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Short communication

Effect of uniaxial deformation to 50% on the sensitization process in 316 stainless steel

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Abstract

The effect of uniaxial deformation to 50% on the degree of sensitization (DOS) in 316 stainless steel was investigated at 625 and 670 °C for 5–100 h using the electrochemical potentiokinetic reactivation (EPR) test. The results showed that the deformation accelerated the sensitization/desensitization process, especially at 670 °C. However, the material is still sensitized after up to 100 h of aging time. Transmission electron microscopy was used to corroborate these results. The deformed material showed more carbide precipitates ($Cr_{23}C_6$) at the grain boundaries and twin intersections than did the nondeformed material.

Keywords: 316 stainless steel; EPR; Sensitization; Carbide precipitates; Grain boundaries

1. Introduction

Despite the high corrosion resistance of austenitic stainless steels (SS), especially 316 SS, these materials are susceptible to stress corrosion cracking in the temperature range of 450–850 °C. The phenomenon that occurs in this temperature range is known as sensitization where precipitates of chromium carbides ($Cr_{23}C_6$) are formed principally in the grain boundaries. Then there is a depletion zone of chromium making the material vulnerable to corrosion [1], particularly intergranular corrosion (IGC).

Plastic deformation has been known to be a crucial parameter that affects the rates of reactions occurring in materials. For example, thermodynamic and kinetic reactions may be altered by the deformation process [2]. As a consequence, the sensitization process in SS is accelerated by the presence of strain [3–13]. However, the effect of deformation up to 50% in tension on the sensitization process has not been studied in the 316 stainless steels. Almanza and Murr [14] showed that the sensitization process was accelerated in 316 SS when the material was uniaxially deformed up to 40% but the desensitization process did not occur at 670 °C for a period of aging

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time of 0.1–10 h at the largest grain size of 280 μm. However, as the grain size was reduced to 10 μm, some desensitization was observed. Therefore, it is important to understand the thermomechanical treatment effects on microstructure development, and as a consequence improve material reliability and performance in service.

In the present study, we quantitatively evaluate the degree of sensitization (DOS) of 316 SS as a function of the amount of deformation in tension (50%) at temperatures of 625 and 670 °C for aging times from 5 to 100 h using the electrochemical potentiokinetic reactivation (EPR) test since there is no information about the effect of high deformation (at 50%) in this material.

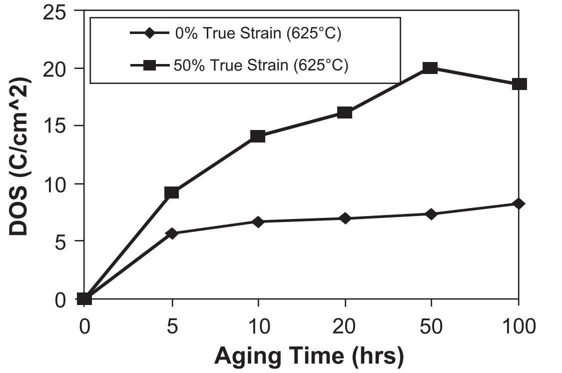

Fig. 1. Comparison of degree of sensitization (DOS) for non-deformed and deformed 316 stainless steel aged at 625 °C.

2. Experimental procedure

The AISI 316 stainless steel used in this study had the composition shown in Table 1. The material was received in mill-processed 0.79 cm plate form, then sectioned into 20×1.25 cm bars, deformed in tension to 50%, and annealed at 1200 °C for 2 h to produce a grain size of 110 μm. Grain size was measured utilizing the three-circle Abrams procedure (ASTM-E112-85) [15]. The samples were uniaxially deformed to 50% true strain then heat treated at 625 and 670 °C for 5–100 h to induce the sensitization process. The EPR test was performed to quantify the DOS of the material with and without deformation as described in more detail elsewhere [14,16,17]. Before the test, standard metallographic techniques were used to obtain a 1-μm diamond polished finish. Samples were studied in the transmission electron microscope (TEM) to corroborate the EPR test results and to document carbide ($Cr_{23}C_6$) precipitation.

3. Results and discussion

Figs. 1 and 2 show the DOS values for 316 SS plotted as a function of aging time for samples with 0% and 50% deformation in tension at the temperatures 625 and 670 °C, respectively. At 625 °C, the nondeformed (0%) samples presented a lower degree of sensitization than the samples deformed 50%. These differences in kinetics are due to changes in chromium diffusivity caused by enhanced dislocation pipe diffusion of chromium [16] because of deformation-induced microstructures—ideally dislocations, and stacking faults and twin faults. Also, it is important to notice that the desensitization process did not occur even up to 100 h of aging time on the samples deformed 50% in tension. Therefore, it will take a longer time to have a complete desensitization process. On the other hand, since 50% of deformation in tension of 316 SS is close to the ultimate tensile

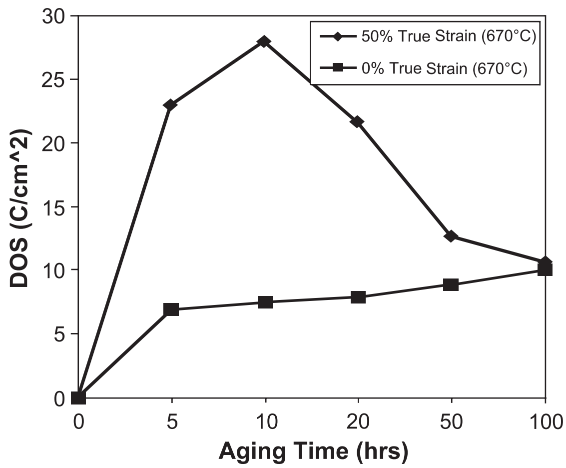

Fig. 2. Comparison of degree of sensitization (DOS) for non-deformed and deformed 316 stainless steel aged at 670 °C.

