IFERC Newsletter

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Final Report

Final Report of DEMO R&D Activity

1. Introduction

The Final Report of DEMO R&D activity composed of the comprehensive activities based on the original PAs (Procurement Arrangements) up to May 2017 is an important deliverable from the IFERC Project. Its submission was proposed in BA SC-18 on 22 Apr. 2016 and its Table of Contents was taken note by PC members in PC-19 on 28-29 Sep. 2016. This report, along with other Final Reports from the IFERC activities, will be used as an explanation on the outcomes of the IFERC project and to support proposals for Post BA activities (BA phase II) after Apr. 2020. DEMO R&D activities in the extended period until Mar. 2020 will be implemented under the DDA PA except for JET ITER like Wall (ILW) tile and dust analysis. TCMs (Technical Coordination Meetings) and TMs (Task Meetings) will be held with participants from both DDA and DEMO R&D. The following sections provide an outline of the Final Report of DEMO R&D.

2. EU-JA collaboration on SiC/SiC composites and JET tile and dust analysis

The EU-JA collaborative studies under the BA framework have produced very fruitful results. An apparatus for SiC/SiC composites was made by ENEA Frascati by using EU knowledge, and has been used for a series of corrosion experiments by JA by using JA knowledge (See Figure 1).

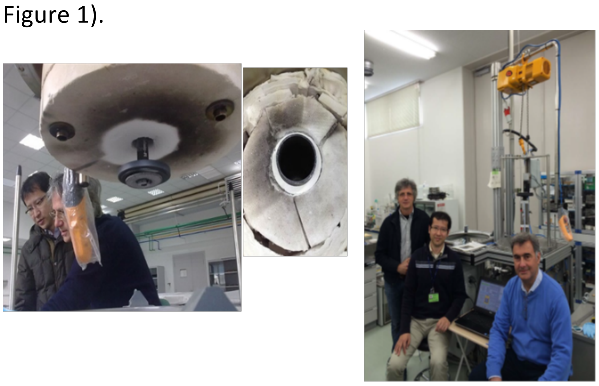

Figure 1: An apparatus produced by ENEA Frascati, and delivered to Rokkasho. A series of tests has been carried out by using this apparatus.

Several samples of JET dust and tiles were sent to JA, and valuable data have been obtained by using unique JA facilities installed in a radiological controlled area (See Figure 2). Several samples of functional materials have been exchanged between EU and JA. A series of valuable data have been obtained under a variety of conditions by using both EU and JA facilities.

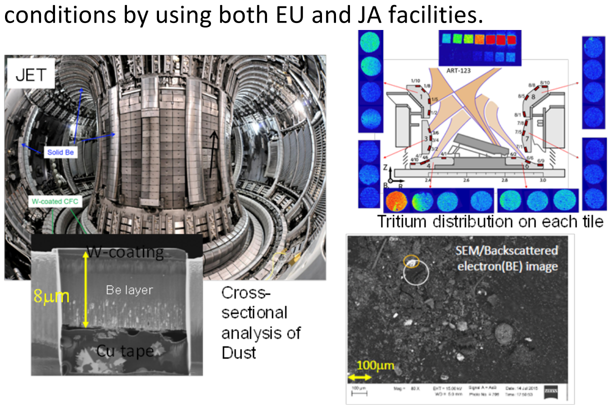

Figure 2 Analysis of JET tiles (Evaluation of amount of tritium in tiles and dust etc.,) has been carried out as one of the significant EU-JA collaborative activities.

3. T1 (SiC/SiC composites)

In JA, the R&D on SiC/SiC composites developed a fundamental database of mechanical/physical/chemical properties, with a primary target of the application of SiC/SiC composites as functional structure to be used in the Dual Coolant Breeding Blanket concept. In JA, good creep and fatigue durability was first demonstrated for nuclear-grade SiC/SiC composites. In-plane and inter-laminar strength anisotropy maps at elevated temperatures were comprehensively established. The apparent dose-dependence of the radiation-induced conductivity and the indicative radiation-induced electrical degradation were demonstrated by various irradiation sources. Deuterium permeability was evaluated for various SiC materials, demonstrating good gas tightness. For the compatibility of SiC and SiC/SiC composites with liquid Pb-Li, it was found that the corrosion of SiC materials with liquid Pb-Li formed a reactive layer under the flow condition. No accelerated corrosion for duration of 3000 h at below 1000 °C was first demonstrated.

