§2. High Temperature Strength of Powder Metallurgical V-1.7Y Alloy with Fine Grains and Finely Dispersed Particles

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A vanadium alloy, V-4Cr-4Ti, is a primary candidate material for fusion reactor structural applications because of its inherently low-induced radioactivity etc. In order to make the alloy more attractive, it is necessary to improve both the resistance to radiation embrittlement and the high temperature strength. The improvement may be achieved by introducing the microstructure of fine grains and finely dispersed, thermally stable particles, the matrix being almost free from solute oxygen and nitrogen that cause significant loss of ductility. Therefore, one of the authors applied powder metallurgical method including mechanical alloying (MA), in which the starting powders of pure vanadium and yttrium were used to remove solute oxygen and nitrogen from vanadium matrix via consuming themselves to form finely dispersed oxide and nitride particles. As a result, the microstructure of fine grains and finely dispersed particles was successfully introduced and the developed alloy exhibits a good ductility even at 77K as measured with impact 3-point bending tests. In this study, the microstructure stability and the tensile behavior of the alloy at high temperatures are examined. The measured high temperature strength is compared with that of V-4Cr-4Ti (NIFS-HEAT-1).

Commercially available pure vanadium (oxygen: 0.08wt%, nitrogen: 0.07wt%) and pure yttrium (1.56wt%, 0.05wt%) powders were mixed to the target composition of V-1.7wt%Y and subjected to MA with planetary ball mill in a purified argon atmosphere. Since the pots and balls made of WC/Co were used, to minimize the contamination from WC/Co optimization of MA condition was made by examining the effects of several parameters, including weight ratio of balls to powder, rotational velocity of vessel and milling time. For MA treated powders, HIP was conducted at 1273K and 200MPa for 10.8ks in an argon atmosphere. The as-hipped compact was cut into sheets, from which miniaturized tensile specimens with a gauge section of 1.2 x 5 x 0.5 mm and TEM disks were prepared. The tensile specimens and TEM disks were wrapped with Zr foil and annealed at temperatures from 1273 to 1573K for 3.6ks in a vacuum of better than 5 x 10^{-5} Pa. The impurity contents of tungsten and carbon were reduced to 0.27 and 0.02wt%, respectively. Assuming that all of oxygen and nitrogen determined by chemical analysis are consumed to form yttrium compounds, the volume fractions of Y_2O_3 and YN are 1.0 and 0.7%, respectively. Tensile tests were performed at temperatures from 873 to 1273K at initial strain rates from 1 x 10^{-5} to 1 x 10^{-2} s^{-1}. Fracture surfaces of tensile-tested specimens were examined using SEM. TEM observations were made with JEM-2000FX operating at 200kV in the Oarai Branch of IMR, Tohoku University.

X-ray diffraction analysis of the developed alloy designated to as V-1.7Y shows that the dispersed particles are Y_2O_3 and YN regardless of annealing temperatures. TEM observation reveals that in the as-hipped condition the average grain size is approximately 300nm and the particle size is 6nm. Annealing from 1273 to 1573K increases the grain size and particle size, but their sizes stay in small ranges from 330 to 750nm for the grains and from 6 to 20nm for the particles. This indicates that the dispersed particles of Y_2O_3 and YN are thermally stable and pin grain boundaries even at 1573K (0.7Tm).

High temperature tensile tests for V-1.7Y show that there is no systematic trend between the strength and the annealing temperature. Therefore, the result stated below is for 1373K-annealed specimen that exhibits the best combination of strength and elongation at room temperature. The test temperature dependence of yield stress at 1 x 10^{-3} s^{-1} for V-1.7Y and NIFS-HEAT-1 shows that below 1073K the yield strength is considerably higher for V-1.7Y than for NIFS-HEAT-1, e.g., at 873K, 1.7 times higher. However, above 1073K the yield strength of V-1.7Y is lower than that of NIFS-HEAT-1, which reflects larger temperature dependence of yield stress for V-1.7Y than for NIFS-HEAT-1. From the results of test temperature and strain rate dependence of yield stress for V-1.7Y it has been determined that the activation energy for deformation is approximately 300kJ/mol, corresponding to the self-diffusion energy in vanadium, and the stress exponent of plastic strain rate is approximately 6 between 973 and 1173K. Therefore, it follows that the high temperature deformation of V-1.7Y is controlled by recovery and an increased amount of dispersed particles is needed to improve the high temperature strength above 1073K.