A Prediction Study of Aluminum Alloy Oxidation of the Fuel Cladding in Jordan Research and Training Reactor

Y. W. Tahk*, J. Y. Oh, B. H. Lee, C. G. Seo, H. T. Chae, J. S. Yim
Research Reactor Design & Engineering Div., Korea Atomic Energy Research Institute, P.O. Box 105, Yuseong, Daejeon 305-600, Republic of Korea
**Corresponding author: ywtahk@kaeri.re.kr*

1. Introduction

U_3Si_2-Al dispersion fuel with Al cladding will be used for Jordan Research and Training Reactor (JRTR). Aluminum alloy cladding experiences the oxidation layer growth on the surface during the reactor operation. The formation of oxides on the cladding affects fuel performance by increasing fuel temperature. According to the current JRTR fuel management scheme and operation strategy for 5 MW power, a fresh fuel is discharged after 900 effective full power days (EFPD) with 18 cycles of 50 days loading. For the proper prediction of the aluminum oxide thickness of fuel cladding during the long residence time, a reliable model is needed. In this work, several oxide thickness prediction models are compared with the measured data from in-pile test by RERTR program. Moreover, specific parametric studies and a preliminary prediction of the aluminum alloy oxidation using the latest model are performed for JRTR fuel.

2. Model Comparison

Griess[2,3], Kritz [4] and modified Griess model with heat flux consideration are based on out-of pile data. All of them were developed for data from out-of-pile loop tests and are power law models. The latest model developed by Kim et al. [1] uses a variable rate-law power in a function of irradiation time, temperature, surface heat flux, water pH, and coolant flow rate, of which the last 3 terms were not considered in a total manner in the previous known aluminum oxidation empirical models [2-5]. These oxide thickness prediction models are compared with the measured data from in-pile test with the longest EFPD in the RERTR program in Fig. 1 and 2.

Fig. 1 shows the prediction comparison result for SIMONE LC-04 plate tested at HFR [1, 6]. Following the history of heat flux and cladding surface temperature, the oxide thickness is calculated. The thickness “X_New” is the result by modifying Kim model with assuming a constant thermal conductivity of the oxide film as 1.85 W/m-K conservatively.

Fig. 2 is the comparison result for the test of Miniplate A101 irradiated in ORR conducted by ANL with collaboration with ORNL in mid-1980s. Following the temperature and heat flux history, the prediction was made assuming that the coolant pH changed from 5.5 to 6.3 linearly with time. The new model by Kim is in good agreement with these two in-pile test data. Although it is not included in this work, this model shows the best prediction for the oxidation of aluminum alloy cladding in various in-pile test data as well as out-of-pile test data. Accordingly, this model could be used for estimating the oxide film thickness for the research reactor such as JRTR.

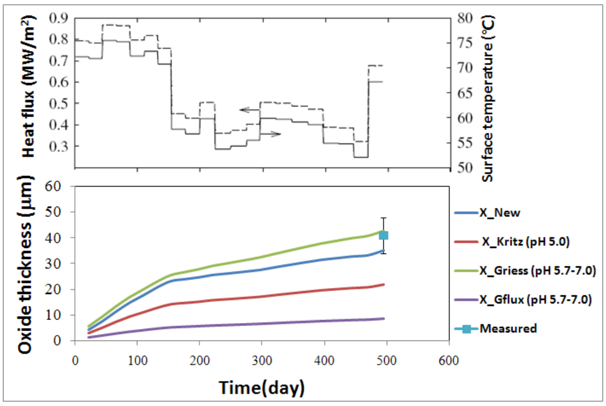


Fig. 1. Prediction comparison of four different models, i.e. modified Kim, Griess, Kritz and modified Griess model using the data from SIMONE LC-04 plate tested at HFR. The test parameters are pH 6.5 and vc = 6.6 m/s. Time dependent cladding surface temperature and heat flux is as the above inset curve.

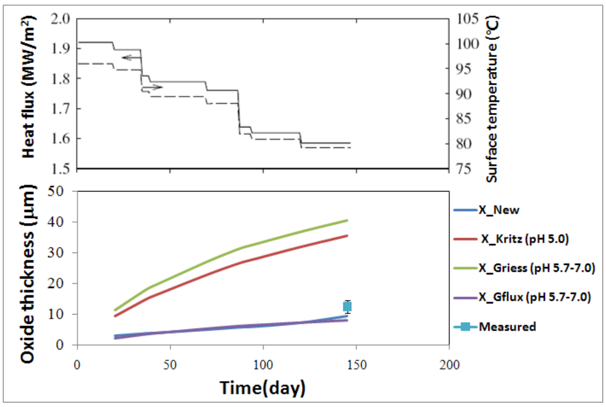


Fig. 2. Prediction comparison for Miniplate A101 irradiated in ORR. The additional test parameters except temperature and heat flux are pH 5.5–6.3 and vc = 8.5 m/s.

3. Prediction Results

In this section, parametric studies for aluminum alloy oxidation in the preliminary JRTR operation condition are conducted using the modified Kim model. If a power history and heat transfer coefficient at oxide-water interface is given, the time or cycle dependent heat flux and oxide–water interface temperature could be calculated which enhance the input accuracy for the model. So, based on the JRTR fuel shuffling scheme, fuel assembly average power history and power peaking data from preliminary core analysis, the heat flux and temperature history of a fuel plate during 900 EFPD were obtained and shown in Fig. 3. The water pH is expected to be about 5.7 in the average and controlled in the range of 5.5–6.5 according to the technical specification.

