DESIGN AND FABRICATION OF REMOTE WELDING SYSTEM FOR THE FUEL BUNDLE ASSEMBLY

Soo-Sung Kim[1], Jung-Won Lee[1] and Geun-Il Park[1]

[1] Korea Atomic Energy Research Institute, Daejeon, Republic of Korea

Abstract

Remote fuel bundle welding equipment in a hot-cell was designed and fabricated. To achieve this, a preliminary investigation of hands-on fuel fabrication outside a hot-cell was conducted with a consideration of the constraints caused by welding in a hot-cell. Some basic experiments were also carried out to improve the end-plate welding process for fuel bundle fabrication. The resistance welding equipment using end-plate welding was also improved. It was found that resistance welding was more suitable for joining an end-plate to end caps in a hot-cell. The optimum conditions for end-plate welding for remote operation were also obtained. Preliminary performances to improve the resistance welding process were also examined, and the resistance welding process was determined to be the best in the hot-cell environment for fuel bundle fabrication. The greatest advantage of fuel bundle welding equipment would be a commercialized welding process in which there is extensive production experience. This paper presents an outline of the developed welding equipment for a fuel bundle fabrication and reviews the conceptual design of remote welding equipment using a master-slave manipulator. The design of the remote welding equipment using the Pro-Engineer method was also reviewed. Furthermore the mechanical considerations and a mock-up simulation test were described. Finally, its performance test results were presented for a mock-up of remote fuel bundle welding equipment.

1. Introduction

Fuel cycle technology is being developed at KAERI and is meant to reuse spent PWR (Pressurized Water Reactor) fuel as raw material for the CANDU reactor [1]. This technology is being developed in the IMEF (Irradiated Material Examination Facility) at KAERI because of the nature of the high radioactivity of spent PWR fuel. In order to fabricate DUPIC* fuels in a hot-cell environment, remote welding technology should be employed to weld between an end-plate and an end-cap. To achieve this, a preliminary investigation of a hands-on fuel fabrication outside a hot-cell was necessary in the consideration of the constraints caused by the remote welding in a hot-cell [2]. The DFDF (DUPIC Fuel Development Facility) is a completely shielded cell made of heavy concrete. As the DFDF is active, direct human access to its in-cell is not possible. All the DUPIC fuel fabrication processes and equipment operations, therefore, are conducted in a fully remote manner, using a

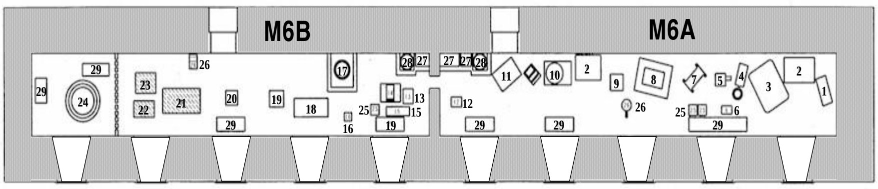
* Direct Use of PWR fuel In CANDU reactors

master-slave manipulator. In order to select a more suitable welding process in a hot-cell environment, various welding processes such as the GTAW (Gas Tungsten Arc Welding), the RW(Resistance Welding) and LBW (Laser Beam Welding) methods which are now available for end-plate welding for commercial fuel bundle fabrication, should be processed as candidates. Even though the GTAW process is widely used for manufacturing fuel bundles, it could not be recommended for the remote end-plate welding of a fuel bundle in a hot-cell facility due to the complexity of the electrode alignment and the difficulty in the replacement of the parts in a remote manner. On the other hand, the RW process has some advantages because it is a qualified process and is extensively used in production. Hence, a remote bundle welding system was needed in order to join end-plates to end-caps in a remote manner. The objective of this paper is to present the development of the fuel bundle welding equipment for use in a highly radioactive zone of the DFDF at KAERI.

