HAZ TOUGHNESS AND MICROSTRUCTURE IN HIGH NITROGEN AUSTENITIC STAINLESS STEEL

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ABSTRACT

HAZ (Heat Affected Zone of weldments) properties were investigated for a high nitrogen austenitic stainless steel with a chemical composition of Fe-0.02C-0.15Si-6.00Mn-10.0Ni-23.0Cr-2.00Mo-0.48N-0.14V. Thermal cycle of HAZ was simulated by the thermal cycle simulator (Gleeble 1500). The heat treatment was applied to the Charpy test size sample without notch under various peak temperatures and/or the holding times condition. V-notch Charpy test was performed at the temperature range of 273 ~ 77 K. Metallographic examination also was carried out by using optical microscopy, scanning electron microscopy and transmission electron microscopy.

The simulated specimens revealed a slight embrittlement compared with the base materials. The impact toughness of the specimens deteriorated with the decreasing test temperature. The results from Charpy V-notch test, however, showed that significant degradation of absorbed energy caused by brittle fracture was not observed for the specimen tested in the test temperature range.

KEY WORDS

High Nitrogen Steel, Welding HAZ, HAZ Toughness, HAZ Microstructure, Austenitic Stainless Steel

1. Introduction

Nitrogen in steel increases the yield and tensile strength, but decreases the ductility. Therefore, nitrogen has long been considered as an impurity element especially in low carbon steel. Recently, nitrogen has received an increasing attention as an alloying element to steel, as the high nitrogen steel which has been developed with the improvement of steel-making technology, reveals several beneficial effects on properties. The advantages provided by high nitrogen steels are the high yield and tensile strength without sacrificing the toughness and ductility [1], and the excellent pitting corrosion resistance [2]. The high nitrogen steels have been expected as advanced materials because of their combination of superior strength, toughness and corrosion resistance. Nitrogen in steel also has an effect of stabilizing austenite, and expected as a nickel replacement element for austenite steels in connection with the nickel shortage and nickel allergy for human body [3]. However, it has some problems, because the high nitrogen steel is a newly developed material. The welding of this material is also one of the problems, since the material is susceptible to nitride precipitation [4] and/or pore formation during thermal cycle of the welding. Especially, the HAZ property of the high nitrogen steel was not always clarified.

Present work describes the HAZ properties of high nitrogen austenitic stainless steel with a chemical composition of Fe-0.02C-0.15Si-6.00Mn-10.0Ni-23.0Cr-2.00Mo-0.48N-0.14V. In particular, the impact toughness and microstructure of the HAZ are examined in detail.

2. Experimental procedure

The chemical composition of the high nitrogen stainless steel in this study is presented in Table 1. The material contains 0.48 mass % nitrogen. Figure 1 exhibits optical microstructure of the base material. Solution heat treatment was carried out at 1373 K for 3.6ks and then water quenched. The base material was fully austenitic without any significant precipitation or inclusions.

Table 1 Chemical composition of base material (mass percent).

C	Si	Mn	Ni	Cr	Mo	N	V
0.02	0.15	6.00	10.0	23.0	2.0	0.48	0.14

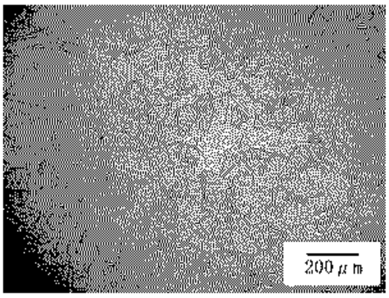

Fig. 1 Optical microstructure of base material.

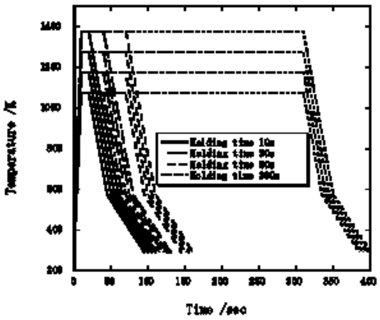

Fig. 2 Thermal cycle conditions.

