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# Doped $UO_2$ Pellet Technology for Advanced Technology Fuels (ATF)

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## 1. Introduction

At Korea Atomic Energy Research Institute (KAERI), additive doped $UO_2$ pellets have been evaluated for advanced technology fuels (ATF). KAERI have designed additives system, developed fabrication processes for additives doped $UO_2$ pellets, investigated doped $UO_2$ pellets properties and conducted an irradiation test in HANARO research reactor for selected candidates.

This article deals with the development status of doped $UO_2$ ATF pellets for LWR in KAERI.

## 2. Doped $UO_2$ Pellet System and Fabrication

Addition of small amount of oxide additives is known to promote a grain growth of $UO_2$. A $UO_2$ grain size enlargement is expected to enhance fuel plasticity at an elevated temperature of transient operation as well as the fission gas retention capability thereby enhance the fuel safety performance. Because of those benefits, doped large grain $UO_2$ pellets have been developed as near-term ATF along with coated Zr claddings.

### *2.1 MnO-$Al_2O_3$ doped $UO_2$*

Binary oxide mixture of $MnO_2$-$Al_2O_3$ was designed to form a liquid phase near the conventional sintering temperature of $UO_2$ pellet. Formation of liquid phase promotes both densification and grain growth. Microstructure analysis for the 1000 ppm of $MnO_2$-$Al_2O_3$ doped $UO_2$ pellet sintered in a $H_2$ atmosphere showed that the averaged grain size was enlarged up to 50μm. [1]

### *2.2 $Cr_2O_3$ doped $UO_2$*

$Cr_2O_3$ doped $UO_2$ is one of the closest ATF pellet technologies to commercialization. The relevant research revealed that the doped $Cr_2O_3$ became liquid phase in optimized oxygen potential and that liquid phase promoted grain growth. Although optimum composition and sintering condition for $Cr_2O_3$ doped $UO_2$ had been suggested, developing a new sintering process which could minimize the initial doped amount of $Cr_2O_3$ and the volatilization of Cr during the sintering remained a challenge.

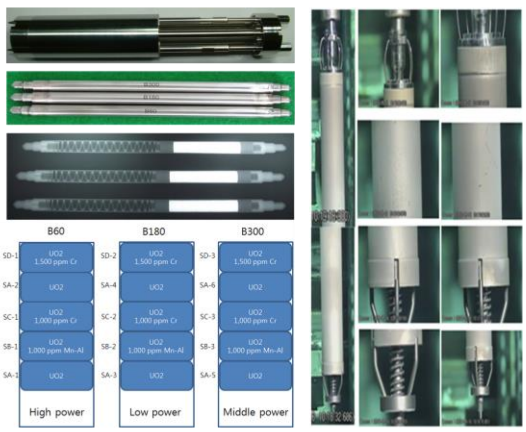
KAERI have proposed the step-wise sintering processes, in which the oxygen potential of sintering atmosphere was increased during the isothermal sintering stage. The experimental investigation demonstrated that the doped amount of $Cr_2O_3$ can be reduced to a minimum level while keeping the large grain size [2]. For an example, by applying the developed step-wise sintering process, the grain size of 1550 ppm of $Cr_2O_3$ doped $UO_2$ pellet was enlarged up to 90 μm which is about 2.5 times larger than that of the pellet fabricated by reference process. The Cr volatilization was reduced by about 40% in this pellet.

### *2.3 Thermo-physical properties of doped pellets*

Thermo-physical properties such as melting temperature, thermal conductivity, thermal expansion and heat capacity of both doped pellets were measured to be very similar to those of $UO_2$ pellet. Compressive creep deformation test showed that the creep deformation of doped pellets was much larger than $UO_2$ in viscoplastic region.

## 2. HANARO Irradiation Test of Doped $UO_2$ Pellets

An irradiation test of three test rods which contain KAERI's doped ATF pellets was started in September 2011 and finished in July 2014. The total effective full power day is 528 days. The discharged burnup of test rods was calculated to be 33MWd/kgU. The purpose of this irradiation test was to investigate the dimensional stability and microstructure change of newly developed doped ATF pellets during the irradiation.




(a) (b)

Fig. 1. HANARO irradiation test
(a) Test rods, rig and sample matrix
(b) Visual inspection of discharged test rig

### 3. Post Irradiation Examination

For kinds of doped ATF pellets were fabricated for irradiation test. Table. 1 lists the details for fuel pellets on the test rods.

Table 4. Additives contents, grain size and density of test pellets

| Name | Additives content in green pellets (M/U, μg/g) | | Additives contents in sintered pellets (M/U, μg/g) | Grain size (μm) | As sintered density (g/cm³) | Resintered density (g/cm³) | Density change (g/cm³) |
|---|---|---|---|---|---|---|---|
| SA | None | | None | 9.3 | 10.673 | 10.713 | 0.040 |
| SB | Mn | 1078 | 420 | 37.0 | 10.680 | 10.717 | 0.036 |
| | Al | 57 | 27 | | | | |
| SC | Cr | 1135 | 631 | 30.0 | 10.711 | 10.699 | -0.012 |
| SD | Cr | 1703 | 883 | 73.9 | 10.749 | 10.729 | -0.019 |

Quantitative optical micrograph analysis was performed to investigate the dimensional stability and microstructure change during the irradiation. Fig. 2 shows the whole cross-sectional images of irradiated samples. The pellets having larger grain size (SB and SD) show a more complex crack pattern and have a tendency to split into smaller parts.

