Effect of Vanadium on the Creep Properties of SFR Fuel Cladding Tube Materials

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1. Introduction

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 since 2007. The purpose of this research is to develop a FM steel having a higher creep strength than the Grade 92 steel.

2. Methods and Results

2.1 Experimental Procedure

2 alloys were designed to investigate the effect of vanadium on the mechanical properties 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. Heat treatment was carried out in a vacuum 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 I: Chemical composition of FM steels

	C	Cr	Mo	W	V	Nb	Ta	N
0.3V	**0.070**	**9.33**	**0.52**	**1.95**	**0.30**	**0.05**	**0.15**	**0.060**
0.1V	**0.066**	**9.00**	**0.53**	**2.20**	**0.11**	**0.05**	**0.15**	**0.073**

The tensile and creep tests were carried out to evaluate the effect of vanadium on mechanical properties of FM steels. 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.

2.2 Phase equilibrium

The phase equilibrium diagrams of alloys were calculated using thermocalc. Fig. 1 shows the phase equilibrium of 0.3V and 0.1V steels. The A_{e1} and A_{e3} temperature of the 0.3V steel were higher than that of the 0.1V steel. V-rich MX particles were formed in the high V steel phase equilibrium, but the mass fraction of these particles was low in the low V steel, so not appeared in phase equilibrium. The mass fraction of Laves phase is higher in the 0.1V alloy. It is due to the high tungsten content in the 0.1V steel.

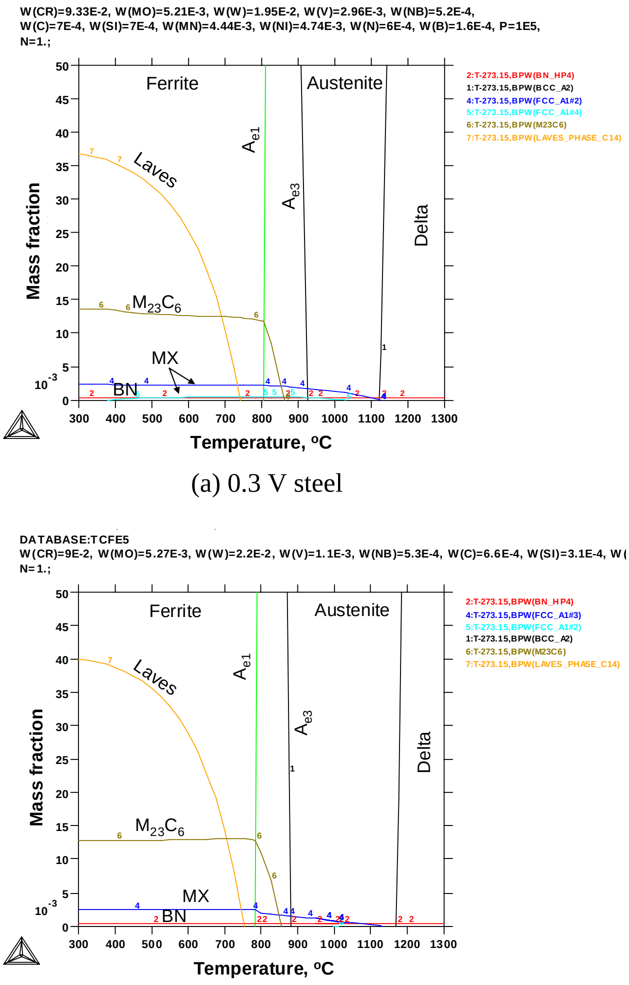
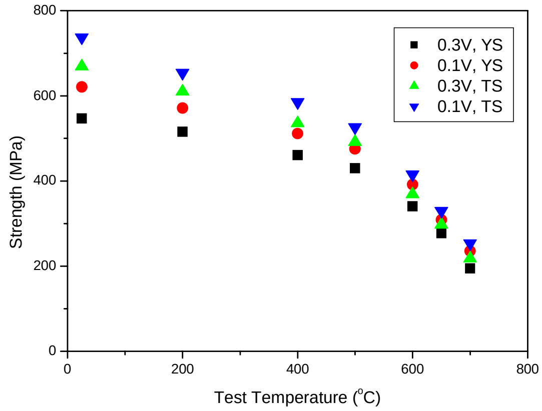


Fig. 1. Phase equilibrium of FM steels

2.3 Tensile Properties

The tensile properties of the alloys were evaluated by the uniaxial tension test. Tensile tests were carried out at a crosshead speed of 3mm/min from room temperature to 700°C. Fig. 2 shows the tensile properties of the alloys. The 0.1V steel showed a higher yield strength than the 0.3V steel regardless of the tensile test temperature. Tensile strength also showed a similar tendency to the yield strength. But the elongation of the 0.1V steel was lower than that of the 0.3V steel. The mass fraction of the V-rich MX particles may increase with the increase of the vanadium content. But the increase of V content had no beneficial effect on the yield and tensile strength of the FM steel.



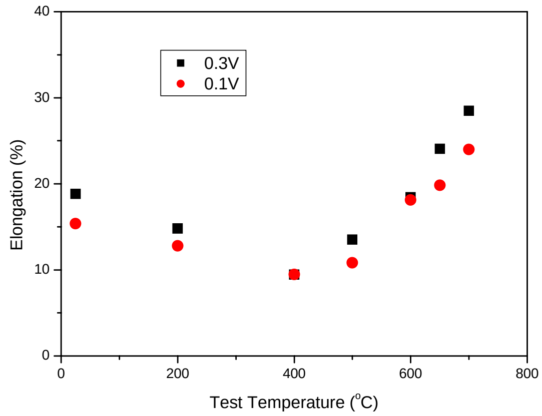


Fig. 3. Tensile properties of FM steels

2.4 Creep Properties

The creep test was performed at 650°C under constant load conditions. Applied loads were varied from 110MPa to 140MPa. Fig. 4 shows the creep rupture strength of the specimens. The creep test duration was up to 4,000 hours. The 0.1V steel had a higher creep rupture strength than the 0.3V steel.

It is known that needle type V-rich MX particles have good effect on creep rupture strength of FM steel.[4] So vanadium content of FM steel increased to form more V-rich MX particles. Thermocalc calculation results showed that the mass fraction of V-rich MX particles increased in high vanadium steel. But the increase of V-rich MX particles had no good effect on the creep rupture strength of FM steel. But further investigation will be continued to confirm the effect of V on the creep rupture strength.

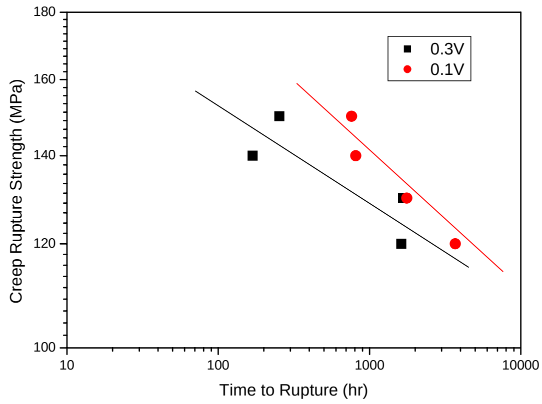


Fig. 4. Creep rupture strength of FM steels at 650°

3. Conclusions

Vanadium content was changed to study the optimum content for the creep rupture strength of FM steels by precipitation of V-rich MX particles. Increase of vanadium content caused the increase of mass fraction of V-rich MX particles. But a high vanadium steel showed lower yield, tensile and creep rupture strength than a low vanadium steel. Further studies are going on to investigate the optimum vanadium contents for the creep properties of the FM steels.

Acknowledgement

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