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Metal Fuel Fabrication for Gen IV SFR in KAERI

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1. Introduction

Pyro-electrochemical processing of LWR and SFR spent fuels extracts uranium and TRU, and separates fission products for disposal. Extracted uranium and TRU are used to fabricate the metal fuel. Metal fuel was selected as a SFR fuel material to meet the four major requirements of the Gen IV SFR such as economy, safety, sustainability and proliferation resistance. For a sustainability and proliferation resistance, long-lived minor actinides such as Np, Am and Cm will be transmuted in the reactor. To enhance economy and safety, the fuel will be irradiated up to a higher burnup while maintaining the fuel integrity.

Metal fuels, U-Zr and U-TRU-Zr, are being developed for sodium-cooled fast reactor (SFR), which will be constructed and operated in 2028 in Korea. Metal fuel is considered the best fuel materials for SFR [1]. It has noble compatibility with sodium reactor coolant which guarantees flexibility and margin in reactor operation. Higher thermal conductivity of metal fuel and adoption of fuel design with sodium fuel gap can keep fuel temperature low during irradiation. Therefore, SFR using metal fuel can be operated with passive safety which implies that fuel integrity is maintained during transients without support of active reactor cooling system.

In this study, fuel slugs have been fabricated by modified injection casting and particulate fuel in KAERI for the prevention in evaporation of volatile elements such as Am. Fuel slugs for SFR were characterized to evaluate the feasibility of the alternative fabrication method. Fabrication methods of fuel rods have been studied to develop the fabrication process of metal fuel rods.

2. Metal Fuel Slug Fabrication

The fabrication method of U-10wt.%Zr fuel slug has been investigated using vacuum injection method in KAERI. The reproducibility of the injection casting process has been drastically improved by the precise control and stabilization of melting and casting temperature during injection casting. In addition, casting experiments have been performed to optimize casting process parameters such as pressurization pressure, casting temperature, and immersion time of mold in melt. Sound U-10Zr fuel slug could be fabricated by adjusting the melting process parameters. Sound metal fuel slug had the diameter of 5.4mm and the length of about 250mm with full length of quartz mold. The Zr content and the density were considerably uniform within the ranges of ± 0.3wt.% and ± 0.3g/cm^3 along the longitudinal direction of the fuel slug.

The U-10wt.%Zr-5wt.%Mn fuel slug containing a volatile surrogate element such as Mn, as shown in Fig. 1, was soundly cast by improved injection casting method for the prevention in evaporation of volatile elements such as Am, where the volatile uranium alloy is melted under inert atmosphere. The general appearance of the slug was smooth, and the diameter and the length were 5.4mm and about 250mm, respectively. The gamma-ray radiography of as-cast surrogate slug was performed to detect internal defects such as cracks and pores. The mass fraction of fuel loss relative to the charge amount after fabrication of U-10Zr-5Mn was so low, upto 0.1%. It is thought that a lower fuel loss in case of casting of U-10Zr-5Mn fuel slugs was related to melting of the U-Zr-Mn alloy in a densely plasma-sprayed graphite crucible with high-temperature ceramic materials. Mn element was most recovered with the prevention in evaporation of the volatile surrogate, Mn. It was seen that the losses of these volatile elements such as Am can be effectively controlled to below detectable levels using modest argon overpressures.

Fig. 1. U-10wt.%Zr-5wt.%Mn fuel slug, fabricated by innovative casting method under atmospheric atmosphere during whole casting process.

Spherical uranium alloy particles with various diameters can be easily produced by a centrifugal atomization method developed by KAERI. Spherical U-10wt%Zr alloy particles were fabricated by centrifugal atomization at about 1500^{o}C. Green compacts of atomized U-10wt.%Zr powder were fabricated with quartz compaction dies. The compacts of U-Zr powder were sintered ranging from 1000^{o}C to 1100 ^{o}C under vacuum. Bonding of particles was not active in U-Zr powder pellets, mainly because of their limited interdiffusion at the sintering temperature. In addition, the use of sodium bond in the metal fuel cladding can be eliminated due to porous particulate fuel so that the handling of spent fuel containing radioactive sodium could be simplified.

