Proceedings of the Korean Nuclear Society Spring Meeting
Cheju, Korea, May 2001

Development of Bundle/Duct Interaction Model in KALIMER Fuel

Hee Young Kang, Woan Hwang, Byoung Oon Lee, Young Il Kim

Korea Atomic Energy Research Institute
150 Dukjin-dong, Yusong-gu,
Taejon 305-353, Korea

Abstract

A bundle-to-duct interaction(BDI) model has been developed to analyze structural behaviors of KALIMER fuel duct assembly under irradiation conditions, especially of a wire spaced fuel pin model. This study has been carried out to assess the mechanical integrity of fuel pin design. The fuel pin is modeled by 3-D finite element method with shell and beam model with contact spring. To construct an appropriate pin model, the BDI analyses are performed on the effects of temperature and inner pressure.

1. Introduction

In the design and analysis on the fuel assembly duct for a fast breeder reactor(FBR), there are a number of problems related to irradiation effects during long-term operation. It is described that the utilization of high-burnup capability of

FBR fuels is important to develop the fuel by reducing the fuel cycle cost. However, when fuel burnup is increased, neutron fluence and pin inner pressure are also increased, and then dilation and bowing of the fuel pin bundle could be so large as to mechanically interact with duct wall. This phenomenon is called bundle-to-duct interaction(BDI). Additional cladding strain and hot spots can be caused in an assembly under BDI condition. Therefore the BDI is one of the factors that restrict the lifetime of FBR fuel [1].

The original fuel pins in an assembly before irradiation are changed into the deformed shape after high irradiation[2]. Fuel pins in an bundle are dispersed by interations with the duct inner walls. This rearrangement of pin arrays from straight to twisted shapes with reducing contact forces is called dispersion. Pin oval deformations were also found by post-irradiation examinations, but until now no fuel pin failures were detected despite their large deflections. This fact explains that the structure of FBR fuel assembly is highly resistant BDI. The fuels have a high burnup capability, not only in neutronics performances but also in structural integrity. Therefore, model development of structural analysis code is necessary to predict high burnup fuel performances.

2. Fuel pin model

The straight pin of an array before irradiation is deformed into the wave form after irradiation. As mentioned before, the basic concept of the BDI phenomenon is shown in Figure 1. One fuel pin is modeled by a combination of three-dimensional model structured by the finite element method[3]. A fuel pin is divided into a combination of basic elements as shown in Figure 2. In a sample calculation, a single fuel pin model for three-dimensional elements are adopted because of contact with adjacent pins and the duct wall. The basic element is composed of one shell element which express fuel pin clad stiffness, and four spring elements which expresses fuel pin oval deformation and expansions.

Expansions are considered by the thermal, swelling and creep strains. The expansion strains are introduced as following load conditions:

$$\begin{aligned} u &= u_t + u_s + u_c \\ u_t &= r\alpha\triangle t \end{aligned} \qquad (1)$$

where, r is the initial width of a fuel pin, α is the thermal expansion coefficient, and Δt is the temperature difference.

$$u_s = r\varepsilon_s$$
$$u_c = r\varepsilon_c \qquad (2)$$

where, ε_s is the swelling strain and ε_c is the creep strain.

The ovalling deformation effect of a pin is modeled by the ring with equivalent pin axial length of l_{eq} . The relation between the diameter decrease D and opposite and equal loads p can be expressed by Eq.(3) and the ovalling stiffness K is defined by Eq.(4) and l_{eq} is expressed by Eq.(5).

$$\triangle D = \frac{0.149PR^3}{EI_R} \ (in) \qquad (3)$$
$$I_R = \frac{l_{eq}t^3}{12}$$
$$K_0 = \frac{EI_R}{0.149R^3} \ (lb/in) \qquad (4)$$
$$l_{eq} = 7R \qquad (5)$$

where, R is the radius of a cladding and t is the thickness of a cladding.

The ovalling creep deformation is simply modeled in this study by the spring creep deformation with a spring constant K [4]. The pin cladding is composed by HT-9 material. HT-9 is martensisitic stainless steel. The yield strength of HT-9 is given in Figure 3. The yield strength profile in general behavior is to decrease as the temperature increases.

3. Analysis and the Results

A series of calculations were performed to analyze a single fuel pin model with a combination of shell and beam element. The ANSYS code[5] was applied to a typical fuel pin model to perform its structural analysis under fuel BDI conditions.

The calculated results are shown in Figure 4 where a series of lines indicate the stress intensities of a single pin model corresponding to internal gas pressure. The maximum stress intensities in each temperaure condition(T=400, 500, 600 and 700℃) increase when the internal pressure is increased. Table 1 shows the maximum stress intensities dependent on temperatures.