2. Development of remote welding equipment

2.1 Remote welding operation

All equipment for the remote fabrication of the DUPIC fuel elements will be installed in a hot-cell as shown in Figure 1. As long as commercial equipment is available, it is purchased and modified for hot-cell use from the viewpoint of easy remote operation and maintenance. Among them, the remote fuel bundle welding equipment was designed to be modular and remotely operable by using a master-slave manipulator as shown in Figure 1(No.21). The main parts of the welding equipment are located inside a hot cell, while the electronic parts are separated to be installed outside the hot cell. The remote welding equipment is developed by adopting a head torch in order to achieve a spot weld metal between an end-plate and end-caps using a master-slave manipulator. As for end-plate welding operation and handling in a remote manner, as shown in Figure 2, the design concept should take into account the remote manipulation, welding procedure, and capabilities and constrains of the remote handling devices that are available in a hot-cell. The design should also include the considerations of an interface with a human operator, modular assembling parts for easy maintenance, electrical power transmission for control, and the radiation effects of materials to be used.



1. MILL
2. OFF-GAS TREATMENT SYSTEM
3. OREOX FURNACE (Oxidation & Dewaxing)
4. MIXER
5. SLITTING MACHINE
6. POWDER QC EQUIPMENT
7. COMPACTION PRESS
8. CENTERLESS GRINDER
9. CUTTER
10. SINTERING FURNACE
11. QC - FURNACE
12. PELLET CLEANER/DRYER
13. PELLET LOADING MACHINE
14. PELLET QC EQUIPMENT
15. PELLET STACK ADJUSTER
16. ROD QC EQUIPMENT
17. S/G-DSNC
18. END CAP WELDER
19. HELIUM LEAK TESTER
20. MINI-ELEMENT ASSEMBLY MACHINE
21. END PLATE WELDER
22. BUNDLE QC EQUIPMENT
23. BUNDLE CLEANER
24. DECON. CHAMBER
25. BALANCE
26. VACUUM CLEANER
27. MATERIAL STORAGE
28. WASTE STORAGE
29. VENTILATION FILTER

EQUIPMENT FOR BUNDLE FABRICATION

Figure 1 Layout of the remote process equipment for DUPIC fuel fabrication in DFDF.

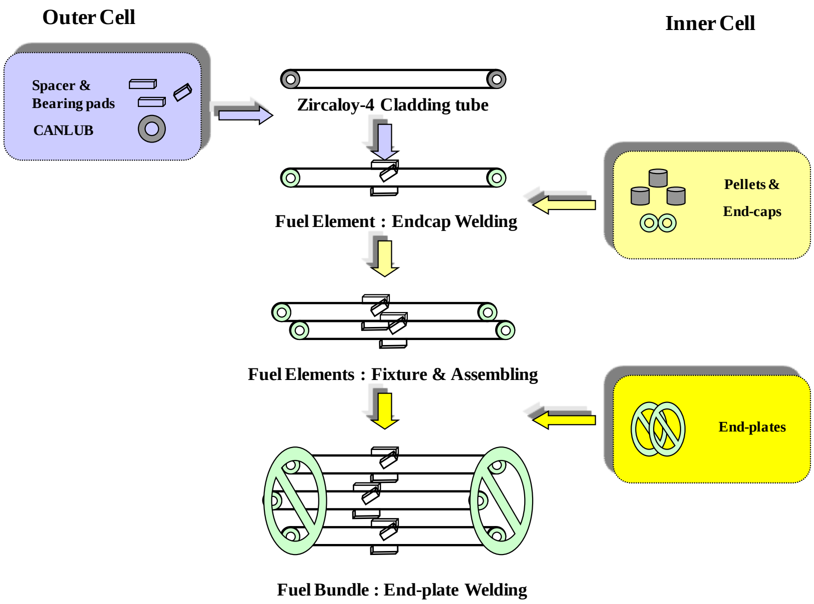


Figure 2 The process of end-plate welding operation and handling.

2.2 Design and fabrication of remote welding equipment

The remote fuel bundle welding equipment of a hot-cell environment consists of a resistance welder, a mater-slave manipulator, and a controller. The main head of welding equipment will be used by the multi-pulse type method. The modular remote welding equipment for fuel bundle manufacturing in a hot-cell was made by upgrading the design of the welding equipment for multi-pin fuel types. In this manufacturing process sequence of fuel bundles, the fuel elements that were welded by the end-caps were firstly positioned in an assembly fixture, in which the top part of fuel bundle was welded. Finally, the bottom part of the fuel bundle after rotating 180° was welded to the bottom end-plate. In this process, a master-slave manipulator was required to be designed and assembled to be handled easily because the remote operation using a slave manipulator in a hot-cell was carried out. The modular welding equipment made up of four subassembly parts was designed with the modular concept and is compact in comparison with a previous welder for multi-pin fuel types in a remote manner.

