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Effect of Cooling Rate on Tensile Properties and Cracking of Ni_3Fe Alloy

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1. Introduction

All austenitic Fe-Cr-Ni alloys such as Alloy 600 tubes, 304 stainless steels and dissimilar welds suffer from intergranular (IG) cracking, which becomes one of the hot issues in the nuclear industry aiming at license renewal. Despite many studies conducted so far, IG cracking in austenitic Fe-Cr-Ni alloys including steam generator tubes, baffle former bolts, and the nozzles in the primary coolant systems has been unresolved. Enhanced corrosion of grain boundaries by Cr depletion was recognized as one of the plausible hypotheses suggested by corrosion workers. However the recently accumulated experiments show that IG cracking has occurred during slow strain rate tensile tests at $3x10^{-7}$/s in argon either at 290°C on irradiated 304 stainless steels [1] up to $1x10^{21}$n/cm^2 (E>1MeV) even without corrosion or at 360°C on unirradiated Ni-xCr-9Fe alloys [2]. This fact clearly shows that IG cracking has nothing to do with corrosion.

Given that austenitic alloys are a kind of solid solution alloys with alloying elements dissolved in the matrix as solutes, ordering of alloying elements of Fe, Cr and Ni would occur during annealing and mechanical deformation. According to a ternary phase diagram of Fe, Cr and Ni, three kinds of ordered phase can be formed: Fe_3Ni, Ni_3Fe and Ni_2Cr. The formation of ordered phases by annealing and plastic deformation at high temperatures will affect mechanical properties of austenitic Fe-Cr-Ni alloys because the ordered phases are hard and brittle. To this end, the Ni_3Fe alloy corresponding to one of the ordered phases to be formed in austenitic Fe-Cr-Ni alloys was made by vacuum induction melting and hot rolling at 900°C, and then given different rates of cooling after solution annealing at 1100°C for 1h followed by tensile tests at room temperature.

2. Experimental Procedures

Ingots of Ni_3Fe alloy were made by vacuum induction melting and hot rolled at 900°C. The Ni_3Fe plate was solution annealed at 1050°C for 1h and cooled at different rates using either water quenching, or furnace cooling. For ordering treatment, the air-cooled Ni_3Fe plate was annealed at 400°C for 6800h, which increases the number of the ordered phases. Tensile tests were conducted at room temperature using four different kinds of Ni_3Fe alloy given different heat treatments. Fracture surfaces were observed with scanning electron microscope.

3. Results and Discussion

With cooling rates, tensile behavior of Ni_3Fe was found to be quite different, as shown in Fig. 1. The water-quenched Ni_3Fe showed the highest ductility and the lowest yield stress. In contrast, the furnace-cooled one had a higher yield stress and just a quite low percent of tensile ductility. The ordering treated one showed a yield drop and larger strain hardening and the lowest ductility. Given that the order-disorder transition temperature of Ni_3Fe is around 510°C, solution annealing at 1050°C for 1h causes Ni_3Fe to be in full disorder. Water quenching after solution annealing maintains the disordered Ni_3Fe after cooling to room temperature. However, as with furnace cooling, the disordered Ni_3Fe transforms to some extent to the ordered one during cooling. Given the increased extent of the ordered phase for the furnace cooled Ni_3Fe, the higher yield stress and lower ductility must be due to short range ordering. The water-quenched was further annealed at 400°C for 6800h to increase the extent of ordered Ni_3Fe. The annealed one with the highest extent of the ordered phase showed a yield drop, the highest yield drop and the lowest ductility. In other words, the higher the ordered Ni3Fe becomes, the higher the yield stress and the lower the tensile ductility. Therefore, it is evident that short range order results in a higher yield stress, lower ductility and furthermore a yield drop.

