§3. Tensile Properties of Low Activation Vanadium Alloy after Liquid Lithium Exposure

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Vanadium alloys are recognized as attractive candidate structural materials for liquid Li cooled blanket for fusion reactor. Transfer of impurities occurs between V alloy and liquid Li. Generally, C and N migrate to V alloy from Li, while O is removed from V alloy by Li. However, the mechanisms of the transfer, distribution of the impurities after Li exposure and the effects on mechanical properties have not been clarified. In the present study, a candidate V-4Cr-4Ti alloy, designated as NIFS-HEAT-2, was exposed to liquid Li for up to 1963 hr. The impurity transfer, impurity distribution and its effect on tensile properties were investigated.

The reference low activation V-4Cr-4Ti alloy, designated as NIFS-HEAT-2, was cold-rolled into 0.25 mm-thick sheets, followed by annealing at 1273 K for 2 hr. The sheets were cut into coupon specimens with the size of 0.25 × 5 × 25 mm. The exposure temperature to Li (T_{Li}) was 973 K and 1073 K. The exposure time was 255 to 1963 hr. After the exposure, Li was chemically removed by liquid ammonia. From the coupons, miniature tensile specimens with a size of 0.25 × 4 × 16 mm (gauge: 0.25 × 1.2 × 5 mm were punched out. The residual punched-coupons were chemically analyzed for C, N and O.

Table 1 lists the results of chemical analysis after the Li exposure. C and N impurity levels were increased with exposure time by contamination from the Li, while O was decreased by scavenging by the Li.

Figure 1 and 2 present the tensile parameters obtained for specimens exposed with liquid Li at 1073 K (T_{Li}). From the data at room temperature (943 hr), miniature tensile tests show data scattering of about 40 MPa in strength (YS, UTS) and 10 % in elongation (UE, TE). Considering these scattering, change in UTS was small until 773 K ($T_{Tensile}$) after Li exposure at 1073 K (T_{Li}) for 428 and 943 hr,, while degradation of UTS at 973 and 1073 K ($T_{Tensile}$), such as 50 and 80 MPa, respectively, was considerable. On the other hand, elongation decrease by Li exposure was observed at RT and 773 K ($T_{Tensile}$), but not at higher temperature. However, all the specimens still keep higher ductility than 6.5 % in UE and 13 % in TE.

Thousands wppm of C and N contamination indicated in Table 1 did not introduce significant hardening in both hardness and tensile tests. From microstructural observations, the contaminated C and N were thought not to induce solid solution hardening, since they were absorbed by the Ti-C-N type precipitates.

Possible mechanisms of 80 MPa softening at 1073 K ($T_{Tensile}$) with impurity reduction are (1) loss of precipitation hardening by Ti-C-O type precipitates existing before the lithium exposure and (2) loss of solid solution hardening by O. Another mechanism independent of O reduction is (3) change of grain boundary condition. Assuming Orowan type strengthening for (1) case, the contribution of Ti-C-O precipitates is estimated as less than 5 MPa. For (2) case, the strength drop of 16 MPa would be explained, if Ti-C-O precipitates release O into the matrix during tensile tests at 1073 K ($T_{Tensile}$). (3) case is the effect of the precipitates covering grain boundaries. Enhancement of grain boundary slip and local fracture of the precipitates are possible. Investigation on the grain boundary effects are undergoing to complete the mechanism analisys of impurity transfer and change in tensile properties at high temperature.

Table 1 Impurity concentrations in NIFS-HEAT-2 (V-4Cr-4Ti) before (t_{Li} = 0) and after (t_{Li} > 0) liquid Li exposure

Exposure temperature, T_{Li} / K	Exposure time, t_{Li} / hr	C, C_C / wppm	N, C_N / wppm	O, C_O / wppm
	0	62	84	158
973	255	142	342	142
	499	280	1000	171
1073	260	238	884	51
	428	130	143	66
	943	477	2273	29
	1443	505	2317	79
	1963	797	3420	47

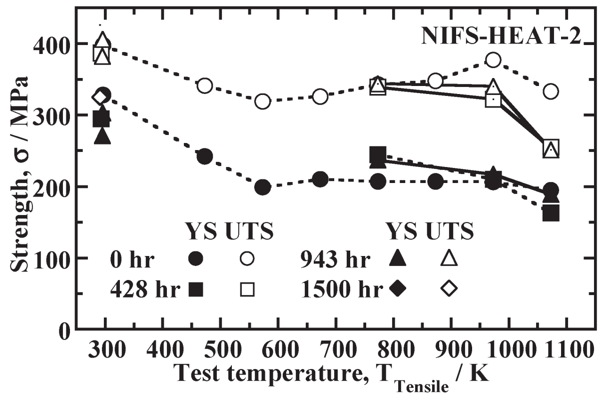

Fig. 1 Tensile test temperature ($T_{Tensile}$) dependence of yield strength (YS, 0.2 % proof stress) and ultimate tensile strength (UTS) of NIFS-HEAT-2 before and after the Li exposures at 1073 K (T_{Li}).

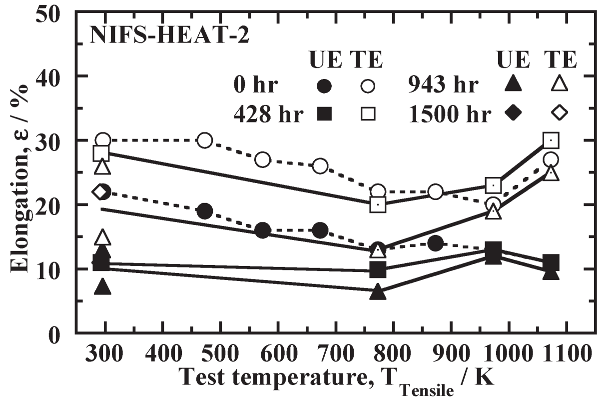

Fig. 2 Tensile test temperature ($T_{Tensile}$) dependence of uniform elongation (UE) and total elongation (TE) of NIFS-HEAT-2 before and after the Li exposures at 1073 K (T_{Li}).