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Tritium release properties of neutron-irradiated $Be_{12}Ti$

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Abstract

$Be_{12}Ti$ has a high melting point and good chemical stability and is a promising advanced material for the neutron multiplier of the DEMO reactor that requires temperatures higher than 600 °C in a blanket. To evaluate the tritium inventory in the breeding blanket, a tritium release experiment of neutron-irradiated $Be_{12}Ti$ with a total fast fluence of about 4×10^{20} n/cm^2 ($E > 1$ MeV) was carried out at 330, 400 and 500 °C. It was clear that tritium could be released easier than from beryllium, and the apparent diffusion coefficient in $Be_{12}Ti$ was about two orders larger than that in beryllium at 600–100 °C. In addition to the good tritium release property, the swelling calculated from the density change of the specimens up to 1100 °C in this test was smaller than that of beryllium.

1. Introduction

Beryllium intermetallic compounds are promising neutron multipliers for the fusion DEMO blanket because of the higher melting point and lower chemical reactivity with water steam than beryllium [1,2]. The high melting point will decrease the swelling, and the lower chemical reactivity with water steam will decrease the risk of hydrogen explosion. From recent studies of $Be_{12}Ti$, it was confirmed that the tritium breeding ratio of the blanket might be satisfied by using $Be_{12}Ti$ pebbles as a neutron multiplier [3]. It was also confirmed that the compatibility with structure materials was much better than that of beryllium [4]. The tritium inventory of a fusion reactor is an important issue for safety and reduction of fuel loss. Therefore a tritium release experiment of neutron-irradiated $Be_{12}Ti$ samples was carried out to evaluate the tritium inventory.

2. Experimental

$Be_{12}Ti$ disk specimens were machined from a rod fabricated by the HIP process of beryllium and titanium powder by Brush Wellman, Inc. The fabrication process of the $Be_{12}Ti$ rod is shown in Fig. 1. The dimension of the disk specimens was about $\varnothing\ 8 \times 2$ mm. The microstructure of the $Be_{12}Ti$ disk is shown in Fig. 2. Porosity that might be caused by the HIP process existed inside the material. The chemical composition of the $Be_{12}Ti$ disk is shown in Table 1. $Be_{12}Ti$ disk specimens were irradiated in the Japan Material Testing Reactor (JMTR) in helium (6 N purity) sealed SUS304 containers. The temperature of the containers was controlled by a heater. The containers were irradiated with a total fast neutron fluence ($E > 1$ MeV) of about 4×10^{20} n/cm^2 at 330 (specimen no. BT-1), 400 (specimen no. BT-2) and 500 °C (specimen no. BT-3). The helium production amount and the dpa of beryllium were about 70 appm He and 0.5 dpa, respectively.

The apparatus for tritium release measurements is shown in Fig. 3 [5]. He + 1%H_2 carrier gas were used for the tritium release experiments, and the flow-controlled carrier gas was introduced at 50 cm^3/min into a small electric furnace. The carrier gas was divided into two measuring lines: IC1 for total tritium ($HT + T_2 + HTO + T_2O$) and IC2 for $HT + T_2$. The $Be_{12}Ti$ disk

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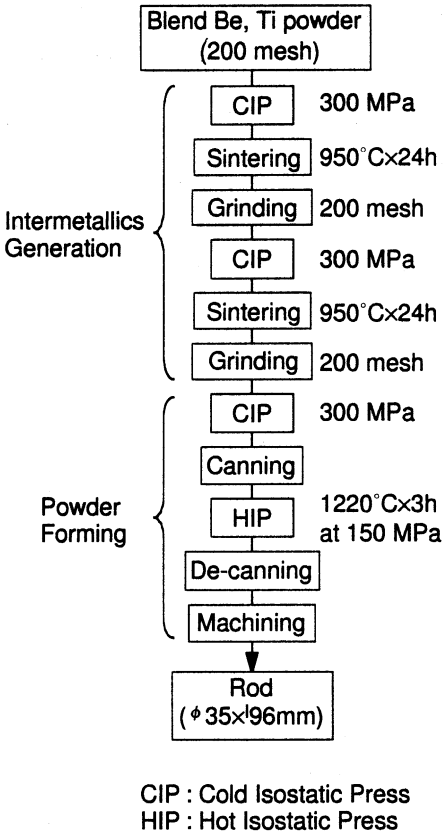

Fig. 1. Fabrication process of $Be_{12}Ti$.

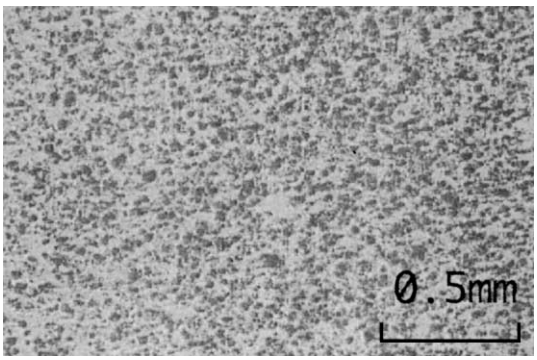

Fig. 2. Microstructure of $Be_{12}Ti$ specimen.