The thermal cycle simulator of Gleeble 1500 was used for the simulation of HAZ thermal cycles. The specimen was 10 x 10 x 55 mm in size without notch. Four peak temperatures of 1073 K, 1173 K, 1273 K and 1373 K, and four holding times of 10 seconds, 30 seconds, 60 seconds and 300 seconds were selected as thermal conditions for the experiment. The heating time to the peak temperature was about 10 seconds and the cooling time from each peak temperature to 573 K was about 30 seconds throughout all the experiments; therefore the heating and cooling rate was constant. The thermal cycle conditions are summarized in Figure 2.

A Charpy V-notch was machined on all the specimens before impact testing. Charpy V-notch impact test was performed at five temperatures of 273 K, 223 K, 173 K, 123 K and 77K. Metallographic examinations also were carried out. The microstructure observation and the grain size measurement for the specimen were made by optical microscopy. The specimen for optical microscopy was anodized in 10 mass % oxalic acid electrolytic solution. The particles of precipitate during the thermal cycles were examined using transmission electron microscopy (TEM) with accelerating voltage of 200 kV. A twin-jet electrolytic polishing technique was employed to produce the thin disc specimen. The fracture surfaces were also examined by scanning electron microscopy (SEM).

3. Results and discussion

Microstructure of the specimens was observed by optical microscopy. Average grain size of the specimen was measured from the photographs for the base material and heat-treated specimens. The grain size of base material was nominally 140 μm. The microstructure of the specimen heated at 1273 K under various holding time is presented in Figure 3 (a) through (d), (a) for 10 seconds, (b) for 30 seconds, (c) for 60 seconds and (d) for 300 seconds. The grain size increases a somewhat with increasing holding time. The grain size measurement result is shown in Figure 4. The average grain size of the heat-treated specimens were a somewhat coarser than that of the base material. However, there was no essential distinction concerning the grain size for the different peak-temperature specimens.

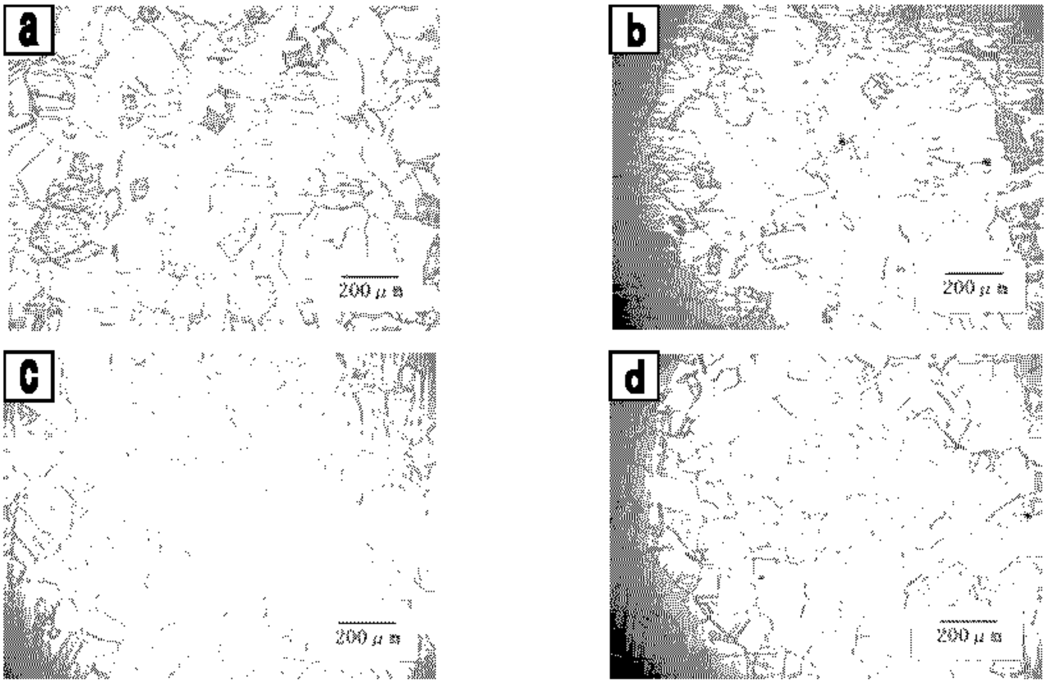

Fig. 3 Microstructure of heat-treated specimen at 1273 K: (a) 10 s; (b) 30 s; (c) 60 s; (d) 300 s.

