Recent Progress of the DUPIC Fuel Fabrication in Korea

J. W. LEE*, W. K. KIM, JAE W. LEE, G. I. PARK and M. S. YANG
Korea Atomic Energy Research Institute
P. O. Box 105, Yuseong, Daejeon, Korea 305-600
E-mail : jwlee3@kaeri.re.kr

SUMMARY

DUPIC powder and pellets were successfully fabricated in accordance with the quality assurance program described in the Quality Assurance Manual for DUPIC fuel fabrication, which was developed on the basis of the CAN3-Z299.2-85 standard. This manual describes the quality management system applicable to the activities performed for DUPIC fuel fabrication. It covers the work processes, policies and procedures used for planning, executing, and verifying the work carried out for DUPIC fuel fabrication. It is important that a Quality Program is in place before the fabrication of the fuel for irradiation testing. In order to qualify the DUPIC pellet manufacturing processes, 3 series of experiments for the pre-qualification and 3 series for the qualification were performed. In these experiments, the optimum process conditions were established. Then, under the control of the QA program, 8 series of production runs were performed to make the qualified DUPIC pellets in a batch size of 1 kg. In these production runs, DUPIC fuel pellets satisfying the standard CANDU fuel pellet specifications could be successfully produced.

INTRODUCTION

Since 1999, DUPIC fuel has been fabricated at KAERI using the spent PWR fuel

discharged from the nuclear power plant Gori #1 in 1986 to develop the DUPIC (Direct Use of spent PWR fuel In CANDU reactor) fuel cycle technology. DUPIC pellets are remotely fabricated using DUPIC powder which was prepared by the OREOX (Oxidation and REduction of OXide fuel) treatment of the spent fuel pellets extracted from the spent PWR fuel rods[1-5]. Based on the experimental results conducted for the development of the optimum process flow and parameters, it should be verified that DUPIC fuel could be continuously produced at the same good quality. In parallel, it is important that a Quality Program is in place before the fabrication of the fuel for irradiation testing.

For the purposes of the quality assurance of the DUPIC fuel, the Quality Assurance Manual (QM) was developed on the basis of the CAN3-Z299.2-85 standard[6]. Procurement Document, Technical Specification and drawings for the DUPIC fuel for the irradiation test were provided by AECL, assuming AECL as the customer. A Manufacturing and Inspection Test Plan (MITP) was prepared by KAERI and accepted by AECL. Other documents such as the Inspection Procedure, MOP (Manufacturing and Operating Procedures), Process Qualification Procedures and Process Qualification Report were prepared and accepted by AECL.

In order to qualify the DUPIC pellet manufacturing processes, 3 series of experiments for the pre-qualification were performed. The sintered density, dimensions, surface roughness, surface defects and the grain size of the DUPIC pellets were measured using remote inspection systems in a hot-cell[7]. The optimum process parameters for the DUPIC pellet fabrication were established via the pre-qualification runs. Then, the qualification test was performed for 3 batches of the experiments[8]. DUPIC pellets satisfying the Technical Specification were successfully fabricated in the qualification runs. Based on the results, the manufacturing processes of the DUPIC pellets were qualified. Then, under the control of the

developed QA program, 8 series of production runs were performed to make the DUPIC pellets in a batch size of 1 kg[9].

DEVELOPMENT OF THE QUALITY ASSURANCE PROGRAM

The supplier should have a Quality Assurance Program, which shall assure the customer that the material selection and supply, control of the manufacture, inspection, testing and documentation fully meet the customer's requirements. For the purposes of the quality assurance of the DUPIC fuel, the Quality Assurance Manual (QM) was developed. The Quality Assurance Policy established by the Quality Assurance Manual is to assure that the DUPIC fuel supplied to the customer conforms to the specified requirements of the customer, applicable codes and standards. The management of KAERI is committed to the implementation and maintenance of the Program described by this Manual. This Manual describes the Quality Assurance Program for DUPIC fuel fabrication to comply with CAN3-Z299.2-85 to the extents needed and appropriate. This Manual also describes the methods which the DUPIC Fuel Development Team (DFDT) personnel must follow to achieve and assure the high quality of the product. Table 1 shows the QA documentation developed in accordance with the Quality Assurance Program for DUPIC fuel fabrication.

FABRICATION OF THE DUPIC FUEL

DUPIC pellets were fabricated in accordance with the DUPIC fuel fabrication process flow shown in figure 1. Based on both the pre-qualification test and qualification test, the process parameters were established[5,6].

