22D09

Mechanical properties and aging effects of 9Cr ODS steel
9Cr ODS鋼 の強度特性と時効効果

Takeo Muroga[1], Yanfen Li[1]*, and Takuya Nagasaka[1]
室賀健夫[1], 李艶芬[1]*, 長坂琢也[1],

[1] *National Institute for Fusion Science*
322-6 Oroshi, Toki, Gifu 509-5292, Japan
核融合科学研究所 〒509-5292 岐阜県土岐市下石町322-6

**Present address : Institute for Materials Research, Tohoku University*
2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan
*現在の所属 東北大学金属材料研究所 〒980-8577 仙台市青葉区片平2-1-1

High-temperature thermal creep properties and microstructure of a 9Cr-ODS steel were examined. The properties were compared with those of normal reduced activation ferritic/martensitic steels (RAFMs) of CLAM and JLF-1. The 9Cr-ODS steel exhibited a superior creep strength. Prediction with Larson-Miller parameter for the typical blanket conditions suggested that the 9Cr-ODS steel can successfully extend the maximum operation temperature to ~923 – 973 K. The effects of thermal aging on microstructure and mechanical properties were also investigated.

1. Introduction

The oxide dispersion strengthened (ODS) steels are advanced alloys produced by Mechanical Alloying methods with high density of nano-particle dispersion and fine grains [1]. ODS steels with 9%Cr are recognized as promising candidates for fusion reactors since good joining capability with RAFMs (9Cr-W steels) is expected because of similar chemical compositions.

In 2009, an ODS alloy with 9%Cr was produced and delivered for examinations under a cooperation program among Japanese universities and National Institute for Fusion Science (NIFS). In this work, the mechanical properties of this alloy, called as the 9Cr-ODS in this paper, were investigated focusing on creep behavior. These properties were evaluated and compared with those of the normal RAFMs of CLAM and JLF-1, Chinese and Japanese candidates, respectively. Thermal aging effects are also investigated with respect to microstructures and mechanical properties.

2. Experimental

The 9Cr-ODS alloy was manufactured by mechanical alloying and further extruded into bar [2]. Then, the hot-extruded bar (length=380mm, diameter=27mm) was forged at 1423 K to a plate of 8 mm thickness. Finally, the plate was heat treated. The chemical compositions are shown in Table 1 and heat treatment conditions are given in Table 2 in comparison with CLAM and JLF-1.

To understand the thermal stability of microstructure, the as-received 9Cr-ODS was heat treated from 973 K to 1423 K with a step of 50 K in vacuum and kept for one hour at each temperature followed by fast furnace cooling. After the heat treatments, the Vickers hardness of the samples was measured with a load of 300 g and a loading time of 30 s at room temperature (RT).

The creep tests were performed using the SSJ-type specimens with a gauge section of 5 mm (L) X 1.2 mm (W) X 0.25 mm (T), which were machined along the extrusion and forging direction. The surface of the SSJ samples were ground with alumina papers in grit sizes up to #4000 and mechanically polished. Uniaxial creep tests were performed from 823 to 1073 K in a vacuum of 10^{-4} Pa. Microstructural observations were carried out with JEM-2000FX Transmission Election Microscope in RIAM, Kyushu University.

3. Results and Discussion

The uni-axial creep experiments for the 9Cr-ODS were carried out from 823 to 1073 K with stresses from 120 to 400 MPa.

Figure 1 shows the typical creep curves of the 9Cr-ODS at 973 K with different stresses. As

Table 1: Chemical compositions of the 9Cr-ODS, CLAM (0603 HEAT) and JLF-1 (JOYO-2-HEAT).

	Cr	C	W	Y	Ti	O
9Cr-ODS	9.08	0.14	1.97	0.29	0.23	0.16
CLAM	8.94	0.13	1.45	-	-	0.0017
JLF-1	9.00	0.09	1.98	-	-	0.0019

Note: the Fe is the balance

Table 2: Heat treatments of the 9Cr-ODS, CLAM (0603 HEAT) and JLF-1 (JOYO-2-HEAT).
(Note: AC: air cooling)

	Normalization	Tempering
9Cr-ODS	1323 K/60 min /AC	1073 K/60 min /AC
CLAM	1253 K/30 min /AC	1033 K/90 min /AC
JLF-1	1323 K/60 min /AC	1053 K/60 min /AC

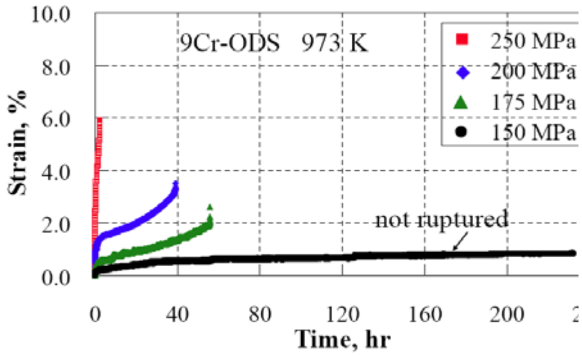

Fig.1 Strain – time creep curves for the 9Cr-ODS tested at 973 K with different applied stresses: 250, 200, 175 and 150 MPa.

