High-density Atomized U_3Si_2 Fuel Development in KAERI: Status and Challenges

Sunghwan Kim*, Hwa Young Song, Kyeong Min Park, Ho Min Kim, Jong Hwan Kim, Kyu Hong Lee, Min Ho Lee, Tae Won Cho, Yong Jin Jeong
Korea Atomic Energy Research Institute, Daedeokdaero 989beon gil 111, Yuseong-gu, Daejeon, Republic of Korea
Corresponding author: shkim2@kaeri.re.kr

1. Introduction

KAERI and SCK CEN have been conducting the qualification program called KIMQI (KAERI High Density AtoMized Silicide Fuel Qualification Irradiation Project) for the high-density atomized LEU U3Si2 dispersion fuels since 2021. The qualifying program is categorized into three phases; Phase1. Fuel Performance Confirmation, Phase2. Generic Fuel Qualification, and Phase3. Reactor Specific Fuel Qualification. KAERI has moved forward to Phase1 providing adequacy of the high-density flat-type U_3Si_2 fuel plates fabricated by themselves. Four(4) 5.3 g-U/cm^3 flat-type atomized U_3Si_2 fuels were successfully fabricated and irradiated for 2 cycles at the BR2. As the next Phase, KAERI is developing the plate forming, and curved fuels swaging processes for the generic fuel assembly irradiation tests at BR2 in 2023.

As part of the KIMQI project, KAERI has installed a fuel fabrication facility, and built equipment such as press braking machine, and a swaging machine for fabrication of the generic fuel assembly. In this paper, from the atomization of U_3Si_2 powders to the fabrication of curved fuel plates, the feasibility of large-scale production for the high-density U_3Si_2 dispersion fuel in KAERI has introduced.

2. Fuel Fabrication Facility

The fuel fabrication facility has been built and is being operated since 2004 by KAERI to provide pin-type fuel elements to the research reactor in KAERI called HANARO. Plate-type fuel fabrication facility was installed from 2011 to 2013 to supply fuels to the KJRR which is the 2nd research reactor in Korea. It took 3 years to finish the installation of all equipment for the fuel plate and fuel assembly fabrication.

During the development and early production stage of the plate-type fuel fabrication, KAERI successfully fabricated HANARO Mini-plate series, two Lead Test Assemblies for irradiation tests at ATR in Idaho.

Since 2021, KAERI has been cooperating with SCK CEN for KAERI High Density Atomized Silicide Fuel Qualification Irradiation Project called KIMQI Project, and four high-density atomized U_3Si_2 flat-type fuel plates called KIMQI-FUTURE were successfully fabricated and irradiated at BR2.

For now, high-density atomized U_3Si_2 curved fuel plates assembly called KIMQI-GTA is being fabricated for irradiation tests at BR2 in 2023.

Fig.1. Fuel Fabrication Facility at KAERI

KAERI developed nuclear fuel powder atomization technology for fabricating U_3Si dispersion rod-type fuel for HANARO research reactor. The rotating disk atomization process enabled easier control for melting process and the atomized particle size has relatively narrow distribution.

In 2011, to fulfill the needs for the high-density LEU dispersion fuel in research reactor KAERI also developed mass production technology for U-Mo powder. The fabrication of U-Mo powder by comminution is extremely difficult due to its higher toughness than that of uranium silicide alloys. However, KAERI successfully developed the mass production of U-Mo atomization powder with high yield and simple process. Needless to say it has high purity.

