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EFFECTS OF HEAT TREATMENTS ON MICROSTRUCTURES AND MECHANICAL PROPERTIES OF DUAL PHASE ODS STEELS FOR HIGH TEMPERATURE STRENGTH

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In the present study, the effects of various heat treatments on the microstructure and mechanical properties of dual phase ODS steels were investigated to enhance the high strength at elevated temperature. Dual phase ODS steels have been designed by the control of ferrite and austenite formers, i.e., Cr, W and Ni, C in Fe-based alloys. The ODS steels were fabricated by mechanical alloying and a hot isostatic pressing process. Heat treatments, including hot rolling-tempering and normalizing-tempering with air- and furnace-cooling, were carefully carried out. It was revealed that the grain size and oxide distributions of the ODS steels can be changed by heat treatment, which significantly affected the strengths at elevated temperature. Therefore, the high temperature strength of dual phase ODS steel can be enhanced by a proper heat treatment process with a good combination of ferrite grains, nano-oxide particles, and grain boundary sliding.

KEYWORDS : Oxide Dispersion Strengthened Steel, Dual Phase, Microstructure, Tensile Properties, Grain Morphology, Oxide Particle, Heat Treatment

1. INTRODUCTION

Oxide dispersion strengthened (ODS) steel is the most promising candidate structural material for next-generation nuclear systems such as Gen. IV fission and DEMO fusion reactors, because of its excellent elevated temperature strength [1], corrosion [2] and radiation resistance [3]. Since a higher operating temperature normally leads to higher efficiency of these systems, high strength at the elevated temperature is the most important issue. ODS steel, having two different phases for harmony between strength and ductility may be a solution. This alloy can usually be fabricated by control of the chemical composition and heat treatment condition to have two phase microstuctures consisting of ferrite and martensite [4].

In the present study, the effects of heat treatments on the tensile properties of dual phase ODS steels were investigated to enhance the high strength at an elevated temperature. Dual phase ODS steels have been designated by control of ferrite and austenite formers, Cr, W, and Ni, C, in Fe-based alloys. The ODS steels were fabricated by mechanical alloying and a hot isostatic pressing process. Heat treatments including hot rolling-tempering and normalizing-tempering with air- and furnace-cooling were carefully carried out.

2. EXPERIMENTAL PROCEDURE

The dual phase ODS steels used in this study are Fe-10Cr-2W and Fe-12Cr-1Mo in wt% with alloying elements including W, Ni, Ti, Ta, V, and C. These ODS steels have been designed by the control of ferrite and austenite formers, which are Cr, W and Ni, C in Fe-based alloys at the consolidation temperature of around 1150 ºC. The ODS steels were fabricated by mechanical alloying and a hot isostatic pressing (HIP) process. Pre-mixed raw metallic powders and Y_2O_3 powder were mechanically alloyed by a horizontal ball-mill apparatus, CM-08, under a high purity Ar gas (purity of 99.999%) atmosphere. The mechanical alloying was performed at an impeller rotation speed of 300rpm for 40h with a ball-to-powder weight ratio (BPWR) of 10:1. MA powders were then charged in a stainless steel capsule. The sealed capsules were degassed at 500 ºC below 5×10^{-3} torr for 1h. The HIP was carried out at 1150 ºC for 4h at a heating rate of 5 ºC/min and followed by furnace cooling. HIPed ODS steels were annealed at 1150 ºC, and then HR (hot rolling) was done in a fixed rolling direction for a plate shape, which resulted in a final reduction rate of 65%. The temperature during the HR was kept between 980 and 1100 ºC, which corresponds to a gamma region of 9-12Cr steels with 0.1C in mass% [5].

To investigate the effects of heat treatment, various heat treatment processes were employed including tempering at 750 ºC for 1h, air cooling at 150ºC/min (designated as ‘HR-T’), as well as a normalizing at 1050 ºC for 1h and air cooling, tempering at 750 ºC for 1h (designated as ‘NT’). Additionally, furnace cooling at 5ºC/min was also examined at the normalizing temperature for 1h (designated as ‘FC’). Schematics of the consolidation and heat treatment process are given in Fig. 1.

For microstructural observation, the ODS steels were mechanically wet ground and chemically etched in 5% aqua regia solution for 10min to observe the microstructure by optical microscope. The grain morphology was observed by FE-SEM after electro-polishing in a 5% $HClO_4$ + 95% methanol solution in vol. % at 18V with 0.5mA at -50 °C to remove the work hardened surface induced by mechanical buff-polishing. To evaluate the mechanical properties, tensile tests were carried out. A sheet- type miniaturized tensile specimen whose gauge length was 15.5mm, width was 3mm, and thickness was 1.4mm was used. Tensile tests were carried out at room temperature and 700 ºC in air at a strain rate of $3.3x10^{-4}s^{-1}$.

