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CONTACT BEHAVIOR OF KEY/KEYWAY STRUCTURE

S. Takada, M. Futakawa, H. Shirai and T. Iyoku

ABSTRACT

The contact behavior of the key/keyway structure in High Temperature Gas–cooled Reactors (HTGRs) is investigated through combination of analyses and experiments. It was shown that the equivalent stiffness of key/keyway structure depends on contact behavior and the stress concentration is independent of that.

1. INTRODUCTION

The key/keyway structure is used to graphite components to keep their arrangement in HTGRs, as shown in Fig.1[1]. The vibrational characteristics or stress concentration of the graphite components are dominated mainly by the contact behavior between key and keyway. It is, therefore, necessary to investigate the contact behavior of key/keyway structure through combination of analyses and experiments.

To investigate the contact behavior of key/keyway structure and the stress distribution of graphite components around the keyway, experiments were performed using a specified model which was composed of sliced hexagonal graphite blocks connected with through key/keyway structures. The equivalent stiffness of key/keyway structure was derived from the relationship between imposed force and relative displacement.

Analyses using FEM code were taken into account the contact behavior between key and keyway to evaluate the stiffness and stress concentration. Because a surface roughness of graphite affects the contact behavior, the surface roughness is varied as a parameter in this analysis.

2. EXPERIMENTAL METHOD

Experiments were performed using a specified model of key/keyway structure to investigate the stiffness of key/keyway structure and the stress distribution of graphite components around the keyway. The experimental model is composed of a hexagonal slice block and two fixed slice blocks connected with through key/keyway structures, as shown in Fig. 2. The reason why the slice blocks are applied to the experimental model of key/keyway structure is to reduce the analytical representation to two dimensions. The materials of key and keyway are an isotropic graphite IG–11 and a near–isotropic graphite PGX. Table 1 shows the mechanical properties of both IG–11 and PGX graphites.

To measure both the stiffness of the key/keyway structure and the stress distribution around the keyway, a static load was imposed to the graphite block by a hydraulic actuater.

To investigate the stress distribution around the keyway, the fracture experiments of the graphite block are also performed with the experimental model. In the fracture experiments, fracture load is imposed to the graphite block until the fracture occurs around the keyway.

3. ANALYTICAL METHOD

To evaluate the stiffness and the stress distribution of key/keyway structure, the analysis taking account of the contact behavior between key and keyway was performed using a finite element method code ABAQUS[2].

The analytical model is a two-dimensional model in which key and keyway contact each other with a geometrical angle, as shown in Fig. 3. The total node number of the analytical model is 3468 nodes. The numbers of six-node plane strain elements and eight-node plane strain elements employed in the analytical model are 36 and 804, respectively.

The contact behavior was represented by using surface contact elements which take account of an overclosure between surfaces due to a surface roughness of graphite. The value of an overclosure between surfaces was varied from 0 to 100μm as a parameter.

The stress-strain curves for the graphite are assumed to be bilinear relation, that is, Young's modulus E: 10GPa, work hardening coefficient H: 1.94GPa and yield stress σ_y: 42MPa for IG-11, while E: 6.3GPa, H: 2.22GPa and σ_y: 19MPa for PGX. Von Mises yield criterion was also applied to the non-linear relation of the graphite. Additionally, the friction coefficient between graphite surfaces was assumed to be 0.25.

4. RESULTS AND DISCUSSION

4. 1 Equivalent stiffness of key/keyway structure

Figure 4 shows the relationship between the imposed force and the displacement at the center of a hexagonal block relating to the equivalent stiffness of the key/keyway. The equivalent stiffness of the key/keyway structure has nonlinear characteristics due to the contact behavior.

The effect of the contact behavior on the equivalent stiffness was investigated in the analysis which takes account of the contact behavior between key and keyway. The contact behavior was represented by using surface contact elements which consider the overclosure due to a surface roughness of graphite. The value of the overclosure C was varied from 0 to 100μm as a parameter. The equivalent stiffness using the value C=0 indicates the linear characteristics. The nonlinear feature of the equivalent stiffness becomes remarkable as increasing the value C. The equivalent stiffness using the value C=30μm agrees with the experimental results sufficiently.

Figure 5 shows a profile of a surface roughness of a PGX graphite block. The maximum value of the surface roughness is 60μm, and the average value of surface roughness is about 30μm. The value of surface roughness 30μm agrees with the value of an overclosure C between the surfaces of key and keyway. Then it is reasonable that the value of an overclosure is due to the surface roughness of a graphite block.

