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Hydrogen retention of carbon dust produced in JT-60

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Abstract

Hydrogen retention of dust produced by hydrogen discharges from June 1987 to October 1987 in JT-60 was measured to contribute for the estimation of in-vessel tritium inventory in the next generation of fusion reactor, such as ITER. After venting the vacuum chamber, several types of dust-like pieces, i.e. flake-like carbon dust, graphite, and metal pieces, were found in the vacuum vessel. The amount of retained hydrogen in flake-like carbon dust was two orders of magnitude larger than that in the graphite and metal pieces. However, the hydrogen concentration of flake-like carbon dust was 0.04 in the atomic ratio of H/C, which was one order of magnitude smaller than that of carbon flake produced in JET. One of possible explanations is the difference of the wall temperature between JT-60 and JET.

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Keywords: Carbon dust; Hydrogen retention; JT-60

1. Introduction

Carbon fiber composite, beryllium and tungsten are employed for plasma facing materials in International Fusion Experimental Reactor, ITER [1,2]. These materials are eroded by the bombardment of high-energy particles and high heat load, and then accumulated as dust in the vacuum vessel. Tritium retention of carbon dust has been predicted to be large, so it is necessary to investigate the hydrogen retention of carbon dust [1]. Carbon dust has been observed in many fusion devices, but the hydrogen retention has been reported for a few cases, JET [3] and TEXTOR [4]. Control of the in-vessel tritium inventory has been regarded as one of the critical issues for the evaluation of the potential hazard of ITER [1,5].

In this study, the hydrogen retention of the dust produced by hydrogen discharge in JT-60 was measured. Surface morphology and atomic composition were also examined for characterizations of the dust. In addition, the carbon dust samples were also prepared by using deuterium arc discharge with carbon electrodes to discuss the relation between the hydrogen retention of carbon dust and the wall condition.

2. Experimental

A hydrogen discharge experiment with 639 shots was carried out in the JT-60 from June 1987 to October

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Table 1
Operation parameters and wall materials of JT-60

Operation period	June to October, 1987
Divertor configuration	Outer divertor
First wall material	TiC coated Inconel 625, TiC coated Mo
Limiter material	Graphite
Divertor material	
Number of shots (normal/abnormal)	639/222
Plasma current	2.7 MA
Baking temperature	573–623 K
Discharge cleaning	Glow discharge cleaning and pulsed discharge cleaning
Hydrogen pressure in divertor region	0.01–0.5 Pa
Wall temperature	≧523 K[a]

[a] It was assumed that the divertor tiles were heated to a temperature above 2000 K.

1987. The main operation parameters are summarized in Table 1 [6–8]. After venting the vacuum chamber, several types of dust-like pieces were found in the vacuum vessel, flake-like dust, graphite, and metal pieces. The sampling positions for these pieces are shown in Fig. 1. The flake-like dust was collected at position A, on the liner opposite the divertor tiles. The graphite and metal pieces were collected in the divertor region at position B.

The amount of retained hydrogen was measured by thermal desorption spectroscopy, TDS [9]. The sample was heated from room temperature to 1273 K with a constant heating rate of 0.5 K/s with a holding time at 1273 K for 30 min in a vacuum ($\sim 10^{-4}$ Pa). The desorption rate of gases was measured by a quadrupole mass spectrometer (QMS). The quantification of hydrogen was based on the measurements for species with masses; 2 (H_2) and 15 (CH_4). The graphite piece samples were prepared by cutting 1 mm into the surface, since hydrogen is mainly trapped in the surface layer [11].

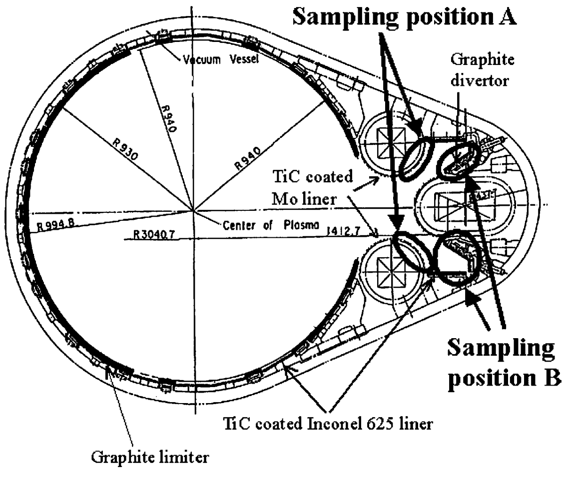

Fig. 1. Sampling positions of dust-like pieces in JT-60.