Table 1
Chemical composition of $Be_{12}Ti$ disks

Element (wt%)						
Be	Ti	BeO	Fe	C	Al	Si
69.0	29.8	1.54	0.090	0.054	0.041	0.033

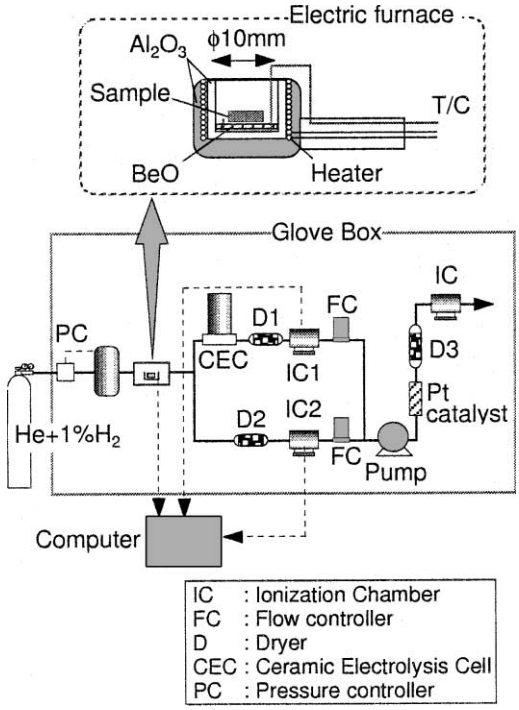

Fig. 3. Apparatus of tritium release measurement.

specimens were heated to 300, 600, 900 and 1000 °C, and were held for 30 min at each temperature.

3. Results and discussion

Results of the tritium release measurement are shown in Fig. 4. The amount of the released tritium from BT-3 was two orders lower than that from BT-1. This result means that most of the produced tritium in BT-3 had been released during neutron irradiation at 500 °C. The comparison with the results of beryllium is shown in Fig. 5 [5]. The tritium release from $Be_{12}Ti$ was larger than that from beryllium at any irradiation temperature, and the difference between the signal of IC1 and IC2 was smaller than that from beryllium. The small difference of the signal of IC1 and IC2 means that the water component of released tritium ($HTO + T_2O$) from $Be_{12}Ti$ was smaller than that from beryllium. The amount of released tritium ($HT + T_2$ and $HTO + T_2O$) is shown in Fig. 6. $HT + T_2$ were measured by the ionization chamber of IC2. $HTO + T_2O$ were measured by the liquid scintillation method in the solution of the D2 dryer [$Mg(ClO_4)_2$]. It was clear that the amount of released tritium of $HT + T_2$ and $HTO + T_2O$ decreased, and the value of $(HTO + T_2O)/(HT + T_2)$ increased with increasing irradiation temperature. The water component of released tritium from Be disk specimens

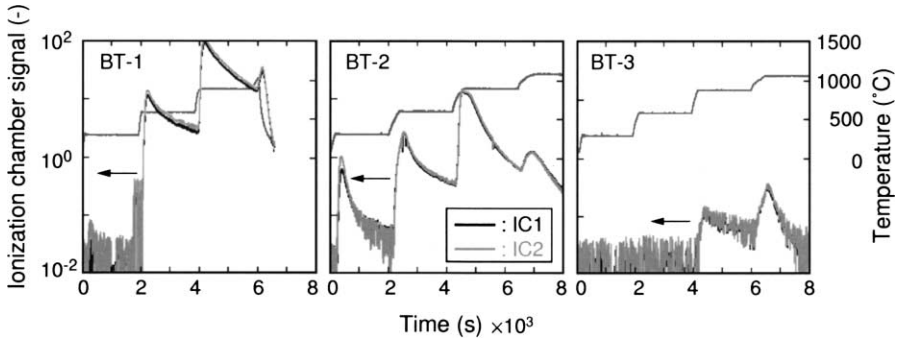

Fig. 4. Results of tritium release measurement.

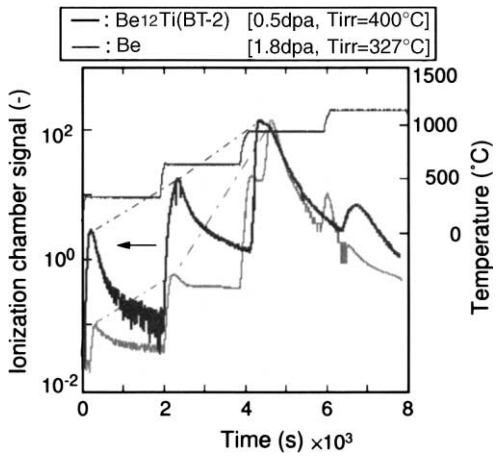

Fig. 5. Comparison of tritium release with beryllium.