Table 1
Composition of 316 SS (% wt.)

C	Cr	Ni	Mo	Mn	Fe
0.071	18.27	7.99	2.10	1.758	balance

strength, this amount of deformation does not help to recover the corrosion resistance at 625 °C.

In the case of samples deformed 50% in tension at 670 °C, (Fig. 2), the desensitization process began after 10 h of aging time and a complete recovery of corrosion resistance occurred in a shorter period of time compared to samples deformed at 625 °C. At both 625 and 670 °C, the deformation increases the amount of carbide precipitate ($Cr_{23}C_6$) and the rate of sensitization.

The results obtained with the EPR technique are corroborated in Fig. 3a, which shows a TEM micrograph of the grain boundary carbides typical for sensitization in 316 stainless steel in the initial undeformed state after aging for 50 h at 625 °C. These observations are similar to those observed for 304 stainless steel in previous work [17]. However, the material deformed 50% at the same heat treatment mentioned above shows more carbides at the intersections of microshear bands (Fig. 3b). At 670 °C, the samples deformed 50% and aged 50 h (Fig. 4b) reveal more carbide precipitates than the aged nondeformed samples (Fig. 4a).

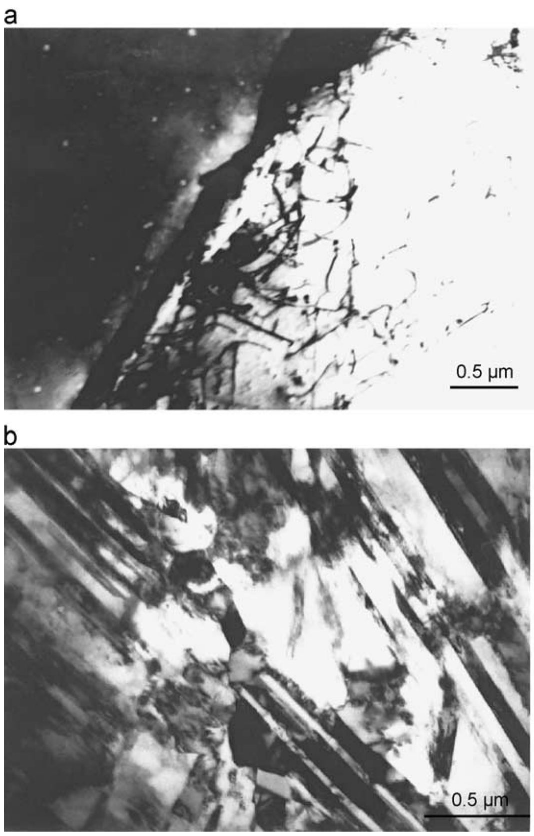

Fig. 3. TEM bright field images for 316 stainless steel aged 50 h at 625 °C: (a) nondeformed sample; (b) tension deformed 50%.

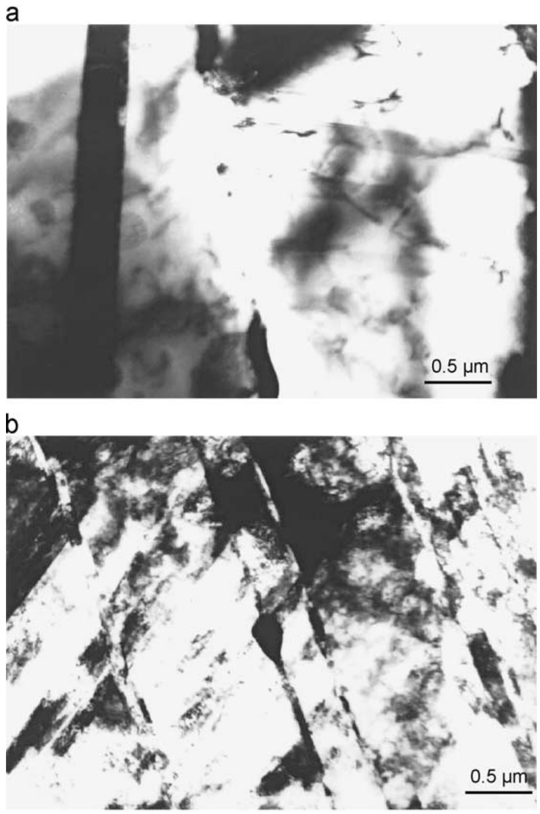

Fig. 4. TEM bright field images for 316 stainless steel aged 50 h at 670 °C: (a) nondeformed sample; (b) tension deformed 50%.

4. Conclusions

The 316 SS samples deformed 50% in tension and heat treated at 625 °C for up to 100 h showed an increasing degree of sensitization. A period of time longer than this would be required to initiate the desensitization process. The desensitization process began much earlier (after 10 h) in the samples deformed 50% in tension and heat treated at 670 °C. TEM micrographs showed more carbide precipitates ($Cr_{23}C_6$) in the samples deformed 50% aged at both 625 and 670 °C temperatures in contrast to the aged undeformed samples.

Acknowledgments

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