The surface morphology was examined by scanning electron microscope (SEM), the atomic compositions by Auger electron spectroscopy (AES), and the crystal structure by Raman spectroscopy.

In addition, the authors also prepared carbon dust samples by using D_2 arc discharge with carbon electrodes. The carbon electrodes were sublimated during the arc discharge and then the carbon dust samples were co-deposited with deuterium on a molybdenum substrate. The deuterium gas pressure was varied from 0.06 to 4.0 Pa and the substrate temperature was varied from 300 to 873 K. Experimental details were shown in Refs. [10,12].

3. Results and discussion

A SEM photograph of flake-like dust is shown in Fig. 2. The flake-like dust had a columnar structure, with a size and thickness of several mm and 20 μm, respectively. The major content was carbon (see Table 2). Raman spectrum of flake-like dust is shown in

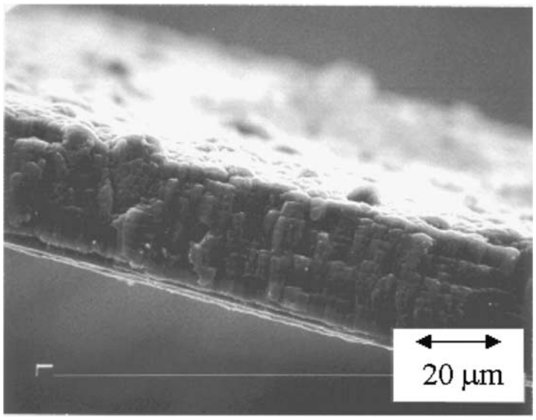

Fig. 2. SEM photograph of flake-like dust.

Table 2
Atomic compositions of the dust-like pieces produced in JT-60

	Atomic composition (at.%)							
	C	Ti	Fe	Cr	Ni	Mo	Nb	O
Flake-like dust	100–99	0-1	–	–	–	–	–	0–1
Graphite piece								
Surface (a)[a]	90	–	3	2	1	1	–	3
Surface (b)[b]	98	–	–	–	–	–	–	2
Bulk	100	–	–	–	–	–	–	–
Metal piece	8	–	–	25	46	–	2	13

[a] Deposition dominated surface.

[b] Erosion dominated surface.

Fig. 3. For the comparison, Raman spectra of carbon dust samples prepared by D_2 arc discharge were also shown in this figure. The spectrum of carbon dust sample prepared at 300K had a single peak at around $1520\,cm^{-1}$, which is a typical peak for hydrogenated amorphous carbon [13]. As the substrate temperature was increased up to 850K, two peaks appeared at around $1580\,cm^{-1}$ (G-band) and $1360\,cm^{-1}$ (D-band). G-band and D-band are attributed to graphite crystal structure and defect structure of graphite, respectively [14]. Thus, the crystal structure of carbon dust samples became graphite-like with increase of substrate temperature. The flake-like dust deposited on the wall with temperature higher than 523K. The spectrum of flake-like dust was similar to that of the carbon dust prepared by the arc discharge at 573K. Then, the structure of flake-like dust was roughly consistent with that of the carbon dust. From the results of the surface morphology, the atomic composition and the crystal structure of flake-like dust, it is assumed that the flake-like dust was produced by the sublimation of graphite tile at the divertor.