1. Raw material

DUPIC fuel pellets were fabricated with spent PWR fuel discharged from the nuclear power plant Gori #1 in 1986. The average burnup of the spent PWR rods used for this experiment is 27,300 MWd/tU.

2. Powder preparation

A spent PWR fuel rod was cut to rodcuts with a length of 20~25 cm. Then, the rodcut was longitudinally slit and decladded. The separated pellets were oxidized to convert them into a powder. All the oxidized powder was blended together to make a homogeneous powder feed. The homogeneity of the blended powder was measured by chemical analysis. U-235 difference from a mean value ranged from 0.62 to 1.7 %. Pu-239 difference from a mean value ranged from 0.46 to 1.27 %. These results satisfied the criteria that the difference from a mean value should be less than 5 %. The homogenized powder was treated by the OREOX process, where the oxidation temperature was 450 °C, and the reduction temperature was 700 °C. The OREOX-treated powder was milled by a attritor at the speed of 450 rpm for 10 minutes and 600 rpm for 10 minutes. The milled powder was pre-compacted at the pressure of 62 MPa, then the pre-compacted pellets were granulated by using a sieve of mesh numbered #18. The granulated powder was mixed with zinc stearate for final pressing.

3. Fabrication of the DUPIC pellets

Green pellets were fabricated by the final compaction process with a pressure range from 96 MPa to 124 MPa. Zinc stearate was removed during the heating of the green pellets for 3 hours at 800 °C in an Ar-4%H_2 atmosphere. The sintering process was performed at 1800 °C for 10 hours in an Ar-4%H_2 atmosphere. The sintered density of a few pellets did not meet the criteria, 10.25 g/cm^3. The pellets were sintered again at 1850 °C for 5 hours in an Ar-4%H_2

atmosphere to increase the sintered density.

The sintered pellets were ground by a dry grinder to adjust the diameter and surface roughness. The pellets were characterized to evaluate their quality in accordance with the Manufacturing and Inspection Test Plan (MITP).

CHARACTERISTICS OF THE DUPIC FUEL

1. Characteristics of the DUPIC powder

The apparent density and the tap density of the powders were measured after the OREOX process and the milling process. The apparent density of the OREOX-treated powder ranged from 0.63 to 0.84 g/cm^3. The tap density of the OREOX-treated powder ranged from 1.04 to 1.27 g/cm^3. After milling, the densities increased to be about 3 times higher than those of the OREOX-treated powder.

2. Characteristics of the DUPIC pellets

2-1. Density of the sintered pellet

Green pellets were sintered at 1800 ℃ for 10 hours in an Ar-4%H_2 atmosphere. In the case of the production runs such as the batches numbered B02-04, B02-05, B02-06 and B02-07, the pellets were sintered again at 1850 ℃ for 5 hours to increase the sintered density. In these cases, nonconformance reports were issued in accordance with the QA program of the DUPIC fuel. Immersion density of the sintered pellet was calculated by measuring the pellet weight both in air and in water as shown in figure 2. The sintered density ranged from 10.278 to 10.379 g/cm^3, which met the Technical Specifications. The shrinkage rate in diameter ranged from 13.88 to 14.38 %.

2-2. Inspection of the ground pellet

The sintered pellets were ground using a dry centerless grinder to adjust the diameter and surface roughness. After grinding, the shoulder width, the surface roughness, and the diameter of the sampled pellets were measured. The shoulder width ranged from 0.69 to 0.79 mm. The surface roughness of the ground pellets ranged from Ra 0.43 μm to Ra 0.79 μm. The diameter of the ground pellets met the standard CANDU fuel specification. Then, visual inspection was conducted to check for any surface defects for all the fabricated pellets. Most of the pellets were defect-free on the surface. Some defects such as micro-crack and end-capping were found in a few pellets. 414 pellets were fabricated in these production runs.

2-3. Microstructure of the sintered pellets

The microstructure was investigated for two sintered pellets in the qualification test. The sampled pellet was divided into two parts by cutting it longitudinally. The cut surface was polished and etched. The microstructure of the pellet was observed by an optical microscope with a magnification of 200. Figure 3 shows the microstructure of a DUPIC pellet. The average grain size ranged from 14.6 to 14.9 μm.

