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Impact Simulation of Spacer Grid Designed for i-SMR Fuel

Youngik Yoo*, Joonkyoo Park, Yoonho Kim
KEPCO Nuclear Fuel, 242, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Republic of Korea
**Corresponding author: yiyoo@knfc.co.kr*

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1. Introduction

Important requirement in i-SMR nuclear fuel design is flexible operation and the ability to operate without boron. Considering the above requirement, improved control rod is necessary to meet the core's subcriticality limitation. Accordingly, the number of control rod fingers has been increased from 24 to 28. To accommodate the 28 control rod fingers, four guide tubes need to be added to the existing 17x17 array fuel assembly, resulting in the exclusion of four fuel rods, as shown in Fig. 1[1].

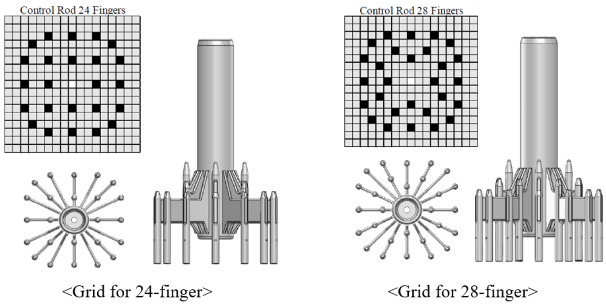

Fig. 1. Design of the spacer grid according to fingers

In nuclear fuel, the spacer grid has mechanical functions to support and protect the fuel rod by absorbing the impact force, and it also has a thermal hydraulic function to enhance the coolant heat transfer capability. However, when the nuclear fuel is subjected to an unwanted excessive load caused by earthquake during operating, it could lead to fuel failure such as spacer grid buckling and cladding tube deformation. For this reason, in order to ensure mechanical integrity of the fuel, spacer grid design is required to withstand the impact load and maintain high strength throughout the lifetime of operation.

In this study, a finite element model has been developed to simulate the impact of the spacer grid. Impact tests were performed using top grids and the test results were used to validate the model.

2. Impact Simulation

2.1. Dynamic Crush Test

The test equipment for the dynamic crush strength consist of the hammer, load cell and high temperature furnace. The weight of the hammer is equivalent to the weight of the fuel rods within one span supported by the spacer grid. Short fuel rod cladding tubes are inserted in each cell of the test grid. The temperature (315 ℃) for the dynamic impact test is chosen considering reactor condition.

The hammer connected to the pendulum applies an impact to one side of the specimen, which is fixed at the opposite side. The impact velocity of the hammer is calculated using energy conservation and the initial test angle of the pendulum. Through the impact test, the impact load on the spacer grid is determined based on the impact velocity of the hammer.

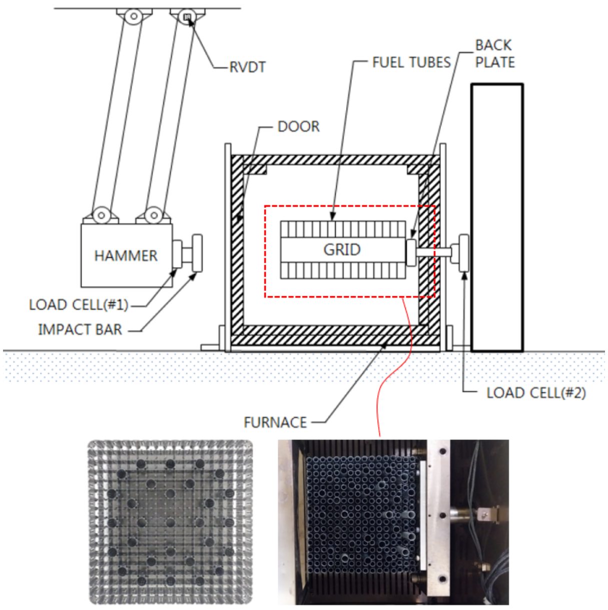

Fig. 2. Schematic of the dynamic crush test equipment

2.2 Finite Element Model

A 3D finite element model was developed for the top spacer grid of i-SMR fuel assembly, as shown in Fig. 3. Abaqus v2019 was used to model the spacer grid. To simplify the shape of the spacer grid, beam elements were used for the spacer grid, fuel rods, guide tubes, and sleeves, while connector elements that could simulate contact and friction characteristics were used for the springs/dimples of the spacer grid and applied friction force to the fuel rods[2]. These connector elements could set the gap between the fuel rod and spacer grid and could express the slip of the fuel rods. Fig. 4 shows the boundary conditions applied for the analysis for impact.

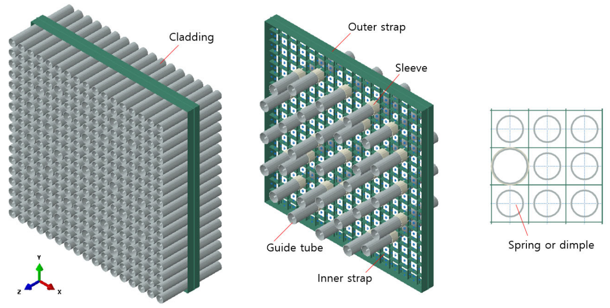

Fig. 3. Spacer grid model

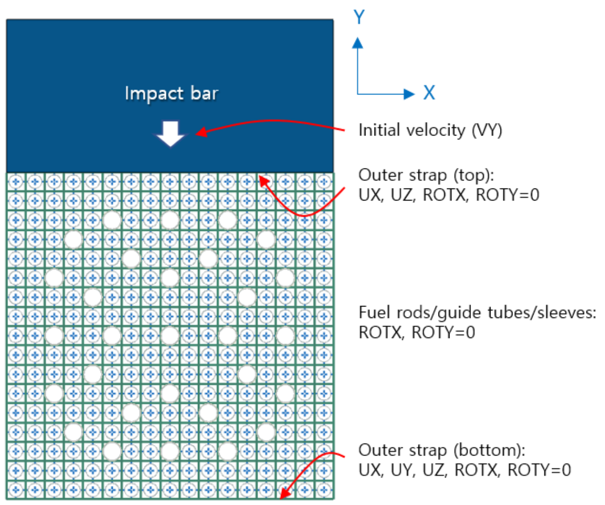

Fig. 4. Boundary conditions

2.3 Simulation Results

Fig. 5 shows the impact test and analysis results. The finite element model well simulated the impact load increase with increasing impact velocity. It also showed that the model was able to predict more conservatively than all the test results.

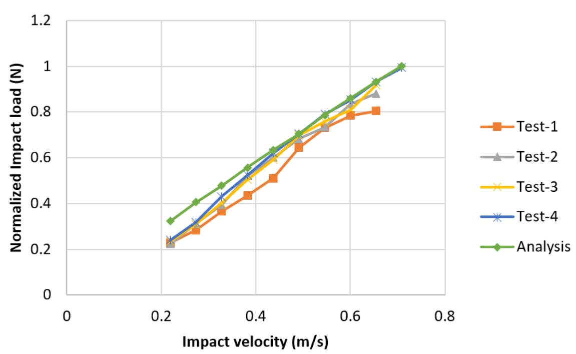

Fig. 5 Impact load results

3. Conclusions

Spacer grid model was developed to evaluate the integrity of i-SMR nuclear fuel under vibration and shock. The grid model has been validated using impact test results and conservatively simulates the loads caused by external impacts. In the future, impact tests and analyses will be performed on all spacer grids (mid and bottom) and the grid model will be used for fuel assembly model.

ACKNOWLEDGMENT

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