Figure 6 shows the frequency responses of the acceleration of key/keyway structure. The key/keyway structure has the nonlinear vibrational characteristics in which the jump-down frequency shifts to the higher frequency region as an input acceleration increasing.

The vibrational analyses were performed by employing both linear and nonlinear equivalent stiffness of key/keyway structure. The analytical results of the linear equivalent stiffness were comparatively higher than the experimental ones. The analytical results of the nonlinear equivalent stiffness agree with the experimental ones. It can be said that the analytical results employing a nonlinear stiffness for the key/keyway structure is suitable to predict the vibrational characteristics of the key/keyway structure.

4. 2 Stress distribution around the keyway

Figure 7 shows the analytical result of contour map of the maximum principal stress. The contour map indicates that a high stress concentration appears around the area along the direction of 45° from the bottom of keyway.

Figure 8 shows the relationship between the imposed force and the strain at the point where the high stress concentration appears. Analytical results depicted by lines on the figure represent the experimental ones sufficiently. Strain was almost proportional to the imposed force. This tendency was described by analytical results in spite of the surface roughness which is represented by an overclosure C between key and keyway. The strain at the area where the high stress concentration occurs is not affected by the contact behavior which is characterized by the surface roughness between key and keyway.

Figure 9 shows the sliced block after the fracture. The crack propagates along the direction of 45° from the bottom of keyway. It was confirmed from the fracture experimental result that the high stress concentration exists along the direction of 45° from the bottom of keyway.

The stress distribution acquired from the analysis employing the analytical model which takes account of contact behavior between the key and keyway sufficiently agrees with the experimental one around the keyway where the high stress concentration appears.

5. CONCLUSIONS

As the results of the experiments and analyses, conclusions were summarized as follows,

(1) The equivalent stiffness of the key/keyway structure has the nonlinear characteristics due to contact behavior.

(2) The equivalent stiffness of the analytical results using the surface roughness of 30μm agrees with the experimental results.

(3) The maximum principal stress on the keyway is independent of the contact behavior between key and keyway.

(4) The analytical result employing a nonlinear stiffness for the key/keyway structure is suitable to predict the vibrational characteristics of the key/keyway structure.

ACKNOWLEDGEMENTS

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REFERENCES

1) IAEA Technical reports series No.312, Gas cooled reactor design and safety, Chapter 6., IAEA, Vienna, 1990.

2) ABAQUS User's Manual, Ver. 4.8, Hibbit, Karlsson and Sorensen, INC., 1990.

Table 1 Mechanical properties of graphite material.

	IG-11	PGX
Bulk density(kg/m^3)	1.78x10^3	1.73x10^3
Tensile strength(MPa)	25.3	8.1
Bending strength(MPa)	40.3	14.5
Compressive strength(MPa)	76.8	30.6
Young's modulus(GPa)	7.9	6.5
Grain size(μm)	mean 20	max. 800

