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Fuel performance analysis for the HAMP-1 mini plate test

Byoung-Jin Cho[a*], Y.W. Tahk[a], J.S. Yim[a], B.H. Lee[a]
[a]Korea Atomic Energy Research Institute, 989-111 Daedeokdaero, Yuseong, Daejeon 305-353, Korea
[*]*Corresponding author: bjcho@kaeri.re.kr*

1. Introduction

In 2012, KAERI launched a project to construct a new research reactor in KiJang district. U-7wt%Mo/Al-5wt%Si dispersion fuel with 8gU/cm^3 is chosen to achieve more efficiency and higher performance than the conventional U_3Si_2 fuel. As part of the fuel qualification program for the KiJang research reactor (KJRR), three irradiation tests with mini-plates are on the way at the High-flux Advanced Neutron Application Reactor (HANARO). The first test among three HANARO Mini-Plate Irradiation tests (HAMP-1, 2, 3) has completed.

PLATE code has been initially developed to analyze the thermal performance of high density U-Mo/Al dispersion fuel plates during irradiation [1]. We upgraded the PLATE code with the latest irradiation results which were implemented by corrosion, thermal conductivity and swelling model.

Fuel performance analysis for HAMP-1 was conducted with updated PLATE. This paper presents results of performance evaluation of the HAMP-1.

2. Input file creation for HAMP-1

Input file is created using irradiation history, burnup and heat flux data in HAMP-1 report [2]. Total irradiation time is 111.4 days during 92 to 95 cycle of HANARO. To perform the evaluation with Plate code, approximate 1 day per a time step was applied. Particle size distribution for HAMP-1 is shown in table 1.

Table 1 Representative particle size distribution for HAMP-1

Particle diameter (μ m)	Mass fraction (%)
under 45	11.00%
45	5.00%
53	27.00%
63	22.00%
75	24.00%
90	9.00%
106	1.00%
125	1.00%

2. PLATE code evaluation

The calculations in this paper are to provide preliminary analysis of the fuel performance of the HAMP-1 experiment, particularly the third plate of total 8 plates in the experimental set up. The analysis provides the thermal behavior in the centerline and surface of the plate, oxidation, and fuel swelling behavior.

Fig. 1 shows fuel meat volumetric heat generation rate during irradiation.

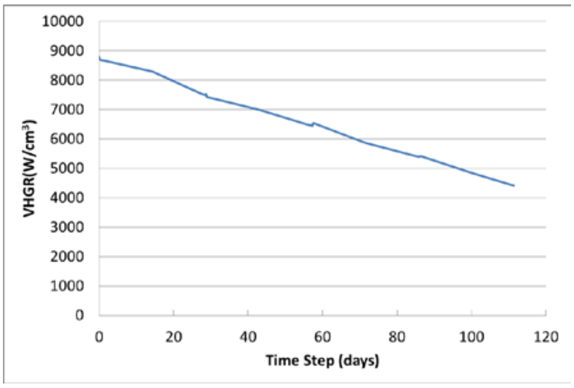

Fig. 1 Fuel meat volumetric heat generation rate during irradiation

2.1 Fuel meat swelling

Kim's swelling model [3] was updated in PLATE code. The result of the meat swelling is shown in Fig 2. The meat swelling surfaced and monotonically increased after 1.1×10^{21} fission density because of porosities. As shown in Fig. 2, the calculated values of the average fuel meat swelling of HAMP-1 are about 13.9%. Fig. 3 also shows fuel meat swelling distribution of the fuel zone calculated using plate code at EOC of each cycle. The fuel zone (fuel meat area) of fuel plate was divided into 4×7 mesh (Transverse 4 nodes in width direction and axially 7 nodes in length direction).