In CIEMAT in EU, electrical conductivity, and diffusion, absorption and desorption of helium and hydrogen isotopes during irradiation have been investigated in different types of ceramics. In addition, the structural damage was characterized. During the first period (from to 2011) HP-SiC and LiNbO3 were implanted with 45 keV He and irradiated with 1.8 MeV electrons. During the second period (from 2012 to 2016) alumina and SiC were studied. In ENEA Frascati, two subjects have been studied: the development of a multi-scale methodology for composite structural modelling and validation of modelling procedure by mechanical testing; and the construction of experimental equipment to be installed in the Rokkasho facility. A constitutive model for a balanced plain weave fabric was developed. To validate the code, the results obtained by Japanese colleagues for a reference CVI- SiC/SiC composites were used. The numerical results were in good agreement with the experimental results, and also the predictions on the type and progression of the damage were in good agreement with the real behaviour.

4. T2 (Tritium Technology)

For the tritium technology, the multipurpose RI facility, DEMO R&D Building, was built in the Rokkasho BA site. The licensing of DEMO R&D Building was finished in 2011 and the storage capacity of initial RI is 7.4TBq for tritium, 500MBq for P-32 and 916MBq for Fe-59, respectively. Some basic data on tritium analysis methods have been obtained. Some basic studies on tritium behaviors (gas, liquid, and vapor) in materials, such as diffusion, sorption, and corrosion, have also been carried out. A joint EU-JA activity was carried out to characterise dust and divertor samples taken from the JET divertor. These were specimens of dust, vacuum cleaned from the divertor of JET after various operational periods (with carbon wall (JET-C) during the shutdown in 2009, with full metal walls (JET ITER-Like-Wall, or JET-ILW, in 2012). The first analyses of surface morphologies of JET-ILW carbon showed dust particles smaller than 100 micron with SEM. The main elements of the dust in the studied samples from the inner divertor were identified: tungsten with admixtures of carbon, nickel, nitrogen, molybdenum and beryllium. In the future study particular emphasis will be given to tritium measurements. Some typical materials have also been tested with tritium water to get a set of basic data for tritium durability: organic compounds; stainless steel; and F82 H.

5. T3 (Structural material)

In JA, our attention has been focused on the technical issues related to the structural material of a breeding blanket which is used in in-vessel fusion environments. Reduced activation ferritic/martensitic steels (RAFMs), F82H in Japan and EUROFER97 in EU, are considered as the main candidate material. In JA, optimization of fabrication technologies of F82H (Fe-8Cr-2W-V, Ta) has been conducted and the secondary re-melting method, ESR (Electro Slag Remelting), was proved to be a potential technique. The optimum welding method was suggested regarding the thickness of weldment, and the torsion test was proved to be an effective destructive testing method to judge the level of the HIP (hot isotopic pressure) joint. An estimation method of fusion neutron irradiation effects has been developed, and the material database of F82H was reconstructed. The impact of irradiation on microstructure, such as dislocation, precipitation, grain boundary etc., was investigated with regard to the specific fusion neutron irradiation effects. Basic engineering for materials property and the structural designing interface has been investigated, and the reduction of ductility was found. It was demonstrated that the thin wall structure of blanket could endure the excess load applied on the structure in case of LOCA (loss of coolant accident). Blanket design windows related to material properties have been investigated, and typical loads on the blanket structure were analyzed to elucidate important failure modes based on the design criteria. On safety issues of plasma facing material (tungsten) have been investigated, and a test apparatus for ICE (ingress coolant experiments) was designed and manufactured. A series of ICE experiments with high-temperature tungsten was conducted and the accumulated experimental data is transferred to verify the safety code simulating the in-vessel LOCA/ICE.

