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Effects of Mo and Al addition on the Mechanical Properties of 15Cr ODS steel

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1. Introduction

Oxide dispersion strengthened (ODS) steel is the most promising candidate for a core structural material for next-generation nuclear systems such as Gen. IV fission and DEMO fusion reactors. This is due to its excellent elevated temperature strength, and irradiation resistance. Since a higher operating temperature leads to a higher efficiency of these systems, the mechanical property at high temperatures is one of the most important issues. Oxide particle controls the strength of the ODS steel and the addition of Mo, W, and Al, which changes the microstructures and remarkably influences the strength of ODS steel [1]. In this study, Fe-based ODS alloys with Mo, W, and Al additions were fabricated by HIP and hot rolling processes, and their microstructures and mechanical properties were investigated.

2. Methods and Results

2.1 Experimental procedure

Fe-ODS alloy samples used in this study are Fe-15Cr-ODS alloy in wt % with alloying elements including Mo, W, and Al.

Raw powders were pre-mixed and mechanically alloyed in a horizontal milling apparatus, CM-08, at a rotation speed of 300 rpm for 40 hrs in an Ar atmosphere. MA powders were then charged in an STS 304 capsule and fabricated by a hot isostatic pressing (HIP) method. Consolidated Fe-15Cr-ODS alloy was hot-rolled at 1150°C and finally heat treated at 1150 °C for 1 h, and then air-cooled.

For a microstructural observation, Fe-15Cr-ODS alloy was mechanically wet grounded and finally electro-polished in a 5% $HClO_4$ + 95% methanol solution in vol. % at 25V with 0.5mA at -50 °C to remove the work hardened surface induced by mechanical buff-polishing. The grain morphology was observed by a field-emission scanning electron microscope (FE-SEM). FE-SEM was used for an observation of oxide particle distributions. To evaluate the mechanical property, vickers hardness measurements and tensile tests were carried out. This specimen was measured with a load of 500 gf applied for a 15 second retention time of micro-vickers hardness. The tensile specimens with a gauge length of 15.5 mm a width of 3 mm and a thickness of 1.4 mm were cut out from the rolled plates in the rolling direction. A tensile test was carried out at room temperature with a strain rate of $3.3x10^{-4}s^{-1}$.

2.2 Microstructural and mechanical property

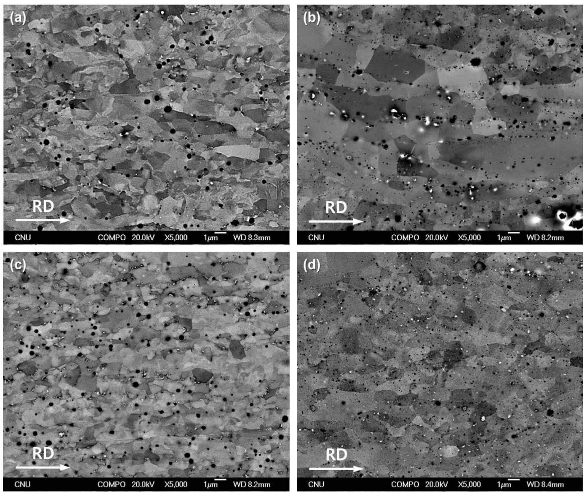

Fig.1. SEM micrographs on grain morphology of Fe-15Cr ODS alloy; (a) ODS-1, (b) ODS-2, (c) ODS-3 and (d) ODS-4

Fe-based ODS alloy plates fabricated by hot isostatic pressing, hot rolling, and a heat treatment process were employed in this study.

An SEM microscope image of W, Mo, and Al added Fe-15Cr-ODS alloy are shown in Fig. 1. Comparably coarsened and equiaxed grains are uniformly distributed in as-hipped Fe-15Cr-ODS alloy. As a result of a microstructure observation, grain refinement occurred in the case of an addition of W and Mo. However, the grain size of Fe-15Cr-ODS alloy consisting of Al became coarsener. Their average grains measured in a plane parallel to the hot rolling direction axes are 3.57 *um* and 2.43 *um* for 2.0 Al and 3.5 Al-added Fe-15Cr-ODS alloy, respectively. It is considered that the oxide particles tend to become aligned along the hot rolling direction, making a favored growth direction. ODS-1(a) exhibits finely elongated grains in the parallel to hot rolling direction.

