Factors Affecting Spent Nuclear Fuel Rod Resistance Against Impact

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1. Introduction

This paper discusses various uncertain factors that affect the structural integrity of spent nuclear fuel rod during a horizontal drop case. Due to the stochastic nature inside the reactor, the spent fuel rods are subject to various types of uncertainty in material properties, interfacial conditions, and so on. They affect the resilience of spent fuel rod against rupture during an impact accident but their relative importance has not been discussed much. In this work, a detailed numerical model of a single fuel rod and structural parts of spent fuel assembly was built and dynamic explicit simulations are performed to calculate structural behavior of fuel rod under impact. Then, the effects of uncertain factors are studied using design of experiments.

2. Numerical analyses of spent fuel rod

2.1 Finite Element Model of Fuel Rod

The fuel rod was modelled with the actual dimensions of 350 fuel pellets in a 4.094-m-long fuel cladding referred to CE16x16 Plus 7 fuel type, as well as 2 end plugs, 2 insulating pellets, 2 guide tubes, top/bottom nozzles, and 12 SGs (see Fig. 1) were all modelled to investigate the interaction of fuel rod against the supporting components. This model is designed in a way to provide useful results that can be transferred to fuel assembly level model in a cask-loaded condition.

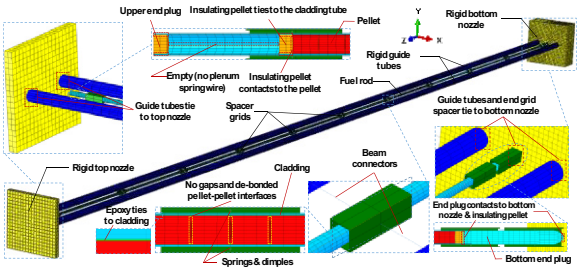

Fig. 1. Finite element model of a single fuel rod.

2.2 Analysis Condition

The fuel rod assembly model is drop from a height to measure the maximum plastic strain on the cladding. The threshold plastic strain for fuel rod rupture is set as 0.1 % which is known to be a typical value for high burnup fuels. The critical drop height which results in the threshold strain value is found by trial and error. The target surface is modeled as a rigid body.

3. Factor Effect Study Using DOE

3.1 Factors to be studied

The four factors of which affects are studied are the material property of cladding, interfacial condition between the pellets and cladding, fuel rod internal pressure, and the stiffness of dimple and spring of spacer grid. Those are some of the uncertain factors that possibly affect the integrity of spent fuel rods during accidents.

3.2 Design of Experiments and Results

The effects of uncertain factors are studied using the full factorial design of experiments. For interfacial condition, 3 levels are selected as, fully bonded, partially bonded, fully debonded. The other factors have 2 levels, each. For material property, a soft and ductile stress-strain relationship with a hard and brittle stress-strain relationship are selected as two bounding cases.

Fig. 2 is the main effect and interaction diagram of those factors on the critical drop height. It is seen that the material property of cladding and the pellet-cladding interaction (PCMI) are those two dominating parameters of critical drop height.

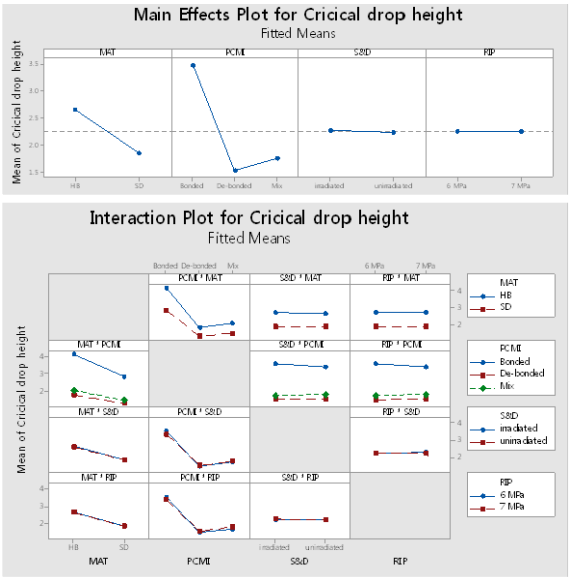

Fig. 2. Main effect and interaction diagram.

It is seen that the fuel rod internal pressure and the spring and dimple stiffness degradation do not have significant effects on the critical drop height of spent fuel rod. It is interesting to see that the difference between the fully bonded case is much bigger than that between partially bonded and fully debonded case. There are no significant interaction effects among factors. Thus the effects of those parameters can be analyzed by one factor at a time basis.

4. Conclusions

Due to its stochastic nature, the structural integrity of spent nuclear fuel is hardly quantifiable. In this work, some important factors that results in the variation of structural performance of spent fuel rods are studied using a sophisticated finite element analysis and design of experiments. It was revealed that the PCMI and the material properties are important factors that determine the impact resistance of spent fuel rod against rupture during impact.

This work considered only horizontal drop case, and the results for vertical drop case will be presented in the future.

REFERENCES

[1] Adkins, H. et al. Used Nuclear Fuel Loading and Structural Performance under Normal Conditions of Transport— Demonstration of Approach and Results on Used Fuel Performance Characterization, US DOE, 2013.