§3. Development of Fine-Grained, Particle Dispersed Vanadium Alloys with Improved Resistances to High-Temperature Deformation and Embrittlement by Neutron and Helium Irradiations

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A V-4Cr-4Ti alloy with reduced contents of solute oxygen and nitrogen processed by electron-beam melting is a primary candidate material for fusion reactor structural applications [1, 2]. In order to make the alloy more attractive, it is necessary to improve both the resistance to embrittlement by neutron and helium irradiations and strength at high temperatures. So far, the authors showed that resistance to radiation embrittlement in vanadium is improved by introducing microstructures of fine grains and finely dispersed particles of Y_2O_3 and YN, which are produced by powder metallurgical methods including mechanical alloying [3, 4].

Since the dispersed particles of Y_2O_3 and YN are thermally stable, they are expected to improve the high temperature strength of vanadium. In addition, fine grains can contribute to improve high temperature strength by grain boundary strengthening as far as grain boundary sliding does not occur significantly. It is thus necessary to examine how the high temperature strength of the fine-grained V-Y alloys dispersed with fine Y_2O_3 and YN particles depends on grain size and dispersed particle density. However, there are no reports on the high temperature strength of vanadium or its alloys with fine grains and finely dispersed particles. In this paper, fine-grained, particle dispersed V-Y alloys are prepared with three different grain sizes and particle densities and subjected to tensile tests up to 1273K.

Powders of pure vanadium (particle size: <150μm, oxygen: 0.08wt%, nitrogen: 0.07wt%), pure yttrium (<750μm, oxygen:1.56wt%, nitrogen:0.05wt%) and Y_2O_3 (<120μm) were used as the starting materials. They were mixed to provide the nominal compositions of V-1.7wt%Y, V-1.3wt%Y-0.8wt%Y_2O_3 and V-1.3wt%Y-1.6wt%Y_2O_3 in a glove box filled with a purified Ar gas (purity 99.9999%). Each of the mixed powders was charged into two pots made of WC/Co or TZM and then subjected to MA in a purified Ar atmosphere. HIP was conducted at 1273K and 200MPa for 3h in an Ar atmosphere. From the as-HIPed compacts, specimens for microstructural observations, X-ray diffraction (XRD) analysis and tensile tests were prepared. The dimensions of the tensile specimens are 16mm x 4mm x 0.5mm with the gauge section of 5mm x 1.2mm x 0.5mm, where the shoulder part was designed to support the applied load. All of the specimens were wrapped with Ta foil and then Zr foil and annealed at 1273 or 1373K for 1 h in a vacuum better than 5 x 10^{-5}Pa. Tensile tests were performed at room and high temperatures from 873 to 1273K at an initial strain rate of 1 x 10^{-3} s^{-1} in a vacuum better than 3 x 10^{-4} Pa. For high-temperature tensile tests, Ta and Zr foils having the dimensions identical to the tensile specimens and being separable into two parts were placed in contact with the specimens in order to suppress pick-up of gaseous interstitial impurities from the surrounding during the test. The fracture surfaces of the tensile-tested specimens were examined by scanning electron microscopy (SEM) with JSM-5400. Microstructural examinations were made by transmission electron microscopy (TEM) with JEM-2000FX operating at 200kV. The main results are as follows.

1) V-(1.7-2.4)Y alloys had average grain sizes of 0.27-0.5μm, average particle size of around 15 nm, and dispersed particle densities of (1.3-7.2) x 10^{21} m^{-3}. The grain size decreased with increasing particle density. The difference in particle density between the alloys is due to the difference in the contents of Y_2O_3 addition.

2) Up to around 1023K V-(1.7-2.4)Y alloys exhibited considerably higher strengths than V-4Cr-4Ti, indicating that the microstructures introduced in V-(1.7-2.4)Y alloys are effective in improving the high temperature strength of V-4Cr-4Ti.

3) Above 1173K V-(1.7-2.4)Y alloys showed lower strengths than V-4Cr-4Ti. This is due to the strong temperature dependence of yield and tensile strengths above around 923K for V-(1.7-2.4)Y, compared with that of V-4Cr-4Ti.

4) In the temperature range from 923 to near 1173K the deformation of V-(1.7-2.4)Y alloys may be controlled by recovery of a long-range internal stress field, where grain boundary strengthening is operating. Above 1173K the deformation of V-(1.7-2.4)Y may be governed by grain boundary sliding.

Reference

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