The remote welding equipment [3] consists of a main frame, weld head using a single electrode, branch electrode indexer, endplate magazine loader, and bottom assembler. Figure 3 show the basic concept of the welding system, and Figure 4 illustrates the design construction of the remote welding equipment. The base frame itself consists of a single W-Cu electrode, step-down transformer, air cylinder, or other means of applying a change of the W-Cu electrode using a head pin as shown in Figure 4(A). A branch electrode indexer provides accurate rotation of the upper and lower fuel bundle during end-plate welding operations. A rotary indexer driven by the servo motor is adjustable to allow the length of the overall shafting to vary as the indexing units are raised and lowered. The shafting for a remote operation is fitted together by means of a linear guide and linear bearing slides. A jigging plate using the Be-Cu branch electrodes as shown in Figure 4(A) provide an accurate seat for the bundle end-plates and 37 elements. This part aligns the W-Cu electrode with the ends of 37 elements during a welding operation. End-plate loading mechanisms were used for the upper and lower units. An end-plate magazine loader, as shown in Figure 4(A), dispenses and loads either the upper or the lower end-plates to the bundle welding operation. A re-loadable magazine provides the supply of end-plates to the units, which are dispensed one at a time by an air cylinder. A tuner unit of a bottom assembler was incorporated into the end-plate transfer gripper tooling to execute rotation of the end-plate required during transfer as shown in Figure 4(B). This unit is very robust and thereby adheres to the permissible load restrictions they will require no maintenance. Each of these subassembly parts of the remote welding equipment was designed in modules to facilitate maintenance by remote manipulation.

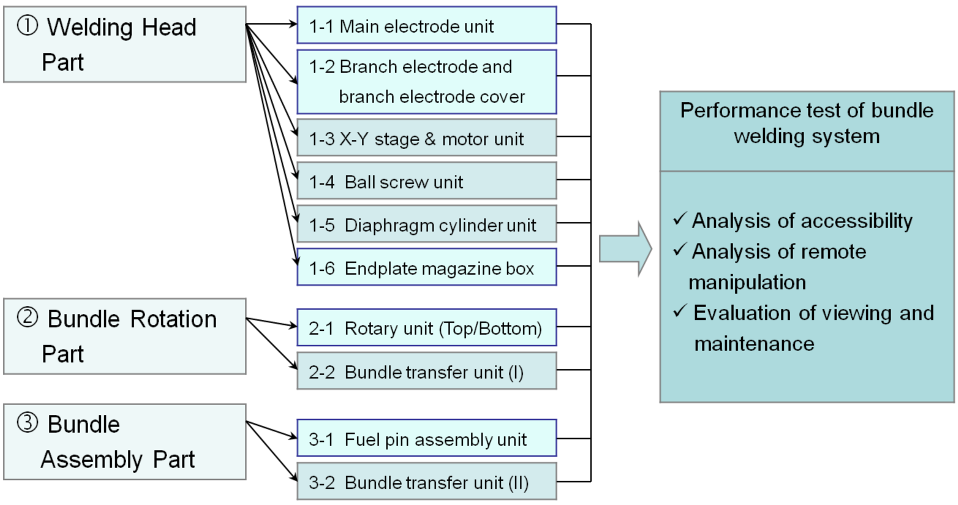


Figure 3 Basic concept of the remote welding equipment.

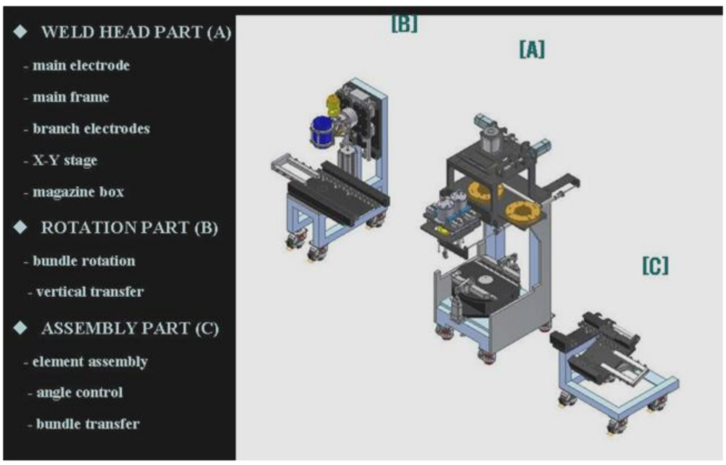


Figure 4 Design construction of the remote welding equipment.