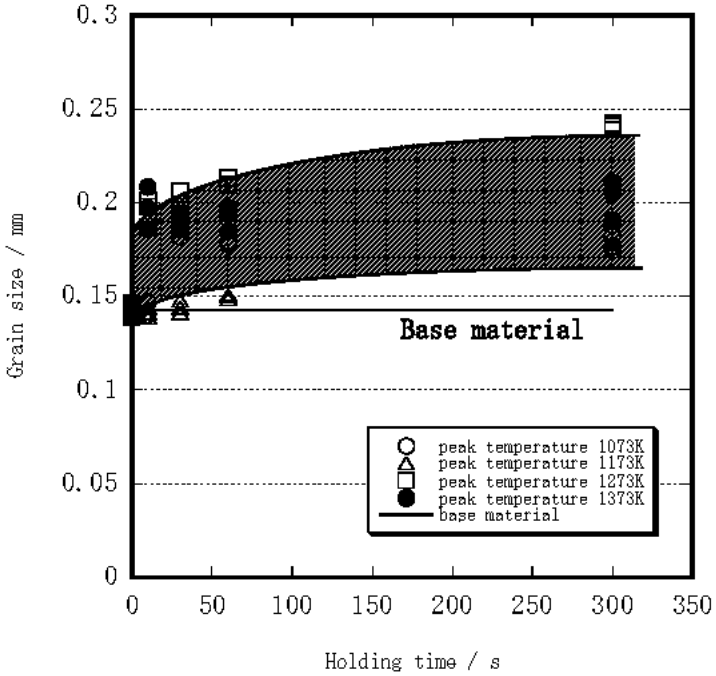

Fig. 4 Grain size of heat-treated specimen.

