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Development of ATF Microcell UO_2 Pellets and Characterization of the Properties

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1. Introduction

Decades of nuclear fuel pellet advancements have focused on optimizing LWR power generation. This includes raising fuel burn-up, extending cycles, and boosting power output. Post-Fukushima, the emphasis has shifted to developing accident-tolerant fuels (ATF) for LWRs. These new fuel concepts aim to enhance safety during severe incidents while maintaining performance. Numerous countries have deliberated the integration of ATFs into conventional power reactors. Subsequently, they have embarked on comprehensive journeys involving the advancement of these fuels, along with the establishment of corresponding licensing and regulatory frameworks for their safe utilization. From the perspective of the role of fuel pellets ATFs, there exists a concept involving the utilization of large-grained pellets that exhibit enhanced mechanical resilience under elevated temperature conditions. This design aims to mitigate the stress experienced by the fuel pellet, consequently reducing the potential for pellet-cladding mechanical interaction (PCMI).

KAERI has undertaken the development of nuclear fuel pellets in the context of ATF, with a primary focus on enhancing the thermal conductivity of UO_2 pellets. One of the current issues for nuclear UO_2 fuel pellet is about its low thermal conductivity. The low thermal conductivity leads to increase thermal gradient in the fuel pellet and centerline temperature when in operation. Enhancing the thermal conductivity of UO_2 fuel pellet is greatly attractive in the aspect of fuel performance [1–3] and also for its safety margin. The fuel pellets having high thermal conductivity can lower fuel temperature and reduce the mobility of the fission gases [4–6]. In addition, a reduced temperature gradient within the pellet probably enhances the dimensional stability, with lower thermal stress of the fuel pellet, thus the pellet cladding mechanical interaction (PCMI) and even in fuel fragmentation, relocation and dispersal (FFRD) can be mitigated. A thermal margin gained from the high thermal conductivity of pellet would be utilized in a safe operation of LWR or even power-uprate operation also.

Yang et al. [7] have shown experimentally that the thermal conductivity of a UO_2 pellet can be increased substantially by providing a UO_2 pellet with connected tungsten channel. KAERI has also developed micro-cell UO_2 fuel pellets consist of granules enveloped by thin metallic cell walls. [8-10] The metallic cell walls in pellets are continuously connected to each other, enhancing thermal conductivity.

This study will present the current state of development for microcell UO_2 pellets. It will encompass discussions on fabrication processes, as well as ongoing endeavors to compile comprehensive characterization data that validates fuel properties and performance. Furthermore, the concepts aimed at improving the thermal conductivity of fuel pellets can also be extended to burnable absorber pellets. Notably, it has been observed that burnable absorber pellets demonstrate an increase in thermal conductivity, which is promising for use of an increased BA pellets with enriched fuels for elongated fuel cycles.

2. Experimental and Result

A Mo metallic microcell pellet was fabricated by composing UO_2 granules and Molybdenum powder particles. UO_2 powder was granulized with crushing pre-compacted greens and sieved. A specific range of size of UO_2 granules could be collected by screening with varying sieve meshes. Less than 5 vol.% of Mo powder were simply mixed in a tumbler mixer with the prepared UO_2 granules. The powder mixtures were compacted using an automatic uniaxial press machine, then the pelletized green body was sintered at conventional sintering conditions. All fabrication processes were designed with compatibility to the conventional process in mind for future adoption.

Characterization of the fuel pellet properties were also proceeded according to meticulous test protocol with fabricated pellet samples. The characterization of properties includes such as thermal conductivity, thermal expansion, specific heat, re-sintering behavior, and also basic properties of fuel pellets. The sintered density of the Mo Microcell UO_2 pellets were determined using an immersion method, and a microstructure of the sintered pellet was observed using optical microscopy and SEM. Fig. 1 shows the microstructure of a Mo microcell UO_2 pellet. The bright phase of Mo particles is interconnected to form a network of channels, which serves as effective thermal conductive pathways for radial heat transfer.

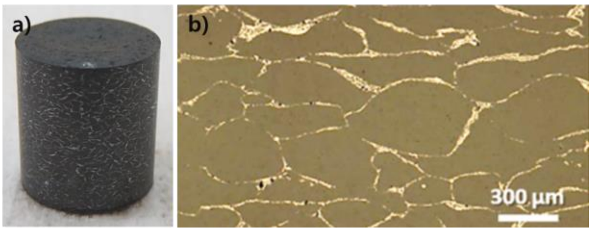

Fig. 1. a) a portrait of Mo microcell UO_2 pellet, and b) the microstructure of the pellet.

Thermal conductivity and thermal expansion coefficient of the pellet was characterized by using LFA and dilatometer apparatus, respectively. While the thermal expansion behaviors remained unchanged between a pristine UO_2 pellet and a microcell pellet, the thermal conductivity significantly increased due to the presence of Mo channels.

DSC analysis was conducted to characterize specific heat, and a high-temperature heat treatment was performed to determine the re-sintered density of the pellets, however, specific behaviors could not be found in either test, as like the thermal expansion behavior. Fig. 2 shows some of the results of property characterization tests mentioned above, more results and detailed explanation will be provided in the presentation.

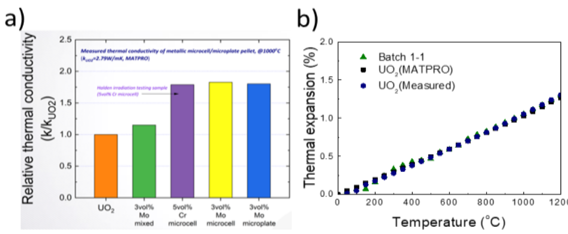

Fig. a) the thermal conductivity comparison of UO_2 and ATF pellets, b) thermal expansion test results of pellets with theoretical property.

3. Summary

In this study, the development status of Mo microcell UO_2 nuclear fuel pellet is presented. Mo metal microcell UO_2 pellets showed significantly improved thermal conductivity, which can have many benefits in both normal operation and also transient conditions in a reactor. Considering the outstanding fuel pellet characteristics, this Mo microcell UO_2 pellet will be one of the promising fuel concepts of ATF pellets in near future.

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