Status of Japanese Design and Validation Activities of Test Facilities in IFMIF/EVEDA

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Abstract. Japanese engineering design and validation's activities of test facilities in IFMIF/EVEDA (International Fusion Materials Irradiation Facility/Engineering Validation and Engineering Design Activities) project have three subjects of (1) Engineering Design of High Flux Test Module with Horizontal Capsule (HFTM-H), (2) Small Specimen Test Technique (SSTT), and (3) Engineering Design of Post Irradiation Examination (PIE) Facilities. The status of Japanese design and validation activities of test facilities in IFMIF/EVEDA project is summarized in this paper. Functional analysis for the design of PIE facility and schematic layout design of PIE facility was performed, and 2-D and 3-D image models for the design of PIE facility of IFMIF are shown. In HFTM-H, as the materials of the heater, two materials, i.e., W-3%Re alloy and/or SiC/SiC_f composite, were selected by the main reasons of high temperature materials, fabrication technology and some suitable properties such as resistance of thermal shock, high temperature re-crystallization, ductility, resistance of irradiation degradation, and low-activation materials. A test machine which is specially designed for fracture toughness tests of very small specimens such as a compact type specimen with a length of about 10 mm. Fracture toughness tests with high accuracy controllability for stress and displacement can be performed for it.

1. Introduction

Structural materials of fusion nuclear reactors will be exposed to neutrons with energies up to about 14 MeV at about 2 MW/m^2 with a fluence up to 10-15 MWy/m^2 during the operation. Radiation damage of materials in fusion reactor environment can be characterized by synergistic effects of displacement damage and nuclear transmutation products such as hydrogen and helium atoms [1-6]. These damages will induce the degradation of mechanical properties. In order to safely operate fusion nuclear reactors, the detailed behaviour of material degradation with respect to 14 MeV neutrons dose must be known. The International Fusion Materials Irradiation Facility (IFMIF) [7,8] is a deuterium-lithium neutron source with high intensity for irradiation experiments of candidate fusion reactor materials to prepare database obtained from series of tests such as small size specimens for the DEMO's design and licensing. About one thousand small size specimens will be irradiated in the IFMIF-High Flux Test Module (HFTM) with a limited volume of about 0.5 liter [9].

Under Broader Approach (BA) Agreement between EURATOM and Japan, IFMIF/EVEDA (International Fusion Materials Irradiation Facility/Engineering Validation and Engineering Design Activities) has been performing from a middle of 2007. The IFMIF has three main facilities such as the accelerator Facility, Li Target Facility and Test Facilities. A previous design report of IFMIF was summarized in IFMIF comprehensive design report [7]. The present EVEDA phase aims at producing a detailed, complete and fully integrated engineering design of IFMIF. Japanese engineering design and validation's activities of test facilities in IFMIF/EVEDA project have three subjects of (1) Engineering Design of High Flux Test Module with Horizontal Capsule (HFTM-H), (2) Small Specimen Test Technique (SSTT), and (3) Engineering Design of Post Irradiation Examination (PIE) Facilities.

2. Engineering Design Activities of Post Irradiation Examination Facilities

The main objective of the design of the PIE facilities in the IFMIF/EVEDA is to prepare the rationalized engineering design of PIE facilities. The material data set obtained from evaluation tests of the small size specimens irradiated in the IFMIF, which will be mainly performed in the PIE Facilities of the IFMIF, provides mainly materials database for the design and licensing of fusion DEMO reactors. Also in the design of PIE facility, it is needed to prepare the repair and analysis of some instruments and maintenance works for radio-activated materials in order to support the operation of IFMIF facility. The lists of evaluation tests, equipments, instrumentations and furthermore the work procedures for some important treatments in the PIE facilities are preparing in the engineering design of PIE facilities of IFMIF/EVEDA. In the design of PIE facilities, functional analysis, evaluation of work process, and materials handling for the materials transfer from test cell area such as High flux test module (HFTM) and back plate of Li target to PIE facilities is very important. In the IFMIF, the specimen reloading in the capsule of HFTM is required to obtain high doses up to about 150 dpa. Functional analysis for the design of PIE facility and schematic layout design of PIE facility was performed, and 2-D and 3-D image models for the design of PIE facility of IFMIF are shown in FIGS. 1 and 2. In the area-I, some cells for handling such as the irradiation rigs and a part of materials of Li back-plate are shown, and rig handling cell, tritium cell, beryllium cell, and specimen reloaded cell are described in the figure. In the area-II, PIE laboratories for small specimens are given and the operation area, service area, auxiliary area are also shown. In PIE tests of the IFMIF, tensile, fracture toughness, Charpy impact, creep, fatigue, crack growth rate, and etc. will be planned. The number of specimens set in the HFTM is about 1,000. In the HFTM, the damage rate is basically calculated as about 20 – 30 dpa per a year for iron based alloys.

