EFDA WORKPROGRAMME 2012

Call for Participation

Materials R&D

CfP-WP12-MAT-01

Deadline for Responses: 06. Feb 2012

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Introduction

At its 49th meeting in Warsaw on 24-25 October 2011, the EFDA Steering Committee approved the EFDA 2012 Workprogramme, including the tasks identified below. This Call covers the activities of the Area of Fusion Materials in the PPPT WP 2012 and will be implemented on the basis of the provisions given in Art.5 of the EFDA Agreement.

Programmatic Background

The development of fusion power generation concept into a commercially viable technology is the problem of optimization and balancing the factors that determine the availability of a fusion power plant against construction and operation costs. The cost of a fusion electricity unit increases both in the limit of large reactor size, due to the high level of investment required at the construction stage *and* in the limit of small reactor size due to the high running costs associated with the need to frequently replace components as well as due to the constraints imposed by the physics laws determining the behaviour of fusion plasma.

Whether the optimum design configuration corresponding to the minimum fusion electricity unit cost – found by optimizing the design for a given set of materials – proves economically viable, depends entirely on the selection of materials. The task of global design-materials optimization involves discovering innovative materials solutions that need to be formulated, developed, tested and manufactured specifically to match the needs of fusion power generation technology. One of the central objectives of the fusion materials programme is to identify innovative materials development routes, using scientific understanding and knowledge of how materials properties evolve and change in the operating environment of a fusion power plant.

1. MAT- HHFM:

Task Agreement WP12-MAT-01-HHFM: High Heat Flux Materials

1.1 Introduction

At its 49th meeting in Warsaw on 24-25 October 2011, the EFDA Steering Committee approved the EFDA 2012 Workprogramme, including the tasks identified below. This Call covers the activities of the MAT- HHFM Research Project on High Heat Flux Materials of the Area of Fusion Materials in the PPPT WP 2012and will be implemented on the basis of the provisions given in Art.5 of the EFDA Agreement.

1.2 Objectives

The use of High Heat Flux materials, mainly tungsten and tungsten alloys, for the helium cooled divertor and possibly for the protection of the helium cooled first wall in reactor designs beyond ITER is being investigated in this programme. The main objective is still to develop and demonstrate possible applications as well as to identify limitations for the use of this kind of materials in future fusion reactors. These will certainly differ significantly from ITER mainly because of much high neutron irradiation dose and transmutation rates. But even neglecting irradiation effects (due to large gaps in the database), there are still unsolved problems related to the use and properties of tungsten materials.

1.3 Work Description and Breakdown

Structure

The original MAT-W&WALLOYS task has been expanded as follows:

Material Technology and Development

Armour materials

Divertor shield

Powder/Metal injection moulding (PIM/MIM) materials showed so far the best compromise between high heat flux properties and production costs. Therefore, this tool will be used as “work horse” for further armour materials prototyping and optimization. Another fabrication route – powder chemistry & sintering – also capable of large scale production will be followed, too. Mechanical alloying (as performed by Kurishita, Japan) led to the best material behaviour but is only applicable for small amounts of material. Therefore, the goal of further investigations is (1) to verify the effect of TiC addition and hot extrusion and (2) to improve the fabrication capacity.

Blanket (FW) protection

The development of first wall shield materials has led to two promising self-passivating alloys. In 2012 the application of these materials will be demonstrated after production of larger amounts by intensive material tests. Coating of EUROFER by tungsten is still under improvement. The investigation of appropriate processes and the evaluation of functional gradient layers will be continued.

Specific qualification and characterization

The only way to determine the possible applicability of tungsten alloys as an armour material is to perform as many as possible beam load, shock, and high temperature tests. Therefore, characterization by e-beam (JUDITH facilities) and H/He beam load (GLADIS) is continued in 2012 as well as all available high temperature mechanical tests.

Mid-term structural materials (for water cooling designs)

Copper materials

For usage in a fusion relevant nuclear environment, copper alloys have to be optimized in terms of low/reduced activation and low-temperature irradiation hardening/embrittlement. Thermal conductivity and the most important mechanical properties have to be balanced for water cooled designs. There are three fabrication routes which are worth following: (1) Solid solution (e.g. Cu-Mn), (2) ODS copper (e.g. Cu-Y2O3), and (3) copper composites (e.g. particle, wire, mesh, or foil reinforcement).

