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FEM analysis of volumetric expansion in the pebble bed

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1. Introduction

In fusion reactor, the role of breeders is the tritium production for nuclear reactions. Breeder is classified into liquid type and solid type, and solid type is made of pebble type. Generally, the allowable temperature of the pebble is 920 degrees, which is the evaporation temperature of lithium [1]. CFD analysis was carried out by applying the heat transfer enhancement idea in order to satisfy the temperature requirement [2]. Li_2TiO_3 pebble bed will be studied and manufactured by National Fusion Research Institute research group. The produced pebbles will function as the breeder in Korea Helium Cooled Ceramic Reflector Test Blanket Module (HCCR-TBM). The physical & thermal properties of the Li2TiO3 pebble was measured with the pebble made under current research state. As shown in Fig. 1, it was found that the sintering occurred between pebbles about 800C and particles stuck together. Pressure is one of the main factors that determine the starting temperature of sintering [3]. The higher the pressure on the pebble, the lower the temperature at which sintering begins. Pressure is directly related to mechanical stress occurring in the pebble. It is necessary to analyze the mechanical stresses arising under the actual operating conditions of the pebble and to estimate the starting temperature of the sintering. In this work, the distribution and the characteristics of stress generated in the pebble bed were studied by the FEM analysis in order to confirm the deformation and damage of the pebbles.

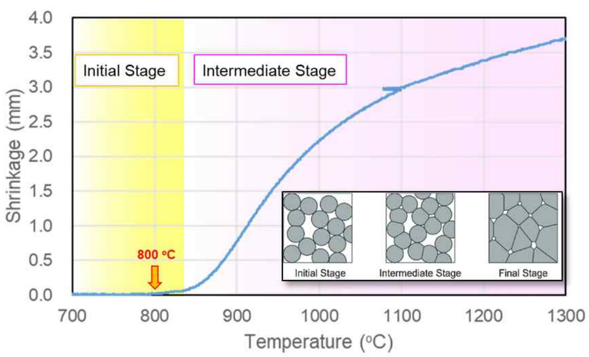


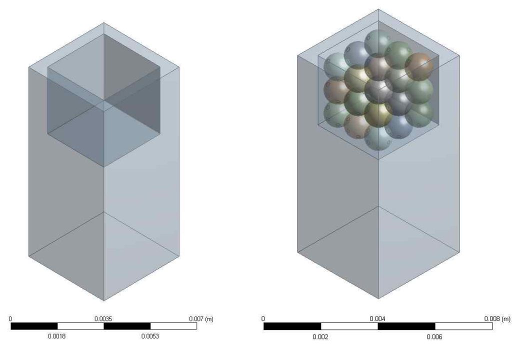
Fig. 1. Li2TiO3 pebble bed shrinkage according to the temperature

2. FEM analysis

In this work, FEM analysis using commercial code ANSYS was performed. Millions of Li_2TiO_3 pebbles are used in HCCR TBM. Modeling an actual shape is limited. The purpose of this study is to confirm the distribution and characteristics of stresses in the pebble. The physical & thermal properties of produced Li_2TiO_3 pebble bed were used.

2.1 Geometry

In order to distinguish the influence of the pebble shape, the analysis was performed in two shapes reflecting the actual pebble size and a box shape as shown in Fig. 2. The size of the simulated space of the Pebble is 3 x 3 x 3 mm. The pebble was assumed to be 1 mm. 27 pebbles are stacked in a simple cubic structure in the same space as the box.



(a) Box type (b) pebble type
Fig. 2. Geometry model

2.2 Material

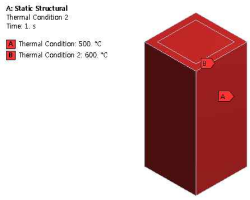
Reduced activation ferritic/martensitic (RAFM) steels are used to reduce the amount of long-lived radioactive waste in the fusion reactor. The pebble containing structure was selected as RAFM steel in the analysis. The material of the pebble was selected as Li_2TiO_3. Li2TiO3 is a kind of ceramic breeder and used as breeder in KO HCCR TBM [4]. Table 1.1 shows the thermal expansion coefficients of RAFM and Li_2TiO_3.