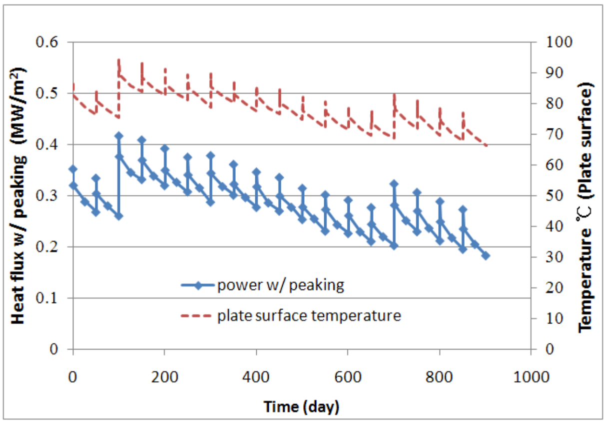
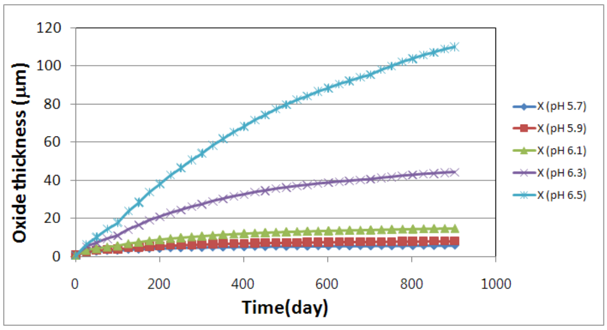


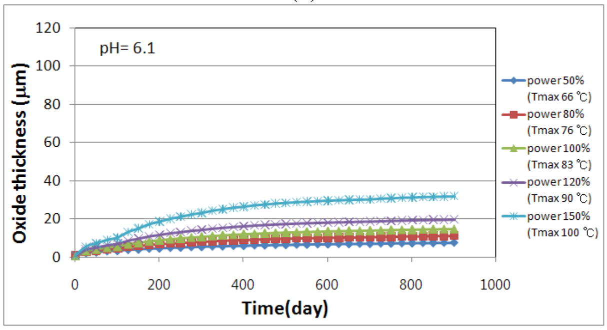
Fig. 3. Time or cycle dependent heat flux and oxide–water interface temperature for the preliminary JRTR operation condition.

Fig. 4 (a) and (b) shows the oxide thickness prediction for 900 EFPD operation condition with various water pH in the range of 5.7~6.5 and variable power density of 50%~150% output (maximum fuel temperature). It is noted that the predicted oxide thickness is sensitive to pH. The oxide thickness of discharged fuel was predicted to be 6 μm at constant pH of 5.7 and 110 μm in the case of pH 6.5. At the current operation condition, the oxide growth is boosted above pH 6.3. At the constant pH 6.1, the power density of 50% and 150% of nominal output shows 50% and 200% oxide thickness compared with the case of 100% power (5MW).

Further accurate prediction can be obtained by following the pH variation history. If the in-situ measurement of real water pH is not available, it is reasonable to assume that the pH changed linearly with time between the pH level at the beginning of cycle and the end of cycle for the best estimation.



(a)



(b)

Fig. 4. Oxide thickness prediction of JRTR fuel cladding with (a) various water pH and (b) changing power density (maximum fuel temperature) at a fixed pH 6.1.

4. Conclusions

The latest Kim model, which is in good agreement with the in-pile test data available in the literature as well as the recent RERTR test data in various operating condition, can be regarded as the best elaborate one for the oxidation of aluminum alloy cladding. Accordingly, this model was used for estimating the oxide film thickness in the fuel cladding of JRTR. The oxide thickness is predicted to be 6~ 110 μm at 900 EFPD of 5 MW operation condition with water pH in the range of 5.7~6.5.

REFERENCES

[1] Yeon Soo Kim, G.L. Hofman, A.B. Robinson, J.L. Snelgrove, N. Hanan, Oxidation of aluminum alloy cladding for research and test reactor fuel, Journal of Nuclear Materials, Vol. 378, p. 220, 2008.
[2] J.C. Griess, H.C. Savage, J.G. Rainwater, T.H. Mauney, J.L. English, ORNL-3230, Oak Ridge National Laboratory, 1961.
[3] J.C. Griess, H.C. Savage, J.L. English, ORNL-3541, Oak Ridge National Laboratory, 1964.
[4] R.S. Ondrejcin, DPST-83-324, Savannah River Laboratory, 1983.
[5] R.E. Pawel, G.L. Yoder, D.K. Felde, B.H. Montgomery, M.T. Mcfee, Oxidat. Met. Vol.36 (1/2), p.175, 1991.
[6] G.L. Hofman, Y. Fanjas, H. Pruimboom, and F. Wijtsma, in: Proceedings of the International Meeting on Reduced Enrichment for Research and Test Reactors, October 4–7, 1993, Oarai, Japan, JAERI Report, JAERI-M-94-042, March 1994.