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Development of a Fabrication Process for a High Strength FM Steel

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1. Introduction

Of the candidate cladding materials being considered in a sodium cooled fast reactor (SFR), ferritic/martensitic (FM) steels are relied on excellent irradiation resistance to a void swelling compared with austenitic steel but these steels are known to show an abrupt loss of creep resistance and tensile strength at temperatures above 600^{o}C [1]. Hence, the mechanical properties of FM steels should be improved for an application of these materials to cladding tubes of a SFR because the maximum temperature of cladding tubes is expected to approach 650^{o}C.

One solution to improve the mechanical properties of these FM steels is to develop the fabrication process parameters during fabricating the cladding tubes [2,3]. This study focuses on the fabrication process for the high strength FM steels by a control of the fabrication process parameters such as the cold working ratio, and the intermediate and final heat treatments.

2. Methods and Results

2.1 Experimental procedure

A 9Cr-2W steel was prepared by a vacuum induction melting process. The steel ingot was hot rolled after a preheating at 1150^{o}C for 2 h. The hot rolled plate was normalized at 1050^{o}C for 1 h, and tempered at 550^{o}C for 2 h. This plate with a 4 mm thickness was cold rolled to a 1 mm thickness without/with an intermediate heat treatment at 750^{o}C followed by the final heat treatment at 750^{o}C. Fig. 1 shows the schematic flow of the experimental procedure for fabricating FM steel sheet with a 1 mm thickness.

Thin foils from the steel were prepared by grindings of 80 μm thickness and they were electrolytically polished by using a twin-jet polisher at -25^{o}C. The microstructure was examined by using a TEM (transmission electron microscope). The precipitates obtained from carbon extraction replicas were examined by using a TEM and EDS (energy dispersive spectroscope) attached to TEM. A Vickers microhardness was measured by using a microhardness tester under a load of 0.5 kgf. The tensile tests were carried out at a strain rate of 2×10^{-3}/sec at room temperature.

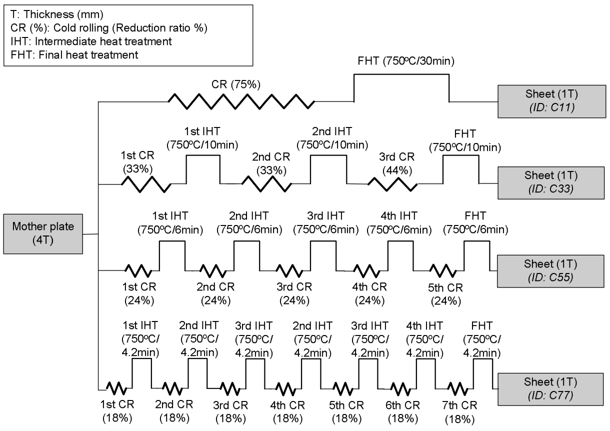
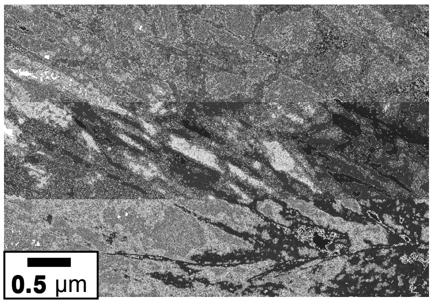


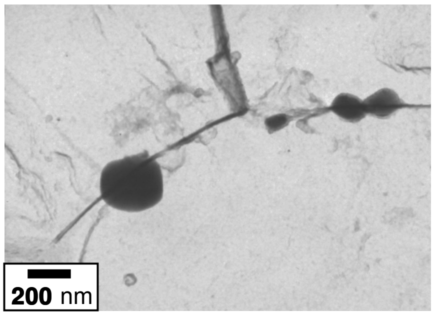
Fig. 1. Schematic flow of the experimental procedure for fabricating FM steel sheet with a 1 mm thickness.