In EU, R&D on the structural materials has been performed by SCK.CEN (Belgium), CRPP (Switzerland) and KIT (Germany), and is continued currently under EUROfusion in various laboratories. In SCK, CEN, the main objectives of the project were to develop the small specimen techniques. A detailed study was carried out with the support of finite element calculations and analytical work to validate the specimen geometry and size. In CRPP, the evolution of the Eurofer97 mechanical properties following neutron irradiation and forging at room temperature was investigated. Two sets of specimens irradiated at temperatures in the hardening regime (Tirr < 673 K), namely 423 K and 623 K, were available at a nominal dose of ~0.3 dpa. Another objective was to develop appropriate models, essentially based upon finite element simulations. Finally, the toughness-temperature behaviour of the un-irradiated, irradiated and cold-forged Eurofer97 has been modelled using a local approach of fracture. In KIT, an activity of optimization of manufacturing technology of RAFM steels was carried out to obtain wrought products. The characterization work on the European side concentrated in RAFM 9Cr-W-V-Ta RAFM steel, EUROFER 97-3, which was produced by Saarschmiede at an amount of 11 tons of different semi-finished product forms heat ranging from 1 mm thick sheets up to 48 mm thick plate. Regarding the joining technologies, electron beam (EB) welding and Tungsten Inert Gas (TIG) welding samples were produced and characterised. A number of samples were sent to Rokkasho for further characterisation.

6. T4 (Neutron multiplier)

In JA, as neutron multiplier material, beryllide pebbles have successfully been made by the rotating electrode method. The electrode was made by a plasma-sintered method. Finally, we could make $Be_{12}V$ pebbles of 1 mm in diameter. The $Be_{12}V$ pebbles can be made by the rotating electrode method only, and no additional process is needed to form single phase beryllide. A series of hydrogen generation experiments has been then carried out for the $Be_{12}V$ pebbles. The materials had superior oxidation properties in comparison with that of pure Be pebbles and of Be-Ti beryllide pebbles. As typical collaborative studies, samples have been exchanged between EU and JA. The Be-Ti beryllide pebbles were successfully made in JA-Rokkasho Site, by using an extruded Be-Ti electrode made by KIT (Karlsrue Institute of Technology).

For Task T4 KIT has constructed equipment to produce beryllium-based alloys, and characterised the beryllium pebbles.

In KIT in EU, relevant properties have been investigated by producing own beryllium-based alloys (Be12Ti) on the laboratory scale. In the first phase, the equipment for the production of rods made of Be-Ti alloys was assembled and licensed. The method of rod fabrication using the preparation of fine Be-Ti powder mixture by wet milling process followed by encapsulation and Hot Isostatic Pressing (HIP) was chosen as the main route of production of titanium beryllide rods. Continuous and long rods were fabricated by extrusion of Be-Ti powder in a double-walled container at 973 K. The microstructure of the produced rods was analysed by XRD, optical microscopy and scanning electron microscopy. Additional high-temperature annealing tests of produced Be-Ti samples were performed in order to study the evolution of the phase composition after the heat treatment.

7. T5 (Tritium breeder)

To develop advanced tritium breeders, a set of studies on fabrication of breeders with that of characterization are needed. A candidate material of Lithium excessive lithium metatitanate ($Li_{2+x}(Ti,Zr)O_{3+y}$: LTZO) pebbles was successfully fabricated in JA. The LTZO pebbles are not a two-phase material but rather a solid solution, and were easily sintered in air. The tritium release properties of the LTZO pebbles have also been investigated, and excellent tritium release properties similar to those of Li_2TiO_3 pebbles have been shown. The released amount of HT gas was greater than that of HTO vapor, which is favorable from the viewpoint of tritium handling. A series of long-term annealing experiments of EU and JA pebbles were carried out as a typical collaborative study. Some lithium orthosilicate (Li_4SiO_4) pebbles with Li_2TiO_3, and lithium alminate ($LiAlO_2$) were also successfully made by the emulsion method developed by JA.

The activity of EU was composed of three phases: fabrication process; pebble characterization; and pebble reprocessing. A novel melt-based pebble fabrication process using the Rayleigh-Plateau-Instability for the decay of ceramic melt jets has been developed. To optimize the pebble quality the production process was modified, and the composition of the melt was varied as well. Two-phase tritium breeder pebbles, consisting of Li_4SiO_4 and Li_2TiO_3, were produced by a melt-based fabrication. Lithium excessive lithium metatitanate $Li_{2+x}(Ti,Zr)O_{3+y}$ pebbles were also produced by a sol-gel method and an emulsion method. For these ceramic pebbles, fabricated by a melt-based process, the reprocessing by re-melting was investigated. In order to determine the accumulation of impurities and possible process contaminations, a large quantity of pebbles was produced from pure starting powders and re-melted several times. The characterization of pebble samples removed after each batch demonstrated that the level of impurities primarily derives from the purity of the starting materials used.

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