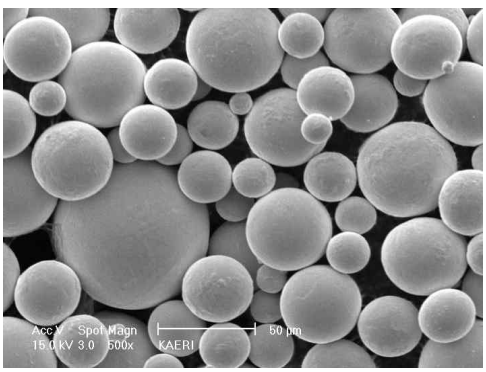
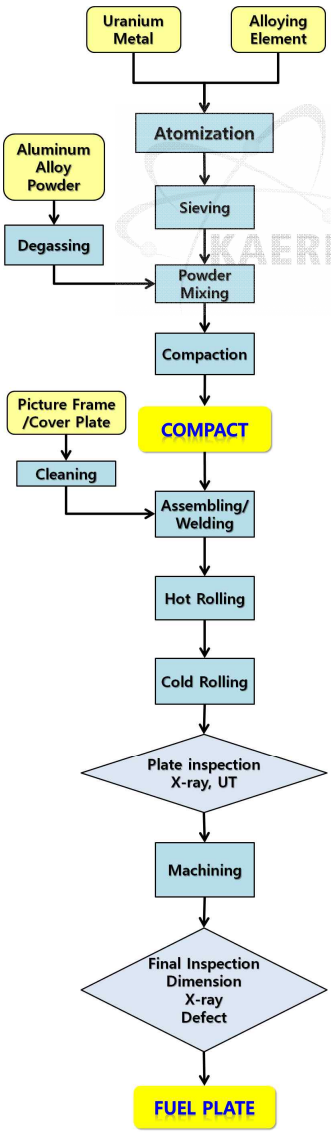


Fig.2. Atomized Nuclear Fuel Powders

Fabrication equipment was installed provided that the flat-type fuel plate assemblies is main products. The fuel core of the fuel plates is fabricated by blending heat treated Al and U alloy powders with shaker mixers, and cold compacting appropriate quantities of powders by 300 Ton press. The pressed compacts are vacuum annealed and then assembled into a picture frame. Cover plates are welded to the frames and the resulting packages are bonded by hot rolling. After a blister anneal, the plates are cold rolled and levelled. Subsequently, fuel core orientation, location, and fuel homogeneity are inspected by X-ray linear scanner. Bond defects are inspected by UT system, and the cladding thickness was inspected by metallographic examination. After the final machining, fuel plates are swaged into the side plates by swaging machine and other components are assembled by EB welder to make into the fuel assemblies. For the final sizing, we use the machining center and the channel gap, final size are measured by gap spacing measuring system and 3D measuring system respectively.