Figure 5 shows the stress contour of single pin model caused by BDI. The condition is given at the internal pressure P=7 MPa and temperature T=600 ℃. The maximum value in stress intensity is represented at contacted node with adjacent pins and duct wall. The pin model is slightly deformed near the contacted nodes. A comparison of the cladding yield strengths with the stress intensity is shown in Figure 6. It shows that the yield strength is higher than stress intensity around temperature T=600 ℃. This predicts that some areas of the fuel pin could be deformed at high temperature and internal pressure.

4. Conclusion

Through the structural analysis of a fuel pin model in a fuel bundle, a BDI model has been developed to investigate the BDI behaviors for KALIMER fuel duct assembly. eventhough a single model approach is not enough to predict completely the BDI phenomenon, it is considered to be a possible method. The present single model is to enhance the accuracy for predicting the real BDI phenomena, and a new method will be continually developed by further study.

Acknowledgment

This work has been carried out under the national nuclear long-term R&D program which is supported by the Korean MOST(Ministry Of Science and Technology).

References

1. R.J. Jackson et al., Development fuel assembly irradiation experience in EBR-2, Proc. FBR Fuel Performance, Monterey, CA, 1979
2. P.F. Cecchi et al., Life limiting features and technical problems to reach high burn-up in fast reactors fuel, Proc. Reliable Fuels for LMR, Tucson, AZ, 1986
3. Hee Young Kang et al., Development of Structural Analysis Modelling for KALIMER Fuel Rod,Proceedings of the Korean Nuclear Society Spring Meeting Seoul, Korea, May 1998
4. K. Itoh et al., Development of 3-D FBR fuel bundle-to-duct interaction analysis code MARSE, Nuclear Engineerin and Design 148(1994)
5. "ANSYS User's Manual," Revision5.2, Swanson Analysis Systems, Inc. Aug. 1995

