Effects of N Concentration on the Tensile and Impact Properties of 9Cr-1W Steels

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1. **Introduction**

Reduced activation ferritic/martensitic (RAFM) steels are regarded as structural materials for future fusion power reactors, owing their excellent mechanical properties and resistance to swelling compared with austenitic stainless steels. There are several RAFM steels currently under extensive research. These include JLF-1, F82H, CLAM, and Eurofer97 in which Cr, W, V, Ta, and C are included as major alloying elements [1]. These steels are strengthened by both precipitation and solution hardening. The strength increase produced by solution hardening relies on the addition of Cr and W, while precipitation hardening is dependent on the types of precipitates such as $M_{23}C_6$ (M=Cr) and MX (M=V, Ta; X=C, N) [2]. High Cr ferritic/martensitic heat resistant steel strengthened by the addition of nitrogen has worked as a structural material for ultra-super critical power generation [3,4]. However, there are few report on the roles of nitrogen in RAFM steel. The present work aims at investigating the effects of nitrogen addition on the mechanical properties of 9Cr-1W based RAFM steels.

2. Methods and Results

2.1 Experimental Procedure

The 9Cr-1W based ingots with three different nitrogen contents (0.01, 0.03 and 0.05 wt.%) were cast by vacuum induction melting, The ingots were hot rolled plates following preheating at 1150°C for 2 hours. The plates thus prepared were subjected to conventional heat treatments, i.e., normalizing at 1050°C for 60 min followed by air cooling and tempering at 760°C for 60 min. The microstructure was characterized by optical microscopy and transmission electron microscopy (TEM). For the analysis of precipitates formed in the tempered sample, the carbon replica was used and the quantitative analysis of chemical composition of precipitate was made by an energy dispersive spectroscopy (EDS). A Vickers micro-hardness was determined under a load of 0.5 kgf and a dwell time of 15sec. The tensile test samples were prepared according to ASTM E8-04 in the longitudinal direction of the tempered plate, and the test was carried out at an initial strain rate of 1.5 mm/min at temperatures between 25°C and 600°C. To determine the ductile brittle transition temperature (DBTT), the Charpy impact test was conducted according to the ASTM E23, for which a full-size notched bar was used.

2.2 Matrix and Precipitates

Fig. 1 shows the optical microstructures of RAFM steel, from which the fully tempered martensite structure was confirmed. Various types of precipitates including $M_{23}C_6$, V-rich MX and TaC were observed in the tempered plates (Fig. 2). From the microstructure analyses, it is found that the size of prior austenite grain (PAG) and the types of precipitate were little affected by the nitrogen contents.

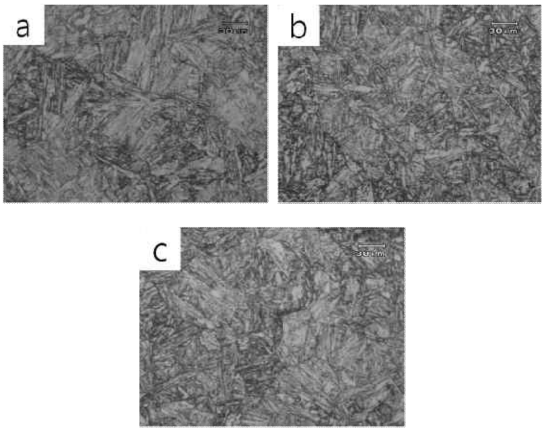


Fig. 1. Optical micrographs of (a) 9Cr-1W-N0.01, (b) 9Cr-1W-N0.03 and (c) 9Cr-1W-N0.05 wt.% steels.

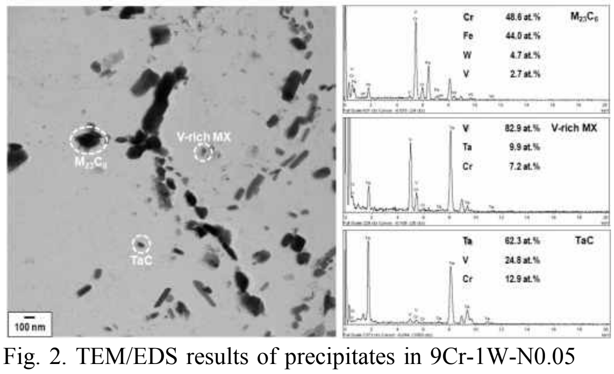
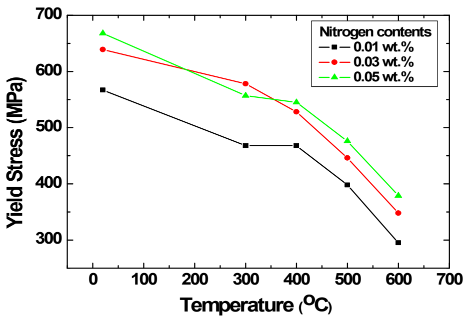


