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Estimation of Graphite Dust Production in ITER TBM

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1. Introduction

The estimation of graphite dust production in a pebble bed was studied in two directions. First, a pebble is modeled to be a rigid sphere and multiple pebbles were analyzed simultaneously using DEM(Discrete Element Method). This scheme uses simple equations and the calculation time is much less than others. However, the contact equation requires a specially tuned material properties and instability of system matrix were reported[1,2]. Second, only a couple of pebbles were modeled using FEM(Finite Element Method) and appropriate boundary and loading conditions are imposed[3]. This scheme gives a detailed information of stress distribution of the pebbles and the stability of calculation is well established. However, the calculation cost is fairly high and only a few pebble can be analyzed in detail at a time with specifically assigned contact conditions.

In this study, a prediction model of graphite dust production in ITER(International Thermonuclear Experimental Reactor) TBM(Test Blanket Module) using FEM was introduced and the amount of dust production for an operation cycle was estimated.

2. Methods and Results

2.1 Dust Production Prediction Equation

The amount of dust production by abrasion of two materials is typically predicted using Archard adhesive wear equation[2] below.

$$V = K_{ad}\frac{N}{H}L \quad (1)$$

where, V is wear volume, K_{ad} is a dimensionless wear constant, N is normal contact force, H is wear pressure which is typically hardness of the softer material in contact, L is the slip distance during contact. For the graphite material, K_{ad} and H are proposed to be used with the values of 0.155 and 55 GPa.

2.2 Analysis Domain and Loading Condtions

In ITER project, the shape and size of the proposed TBM is shown in Fig. 1. By the neutron flux generated in the reactor core, H2 is produced in the breeding zone. In the reflector zone, graphite pebbles of 1 mm-diameter are filled and reflect the neutrons. The analysis domain in consideration is the graphite reflector zone as shown in Fig. 2. Fig. 3 shows the temperature profile of the analysis domain. In the graph, T_center and T_side are temperature at the center point and at the sides of in x-y cross-section of the domain respectively. The sizes in Fig. 1 and Fig. 2 are different. The information in Fig. 2 is the recent data from ITER TBM team.

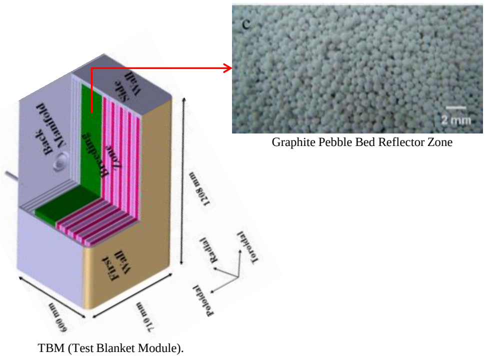


Fig. 1. ITER TBM(Test Blanket Module).

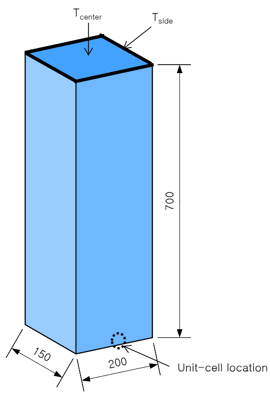


Fig. 2. Analysis domain of graphite reflector zone.

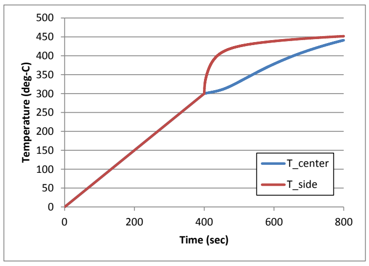


Fig. 3. Temperature profile.

2.3 Finite Element Modeling

FE analsys was performed to estimate the normal contact forces and slip distances. A commercial FE program, Abaqus V6.10, was used in this study. A unit-cell model in which a center pebble is surrounded by 12 exterior pebbles was modeled as shown in Fig. 4. To impose a conservative loading condition, three lower pebbles was placed on a flat surface and their center points are kept in same positions. Symmetric conditions were imposed on the symmetry surfaces of six middle pebbles. Three upper pebbles had constraints in rotation and the center points kept moving in only vertical direction. The dead-weight of the all the pebbles stacked on the unit-cell was calculated and imposed on the symmetry surfaces of the upper pebbles of the unit-cell. To impose the largest dead-weight and temperature, the unit-cell was assumed to be placed on the bottom and the middle end of the x-axis as shown in Fig. 2. At this location, the dead-weight is 0.752 g from 807 pebbles which are stacked on the unit-cell, and the temperature distribution is between 451.5 C° and 451.8 C°at the end of the operation cycle.