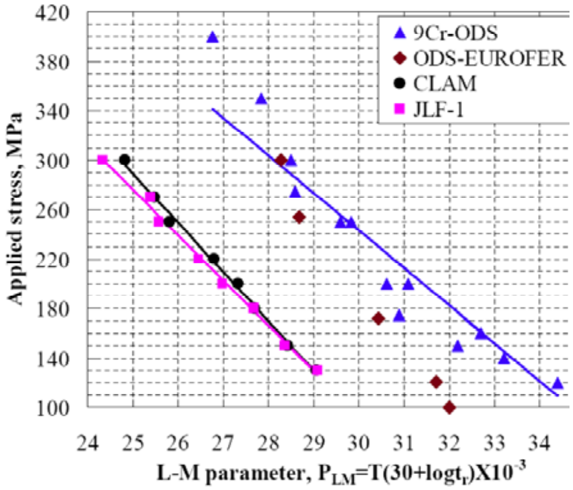

Fig.2 Dependence of stress on Larson-Miller parameter for the 9Cr-ODS, comparing with CLAM, JLF-1 and ODS-EUROFER [3] steels.

(T: temperature, K; t_r: rupture time, hr).

shown in the figure, the minimum creep rate increased and the rupture time decreased with the increase in stress. The sample with the stress of 250 MPa ruptured after several hours. While with 150 MPa, the rupture time exceeded 230 hours.

All the results of creep rupture tests are summarized in the Larson-Miller (L-M) plot using a constant of 30, as shown in Fig.2. For comparison, the data for CLAM, JLF-1 and ODS-EUROFER97 are also presented in the figure.

Obviously, the L-M parameter of the 9Cr-ODS steels are much higher than those of CLAM and JLF-1. In the typical blanket condition for RAFMs, the operation limit is set at 823 K for 100000 h, which corresponds to the L-M parameter of 28.8 with rupture stress of ~140 MPa. By increasing the blanket temperature to 923 K and 973 K with the same service life of 100000 h, where the L-M parameter are equal to 32.3 and 34.0, the rupture stress for 9Cr-ODS was predicted to be ~173 and

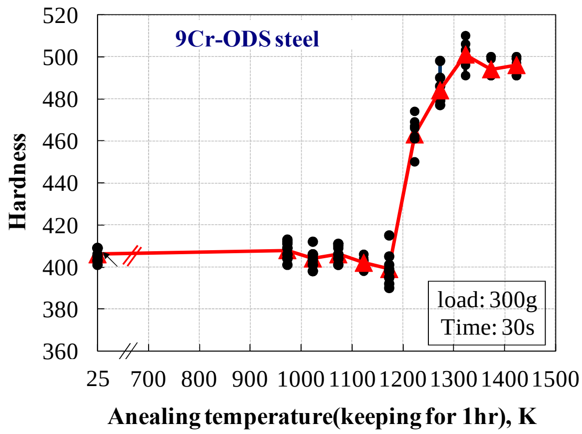

Fig.3 Hardness after annealing for 1 hour at various temperatures.

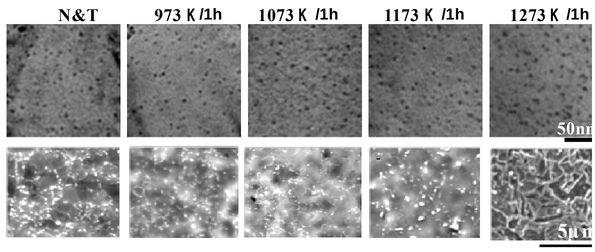

Fig.4 TEM microstructure (upper) and SEM surface morphology (lower) after annealing.

~120 MPa, respectively, which are comparable to those of RAFMs at 823 K for 100000 h. The present data suggest that the maximum operation temperature can be extended to about 923 – 973 K for the 9Cr-ODS steel from the creep viewpoint.

Fig. 3 and 4 show the hardness and TEM/SEM microstructure of the 9Cr-ODS after the heat treatments at various temperatures for 1 h. Remarkable hardening and change in SEM images occurred at >1200 K, but no significant change was observed for the nano-particles by TEM, suggesting high thermal stability of the particles.

Acknowledgments

The authors are grateful to Profs. S. Ukai of Hokkaido University and A. Kimura of Kyoto University for manufacturing the 9Cr-ODS. They are also thankful to Prof. H. Watanabe of Kyushu University for the use of TEM.

This study was supported by NIFS Budget Code NIFS12UFFF022

References

[1] A. Kimura, et al., J. Nucl. Mater., 367-370, 60 (2007)..

[2] S. Ukai, et al., Mater. Sci. Eng. A 510-511, 115 (2009).

[3] R. Lindau, Fus. Eng. Des., 61-62, 659 (2002).