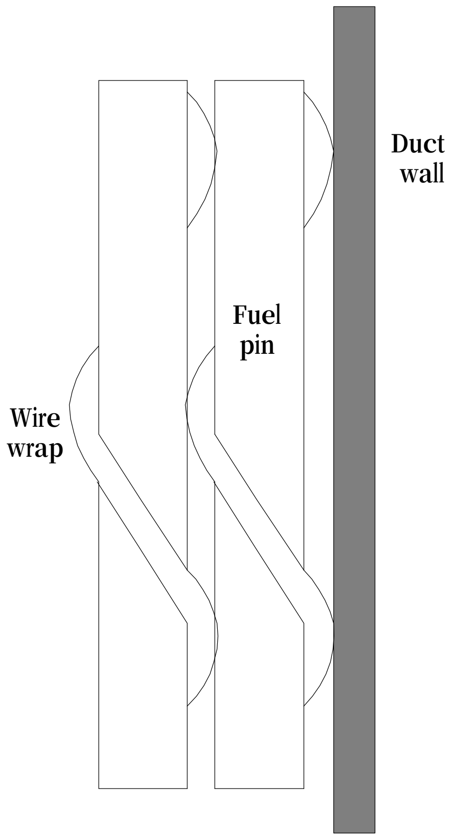

Figure 1 Fuel pins and duct contact configuration

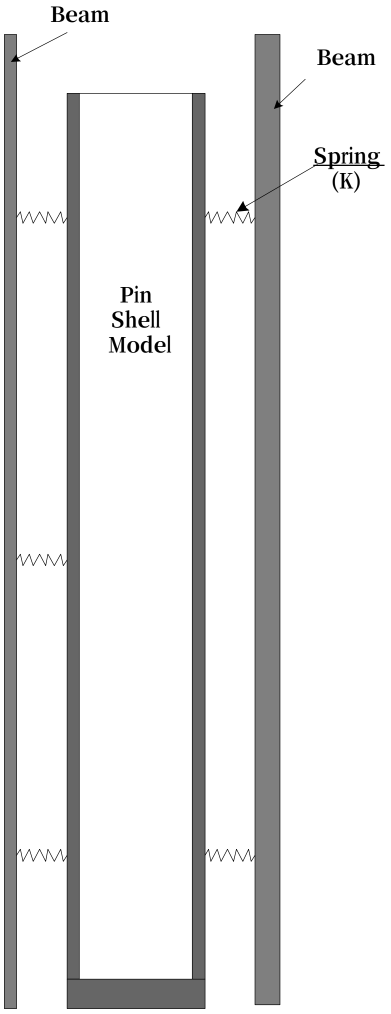

Figure 2 Single fuel pin model for BDI analysis

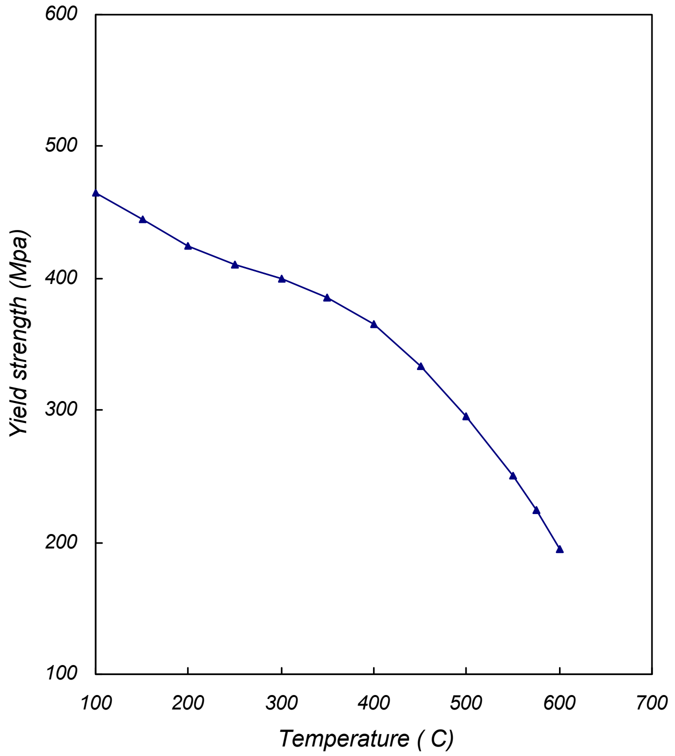

Figure 3 Yield strength versus temperature for fuel cladding(HT-9)

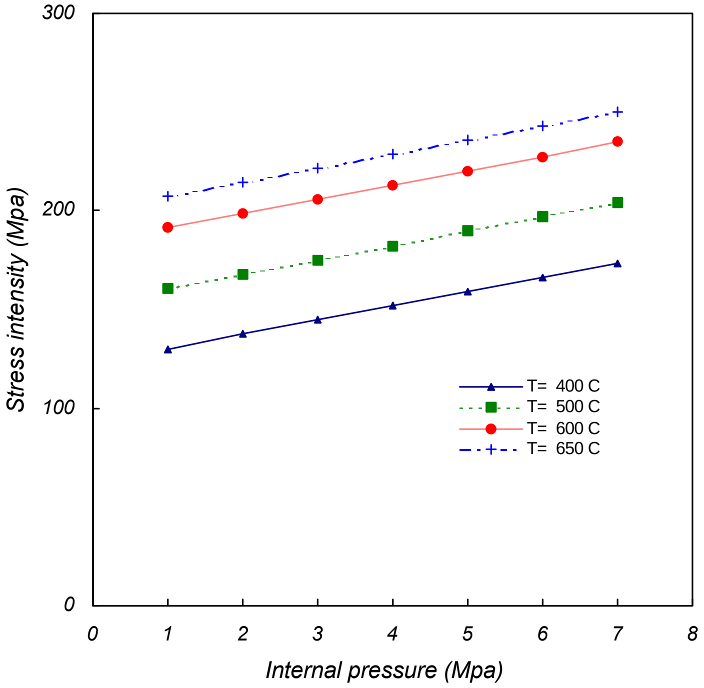

Figure 4 Maximum stress intensities of single pin model versus internal pressure

Table 1. Maximum stress intensities of pin cladding versus temperatures in internal pressure(P=1,3,5,7 MPa)

Temperatures (℃)	Maximum stress intensity (MPa)			
	P=1 MPa	P=3 MPa	P=5 MPa	P=7 MPa
400	130.2	144.5	158.9	173.2
450	145.5	160.0	174.2	188.6
500	160.9	175.3	189.6	204.0
550	176.3	190.6	205.0	219.3
600	191.6	206.0	220.4	234.7
650	207.0	221.4	235.7	250.1