2-4. Chemical analysis of the DUPIC fuel

The composition of the DUPIC powder and a pellet was chemically analyzed. The Cs-134/Cs-137 content of a sintered pellet was less than 1 % of that of the powder. 99 % of the Cs was removed during sintering. It was confirmed that the vaporized cesium was trapped by the fission gas trapping filter of the off-gas treatment system.

5. CONCLUSIONS

10 kg of spent PWR fuel was used for the qualification and production of DUPIC fuel. A pre-qualification experiment was performed to establish the process conditions of the DUPIC pellets. Then, a qualification test was performed on the basis of the results of the pre-qualification experiment. And, the optimum manufacturing processes of the DUPIC pellets were established. Then, under the control of the QA program developed with the assistance of AECL, 8 series of production runs were performed to make the DUPIC pellets. The results were as follows:

The qualified DUPIC pellets were fabricated in a batch size of 1 kg in accordance with the developed QA program.

The defect-free pellets with high sintered densities ranging from 10.26 to 10.43 g/cm^3 were successfully produced.

The DUPIC pellets meeting the standard CANDU fuel specifications were fabricated in a series of batch productions.

ACKNOWLEDGEMENTS

This project has been carried out under the Nuclear R&D Program of Korean Ministry of Science & Technology.

REFERENCES

1. HASTING, I.J., et al, "Synergistic CANDU-LWR Fuel Cycles", Proceedings of the 6th KAIF/KNS Annual Conference, Seoul, Korea, p.527 (1991).
2. YANG, M.S., et. al, " The DUPIC Fuel Program in KAERI", Proceedings of DUPIC Fuel Workshop, pp.1-6 (1997).
3. YANG, M.S., et al, " A Study on Manufacturing and Quality Control Technology of DUPIC Fuel", KAERI/RR-1744/96, Korea Atomic Energy Research Institute, pp.601-610 (1997).
4. YANG, M.S., et al, " Development of DUPIC Fuel Fabrication and Inspection Equipment", KAERI/TR-1319/99, Korea Atomic Energy Research Institute, pp.72-75 (1999).
5. YANG, M.S., et al, "A Study on the Manufacturing and Processing Technologies of DUPIC Fuel", KAERI/TR-1336/99, Korea Atomic Energy Research Institute (1999).
6. LEE, Y.G., et al, "Development of Quality Assurance Manual for Fabrication of DUPIC Fuel", KAERI/TR-1915/2001, Korea Atomic Energy Research Institute (2001).
7. KIM, W.K., et al, "Pre-Qualification Experiments of DUPIC Fuel Pellets for Irradiation Testing in the NRU Reactor", KAERI/TR-2040/2002, Korea Atomic Energy Research Institute (2002).
8. KIM, W.K., et al, "Qualification Test of DUPIC Fuel Pellets for Irradiation Testing in the NRU Reactor", KAERI/TR-2175/2002, Korea Atomic Energy Research Institute (2002).
9. KIM, W.K., et al, "Development of Manufacturing, Inspection and Test Plan for Fabrication of DUPIC Fuel Pellets and Elements", KAERI/TR-2349/2002, Korea Atomic Energy Research Institute (2002).

TABLE 1. List of the Documents for DUPIC Fuel Fabrication

No.	QAProcess	Documents
1	Supplier's Documents	QAM : Quality Manual for DUPIC fuel fabrication MITP : Manufacture, Inspection and Test Plan ITP : Inspection and Test Plan for DUPIC fuel QR-NRU-01 : Qualification Report of Sintering Process WQR-NRU-01 : Welding Qualification Report
2	Customer's Documents	Procurement Document Drawing Technical Specification
3	Manufacturing Operating Procedures (MOP)	MOP-100 Slitting MOP-200 Oxidation Process MOP-300 Blending MOP-400 OREOX Process MOP-500 Off-gas Treatment System for OREOX Process MOP-600 Milling of the OREOXed Powder MOP-700 Mixing MOP-800 Pre-pressing and Granulation MOP-900 Final Pressing MOP-1000 Dewaxing MOP-1100 Sintering MOP-1200 Off-gas Treatment System for Sintering MOP-1300 Centerless Grinding MOP-1400 Stack Adjusting and Pellet Loading MOP-1500 Endcap Welding MOP-1600 Surface Cleaning