Design of the modular remote welding equipment was conducted by making structural configurations and developing with Pro-Engineer Wildfire 3.0 program produced by the PTC (Parametric Technology Corporation) after completing the basic drawing for the remote welding equipment. Based on the modular design, the remote operation in a hot-cell using the manipulator was checked with the aid of auxiliary exploded and re-assembled functions using the Pro-Engineer design method as shown in Figure 5. The installing and exchanging of main parts such as, a damaged weld head using the W-Cu electrode and Be-Cu branch electrodes for remote operation in a hot-cell, as shown in Figure 6, were also checked and analyzed. All the modular components of the assembling parts can also be remotely exchanged or maintained. In order to prevent the weld head part from dropping the master-slave manipulator during remote operation, the weld head part is used by an assistant gripper. The assistant gripper is connected using the crane of the roof door. As with a real operation, the maximum weight that the master-slave manipulator can grasp is about 6 kg, and the operator can then feel that the weight of the weld head part is about 1.7 kg. The mock-up simulation test was also carried out to check technical matters for remote operation and each element for the processing sequence. It was confirmed that the mock-up simulation test showed the process sequence and remote welding operation in the hot-cell environment using the Pro-Engineer design method.

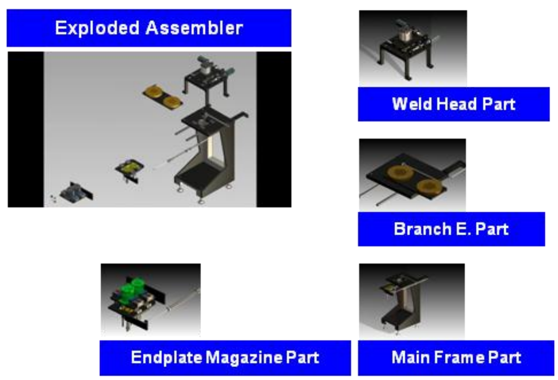


Figure 5 Auxiliary exploded and re-assembled functions of top assembler.

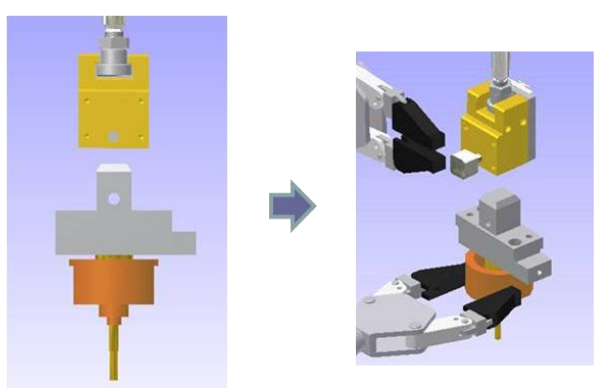


Figure 6 Illustration of installing and exchanging weld head.

2.3 Remote operation in mock-up facility

A remote welding equipment has been tested to verify its performance and capabilities in a mock-up of the DUPIC simulation test room. The mock-up test environment of a remote welding equipment for in-cell operation is shown in Figure 7. The human operator and manipulation are located outside of the mock-up of the simulation test room, and a remote welding equipment is located inside. Through the design and fabrication of remote welding equipment, Figure 7 shows the combined welding equipment including the main frame part, rotation part, and element assembly part in the mock-up simulation test room. Among them, the weld head of the main frame part is designed, and there is a reason why it was very interchangeable to replace a new one. Figure 8 illustrates remote operations using the master-slave manipulator. From the mock-up performance test using a remote welding equipment, it shows that satisfactory results were obtained in aspect of the access ability, master-slave manipulation, replacement of the subassembly parts and operation repeatability, as shown in Table 1. Currently, the weld head and branch electrode parts are under performance tests in order to acquire their reliability and stability before put into the DFDF. From the mock-up test, the remote welding equipment is improved and implemented to verify its performance and capabilities of all assembly parts. The mock-up test environment and functional connections of welding equipment for the bundle end-plate welding operation, where a real operation though the hot-cell window is controlled by using the remote and automatic process mode are under development at the DUPIC simulation test room..

