Effect of Ferrite Morphology on Sensitization of 316L Austenitic Stainless Steels

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1. Introduction

Sensitization of stainless steels (SSs) is a common phenomenon when they are exposed to temperature range of 500 to 800 °C. From extensive studies for several decades, it was found that the sensitization is mainly caused by grain boundary (GB) chromium depletion [1]. It is known that the duplex SSs is more resistance to sensitization compared with austenitic SSs due to the ferrite phase in duplex SSs [2]. However, the sensitization behaviors of L–grade SSs having predominant austenitic structure with small amount of ferrite have not been well understood. In this regard, the effect of ferrite morphology on sensitization was investigated in this study.

2. Materials and Methods

The test materials were three heats of 316L and 316LN SSs. Two heats of 316L SS have stringer type of ferrite and, were classified as heat A with 0.93% of ferrite and heat B with 3.20% of ferrite in predominant austenitic structure. And, another heat has blocky type of ferrite and, was designated as heat C with 2.85% of ferrite. Finally, 316LN SS had fully austenite structure. The heat treatment was performed at 700 °C, and then cooled in air. Double loop – electrochemical potentio–kinetic reactivation (DL–EPR) tests were performed for the quantitative evaluation of degree of sensitization (DOS). The test solution was 0.5 M H_2SO_4 with 0.01 M KSCN. The scan rate was 1.67 mV/sec. The specimen area was 0.5 cm^2.

3. Results & Discussion

3.1 Sensitization Behaviors of SSs

Fig. 1 shows the DL–EPR test results of test materials. In 316L – heat A and B, the early sensitization and de-sensitization, and then, re-sensitization behaviors were observed with increase in heat treatment time. On the other hand, in 316L – heat C, the DOS value was slightly increased up to heat treatment for 30 hours, and then, stable with further heat treatment. Because the ferrite content of three heats was different, the difference of sensitization kinetics was not caused by the ferrite content. In addition, 316LN having fully austenite structure is significantly sensitized with increasing heat treatment time.

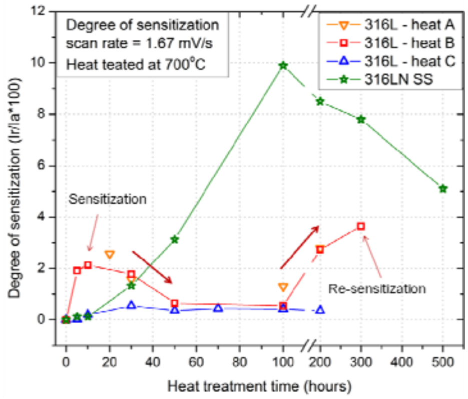


Fig. 1. DOS value of three heats of 316L and 316LN SSs.

Fig. 2 shows the microstructures of 316L – heat B. After heat treatment for 10 hours, the ferrite was completely transformed to small particles, while the GB carbides were not observed. The small particles showed very high chromium content from auger electron spectroscopy (AES), though it is not shown in this paper. Therefore, it could indicate chromium carbides because it could be readily formed at the ferrite phase boundary [3]. And, the heat-treated heat B for 100 hours revealed the GB carbides. Therefore, it is thought that the sensitization of 316L – heat B in early stage could be induced by sensitization at ferrite phase boundaries, while the latter sensitization could be mainly due to GB sensitization. On the other hand, in 316L – heat C as shown in Fig. 3, after heat treatment for 50 hours, the slight increase in DOS could be caused by sensitization at ferrite phase boundary. After heat treatment for 200 hours, the GB sensitization did not occur, and the ferrite phase was completely transformed to intermetallics or carbides. Relatively lower DOS of 316L – heat C compared to that of heat B could be due to the sufficient chromium in large ferrite phase. In 316LN as shown in Fig. 4, the GB carbides were observed after heat treatment for 100 hours. Therefore, the GB sensitization of 316LN could be the main cause of the sensitization.

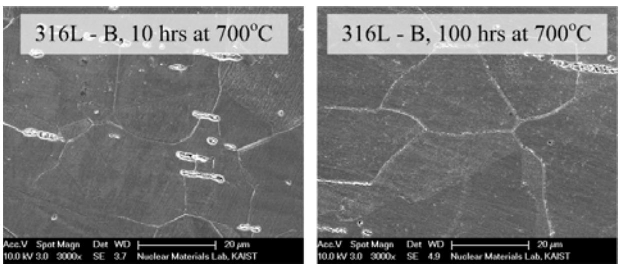


Fig. 2. Microstructure of 316L – heat B after sensitization.

