Stress Corrosion Cracking Susceptibilities of Carbon Steels in High Temperature and High Pressure Water†

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Abstract

This study was carried out in order to understand the behavior of Stress Corrosion Cracking (SCC) resistance of carbon steel in pure water under high temperature and high pressure. Its result was evaluated from point of view to develop high resistance steel for SCC. Susceptibility of SCC and mechanism of crack initiation process were examined under various temperatures and dissolved oxygen concentrations as environmental factors using slow strain rate test.

KEY WORDS: (Stress Corrosion Cracking) (Slow Strain Rate Test) (Carbon steel) (High Temperature) (High Pressure) (Pure Water)

1. Introduction

Carbon steels such as S45C and STPT42 are widely used as a part of the structural material in many industrial plants, are their corrosion resistance has been clarified in various environment. However, its SCC susceptibility has been not always clarified so far.

This study was carried out using slow strain rate test (SSRT) [1] in order to confirm the stability for SCC susceptibility of carbon steel under high temperature and high pressure pure water. [2,3,4]

Susceptibility of SCC was examined under various temperatures under 561 K (288 ℃) and dissolved oxygen concentrations under 8 ppm as environmental factor in pure water.

2. Experimental Procedures

2.1 Test specimen

Specimens for SSRT were middle carbon steel S45C for machine structural use and low carbon steel STPT42. The chemical compositions are shown in **Table 1.**

Constant strain rate method of SSRT was used in this study.

Table 1 Chemical compositions of steels used

Material	Chemical Composition (mass%)								Ceq*	Hardness,Hv (9.8 N)
	C	Si	Mn	P	S	Cu	Ni	Cr		
S45C	0.45	0.17	0.78	0.027	0.017	0.02	0.03	0.14	0.616	210
STPT 42	0.20	0.25	0.62	0.022	0.006	0.01	0.03	0.05	0.325	177

* Ceq=C+Mn/6+Si/24+Ni/40+Cr/5+Mo/4+V/14 (WES)

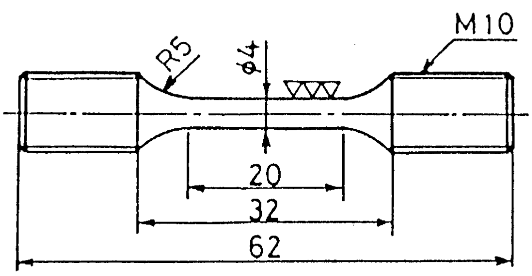

Fig. 1 Shape and dimension of the SSRT specimen

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The shape and the dimension of the specimen tested were shown in **Fig. 1**.

The specimens were washed in an ultrasonic cleaning equipment with an acetone before testing.

2.2 Experimental condition

Tests were carried out under the three levels of dissolved oxygen (DO), 0.2, 2 and 8 ppm, of water in the autoclave and at the three levels of temperature, 373 (100), 473 (200) and 561 K (288 ℃) also. The pressure is 8.3 MPa and the strain rate is 8.3 $\times 10^{-7}$ s^{-1}. Test conditions were kept constant through all the test. The prescribed concentration of DO in the water was controlled by supplying ion exchanged pure water from the tank. Oxygen and nitrogen were automatically bubbled into the pure water in the tank to control the DO. DO was measured using the DO checking meter.

Pure water was prepared by the ion method, the electrical conductivity of which is checked and controlled to less than 1 μs/cm through all the test. The corrosion potentials of the samples were natural potential.

Selected experimental conditions, 8 ppm of the DO and test temperature 561K were referred by condition of nuclear power plant.

2.3 Fractography

After fracture, the specimens were treated with rust-proofing. Then fractured surface was observed by scanning electron microscope (SEM). The ratio of the fracture area of fan-shaped pattern to total fractured cross section of the specimens is defined as the area of SCC fracture. The metallurgical structure of the fractured surface was observed by the optical microscope.

Also crack at surface of specimen was observed. Microstructual observation and analysis of crack propagation were carried out at crosssection of specimen.

3. Results and Discussion

3.1 The relationship between the temperature and the time to failure, the elongation

Figure 2 shows the relationship between the temperature and the time to failure. Generally the time shows positive dependence on the temperature for all DO of both steels except 8 ppm DO. Open marks mean S45C and closed marks mean STPT42 respectively.

The time decreases at 561 K under the 8 ppm DO concentration for both steels. **Figure 3** shows the relationship between the temperature and the elongation. This figure shows the same tendency as in **Fig. 2**.

