§10. Radiation Resistance and Mechanical Properties of Solution and Dispersion Hardened Vanadium Alloys with Fine Grains of High Purity Matrix

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In order to mitigate both radiation embrittlement and strength decrease at high temperatures in vanadium (V) and its alloys, one of the authors has processed V alloys with very fine grains and nano-dispersoids of Y_2O_3 and YN by powder metallurgical (P/M) methods utilizing mechanical alloying (MA) and hot isostatic pressing (HIP). The authors have shown that the fabricated alloys exhibit good resistance against neutron irradiation to 0.25 and 0.6 displacement per atom (dpa) at 563 and 873K and good ductility in the HIPed and annealed state (no plastic working). In addition, V-(1.7-2.4)Y (in mass%) alloys exhibit higher strengths up to around 1023K than solution hardened V-4Cr-4Ti (Nifs heat-1), however above 1173K the alloys showed lower strengths. The deformation mode of the V-Y alloys changed from a recovery controlling process of a long-range internal stress field to grain boundary sliding. It is thus likely that the lower strength above 1173K is attributed to grain boundary sliding caused by a very fine grain size and much less solution hardening. Since solution hardening significantly contributes to high temperature strength and is an important mechanism for improvement of the strength, the authors have studied the effect of solution hardening by 4%Ti addition on the high-temperature strength of V-2.4%Y. It was found that the effect of solution hardening by 4%Ti addition is not effective in improving the lower strength above 1173K. According to our recent study [1] it is expected that solution hardening by W and precipitation hardening by V_2C will be very effective in improving the high-temperature strength of V-Y alloys. In this study, therefore, V-Y-W-V_2C alloys were fabricated and their microstructures and high-temperature tensile properties were examined.

Two types of alloys, A (V-1.6Y-8.5W-0.8VC) and B (V-1.6Y-8.5W-0.4VC) were fabricated from commercially available powders of pure V, Y, W and VC by the P/M method utilizing MA and HIP. For the MA process three mutually perpendicular directions agitation ball milling with vessels and balls made of TZM (Mo-0.5%Ti-0.1%Zr) was performed for 60 h in a purified H_2 atmosphere. The MA processed powders were HIPed at 1273K and 200MPa for 3 h, followed by annealing at 1273 or 1473K for 1h in a vacuum. The annealed specimens of A and B were subjected to XRD, TEM observations and tensile tests at temperatures from 285 to 1373 K at initial strain rates from 2.5×10^{-5} to 1.0×10^{-1} s^{-1} in a vacuum better than 3×10^{-4} Pa. The results were compared with those for V-2.4Y, V-1.7Y-2.1Ti, V-2.3Y-4Ti-3Mo, which were reported previously. The main results obtained are as follows.

1. XRD patterns of the A and B specimens annealed at 1273K show distinct peaks of W, whereas those annealed at 1473K show no peaks of W. This indicates that the strength of alloy A is mainly attributable to precipitation hardening by V_2C and that of alloy B to both precipitation hardening and solution hardening by W.

2. The average grain sizes are 200 nm for alloy A and 220 nm for alloy B, which are considerably smaller than those for alloys V-2.4Y (270 nm), V-1.7Y-2.1Ti (520 nm), V-2.3Y-4Ti-3Mo (620 nm). The average diameter of the dispersoids, such as Y_2O_3 and V_2C, is less than 20 nm.

3. The yield stresses, σ_y, of alloys A and B at 1173K are strongly dependent on annealing temperature, 167 and 93 MPa for 1273K anneal, respectively, and 190 and 112 MPa for 1473K anneal; 1473K anneal leads to increase in the high temperature strength of alloys A and B. The strength increase is mainly attributable to solution hardening by W. Comparison of the strengths of the two alloys shows that alloy A is stronger by approximately 70 MPa than alloy B, independent of annealing temperature. This indicates that the strength difference between alloys A and B is attributable to precipitation hardening by V_2C due to the difference in VC addition for alloys A and B. It should be noted from table 1 that the strength of alloy A is superior to the other alloys developed so far. The conclusion drawn from the results is that precipitation hardening by V_2C is very promising for improvement of the high-temperature strength of V-Y alloys with fine grains of a high purity matrix.

Table 1 Yield strength of developed alloys at 1173K at 25 x 10^{-3} s^{-1} (MPa).

Anneal Tem.	A	B	V-2.4Y	V-2.3Y-4Ti-3Mo
1273K	167	93	90	60
1473K	190	112	---	---

1) H. Kurishita, T. Kuwabara and M. Hasegawa, Mater. Sci. Eng. A, 432 (2006) 245-252