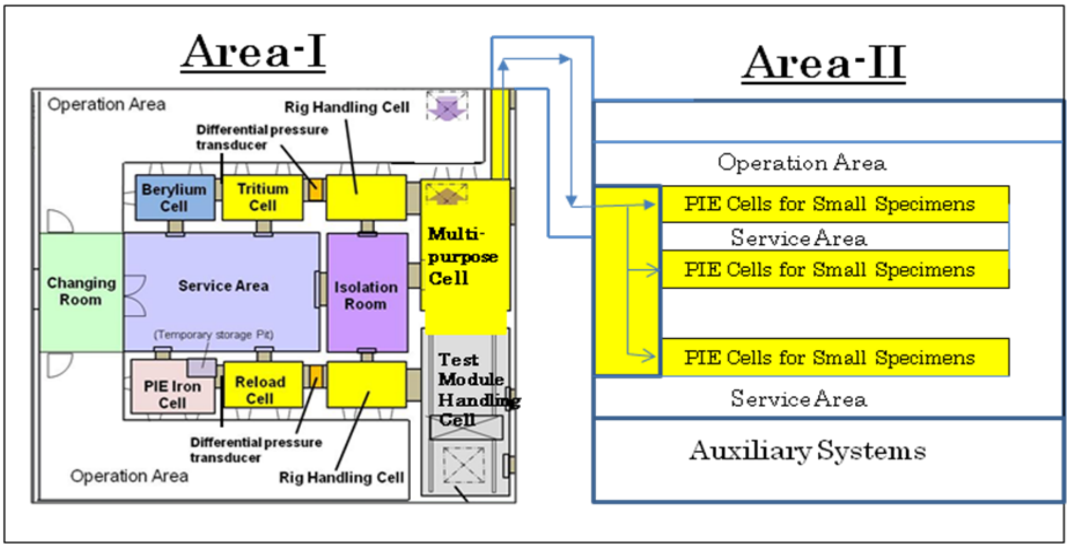

FIG. 1. 2-D image of hot cells for PIE facility. The irradiation rigs are handled in Area-I and PIE for small specimens is mainly performed in Area-II.