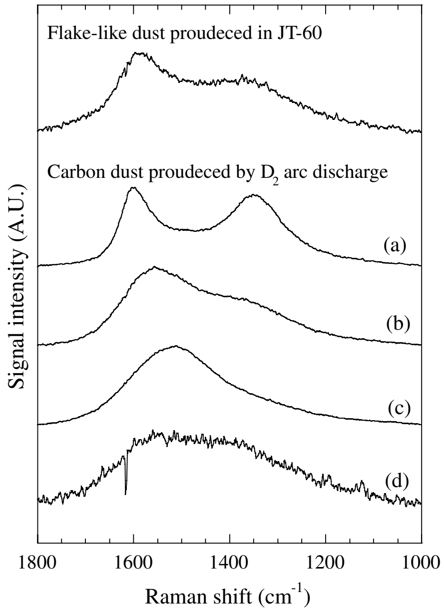

Fig. 3. Raman spectrum of flake-like dust. Raman spectra of carbon dust samples produced by deuterium arc discharge were also shown; (a) deuterium gas pressure is 1.6Pa and wall temperature is 850K, (b) 1.6Pa and 573K, (c) 1.6Pa and 300K, (d) 0.06Pa and 573K.

The graphite pieces were produced by cracking of the divertor tile due to thermal shocks during plasma disruptions. The size of the graphite piece was from one to several tens of millimeters. The SEM photograph (Fig. 4) shows that the graphite pieces had two different surface morphologies, (a) a deposition-dominated surface and (b) an erosion-dominated surface. The deposition-dominated pieces (a) had a thick deposition layer and metal deposits of a few atomic percents of Fe, Cr, Ni, and Mo (see Table 2). In the erosion-dominated piece (b), the surface morphology was rougher than that of the deposition-dominated piece and no metal deposition was observed.

A SEM photograph of a metal piece (Fig. 5) shows that this piece consists of molten metal. The metal piece consisted of elements such as Ni and Cr (see Table 2). It is possible that the metal piece was produced by the melting of Inconel 625, which was used as the first wall material in JT-60.

The amounts of retained hydrogen in the dusts produced in JT-60 are shown in Fig. 6. These values include the hydrogen absorbed from the atmosphere after air ventilation. In the case of flake-like dust, the hydrogen concentration in the atomic ratio of H/C was obtained based on the assumption that retained hydrogen distributed uniformly in the entire region of sample. The retained amounts of carbon flake produced in JET [3] and TEXTOR [4] are shown in Fig. 6. The amount of retained hydrogen in the flake-like dust was two orders of magnitude larger than that in the pieces of graphite and metal. The hydrogen concentration of flake-like dust was 0.04 in the atomic ratio, H/C. This value was

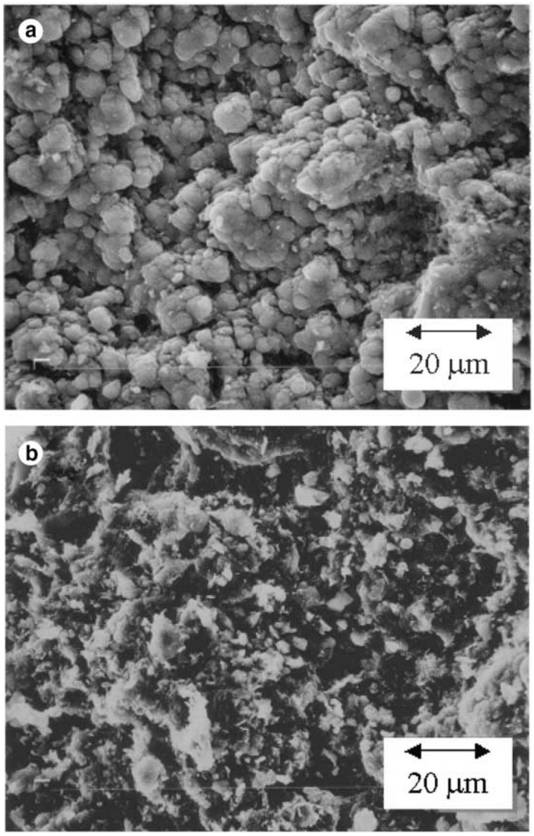

Fig. 4. SEM photographs of deposition-dominated (a) and erosion-dominated (b) graphite pieces.