2.2 Microstructure

Figure 1 shows the TEM images of the FM steel after a tempering at 550^{o}C for 2 h. A tempered martensitic structure composed of prior austenitic grains, sub-grains and laths was observed. The lath width was determined to be about 200 nm. Nano-sized precipitates were observed in the grain and lath boundaries (Fig. 1b), and their representative composition was determined to be (in at.%) 85Nb, 9V, 4Cr and 2W, indicating that they were a Nb-rich MX-type carbonitride. No other type of precipitates was observed. It is considered that the $M_{23}C_6$ carbides dissolves into the matrix during a normalizing at 1050^{o}C, but the MX precipitates still remain after a normalizing. The driving force for a precipitation reaction is not sufficient with a tempering at 550^{o}C, thus the remaining precipitates are MX carbonitrides only. However, the $M_{23}C_6$ carbides are expected to form during the intermediate and final heat treatments at 750^{o}C.



(a)



(b)

Figure 1. TEM images of the FM steel tempered at 550°C for 2 h; (a) microstructure, and (b) extraction replica for the precipitates.

2.3 Mechanical properties

Fig. 2 shows the Vickers microhardness of the cold rolled and final heat treated FM steels with a 1 mm thickness. The hardness was continuously increased with an increasing intermediate heat treatment time. It was identified that the softening after a final heat treatment was mainly attributed to the recrystallization.

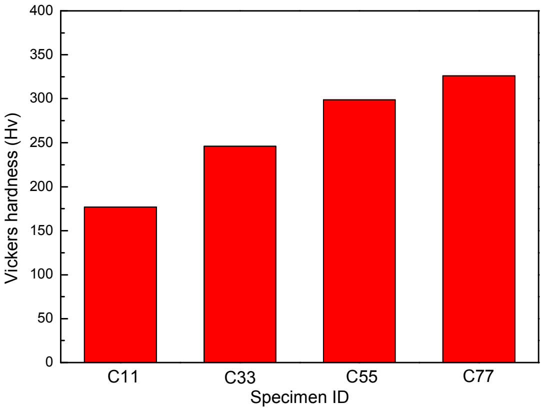


Figure 2. Results of Vickers microhardness tests of the cold rolled and final heat treated FM steels with a 1 mm thickness.

Fig. 3 shows the tensile test results of the cold rolled and final heat treated FM steels at room temperature. It was observed that the yield and tensile strengths were continuously increased with an increasing intermediate heat treatment time. The significant softening of the C11 specimen was mainly attributed to the fully recrystallized matrix caused by an excess strain energy accumulated during a cold working. However, the intermediate heat treatment during a cold rolling prevented a recrystallization, thus an improved tensile strength.

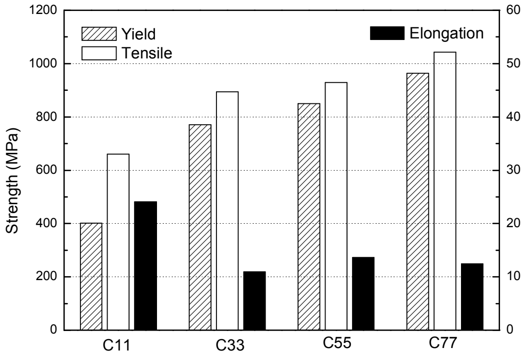


Figure 3. Tensile test results of the cold rolled and final heat treated FM steels at room temperature.

3. Conclusion

In order to develop a fabrication process for a high strength FM steel, a plate tempered at 550°C was cold rolled without and with intermediate heat treatments. The tensile test results indicated that high strength FM steels could be obtained by an intermediate heat treatment which restrains the recrystallization.

Acknowledgements

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REFERENCES

[1] T.R. Allen, J. Gan, J.I. Cole, M.K. Miller, J.T. Busby, S. Shutthanandan, S. Thevnthasan, J. Nucl. Mater. Vol. **375**, p. 26, 2008.

[2] T.K. Kim, J.H. Baek, C.H. Han, S.H. Kim, C.B. Lee, J. Nucl. Mater. (2009), doi: 10.1016/j.jnucmat.2009.01.302.

[3] R.L. Klueh, A.T. Lelson, J. Nucl. Mater. Vol. **371**, p. 37, 2007.