§ 1. Examination of Fabrication Process Parameters for Improvement of Low-Activation Vanadium Alloys

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Vanadium alloys are the promising candidate blanket structural materials for a liquid-lithium-cooled fusion reactor, because of their higher strength at elevated temperature, low-activation properties and good resistance against neutron irradiation damage. An alloy of V-4 mass % Cr-4 mass % Ti has been the leading candidate. Since the properties of the alloy products are known to be sensitive to microstructure, detailed analysis on microstructure of the products in relation to the processing condition is necessary to obtain the procedure to improve the products. In this study, plate products of thickness 0.25-26 mm were evaluated, for the reference V-4Cr-4Ti alloy (NIFS-HEATs). From the results, the optimum fabrication process parameters for vanadium alloys are discussed.

A hot-forged bar of 100 mm in thickness was made from NIFS-HEAT-2 (B) ingot. Plates of 26, 6.6, 4.0, 1.9, 1.0, 0.5 and 0.25 mm in thickness were made from the hot-forged bar by cold rolling. The final heat treatment on the plates for recrystallization was at 1273 K or 1223 K for 2 hours. At each stage of the breakdown process, microstructures were analyzed by scanning electron microscope with energy-dispersed X-ray analysis (EDX) and optical microscope. Impact tests were performed at 77 K with Charpy V-notch (CVN) specimens, which are taken from the center of thickness of 1.9t, 4.0t, 6.6t and 26t plates. The specimen size was 1/3 size (3.3 X 3.3 X 25.4 mm) and 1.5 size (1.5 X 1.5 X 20 mm). Definition of the codes indicating observation direction and CVN specimen orientation is shown in Fig. 1.

From the microstructural observations and EDX analysis, Ti rich precipitates were observed in all the plates. In the 1.9, 4.0, 6.6 and 26 mm-thick plates, the precipitates were dispersed as band structure lying on LT plane. In the 26 mm-thick plates, local clusters of the precipitates were also observed. The precipitates bands disappear from plates with thickness of 1.0 mm or lower. By large extent of working, areal number density of precipitates on LT plane can be decreased, and also the spacing of the bands can be smaller. As a result, precipitates are considered to be distributed more homogeneously after large working, and their band structure to be invisible.

Figure 2 shows fracture surfaces of CVN specimens taken from the center of the plate thickness. 3 types of fracture surface were observed. Type A is a brittle fracture characterized by cleavage and secondary crack with random directions. In type B and C, ductile fracture surface with dimples and brittle secondary crack were observed. Type B shows many secondary cracks, whereas only one large secondary crack was produced in type C. The secondary crack was parallel to the Ti-rich precipitate bands in types B and C. Table 1 shows the type of fracture for each specimen. The fracture type was changed with decreasing plate thickness from type A to type B and C in LT and LS oriented CVN specimens, respectively.

The brittle behavior at 77 K described in Table 1 seems to be caused by the local clusters of Ti-rich precipitates observed in 26 mm-thick plate. The local clusters remained due to lack of local working degree around them. Since hot working is known to be more effective to increase the level of deformation homogeneously than cold working, sufficient hot working is required to eliminate the clusters.

From Fig. 2, Ti-rich precipitate bands could stop crack propagation running to S direction. S directional crack is understood to be stopped by nucleation and propagation of secondary crack. However, the band structure is possibly weak to other directional crack, for example, running on LT plane with L or T directional sheer stress. To avoid such anisotoropy of fracture mode, homogenization of the precipitate distribution may be effective. One of the methods for this might be to increase the working degree. The precipitates bands were invisible in 1 mm-thick plate, which was cold rolled from the forged bar of 100 mm in thickness. The degree necessary to homogenize the precipitates, therefore, is estimated as around 99 % in cold working process. Assuming that vanadium alloys are used as several mm-thick plate in fusion reactor, starting materials for cold rolling have to be several hundreds of mm in thickness, in order to obtain 99 % degree. This is not necessarily realistic. It seems to be necessary to evaluate the effect of the anisotoropy on mechanical properties, and to apply the evaluation to design of the stress condition in the fusion reactor.

Table 1 Fracture type at CVN impact tests at 77 K.

Orientation	LT		LS	
Specimen size	1/3	1.5	1/3	1.5
26t	A	A	A	A
6.6t	A	B	C	A
4.0t	B	B	C	C
1.9t		B		C

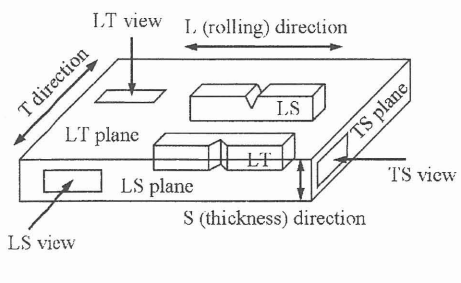

Fig. 1 Definition of observation direction and CVN specimen orientation.

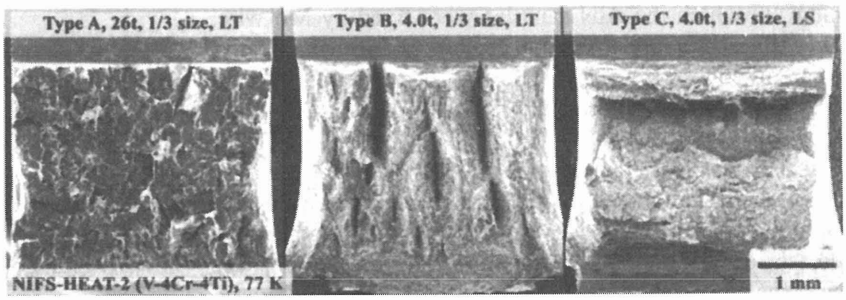

Fig. 2 Fracture surfaces after CVN impact tests at 77 K. Fracture type, plate thickness, specimen size and orientation are indicated