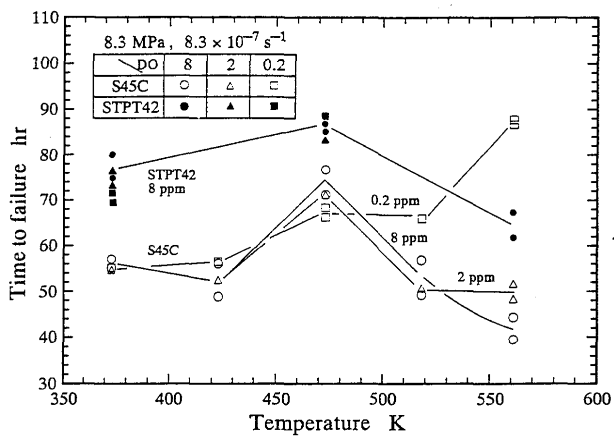


Fig. 2 Relation between time to fracture and temperature

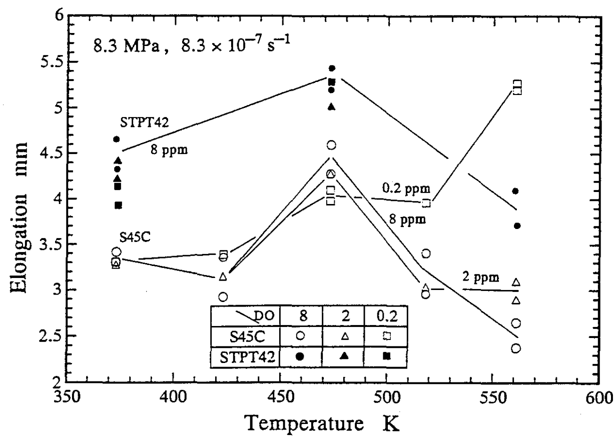


Fig. 3 Relation between elongation and temperature

3.2 The relationship between the temperature and the tensile strength and the hardness of specimens

Figure 4 shows the relationship between the temperature and the tensile strength. The tensile strength slightly increases with the temperature up to 473 K under all the DO conditions. On the other hand, it decreases at 561 K under all DO conditions.

Vicker's hardness (load: 9.8 N) was measured more than five positions at the neighborhood of fractured position.

3.3 The relationship between the temperature and the stress corrosion cracking fractured area

Figures 5(a) and **5(b)** were two examples of the

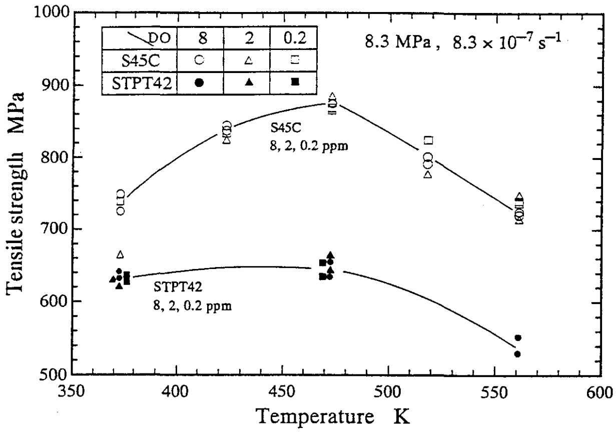


Fig. 4 Relation between tensile strength and temperature

observed micrographs of S45C and STPT42 by SEM, respectively. The quasi-cleavage plane which was recognized as a SCC fracture was partly observed at the edge of the fractured surface in both figures and spreaded as fan-like feature, the area of which was surrounded by dimple mode fracture surface.

It is generally said that the susceptibility of stress corrosion cracking increases with temperature and DO content.

Figure 6 shows the relationship between the temperature and the ratio of SCC fractured area for 0.2, 2 and 8 ppm DO in S45C. From the result on 8 ppm DO the SCC fracture ratio is increasing with test temperature but on 2 and 0.2 ppm DO the SCC fracture ratio shows almost same fashion with maximum in 473K. The reason why the SCC ratio is maximum in 473K is not clear now.

3.4 Observation of the characterization of the SCC crack propagation

Figures 7 and **8(a)** show examples of morphology of the crack propagation under the condition at 561 K with 8 ppm DO observed in S45C. A dark part indicates ferrite and a white part indicates pearlite. From both figures, the crack propagation is observed to mainly proceed in intergranular. [5]

Figures 8(b) and **8(c)** shows the position of small void occurred around the tip of the crack observed in the specimens. From these figures, voids are thought to be occurring before advancing the crack developing and to be mainly generated in cementite or between cementite and ferrite in pearlite.