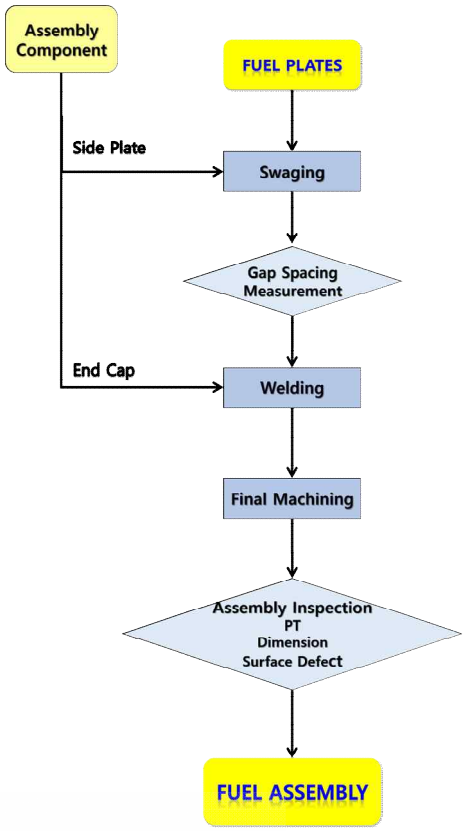


Fig.3. Fuel Fabrication Flow Charts

3. Fabrication Capability of High-density Atomized U_3Si_2 Fuels

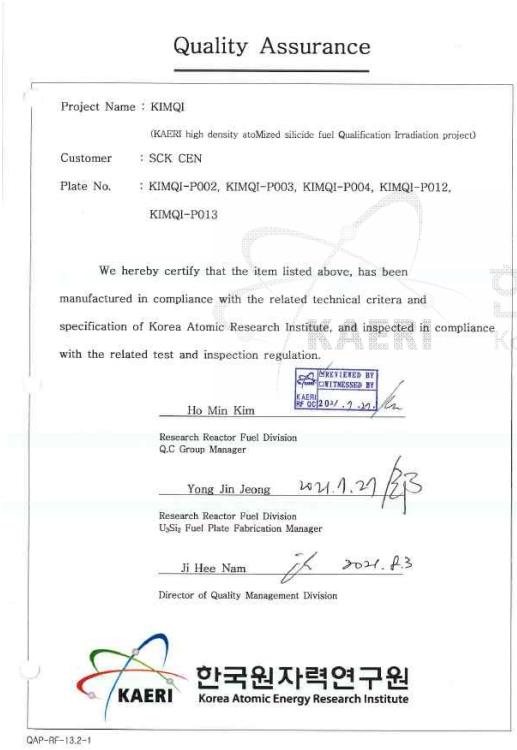
The goal of the first year of the KIMQI project is FUTURE type fuel performance confirmation called KIMQI-FUTURE.

In the KIMQI-FUTURE, four 970 mm in length 61mm in width FUTURE type high-density U_3Si_2 fuel plates were successfully fabricated . Fabrication of fuel plates followed the same procedures which had been established for U-Mo fuels of KJRR.

KAERI also proved fabricated fuel suitability and adequacy of quality assurance and process instructions during the audit.

From the results, it should be noted that because of the brittle nature of U_3Si_2 and the high volume loading of the fuels, some of the larger fuel particles are broken in the process. High-density atomized U_3Si_2 fuel plates contained almost 50 vol. % of fuel in the fuel meat, considerably in excess of the loadings of HEU dispersion fuels. Accordingly, special consideration must be given to the dog-bone area and the minimum cladding thickness. Another consequence of increased fuel loading is an increased number of fuel particles at the surface of compact which can induce the stray particles. However, KAERI's first high-density atomized U_3Si_2 fuel plates have fulfilled the criteria of the KJRR fuel specifications.

Fig.4. KIMQI-FUTURE Fuel Plates for irradiation tests at the BR2



Quality Assurance

Project Name : KIMQI
(KAERI high density atoMized silicide fuel Qualification Irradiation project)
Customer : SCK CEN
Plate No. : KIMQI-P002, KIMQI-P003, KIMQI-P004, KIMQI-P012, KIMQI-P013

We hereby certify that the item listed above, has been manufactured in compliance with the related technical critera and specification of Korea Atomic Research Institute, and inspected in compliance with the related test and inspection regulation.

Ho Min Kim
Research Reactor Fuel Division
Q.C Group Manager

Yong Jin Jeong 2021.1.27
Research Reactor Fuel Division
U_3Si_2 Fuel Plate Fabrication Manager

Ji Hee Nam 2021.1.3
Director of Quality Management Division

KAERI 한국원자력연구원 Korea Atomic Energy Research Institute

QAP-RF-13.2-1

Fig.5. Quality Assurance for the KIMQI-FUTURE Fuel Plates

The new challenge is the plate forming for the KIMQI-GTA, curved fuel plates swaged generic test assembly for the irradiation tests at BR2.

It is on the stage of optimizing press-braking process for the mass production. In this sense, KAERI will be able to perform plate forming process from radius of 55 to 70 mm with +-0.25mm tolerances. Furthermore, KAERI is expecting to fabricate various types of fuel assemblies from the flat-type to the curved-type.

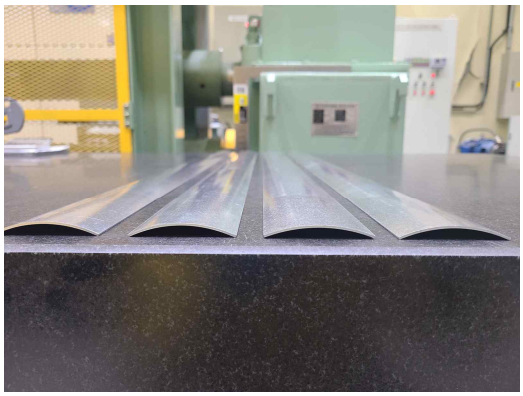


Fig.6. KAERI's first atomized U_3Si_2 curved fuel plates for the KIMQI-GTA