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Irradiation–coupling techniques using JMTR and another facility

Y. Matsui [a,*], Y. Itahashi [a], M. Shimizu [a], H. Tsuji [b]

[a] *Japan Atomic Energy Research Institute, Oarai Research Establishment, Narito-cho, Oarai-Machi, Higashi Ibaraki-Gun, Ibaraki-Ken 311-1394, Japan*

[b] *Japan Atomic Energy Research Institute, Tokai Research Establishment, Tokai-Mura, Naka-Gun, Ibaraki-Ken 319-1195, Japan*

Abstract

The study of neutron irradiation damage is inevitable for the development of fusion reactors such as the International Thermonuclear Experimental Reactor (ITER). In general, it is difficult to simulate the characteristics of irradiation damage, such as the relationship between helium production and displacement damage, expected in fusion reactors by using the existing test reactors. This is due to the neutron spectrum of test reactors, which are more thermalized than expected in fusion reactors. Despite such limitation, irradiation damage expected to occur in fusion reactors can be simulated in test reactors by spectrum tailoring techniques and/or a combination of irradiation at different conditions, so called irradiation–coupling. In Japan Atomic Energy Research Institute (JAERI), the technique of re-irradiation for irradiated specimens was developed to realize irradiation–coupling as stated above. The key technology in establishing such a technique is the development of a specially designed coupling capsule which can be assembled and loaded with irradiated specimens by remote handling devices in the hot cell. JAERI has recently developed the coupling capsule and successfully completed its irradiation in the Japan Materials Testing Reactor (JMTR).

1. Introduction

In the Japan Materials Testing Reactor (JMTR), irradiation tests are increasing for the development of materials to be used in fusion reactors such as the International Thermonuclear Experimental Reactor (ITER). In these recent irradiation tests, the ratio of helium generation by thermal neutrons (He-appm) to dpa is taken as a fundamental parameter in the irradiation studies.

According to such a circumstance, a re-irradiation technique is proposed as a method for simulating a fusion reactor environment in the JMTR. As applications of this irradiation–coupling technique [1], various combinations of irradiation can be considered such as the fast reactor/JMTR, LWR/JMTR, accelerator/JMTR or JMTR/JMTR to control the ratio of He-appm/dpa in irradiated materials. The re-irradiation technique will contribute not only to simulate the irradiation in fusion reactors but also to promote new irradiation research projects. Proposed new research projects are as follows:

1.1. The irradiation–coupling using fast reactors and JMTR

Fig. 1 shows the relationship between helium production (appm) and displacement damage (dpa) by a fast reactor and JMTR [2] for type 304 stainless steel. Intensive fast neutrons in the fast reactor are effective in producing the dpa in the specimen, while the thermal neutrons of JMTR are effective to generate helium atoms in it. Though it is difficult to arrive alone at the point B in either reactor, the coupling–irradiation can reach the point B by changing the irradiation environment from the fast reactor to the JMTR at point A. Therefore, the coupling–irradiation using the fast reactor and JMTR can be used to control the ratio between

* Corresponding author. Tel.: +81-29 264 8327; fax: +81-29 264 8480.

E-mail address: matsu@oarai.jaeri.go.jp (Y. Matsui).

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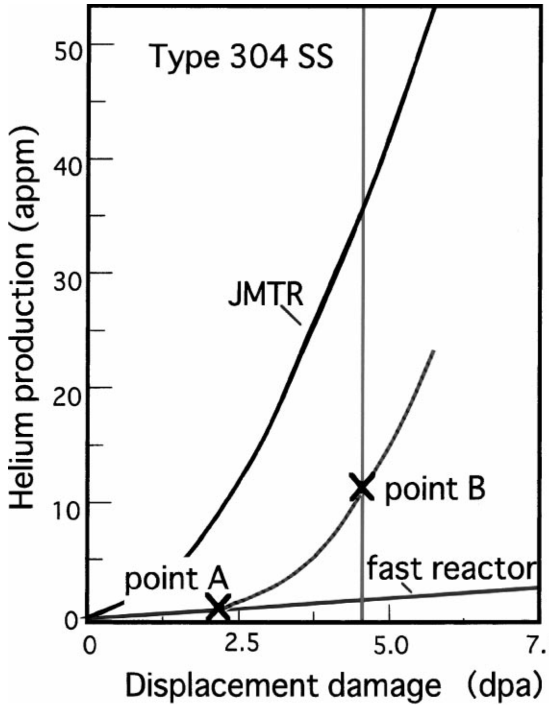

Fig. 1. Relationship between helium production and displacement damage.

appm and dpa, and to arrive at a target in short irradiation time. This method will be a powerful tool to study the cause of irradiation creep in relation to appm and dpa.