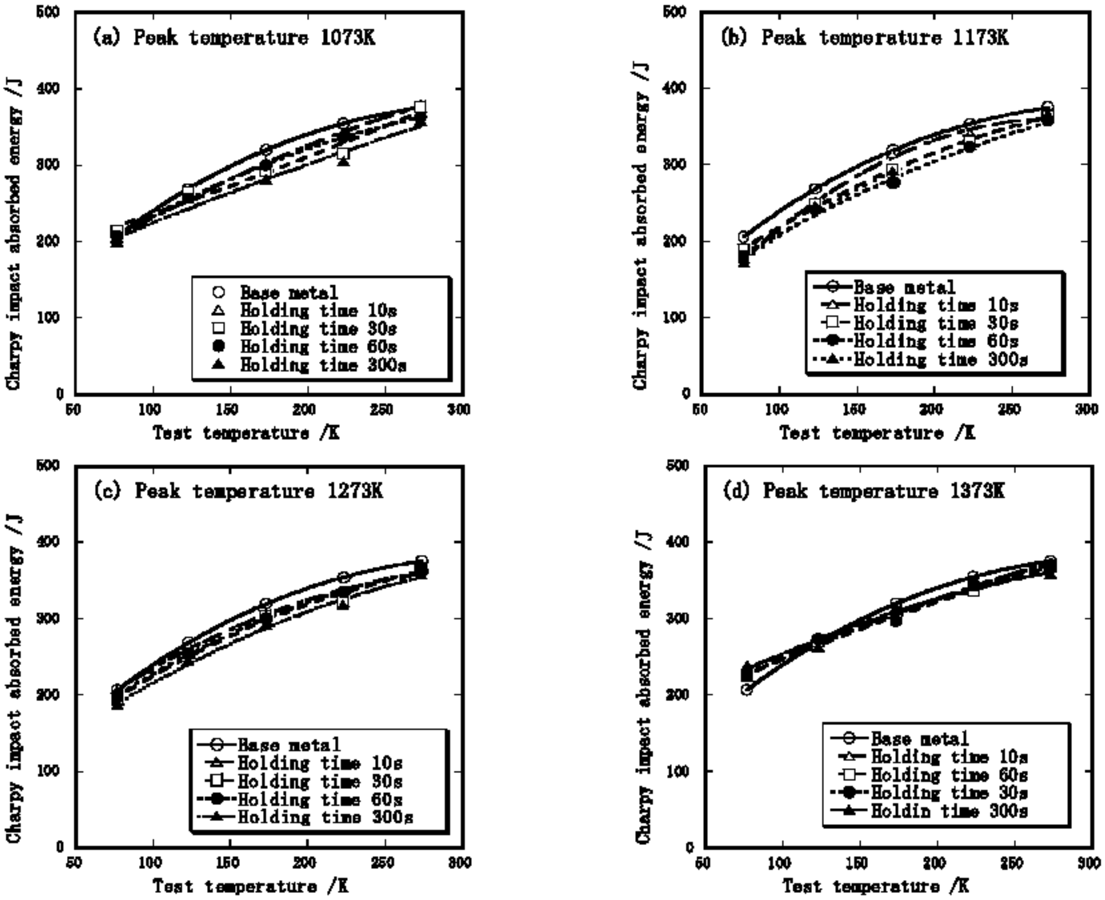

Fig. 5 Charpy impact absorbed energy: (a) 1073 K; (b) 1173 K; (c) 1273 K; (d) 1373 K.

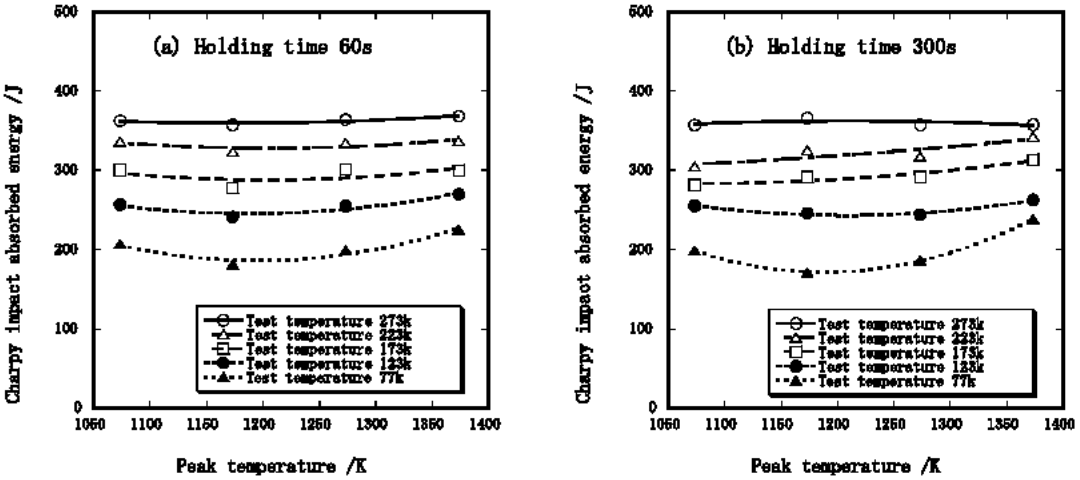

Fig. 6 Charpy impact absorbed energy as a function of peak temperature: (a) 60 s; (b) 300 s.

The Charpy V-notch impact test results are shown in Figures 5(a) through (d), (a) for the result from the peak temperature of 1073K, (b) for 1173 K, (c) for 1273 K and (d) for 1373 K respectively. The absorbed energy obtained from different peak temperature specimens reveals similar tendency, the impact toughness of the specimens deteriorates with the decreasing test temperature and the simulated specimens present a slight embrittlement compared with the non- heat-treated base materials. There is no distinguishable difference in the energy absorbed as a function of holding time. The remarkable fact is that the significant degradation of absorbed energy caused by brittle fracture can not be seen throughout the impact test. The absorbed energy decreases gradually with decreasing temperature without any sharp drop of absorbed energy for all the specimens. The fracture surfaces were examined by scanning electron microscopy (SEM). Many spherical dimples characteristic of ductile fracture were observed at 273 or 223 K, while brittle fracture is dominant in the specimens tested at 123 or 77 K. Surface steps related to brittle fracture could be seen in the specimen tested at 77 K. These results indicated that fracture was maintained ductile at relatively high temperature, and the fracture was changed to more brittle behavior with decreasing temperature. However, the fracture was not completely brittle at even 77 K, and the absorbed energy was maintained at relatively higher levels