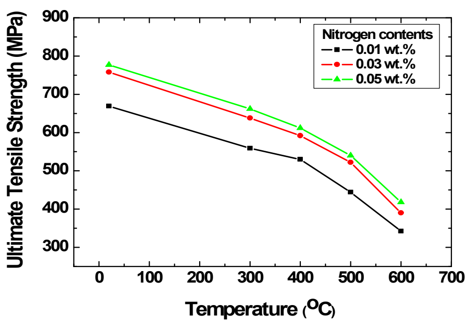
Fig. 2. TEM/EDS results of precipitates in 9Cr-1W-N0.05 wt.% steels.

2.3 Tensile Properties

The effects of nitrogen concentration on the tensile strength of RAFM steel were evaluated. Fig. 3 shows that the tensile strength of the RAFM steel increases with the nitrogen content. As the test temperature increases, the yield and tensile strength decrease. A notable drop in strength was observed at temperatures higher than 400°C. The total elongation was decreased with nitrogen contents below 400°C, but the effects were weakened at higher temperatures. The elongation decreases with an increasing temperature up to 400°C, and then increases with a further increase in the test temperature.



(a)



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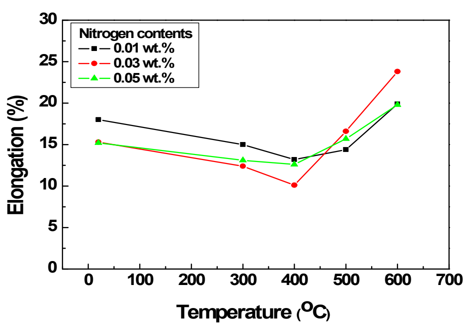

(c)

Fig. 3. Tensile test results of 9Cr-1W steels: (a) yield Stress (b) ultimate tensile strength and (c) elongation.

2.4 Impact Properties

A charpy impact test reveals that an increase in nitrogen content from 0.01wt.% to 0.03wt.% reduces the DBTT of the model alloys significantly (Fig. 4). A further increase in nitrogen content to 0.05wt.% has little effect on the DBTT of the alloys. The variation of the upper shelf energy with nitrogen contents is insignificant.

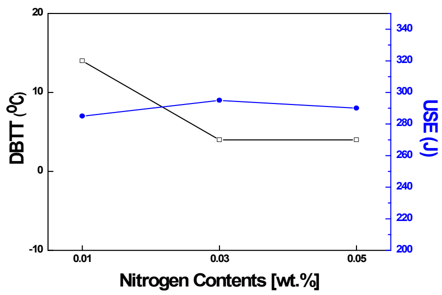

Fig. 4. The upper shelf energy and DBTT of 9Cr-1W steels.

3. Conclusions

The yield strength and ultimate tensile strength of the 9Cr-1W steels are increased with increasing nitrogen contents, which can be attributed to the formation of V-rich MX precipitates. The addition of nitrogen decreases the DBTT of the 9Cr-1W steels, the effect being saturated at nitrogen contents above 0.03 wt.%. It is concluded that the addition of 0.03-0.05 wt.% nitrogen is beneficial to the mechanical properties of 9Cr-1W steels.

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REFERENCES

[1] N. Baluc, D.S. Gelles, S. Jitsukawa, A. Kimura, R.L. Klueh, G.R. Odette, B. van der Schaaf, Jinnan Yu, Status of reduced activation ferritic/martensitic steel development, Nucl. Mater. 367-370 (2007) 33-41.
[2] Ping Hu, Wei Yan, Li-fen Deng, Wei Sha, Yi-yin Shan, Ke Yang, Nitride-strengthened reduced activation ferritic/martensitic steels, Fusion Engineering and Edsign 85 (2010) 1632-1637.
[3] F. Abe, T. Horiuchi, M. Taneike, K. Sawada, Stabilization of martensitic microstructure in advanced 9Cr steel during creep at high temperature, Materials Science and Engineering A 378 (2004) 299-303.
[4] Y. Toda, H. Tohyama, H. Kushima, K. Kimura, Improvement in creep Strength of Precipitation Strengthened 15Cr Ferritic Steel by Controlling Carbon and Nitrogen Contents, JSME Int. J. Ser. A 48 (2005) 35-40.