§20. The Effect of Yttrium Addition on Hardening and Tensile Strength of the Low Activation Vanadium Alloy

Miyazawa, T. (Dept. Fus. Sci. Grad. Univ. Advanced Studies),
Nagasaka, T., Hishinuma, Y., Muroga, T., Li, Y.F.

V-4Cr-4Ti alloy is considered as an attractive structural material for the first-wall and blanket components of fusion reactor systems due to their low neutron-induced activation, favorable mechanical properties at high temperatures and good compatibility with lithium coolant.[1] Low-temperature irradiation embrittlement is one of the most important issues determining operation temperature limit. The low-temperature embrittlement is known to be enhanced by irradiation defects decorated by solute oxygen impurities.

It has been reported that small addition of yttrium (Y) was effective to reduce oxygen impurity and improve ductility after neutron irradiation without severe degradation of low-temperature impact properties.[2, 3] Y addition, on the other hand, can degrade high-temperature strength, because Y could scavenge solute oxygen, which is a strong hardening agent in vanadium alloys, by a formation of Y_2O_3.[2] The effect of Y addition must be evaluated from the view points of both the room temperature hardness and the high-temperature strength.

Figure 1 shows Vickers hardness as a function of oxygen concentration. Vickers hardness increased with increasing oxygen concentration. The slope for the trend line for V-4Cr-4Ti alloy and V-4Cr-4Ti-0.15Y alloy was 0.017-0.070 Hv/wppm O and 0.006 Hv/wppm O, respectively. The figure suggests that the hardening by oxygen is suppressed by Y addition. In the previous study, precipitations of Y_2O_3 were observed in the Y-added alloy.[2] Oxygen concentration in solution is considered to be reduced by the formation of Y_2O_3. Thus Y addition can moderate solid-solution hardening by oxygen.

Figure 2 shows the dependence of tensile strength on test temperature. Between 600 to 700 ^{o}C, ultimate tensile strength (UTS) for V-4Cr-4Ti alloys slightly increased, while that for V-4Cr-4Ti-0.15Y alloys decreased. UTS at 700 ^{o}C was decreased with Y addition. The reduction of yield stress (YS), however, was smaller than that of UTS.

Thermal and structural analyses on Li cooling channels in fusion blanket have given the maximum equivalent stress as 56 and 35 MPa for a stainless steel and a vanadium alloy, respectively.[4, 5] According to these examples, the design stress required for vanadium alloys will be several 10 to around 100 MPa. The YS and UTS at 700 ^{o}C for V-4Cr-4Ti-0.15Y-0.011O alloy were 194 MPa and 339 MPa, respectively. The YS (UTS) is 5.5 times (9.7 times) larger than the equivalent stress for the vanadium alloy (35 MPa), and 1.9 times (3.4 times) larger than the expected design stress (100 MPa). Though the design criteria and safety factor to the design stress have not been determined for fusion structural materials, the above margins are considered to be still enough as the safety factor to blanket design. Especially for V-4Cr-4Ti-0.15Y-0.011O alloy, the reduction in UTS by Y addition was 25 MPa, however, is thought to be acceptable for the application to structural materials.

The effect of Y addition on hardness and tensile properties has been clarified. Y addition suppressed the hardening by oxygen. Y is considered to reduce solute oxygen by the formation of Y_2O_3. Thus, Y addition moderated the hardening by oxygen impurity to a high level of 0.27 wt%. With Y addition, the UTS was reduced above 700 ^{o}C. The reduction in UTS by Y addition, however, was as small as 25 MPa at 700 ^{o}C, which is thought to be acceptable for the application to structural materials.

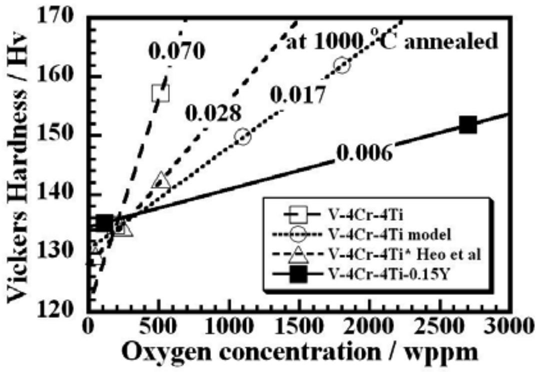

Fig. 1. The dependence of Vickers hardness on oxygen concentration. Final annealing condition was 1000 ^{o}C for 3.6 ks. Attached numbers mean the hardening coefficient per unit oxygen concentration.

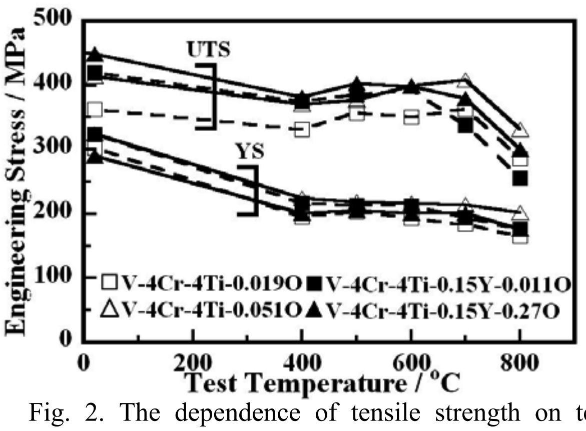

Fig. 2. The dependence of tensile strength on test temperatures.

1) Muroga, T. et al.: J. Nucl. Mater., **307-311** (2002) 547.
2) Nagasaka, T. et al.: J. Nucl. Mater., **367-370** (2007) 823.
3) Chuto, T. et al.: J. Nucl. Mater., **326** (2004) 1.
4) Sviatoslavsky, I.N. et al.: Nucl. Eng. Des., **39** (1976) 73.
5) Hasan , M.Z. et al.: Nucl. Eng. Des., **23** (1993) 115.