Fracture Behaviors of Oxide Dispersion Strengthened 9Cr Steel and E911 Steel at Various Temperatures

Ji Hyun Yoon, Yongbok Lee, Suk Hoon Kang, Sung Soo Kim
Korea Atomic Energy Research Institute
jhyoon4@kaeri.re.kr

1. Introduction

The oxide dispersion strengthened (ODS) alloy, the advanced material showing the enhanced high temperature strength by adding nano scale oxide particles into mainly ferittic/martensitic (FM) steels. The high chromium ODS alloys are under intense research worldwidely as a candidate material for components of next generation nuclear systems like fuel cladding, duct, turbine blade [1-3].

However, characterizations for ODS alloys have been limited to tensile strength and creep strength. Although the ODS alloys were designed to operate at high temperatures, typically above 550^{o}C, fracture behaviors describing the material resistance to crack initiation and growth in this temperature region were investigated rarely [4].

The objective of this study is to investigate fracture behavior of 9Cr-ODS alloy preliminarily produced in laboratory scale by performing J-R fracture resistance tests and tensile tests at various temperatures up to 700^{o}C.

The 9%-Cr containing FM steel, E911 was tested concurrently to compare fracture characteristics of ODS alloys with commercial FM steel with similar chemistry of matrix. To obtain a deeper understanding of the fracture mechanism of 9Cr-ODS alloy at various temperatures, the fractography was performed for tested samples.

2. Experimental

The production route started from 4 kg of base alloy and included; mechanical alloying of the power with 0.3 wt% Y_2O_3; spark plasma sintering (SPS); hot isostatic pressing (HIP); hot rolling at 1250^{o}C. The chemical composition of the material is listed in Table 1.

Table 1. Chemistry of 9Cr-ODS alloy.

element	Cr	W	C	O	N	Y	V	Mo
wt %	8.3	1.2	0.094	0.42	0.011	0.18	0.17	0.006

The specimens for the J-R fracture resistance tests were 8.5 mm (1/3 inch) thick of compact type (CT) with the side grooves of 0.85 mm on each side. The CT specimens were oriented such that the crack growth proceeded along the transverse direction (L-T orientation). Round tensile specimens with a gage section 4 mm in diameter and 16 mm in length were used for tensile tests. The tensile specimen were oriented such that specimen loaded along the rolling direction.

J-R fracture resistance and tensile tests were conducted at room temperature, 300^{o}C, 500^{o}C and 700^{o}C using 100kN-capacity servohydraulic test machine in general accordance with ASTM E1820-09 and E8/8M-09 respectively. All tests were conducted in specially designed vacuum furnace. A single specimen approach was used, and crack extension was measured via normalization data reduction technique to generated J-R curves.

3. Results

The trend curves for 0.2 % offset yield strength and ultimate tensile strength of 9Cr-ODS and E911 steel are presented in Fig. 1. The yield and tensile strengths of 9Cr-ODS were about 40% higher than those of E911 steel at room temperature. However, the strength difference tends to dramatically reduced up to vanishing at 700^{o}C.

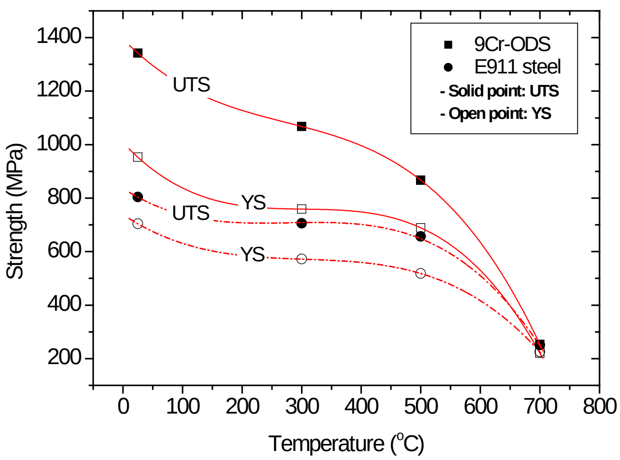

Fig. 1. Strength dependence of 9Cr-ODS and E911 steel on temperature.

The fracture behaviors of 9Cr-ODS were varied significantly with temperature. The brittle fracture, quasi-brittle fracture, crack pop-in and fully ductile crack growth were observed in the order of increasing temperature. On the other hand, E911 steel showed stable crack growth behavior at all temperature range. Fig. 2 shows load-displacement curves for 9Cr-ODS and E911 steel at 500^{o}C which indicates remarkable difference in fracture resistance of them. The maximum load for 9Cr-ODS was much lower compared with E911 steel though the initial crack lengths of two samples were almost same. The resistance to crack growth was also much lower than that of E911 steel.