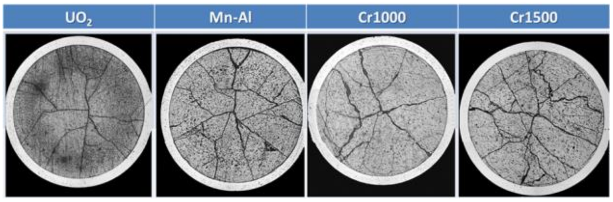
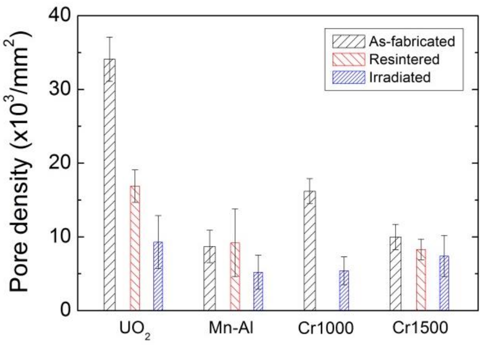



Fig. 2. Cross sectional optical micrographs of irradiated sample pellets

Fig. 3 shows the pellet averaged pore number density and pore size changes of pellet samples after the resintering and irradiation, respectively. Doped large grain pellets have lower pore density and higher pore size than standard $UO_2$ pellet. Moreover, the change in pore densities after the irradiation was lower than that of the standard $UO_2$ pellet. The microstructural change indicates that pore structure of doped pellets was more stable, compared to standard $UO_2$ sample.



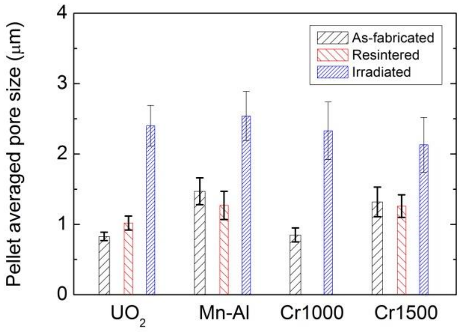




Fig. 3. Pore density and pore size changes after the resintering and irradiation.

Fig. 4 shows the porosity and density changes. The porosity was calculated using Fig.3. The density was acquired by the Archimedes' method using irradiated sample fragments. Even though the density drop after the irradiation was slightly larger in the density data, the porosity increase and density drop were within an expected range, considering the pellet swelling owing to the fission products and the range of observational uncertainty.

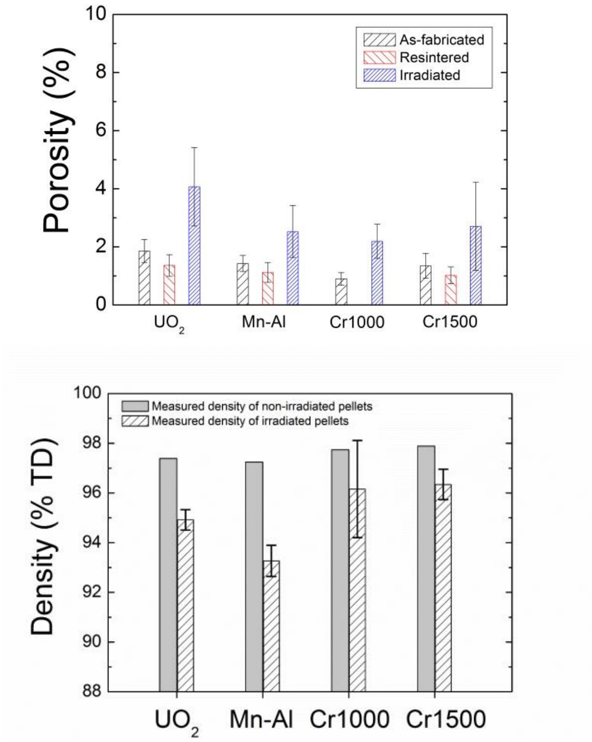



Fig. 4. Porosity and pellet density changes after the resintering and irradiation.

Fig. 5 shows the changes in averaged grain size of the pellets. The grain sizes of SA and SB pellets did not changed relatively, but the grain size of the Cr doped pellets was increased after the irradiation. Especially, the grain size of the SC pellet was found to be much increased, indicating the possibility that grain growth by the residual Cr particles was reactivated by the irradiation.

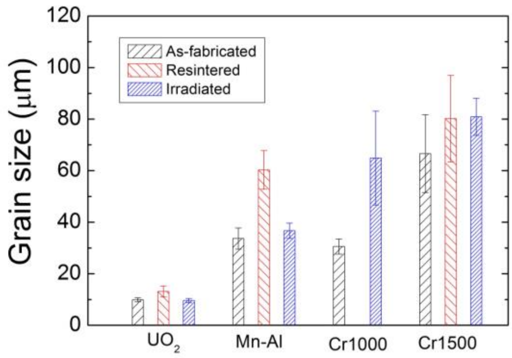



Fig. 5. Averaged grain size change of the samples after the resintering and irradiation.

## 3. Conclusions

KAERI has developed additive systems and fabrication processes for doped ATF pellets and demonstrated technical superiority in both commercial process applicability and pellet properties. The irradiation test in HANARO up to 33MWd/kgU also showed stable structural change and irradiation performance.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] K. W. Kang et al, JNST, 47, (2010) 304
[2] J. H. Yang et al, JNM, 429 (2012) 25–33