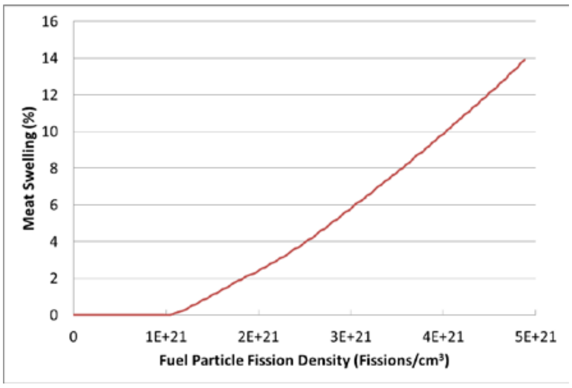

Fig. 2 Fuel meat swelling vs Fuel particle fission density

Cycle 92, EOC					Cycle 93, EOC				UNIT : %
Position	-0.9375	-0.3125	0.3125	0.9375	Position	-0.9375	-0.3125	0.3125	0.9375
-3.5	2.4	2	2	2.4	-3.5	7.2	6.6	6.8	7.2
-4.5	2	1.9	1.7	2	-4.5	6.8	6.5	6.1	6.8
-5.5	2.1	1.9	1.7	2.1	-5.5	6.8	6.3	5.9	6.8
-6.5	1.7	1.5	1.5	1.7	-6.5	6.4	5.8	5.4	6.4
-7.5	1.9	1.5	1.5	1.9	-7.5	6.4	5.8	5.6	6.4
-8.5	2.2	1.5	1.7	2.2	-8.5	6.6	5.6	6	6.6
-9.5	2.5	2.2	2.2	2.5	-9.5	7.6	7	7.2	7.6
Cycle 94, EOC					Cycle 95, EOC				
Position	-0.9375	-0.3125	0.3125	0.9375	Position	-0.9375	-0.3125	0.3125	0.9375
-3.5	11.8	10.9	11.1	11.8	-3.5	15.1	14.3	14.1	15.1
-4.5	11.1	10.5	10.1	11.1	-4.5	14.3	13.8	13.2	14.3
-5.5	11	10.5	10.1	11	-5.5	14.2	13.7	13.3	14.2
-6.5	10.9	10.1	9.3	10.9	-6.5	14.3	13.3	12.5	14.3
-7.5	10.7	10	9.6	10.7	-7.5	13.8	13	12.6	13.8
-8.5	10.9	9.7	10.3	10.9	-8.5	14.2	13	13.6	14.2
-9.5	12	11.5	11.7	12	-9.5	15.2	14.7	14.9	15.2

Fig. 3 Estimated fuel meat swelling distribution at EOC of each cycle

2.2 Thermal conductivity of the fuel meat

New thermal conductivity model for U-Mo/Al dispersion fuel [4] was augmented in PLATE code. The effective thermal conductivity of the fuel meat is calculated to be 0.65W/cm-K at 298 K.

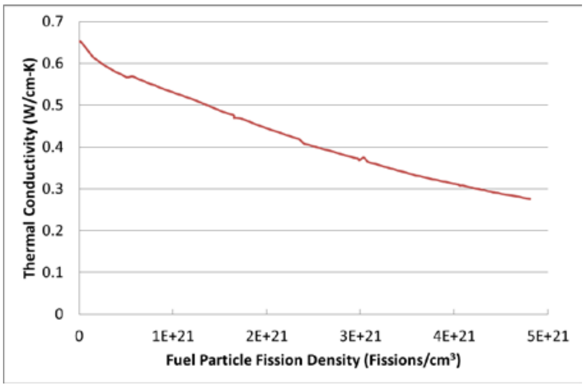

Fig. 4 Thermal conductivity vs fuel particle fission density

2.3 Fuel meat centerline temperature

Fig. 5 and 6 show the fuel centerline temperature of the fuel zone of 4×7 mesh calculated at BOC and EOC of each cycle. The maximum peak centerline temperature is about 139.2 °C at a burnup of around 11.4 % U235 depletion. Up to a maximum burnup, the fuel temperature was kept below the design limit of 200°C during the irradiation test.

Cycle 92, BOC					Cycle 93, BOC				UNIT : ℃
Position	-0.9375	-0.3125	0.3125	0.9375	Position	-0.9375	-0.3125	0.3125	0.9375
-3.5	128.3	119.6	124.3	128.3	-3.5	130.4	125.1	123.7	130.4
-4.5	122.3	113.7	116.6	122.3	-4.5	129.9	120.4	118.5	129.9
-5.5	118.7	110.9	112.0	118.7	-5.5	124.9	119.1	117.6	124.9
-6.5	119.8	111.3	114.0	119.8	-6.5	120.0	117.0	114.6	120.0
-7.5	119.4	112.7	113.3	119.4	-7.5	124.7	118.5	115.4	124.7
-8.5	123.2	114.0	114.8	123.2	-8.5	127.3	119.5	120.8	127.3
-9.5	126.8	121.1	121.5	126.8	-9.5	133.6	128.7	131.7	133.6
Cycle 94, BOC					Cycle 95, BOC				
Position	-0.9375	-0.3125	0.3125	0.9375	Position	-0.9375	-0.3125	0.3125	0.9375
-3.5	124.0	123.0	119.6	124.0	-3.5	110.0	109.1	110.0	110.0
-4.5	120.9	115.8	114.0	120.9	-4.5	109.8	105.3	107.1	109.8
-5.5	119.0	117.6	116.0	119.0	-5.5	102.5	108.7	108.7	102.5
-6.5	119.4	111.7	110.9	119.4	-6.5	107.8	106.5	103.7	107.8
-7.5	114.2	110.9	111.2	114.2	-7.5	108.7	105.4	104.1	108.7
-8.5	117.6	112.4	115.8	117.6	-8.5	107.0	105.4	107.8	107.0
-9.5	126.9	124.6	125.3	126.9	-9.5	112.9	112.6	111.7	112.9

