Development of SFR Fuel Cladding Tube Materials

S. H. Kim [a*], W. G. Kim [a], J. H. Baek [a], T. K. Kim [a], C. H Han [a], J. H. Kim [a], C. B. Lee [a] Dohee Hahn [a]
[a] *SFR Fuel Develpment, KAERI, 1045, Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea*
[*] *Corresponding author:shkim7@kaeri.re.kr*

1. Introduction

The environment of a SFR core is more severe than that of a PWR core. The peak cladding temperature is about 650°C and the neutron fluence can reach up to 200dpa. So, ferritic/martensitic steels have been receiving attention for an application to a SFR fuel cladding because of the excellent irradiation characteristics (e.g. excellent irradiation swelling resistance). [1,2] Until now many out-of-pile and in-pile tests have been performed to apply HT9 and PNC-FMS steels to SFR cladding tubes. HT9 steels were irradiated at FFTF up to 200dpa and PNC-FMS steels have been irradiated at JOYO. [3] However, the HT9 cladding materials were not conserved enough to satisfy the discharge burnup goal, because of the high coolant outlet temperature and the low creep resistance characteristics. So HT9 will be changed to another ferritic/martensitic steel which has high a thermal creep resistance characteristics. Development of new FM steel for SFR fuel cladding tubes has been in progress. The purpose of this research is to develop a FM steel having a higher creep strength than the Grade 92 steel.

2. Experimental Procedure

10 alloys (B001 to B010) were designed to investigate the effect of minor elements such as B, C, V, Nb and Ta on the creep property of FM steels. The chemical composition of the steels is shown in Table 1. These steels were laboratory melted in a vacuum by an induction furnace. The heat treatment consisted of an austenitizing at 1050°C for one hour followed by an air cooling and tempering at 750°C for two hours also followed by an air cooling.

Table 1. Chemical composition of test alloys.

	C	B	V	Nb	Ta	Cr	W
B1	0.106	-	0.20	0.21	-	8.95	2.13
B2	0.083	0.008	0.20	0.20	-	9.02	1.96
B3	0.091	>0.01	0.20	0.20	-	8.95	1.98
B4	0.070	-	0.20	0.21	-	8.94	2.11
B5	0.051	-	0.21	0.20	-	8.62	2.08
B6	0.046	-	0.32	0.13	-	9.01	2.11
B7	0.037	-	0.31	0.06	-	8.97	2.08
B8	0.037	-	0.31	0.04	-	9.02	2.12
B9	0.049	-	0.31	0.09	0.08	9.09	2.09
B10	0.052	-	0.31	0.06	0.14	8.98	2.07

The tensile tests were carried out at a crosshead speed of 3 mm/min from room temperature to 700°C. The creep test was performed at 650 °C under constant load conditions. Applied loads were varied from 110MPa to 140MPa. Here, the steady state creep rate was measured. The microstructures were observed by using a transmission electron microscope (TEM), and the elemental analyses on the particles were made by using an energy dispersive spectroscope (EDS) attached to a TEM.

3. Results and Discussion

2.1 Tensile Properties of New Cladding Tube Materials

Fig. 1 shows the yield strength of B001 to B005 steels. B001-B005 steels had a higher yield strength than the Grade 92 steel regardless of the tensile test temperature. B003 and B004 steels showed the highest yield strength. Addition of boron had a good effect on the increase of the yield strength. Decrease of carbon content also had a good effect on the increasing the yield strength. However as the carbon content decreased to 0.05wt%, the yield strength was decreased. Optimum carbon content for strength was 0.07wt%.

Fig. 2 shows the yield strength of B006 to B010 steels. B006-B010 steels showed lower yield strength than the Grade 92 steel. Ta had a good effect on the yield strength of the FM steel. Tensile strength also showed a similar tendency to the yield strength. But the elongation of the B001-B005 steels was lower than that of the Grade 92 steel. Increase of the vanadium content and decrease of the niobium content had no beneficial effect on the strength of the FM steels.