3. Metal Fuel Rod Fabrication

Sodium bonding is the process of wetting sodium between the fuel slug and cladding, and removing any voids present in the gap between the fuel and cladding. The lower end of the fuel rod in the bonder magazine rested on an impact plunger or a vibrator. The bonder magazine was soundly bonded at about 500^{o}C, as shown in Fig. 2. The fuel rod displacement was set to a specific range to provide the necessary amount of energy for sodium bonding without damaging the rod.

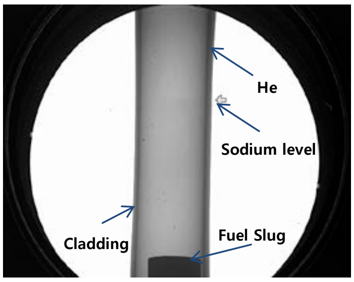


Fig. 2 X-ray radiograph of the fuel rodlets after sodium bonding.

Various welding processes are now available for end plug closure of fuel rod such as gas tungsten arc welding (GTAW), magnetic resistance welding and Nd:YAG laser beam welding (LBW). Nd:YAG LBW using optical fiber transmission was selected for lower end plug welding using HT9 alloy cladding tube. To establish LBW process, and satisfy the requirements of weld quality, experiments for optimizing welding conditions which had test specimens using lower end plug to cladding tube were performed. As a result of examining the characteristics of undercut depth measurements using various configurations of bottom end caps, it was found that suitable conditions of circumferential welding would be w=0.35mm, h=0.14mm and an average power of at least 185 Watt to keep a min. 0.6mm of penetration depth, as shown in Fig. 3.

To make sure proper welding process, GTAW, LBW and EBW apparatus using welding head and vacuum chamber was used [2]. The mechanical properties of GTAW, LBW and EBW joints of HT9 alloy were investigated. Sound welds of the mechanical test specimens were also found. In comparison with the GTA, LB and EB welds of test specimens, the tensile strengths showed no difference between the end plug and cladding tube welds using HT9 alloy.

Wire wrapping system has been designed, manufactured, and tested to fabricate to wrap full-sized fuel rods of 3.6m in length with a HT-9 wire of 1.4mm in diameter. The wire wrapping system is composed of horizontal-type wrapping bed, tension control equipment, wrapping control part, and arc spot welder the end wire. The test-run results revealed that the wire wrapping pitch of 186cm is well satisfied in wrapping

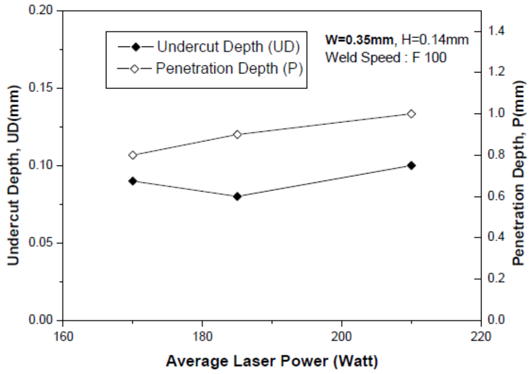
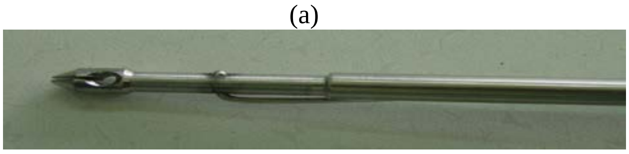


Fig. 3 Results of UD measurements using w=0.35mm.

system with no bending of wire wrapped tube and appropriate welded spot of the end wire, as shown in Fig. 4.

(a)



(b)

Fig.4 Wire wrapped pitch (a) and spot welded wire (b) after wire wrapping.

4. Summary

In this study, fuel slugs have been fabricated by innovative casting method and particulate fuel method in KAERI for the prevention in evaporation of volatile elements such as Am. Fuel slugs for SFR were characterized to evaluate the feasibility of the alternative fabrication method. Fabrication processes of fuel rods such as sodium bonding, end-plug welding, and wire wrapping have been studied to develop the fabrication technology of metal fuel rods for SFR.

ACKNOWLEDGEMENTS

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