Low/reduced activation austenitic stainless steels

Austenitic stainless steels like, for example the 316 steel, could in principle and under certain conditions be used for fusion applications. High activation and sub-optimal mechanical properties under neutron irradiation are the main issues which could be improved for water-cooled divertor applications. The program comprises three steps: (1) development of a suitable base composition (using past developments as prototype), (2) optimizing the commercial melt metallurgical approach (e.g. using stabilizing elements like Ti, Si, etc.), and (3) follow new developments by powder metallurgy. In addition, the joining of W armour to SS pipes has to be analysed, investigated, and optimized

Long-term structural materials (for helium cooling designs)

Development

Here, the improvement of ductility is still one of the most pressing issues. Three methods were followed so far: (1) alloying (solid solution), (2) nano-structuring, and (3) composite materials. The improvement by alloying was not successful so far. The remaining options (W-Ti, W-TiC) will be tested in 2012.

Pure tungsten plate material with thickness of 1-2 mm showed best ductility among all alloys. Therefore, the only remaining and promising methods which need more investigation efforts are (1) the optimization of plate production (usage of grain stabilizers, cross-rolling) and (2) the development of composites. The already started initiatives (short Ta fibre, W fibre reinforcement, and W-Cu laminates) will be continued in 2012.

Specific high temperature characterization

The characterization experiments have to be continued to fill the database. Missing data for the structural tungsten materials still include long-term recrystallization/grain growth, long-term creep, and low cycle fatigue. These data points should be produced in the near future due to their high impact on the design.

Material Technologies

Machining parts by standard mechanical as well as by electro-chemical methods have been demonstrated for all tungsten materials and therefore, further investigations are not necessary. Mass fabrication process development (powder injection moulding, deep drawing/bending) are promising and will be continued. The joining process development (W to W and W to steel) has not been successful so far with respect to low activation brazing materials. Therefore, the low activation criterion will be relaxed as much as necessary. Diffusion bonding (W to steel) has been shown to be feasible with a vanadium layer at maximum 700°C which is the end result for this task. Explosive bonding and gradient materials seem to be too difficult to be applied to structural components. Therefore, these topics are not further followed. Pulse plasma sintering, however, is a promising alternative to brazing and has to be developed and investigated more in detail.

Joining

Cu, Pd, Ti are the remaining and most promising chemical elements for brazing materials. Structural joints are needed for W-steel and W-W while functional joints are only necessary for attaching the W armour to the W structure (which is less demanding). While the Cu-Pd system is ideal for standard brazing, Ti could probably be better applied to diffusion brazing technologies, due to its high melting temperature (to avoid grain growth in the tungsten parts).

An alternative to brazing is pulse plasma brazing. First encouraging results necessitate further and more extensive investigations.

Fabrication by shaping the microstructure

Previous investigations have demonstrated that in structural parts the microstructure has to be aligned to their contours. Therefore, tungsten plate materials should be machined by bending, deep drawing, pressure forging or similar techniques which have to be further developed, investigated, and applied to mock-up fabrication.

Process development

PIM has been developed into a very promising tool for mass fabrication of tungsten armour parts. However, this method could provide even more applications like, for example, producing parts consisting of different materials. First development steps for two-component PIM or PIM with integrated joining layers are strongly supported in 2012.

The feasibility of electro-chemical deposition of functional layers like, for example, Pd-Cu films on tungsten was demonstrated on a small laboratory scale. In 2012 the according processes will be scaled up and used for producing brazing layers and/or for an alternative synthesis of tungsten laminate material.

Prototype Cooling Structures

Up to now, the finger module with helium jet cooling (steel pipe, tungsten thimble and armour on top) was used as reference/test case for the whole program. Due to many open questions and a still missing general divertor design, a concentration to such a specific part could be a constraint which would then probably prevent the follow-up of other possible options. Therefore, the 2012 program works without a specific test case. This should open the way for more or different joining and fabrication options.

Mock-up fabrication

The newly developed or investigated materials, fabrication, and joining processes should be applied to the fabrication of demonstrators or mock-ups in an as early as possible stage. This would not only show that the whole programme is clearly application oriented but would also reveal technological problems right from the beginning.