2.4 PM test of welding equipment

In order to investigate weld performance of remote welding equipment in a mock-up test room, a PM (Process Monitoring) test was conducted and a special fixture using Zircaloy-4 weld specimens was designed and fabricated as shown in Figure 9. The PM test using a special fixture was performed according to the quality control procedure (Doc. No. HQP-33-02), and the welding samples provided for four specimens (Zircaloy-4 specimen No. = 12, 16, 31, 37). Torque strengths of the PM test were measured by the average values of four weld specimens, as shown in Figure 10. In the real experiment, a special fixture was installed on the assembly floor of the remote welding equipment, and the operator performed the welding operation by handling the master slave manipulator. This experiment was carried out by varying the welding parameters of the weld current and pressure of the main electrode, while the working sequence controlled by the operator is constant. Table 2 shows the resistance welding conditions of the PM test. The experimental results show that the weld current and pressure of the main electrode influence the extent of the torque strength. Figure 11 shows the relationship between the weld current and torque strength using the Zircaloy-4 weld specimens. As for the effect of the torque strength during the welding operation, it was found that the torque values increased by increasing the weld current. Figure 12 shows the relationship between pressure of the main electrode and torque strength of the Zircaloy-4 welded specimens at a current of 4200A. In the extent of 3.5 BAR to 5 BAR of a pressure of main electrode, the torque strengths of Zircaloy-4 welded specimens are found to be approximately 13-15 Nm, which is larger than that of the acceptable criteria (9 Nm) as followed by the quality control procedure. It is concluded from the experiment that for the welding condition of the weld current and pressure of the main electrode, the torque strength reaches 99.9% for accomplishing perfect values of the resistance Zircaloy-4 welded specimens.

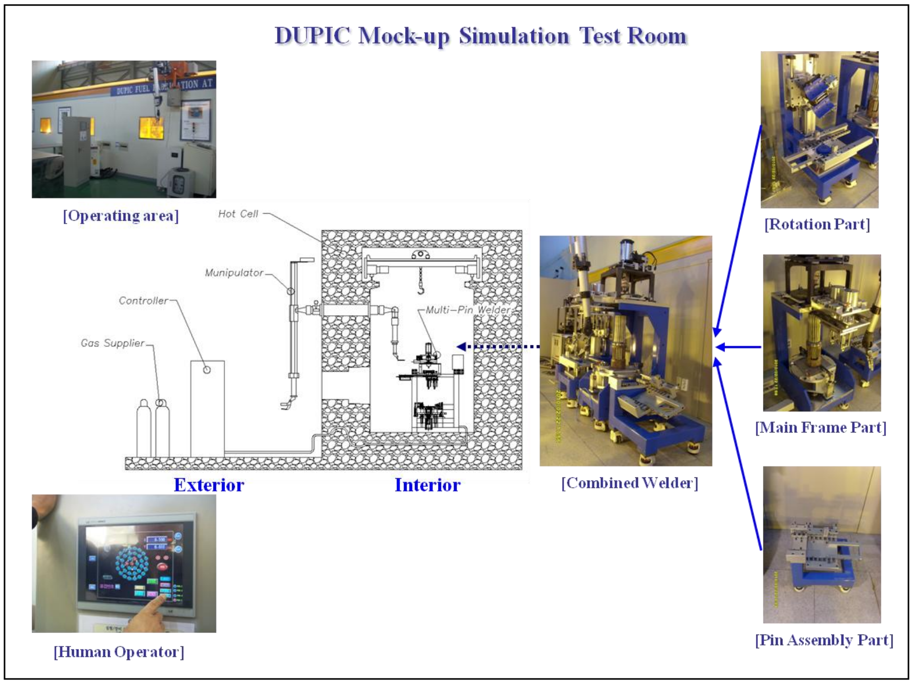


Figure 7 The remote welding equipment and its operation in DUPIC mock-up facility.