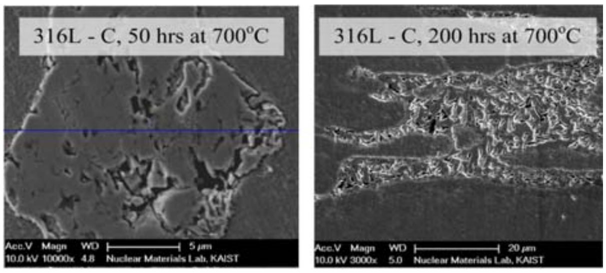


Fig. 3. Microstructure of 316L – heat C after sensitization.

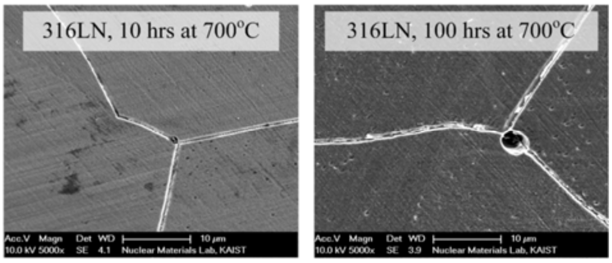
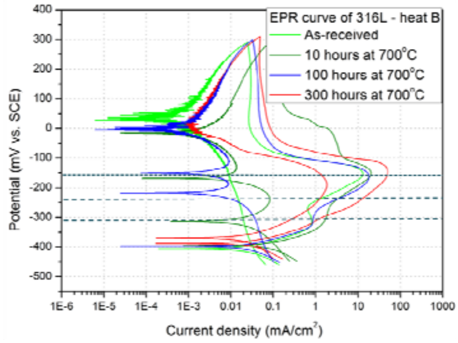


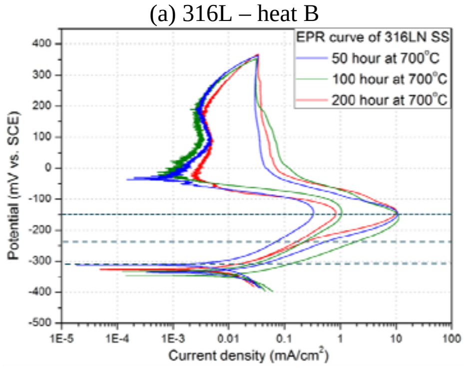
Fig. 4. Microstructure of 316LN after sensitization.

3.2 Discrimination of Sensitized Region by DL-EPR test

The sensitized region could be quantitatively discriminated by DL–EPR tests. When the specimen contains ferrite and austenite phase, the anodic polarization curve showed mixture of austenitic and ferrite phase [4]. Fig. 5 shows the DL–EPR curve of 316L – heat B and 316LN SS. In case of 316L – heat B, two critical potentials were measured from DL–EPR curves. One smaller peak was measured at the range of – 325 mV ~ - 300 mV vs. saturated calomel electrode (SCE). And, another greater peak was measured at the potential of – 150 mV vs. SCE. To confirm the indicating phase of two critical potentials, the specimens were potentiostatically treated at each critical potential in same aqueous solution. After exposure at – 150 mV vs. SCE, the austenite phase is significantly dissolved but ferrite phase still remain. On the other hand, after exposure at – 305 mV vs. SCE, the ferrite phase is selectively dissolved. Therefore, two critical potentials from DL–EPR curve could indicate dissolution of ferrite phase at – 305 mV vs. SCE and of austenite phase at – 150 mV vs. SCE. The 316L – heat B which is sensitized at ferrite – austenite phase boundary showed reactivation current peak at – 230mV vs. SCE as shown in Fig. 5 (a). This potential is mixed potential of two critical potentials. Because the ferrite and austenite are corroded on time at mixed potential, the maximum current density could be detected at mixed potential. On the other hand, in 316L – heat B which is definitely sensitized at grain boundary showed the current peak at – 150 mV vs. SCE. In case of fully austenite 316LN as shown in Fig. 5 (b), the critical potential was about – 150 mV vs. SCE. It is well accepted with SEM which showed GB carbides. Therefore, the sensitized region was distinguishable from results of DL–EPR tests. It can be used as an effective method for evaluation of the type of sensitization.



(a) 316L – heat B



(b) 316LN SS

Fig. 5. DL–EPR curve of; (a) 316L – heat B, (b) 316LN.

4. Conclusions

The sensitization behaviors of three heats of 316L and 316LN SSs were investigated

1. Stringer type of ferrite (316L – heat A and B) showed the early sensitization by chromium depletion at ferrite – austenite interface. And, later sensitization is due to GB sensitization.
2. On the other hand, blocky type of ferrite (316L – heat C) showed lower DOS and higher resistance to GB sensitization. It could be due to sufficient supply of chromium from relatively large ferrite phase. As a consequence, the sensitization of 316L SSs could be affected by their ferrite morphology rather than ferrite content.
3. The sensitized region was distinguishable from results of DL–EPR tests. It can be used as an effective method for evaluation of type of sensitization.

REFERENCES

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