§22. Production and Development of Tungsten Materials for High Heat Flux Components Corresponding to Neutron Irradiation Environment of Fusion Reactor

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1. Objective

Tungsten (W) is considered to be a candidate material for the plasma-facing component (PFC) in fusion reactors, because of its high melting temperature, high resistance to sputtering and low hydrogen retention. On the other hand, recrystallized W is well known as brittle materials in low temperature region (<300-500 °C). In order to apply W materials as structural materials, degradation of mechanical properties must be suppressed. To improve the low temperature mechanical properties of W, wrought, grain refining or alloying have been applied. The resistance to recrystallization embrittlement of W can be also increased by alloying or introducing dispersed obstacles to inhibit grain growth at high temperature. In addition, the dispersion of second phases such as oxide, carbide particles or bubbles are typical methods to improve mechanical properties at high temperatures. These materials have been used as high temperature applications such as filament of light bulb, electrodes of welding apparatus or heater. Among these fabrication processes for microstructural control, we selected Potassium (K)-dope and Lanthanum (La)-dope W for fusion reactor applications from the view point of industrial background. These materials have not been used under neutron irradiation conditions, but our previous works showed that radiation response of these dispersion strength W alloys were almost the same as pure W. In addition, Re containing W alloys showed void formation resistance under neutron irradiation conditions, therefore, new alloys which contain Re and dispersoid are expected to have higher radiation resistance. The objectives of this work are fabricating these alloys in large scale, confirming unirradiated properties and preparing specimens for future neutron irradiation experiments. Current status of the material characterization such as microstructure, recrystallization behavior, thermal diffusivity, and mechanical properties of the grain refined W alloys will be reported.

2. Experimental

Powder metallurgically processed pure W, W-1 or 3%Re, K-doped W, K-doped+3%Re W and La-doped+3%Re W plates were fabricated under support of NIFS-LHD project in Japan. These materials were fabricated by A.L.M.T. Corporation in Japan as 5mm thick plates and heat treated at 900 ^{o}C for 20 min. for stress relief. The reduction of area in the final hot rolling processes of these alloys was about 80%. Concentrations of interstitial impurities (C,N,O) of these were below 10 ppm. Specimens for microstructural observation, tensile test and thermal property test were cut out from the plates. Recrystallization behavior was examined in vacuum at temperature from 900 to 2000 ^{o}C for 1 hour. Grain size measurements were conducted on chemically etched surfaces using grain boundary intersections method by an optical microscope. Tensile tests were conducted at from RT to 1800 ^{o}C with the strain rate of 10^{-3} s^{-1} in vacuum using a SS-J and VS-T1 type small tensile test specimen. Thermal diffusivity measurements were conducted using a laser flash method in high-purity Ar atmosphere using a disk type specimen with 10 mm diameter and 2 mm thickness.

3. Results and discussions

Grain growth by recrystallization of pure W was observed above 1100 ^{o}C, but the grain growth of K-doped, 3%Re and K-doped+3%Re were observed above 1500 ^{o}C. Resistance to recrystallization was successfully obtained by the K-doping and Re addition.

The results of mechanical properties measurement of the W alloys are summarized as follows; K-doped W and K-doped W-3%Re showed ~67 and ~186% higher tensile strength than pure W, respectively at the maximum. The UTS and its temperature dependence in W materials showed anisotropy, although K-doped W-3%Re alloy did not clearly show any effects on this anisotropy. K-doped W and K-doped W-3%Re showed better deformation ability than pure W. The ductile-brittle transition temperatures in K-doped W and K-doped W-3%Re, which were obtained from the results of the tensile tests, decreased by ~200 and ~800 °C in the parallel to rolling direction and through thickness-directions, respectively. The results showed that K-doped W-3%Re has better tensile properties than pure W in non-irradiation conditions. Since irradiation hardening is suppressed by Re addition, K-doped W-3%Re is expected to have more advantageous as a PFM in fusion reactors than pure W and K-doped W.

Results of thermal diffusivity of the pure W and W-alloys are summarized as follows; The thermal diffusivity of poly-crystalline W is about 95% of single-crystal at 1000 ^{o}C and thermal diffusivity of the rolled plate was isotropic in spite of anisotropy of the grain structure. Thermal diffusivity of the W-alloys was lower than that of pure W. The 3%Re addition decreased thermal conductivity of pure W about 30% at around RT and 10% at around 1000 ^{o}C. Considering about the temperature distribution of divertor component by heat load, lower thermal conductivity will lead higher surface temperature. Trade-off between the thermal conductivity and mechanical property, embrittlement resistance by the structural control must be considered quantitatively. Strain and stress distribution of PFM component during heat load or cyclic heat load were estimated by finite element analysis (FEA). The FEA results showed that the effect of K-doped W-3% Re on thermal stress distribution and its value during heat load was not clearly observed.

Neutron irradiation experiments of these W materials by a fission reactor (HFIR at ORNL, USA) started in 2014 under J-US collaboration program PHENIX. The specimen preparation for the next reactor irradiation experiment is on-going using the fabricated materials in this study.