The Effect of Cooling Rate on the Microstructure and Hardness of 9Cr-1Mo ODS Steel

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1. Introduction

Oxide dispersion strengthened(ODS) steel has superior high-temperature strength and creep properties because fine oxide particles having an excellent stability at high temperatures are uniformly distributed in the matrix. ODS steel has being developed for structure materials of sodium fast cooled reactor(SFR) because of its excellent irradiation resistance and mechanical properties[1]. In addition, it is expected to be applied to the gas turbine blade materials for thermal power plant and the fuel injector materials for automobile[2]. 9Cr-1Mo ODS steel has better high temperature strength and irradiation resistance than common 9Cr-1Mo steel because Y_2O_3 nano-sized particles which interrupt dislocation movement and grain boundary slip are uniformly dispersed in the martensite matrix[3]. The mechanical properties of the ODS steels are mainly determined by their microstructures, and the microstructure is considerably decided by the heat-treatment conditions.

This study focused on the effect of heat treatment cooling rate microstructure and hardness of 9Cr-1Mo martensitic ODS steel so as to optimize the heat-treatment condition.

2. Experimental Setup

2.1 Experimental procedure

The chemical composition of 9Cr-1Mo ODS steel used in this study is given in Table I.

The ODS steel sample was fabricated by mechanical alloying(MA), hot isostatic pressing(HIP) and hot rolling(HR). Fe, Cr, Mo and yttria powders were continuously collided in a high energy horizontal ball-mill apparatus, Simoloyer CM-20, under ultra-high purity argon atmosphere. The ball to powder weight ratio was 10:1 in this MA process. The HIP was performed at 1150℃ for 4 hours. After the HIP process, the HR process accomplished with a cross-section reduction ratio of 23%(Thickness: 15T) at 1150℃ for 2 hours. The Normalizing was performed at 1150℃ for an hour and furnace cooling at 0.1℃/s (designated as 'F.C.'), air cooling at 1℃/s (designated as 'A.C.'), oil quenching at 360℃/s (designated as 'O.Q.') and water quenching at 1200℃/s (designated as 'W.Q.') respectively. After the normalizing, microstructures of 9Cr-1Mo ODS steel was observed using the transmission electron microscope (JEOL JEM-2100). The TEM samples of the ODS steel was prepared by mechanical grinding and electro-polishing. Mechanical property of ODS steel was investigated by hardness measurement.

Table I: The Chemical Composition of ODS steel(wt.%)

Fe	C	Mn	Si	Cr	Mo
Bal.	0.1	0.4	0.3	9	1
V	Nb	Ni	Al	Y_2O_3	
0.2	0.08	0.2	0.01	0.2	

3. Results and Discussion

3.1 Microstructure

Fig. 1 shows the TEM images of 9Cr-1Mo ODS steels after various heat treatment. The F.C. specimen consists of ferrite and it is expected that austenite was transformed into ferrite during the cooling stage(Fig. 1(a)). However, A.C. specimens are considered to be feritic-martensitic dual phase as shown if Fig.1(b). On the other hand, fully martensite matix in the O.Q. and W.Q. specimens as shown in Fig.1(c,d). Because of a very high cooling rate in the oil and water, a austenite was transformed into martensite during the cooling stage.

Typical martensitic structures consisting of prior austenitic grain, packet grain and lath were observed in all the samples. The value of lath width after heat treated is shown in Fig. 2. The lath widths were measured to be about 0.378 at A.C., 0.375 at O.Q .and 0.379 ㎛ at W.Q., respectively. It is considered that the cooling rate did not affects the lath width.

To investigate the effects of heat treatment on carbide precipitation distribution, A SEM micrographs were carried out(Fig.3). As the cooling rate increases, the number of carbides does not change but the number of carbides were decreased.

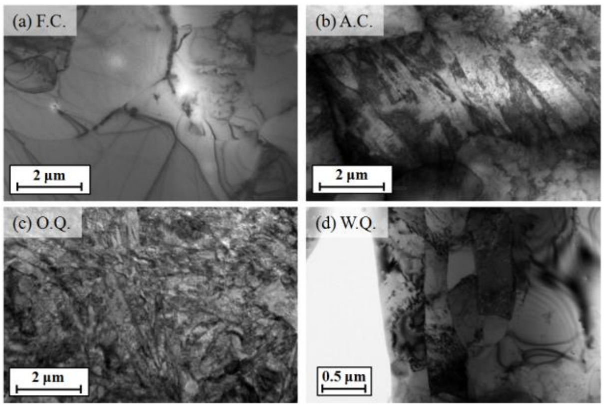

Fig. 1. TEM micrographs of 9Cr-1Mo ODS steel with different cooling rate of (a) F.C., (b) A.C., (c) O.Q. and (d) W.Q.

