A Conservative Width of High Burnup Structure in LWR UO_2 Fuel

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1. Introduction

The high burnup structure (HBS), which is formed in the outer part of LWR UO_2 fuel as a result of excessive fission damage and in-growth of fission products [1], is important in terms of in-reactor fuel performance and spent fuel disposal due to its characteristics of lower thermal conductivity, small grain size and very high porosity. Especially under accident conditions such as RIA and LOCA, the amount of fission gas retained in the HBS can have a decisive role in the way that a fuel rod with high burnup would respond when the fuel temperature increases very rapidly.

Therefore, in this paper, based on the available data on the HBS width, a conservative HBS width which can be used for safety analysis is derived as a function of pellet average burnup up to 100 GWd/tU.

2. The Data on the Width of HBS

A total of 210 data for the HBS width available in the open literature is plotted in Fig. 1 as a function of pellet average burnup (i.e., cross-sectional average burnup) together with the calculation results of two models shown as solid [2] and dotted line [3]. The data was obtained from various kinds of fuels that had different design and fabrication methods and were irradiated under different operating conditions in different reactors.

In describing the HBS width, the pellet average burnup was used rather than pellet edge burnup, because most of the measured data in the literature were provided in terms of the pellet average burnup. Moreover, this would be more convenient from the viewpoint of a fuel performance analysis, where the effect of HBS on fuel behavior should be considered. In a case that the HBS width was expressed by the pellet edge burnup only, the pellet average burnup for the data was derived by using the assumption that the ratio of pellet edge burnup to average one is 1.33 [4].

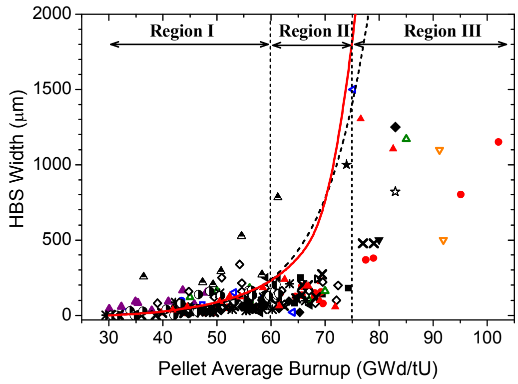

Fig. 1. The HBS width versus pellet average burnup.

3. A Conservative Width of HBS

Fig. 1 shows that the HBS width can be divided into three regions according to the pellet average burnup [5]. Thus, a conservative correlation for each region will be proposed below.

3.1. For a pellet average burnup below 60 GWd/tU

In region I where the burnup is below 60 GWd/tU, the HBS width increases almost linearly with burnup. Although the most conservative HBS width would be obtained by covering all the data available in region I, Fig. 1 shows that, if the two data points from BWR fuel [6] lying well outside the range of other data are included, it would lead to an unrealistic HBS width especially at around 60 GWd/tU. Therefore, based on the arguments that the threshold burnup for HBS formation is 30

GWd/tU, the HBS width increases linearly with burnup in region I, and drawing a linear line from zero HBS width at 30 GWd/tU through the data − except for the two data mentioned above − located in the upper part of the region I gives 400 μm at 60 GWd/tU, a conservative HBS width for region I is derived as follows for the pellet average burnup below 60 GWd/tU:

$$w_{HBS}=13.3\ (bu_{avg}-30), \qquad (1)$$

where w_{HBS} is the HBS width in μm and bu_{avg} is the pellet average burnup in GWd/tU.

3.2. For a pellet average burnup of 60-75 GWd/tU

In contrast to region I, as was suggested in an earlier paper [2], it is reasonable to assume that the HBS width in region II increases exponentially with a pellet average burnup of 60-75 GWd/tU. Therefore, we introduce the TUBRNP model to obtain a conservative HBS width, which is given as w_{HBS}=0.20 exp(bu_{avg}/8.48) [2].

It is to be noted that there should be continuity in the HBS width at 60 GWd/tU, meaning that the TUBRNP model needs to be modified in such a way that the HBS width at 60 GWd/tU obtained by Eq. (1), 400 μm, should be the same as that calculated by the TUBRNP model (240 μm). Hence the original model given above was modified so that, while a modified one gives the width of 1500 μm at 75 GWd/tU as in the original one, it can produce the width of 400 μm at 60 GWd/tU. From this argument, a conservative HBS width in region II can be described as follows:

$$w_{HBS}=2.02\ \exp(bu_{avg}/11.35). \qquad (2)$$

3.3. For a pellet average burnup of 75-100 GWd/tU

As for the HBS width in region III, while the number of data on HBS width is not enough to draw a definite conclusion, the data available at present indicates that a conservative value can be given as a constant width of 1500 μm for a pellet average burnup up to at least 100 GWd/tU; that is, for a pellet average burnup between 75 and 100 GWd/tU

$$w_{HBS}= 1500. \qquad (3)$$

In conclusion, a conservative HBS width, derived in the three regions based on the measured data and expressed as Eqs. (1)-(3), is illustrated in Fig. 2.

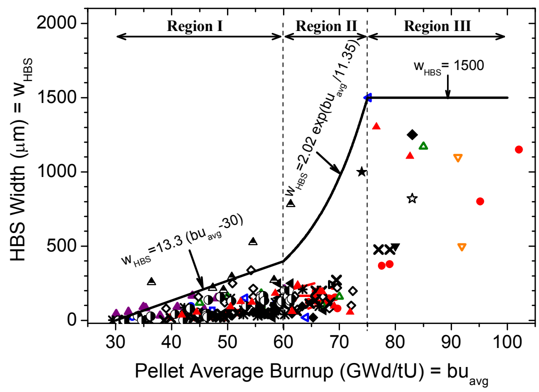

Fig. 2. A conservative HBS width as a function of pellet average burnup.

4. Conclusion

A conservative HBS width, which can be used for safety analysis of fuel behavior under accident conditions such as RIA and LOCA, is derived as follows based on the available data; w_{HBS}=13.3 (bu_{avg}-30) for bu_{avg}<60 GWd/tU, w_{HBS} = 2.02 exp(bu_{avg}/11.35) for 60-75 GWd/tU, and w_{HBS} = 1500 for 75-100 GWd/tU.

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