1.2. The irradiation–coupling using accelerators and JMTR

It is easy to make initial defects in materials by using an accelerator. Such defects will grow by neutron irradiation in the JMTR. This method will be used to study how defects grow under neutron irradiation.

1.3. The irradiation–coupling using LWRS and JMTR, or re-irradiation in the JMTR

Material specimens irradiated in the reactor can be used for welding tests, annealing and post irradiation tests (PIE) in the hot cell. Then the specimen will be irradiated in the JMTR again. This technique will be used for the study of repair techniques in LWRs and the study of irradiation effects after annealing. Re-irradiation of the specimen after being examined in the hot cell will be an effective tool to trace irradiation effects on the material.

2. Development procedures

The first capsule for the new technique was developed for the irradiation–coupling in the fast reactor and JMTR. The conceptual design and development items for the coupling capsule are given in the following.

2.1. The conceptual design

The capsule must be assembled after being loaded with irradiated specimens in the hot cell. The detail of the assembling process is described in Section 2.2. There are limits on the diameter and the length of the capsule. The diameter must be 40 mm at maximum according to the size limitation of the remote welding machine. The length must be less than 2000 mm for adopting working space in the hot cell. After hot cell work, thermocouple cables, vacuum control tubes and guide tubes must be connected for irradiation condition control and measurement. The connecting process is described in Section 2.3.

The desired temperature of the specimens is 773 K, which is the temperature during pre-irradiation in the fast reactor. The irradiation temperature is controlled by a vacuum control system. The system regulates the degree of vacuum in the helium gap of the capsule. Additional electric heater system is often used for control of the temperature in the JMTR. However, the electric heater control system is not applicable for this capsule due to the limit of space.

Dimensions of the specimens to be re-irradiated are shown in Fig. 2. Two round tensile specimens were placed on the core side of the capsule, and another tensile specimen placed on the reverse side in a holder unit. Two of these units were stacked vertically in the capsule.

2.2. Assembly of the capsule in the hot cell

There are three major steps to assemble the capsule in the hot cell. The first step is loading the irradiated specimens into the capsule. The second step is welding of an outer tube and an upper plug. The third step is in-

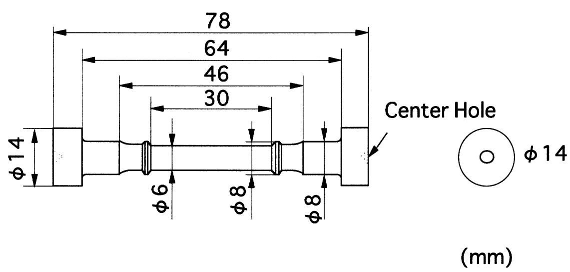

Fig. 2. Dimensions of the specimen.

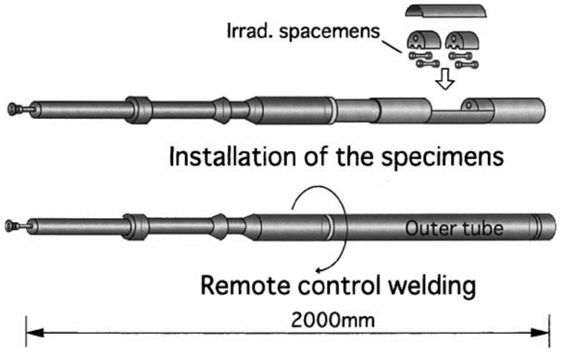

Fig. 3. Assembly of the capsule in the hot cell.

spection of the capsule. Using manipulators and remote control welding, the machine must carry out all processes. The conceptual scheme of the work is shown in Fig. 3. Many discussions were held with experienced operators in the hot laboratory on details of the procedure. The hot cell work consists of the following:

2.2.1. Loading of the irradiated specimens into the capsule
The concept of the capsule structure is simple. Thermocouples are assembled into specimen holders, and the specimens are set into the holders by manipulators.

2.2.2. Welding of outer tube and upper plug
After the capsule outer tube is placed over the capsule body, the capsule is setup in the remote control welding machine. The welding point is the connection of a capsule upper plug and an outer tube. The welding parameters were determined by several trial tests. A photograph of the welding work is shown in Fig. 4.

2.2.3. Inspection of capsule
In the hot cell, the X-ray inspection of the welding point, the pneumatic test and the helium leak test are

Fig. 4. Remote control welding work in the hot cell.

