Evaluation of the Sensitization of 316L Stainless Steels After the Post Weld Heat Treatment

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1. Introduction

The primary water stress corrosion cracking (PWSCC) of alloy 82/182 weld metals has been frequently observed during operations of nuclear power plants (NPPs) [1]. The post-weld heat treatment (PWHT) is considered as one of mitigation method that induces a relaxation of local residual stress that has been known as one of important factors for PWSCC initiation and a modification of the fine intergranular precipitation [2]. It was observed that the PWSCC growth rate of alloy 182 was markedly decreased after PWHT [2]. However, the PWHT of components made of stainless steels (SSs) would be limited because of the concerns about sensitization when they are exposed to temperature range of 500 to 800 °C [3]. Also, the sensitization of austenitic stainless steels could increase the susceptibility to intergrannular stress corrosion cracking. Therefore, the effect of PWHT on the sensitization behaviors of 316L SSs having predominant austenitic structure with small amount of ferrite was investigated to assess the applicability of PWHT to dissimilar weld area with austenitic stainless steels.

2. Experimental

2.1 Test material

Two heats of 316L SSs with different ferrite content and morphology were used as test materials. The microstructures are shown in Fig. 1 and several factors important to sensitization are shown in Table I.

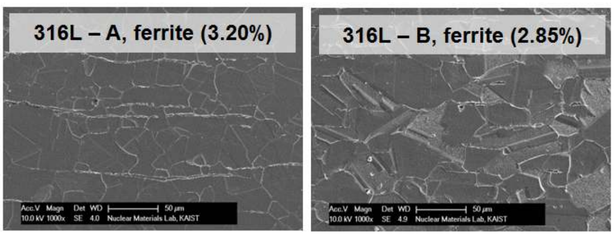

Fig. 1. Microstructure of two heats of 316L SSs

2.2 Test procedure

The heat treatment simulating the PWHT was performed at 600, 650 and 700 °C with various exposed time. After the heat treatment, double loop – electrochemical potentio–kinetic reactivation (DL–EPR) tests were performed for the quantitative evaluation of the degree of sensitization (DOS). In addition, to distinguish the sensitized region of test materials, the oxalic acid etching test based on ASTM 262 practice A was performed [4].

3. Results and Discussion

3.1 DL-EPR test

Fig. 2 shows the DL-EPR test results of two heats of 316L SSs after the heat treatment at 600, 650, 700 °C and SA. As a result, it could be revealed that the sensitization of 316L SSs does not occur in PWHT condition. And the DOS values of 316L – heat A was higher than those of 316L – heat B. Furthermore, degree of early time sensitization of 316L – heat A was decreased after SA, as shown in Fig. 2 (c) where sensitization behaviors after the heat treatment at 700 °C is summarized.

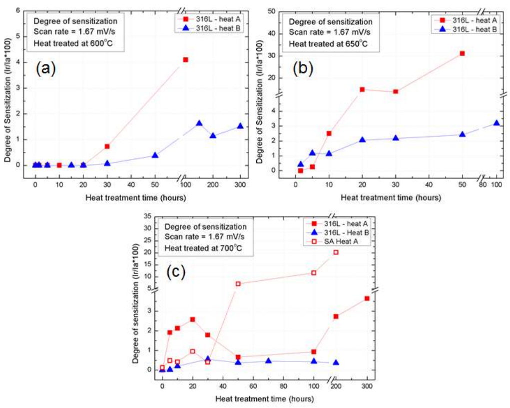

Fig. 2. DOS values of two heats of 316L SSs after the heat treatment at: (a) 600 °C, (b) 650 °C, (c) 700 °C & SA

Table I. Important factors to sensitization of two heat of 316L SSs

Materials	Microstructure	Grain size (μm)	Carbon content (wt.%)	Chromium content (wt.%)	Solution annealing	Ferrite morphology
316L – heat A	Austenite + ferrite (3.20%)	38.9	0.02	16.40	1100 °C	Stringer type
316L – heat B	Austenite + Ferrite (2.85%)	48.3	0.03	18.00	N/A	Blocky type

3.2 Sensitization behaviors of 316L SS containing few amount of ferrite phase

Fig. 3 shows oxalic etching test results (ASTM A262 practice A) of 316L – heat A after the heat treatment at 700 ^{o}C. With increasing the heat treatment time, the dual and ditch structures were not observed. It could suggest that the grain boundaries of 316L – heat B was not sensitized. However, SA of 316L – heat A, the dual and ditch structures were observed.

