§9. Development of Highly Pure, Ultra-fine Grained Vanadium Alloys with Improved Strength at High Temperatures

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Powder metallurgical (P/M) vanadium alloys with a highly pure matrix of ultra-fine grains and nano-scale dispersoids of Y_2O_3 and YN [1-3] are favorable for use in irradiation environments such as fusion reactor structural applications because it has been demonstrated that the alloys are very resistant to neutron irradiations [2, 4]. They exhibited considerably higher yield strength below 900°C, but exhibited lower yield strength above 900°C than V-4Cr-4Ti (Nifs heat-1) [5], which is associated with grain boundary sliding [6]. It is thus required to improve the high temperature strength.

For this purpose we investigated the effect of solution hardening by Ti addition in V-1.7Y-2.1Ti[7] and V-2.3Y-4Ti-3Mo[8]. However, its solution hardening was found to be insufficient to improve their high temperature strength above 900°C. Our recent studies showed that a V alloy containing W solute and V_2C dispersoid has a thermally very stable microstructure[9]. This result suggests that the V alloy may exhibit improved strength above 900°C.

In this study, V alloys containing W solute and V_2C dispersoids were fabricated by P/M methods utilizing mechanical alloying (MA) and hot isostatic pressing (HIP). The high temperature deformation behavior of the alloys in the as HIPed condition (without no plastic working after HIP) was investigated over wide temperature and strain rate ranges.

Commercially available powders of pure V, Y, W and VC were mixed to provide nominal compositions of V-1.6Y-8.5W-0.4VC (V-1.6Y-8.5W-0.08C) and V-1.6Y-8.5W-0.8VC (V-1.6Y-8.5W-0.15C) in a glove box. The mixed powder and balls made of TZM (Mo-0.5Ti-0.1Zr) were subjected to MA with a three mutually perpendicular directions agitation ball mill in a purified H_2 atmosphere, followed by HIPing at 1000°C and 196 MPa for 10.8 ks. The details of the processing are reported elsewhere [1-3].

The as-HIPed compact was machined to prepare specimens for X-ray diffraction (XRD) analyses, transmission electron microscopy (TEM) observations and tensile tests. All the specimens were wrapped with Zr and Ta foils and annealed at 1000 and 1200°C for 3.6ks in a vacuum of approximately 2.4×10^{-4} Pa. Tensile tests were performed at temperatures from 800 to 1100°C at initial strain rates from 1.0×10^{-4} to 1.0×10^{-2} s^{-1} in a vacuum better than 3×10^{-4} Pa. For the test, miniaturized specimens were used which have the gage section of 1.2 mm × 0.5 mm × 5.0 mm [3].

The main results obtained are as follows.

1. V-1.6Y-8.5W-0.4VC and V-1.6Y-8.5W-0.8VC contain dispersoids of Y_2O_3, V_2C, Y_2C, WC and W_2C. The average diameters and number densities of the dispersoids are 32nm and $2.2\times10^{21}m^{-3}$ for V-1.6Y-8.5W-0.4VC and 30 nm and $3.5\times10^{21}m^{-3}$ for V-1.6Y-8.5W-0.8VC, respectively. The average grain diameters for V-1.6Y-8.5W-0.4VC and V-1.6Y-8.5W- 0.8VC are 420 and 410 nm, respectively. W dissolves in the V matrix after annealing at 1200°C.

2. V-1.6Y-8.5W-0.8VC annealed at 1200°C shows the highest yield strength in the temperature range of 900-1100°C among the alloys fabricated by the P/M methods, which is approximately two times as high as that of V-4Cr-4Ti at 900°C. This high strength is attributable to the combination of solution hardening by W and dispersion hardening.

3. The stress exponent of yield stress, *n*, at 1050°C, in V-1.6Y-8.5W-0.4VC and V-1.6Y-8.5W-0.8VC are 3.6 and 4.0, respectively. These values of *n* indicate that the contribution of solute atmosphere dragging stress to the yield stress is large for both alloys and decreases with increasing VC addition.

4. The activation energies for deformation in the temperature range 900-1100°C are 350kJ/mol for V-1.6Y-8.5W-0.4VC and 380kJ/mol for V-1.6Y-8.5W-0.8VC annealed at 1200°C. These values are very close to the activation energy for interdiffusion of W in a V-W solid solution (357-393 kJ/mol [10]). It is thus concluded that the high temperature deformation of both alloys is controlled by solute atmosphere dragging.

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