Effect of Defect on the Dynamic Strain Aging Behavior of Low Carbon Ferritic Steels

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1. Introduction

Low carbon ferritic steels, such as A106 Gr.B, A106 Gr.C, and A333 Gr.6, are commonly used as piping material in nuclear power plants (NPPs). These ferritic steels are known to exhibit dynamic strain aging (DSA) when exposed to a certain range of elevated temperatures, including operating temperatures of NPPs, during tensile deformation[1-4]. DSA in low carbon steels is related to the interactions between free carbon and nitrogen atoms and dislocations during plastic deformation[1,2], and it leads to abnormal increase in strength and decrease in ductility and fracture toughness[3,4]. Also, the DSA behavior is sensitive to the deformation rate. Therefore, DSA phenomenon has been considered to be a cause of uncertainty in the integrity evaluation of carbon steel components in NPPs, and a number of studies have been investigated the behavior of DSA under uni-axial tensile deformation. However, the DSA behavior under notched and defective conditions has not been investigated extensively, although in real components the plastic deformation and damage occur at stress concentrated area, such as notch and defects. The objective of the present study is to investigate the effect of defect on the DSA behavior of low carbon ferritic steels. For this objective this study conducted a series of tensile tests using notched-bar specimens as well as standard tensile specimens. DSA behavior in notched-bar specimens was investigated and the effect of structural defect on the DSA behavior was discussed.

2. Experimental Procedure

2.1Material and specimens

As shown in Fig. 1, round-bar type tensile specimens with various notch radii, including smooth-bar and V-notch types were used in the experiments. The specimens were machined from 100A Sch.80 carbon steel pipe (D_{nom} = 114.3 mm, t_{nom} = 8.9 mm) designated as ASTM A106 Gr.B, which is commonly used in the secondary piping systems of NPPs. For the notched-bar specimens, three different notch radii were considered: V-notch with a notch radius (R_n) of 0.5 mm, and round-notch with notch radii of 1.5, and 9.0 mm.

2.2 Tensile tests

Tensile tests were conducted under displacement-controlled loading with two different displacement rates (V_{LL}) of 0.5 mm/min and 50 mm/min at various temperatures from RT to 350°C or 400°C. Displacement rates of 0.5 mm/min corresponds to strain rate of 2.6×10^{-4}/s in standard tensile specimen. All tests were conducted using a motor-driven universal testing machine with high temperature furnace. The specimen temperature was controlled within ± 1°C at setting temperature. Displacement was measured by an extensometer with a gauge length of 25 mm.

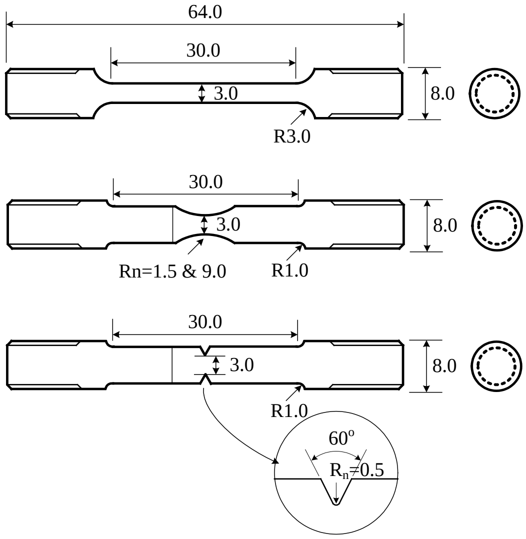

Fig. 1 Dimensions of standard and notched-bar specimens used in the experiment

3. Results and Discussion

3.1 Load-displacement curves

Figure 2 presents load-displacement curves obtained from notched-bar specimens with V-notch under displacement rate of 0.5 mm/min. It is seen that the load-displacement curves show serrations in the temperature range of 100~177°C. But, the serrations could not be observed for V_{LL}=50 mm/min. The serration, which is generated by interactions between solute atoms and dislocations during plastic deformation, is an evidence of DSA in low carbon ferritic steels[1-2]. The load-displacement curves of standard specimens also showed the serrations in the temperature range of 125~200°C. Thus, this indicates that an apparent evidence of DSA, i.e., serration, can be observed from the tensile deformation of notched-bar specimens, which exhibit multi-axial stress state and high strain concentration.