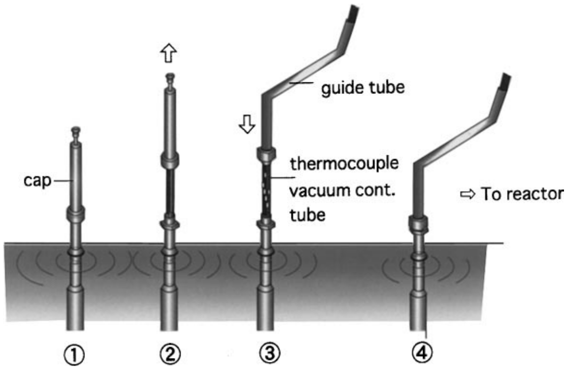

Fig. 5. Connecting of the capsule on the water canal.

made. The pneumatic test and the helium leak test were carried out from the nozzle of the capsule cap.

2.3. The connecting work in the water canal area

In order to lead thermocouple cables and the vacuum control tube out through the pressure vessel, the cables and the tube must be connected. Then the total length of the capsule body and guide tube becomes 6700 mm. These connecting tasks must be done with shielding because of the radiation from irradiated specimens. The water canal in JMTR, which connects the reactor pool and the hot cell, was chosen as the working place. The conceptual figure of the connecting work is shown as Fig. 5. The water canal, 3 m wide and 6 m deep, has sufficient water depth for the gamma shielding and enough space for the connecting tasks.

The workers' dose was estimated by using ORIGEN code, and actual records were less than the detectable limit of the film badge.

The inspections of the capsule in the canal are the continuity test and the insulation test of thermocouples, and the pneumatic test of connection parts.

In the development of the irradiation–coupling technique, the unique arrangement in JMTR facility, in which hot laboratories are adjacent to the reactor building, contributed significantly to the work efficiency. The irradiation rig (coupling capsule) assembled in the hot cell can be easily transferred to the reactor pool through the canal, and installed into the irradiation hole in the reactor core.

3. Irradiation test

The capsule was inserted into the irradiation hole (M-6) in the first layer of the reflector region in which the gamma-heating ratio is 4.0 W/g. Then the common work was carried out to set the thermocouples and vacuum control tube to the irradiation temperature

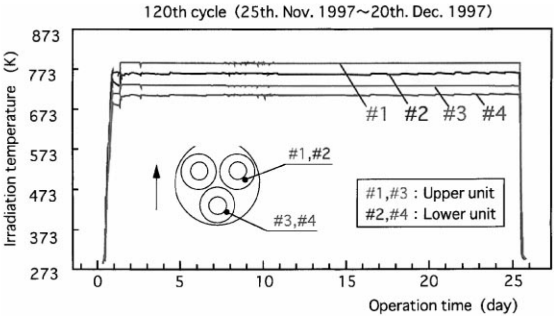

Fig. 6. Irradiation temperature in the 120th cycle.

control system. Irradiation of the coupling capsule was carried out for four operation cycles (100 days in full reactor power of the JMTR) from the 120th cycle (November 1997) to the 123rd cycle (May 1998). The irradiation was successfully completed. The operating temperatures in the 120th cycle are shown in Fig. 6. Differences in the irradiation temperatures were found between the core side and the reverse side, and between the upper and the lower side. The thermocouple at the controlled point (#1 in Fig. 6, upper, core side) showed the temperature within 788 +/− 10 K and another thermocouple in the core side (#2 in Fig. 6) showed the temperature within 762 +/− 11 K. These temperature differences among the locations of the specimens will be compensated by adjusting gap sizes of specimen holes in the holders and by installation of electric heaters in the next capsule. No trouble was found on the structures and the connections of the coupling capsule.

4. Conclusions

The coupling capsule, which realizes the irradiation–coupling technique was recently developed and irradiated in the JMTR. Validity of the structure and the process of assembly for the coupling capsule were confirmed. Principal results obtained are as follows:

1. The coupling capsule was assembled by using manipulators and the remote control welding machine in the hot cell.
2. The thermocouple cables, vacuum tube and guide tube were connected safely in the water canal area.
3. The coupling capsule was successfully irradiated within the desired irradiation temperature range.

At present, the second coupling capsule is being designed based on the experience of the first capsule. The second capsule will be used for study of irradiation effects after annealing of the material and the capsule itself will be re-used.

According to such applications, this newly developed irradiation–coupling technique has a possibility to enlarge the horizon of irradiation studies.

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