Fig. 5 Fuel centerline temperature calculated at BOC of each cycle

Cycle 92, EOC					Cycle 93, EOC				UNIT : ℃
Position	-0.9375	-0.3125	0.3125	0.9375		-0.9375	-0.3125	0.3125	0.9375
-3.5	133.3	123.4	127.5	133.3	Position	124.7	122.7	123.9	124.7
-4.5	128.4	123.1	123.0	128.4	-3.5	121.1	119.3	118.6	121.1
-5.5	124.4	120.7	118.0	124.4	-4.5	119.5	114.5	114.9	119.5
-6.5	120.9	117.9	115.3	120.9	-5.5	116.4	110.9	109.5	116.4
-7.5	122.9	113.8	114.4	122.9	-6.5	115.0	110.9	112.6	115.0
-8.5	125.0	117.1	118.6	125.0	-7.5	119.4	112.8	116.6	119.4
-9.5	130.6	127.8	129.4	130.6	-8.5	123.0	120.2	122.8	123.0
Cycle 94, EOC					Cycle 95, EOC				
Position	-0.9375	-0.3125	0.3125	0.9375	Position	-0.9375	-0.3125	0.3125	0.9375
-3.5	112.7	111.3	109.5	112.7	-3.5	99.1	97.3	97.4	99.1
-4.5	108.0	106.6	106.6	108.0	-4.5	95.8	96.1	94.9	95.8
-5.5	108.3	107.2	108.9	108.3	-5.5	97.5	98.1	96.8	97.5
-6.5	109.5	104.6	102.3	109.5	-6.5	98.0	94.6	93.8	98.0
-7.5	104.9	102.6	102.2	104.9	-7.5	95.6	94.3	92.5	95.6
-8.5	107.9	104.6	108.0	107.9	-8.5	96.6	93.9	96.1	96.6
-9.5	110.2	109.9	110.3	110.2	-9.5	96.4	97.8	98.1	96.4

Fig. 6 Fuel centerline temperature calculated at EOC of each cycle

2.4 Cladding corrosion

Kim-Hofman corrosion model [5] also was updated in PLATE code. Fig. 7 shows the corrosion thickness at the position with peak heat flux and fission density. The corrosion thickness steeply increased during the first cycle and growth rate gradually was reduced. The maximum boehmite layer thickness is predicted to be about 22.7µm. Fig. 8 shows corrosion thickness of the fuel zone of 4×7 mesh calculated at EOC of each cycle. The boehmite corrosion layer thickness was evaluated to be in the range of 10.5 to 22.7 µm at the end of irradiation.

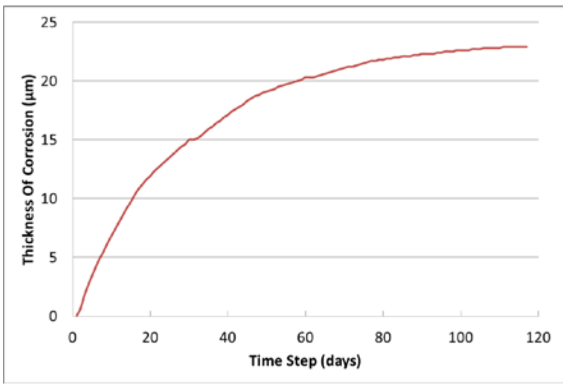

Fig. 7 Corrosion thickness during irradiation

Cycle 92, EOC					Cycle 93, EOC				UNIT : μm
Position	-0.9375	-0.3125	0.3125	0.9375	Position	-0.9375	-0.3125	0.3125	0.9375
-3.5	14.2	12.3	12.6	14.2	-3.5	19.2	17.4	17.9	19.2
-4.5	12.5	11.5	10.9	12.5	-4.5	17.7	16.3	15.6	17.7
-5.5	12.6	11.3	11.0	12.6	-5.5	17.6	15.7	15.0	17.6
-6.5	10.5	9.8	9.6	10.5	-6.5	15.7	13.5	12.9	15.7
-7.5	11.5	9.8	9.8	11.5	-7.5	15.6	13.4	13.4	15.6
-8.5	13.1	9.6	10.5	13.1	-8.5	16.7	13.5	14.6	16.7
-9.5	15.0	12.6	13.4	15.0	-9.5	20.3	18.0	19.0	20.3
Cycle 94, EOC					Cycle 95, EOC				
Position	-0.9375	-0.3125	0.3125	0.9375	Position	-0.9375	-0.3125	0.3125	0.9375
-3.5	21.6	19.5	20.0	21.6	-3.5	22.3	20.1	20.6	22.3
-4.5	19.6	17.9	17.3	19.6	-4.5	20.3	18.7	18.1	20.3
-5.5	19.2	17.7	17.1	19.2	-5.5	20.0	18.5	17.9	20.0
-6.5	18.0	15.5	14.7	18.0	-6.5	18.9	16.3	15.5	18.9
-7.5	17.5	15.4	15.3	17.5	-7.5	18.2	16.1	15.9	18.2
-8.5	18.6	15.5	16.9	18.6	-8.5	19.4	16.4	17.8	19.4
-9.5	22.1	20.5	21.4	22.1	-9.5	22.7	21.2	22.1	22.7

Fig. 8 Corrosion thickness estimation at each EOC

3. Conclusions

The PLATE code was updated with new latest models. The fuel performance for HAMP-1 was analyzed with the updated PLATE code.

The maximum fuel temperature was obtained 136℃, which is far below the preset limit of 200℃ for the irradiation test. The meat swelling and corrosion thickness was also confirmed that the developed fuel would behave as anticipated.

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