Table I: Problem Description

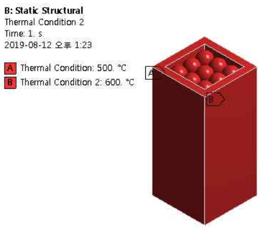
	Thermal expansion coefficient (/K) at 500 ~ 600 C
RAFM	1.23×10^{-5}
Li_2TiO_3	1.6×10^{-5}

2.3 Constraint condition

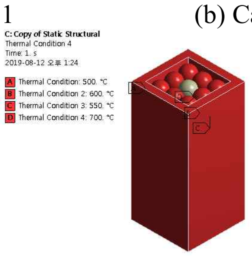
The pebble and the structure containing the pebble only reflect specific temperature conditions. Because Breeder reacts with neutrons and generates heat, the temperature is set higher than that of the structure. As shown in Figure 3, the pebble was set at 600 C and the structure was set at 500 C. In addition, since a higher temperature is formed inside the pebble bed than the outside, the analysis is also performed with a model that reflects such temperature characteristics. There is no condition for internal pressure or external force on the pebble and structure. The contact condition between the pebble and the box as well as between the pebbles was set to frictional, and the value was set to 0.3.



(a) Case 1



(b) Case 2



(c) Case 3

Fig. 3. Temperature condition

2.4 Result

Figure 4 shows the maximum stresses occurring in the pebble. When the pebble was simulated in a box type, low stress was generated in the outside exposed area. It can be seen that stress concentration occurs at the corners. The actual pebble model shows different stress distributions. High stress values occur at the contacts between the pebbles and between the pebbles and the wall. High stress values occur at the contacts between the pebbles and between the pebbles and the wall. Higher stress values occur at higher temperatures region. This is because the higher the temperature, the larger the volume expansion occurs.

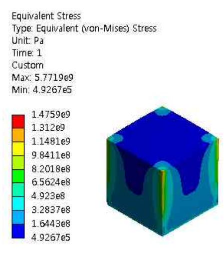
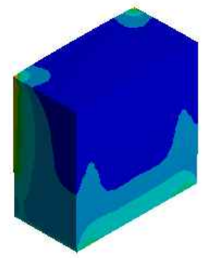
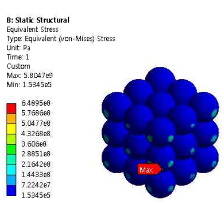
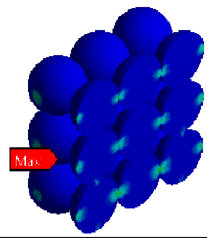
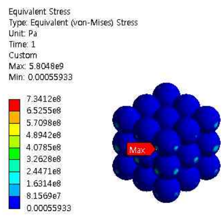
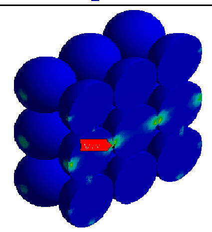
	Stress distribution	
	Maximum value	Section view
Case 1		
Case 2		
Case 3		

Fig. 4. Stress distribution

3. Further work

FEM analysis confirmed the stress distribution in the pebble bed. Since the coefficient of thermal expansion of the pebble is larger than that of the structure surrounding the breeder, high stress concentrations occur at the contacts of the pebbles. As a result, the valid stress distribution was confirmed in the analysis. A qualitative evaluation of the damage of the pebble according to the stress value will be performed. By comparing the values obtained from the analysis results with the experimental results as shown on Fig. 5, an appropriate temperature for the breeder pebble in KO HCCR TBM environment will be studied.


(a) 1 MPa


(b) 2 MPa


(3) 3 MPa

Fig. 5. Sintered Li2TiO3 sample

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