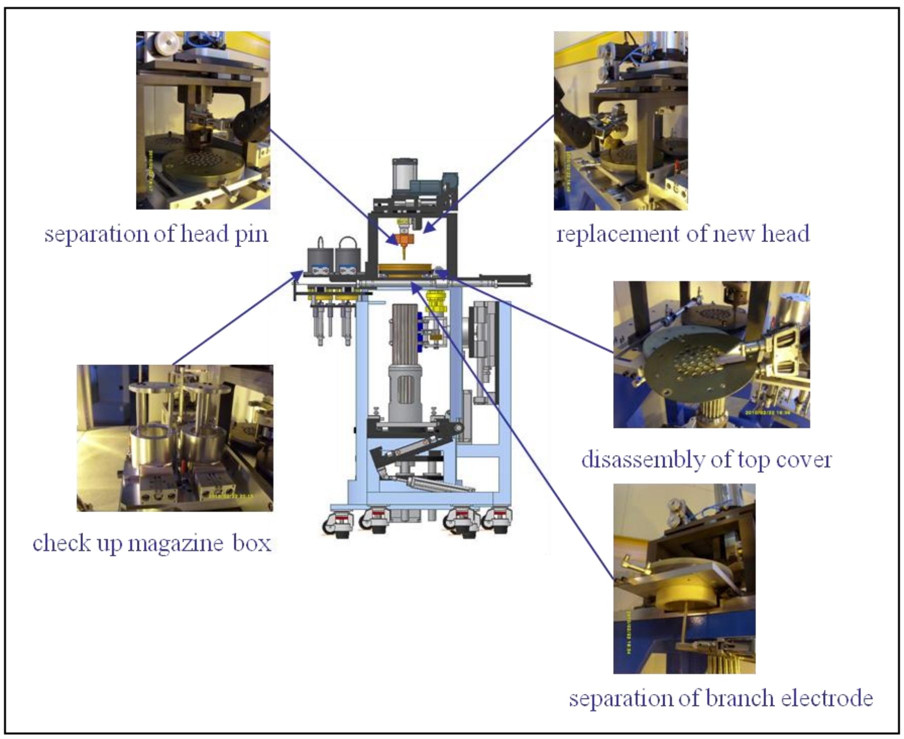


Figure 8 Illustration of manipulating various main parts.

Table 1 Results of performance tests for the remote welding equipment.

Main Parts	Subassembly Parts	Performance Tests			
		Access ability	Master-slave manipulation	Replacement of subassembly parts	Repeatability (technical lessons*)
1. Weld head part	1-1 main electrode unit	O	O	O	O
	1-2 branch electrode unit	O	O	O	O
	1-3 X-Y stage unit	△	△	△	△
	1-4 servo-motors	△	△	△	△
	1-5 ball screw unit	△	△	△	△
	1-6 diaphragm cylinder	△	△	△	△
	1-7 end-plate magazine box	△	△	△	△
2. Rotation part	2-1 rotary unit	O	O	O	O
	2-2 bundle transfer unit(I)	O	O	O	O
3. Fuel elements assembly part	3-1 fuel elements assembler	O	O	O	O
	3-2 bundle transfer unit(II)	O	O	O	O
	O (Good), △ (Medium), × (Bad)				

* This is to be required in order to acquire its reliability and stability of the remote welding equipment.

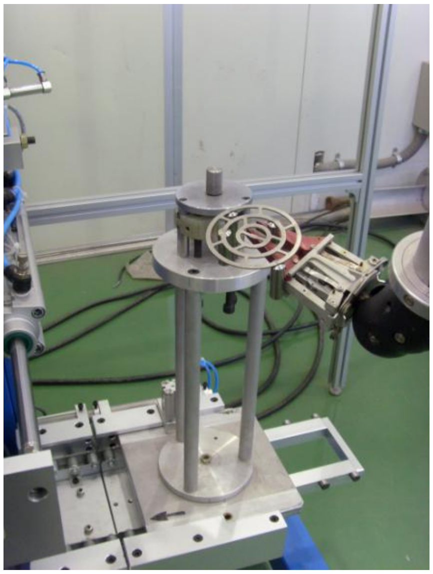


Figure 9 Photograph of the special fixture using Zircaloy-4 weld specimens.