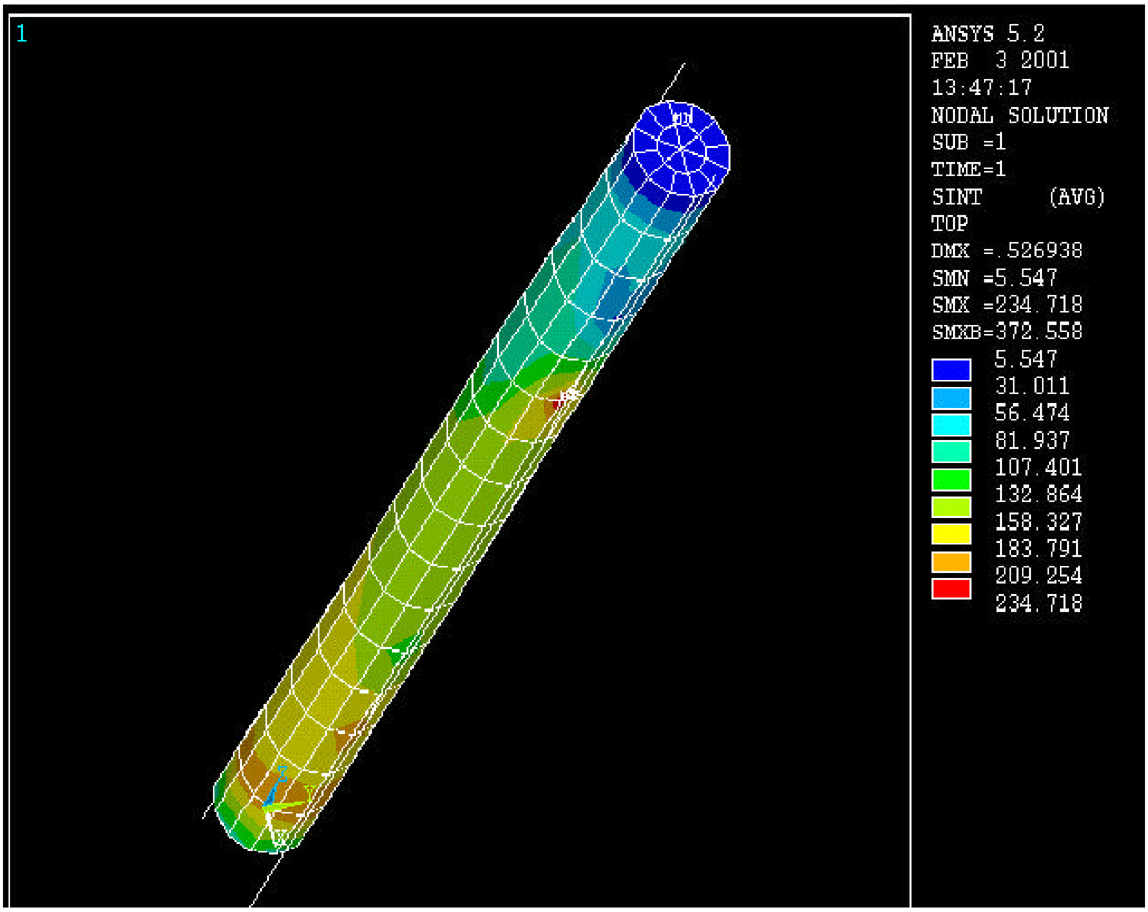

Figure 5 Stress contour of BDI single pin model

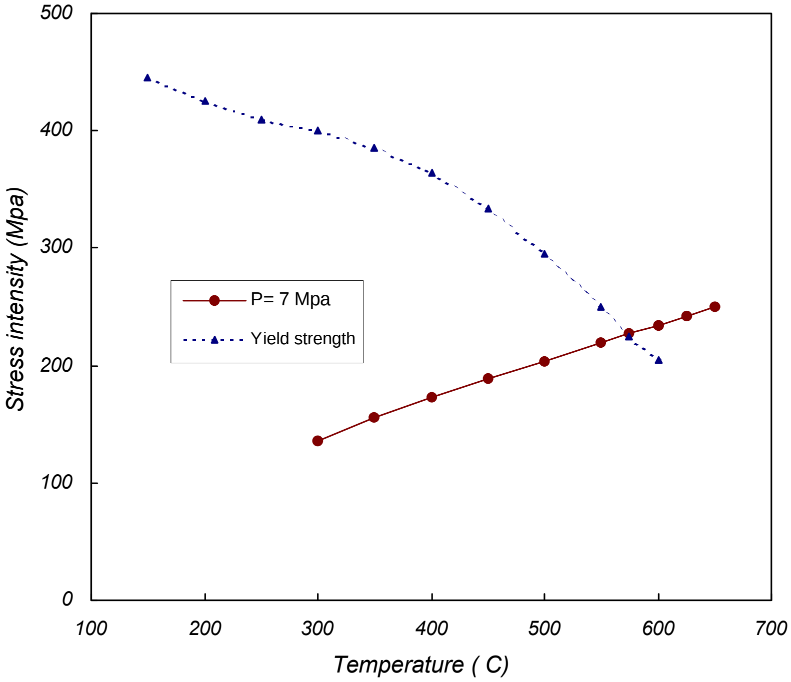

Figure 6 Stress intensities of single pin model compared with yield strength versus temperatures at P=7 Mpa