Mock-up testing

The fabricated mock-ups will be tested mechanically and/or by high heat flux. For that, all available devices are used, like for example, JUDITH and GLADIS. At the same time, new testing equipment has to be developed as far as possible (rupture test for cooling channels, helium & water loops, etc.).

Material Science and Simulation

These activity includes the following:

- Plasticity studies for the case of W-Re are almost finished and have delivered interesting answers. Micromechanical tests are further applied to study either irradiated specimens or to examine specific boundaries. Modelling of macroscopic material properties is encouraged for contributing the database (filling in gaps by inter- and extrapolation).The multiscale approach to simulate irradiation damage is continued as well as the validation experiments (JANNUS, etc.). The refinement of transmutation/activation codes is also continued and applied to specific topics (brazing, divertor components).

Work Breakdown

WP12-MAT-01-HHFM-01

WP12-MAT-HHFAM-01: Armour materials

This activity is dedicated to the study of Divertor shield, Blanket (First Wall) Protection, and Specific qualification and characterization of armour materials. For Divertor shielding, W alloys produced by mechanical alloying, PIM/MIM and powder chemistry will be considered. In the field of Blanket Protection, self – passivation W alloys, W coating of EUROFER, functional gradient layers and special steels are the main lines of the programme. Special Qualification and characterization cover thermal shock, thermal fatigue, H/He Beam loads, and standard properties (tensile, LCF, etc…) experiments.

<u>Priority tasks</u> include:

· Fabrication of a variety of different armour prototype materials by PIM/MIM

· Screening tests of the armour prototype materials by available high heat flux tests (thermal shock & fatigue, H/He beam load)

WP12-MAT-01-HHFM-02

WP12-MAT-HHFAM-02: Mid-term Structural Materials

This activity is dedicated to the study of Copper materials and Low Activation Austenitic Stainless Steels. For Copper materials, copper alloys, ODS copper and copper composites will be considered. The main lines for the development of low-activation Austenitic SS cover standard alloys, stabilized alloys and possible new developments.

Priority tasks include:

· Investigation of the possibilities to improve the neutron radiation resistance and strength of reduced activation copper materials for water cooling applications.

· Development, fabrication and characterization of low/reduced activation austenitic stainless steel as a replacement of 316 alloys.

WP12-MAT-01-HHFM-03

WP12-MAT-HHFAM-03: Long-term Structural Materials

This activity is dedicated to the study of long – term structural materials. Mainly to the development of W sheet materials (thin plates), and W and SiC- based composites, together with specific high temperature characterisation of this materials, i.e., Charpy, 3PB, tensiles tests, Fracture toughness, grain growth, recrystallization, creep and fatigue experiments.

Priority tasks include:

· Fabrication and characterisation of tungsten composite materials with respect to application limits.

· Extending the database: fracture-toughness and long term grain stability of thin plates.

WP12-MAT-01-HHFM-04

WP12-MAT-HHFAM-04: Material Technologies

This activity is dedicated to the study of material Technologies: Joining, and fabrication by microstructural shaping. Joining studies cover brazing W-W (structural and functional), brazing W-steel (structural joint), plasma pulse welding and possible alternatives. Fabrication by structural shaping is mainly devoted to deep drawing W, bending W and pressure forging W. Other more innovative technologies as two – or multiphase PIM/MIM, and electro – chemical layer deposit are also included in this activity.

Priority tasks include:

· The development of fabrication processes for structural joints (W-Eurofer and tungsten-tungsten) is very important Therefore, brazing with the systems Cu, Pd, Ti and pulsed plasma welding/brazing are of highest interest.

· Investigation of multi-phase PIM/MIM to extend the fabrication process for more complex functional high heat flux parts.

WP12-MAT-01-HHFM-05

WP12-MAT-HHFAM-05: Prototype Cooling Structures

This activity is dedicated to the development of prototype cooling structures: Mockup fabrication and testing. Fabrication of pipes (Cu, SS, W), channels (W), mockups with W monoblocks and with alternative designs (cooling plates, etc.) Tests of pressurized rupture, creep rupture and heat flux are included in this activity.

