel pipe (wt.%)

C	Si	Mn	P	S
0.0491	0.0110	0.2251	0.0142	0.0131

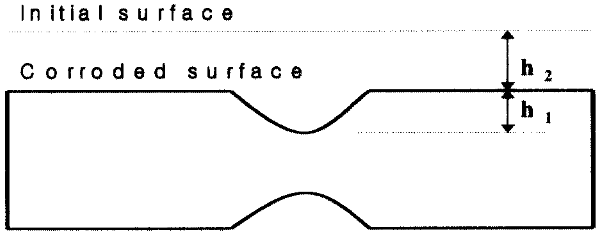
Table 2. Welding conditions of ERW steel pipes

sample No.	weldig condition			
	voltage (kV)	current (A)	line speed (m/min)	heat input (kJ/sec)
A	10.3	22.4	40	346.1
B	10.6	23.0	40	365.7
C	10.9	23.7	40	387.5
D	11.2	24.4	40	409.9
E	11.5	25.0	40	431.3
F	11.8	25.7	40	454.9
G	12.1	26.3	40	477.3
H	12.4	27.0	40	502.2
I	12.7	26.6	40	506.7

weld bead and base metal were examined after etched in the 2% nital and saturated picral solutions, respectively. The post-weld heat treatment , for which the sample size was 40 x 40 mm, was executed from 650℃ to 900℃ in N_2 environment for 30 minutes

2.2 Accelerated corrosion test

The chromnoamperometry test were performed in 3% NaCl solutions at -500mV vs. SCE(saturated calomel electrode) for 48hrs to accelerate the grooving corrosion of ERW pipes . The surfaces to be exposed were polished with #1000 emery paper(SiC) before the experiment. All the metal except the exposed area were insulated with lacquer. During the experiment, air was purged into the solution to maintain the constant oxygen contents. By measuring the depth of groove and thickness reduction, grooving corrosion index were calculated as following.



$\alpha = 1 + h_1 / h_2$

Where α = grooving corrosion index,
h_1 = depth of groove,
h_2 = thickness reduction

Fig. 1. schematic diagram of corroded specimen

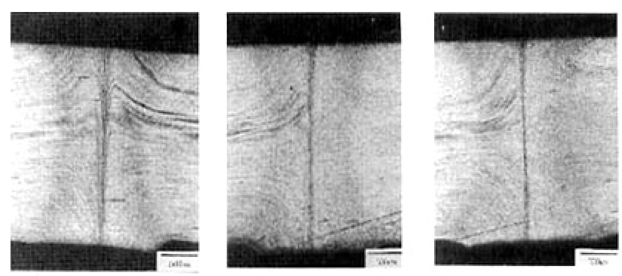
2.3 Polarization test

For the potentiodynamic test, specimen B, E, and H were selected. To obtain the results of weld and base metal separately, only selected area(the effective ares was 0.02986 cm^2 in weld and base) was remained intact, while others were insulated with masking tape. Before the experiment, the specimen was immersed in the aerated 3wt% NaCl solution for 30 minutes to stabilize the surface in the environment. The scan rate was 1mV/second and SCE was adopted as a reference electrode.

3. Results and discussion

3.1 Macrostructures

Fig. 2~3 shows the macrostructures and microstructures of ERW pipes of various heat inputs during the welding. The macrostructures in Fig. 2 show the distinct metal flow, while bond zone appeared as a dark line in the center.



