The Thermal Conductivity Dependence on the Microstructure in Porous B_4C absorber for Control Element Assembly

Oh-Hyun Kwon *, Hyun-Jun Kim, Hong-Jin Kim, Jung-Cheol Shin
KEPCO Nuclear Fuel Co. Ltd., 989beon-gil 242, Daedeok-daero, Yuseong-gu, Daejeon 305-353, Korea
KW Nuclear Components Co. Ltd., 989beon-gil 242, Daedeok-daero, Yuseong-gu, Daejeon 305-353, Korea
**Corresponding author: ohkwon@knfc.co.kr*

1. Introduction

Generally, The CEA (Control Element Assembly) has the functions as follows. In conjunction with the fuel assemblies and reactor internals, CEA supports and locates the neutron absorbing material so that all clusters (fingers) move as required for both insertion and withdrawal. And it contains the nuclear poison material and activation products produced by irradiation of the poison material without CEA cladding failures. It supports and locates the poison material such that its location with respect to the CEA extension shaft (the position of which is tied to the CEA position) is maintained. It limits the magnitude of stresses and the range of stresses for cyclic conditions to values which will not result in damage to any piece of the control element assembly to an extent which would preclude satisfaction of functional requirements. Lastly, it provides sufficient negative reactivity insertion and insertion rate (through scram capability) for adequate control and shutdown of the reactor for specified conditions.

The CEA consists of a cluster of control rods attached to a spider assembly. The spider has a specially machined hub to engage the extension shaft of the control element drive mechanism. The control rods consist of a length of neutron absorber (B_4C pellets) enclosed in hermetically sealed tube as shown in Fig. 1.

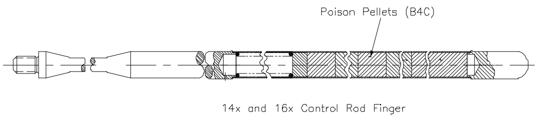

Fig. 1. The Typical Control Rod Configurations for KSNP

The neutron absorber material is boron carbide (B_4C) that is in the form of cylindrical pellets which are stacked within the cladding. In addition to standard poison pellets, short poison pellets are used at the upper end of the stack to control stack length, while reduced diameter pellets are used at the lower end of the stack to interface with the feltmetal.

The boron carbide is used as a neutron absorber material in the fingers of the CEA in the form of sintered pellets (73% of theoretical density). The melting temperature of boron carbide has been measured to be 2450^{o}C at unirradiated condition. Change in composition of the boron carbide due to the depletion of B-10 results in decreasing the melting temperature of boron carbide. Therefore, it is required to evaluate that the boron carbide remains well below the melting point during irradiation. In general, the temperature depends on the thermal conductivity. Therefore, for the calculation of temperature, the thermal conductivity model is required. However, generally accepted current thermal conductivity model does not consider well the microstructure of boron carbide.

The theoretical thermal conductivity of boron carbide is well known as 0.07 cal/cm·s·K at room temperature. Generally, the thermal conductivity decreases as the true density decreases. Therefore, theoretical thermal conductivity (0.07 cal/cm·s·K) is not applicable to the boron carbide which has 73% of theoretical density. The main reason for the thermal conductivity drop seems that the pores act as the barrier which restricts the heat flux. In this study, three kinds of the thermal conductivity models are suggested depending on the pore morphology and fraction of pores in a boron carbide matrix. The suggested models should be studied furthermore for the applicability to the evaluation of boron carbide temperature.

2. Composite Models

The conductivity dependence on the microstructure is well established in the previous studies [1,2]. According to the study, the conductivity depending on the microstructure of two composite could be classified as three models. Each model relating to the composite microstructure is shown in Fig.2, Fig.3 and Fig.4. According to the Bruggeman's asymmetric composite microstructure shown in Fig.2., the asymmetric conductivity model is expressed as equation 1 below. In this model, the form of pores seems to be oval shape. Secondly, the intermediate wetting composite microstructure model is shown in Fig.3. The relating conductivity model is suggested as equation 2. In the model, the pores form sharp shape. Thirdly, the Bruggeman's symmetric composite microstructure is shown in Fig.3. In the model, pore shape seems to be polygonal. The conductivity model is suggested as equation 3. [1,2].

