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Effects of Tempering Temperature and Path on the Microstructural and Mechanical Properties of ASTM Gr.92 Steel

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1. Introduction

SFR (Sodium-Cooled Fast Reactor) is one of the prospective nuclear reactor for the next generation (Gen-IV) systems. The fuel claddings in the SFR are subject to a high fast nuclear irradiation and a high temperature. Fuel technology is a key aspect of an SFR system, with implications for reactor safety, reactor operations, fuel reprocessing technology, and overall system economics[1].

ASTM Gr.92 steel has been considered as the one of the main candidate fuel cladding materials in the design of SFR in that it has higher thermal conductivity as well as dimensional stability under irradiation when compared as austenitic stainless steel[2]. The changes in microstructure and heat-treatment varying $M_{23}C_6$, MX, M_2X, and precipitation by ASTM Gr.92 steels to improve high temperature mechanical properties is the attention[3]. According to several researchers, it plays an important role in the mechanical properties of precipitates V, Nb, Cr, C, N as a form of MX and M_2X precipitates. These fine precipitates formed in the sub-grain by preventing the movement of dislocations in high-temperature mechanical properties will contribute effectively[4]. This study investigated the effects of tempering temperature and heat-treatment path on microstructure and mechanical properties of ASTM Gr.92 steels.

2. Experimental procedure

The chemical composition of ASTM Gr.92 steels used in this study are shown in Table.1. Chromium contents were 9 wt.%. molybdenum and tungsten contained 0.47 wt.% and 1.6 wt.%, respectively for solution hardening. For the precipitate hardening, vanadium, niobium, carbon, and nitrogen were contained 0.2 wt.%, 0.07 wt.%, 0.1 wt.%, and 0.04 wt.%, respectively. And the boron contents were 0.0039 wt.%. Ingots were melted by a VIM (vacuum induction melting) method and hot-rolled to a 15mm thickness at 1150°C. Heat-treatment process was executed as shown in Table. 2.

To observe the microstructure, optical microscope of specimen etched by a dissolution of the metallic matrix in an etchant of 93% of H_2O, 5% of HNO_3, 2% of HCl. And the precipitate characteristics were analyzed with thin foil and carbon replica specimens using by a TEM with EDS. In order to investigate the mechanical properties, Vickers micro-hardness tester and tensile tester utilized for the specimen normal to the rolling direction of the plate. The average hardness was taken from 10-measured values, which were obtained under a load of 500g. The tensile tests were carried out by using specimens with a 25mm gage length at 650°C.

Table. 1 Chemical composition of ASTM Gr.92 steel

Chemical composition, wt.%						
C	Si	Mn	Ni	Cr	Mo	W
0.10	0.454	0.440	0.494	9.00	0.467	1.60
V	Nb	N	B	P	S	
0.202	0.072	0.042	0.0039	0.020	0.009	

Table. 2 Heat-treatment process

Process	Heat-treatment process
HT1	1050°C X 1h(A/C) → RT → 810°C X 2h(A/C) → RT
HT2	1050°C X 1h(A/C) → RT → 810°C X 2h(A/C) → RT
HT3	1050°C X 1h(A/C) → 780°C X 2h(A/C) → RT → 750°C X 1h(A/C) → RT
HT4	1050°CX 1h(A/C) → 810°C X 2h(A/C) → RT → 750°C X 1h(A/C) → RT

3. Results and Discussion

3.1. Microstructural Properties

From the optical microstructure and TEM observation, the steels show a typical tempered martensitic microstructure after the normalizing and different tempering temperature and isothermal heat-treatment processes. But a sample tempered at 810°C was presumed to retain partially untempered martensitic microstructures due to the tempering at lower $\alpha + \gamma$ phase regime.

The PAG (prior-austenite grain) size, lath width and precipitate size increased with an increase of the tempering temperature. Especially, the PAG size, lath width and precipitate size in isothermal heat-treated samples were much smaller than those of tempered-only ones. The PAG size of HT1 tempered at 780°C was measured in 25.8 ㎛, HT2 tempered at 810^{o}C was slightly coarsened to 27.1 ㎛. The PAG size of HT3 and HT4 were reduced by isothermal heat-treatment(HT1 : 25.8 ㎛ → HT3 : 20.9 ㎛, HT2 : 27.1 ㎛ → HT4 : 23.1 ㎛). Also, the lath width of HT1 was 370nm, and HT2 was 420nm. The lath width of HT3 was similar to HT1, but HT2 was reduced about 10% (380nm) when compared with the sample tempered at 810^{o}C only.

$M_{23}C_6$, V(C,N) and Nb(C,N) precipitates were observed in all samples. In addition, the hcp Cr_2N was observed to be precipitated finely and uniformly by isothermal heat-treatment. This was thought that precipitate of Cr_2N promoted when the steel was heat-treated by isothermal aging, due to supersaturate nitrogen in matrix[5]. Hence, Cr_2N was observed in HT3 and HT4 due to isothermal heat-treatment. Precipitates size were reduced with a decrease tempering temperature and isothermal heat-treatment ;HT1 : 95nm, HT2 : 120nm, HT3 : 85nm, HT4 : 81nm.

3.2 Mechanical properties

Vickers hardness slightly decreased with an increase of tempering temperature; the sample tempered at 810^{o}C was reduced when compared with the sample tempered at 780^{o}C (HT1). Hardness of HT3 and HT4 were much increased than those of tempered-only ones by isothermal heat-treatment. This was thought that the fine and uniform Cr_2N would enhance the precipitation hardening, it was shown that hardness of the steels were improved by isothermal heat-treatment.

Fig. 1. shows the result of the 650^{o}C tensile properties of the steel. The YS (yield strength), UTS (ultimate tensile strength) tend to decrease with the tempering temperature from 780^{o}C (HT1) to 810^{o}C (HT2). YS of HT1 sample was slightly increased by about 8MPa, and UTS was increased by about 5MPa when compared with HT2 sample. However, TE (total elongation) was decreased from 27% to 25% due to untempered martensite in HT2 sample. In the case of isothermal heat-treatment, YS and UTS of HT3 sample were increased by about 15% and 13% respectively when compared with HT1. However, TE of HT3 was decreased by about 6%. Because HT3 was lower tempering temperature than HT1 sample. Although tensile properties of HT4 sample showed similar to HT3, TE maintained 25% when compared with HT2 .

4. Conclusions

The ASTM Gr.92 steels showed the tempered martensitic microstructures, but a sample tempered at 810^{o}C was presumed to retain partially untempered martensitic microstructure. $M_{23}C_6$, V(C,N), and Nb(C,N) precipitates were observed in all samples. In addition, Cr_2N was observed to be precipitated by isothermal heat-treatment. Because of the fine and uniform precipitate, the reduction of PAG size and lath width would enhance the precipitation hardening. It was shown that mechanical properties including hardness and tensile properties of the steel would be improved by isothermal heat-treatment.

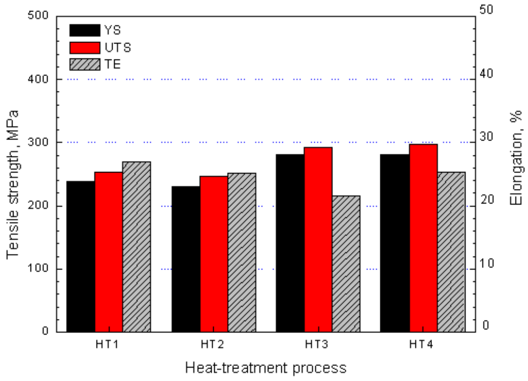

Fig. 1. Tensile properties at 650 ^{o}C

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