(a) specimen 365.71KJ/mL (b) specimen 431.31KJ/mL (C) specimen 502.2KJ/mL

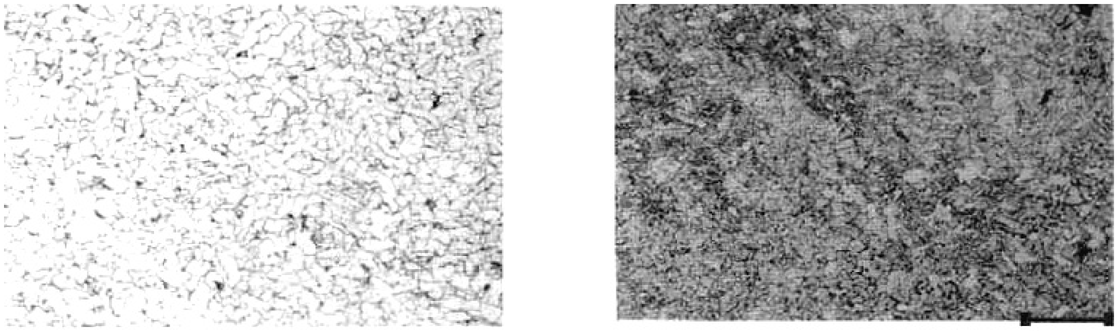
Fig. 2. Macrostructures of ERW pipes with input heat

As shown in the Fig. 2(a), underheated specimen does not show the bond zone clearly, which means insufficient diffusion bonding at the mating surfaces. On the other hand, (b) and (c) represent bond zones with definite widths. Over heated specimen in Fig. 2(c) shows too wide heat-effected zone.

The iron surfide(FeS) couldn't diffuse in weld metal due to low heat input, so the highly grooving corrosion of ERW steel pipe is caused mainly by the FeS.

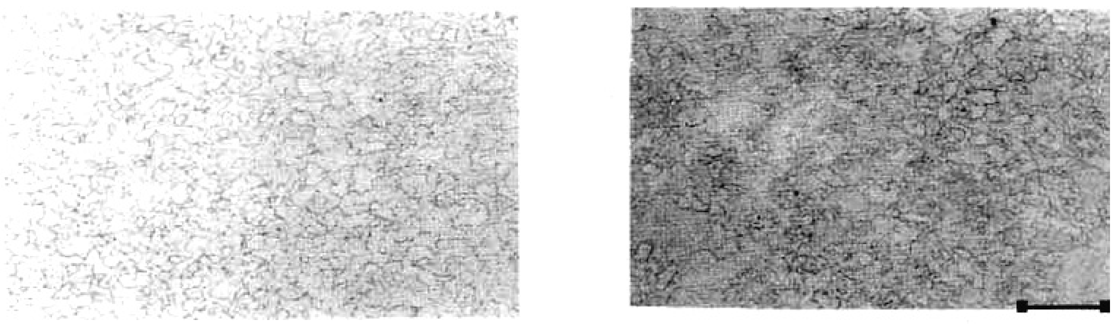
In this study, We observed microstructures at room temperature, 700℃ and 900℃, due to changing their grooving corrosion resistance. Other microstructures would be important to compare among them. But Our purpose is to find it that the best grooving corrosion resistance at each other the post-weld heat treatment temps.

The microstructures of specimen E welded with optimal heat input as-received and after post-weld heat treatment at 700℃ and 900℃ are shown in the Fig. 3-5. It can be seen that the grains become coarser as the heat treatment temperature increases.



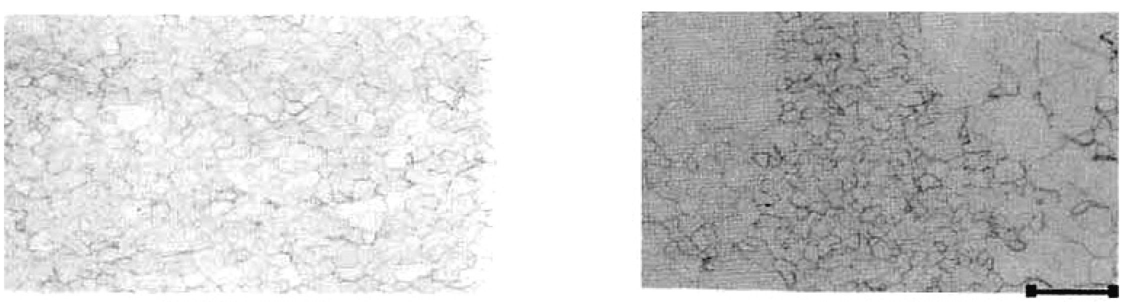
(A) base metal (B) weld metal 75㎛

Fig. 3. Optical microstructures of ERW pipe(specimen E).



