Performance of UO_2-Graphene Composite Fuel and SiC Cladding during LOCA

Seung Won Lee [a], Hyoung Tae Kim [b], In Cheol Bang [a*]
[a]*Ulsan National Institute of Science and Technology (UNIST)*
100 Banyeon-ri, Eonyang-eup, Ulju-gun, Ulsan Metropolitan City 689-798, Republic of Korea
[b]*Korea Atomic Energy Research Institute (KAERI)*
Deokjin-dong, Yuseong-gu, Daejeon, 305-600, Republic of Korea
[*]*Corresponding author: icbang@unist.ac.kr*

1. Introduction

The commercial nuclear power industry is interested in advanced fuels and claddings that can produce higher power levels with a higher safety margin and be manufactured at low cost [1]. Although UO_2 fuel is chemically stable, its thermal conductivity is low. If the graphene is mixed in UO_2 fuel, it is chemically stable and its thermal conductivity will be enhanced. Advantages of the graphene are high thermal conductivity (5,200 W/mK) and low absorption cross section.

Zircaloy-4 and Zirlo are cladding materials used in PWR. They have high resistance to the high temperature and high radiation environment, but, zirconium reacts easily water above 1,100 ℃ and generates hydrogen. The resistance of SiC to the high-temperature and high-radiation environment can be a good reason for applying SiC as a cladding material for light water nuclear reactor. [2]. Analysis tests about the radial fuel rod temperature and the peak cladding temperature using MARS-KS (Multi-dimensional Analysis of Reactor Safety-Korean Standard) were simulated in 12 cases.

2. MARS-KS Modeling

The OPR-1000 was used as the reference plant model for MASR KS modeling and employs 16X16 fuel assemblies.

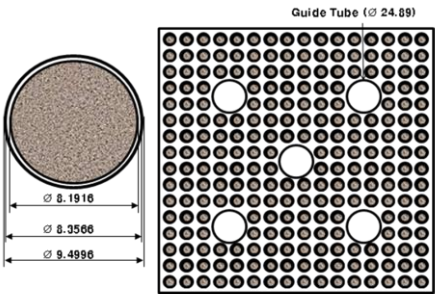


Fig. 1. Configuration of the fuel rod and 16X16 fuel assembly.

For modeling of fuel rods, it is standard practice to use three material layers: fuel, gap, and cladding. Temperature-dependent thermal conductivities and volumetric heat capacities for these materials are provided in tabular or functional form from either built-in or user supplied data [3]. The configuration of the fuel rod and 16X16 fuel assembly are shown in Fig. 1.

3. Analysis Results

The number of axial node is 20. In all cases, the temperature of node 14 is the highest as shown in Fig. 2 because the linear heat generation rate (LHGR) was set as a top-skewed cosine shape by referring to the final safety analysis report (FSAR). Also, the peak cladding temperature is the highest at node 14 as shown in Fig. 3 in all cases. So, the radial fuel rod temperature and the peak cladding temperature are analyzed at node 14.

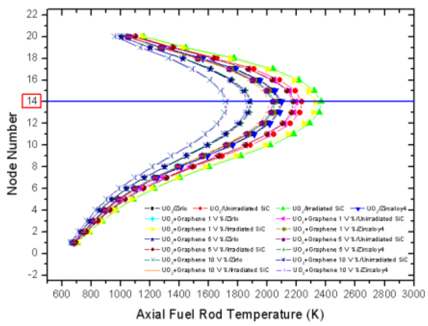


Fig. 2. Axial fuel rod temperature according to node number.

As shown in Fig. 4 (a), the radial fuel rod temperature according to volume fraction of UO_2/graphene with unirradiated SiC cladding is lowered (2235.0 K, 2194.0 K, 2037.7 K, 1869.1 K) due to increase of thermal conductivity of UO_2 and graphene composites. The radial fuel rod temperature of UO_2/graphene (5 volume %) composite with unirradiated SiC cladding is lower than that of UO_2 with Zircaloy-4 cladding as shown in Fig. 4 (b). And, peak cladding temperature according to volume fraction of UO_2/graphene with unirradiated SiC cladding is lowered (safety margin is increased, 11.86 %, 12.65 %, 15.86 %, 18.89 %) due to increase of thermal conductivity of UO_2 and graphene composites as shown in Fig. 5 (a). The peak cladding temperature of UO_2/graphene (5 volume %) composite with unirradiated SiC cladding is lower than that of UO_2 with Zircaloy-4 cladding as shown in Fig. 5 (b).

