Tantalum-Addition Effect on Tensile and Creep Properties in 9Cr-0.5Mo-2W-V-Nb Steels

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1. Introduction

Ferritic/martensitic steels (FMS) are being considered prospectively as cladding materials of a SFR fuel in Gen-IV nuclear systems. There are sound technical justifications for these material selections, and the adoption of the FM steels for a wide range of nuclear and non-nuclear applications has generated much industrial technology and experience. However, there are strong incentives to develop advanced materials, especially cladding, for a Gen-IV SFR [1].

To develop an improved FM steel for the Gen-IV SFR fuel cladding in Korea, a R&D program has been progressed since 2007 [2-4]. Categories of materials considered in the program included 8~12% Cr FM steels. A strong recommendation was made for the development of a high strength steel equivalent to or superior to ASTM Gr.92 steel (hereafter Gr. 92) to offset the difficulties encountered with commercial available high Cr (8~12%) steels. Since the fuel cladding in a Gen-IV SFR would operate under higher temperatures than 600^{o}C, contacting with liquid sodium, and be irradiated by neutrons to as high as 200dpa, the developed cladding should thus sustain both superior irradiation and temperature stabilities during its operational life. The newly developed advanced steel should also overcome severe drawbacks; mechanical properties, especially creep, are deteriorated at a higher temperature over 600^{o}C.

The aim of this study is to investigate the effect of Ta addition on the tensile and creep properties of the three alloys which are designed, manufactured and tested. Their properties are obtained and compared for developing new FM fuel cladding materials.

2. Methods and Results

2.1 Experimental procedures

The three 9Cr-0.5Mo-2W FM steels (hereafter, B201 to B203) used mainly consisted of 9% Cr, 0.5% Mo, 2% W, and 0.2% V+Nb, and 0.070% carbon, about 0.07-0.09% nitrogen, and 0.02-0.10% Ta, respectively. Experimental three alloys were prepared to investigate the effect of Tantalum (Ta) addition on the tensile and creep properties in FM steels. The three alloys are almost similar to minor elements, but Ta elements are different such as the B201 (Ta=0.05%), B202 (Ta=0.02%) and B203 (Ta=0.10%). The ingots of the each steel were about 30 kg (per 1 batch) and prepared by using an vacuum induction melting process. The heat treatments were carried out for an austenitizing at 1050^{o}C for 1 hour followed by an air cooling, and for a tempering at 750^{o}C for 2 hours also followed by an air cooling.

Tensile specimens were machined with a rectangular cross section of a 1mm thickness and 3.5mm width, and with a 25mm gauge length. Creep 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^{o}C. The creep tests were conducted at 650^{o}C with different stress levels of 150MPa, 140MPa, 130MPa, and 120MPa.

2.2 Ta-addition effect for tensile properties

Fig.1 show the yield stresses of the B201 to B203 steels with high temperature variations. All of the three experimental steels had higher tensile strengths than the ASTM Gr. 92 steel. The B201 steel showed the highest yield strength when compared with B202 and B203 ones. The order of the strength values was B201>B202>B203. On the contrary, the three experimental steels had lower tensile rupture elongation than the Gr. 92 steel. The order of the rupture elongation values was B203>B202>B201.

Also, as shown in Fig. 2, tensile strengths at 650^{o}C were the order of B201>B202>B203, and the rupture elongation was in reverse order of B203>B202>B201. It is supposed that addition of proper Ta had a good effect on the increase of the tensile strengths, because the B201 steel which had proper Ta contents (0.05wt. %) showed a higher tensile strength than the other 2 ones, especially at the interesting temperature of 650^{o}C.