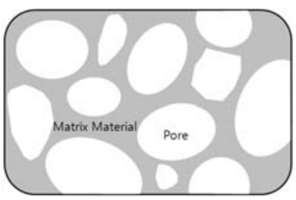

Fig. 2. The Bruggeman's asymmetric composite microstructure

$$\sigma_c = \sigma_m (1 - f)^{3/2} \qquad (1)$$

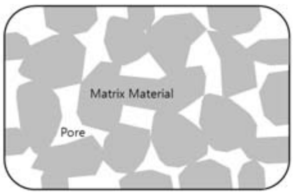

Fig. 3. The Intermediate wetting composite microstructure

$$\sigma_c = \sigma_m (1 - f / f_c)^t \qquad (2)$$

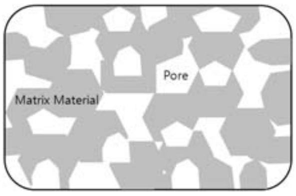

Fig. 4. The Bruggeman's symmetric composite microstructure

$$\sigma_c = \sigma_m (1 - 1.5 f) \qquad (3)$$

Where,

σ_c = Net thermal conductivity of the composite
σ_m = Thermal conductivity of matrix material
f = Volume fraction of pore
t = Percolation multiplier ($1.65 < t < 2$)
f_c = Critical Parameter for bond site percolation (0.16 ± 0.02)

In these models, the matrix material is assumed as dense boron carbide (100% theoretical density) and the thermal conductivity is 0.07 cal/cm·s·K at room temperature. The pores are assumed as fine dispersant vacant particles and do not transfer the heat. Therefore, two composite consists of dense boron carbide and pores and the net thermal conductivity depends on mainly on the morphology and fraction of pores.

3. Results and Discussion

3.1 The microstructure of Boron Carbide composite

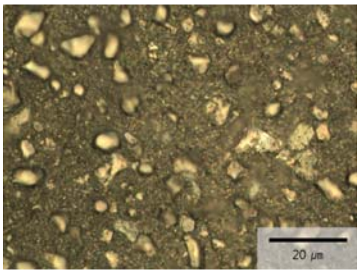

Fig. 5. The Microstructure OM image of boron carbide with 73% of theoretical density (Bright color indicates pores inside the boron carbide)

Fig. 5 shows the microstructure of CEA boron carbide composite. Most of the pores do not connect to the next pore. Therefore, the close pore seems that the boron carbide matrix is not intermediately wetted by the pore. In this case, the composite microstructure seems that the boron carbide matrix and pore consists symmetrically or asymmetrically.

3.2 The net thermal conductivity depending on the pore morphology and fraction

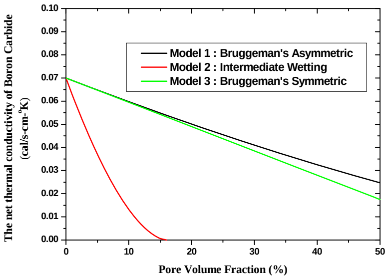

Fig. 6. The net thermal conductivity of boron carbide depending on the microstructure due to the pore morphology and fraction

Fig. 6 shows each of net thermal conductivity in boron carbide composite. The conductivity is plotted based on the relating model equation 1,2 and 3. If the boron carbide matrix is wetted by the pore, the net thermal conductivity decreases rapidly with the pore fraction increase. However, the asymmetric and symmetric matrix material does not show the rapid conductivity drop. Based on the microstructure as shown in Fig.5., it is reasonable to apply the asymmetric or symmetric model to the boron carbide temperature evaluation.

4. Conclusions

The boron carbide is used as neutron absorber in the CEA. And temperature design analysis ensures that the boron carbide remains well below the melting point throughout during irradiation. Since the as-built boron carbide in CEA has approximately 73% theoretical density, the net thermal conductivity is a little different from 0.07 cal/cm·s·K. Based on the microstructure which covers the pore morphology and fraction of pores in boron carbide, the asymmetric or symmetric model is recommended to the CEA. For the more reliable analysis, the applicable net thermal conductivity of boron carbide should be researched with experimental study in the forseeable future.

REFERENCES

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