§22. Kinetics of Hydrogen Isotopes at Surfaces and Bulks of Plasma Facing Materials Based on Group 5 Metals

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Group 5 metals including V are candidate materials of superpermeable membranes for pumping fuel particles in a divertor region. In addition, V alloys have attractive mechanical and nuclear properties as structural materials of fusion blankets. From these viewpoints, the interactions of hydrogen isotopes including tritium with V and V alloy were investigated by different experimental techniques.

Reduction in permeability due to carbon deposition is a critical problem to use superpermeable membranes in fusion devices with carbon divertor plates. For Nb membranes, the permeation rate can be recovered by heating above 750 ºC through the conversion of deposited carbon to Nb carbides [1]. The effect of carbon deposition for V membranes, however, has not been investigated. In the present study, thermal stability of carbon layer formed on a V alloy by exposure to LHD plasma was examined to understand the heat-treatment conditions necessary for the recovery of permeation rate of V membranes.

The specimen used was a sheet of V-4Cr-4Ti alloy (NIFS-HEAT-2) exposed LHD plasma in 6th experimental campaign. Analyses by Auger electron and Raman spectroscopy showed that the specimen surface was covered by carbon containing hydrogen, oxygen and Fe. After installation in an ultra-high vacuum chamber, the specimen was heated for 1 h at given temperatures, and the change in surface state was examined by means of X-ray photoelectron spectroscopy.

The result thus obtained is shown in Fig. 1. The drop of carbon concentration accompanied by sharp increase in V concentration was observed after heating at 500 ºC. This temperature is significantly lower than the temperature at which the recovery of permeation rate was observed for Nb [1]; the permeation rate of V could be recovered at lower temperature than Nb. Such difference between V and Nb can be attributed to, at least in part, higher solubility and diffusivity of carbon in V. More detailed study is currently in progress. The influence of formation of V_2C layer on plasma-driven permeation rate was also examined, and no significant reduction was observed up to thickness of 4 μm in a temperature range 500 to 1200 ºC.

For the application as structural materials, the correlation between fabrication conditions and susceptibility to hydrogen embrittlement was studied for the NIFS-HEAT-2. Impact specimens (1.5×1.5×20 mm) with V-notch were prepared from central parts of two types of sheets with different thickness; the thickness and extent of cold rolling of one sheet were 4.0 mm and 96 %, while those of another sheet were 6.6 mm and 93 %, respectively. After recrystallization annealing at 1273 K, some of these specimens was loaded with hydrogen up to 2000 appm, and the impact strength was examined at 173 K. Mixture gas of deuterium and tritium was also introduced into the specimens, and the distribution of hydrogen isotopes in the alloy was observed by imaging plates (IPs).

Fig. 2 shows the results of impact tests. Although ductile behaviors were still observed, the absorbed energy of both types of specimens was reduced with increasing hydrogen concentration. The extent of reduction, however, was significantly smaller for the specimens prepared from the thinner sheet; this type of specimens had lower susceptibility to hydrogen embrittlement. The analyses with IPs showed that hydrogen was concentrated in band-like regions where Ti-rich precipitates were distributed in high density. The difference in hydrogen concentration between such band-like regions and matrix was smaller for the specimen prepared from the thinner sheet; the fraction of hydrogen trapped by the precipitates was lower for this type of specimen. These observations indicated that fabrication conditions realize the uniform distribution of fine precipitates are suitable to mitigate the effect of hydrogen. The influence of heat treatment on tritium diffusivity was also examined as well as hydrogen permeability through insulation coating.

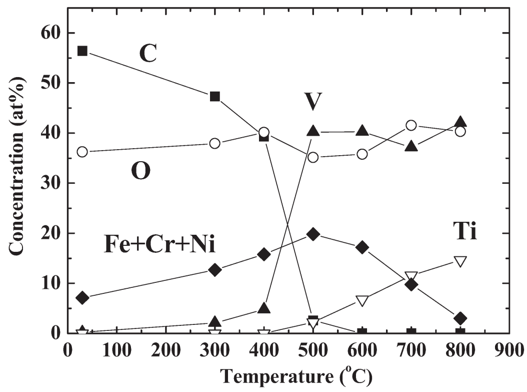

Fig. 1 Change in surface composition of V alloy specimen heated in vacuum after exposure to LHD plasma.

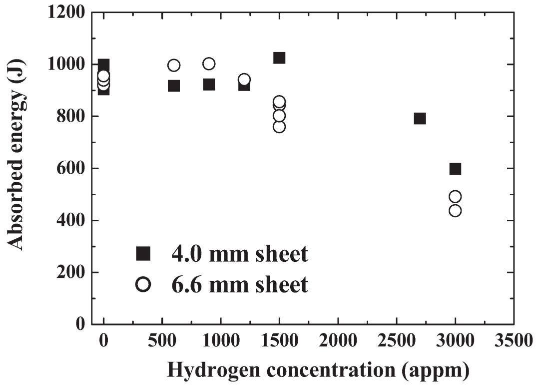

Fig. 2 Correlation between hydrogen concentration and impact strength at 173 K.

Reference

1) Ohyabu N., et al.: J. Nucl. Mater. **283-287**(2000)1297.