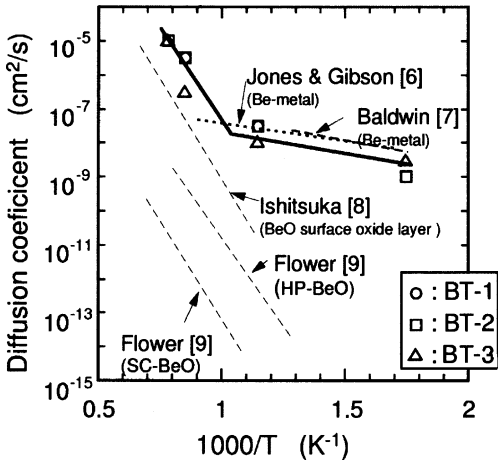

Fig. 7. Apparent diffusion coefficient of $Be_{12}Ti$.

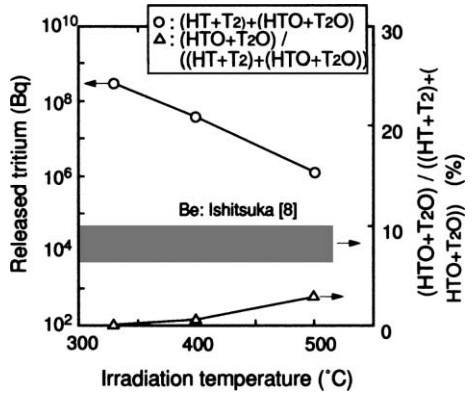

Fig. 6. Relationship between tritium release amount and irradiation temperature.

was about 10% [7], while it was less than 3% for $Be_{12}Ti$ disk specimens. It is clear that some effects of the surface affect this phenomenon. Further studies are needed.

The apparent diffusion coefficients determined by curve fitting is shown in Fig. 7 [5]. Tritium diffusion coefficients of $Be_{12}Ti$ in the temperature range of 300–600 °C show almost the same value as those of Jones and Gibson [8] or Baldwin and Billone [6] for beryllium. In the range of 600–1100 °C, the gradient is almost the same as in case of beryllium with a beryllium oxide layer measured by Ishitsuka et al. [5] and in the beryllium oxide reported by Flower et al. [9]. The diffusion coefficients are 1–2 orders larger than in beryllium with an oxide layer and 4–7 orders larger than in beryllium oxide.

This phenomenon might show that the tritium release of $Be_{12}Ti$ at high temperature depends upon the tritium release at the surface and that at low temperature depends upon the tritium diffusion inside the material. The thickness, the chemical composition and the structure of the surface oxide layer (BeO) might cause this phenomenon. The appearance of the specimen before and after heating up to 1100 °C was observed to compare the surface between $Be_{12}Ti$ and beryllium. It was observed

Table 2
Swelling of neutron-irradiated $Be_{12}Ti$ disks

Specimen	T_{irr} (°C)	After irradiation $\Delta V/V$ (%)	After heating $\Delta V/V$ (%)
BT-1	330	0.8	0.8
BT-2	400	1.0	1.5
BT-3	500	0.5	1.3

that a white oxide layer has formed on the surface of beryllium by heating up to 1100 °C. However, no significant change was observed for $Be_{12}Ti$ after heating up to 1100 °C. It is obvious that $Be_{12}Ti$ is hard to be oxidized compared with beryllium. It is considered that the small oxide formation might affect the tritium release property. It is desirable to analyze the surface structure in detail to make clear the cause of this characteristic phenomenon. This information will contribute to understand the tritium properties in beryllides.

Swelling of neutron-irradiated $Be_{12}Ti$ disk calculated from the dimension and weight is shown in Table 2. The swelling was less than 2%. Similar experiments for neutron-irradiated beryllium disks had been performed, and it was reported that the maximum swelling after heating up to 1200 °C was 60% [8]. From these results, swelling of $Be_{12}Ti$ under high-temperature neutron irradiation is expected to be smaller than that of beryllium. It is considered that high strength at high temperature might be the cause of low swelling or it is also considered that He retention might be low. Neutron irradiation tests at high temperature are needed to make clear this cause.

4. Conclusion

The tritium release properties for neutron-irradiated $Be_{12}Ti$ disk specimens were studied. $Be_{12}Ti$ showed some advantages in comparison with Be and the following conclusions were obtained:

- The tritium inventory of $Be_{12}Ti$ was lower than that of beryllium.
- The characteristic phenomenon concerning tritium release might depend upon the surface oxidation and the oxidation was lower than that of beryllium (visual inspection). It is desirable to study the surface structure to make clear the mechanism of tritium release of $Be_{12}Ti$.
- According to the obtained results, the swelling of $Be_{12}Ti$ might be much lower than that of beryllium. The neutron-irradiation test is hoped to confirm the behavior.

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