

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

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1. Introduction

The SFR (Sodium-Cooled Fast Reactor) is one of the prospective nuclear reactors for the next generation of (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 the 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 to austenitic stainless steel[2]. However, Fuel claddings of SFR were loaded from high temperature (650°C) and high speed neutron (200dpa) atmospheres for 50,000h. And its mechanical stabilities should be maintained. One way of improving mechanical properties is change of the microstructure by heat-treatment[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 M₂X precipitates. These fine precipitates formed in the sub-grain by preventing the movement of dislocations in high-temperature mechanical properties will be contribute effectively[4]. This study investigated the effects of double tempering on microstructural and mechanical properties of ASTM Gr.92 steels.

2. Experimental procedure

The chemical composition of ASTM Gr.92 steel 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 specimen was etched by the dissolution of the metallic matrix in an etchant of 93% of H₂O, 5% of HNO₃, and 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 were

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 of ASTM Gr.92 steel

Process	Heat-treatment process
A	1050°C X 1h(A/C) → RT → 750°C X 1h(A/C) → RT
B	1050°C X 1h(A/C) → RT → 620°C X 1h(A/C) → RT → 750°C X 1h(A/C) → RT
C	1050°C X 1h(A/C) → 620°C X 1h → 750°C X 1h(A/C) → RT

3. Results and Discussion

3.1. Microstructural Properties

From the optical microstructure and TEM observation, the three processes showed a typical tempered martensitic microstructure. The lath width and precipitate size slightly increased with the double tempering. Lath width increased by the recovery of dislocation. Lath width of A-process was 340nm, B-process was 350nm, and C-process was 350nm.

As shown in Fig. 1, PAG (Prior Austenite Grain) size of the double tempered process (B-process: Fig. 1 (d) ~ (f)) when compared to the single tempered process (A-process: Fig. 1 (a) ~ (c)) did not change. However, precipitates in B-process was observed more finely and uniformly that those of A-process by double tempering heat-treatment. The other precipitates of the single tempered process were agglomerated at the vicinity of PAG. It was thought to be the precipitates of many V(C,N) during the heat-treatment by the double tempering. M₂₃C₆, V(C,N) and Nb(C,N) precipitates were observed in all processes.

Conducted the double tempering, the precipitates were presumed that this will be refined compared to the

single tempering due to finely V(C,N). However, when executed the double tempering, $M_{23}C_6$ precipitates were coarsened. For this reason, precipitate size of the double tempered process somewhat increased. (A: 72nm, B: 79nm, C: 76nm)

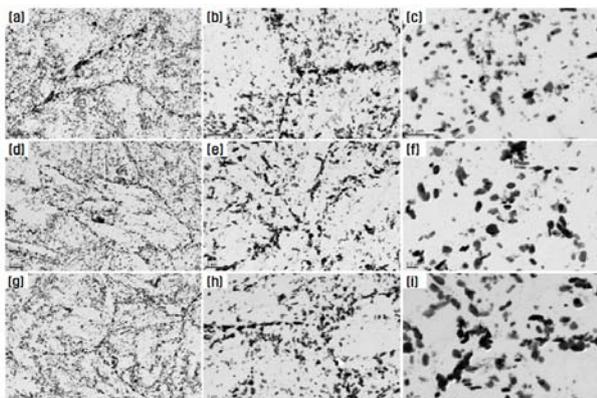


Fig. 1. TEM images of carbon replicas; (a), (b), and (c) were A-process, (d), (e), and (f) were B-process, and (g), (h), and (i) C-process.

3.2 Mechanical properties

Vickers hardness of three processes were measured almost same (A: 276H_v, B: 279H_v, and C: 235H_v), because all processes last tempering temperature were 750°C. Fig. 2 shows the result of the Vickers hardness.

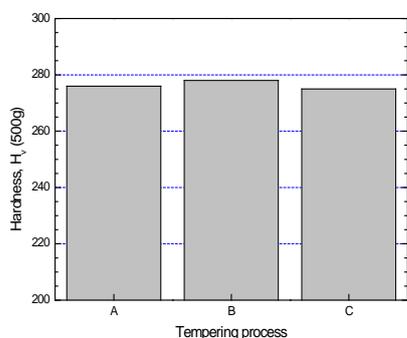


Fig. 2. Hardness of different tempering process.

Fig. 3 shows the result of the 650°C tensile properties of the three processes. The YS (yield strength) and UTS (ultimate tensile strength) tend to increase by about 3% in case of the double tempering process. However, TE (total elongation) increased from 22% to 23%. In the case of the isothermal heat-treatment after 620°C tempering, YS, UTS, and TE of C-process were almost same when compared to B-process. Therefore, if conducted the double tempering, the slight increase in YS and UTS, but TE tended to be maintained.

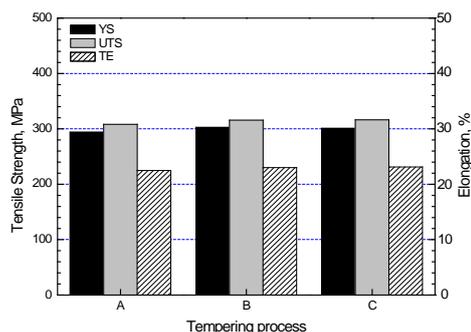


Fig. 3. Tensile properties of the different tempering process at 650°C.

4. Conclusions

Three different processes showed the tempered martensitic microstructures. $M_{23}C_6$, V(C,N), and Nb(C,N) precipitates were observed in all processes. Also, V(C,N) frequently observed to the double tempered process at the vicinity of PAG and lath boundaries. The lath width and precipitate size of double tempered process and 750°C isothermal heat-treatment process were slightly larger than that of 750°C tempered process. Although hardness and tensile properties of three processes were almost same, V(C,N) precipitates influenced on the creep were plenty of observed in PAG and lath boundaries of the double tempered process.

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