(A) base metal (B) weld metal 75㎛

Fig. 4. Optical micrographs of ERW pipe heat treated at 700℃ for 30min(specimen E).



(A) base metal (B) weld metal 75㎛

Fig. 5. Optical micrographs of ERW pipe heat treated at 900℃ for 30 min.(specimen E. x250).

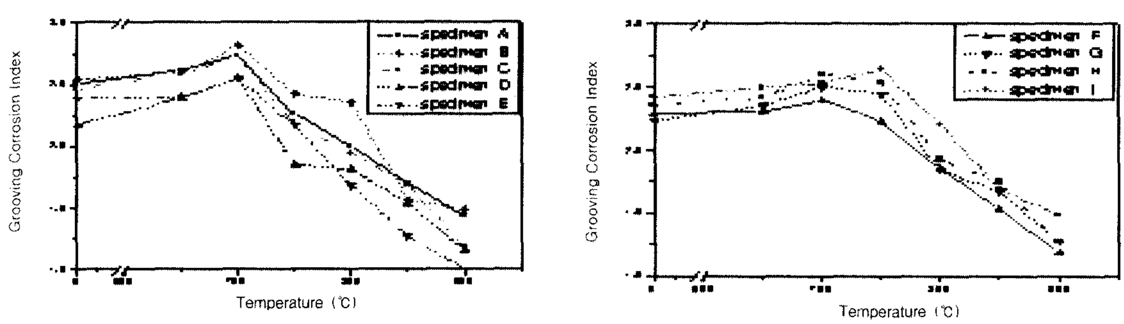


Fig. 6. Results of accelerated corrosion test. (specimen B,E,H)

As shown in the microstructures, heat treated at 700℃ and 900℃ (Fig. 4(b) and 5(b)), the micorstructural heterogeneity are decreased by heat treatment.

3.2 Chronoamperometry test

The results of the chronoamperometry test are shown in Table 3 and Fig. 6.

Table 3. Results of accelerated corrosion test. (specimen B,E,H)

specimen	corrosion weight/area (g/cm^2)	thickness reduction (h2, mm)	depth of groove (hl, mm)		α		
			top	bottom	top	bottom	average
B	0.2571 (0.3264mm)	0.2360	0.3612	0.3716	2.494	2.681	2.638
700B	0.2347 (0.0.02971mm)	0.2760	0.4937	0.6043	2.795	2.834	2.816
900B	0.1466 (0.1843mm)	0.2000	0.0604	0.1444	1.254	1.722	1.488
E	0.2812 (0.0.3559mm)	0.3376	0.4398	0.4959	2.303	2.469	2.386
700E	0.0.3384 (0.4288mm)	0.3326	0.4987	0.6313	2.600	2.598	2.549
900E	0.0888 (0.1124mm)	0.0625	-	-	-	-	1
H	0.2367 (0.2963mm)	0.3375	0.4613	0.4641	2.337	2.376	2.366
700H	0.2969 (0.3784mm)	0.2260	0.3642	0.3678	2.574	2.636	2.606
900H	0.0933 (0.1181mm)	0.1376	-	0.0368	-	1.266	1.266

The results show that heat treatments increase the grooving corrosion index below 750℃, while it decreasing above 750℃. Above 900℃, the index decreased to 1.2 or less, which indicates the pipes become almost immune to grooving corrosion in studied environment.

This results agrees well with the Hetman's study.[4] Because heat heat treatment changes the microstructures between base and weld metal by helping diffusion of FeS in weld metal and reducing the microstructural heterogeneities. It should be emphasized that any effect of the heat input on the grooving corrosion was found in this experiment.

3.3 Polarization Test

To study the effect of galvanic corrosion between weld and base metal, polarization curves of those portion were obtained. The data of the potentiodynamic experiments are summarized in Table.4 and Fig. 7.