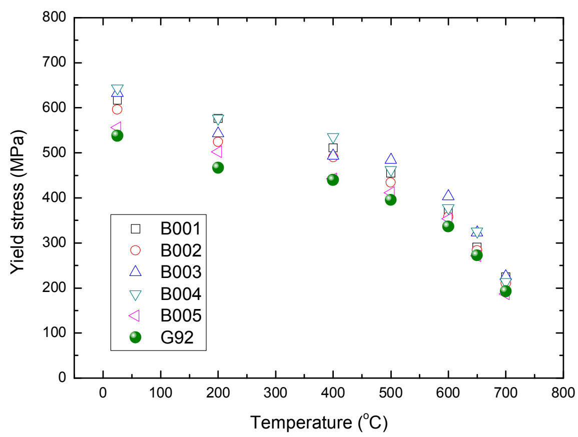

Fig. 1. Yield strength of B001 to B005 materials.

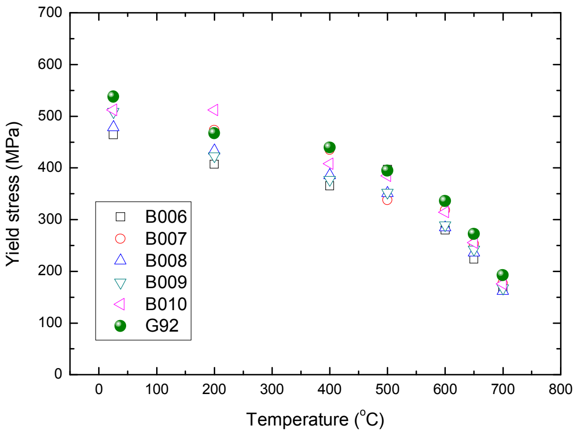

Fig. 2. Yield strength of B006 to B010 materials.

2.2 Creep Property of New Cladding Tube Materials

Fig. 3 shows the steady state creep rate of the specimens. Steady state creep rate was measured from the creep curve which was obtained by a creep test. The creep test duration was at least 2,000 hours. B001 steel is a reference steel. B003 and B004 steels had a lower steady state creep rate than the B001 steel. B003 steel containing boron showed the lowest steady state creep rate. So the addition of B^{11} may improve the creep rupture strength of the FM steel because B^{11} does not undergo the (n, α) reaction. This reaction produces helium and lithium which could have a harmful effect on the mechanical properties of the FM steel.

The creep resistance of FM steel was also improved by a decreasing the carbon content to 0.07wt%. However as the carbon content decreased to 0.05wt%, the steady state creep rate was increased. Decrease of the Nb content caused the increase of steady state creep rate of FM steels. However Ta had a beneficial effect on the creep property of the FM steel. Further investigation will be continued to evaluate the effect of minor elements such as V, Nb, C, and N on the creep properties.

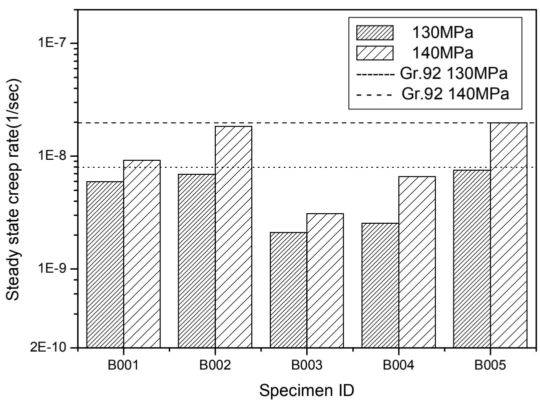

Fig. 3. Steady state creep rate of new cladding tube materials.

4. Conclusions

To investigate the effect of alloying elements on the mechanical properties of FM steel, 10 alloys were designed, manufactured and tested. Boron and Tantalum had a beneficial effect on the yield/tensile strength and creep property of the FM steel. Optimum carbon content of tensile and creep properties were 0.07wt%. Four new alloys showed a lower minimum creep rate than the Grade 92 steel. Further studies are going on to investigate the optimum carbon, niobium, nitrogen, and vanadium contents for the creep properties of the FM steel.

Acknowledgements

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