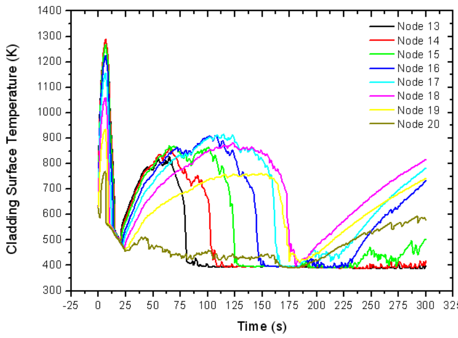
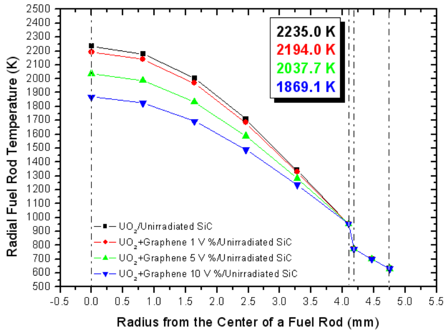
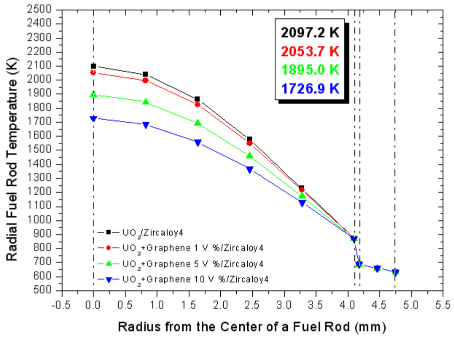


Fig. 3. Cladding surface temperature according to node number in UO_2/graphene with unirradiated SiC cladding.

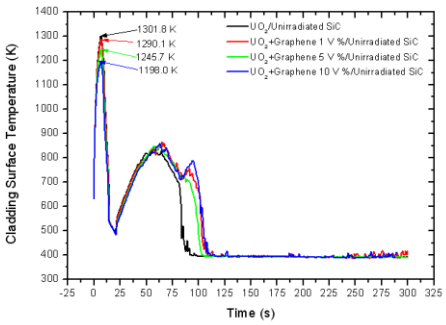


(a)

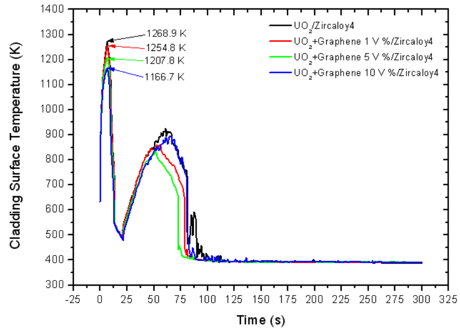


(b)

Fig. 4. Radial fuel rod temperature according to volume fraction of UO_2/graphene with (a) unirradiated SiC cladding, (b) Zircaloy-4 cladding.



(a)



(b)

Fig. 5. Cladding surface temperature according to volume fraction of UO_2/graphene with (a) unirradiated SiC cladding, (b) Zircaloy-4 cladding.

4. Conclusions

The following results are obtained.

(1) Low thermal conductivity of UO_2 limits the linear heat generation rate. It is confirmed that UO_2 and graphene composites can lower radial fuel rod temperature and peak cladding temperature using MARS-KS code.

(2) If UO_2 and graphene composites are used in PWR, the energy can more quickly be extracted from the fuel rod, relax the time available to respond to coolant transient and enhance safety margin.

(3) Zirlo and Zircaloy-4 are good cladding material from thermal hydraulic perspective. But, zirconium reacts easily water above 1,100 ℃ and generates hydrogen.

(4) SiC is in the spotlight of cladding material. But, a disadvantage of SiC is low thermal conductivity. It is confirmed that the use of SiC with UO_2 and graphene composites can compensate for low thermal conductivity of SiC using MARS-KS code.

REFERENCES

[1] D. H. Hollenbach and L. j. Ott, Improving the thermal conductivity of UO_2 fuel with the addition of graphite fibers, ANS Summer Meeting, San Diego, CA, USA, 2010.

[2] Kwangwon Ahn, Comparison of silicon carbide and zircaloy4 cladding during LBLOCA, MIT, Department of Nuclear Engineering, 2006.

[3] Hyoung Tae Kim, Pavel Hejzlar, Hee Cheon No, Mujid S. Kazimi, Performance of internally and externally cooled annular fuel in a loss of coolant accident, ICAP, Cambridge, Massachusetts, USA, 2002.