As shown in the Table, the corrosion potentials of weld was anodic compared to those of base metal, regardless of welding heat input and temperature of heat treatment. However, the difference of weld and base metal was greatly reduced by heat treatment. Those of as-received was measured in the range of 61 ~ 71mV, while the the potential of the heat treated at 900℃ measured about 10mV. From this results, the localized attack in the weld could be ascribed to the potential differences between them, causing galvanic corrosion. The big ratio of cathodic to anodic area exaggerated the galvanic effect.

Table 4. Result of polarization test. (specimen B,E,H)
(exposed area ; $0.03cm^2$)

specimen	corrosion rate (μ A/cm^2)	current density (mm/yr)
B- Weld	11.792	1021
700B-Weld	2.522	218
900B-Weld	1.068	92
B-Base	0.132	11
E- Weld	2.903	251
700E-Weld	1.27	110
900E-Weld	0.773	63
E-Base	0.645	56
H- Weld	7.476	647
700H-Weld	1.19	103
900H-Weld	0.588	49
H-Base	0.177	15

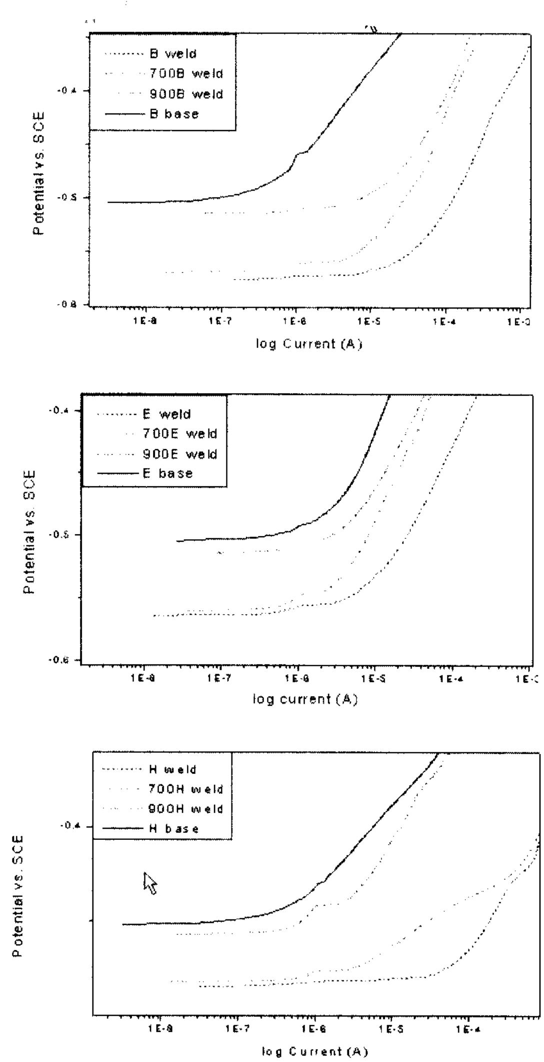


Fig. 7. Polarization curves of ERW pipes (E,B,H specimen)

However, any noticeable difference of corrosion potentials were identified. This result coincides well with the chronoamperometry tests. It can be concluded that the post-weld heat treatment could improve the resistance of ERW pipes after heat treating above 750℃. The optimal temperature to improve the grooving corrosion resistance could be 900℃.

4. Conclusions

1. The effect of heat input on the grooving corrosion was not noticeable.

2. The potential difference of weld and base metal was greatly reduced by heat treatment. Those of as-received was measured in the range of 61～71mV, while that of the heat treated at 900℃ was about 10mV. Thus, mechanism of grooving corrosion was galvanic corrosion, with potential difference and large area ratio.

3. The grooving corrosion-index of as-received specimen(2.46～2.54) was higher than those of post weld heat treated specimen above 750℃, and especially at 900℃, decreased the grooving corrosion index to 1.2 or less, from the result of the chromnoamperometry test. The heat input of welding process does not show a considerable effect on the grooving corrosion.

4. The grooving corrosion corrosion could be improved by post-weld heat treatment. The optimal temperature was 900℃.

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