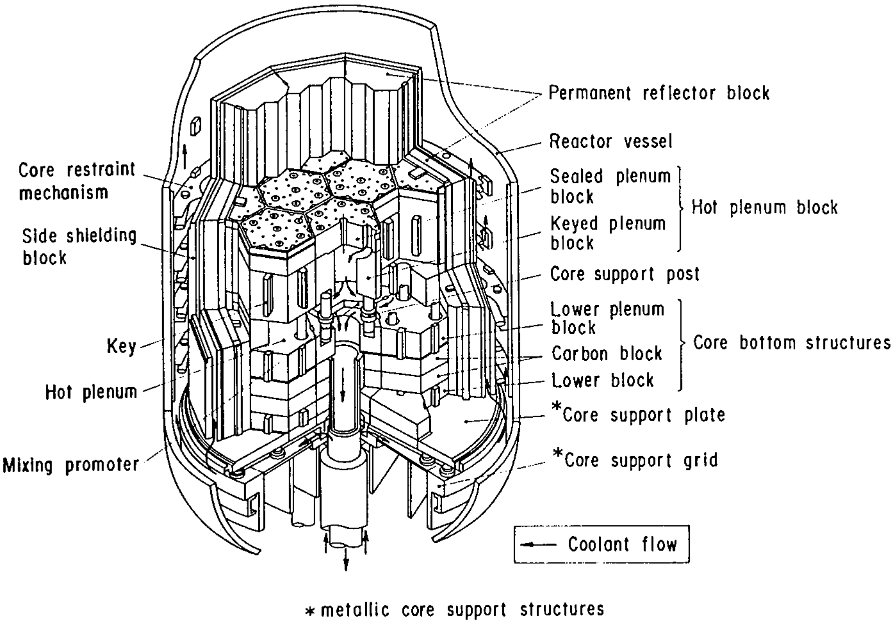

Fig. 1 Graphite components connected with through key/keyway structure in HTGR

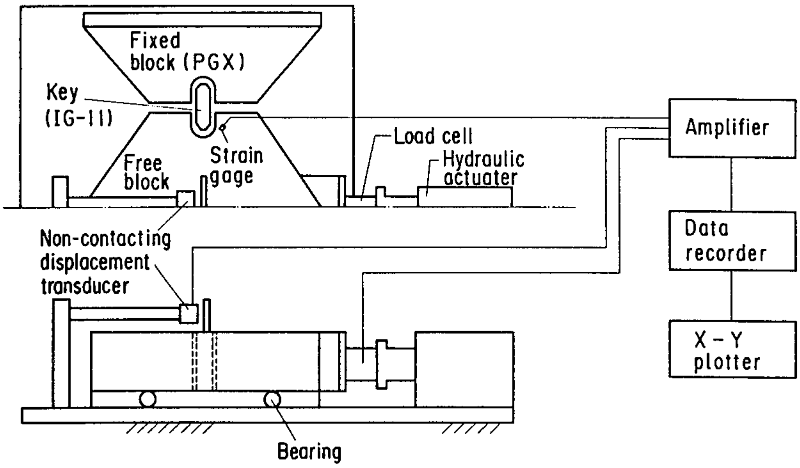

Fig. 2 Schematic drawing of experimental model

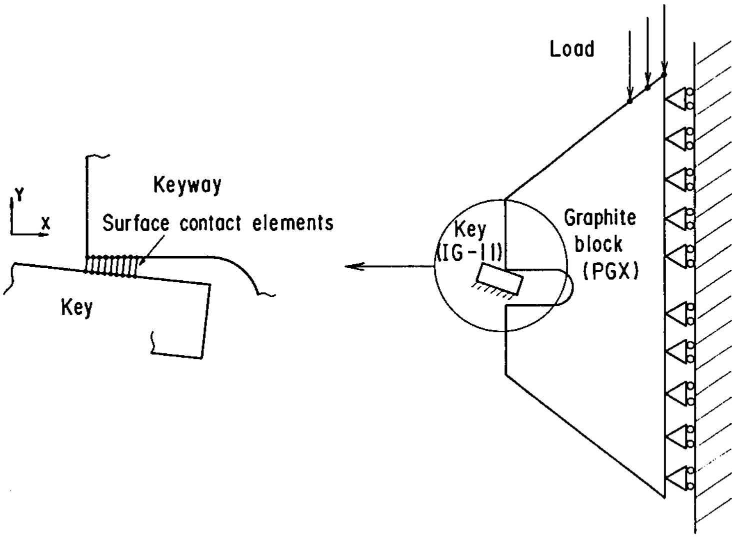

Fig. 3 Schematic drawing of analytical model

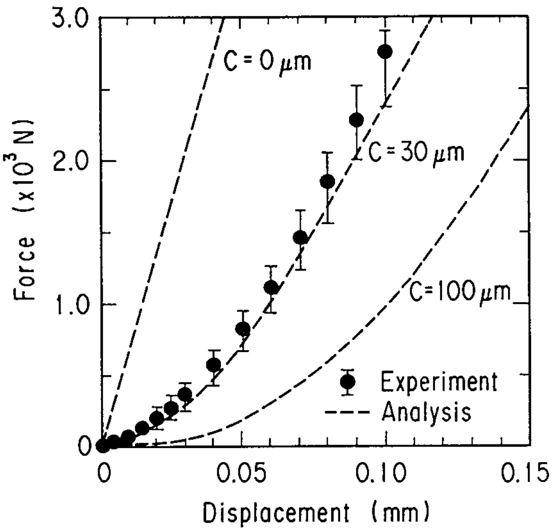

Fig. 4 The equivalent stiffness of the key/keyway structure

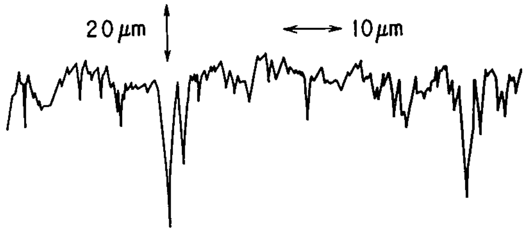

Fig. 5 Surface roughness on the graphite PGX