4	Inspection Procedures (IP)	- Powder Homogeneity - Density of Slug - Density of Green Pellet - Density of Sintered Pellet - Chemical Analysis of Powder & Pellet - Microstructure of Sintered Pellet - Visual Inspection of Ground Pellet - Dimension of Pellet - Surface Roughness of Ground Pellet - Stack Length - Helium Leak Test - Microstructure of Weld of the Element - Dimension of Element - Visual Inspection of Element - Incoming Inspection
5	Miscellaneous	- Master List of Measuring and Test Equipment - Nonconformance Report - Travellers (Powder, Pellet, Element)

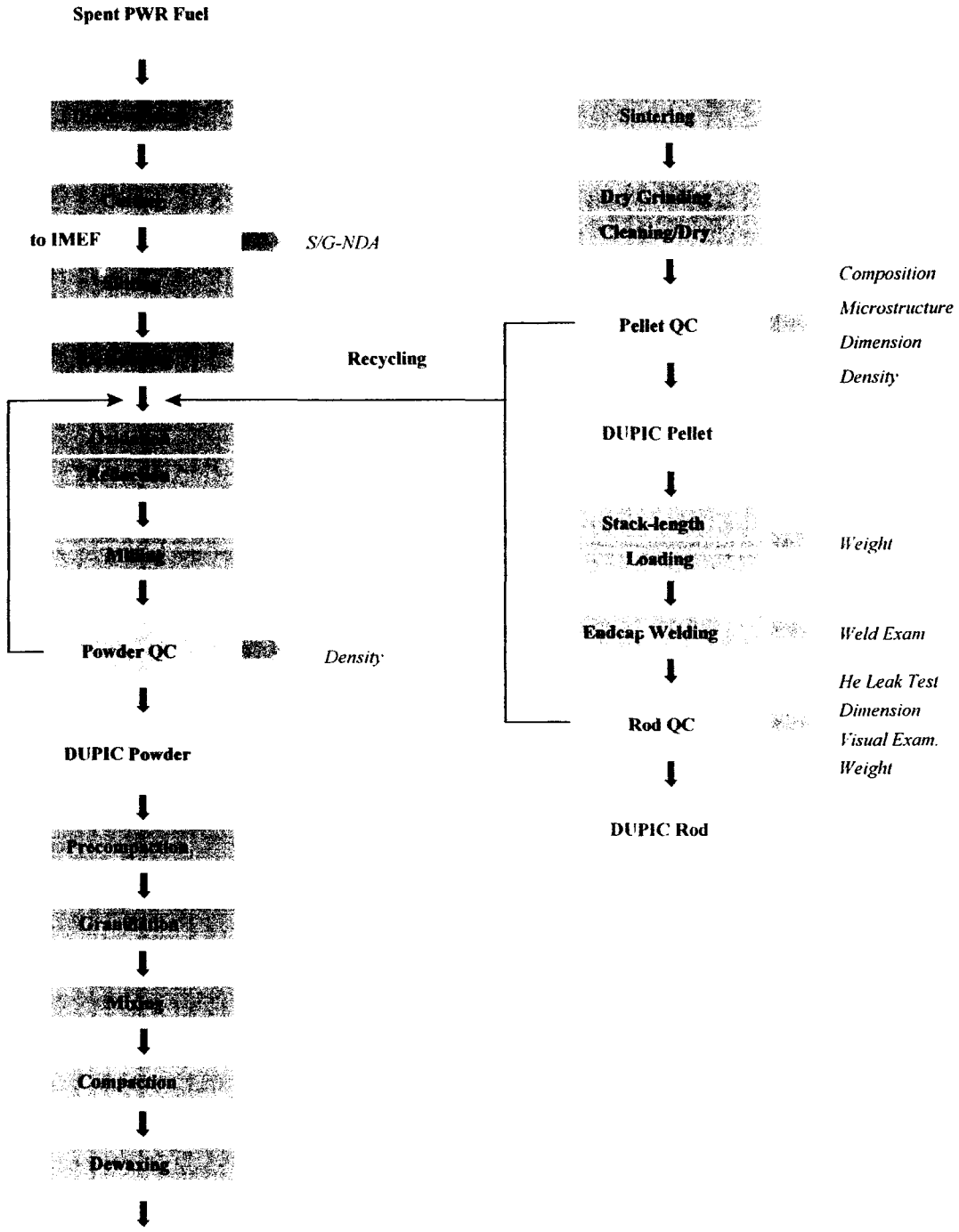

FIGURE 1. DUPIC Fuel Fabrication Process Flow

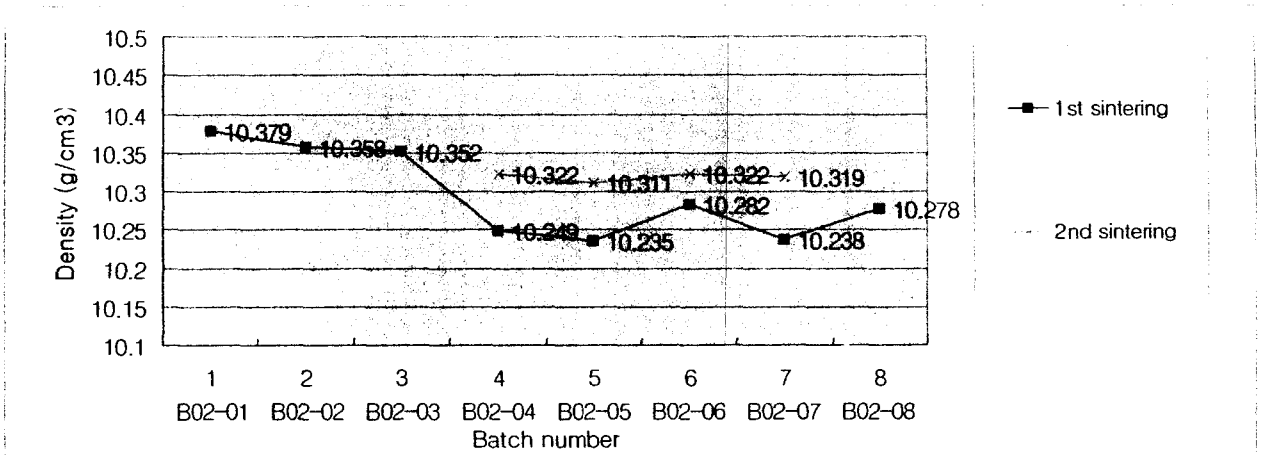

FIGURE 2. Density of the Sintered DUPIC Pellets

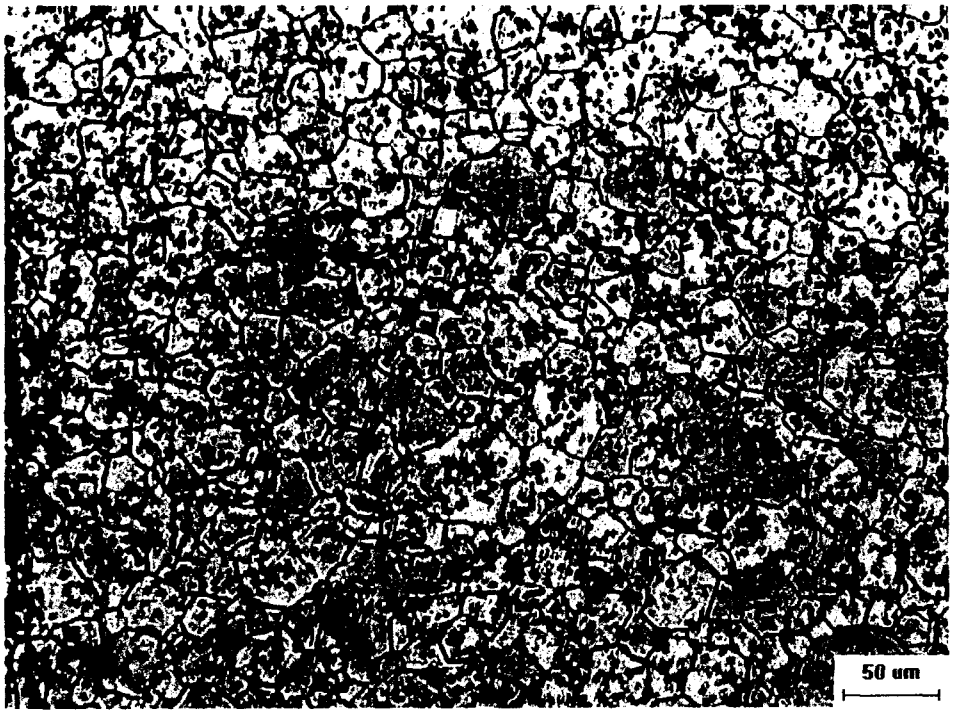

FIGURE 3. Microstructure of the Sintered DUPIC Pellet