Effect of an Annealing on the Mechanical Properties of Cold Rolled 9Cr-2W-NbV Steel

Tae Kyu Kim, Chang Hee Han, Jong Hyuk Baek, Sung Ho Kim, Chan Bock Lee
SFR Fuel Cladding Development, KAERI, 1045 Daedeokdaero, Yuseong, Daejeon, 305-353, tkkim2@kaeri.re.kr

1. Introduction

Ferritic/martensitic (F/M) steels are being considered as cladding materials for a sodium cooled fast reactor (SFR) which is one of the next generation nuclear powder reactors due to their high thermal conductivities, low expansion coefficients and excellent irradiation resistances to a void swelling compared to austenitic stainless steel [1,2]. When this steel is applied as the fuel cladding in a SFR, its maximum temperature is expected to approach 650℃, and helium gas produced by transmutation of fissioning fuel will become the source of stress on the cladding [3]. Such a cladding should thus have excellent mechanical properties at higher temperatures.

In the fabrication processes of the F/M steel cladding, the extruded and heat treated steel tubes are usually subject to a cold working. The plastically deformed tubes should be annealed to relieve the stress from the cold working, and to recover their degraded mechanical properties from their working. The annealing conditions thus have become a subject of interest. This study was performed to evaluate the effects of an annealing on the mechanical properties of a cold rolled steel sheet.

2. Methods and Results

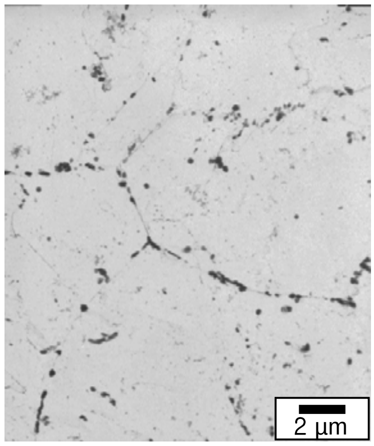
2.1 Experimental procedure

A 9Cr-2W-NbV steel was designed which was prepared by a vacuum induction melting process. The steel ingot was preheated at 1150℃ for 2 h, and then hot rolled. The hot rolled plate was normalized at 1050℃ for 1 h, and tempered at 750℃ for 2 h. This plate with a 4 mm thickness was cold rolled to a 1 mm thickness followed by an annealing heat treatment in the temperature range from 500 to 750℃ for 30 min, respectively.

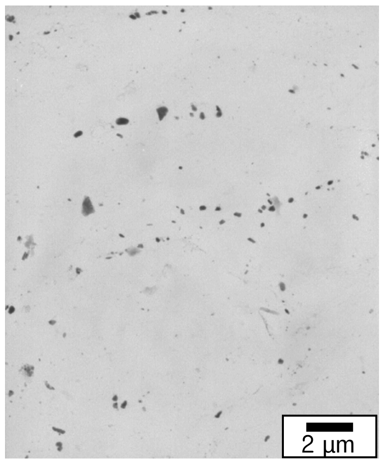
The precipitates obtained from carbon extraction replicas were examined by using a TEM (transmission electron microscope) and EDS (energy dispersive spectroscope) attached to TEM. Microhardness was measured by using a microhardness tester under the load of 0.5 kgf. The tensile tests were carried out at a strain rate of 2×10^{-3}/sec in the temperature range from 20 to 700°C.

2.2 Precipitates

Figure 1 shows the TEM images of extraction replicas of precipitates in a 9Cr-2W-NbV steel. The hot rolled and heat treated specimen contained two types of precipitates; $M_{23}C_6$ (M=Cr, Fe, W, Nb, V) and MX (M=Nb, V, W, Cr, X=C,N). The $M_{23}C_6$ precipitates were found in the prior γ grain boundaries, but occasionally in the grains. Most of the nano-size MX ones were found in the grains. After a cold rolling, there was no change in the kind of precipitates, but the fragmentations of the $M_{23}C_6$ precipitates were observed.



(a)



(b)

Figure 1. TEM images of extraction replica of precipitates in a 9Cr-2W-NbV steel; (a) hot rolled and heat treated, and (b) cold rolled.

2.3 Mechanical properties

Fig. 2 shows the results of the tensile tests of the hot rolled and heat treated steel in the temperature range from 20 to 700℃. The yield and tensile strengths were continuously decreased with an increasing tensile test temperature, but abruptly dropped after a temperature of 600°C. On the other hand, the elongation was decreased with an increasing tensile test temperature up to 400°C, and it was increased with an increasing temperature after a temperature of 500°C.

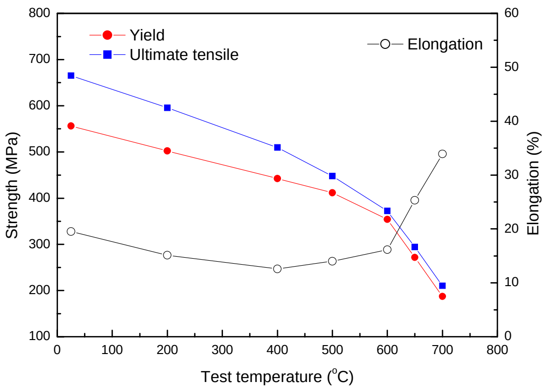


Figure 2. Tensile test results of the hot rolled and heat treated 9Cr-2W-NbV steel plate in the temperature range from 20 to 700℃.

Fig. 3 shows the effect of an annealing on the microhardness of the cold rolled 9Cr-2W-NbV steel. The effect of a stress relief of the cold rolled steel was observed when the annealing was performed in the temperature range from 600 to 750°C, showing a reduction of the hardness at this temperature region. However, there was little effect of an annealing at 500°C on the stress relief. In addition, the annealing at 700°C of the cold rolled steel induced a similar value of the hardness compared with that of the hot rolled and heat treated one. The results of the tensile tests after an annealing of cold rolled steel also exhibited a similar tendency. It is thus concluded that an annealing at 700°C for 30 min is necessary to recover the degraded mechanical properties from the cold working.

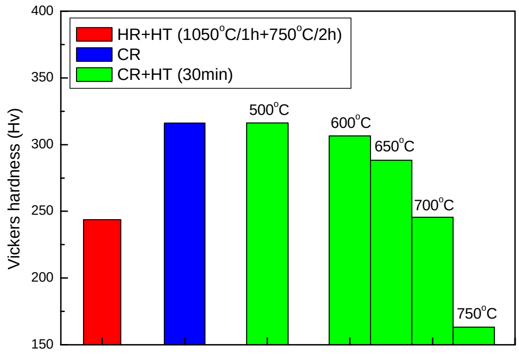


Figure 3. Effect of an annealing on the microhardness of the cold rolled 9Cr-2W-NbV steel sheet.

3. Conclusion

In order to find the optimum annealing condition which can recover the degraded mechanical properties from a cold working, the effects of an annealing on the mechanical properties of a cold rolled 9Cr-2W-NbV steel sheet were evaluated. A cold rolling of the hot rolled and heat treated steel induced a fragmentation of the $M_{23}C_6$ (M=Cr, Fe, W, Nb, V) precipitates. The microhardness was decreased with an increasing annealing temperature mainly due to the stress relief. The annealing at 700°C for 30 min appeared to provide a recovery of the degraded microhardness and tensile properties from the cold rolling.

Acknowledgements

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