3.2 Temperature and displacement rate dependences

Figure 3 presents normalized maximum loads of notched-bar specimens and standard specimens tested

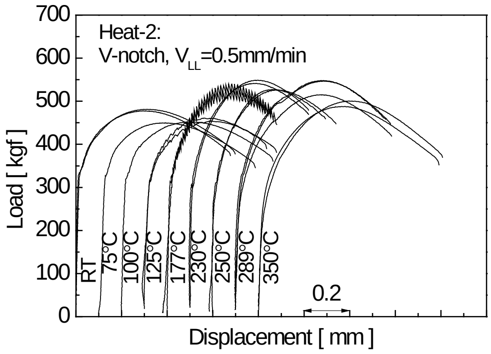

Fig. 2 Load-displacement curves of notched-bar specimens tested under V_{LL}= 0.5 mm/min

under displacement rates of 0.5 mm/min and 50 mm/min as a function of test temperature. The normalized maximum load was defined by normalizing maximum load in the load-displacement curves with respect to the minimum cross section of specimen. As shown in Fig. 3(a), under V_{LL}=0.5 mm/min, the normalized maximum load started to increase at 100°C with increasing temperature and reached the maximum at 230°C, and then decreased above temperatures. The same temperature dependence was observed for V_{LL}=50 mm/min, but the overall pattern shifted to higher temperature region, by about 70~120°C, and an increment of normalized maximum load was less significant compared to V_{LL}=0.5 mm/min. Also, it is seen that the negative strain rate sensitivity appeared in the range of 125~330°C. These temperature and displacement rate dependences were also exhibited from standard tensile specimen as shown in Fig. 3(b). Therefore, it is indicated that all characteristics of DSA observed from tensile test on standard tensile specimen can be also observed in the deformation of defective specimen, although the temperature region, where DSA is activated, is slightly different with specimen types.

4. Conclusions

The evidences of DSA in low carbon ferritic steels, such as serration, increase in maximum load, and negative strain rate sensitivity, could be observed from the defective specimen. However, the temperature region, where DSA is activated, was slightly different from the DSA region indicated by standard tensile specimen and depended on the defect of geometry.

Acknowledgement

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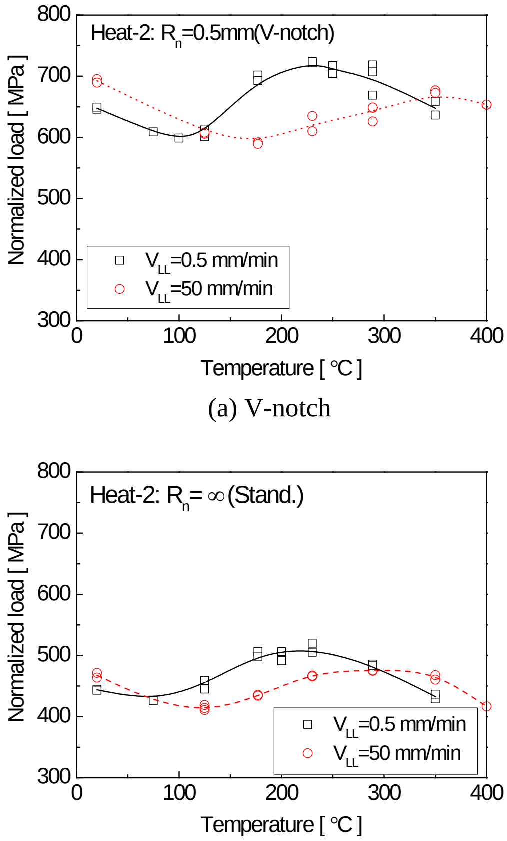

(a) V-notch

(b) Standard specimen

Fig. 3 Temperature and displacement rate dependences of normalized maximum load

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