Fig. 4 shows the microstructures of 316L – heat A and B after the heat treatment at 700 ^{o}C. The small particles were formed in ferrite phases during the heat treatment while grain boundary carbides were not observed. With further heat treatment up to 100 h, the carbides at grain boundary were observed. Therefore, it is thought that the increase in early DOS value after heat treatment at 700 ^{o}C could be caused by reduction of corrosion resistance in ferrite phases rather than grain boundary sensitization.

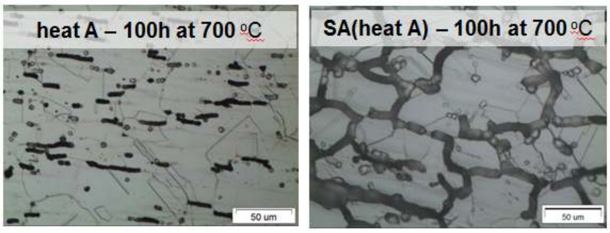

Fig. 3. Oxalic etching test results of 316L – heat A (b) SA of heat A.

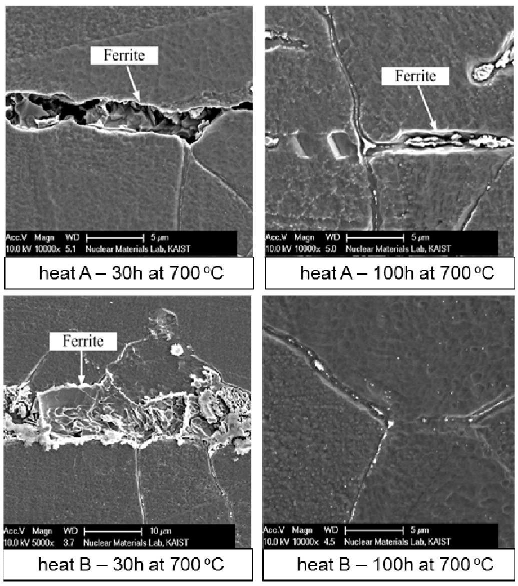

Fig. 4. Microstructure of 316L – heat A((a), (b)) and heat B((c), (d)) after the heat treatment at 700 ^{o}C.

On the other hand, in case of SA heat A as shown in Fig. 5, the precipitates were observed at the grain boundaries. As results, the increase in early DOS value was caused by precipitates on ferrite phase boundary and ferrite – austenite interface.

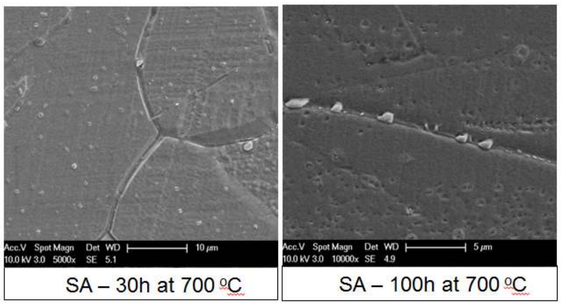

Fig. 5. Microstructure of SA 316L – heat A.

4. Conclusions

The sensitization behaviors of two heats of 316L SSs with small amount of ferrite were investigated after heat treatment at 600, 650 and 700 ^{o}C.

1. Grain boundary sensitization was not observed in 316L SSs after the heat treatment at 600, 650 and 700 ^{o}C up to 30 h. The increase in degree of sensitization (DOS) was caused by reduction of corrosion resistance in ferrite phase due to formation of chromium carbide and intermetallic phases during heat treatment.

2. The DOS value of 316L SSs depended on the ferrite morphology. The stringer type of ferrite (316L – heat A) showed relatively higher DOS in comparison with 316L containing blocky type of ferrite (316L – heat B). It could be due to sufficient supplement of chromium in larger size of ferrite phase.

Acknowledgements

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