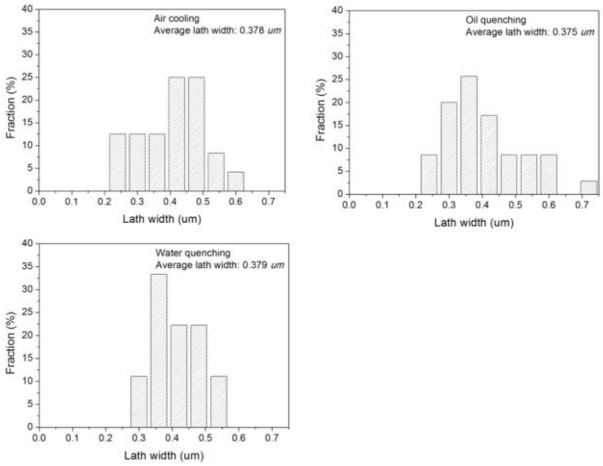

Fig. 2. Lath width of 9Cr-1Mo ODS steel with different cooling rate.

In Fig.4, TEM micrographs of dual phase ODS steel after air cooling process are presented. A number of dislocation were found at the ferrite and the martensite boundaries. It is considered that the cause of the dislocation near the grain boundary is the volume change because of phase transformation of austenite into martensite.

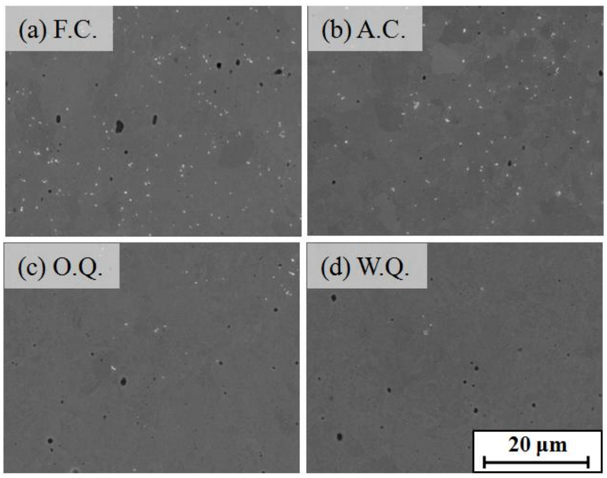

Fig. 3. SEM micrographs of 9Cr-1Mo ODS steel with different cooling rate of (a) F.C., (b) A.C., (c) O.Q. and (d) W.Q.

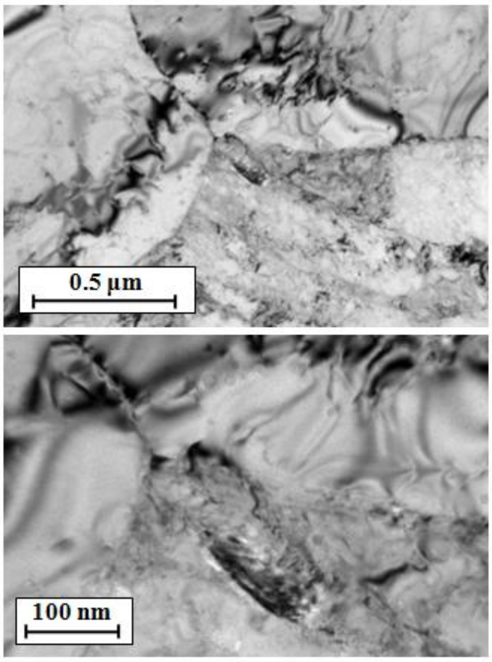

Fig. 4. TEM micrographs of 9Cr-1Mo ODS steel with air cooling

3.2 Hardness

Vickers micro-hardness of 9Cr-1Mo ODS steel is shown in Fig.5. The hardness of ODS steel was continuously increased with the increase of cooling rate. The hardness of F.C. specimen was measured to be about 187 Hv and it increased to 230, 320 and 350 Hv for the specimens A.C., O.Q. and W.Q., respectively. It may be explained by decrease of carbide. As the cooling rate increases, the growth of carbides is suppressed, and the hardness increases as the interstitial atoms are present in the matrix. Therefore, the decrease of number of carbide is closely related with hardness.

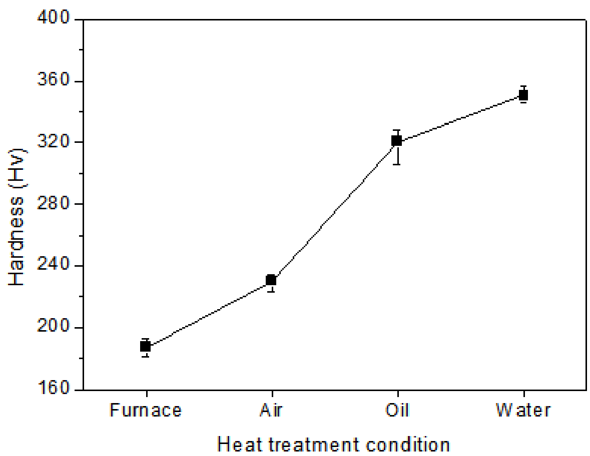

Fig. 5. Change of hardness with different heat treatment cooling rates

4. Conclusions

In this study, the effect of heat treatment cooling rate on mechanical property and microstructures of 9Cr-1Mo martensitic ODS steel was investigated. It was shown that the microhardness was steadily increased with increasing of the cooling rate. According to TEM observation, mechanical property of 9Cr-1Mo ODS steel was significantly affected by carbides. However, lath width did not affect. These observations, could be useful to understand the relationship between normalizing temperature and microstructure.

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