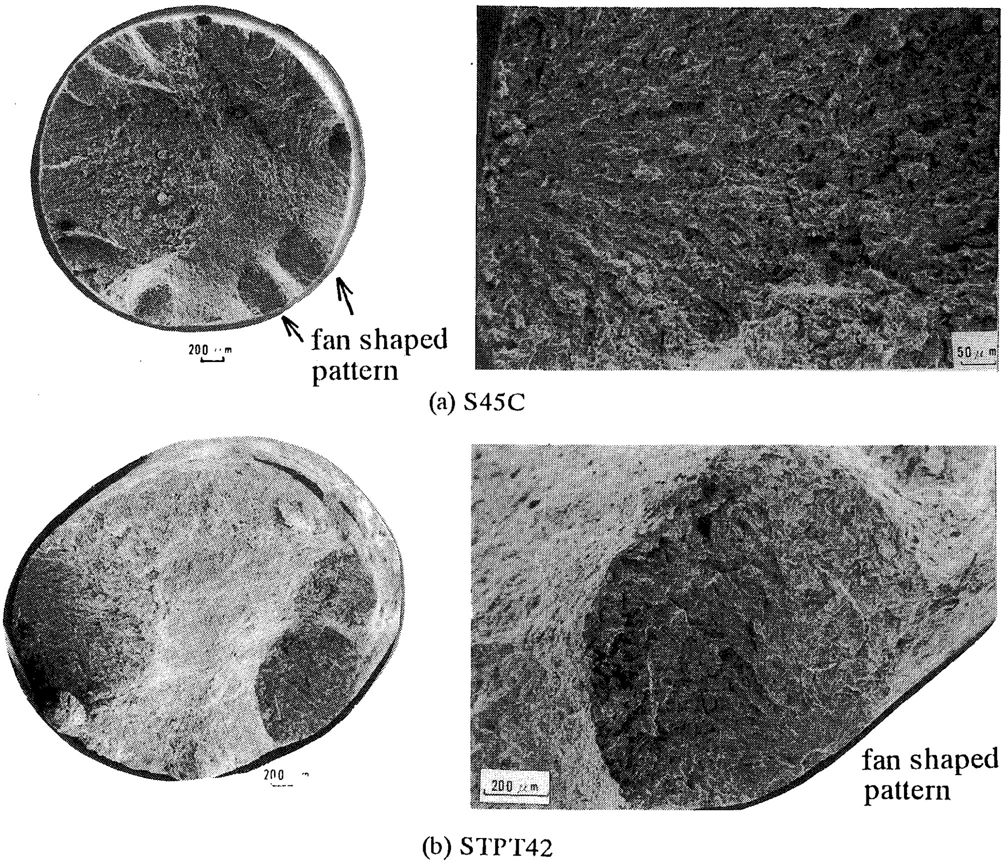


Fig. 5 SEM fractographs of specimen tested in 561 K, 8ppm

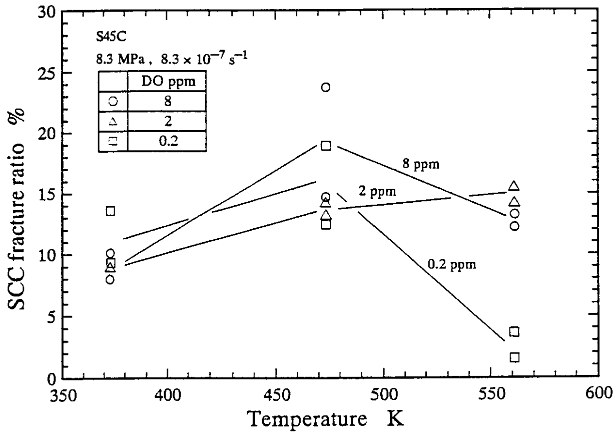


Fig. 6 Relation between SCC fracture ratio and temperature

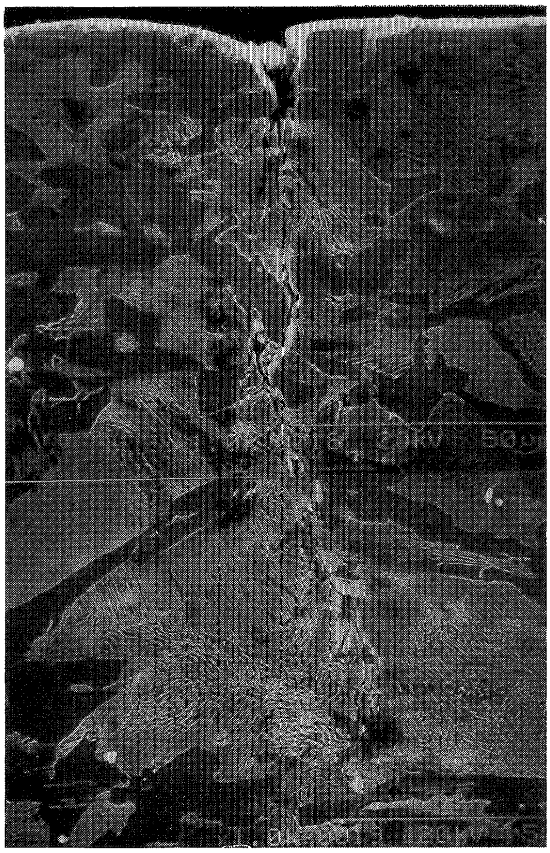
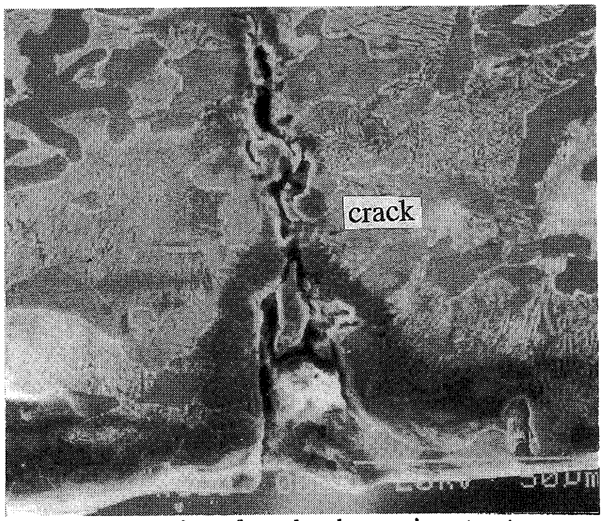
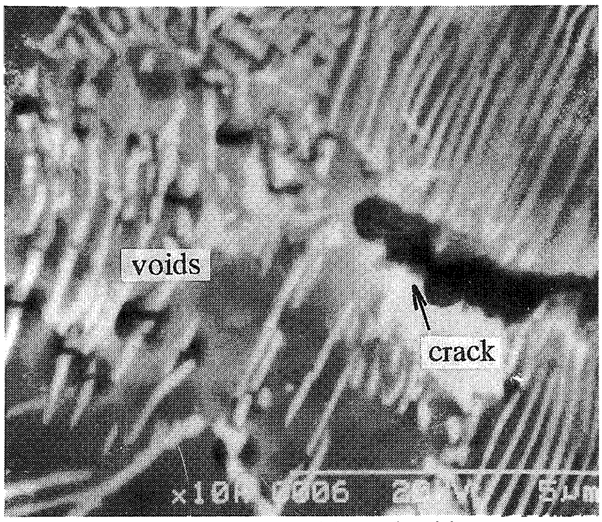


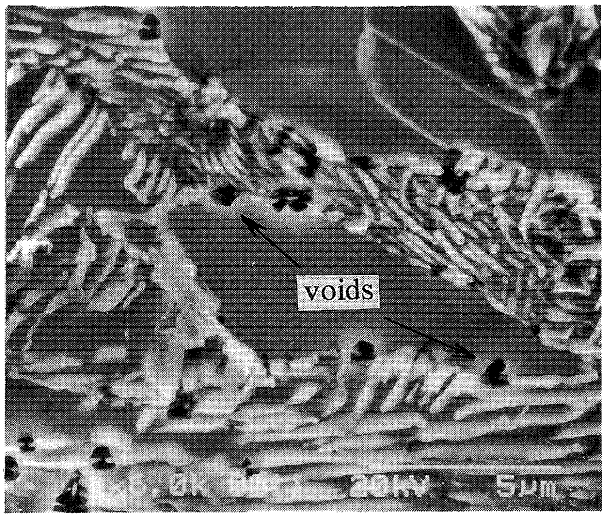
Fig. 7 Branching of cracks along microstructure of S45C specimens on cross sectional area in 561 K,8 ppm



(a) Branching of cracks along microstructure



(b) The occurring position of voids



(c) A high magnification

Fig. 8 Examples of S45C specimens on cross sectionl area in 561 K,8 ppm

4. Conclusion

The object of this study is to clarify some characteristics of SCC susceptibility of carbon steels, S45C and STPT42 under high temperature and high pressure pure water using SSRT method. The influence of DO (dissolved oxygen) and temperature which are main environmental factors affecting the susceptibility of SCC and the observation of crack initiation were investigated. The results are summarized as follows:

(1) Time to failure and elongation of the specimens fractured were minimized and the SCC fracture area ratio was maximized at the temperature of 561 K in both S45C and STPT42 under 8 ppm DO concentration. Susceptibility of SCC under the condition of 8 ppm DO concentration was thought to be the highest at 561 K.

(2) Susceptibility of SCC was revealed to be considerably low at 561K under 2 and 0.2 ppm DO in S45C, at 561 K under 0.2 ppm DO in STPT42. Decreasing DO was considered to make sensitivity of SCC improved even at 561 K.

(3) The crack propagation was observed with intergranular cracking at 561K at which the susceptibility of SCC was high.

(4) The initial formation of void was observed around the end of the crack. The position of the void formed was considered to be in cementite or at the boundary between cementite and ferrite in pearlite.

Acknowledgements

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