To clarify the effect of peak temperature, furthermore, the absorbed energy as a function of peak temperature is replotted and shown in Figures 6 (a) and (b), (a) for holding time 60 seconds and (b) for holding time 300 seconds. A slight embrittlement can be detected for the specimens heated to 1173 K and 1273K. In high nitrogen steel, it is well known that precipitation of chromium nitride, which reduces mechanical properties, occurs easily within a temperature range. Many studies [5]-[9] have been carried out on the precipitation of chromium nitride in high nitrogen steels, and reveal that intergranular and/or intragranular precipitation occurs depending on the aging time. Simmons [7] *et. al* presented isothermal precipitation diagram for Cr_2N in high nitrogen austenitic stainless steel, and discussed the detrimental effect of the chromium nitride on the mechanical properties. The nose temperature of C type curves can be read approximately at 1173 to1223 K from the diagram. Similar temperature [9] has been reported on the precipitation of nitride in high nitrogen steels. Further detailed examination on the microstructure by transmission electron microscopy (TEM) was performed for the heat-treated specimens to detect the precipitation of nitride. The microstructures of the heat-treated specimen heated at 1173 K and 1273K for 300 seconds are presented in Figure 7 (a) and (b), (a) for 1173 K and (b) for 1273 K respectively. Both TEM microstructures show no particles of precipitate. Although many grain boundary or matrix were observed carefully, any particles were scarcely found out in the specimens. Only a small number of particles observed in the specimens were oxide containing iron, chromium, aluminum and manganese.

The high nitrogen austenitic stainless steel used in this study did not essentially exhibited considerable embrittlement in impact toughness, but a certain extent of deterioration was observed in the cases of heated at 1173 K and 1273K. In an investigation [4], which researched the impact toughness of SUS 316-type weld metal as a function of nitrogen content, it was reported that brittle fracture occurred in excess of 0.4 mass % nitrogen. The embrittlement was explained by the precipitation of nitride that formed at grain boundary during welding process or following heat treatment. An available reason to interpret a slight embrittlement detected in this study is not proposed, however, the possibility that the only limited particles precipitated during heat treatment relate with the embrittlement may be retained.

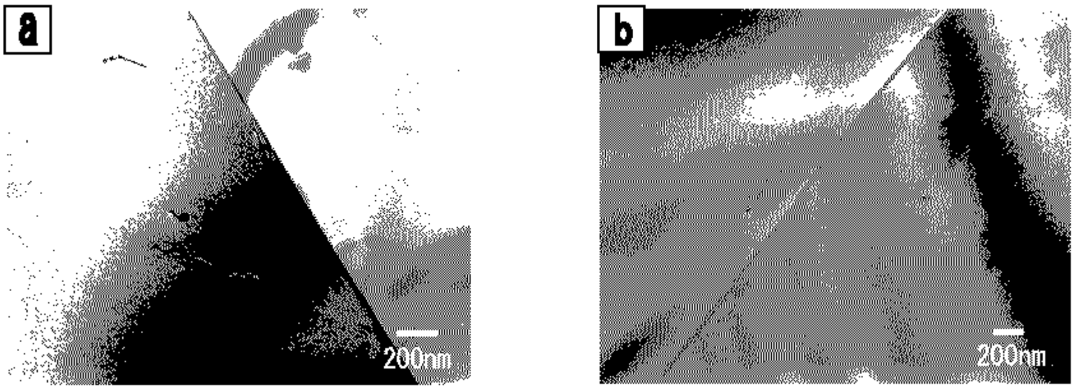

Fig. 7 TEM images of heat-treated specimen: (a) 1173 K, 300 s ;(b) 1273 K, 300 s.

4. Conclusion

HAZ properties were investigated for a high nitrogen austenitic stainless steel with a chemical composition of Fe-0.02C-0.15Si-6.00Mn-10.0Ni-23.0Cr-2.00Mo-0.48N-0.14V. The impact toughness of the specimens deteriorates with the decreasing test temperature, however, ductile-to-brittle transition behavior is not observed. The impact toughness is maintained at relatively higher levels in the temperature range of 273 ~ 77 K. A slight embrittlement is detected in specimens heated at 1173 and 1273 K.

Acknowledgement

The authors wish to thank Mr. Masashi Irie Dr. Makoto Takahashi for his technical supports. They also thank The Iron and Steel Institute of Japan and Dr. Takeshi Koga of Daido Steel Co.Ltd. for providing the materials.

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