Priority tasks include:

· All kind of mockup fabrications that can be used in high heat flux tests or which clearly demonstrate the feasibility of fabrication processes.

· Mockup testing by (1) high heat flux tests and (2) pressure-rupture tests.

WP12-MAT-01-HHFM-06

WP12-MAT-HHFAM-06: Material Science and Simulation

This activity is dedicated to simulation and prediction of irradiation performance of this kind of materials (transmutation, damage); understanding of basic mechanism of materials behaviour, modelling of macroscopic material properties; and a part of Validation experiments (JANNuS, micromechanics, etc).

Tasks under this activity are devoted to:

Priority tasks include:

· Prediction of irradiation performance.

· Validation experiments in JANNuS

JET related activities

Not applicable

1.4 Scientific and Technical Reports

Progress Reports

At the end of each calendar year, and at intermediate times where appropriate, the Task Coordinator shall present a report on activities under the Task Agreement to the EFDA Leader for his approval. These reports shall integrate the progress made by each Association on each activity, and they shall indicate the level of achievement of the objectives, the situation of the activities, the allocation of resources and recommendations for the next year when applicable. The EURATOM financial contribution will be made through the usual procedures for baseline support through the Contract of Association.

Report of achievements under Priority Support (final report and, when appropriate, intermediate reports)

Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report (and intermediate reports marking substantial progress in the achievement of deliverables, if the EFDA Leader so requests) shall be prepared by the Task Coordinator and submitted to the EFDA Leader. If part of or all the activities carried out relate to JET, the Associate Leader for JET will be involved in clearing the report. These reports shall include specific sub-sections for each of the Associations involved. They shall document the degree to which the deliverables have been achieved. The EURATOM financial contribution will be made after approval by the EFDA Leader of these reports.

Milestones and Deliverables

The results obtained within the Research Project High Heat Flux Materials will be presented by the principal investigators and reviewed during joint monitoring meetings held twice a year. On this basis the progress accomplished by the contributing Associations will be reported by the Coordinator to the EFDA Leader.

The report on the Association activities under Priority Support will be prepared by the Coordinator to be presented to the EFDA Leader at the end of every calendar year.

The final and technical report will be submitted to the EFDA PPPT Responsible Officer for review and final approval and uploading in the IDM database.

2. WP12-MAT-IREMEV:

Task Agreement WP12-MAT-01-IREMEV: Integrated Radiation Effects Modelling and Experimental Validation

2.1 Introduction

At its 49th meeting in Warsaw on 24-25 October 2011, the EFDA Steering Committee approved the EFDA 2012 Workprogramme, including the tasks identified below. This Task Agreement covers the activities of the 2012-WP of MAT-IREMEV Research Project of the Fusion Materials Topical Group on Integrated Radiation Effects Modelling and Experimental Validation (IREMEV). It will be implemented on the basis of the provisions given in Art. 5 of EFDA Agreement.

2.2 Objectives

The overall objective of Integrated Radiation Effects Modelling and Experimental Validation (IREMEV) project is to develop experimentally validated mathematical algorithms for predicting the rate of degradation of materials under fusion neutron irradiation in the high temperature operating environment of a fusion power plant. The near-term objective is the minimization of uncertainties and identification of critical modes of operation of materials, potentially leading to failures and long shutdown periods required for maintenance and repair work.

Presently there are limited means for acquiring quantitative information, required for engineering design, about changes in physical and mechanical properties and potential breakdown modes of structural and plasma-facing materials under fusion neutron irradiation and thermal loading in DEMO. Operation of the present generation of fusion devices have already highlighted a range of generic materials-science problems not foreseen in the past, for example the problem of materials compatibility in the divertor, the fact that a substantial amount of tritium is retained in the plasma-facing materials, or the fact that erosion and transport of eroded material in a plasma device could lead to the formation of complex alloys. There is a need to develop capabilities for identifying the fundamental causes of degradation of materials in the DEMO environment, understanding changes in the properties of materials occurring under fusion neutron irradiation, and develop innovative materials concepts for engineering applications, using the significantly expanded computer resources and new experimental testing capabilities that became available relatively recently.