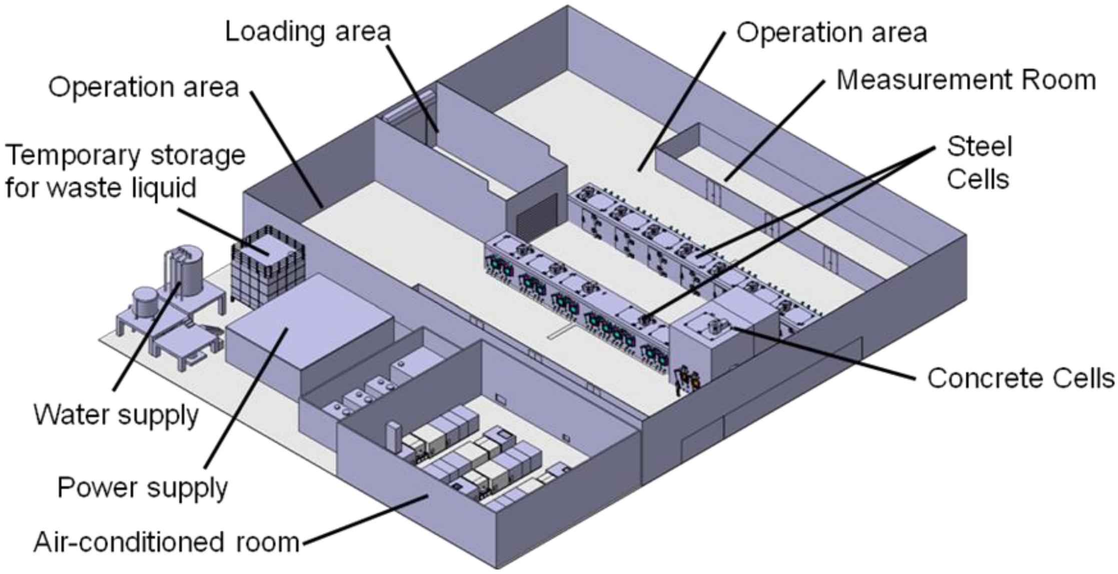

FIG. 2. 3-D image of PIE laboratory.

3. Engineering Validation and Design Activities of High Flux Test Module with Horizontal Capsule

The objective of the engineering design and validation of Japanese HFTM is to create the design based on a concept of heater-integrated capsules to enable irradiation temperatures up to 1,000 °C and to evaluate the manufacture technologies and performance tests for heater system of the irradiation capsule of HFTM. A design of high flux test module with 9 capsules is given in FIG. 3. The first experiment of heater fabrication and tests of HFTM was performed, and Pt was selected as heater material in the heater-integrated Al_2O_3 plate, because the thermal expansion coefficients of them were nearly equal. As seen in Fig. 3, uniform temperature distribution of heater-integrated Al_2O_3 capsule at 760°C was observed. However, both of Pt heater and Al_2O_3 plate in the integrated heater plate was broken at about 900°C during elevating temperatures because of the influence of the inhomogeneity such as small voids in the heater-integrated Al_2O_3 plate. To solve this problem the heater materials and the structure of plate and heater for the irradiation capsule was improved. As the materials of the heater, two materials, i.e., W-3%Re alloy and/or SiC/SiC$_f$ composite, were selected by the main reasons of high temperature materials, fabrication technology and some suitable properties such as resistance of thermal shock, high temperature re-crystallization, ductility, resistance of irradiation degradation, and low-activation materials. The plate and heater for the irradiation capsule was adapted to compose a separate structure. Further analyses for the preliminary engineering design of HFTM were performed as described below: (i) the connector connection structure in remote handling was examined; (ii) physical and mechanical properties of capsule materials were evaluated as a function of displacement damage.

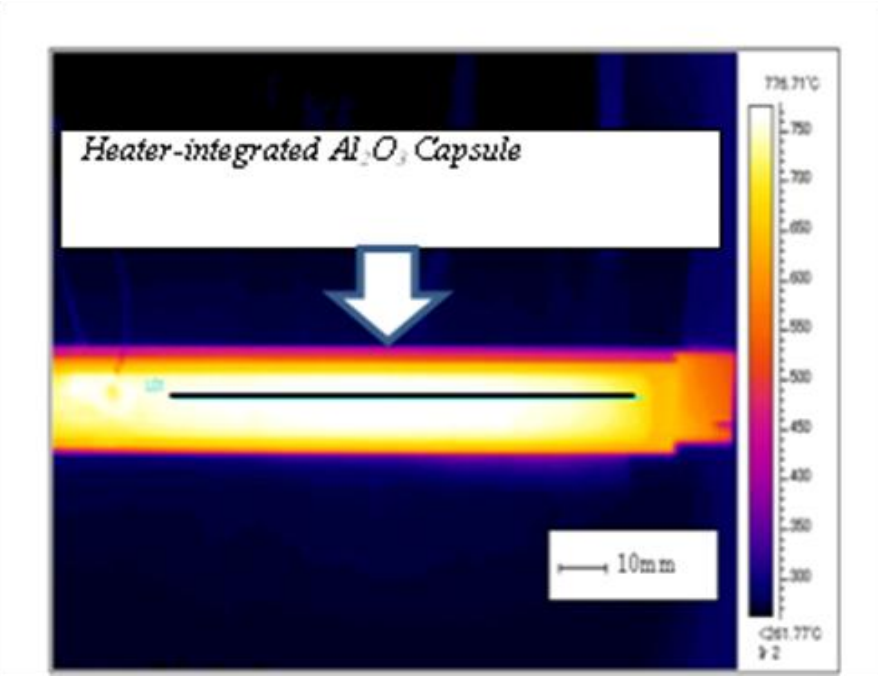

FIG. 3. Uniform temperature distribution of heater-integrated Al_2O_3 capsule can be seen at 760°C. *The deviation of temperature is within about 5°C as shown in the black line.*

