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Creep Properties of New 9Cr-2W Steels for a SFR Fuel Cladding

Woo-Gon Kim[a*], Chang-Hee Han[a], Sung-Ho Kim[a], Jong-Hyuk Baek[a], Tae-Kyu Kim[a], Chan-Bock Lee[a]
[a]SFR Fuel Development, Korea Atomic Energy Research Institute,
1045 Daedeokdaero, Yuseong-gu, Daejeon, 305-353, Korea
** Corresponding author: wgkim@kaeri.re.kr*

1. Introduction

The Gen-IV SFR (sodium cooled fast reactor) which is one of the next generation nuclear power reactors is to have a considerable increase in safety and be economically competitive when compared with the conventional water reactors. To accomplish these objectives, a superior fuel-cladding material should be developed because its integrity is directly related to those of the reactor system as well as the fuel in the Gen-IV SFR [1].

Currently, F/M (ferritic/martensitic) steels of 8~12% Cr are being considered as fuel cladding materials for a Gen-IV SFR due to their high thermal conductivities, low expansion coefficients and excellent irradiation resistances to a void swelling compared to austenitic stainless steel. Since fuel cladding in the Gen-IV SFR would be operated under higher temperatures than 600°C, contacting with liquid sodium, and be irradiated by neutrons to as high as 200dpa, the cladding materials should sustain superior irradiation, thermal stabilities, and superior creep strength during a service life at a higher temperature over 600°C [2-6].

In this study, to develop a new cladding material for the Gen-IV SFR fuel, the effects of B and C contents for 9Cr-2W F/M steels was investigated on the creep properties, which were obtained by a series of creep tests at 650°C. And, the results of creep properties were compared with ASTM Grade 92 steel used as a reference steel.

2. Experimental Method

Five alloys (B01 to B05) were intentionally changed to investigate the effect of B and C on the creep property of the F/M steels. The chemical composition of the five steels is given in Table 1. The ingots of the each steel were 30 kg and prepared by using a vacuum induction melting (VIM). Plates of the steels were hot-rolled into 15mm in thickness after an annealing at 1150°C for 2 hours. The hot-rolled plates were normalized at 1050°C for 1 hour, and then followed by a tempering at 750°C for 2 hours. After both of the normalizing and tempering heat-treatments, the samples were cooled to room temperature in air.

Tensile testing specimens were machined with a rectangular cross section of a 1mm thickness and 3.5mm width, and with a 25mm gauge length. Also, creep testing specimens were taken in the rolling direction and machined to a cylindrical shape with a 30mm gauge length and 6mm diameter.

The tensile tests were carried out at a crosshead speed of 3 mm/min from room temperature to 700°C. The creep test was conducted at 650°C with applied stress levels of 140MPa, 130MPa, 120MPa, and 110MPa. Creep strain data with elapsed times was taken automatically by a PC. The steady state creep rate was measured from the creep curves. The microstructures of the crept specimens were observed using OM, SEM and TEM.

Table 1. Chemical composition of five manufactured alloys

	C	B	V	Nb	Cr	W
B01	0.106	-	0.20	0.21	8.95	2.13
B02	0.083	0.008	0.20	0.20	9.02	1.96
B03	0.091	0.017	0.20	0.20	8.95	1.98
B04	0.070	-	0.20	0.21	8.94	2.11
B05	0.051	-	0.21	0.20	8.62	2.08

3. Results and Discussion

3.1 Tensile properties

Fig. 1 shows results of the yield strengths for B01 to B05 steels. All steels of B01-B05 had a better yield strength than the Grade 92 steel regardless of the tensile test temperature. Especially, B03 steel which the boron content was added to 170 ppm showed the highest yield strength over all temperatures. Also, B03 and B04 steels which were properly added for B and C contents showed a higher yield strength than other steels, and especially at 650°C.

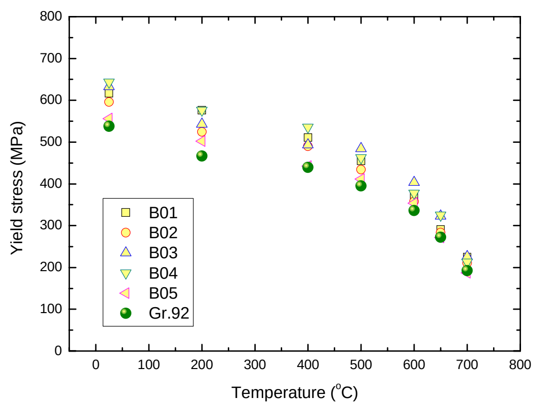

Fig. 1. Yield strength of B01 to B05 steels with temperatures.