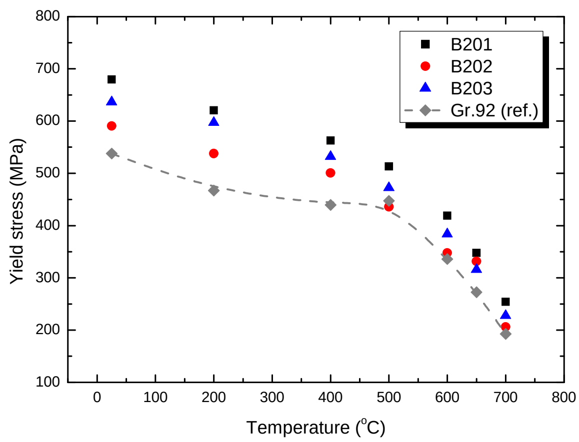

Fig.1. Yield stress for the B201 to B203 steels

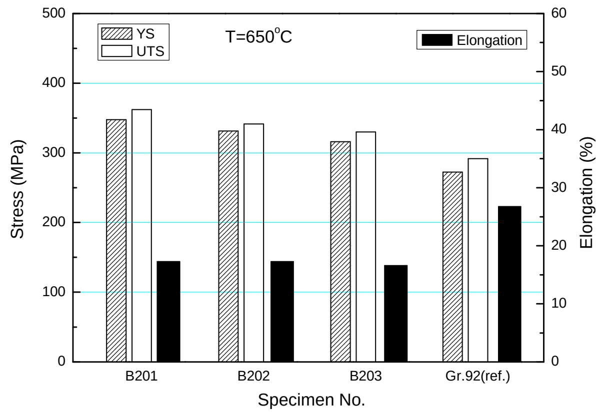

Fig.2. Tensile properties for the B201 to B203 steels at 650°C

2.3 Ta-addition effect for creep properties

Fig. 3 shows the results of the time to a rupture with different applied stress levels for the B201 to B203 steels. All the three steels had a longer rupture time than the ASTM Gr. 92 steel or HT9 steel. The B201 steel containing Ta content of 0.05wt. % showed a higher rupture time than the other two steels (B202 and B203). Thus, the optimum Ta content for creep rupture life and strength is believed to be about 0.05wt.% in the FM steel. Also, it is investigated that all the three steels had a lower steady state creep rates (SSCR) than the ASTM Gr. 92 steel or HT9 steel. B201 steel had lower creep rates than the other two steels (B201 and B203). The B201 steel containing Ta content of 0.05wt. % showed the lowest creep rate. Thus, it is supposed that the proper addition of Ta can improve the creep rupture strength of the FM steels.

In the case of creep rupture ductility, there were not large differences among the three experimental steels, and they showed a similar tendency to the ASTM Gr. 92 steel. The B201 steel containing the Ta of 0.05wt. % exhibited high creep strength without a reduction of creep ductility.

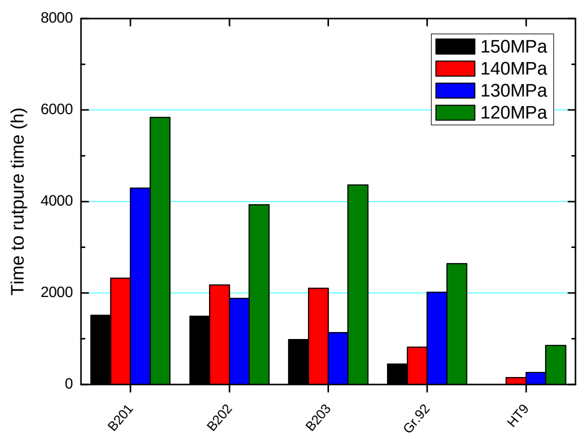

Fig. 3. Time to rupture with stress levels for the B201 to B203 steels

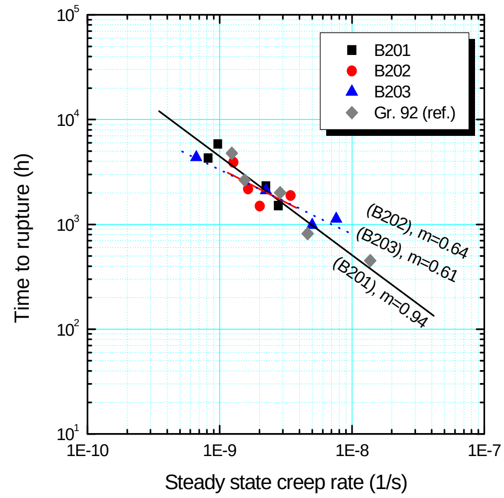

Fig. 4. Monkman-Grant relation for the B201 to B203 steels

Fig. 4 shows the plot of Monkman-Grant (M-G) relation for the B201 to B203 steels. In the M-G plot, the B201 (m=0.94) steel revealed a sharp slope compared with the B202 (m=0.64) ans B203 (m=0.61) ones. It means that the B201 steel predicts longer rupture time than the other two steels.

3. Conclusions

The three alloys were designed, manufactured and tested to investigate the effect of Ta addition on the tensile and creep properties of the FM steels. A proper addition of Ta contents had a beneficial effect on the tensile and creep properties of the FM steels. Especially, the B201 steel containing the 0.05 wt.% Ta showed the lowest SSCR and the longest rupture time compared with the B202 and B203 ones. It is believed that optimum Ta content was about 0.05wt.%.

Acknowledgements

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