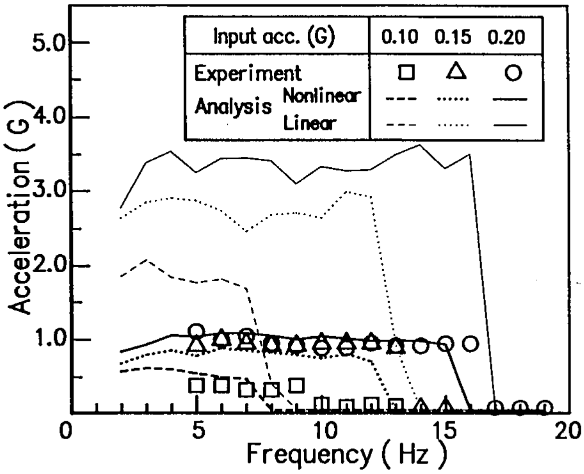

Fig. 6 Frequency responses of the acceleration of key/keyway structure

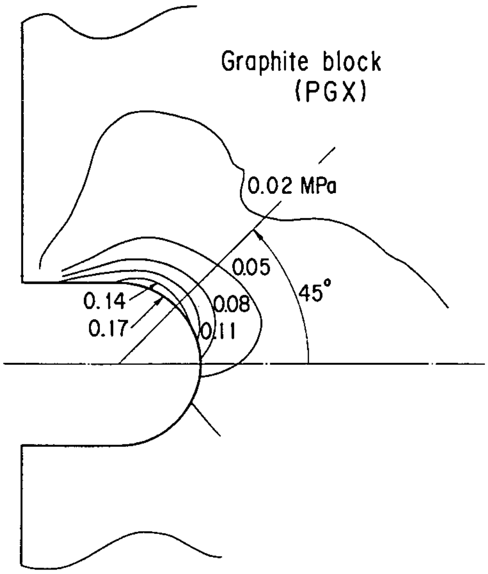

Fig. 7 Contour map of maximum principal stress

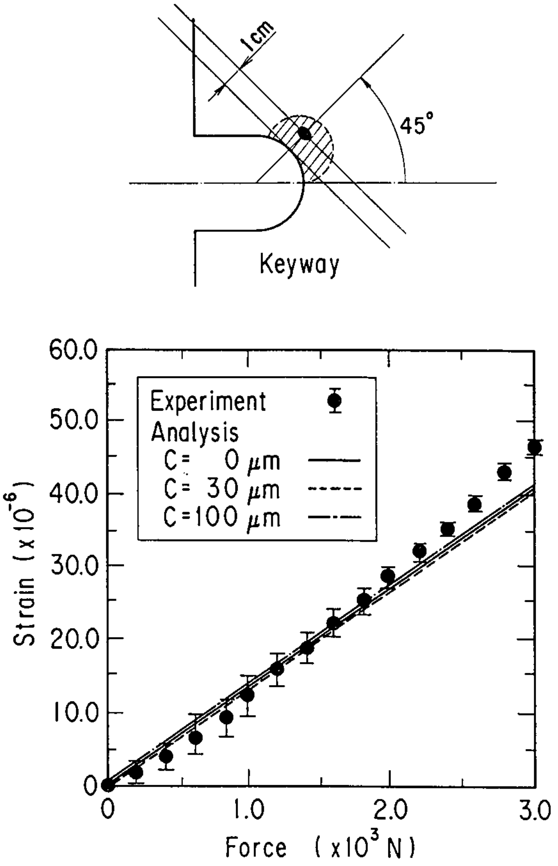

Fig. 8 The relationship between imposed force and the strain at the region where the high stress concentration appears

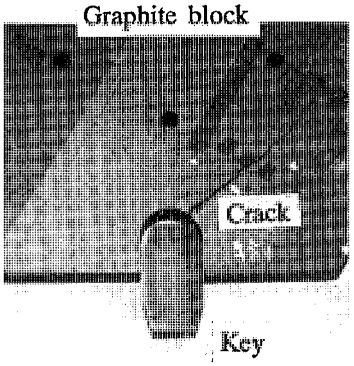

Fig. 9 Sliced graphite block after fracture