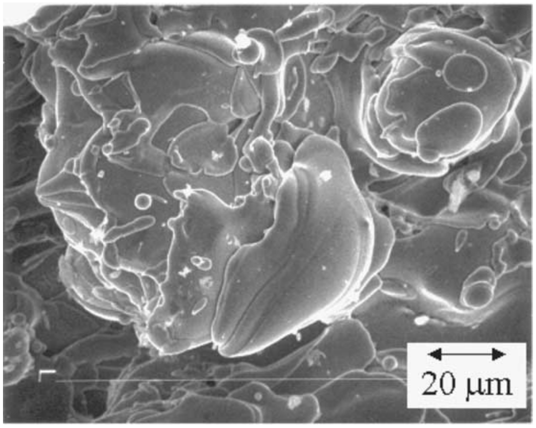

Fig. 5. SEM photograph of metal piece.

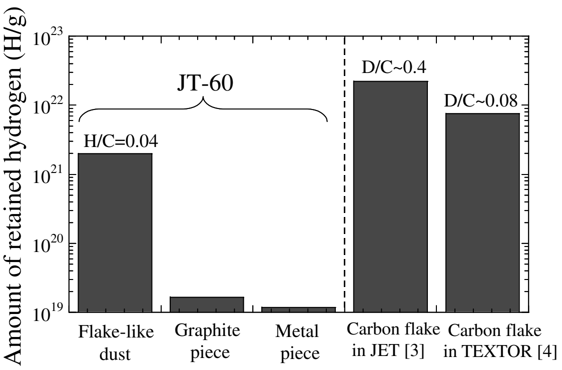

Fig. 6. Amount of retained hydrogen in the dust-like pieces produced in JT-60 and other devices.

comparable with those in re-deposited layer on divertor tiles in JT-60 [15] and carbon flake produced on ALT II limiter in TEXTOR. However, this value was one order of magnitude smaller than that of the carbon flake produced in JET. The temperatures of wall with deposition of carbon dust in JT-60 and TEXTOR were higher than 523 K and higher than 623 K [4], respectively, while the wall temperature in JET was low, 300–423 K since the position deposited carbon flake was cooled by water and shadowed from the plasma [3]. The difference of wall temperature is one of possible reasons that the hydrogen concentration of the flake-like carbon dust in JT-60 was much smaller than that in JET. In the case of carbon dust samples prepared by deuterium arc discharges, the deuterium concentration in the atomic ratio, D/C, decreased with the increase of the wall temperature as shown in Fig. 7. The deuterium concentrations were 0.33 and 0.12 when the substrate temperatures were 300 and 850 K, respectively, when the gas pressure was 1.6 Pa. This result indicates the hydrogen concentration of carbon dust depends on the wall temperature.

In the graphite pieces, the amount of retained hydrogen was very small since the divertor temperature might have exceeded 2000 K during the disruption. The

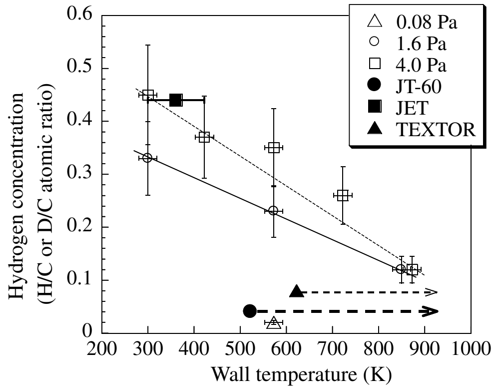

Fig. 7. Relation between the deuterium concentrations of carbon dust produced in current fusion devices and produced by deuterium arc discharge, and the wall temperature. The condition of carbon dust was shown below, JT-60; wall temperature: >523 K and hydrogen gas pressure: 0.01–0.5 Pa, JET; 300–423 K [3], TEXTOR (Inconel liner); >623 K [4].

amount of retained hydrogen in the metal pieces was also small since the temperature was similarly higher.

4. Conclusion

Several types of dust-like pieces, i.e. flake-like dust, graphite, and metal pieces, were found in JT-60 after hydrogen discharge campaigns. The amount of retained hydrogen in the flake-like dust was two orders of magnitude larger than that in the graphite and metal pieces. The hydrogen concentration in the atomic ratio, H/C, of the flake-like dust in JT-60 was 0.04, which was one order of magnitude smaller than that in JET. One of the explanations for this difference is the difference of the wall temperature. The additional experiment by using deuterium arc discharge indicates the hydrogen concentration of carbon dust depended on the wall temperature. The present data may be useful for the estimation of tritium inventory in ITER.

Acknowledgments

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