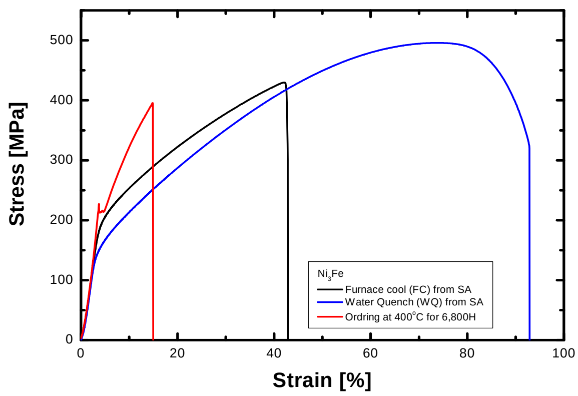

Fig. 1. Room temperature tensile behaviors of water quenched, furnace cooled and the ordering treated Ni_3Fe the last of which was obtained by annealing at 400°C for 6800h.

Fracture surfaces of the water-quenched Ni3Fe showed a typical dimple structure, exhibiting ductile and transgranular fracture, as shown in Fig. 2. In contrast, both the furnace-cooled and the water-quenched and then annealed Ni3Fe displayed brittle fracture, as shown in Fig. 2, demonstrating that the intergranular cracking occurs during tensile tests in air and at room temperature. This fact shows that short range ordering causes intergranular cracking, leading the Ni3Fe to a lower ductility and higher yield stress.

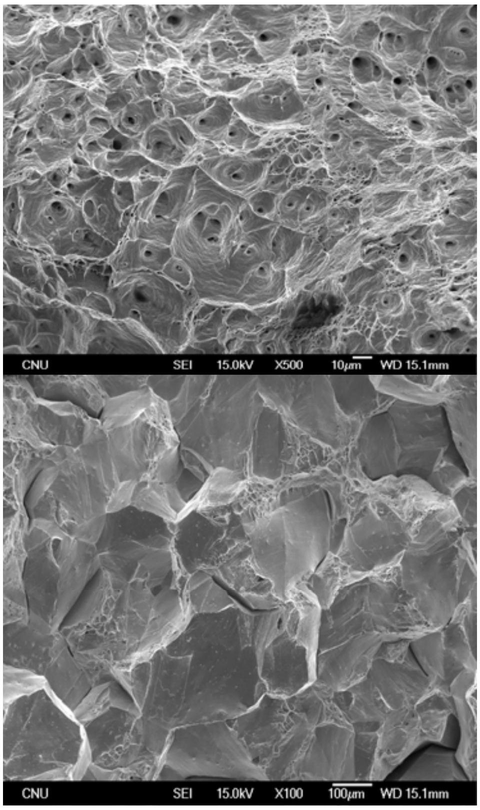

Fig. 2. Fracture surfaces of the water-quenched and the annealed Ni_3Fe at 400°C for 6800h after solution annealing at 1050°C for 1h.

4. Conclusions

The tensile behaviors of Ni3Fe changed with the cooling rate after solution annealing at 1050oC: the water-quenched one showed dimple fracture surfaces, leading to the largest ductility and the lowest yield stress. However, the furnace-cooled or the water-quenched one exhibited brittle and intergranular cracking, leading to the lowest ductility and the higher yield stress. Furthermore, for the water-quenched and annealed one, a yield drop occurred during tensile testing at room temperature. Given that annealing after water quenching or furnace cooling facilitates the disordered Ni3Fe to transform to the ordered one, it is demonstrated that short range ordering is the cause of intergranular cracking in Ni_3Fe alloy even in air. This study suggests that intergranualr cracking in austenitic Fe-Cr-Ni alloys is related to short range ordering.

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REFERENCES

[1] T. Onchi, K. Dohi, N, Soneda, M. Navas, M.L. Castafio, J. Nucl. Mater. Vol. 340, p. 219, 2005.
[2] T.M. Angeliu, D.J. Paraventi, G.S. Was, Corrosion Vol. 51, p. 837, 1995.