The FE-TEM analysis results of fine oxide particles in the hipped Fe-15Cr-ODS alloy are shown in Fig. 2. To investigate this reduction of strength by Al addition, TEM observations were performed, and it was revealed that the dispersion morphology of the oxide particles were different between the Fe-15Cr-ODS alloy with and without Al addition.

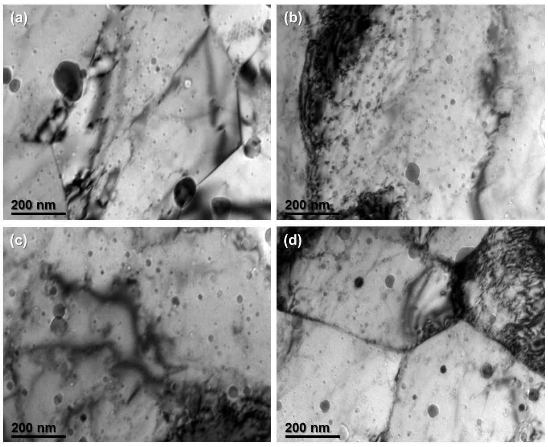

Fig.2. Bright field TEM images of Fe-15Cr ODS alloy in heat treatments; (a) ODS-1, (b) ODS-2, (c) ODS-3 and (d) ODS-4.

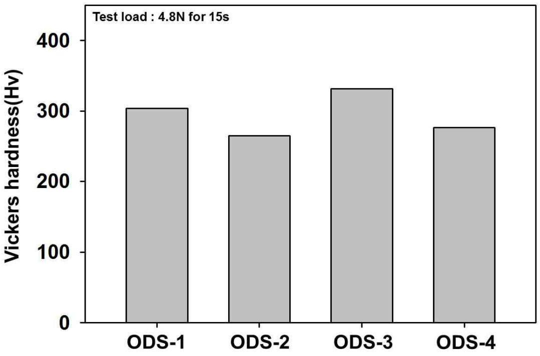

Fig.3. Vickers hardness of Fe-15Cr ODS alloy.

The hardness of the Fe-15Cr ODS alloy is shown in Fig. 3. The results show that the hardness of the ODS-3 is higher than that of the ODS-1. Fe-15Cr ODS alloy with Mo exhibited 265Hv despite the Al addition. Al is well known as a very effective element to improve the formability, while the strength inevitably decreased.

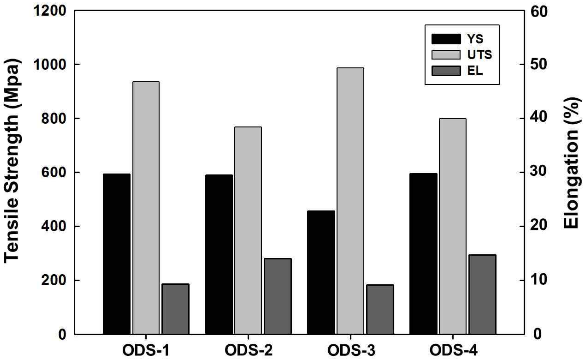

Fig.4. Tensile test results of the Fe-15Cr ODS alloy deformed at room temperature.

The yield strength (YS), ultimate tensile strength (UTS), and the elongation (EL) of the Fe-15Cr ODS alloy were determined at room temperature. High temperature strength and elongation were not significantly increased when compared to ODS-3 Fe-15Cr ODS alloy because most oxide dispersoids were too large to inhibit dislocation motion effectively.

3. Conclusions

Some Fe-based ODS alloys were fabricated by a HIP process, and their microstructures and mechanical properties were investigated. Mo, W, and Al are considered to be very effective alloying elements for high strength and formability in Fe-based ODS alloys. As a result of a microstructure observation, grain refinement occurred in the case of the addition of W and Mo. However, the grain size and oxide particles of Fe-15Cr-ODS alloy Al added became coarse. Therefore, the hardness and tensile strength were decreased. On the other hand, the elongation was increased owing to the coarser grain.

These preliminary results will be useful for developing advanced Fe-15Cr ODS alloy. The structural components for nuclear systems need to have formability as well as strength.

Acknowledgements

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