Effect of Granule Size on Diametric Tolerance of Annular Fuel Pellet

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1. Introduction

A dual cooled annular fuel has been seriously considered as a favorable option for an extended power uprate of a Pressurized Water Reactor fuel assembly. An annular fuel shows a lot of advantages from the point of a fuel safety and its economy due to its unique configurational merit such as an increased heat transfer area and a thin pellet thickness [1].

From the viewpoint of the fuel pellet fabrication, however, the unique shape of annular fuel pellet causes challenging difficulties to satisfy a diametric tolerance. A sintered cylindrical PWR fuel pellet fabricated by a conventional double-acting press has an hour-glass shape due to an inhomogeneous green density distribution in a powder compact. Thus, a sintered pellet usually undergoes a centerless grinding process in order to secure diametric tolerance specifications. In the case of an annular pellet fabrication using a conventional double-acting press, the same hour-glass shape would probably occur.

An inhomogeneous green density distribution in a powder compact is attributed to granule-granule frictions and granule to pressing mold wall frictions. Frictions result in an irregular pressing load distribution in a powder compact. In order to mitigate the frictions, a lot of process variables should be considered such as pre-compaction pressure, lubricant content, granule size and compaction pressure.

The purpose of this study is to investigate the effect of a granule size on the amount of deformation after sintering, in other words, the amount of an hour-glassing. The granules with classified size ranges were made to green annular pellets with the same height and diameters. The hour-glassing amounts of the sintered annular pellets were measured and compared with that of the annular pellet made by unclassified granule.

2. Experimental

Samples were prepared from the ADU route UO_2 powder. The powder was pre-compacted under 70 MPa by using a cold isostatic press. Pre-compacted lump of UO_2 powder was crushed and granulated. Granules were classified to a certain size range with 20, 30, 50 and 100 mesh sieves, which correspond the size range of 600-850 μm, 300-600 μm, 150-300 μm and <150 μm, respectively.

The classified granules were mixed with a 0.3 wt% of zinc stearate in a tumbling mixer for 30 min. The compaction was conducted in a double acting press by using an annular shape mold. The green annular pellets have the same height. The dimensions of the annular compacts were measured by using a 3-dimensional measuring system (VERTEX 230, MicroVu). The compact is about 14 mm in height and about 18 mm and 12 mm in outer and inner diameter, respectively.

The compacts were sintered at 1730 °C for 4h in H_2 atmosphere. The heating and cooling is at a rate of 5 K/min. Sintered density was measured by the water immersion method. The inner and outer diameters of the sintered pellets were carefully measured as a function of pellet height by using a 3-dimensional measuring system (VERTEX 230, MicroVu).

3. Results

Figure 1 shows the green densities of the annular compacts depending on the granule size. The green density of the annular compact using the unclassified granule was around 47 % of the theoretical density (TD). The annular compacts using classified granules have lower green densities than that of the unclassified one by about 4 %TD. Lower green density may be attributed to the lower packing factor which is affected by the granule size distribution. The green density of the annular compact using a granule under a size of 150 μm is around 36 %TD, which is much lower than those of the others due to the poor flow ability of small particle.

Density differences between the annular pellet of the unclassified granule and those of classified granules decrease to around 1 %TD after sintering as shown in Fig. 2. Annular pellet using the granule under 150 μm has only about 91 %TD, which resulted from the lowest green density.

Figure 3 shows the diametric tolerance of the annular

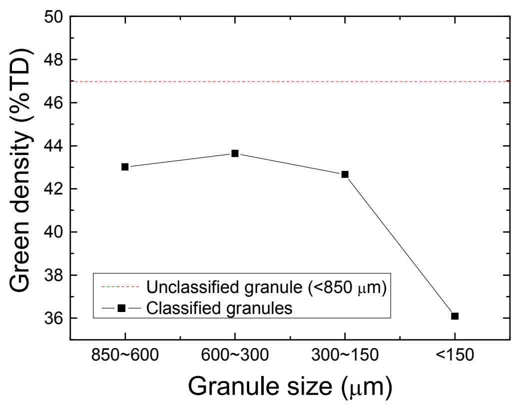

Fig. 1. Green densities of annular compacts depending on the granule size.

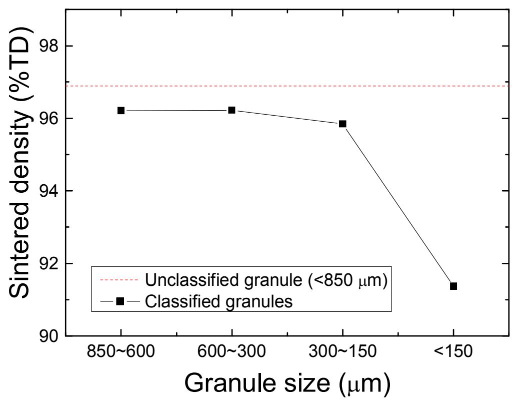

Fig. 2. Sintered densities of annular pellets depending on the granule size.

pellets made from various sizes of granules. The diametric tolerance was defined as the standard deviation of diameters which measured at different pellet heights. It also represents the amount of an hour-glassing in each annular pellet after the sintering deformation occurred.

For an annular pellet made by using an unclassified granule, inner and outer diametric tolerances were about 30 μm and 60 μm, respectively. It appeared that the outer diametric tolerances became rather smaller in the annular pellets using classified granules. The inner diametric tolerance showed a slight decrease or no difference. Classified granule appeared to have a great effect on decreasing the tolerances in the annular pellet using a granule under a size of 150 μm. However, it seemed to result from the low shrinkage as shown by the poor density of that pellet, only 91 %TD.

It is stipulated in the provisional specification of an annular fuel pellet that a diametric tolerance should be less than ± 30 μm [1]. The annular pellets fabricated by using classified granules could manage to satisfy the specification of the inner diametric tolerance. The outer diametric tolerance can be satisfied easily similar to that of a conventional cylindrical PWR pellet through a centerless grinding.

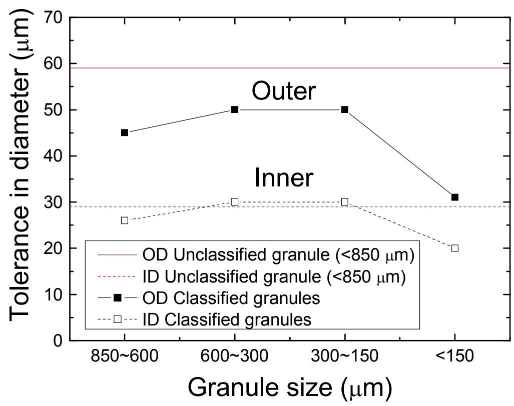

Fig. 3. Diametric tolerances of annular pellets depending on the granule size.

However, the improved tolerance in this study is still insufficient to meet a new solution for the gap conductance asymmetry problem, i.e., 'the "Tight and Loose" inner and outer gap approach' which requires a very small inner gap tolerance [2]. It appears not to be simple in the case of an inner surface grinding. Thus, it would be the best way to satisfy the specifications for the inner diameter in an as-fabricated pellet. It seems that a new approach is demanded to homogenize the green density distribution in an annular compact.

4. Conclusions

Granule size effect on the hour-glassing of an annular pellet has been investigated. The fabrication method of using classified granules improved the inner and outer diametric tolerances of the annular pellets. However, it appears to be inadequate to meet a recent enhanced specification. A new approach seems to be demanded to obtain an annular compact of a more homogenized green density distribution.

Acknowledgement

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