Addition of boron had a good effect on the increase of the yield strength. Optimal decrease of carbon content also had a good effect on the increasing the yield strength. However, as shown in B05 steel of Table 1, in case that the carbon content decreased to 0.051wt%, the yield strength was decreased. Thus, optimum carbon content for strength is believed to be about 0.07wt%. In addition, the tensile strength for the five steels showed a similar tendency to the yield strength. But, creep-rupture elongation of the five steels was lower than that of the Grade 92 steel.

3.2 Creep Properties

Fig. 2 shows the results of time to rupture with different applied stress levels for B01 to B05 steels. B03 and B04 steels had a higher rupture time than other three steels, and especially, B03 steel containing the boron of 170ppm showed the higher rupture time than Gr. 92 at 120MPa. Now, the creep tests for B03 and B04 specimens are ongoing at 110MPa.

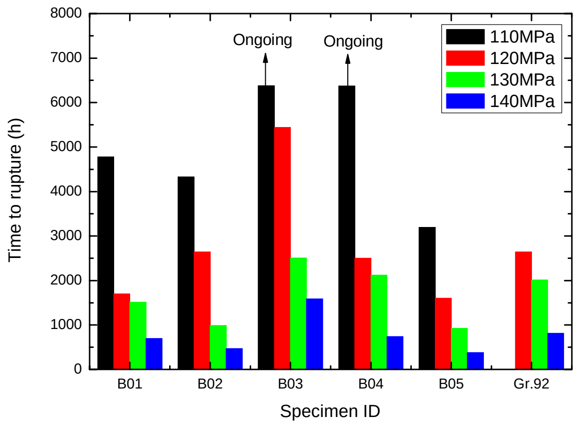

Fig. 2. Results of the time to rupture with different stress levels for B01 to B05 steels.

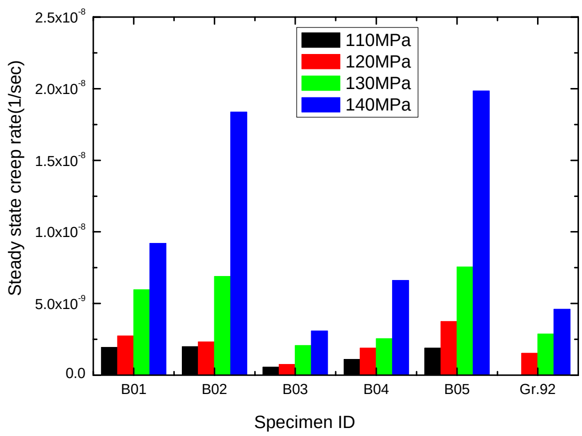

Fig. 3. Results of the steady state creep rate with different stress levels for B01 to B05 steels.

Fig. 3 shows the steady state creep rate with different applied stress levels for B01 to B05 steels. The steady state creep rate was measured from the creep curve which was obtained by a creep test. B03 and B04 steels had a lower steady state creep rate than other three steels. Especially, B03 steel containing boron showed the lowest steady state creep rate. Thus, it is identified that the addition of B can improve the creep rupture strength of the F/M steel. Behavior of creep-rupture elongation showed a similar tendency to the steady state creep rate.

In addition, the creep resistance of F/M steel was improved by a decreasing the carbon content to 0.07wt%. But, when the carbon content was decreased up to 0.051wt%, the steady state creep rate was increased reversely. Further investigation will be continuously investigated the effect of minor elements such as V, Nb, C, and N on the creep properties.

4. Conclusions

The effect of B and C contents on creep properties of 9Cr-2W steel was investigated for five designed alloys. It is found that the addition of Boron had a beneficial effect on the yield strength, tensile strength and creep property of the F/M steel. Especially, B03 steel containing the boron of 170ppm showed the lowest steady state creep rate when compared with ASTM Grade 92 steel as well as other four steels. Optimum carbon content was to be about 0.07wt%. B03 and B04 steel showed a lower minimum creep rate than other three steels. Further studies are ongoing to investigate the optimum carbon, niobium, nitrogen, and vanadium contents for the creep properties of the F/M steel.

Acknowledgements

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