2.3 Work Description and Breakdown

Structure

The programme of work outlined in the task agreement below is based on the extrapolation of recent advances in modelling and experimental validation techniques. The experimental irradiation and testing methods, which prove to be effective if applied in combination with quantitative modelling of materials, include ion-beam irradiation experiments, fission reactor irradiation experiments, micromechanical tests, advanced TEM, *in-situ* electron microscopy, atom probe microscopy, small-angle neutron scattering, electron energy loss spectroscopy, and positron annihilation spectroscopy.

The IREMEV research project aims to further the development of quantitative framework for interpreting experimental tests on steels, iron-based alloys, and several other types of candidate structural materials, and predicting the performance of these materials under DEMO-relevant operating conditions. Also, the programme includes several generic tasks linking it to the effort on plasma-wall interaction as well as tasks focused on exploring alternative materials options and innovative solutions.

The structure MAT-REMEV research project is based on the established principles of multi-scale mathematical modelling of materials, which are applied to steels, iron-based alloys, and several other types of candidate structural materials, and focuses on:

- **Phase stability and bonding**.

Priority issues: dynamics of defect production and migration in binary and ternary Fe alloys and steels at high temperature, phase stability of such materials, irradiation-driven precipitation and mixing of alloys by the combined action of high temperature and irradiation, radiation stability of oxide precipitates, effects of impurity atmospheres on defects and dislocations.

- **Evolution of microstructure and accumulation of radiation damage**.

Priority issues: stability of microstructure under fusion irradiation and high temperature operating conditions, integration of neutron activation and transport calculations with models for microstructural evolution and transmutation/irradiation-induced embrittlement, hardening and radiation embrittlement effects associated with evolution of defect and dislocation networks under irradiation and thermal recovery.

- **Mechanical deformation and plasticity of irradiated materials**.

Priority issues: modelling high-temperature deformation and fracture, dynamics of radiation hardening and embrittlement, α′ precipitation and other phase decomposition-mediated embrittlement, temperature-dependent dimensional changes in alloys induced by irradiation and transmutation.

- **Experimental validation of models**.

Priority issues: dual/triple ion beam irradiation, *in-situ* electron microscope examination of microstructure developed under ion-beam and fission neutron irradiation, thermal recovery tests, helium migration analysis, atom probe tomography of irradiated model alloys and steels, micromechanical tests, small-angle neutron scattering, electron energy loss spectroscopy, and positron annihilation spectroscopy.

The objective of priority tasks is the development of quantitative scientific understanding of how mechanical and physical properties of EUROFER-type steels and ferritic steels, including ODS steels, as well as several other types of structural fusion materials, change under DEMO-relevant operating conditions.

The modelling methods and the corresponding experimental database will provide the basis for the optimisation of fusion materials testing programme, engineering design studies, and for assessing and extrapolating the relevant experimental data to DEMO operating conditions, for licensing purposes. Activities related to modelling high heat flux materials are integrated in a separate research project of the same Work Programme.

The objectives for the 2012 MAT-IREMEV Work Programme are defined according to the Strategic Objectives for Fusion Materials Modelling and Experimental Validation (2010-2015) [1], and are the continuation of activities performed within WP-2008-2009-2010-2011.

Work Breakdown

WP12-MAT-01-IREMEV-01

WP12-MAT-IREMEV-01: Phase Stability and Bonding

This activity is focused on predictive modelling of generation of defects, high-temperature phase stability, and accumulation of helium in Fe-Cr and Fe-Cr-Ni model alloys, as well as in EUROFER-type and ferritic steels. Special attention is devoted to the problem of high-temperature and radiation stability of oxide particles in ODS steels. The activity also includes the investigation of helium and other noble gas defects, analysis of accumulation of these defects at dislocations and grain boundaries, trapping of helium at interfaces between the steel matrix and ODS particles, analysis of reaction pathways giving rise to the formation of ODS particles, and the investigation of interaction of defects with impurity atmospheres at high temperature.

