§23. Development of Nanostructured, Recrystallized V-1.6Y-8W-0.8TiC Alloy with Enhanced Creep Resistance and Radiation Tolerance

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Nanostructured vanadium (V) alloys are expected to exhibit high performance under neutron irradiation environments. However, their ultra-fined or refined grains cause significant decrease in flow stress at high temperatures due to grain boundary sliding (GBS), which is the major concern for their high-temperature structural applications such as future fusion reactors. The contribution of GBS to plastic deformation is known to depend strongly on grain size (GS) and may give more significant influence on long-time creep test results than on short-time tensile test results. In order to improve the creep resistance through elucidation of the effect of GS on the uniaxial creep behavior of nanostructured V alloys, a solution and dispersion hardened V alloy, V-1.6Y-8W-0.8TiC (in wt%), with GSs from 0.58 to 2.16μm was developed by powder metallurgical methods and creep tested at 1073K and 250MPa in vacuum. It is shown that the alloy with 2.16 μm in GS exhibits enhanced creep resistance at 1073K and 250MPa, which is 30 times as high as that with 0.58μm in GS. This result strongl possibility of structural applications of nanostructured V alloys in radiation environments.

An alloy with the composition of V-1.6Y-8W-0.8TiC and relative density of 99.7% was fabricated from commercially available powders of pure V, Y, W and TiC utilizing mechanical alloying (MA) and HIP. The MA treatment was conducted by three mutually perpendicular directions agitation ball milling with vessels and balls made of TZM (Mo-0.5%Ti-0.1%Zr) for 50h in a purified H_2 atmosphere. The MA processed powders were HIPed at 1273K and 200MPa for 3h and the HIPed compact was machined to prepare specimens for transmission electron microscopy (TEM) observations, X-ray diffraction (XRD) analyses and creep tests: The dimensions of the creep specimens were 16mm x 4mmx 0.5mm with the gauge section of 5mm x 1.2mm x 0.5mm. All of the specimens were annealed at 1473, 1573, 1673 and 1773K for 1h in a vacuum. The creep tests were performed at 1073K and 250MPa. For comparison, creep specimens (dimensions: 16mm x 4 mm x 0.25mm) of V-4Cr-4Ti (Nifs Heat 2) were annealed at 1273K for 2 hours and creep tested at the same condition as V-1.6Y-8W-0.8TiC. It should be noted that the V-1.6Y-8W-0.8TiC alloy used in this experiment is in the annealed states without any plastic working after HIP. The main results obtained are as follows.

1) The creep resistance for V-1.6Y-8W-0.8TiC depends strongly on GS and significantly increases with increasing GS. The specimen with 2.16 μm in GS exhibits a creep life of 114 hours, which is longer by a factor of 30 than that with 0.58μm in GS and by two orders than that for V-4Cr-4Ti.

2) The steady state length and creep life linearly increase with GS. The steady state creep rate decreases with increasing GS and the following relationship is held between the steady state creep rate and the reciprocal of GS:

$$\dot{\varepsilon}_s \propto (1/\ell)^3,$$

where $\dot{\varepsilon}_s$ is the steady state creep rate and ℓ is the average grain diameter.

3) The steady state creep of V-1.6Y-8W-0.8TiC mainly occurs by GBS, whereas that of V-4Cr-4Ti occurs by dislocation creep (glide/climb).

4) The observed difference in creep resistance between V-1.6Y-8W-0.8TiC and V-4Cr-4Ti can be attributed to the followings: (1) One is much higher resistance to dislocation creep (glide/climb) in V-1.6Y-8W-0.8TiC than in V-4Cr-4Ti. (2) The other is that the applied stress level of 250MPa is assumed to be between σ_B and σ_C, as shown in Fig.1. Since creep test results only at 250MPa are currently available, further tests at lower applied stresses than σ_B should be performed to demonstrate the applicability of Fig.1.

5) The Larson-Miller parameter, P, at 250MPa for V-1.6Y-8W-0.8TiC except for the smallest GS of 0.58μm lies above the Larson-Miller plots at 250MPa for V-4Cr-4Ti, but below the plots for V-(10-15)Cr-5Ti. However, the radiation tolerance performance of V-(10-15)Cr-5Ti is inferior to that of V-4Cr-4Ti.

6) The developed V-1.6Y-8W-0.8TiC with solute W and Mo, dispersoids of Y_2O_3 and TiC and GS of ~2 μm are sufficiently capable of suppressing creep deformation by dislocation glide/climb and GBS at 1073K and 250MPa.

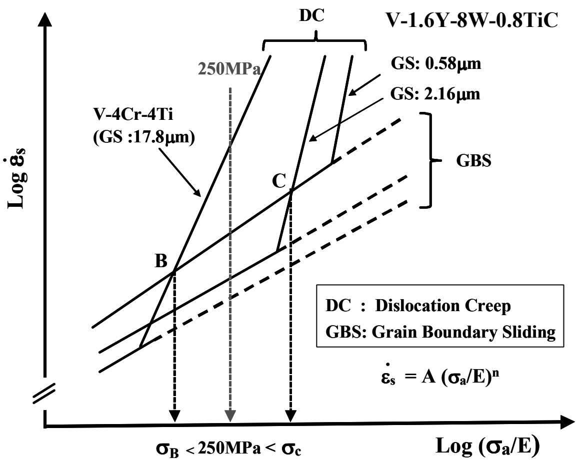

Fig.1 Schematic illustration explaining the observed creep resistance for nanostructured, solution and dispersion hardened V-1.6Y-7W-8Mo-0.8TiC with different grain sizes and coarse-grained V-4Cr-4Ti.