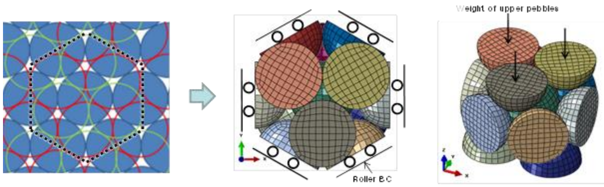


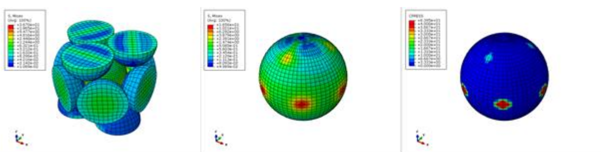
Fig. 4. Unit-cell definition and finite element model.

The material was assumed to be IG-110 nuclear-grade graphite of Toyo Tanso. The maximum neutron fluence was estimated to be 1 dpa by ITER TBM team and the material properties[5] of 1 dpa were applied in the FE analysis.

2.4 Analysis Result

The FE analysis was done by Abaqus Standard solver. The temperature variation was nonlinear in time and a user-subroutine, UTEMP, was programmed to apply the nonlinearity.

In Fig. 5, it shows Von Mises stress and normal contact pressure when the friction coefficient of graphite is 0.5. The center pebble contacted all 12 surrounding pebbles. Fig. 6 shows the wear mass per volume changes versus time when the friction coefficients of graphite were 0.3, 0.5, and 0.7. In the figure, in the warming-up (before 400 sec), the wear increase smoothly and the amount is almost 50% of the total wear. During the breeding operation (after 400 sec), a rapid increase of wear appeared at first caused by the temperature increase. At the middle of operation (800 sec), the wear amount showed saturation. Table I showes summary of the result. The center pebble produced 1.57~2.60e-13 g of dust. For explosion prediction, mass per volume is required. The values were 2.22~3.67e-4 g/m^3 when the amount of dust production was assumed to be same as in the center pebble of the unit-cell in all reflector region which was expected to be a conservative result and the value is too much small for a dust explosion.



(a) Von Misses stress　　(b) Normal contact pressure

Fig. 5. Von Mises stress and contact pressure distribution.

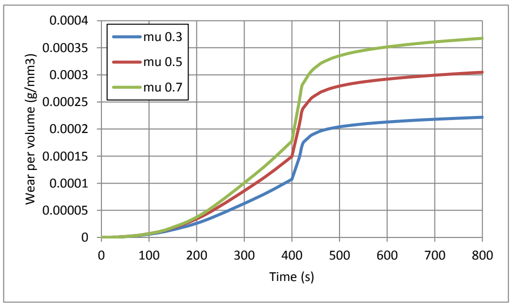


Fig. 6. Wear per volume in the graphite reflector zone of TBM (friction coefficient=0.3, 0.5, 0.7).

Table I: Summary of wear per volume in the graphite reflector zone of TBM.

Friction coefficient	0.3	0.5	0.7
Wear per pebble (mm^3)	8.81E-11	1.21E-10	1.46E-10
Graphite density (g/mm^3)	1.78E-03		
Wear per pebble (g)	1.57E-13	2.15E-13	2.60E-13
No. of pebbles per unit-cell	8		
Wear per unit-cell (g)	1.25E-12	1.72E-12	2.08E-12
Volume of unit-cell (m^3)	5.66E-09		
Wear per volume (g/m^3)	2.22E-04	3.05E-04	3.67E-04

3. Conclusions

In this study, graphite dust generation in the reflector zone of ITER TBM was estimated using FE analysis. A unit-cell model was defined to simulate normal contact forces and slip distances on contact points between the center pebble and the surrounding pebbles. The dust production was calculated using Archard equation. The simulation was repeated with different friction coefficient of graphite material to investigate the effect of friction on the dust production. The calculation result showed that the amount of dust production was 2.22~3.67e-4 g/m^3 which was almost linearly proportional to the friction coefficient of graphite material. The amount of graphite dust production was considered too much small for a dust explosion.

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