Figure 10 Photograph of the weld specimens for PM torque test.

Table 2 The resistance welding conditions of the PM test.

Sample No.	Weld Current (A)	Pressure of main electrode (Bar)	Pressure of branch electrode (Bar)
# 01	4200	3.5	5.5
# 02	4200	4.0	5.5
# 03	4200	4.5	5.5
# 04	4200	5.0	4.5

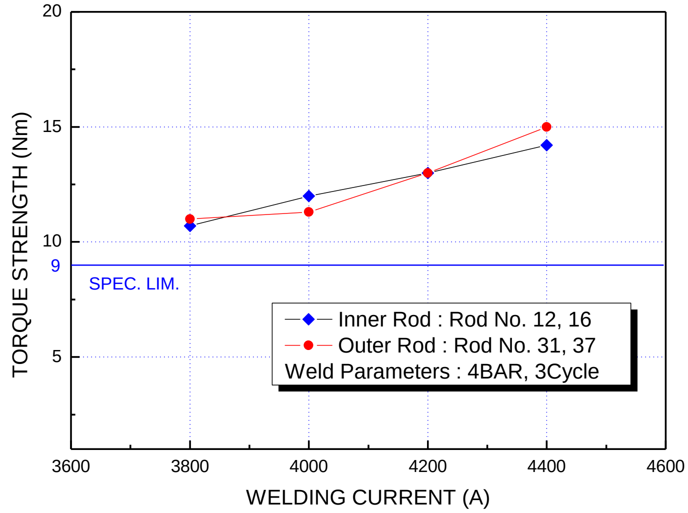


Figure 11 The torque strength of the welded specimens as a function of the weld current.

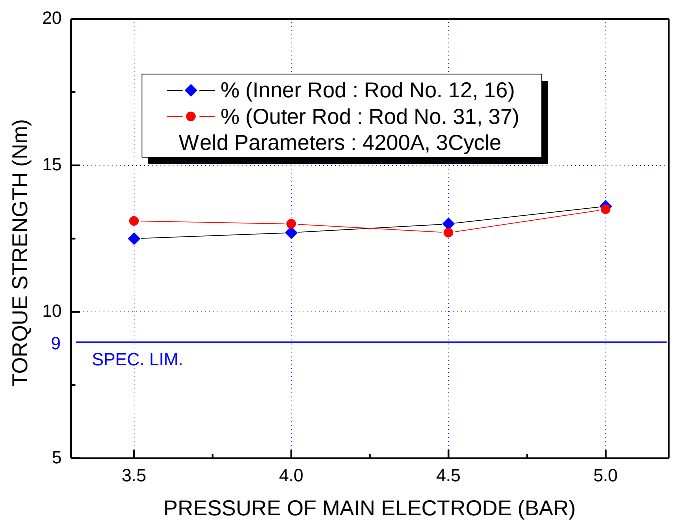


Figure 12 The torque strength of the welded specimens as a function of the pressure of main electrode.

3. Conclusions

This work was conducted to develop the remote welding equipment for a DUPIC fuel bundle fabrication and to review the basic drawing by means of a Pro-Engineer design method. In the future, the optimum welding equipment and detailed drawings obtained in this study will be applied to the end-plate welding process. From the mock-up performance test using the remote welding equipment, it shows that satisfactory results were obtained in aspect of access ability, master-slave manipulation, and replacement of some parts, respectively. Furthermore, to establish the reliability of remote operations using resistance welding equipment, it was necessary to carry out a welding sample test using the end-plates for fuel bundle fabrication in a DUPIC mock-up facility.

4. Acknowledgment

This work was performed under the Long-term Nuclear R&D Program sponsored by the Ministry of Science and Technology.

5. References

[1] M. S. Yang, et al., “Direct use of spent PWR fuel CANDU reactor – DUPIC manufacturing and process technology”, *KAERI-1022/99*, Korea Atomic Energy Research Institute, 2000.

[2] J. D. Sullivan, “AECL’s Progress in Developing the DUPIC Fuel Fabrication Process”, The 10th KAIF/KNS Annual Conference, 1995.

[3] Bundle Assembly Welder, “GE Canada Nuclear Products”, Contract Item No. A7.2 1995.