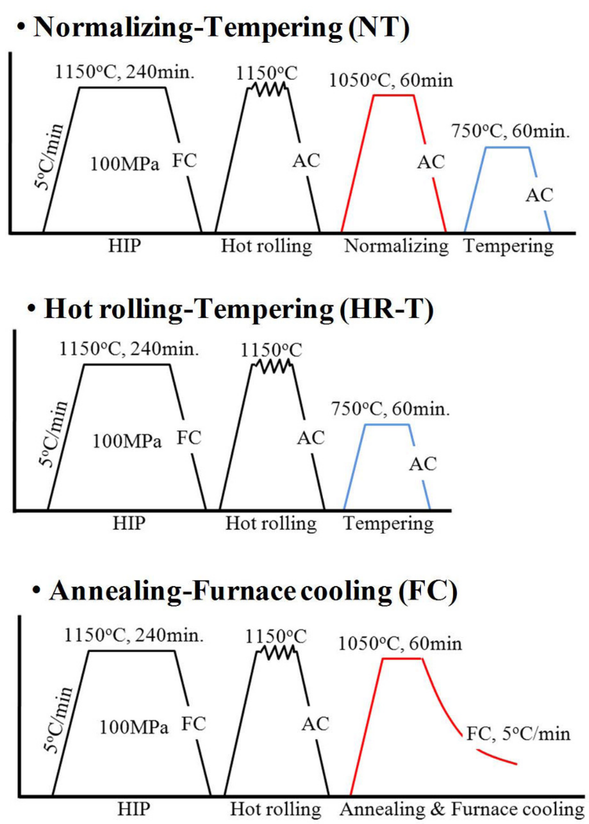

Fig. 1. Schematics of HIP and Heat Treatment Process of Dual Phase ODS Steels

3. RESULT AND DISCUSSION

3.1 Microstructure Differences Induced by Heat Treatments

Various heat treatment conditions including temperature and cooling rate usually affect the microstructure and mechanical properties of ODS steels. In this study, 10Cr and 12Cr dual phase ODS steels mainly underwent three kinds of heat treatment. Optical micrographs of 10Cr ODS steels after various heat treatments are shown in Fig. 2, where the horizontal direction corresponds to the hot rolling direction. The NT specimen consists of fine equiaxed grains and a small portion of elongated grains toward the hot rolling direction, as shown in Fig. 2(a). It is considered that fine equiaxed grains are martensite and the elongated grains parallel to the rolling direction are delta-ferrite, which reside untransformed without transforming into gamma when the temperature is increased from room temperature

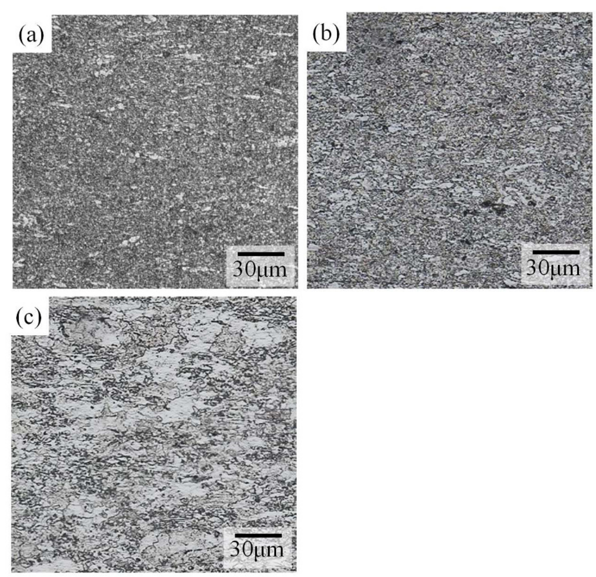

Fig. 2. Optical Micrographs of 10Cr ODS Steels in Various Heat Treatments; (a) NT, (b) HR-T, and (c) FC.

Table 1. Chemical Compositions of the ODS Steels

	C	Cr	W	Mo	V	Ta	Ti	Ni	Y_2O_3	*Ex.O
10Cr ODS	0.17	9.88	1.92	-	0.18	0.18	0.28	-	0.32	0.20
12Cr ODS	0.21	11.70	0.61	0.90	0.28	-	0.29	0.46	0.32	0.21

*Ex. O: Total oxygen concentration - oxygen concentration in Y_2O_3