4. Small Specimen Test Technique (SSTT)

In the SSTT subject of IFMIF/EVEDA project, the test methodology for the extrapolation from the small specimen data to standard specimen data is a target, and the effects of the shape of specimens on mechanical properties and the handling techniques on the setting of small specimens to test machines are also important. Recommendation of specimen matrix of the test modules based on the work under SSTT task is also requested within this project. The ultimate objective of SSTT, beyond the current EVEDA, is the acceptance by international standards, such as ASTM and ISO of the methodology developed in the framework of IFMIF/EVEDA project, as well as their inclusion in codes such as ASME. In this study, some subjects of SSTT was examined for the methodology enabling the extrapolation from the small specimen data to standard specimen data, and some experimental data were obtained for standardization of test methodology and specimens' size and shape for fatigue, fracture toughness and crack growth in a F82H steel. For mechanical tests using small specimens, high accuracy controllability in the applied stress and displacement should require, however the commercial test machines are not designed typically to cover the controllability. In FIG. 4, a test machine which is specially designed for fracture toughness tests of very small specimens such as a compact type specimen with a length of about 10 mm. Fracture toughness tests with high accuracy controllability for stress and displacement can be performed for it. Guidelines of mechanical tests such as ASTM-international and ISO have already prepared, but the results of recent some research do not match with it, i.e., master curve method for fracture transition behaviour, and we have to modify and develop these standards, and we would be needed further developments of test methodology in the tests using small specimens such as fracture toughness, Charpy impact, and fatigue crack growth rate.

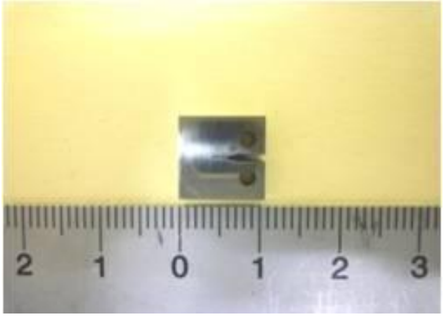

FIG. 4. Developed test machine (Left side) of fracture toughness for small size specimen (Light side).

5. Summary

Japanese engineering design and validation's activities of test facilities in IFMIF/EVEDA (International Fusion Materials Irradiation Facility/Engineering Validation and Engineering Design Activities) project have three subjects of (1) Engineering Design of High Flux Test Module with Horizontal Capsule (HFTM-H), (2) Small Specimen Test Technique (SSTT), and (3) Engineering Design of Post Irradiation Examination (PIE) Facilities. Under Broader Approach (BA) Agreement between EURATOM and Japan, IFMIF/EVEDA (International Fusion Materials Irradiation Facility/Engineering Validation and Engineering Design Activities) has been performing from a middle of 2007. The IFMIF has three main facilities such as the accelerator Facility, Li Target Facility and Test Facilities. In this study, status of Japanese Design and Validation Activities of Test Facilities in IFMIF/EVEDA is summarized, and the main results are shown as below:

(a) Functional analysis for the design of PIE facility and schematic layout design of PIE facility was performed, and 2-D and 3-D image models for the design of PIE facility of IFMIF are shown.

(b) The first experiment of heater fabrication and tests of HFTM was performed, and Pt was selected as heater material in the heater-integrated Al_2O_3 plate, because the thermal expansion coefficients of them were nearly equal. In the second step, as the materials of the heater, two materials, i.e., W-3%Re alloy and/or SiC/SiC_f composite, were selected by the main reasons of high temperature materials, fabrication technology and some suitable properties such as resistance of thermal shock, high temperature re-crystallization, ductility, resistance of irradiation degradation, and low-activation materials.

(c) A test machine which is specially designed for fracture toughness tests of very small specimens such as a compact type specimen with a length of about 10 mm. Fracture toughness tests with high accuracy controllability for stress and displacement can be performed for it.

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