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Effect of Burnup and Grain Size on the Width of High Burnup Structure of UO_2 Fuel

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1. Introduction

When pellet burnup exceeds 30-40 GWd/t, high burnup structure (HBS), which is also referred to as rim structure, begins to be formed as a result of excessive fission damage and in-growth of fission products [1]. Due to the characteristic of the HBS, lower thermal conductivity and very high porosity could raise a concern in LWR UO_2 fuel's performance under operating conditions as well as during storage of spent fuel [2]. In this paper, the HBS width is analyzed as a function of main operating and fabrication parameters such as pellet burnup, temperature, enrichment, and grain size.

2. Width of High Burnup Structure

Around 220 data of HBS width which have been collected from the open literature are analyzed in terms of burnup, grain size and enrichment.

2.1 Effect of burnup on the HBS width

The following two requirements must be satisfied simultaneously for the HBS to be formed [3]. First, local burnup should be higher than 60-70 GWd/t so that accumulation of fission damage exceeds some threshold value above which subdivision of as-fabricated grain starts to occur. Second, fuel temperature should be lower than the threshold temperature of 1100±100°C.

We can find in Fig. 1 two trends for the increase in HBS width with pellet burnup. When the pellet average burnup is less than 70 GWd/tU, the HBS width increase almost linearly with burnup up to around 500 µm. This implies that when the pellet burnup is relatively low and hence the temperature of pellet periphery is low compared to the threshold value, the accumulation of fission damage, i.e. burnup, is one of the most important factors that would determine the HBS width. In other words, the pellet area whose local burnup exceeding the threshold value would be changed into the high burnup structure.

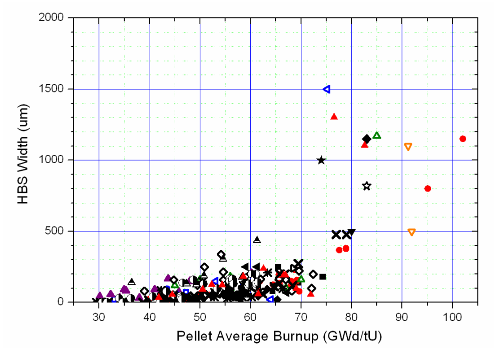

Figure 1. The HBS width versus pellet average burnup.

On the other hand, in case that pellet average burnup is higher than around 70 GWd/t, the local burnup of almost entire cross-section of a fuel pellet would be higher than the threshold value, thereby suggesting that the entire region of the fuel pellet would have changed into the high burnup structure. However, even if the local temperature was lower than the threshold value of 1100°C, the HBS width was not extended to the whole region of the fuel pellet. Instead, the measured data up to 102 GWd/t showed that the HBS width at burnup above 70 GWd/t did not exceed 1.5 mm. This suggests that the restructuring accompanying thermally activated fission gas release could have limited the distance over which the microstructure changes take place [4].

2.2 Effect of grain size on the HBS width

Fig. 2 shows the HBS width as a function of both grain size and pellet average burnup. Although the data are not sufficient enough to make a clear conclusion on the effect of grain size on the HBS width, a general trend that for the same pellet average burnup the HBS width decreases with grain size is found. This might be because the number of nucleation sites for recrystallisation decreases due to decrease in grain boundary area [5] or because large grains accumulate fewer irradiation induced defects than smaller grains [6]. This implies that higher burnup is required to reach the level of lattice strain needed for recrystallisation.

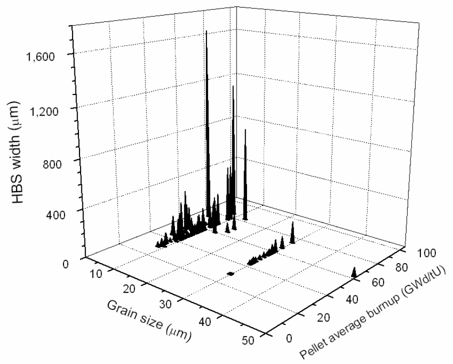

Figure 2. The HBS width versus grain size.

2.3 Effect of enrichment on the HBS width

Fig. 3 shows the HBS width as a function of both ^{235}U enrichment and pellet average burnup. It is known that the use of higher enrichments in LWR fuels may shift the formation of HBS to higher local burnup [7], since high enrichment leads to a lower Pu conversion rate and a flatter Pu distribution, causing the edge burnup increase to be less pronounced than in a standard LWR fuel with a similar average burnup. However, according to Fig. 3, although lower enrichment yields somewhat higher HBS width, a clear relationship between the enrichment and HBS width does not appear to exist.

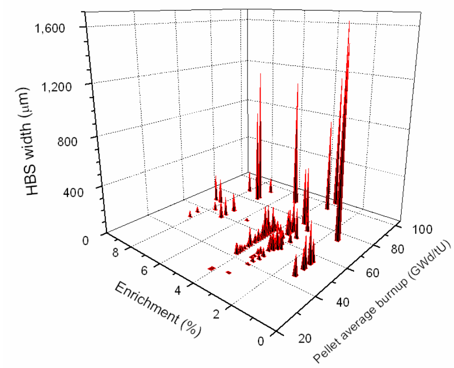

Figure 3. The HBS width versus enrichment.

3. Conclusion

While the HBS width increases almost linearly with burnup up to pellet average burnup of 70 GWD/tU, the HBS width doest not exceed about 1.5 mm at burnup beyond 70 GWd/tU. Large grain size of fuel pellet seems to be effective in delaying the HBS formation.

Acknowledgements

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