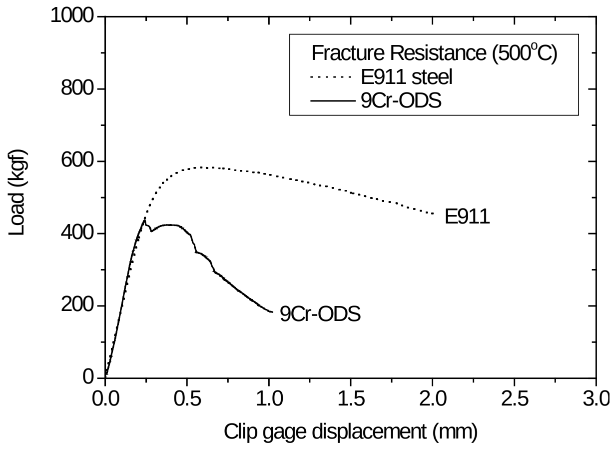

Fig. 2. Load-displacement curves for 9Cr-ODS and E911 steel obtained from J-R tests at 500°C.

4. Discussion

It was observed that the large 2nd phase particles on fracture surface of 9Cr-ODS after tensile tests. The

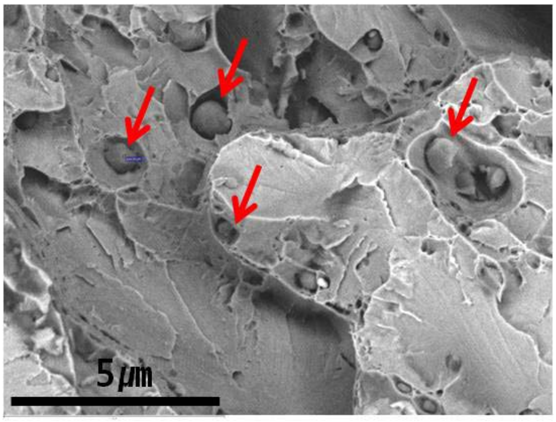

Fig. 3. Scanning electron micrograph of fractured surface of 9Cr-ODS. The arrows indicate Cr-rich oxides.

large particles pointed by arrows in Fig. 3 were identified as Cr-rich oxide through SEM-EDS analyses. It was deduced that the large chromium oxides were the initiation sites for brittle fracture of 9Cr-ODS at the lower temperature. It was also deduced that the role of chromium oxide in fracture process at the higher temperature was almost ignorable because the matrix was ductile enough to generate dimpled fracture surface as shown in Fig. 4. The size of dimples is almost same with the grain size of 9Cr-ODS.

The chromium oxides are not the expected particles in alloy designing but it might be formed during the thermo-mechanical process due to a poor atmosphere control. Therefore it is suggested that the improved

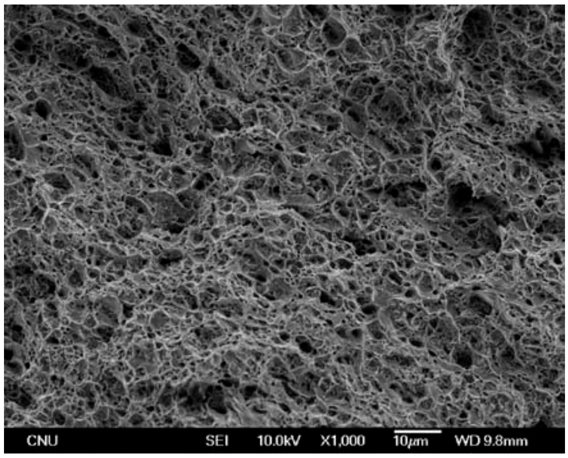

Fig. 4. SEM micrograph for fracture surface of 9Cr-ODS at 700°C.

atmosphere control method should be considered to enhance the fracture resistance of ODS alloy.

5. Conclusions

The yield and tensile strengths of 9Cr-ODS were about 40% higher than those of E911 steel at room temperature. However, the strength difference tends to dramatically reduced up to vanishing at 700°C.

The fracture behaviors of 9Cr-ODS were varied significantly with temperature. The brittle fracture, quasi-brittle fracture, crack pop-in and fully ductile crack growth were observed in the order of increasing temperature.

The lower fracture resistance at the lower temperature was attributed to the large chromium oxide particles formed during ODS production process.

REFERENCES

[1] R. Lindau et al., Fus. Eng. Des., Vol. 75, pp. 989, 2005.
[2] R. L. Klueh et al, J. Nucl. Mater., Vol. 341, pp. 103, 2005.
[3] D. A. McClintock et al., J. Nucl. Mater., Vol. 392, pp. 353, 2009.
[4] R. Chaudi et al., J. Nucl. Mater. Vol. 403, pp. 15-18, 2010.