The activity focuses on the investigation of (i) phase stability of Fe-Cr-Ni alloys and kinetics of evolution of Fe-Cr alloys, including the combined effects of temperature and irradiation, generation of defects in Fe and Fe-based alloys including magnetic γ-phase high-temperature instabilities, (ii) analysis of thermally activated migration of defects and dislocations at high temperatures, properties of helium and other noble gas defects and accumulation of defects at dislocations and grain boundaries, including interaction of He and noble gas defects with solutes and impurities, aiming at the formulation of a quantitative model of helium embrittlement, and (iii) analysis of reaction pathways of formation, and factors determining the stability of oxide particles in ODS steels.

Priority tasks include:

The development of atomistic methods for simulating defect production in Fe and Fe-alloys, including magnetism and high-temperature α-γ instabilities.

Comprehensive analysis of thermally activated migration of vacancies and dislocations in Fe and refractory metals, including high-temperature entropic modification of migration barriers and identification of pathways of migration of dislocations, for modelling brittle-ductile transitions.

Ab-initio investigation of helium and other noble gas defects, interaction of these defects with dislocations and grain boundaries, as well as with solutes and impurities (e.g. carbon).

Analysis of low- and high-temperature phase stability of Fe-Cr-Ni alloys, development of a kinetic model describing precipitation and radiation-driven dissolution of FeCr alloys in the presence of irradiation.

Generation of a database of *ab-initio* parameters for modelling pathways of formation of ODS precipitates.

WP12-MAT-01-IREMEV-02

WP11-MAT- IREMEV -02: Evolution of microstructure

This activity includes assessment of stability of microstructure under fusion irradiation and high temperature operating conditions, including the formation of irradiation-driven instabilities, integration of neutron activation and transport calculations with models for radiation defects and helium embrittlement, models for helium microstructures, assessment of sensitivity of microstructures to both initial and environmental conditions, hardening and radiation embrittlement effects associated with evolution of defect and dislocation networks under irradiation and thermal recovery.

Priority tasks include:

The development of realistic long-time-scale models for evolution of helium microstructures, including the investigation of high-temperature structures of grain boundaries, combined DFT and AKMC models for the accumulation of helium at grain boundaries, dislocations, as well as precipitation of helium clusters at impurities.

Integration of neutron activation and neutron transport calculations with models for transmutation and irradiation induced embrittlement, to provide estimates for component's lifetime and identify regulatory constraints for innovative materials.

Development of kinetic Monte Carlo models for solute diffusion under mechanical attrition or/and at high temperature, and for assessing the radiation stability of ODS steels.

Development of models for assessing the sensitivity of microstructure to the initial radiation damage configurations and environmental effects.

WP12-MAT-01-IREMEV-03

WP11-MAT- IMMEV -03: Deformation and plasticity

This activity is primarily focused on the quantification of effects of irradiation on mechanical properties of materials, and includes the development of computationally efficient models for high-temperature deformation and fracture, dynamics of radiation hardening and embrittlement, α´ precipitation;σ, Laves, and other phasedecomposition-related embrittlement, brittle fracture of ODS steels, the synergetic hydrogen and helium effects, temperature-dependent dimensional changes in alloys induced by irradiation and transmutation.

Priority tasks include:

Analysis of interaction of dislocations with precipitates and phase inclusions, to rationalize the observed embrittlement of irradiated materials.

Assessment of synergetic effects associated with the accumulation of hydrogen and helium on microstructure, including the combined effects of interaction of hydrogen and helium with impurities, dislocations and grain boundaries, both in the low and high-temperature limits.

Development of computationally efficient models for modelling the mechanical response of ensembles of interacting dislocation and defect microstructures, especially in the high temperature limit.

Assessment of hardening impurity effect in the low and high temperature limit, including the dislocation dynamics based model for the synergetic effect of radiation damage and impurity atmospheres.

WP12-MAT-01-IREMEV-04

WP12-MAT- IMMEV -04: Experimental validation of models

This activity is dedicated to the experimental validation of models, and includes the combined application of advanced experimental techniques and modelling to the interpretation of ion irradiation experiments, fission reactor and spallation source irradiation and advance characterization of irradiated materials. In ion-irradiation experiments the specific questions include analysis of dose rate effects, defect accumulation and patterning, defect and dislocation microstructures, micromechanical tests, Helium accumulation and microfracture, grain boundary and surface effects, and dimensional changes associated with the accumulation of radiation damage. Fission reactor and spallation source irradiation is used for validation of radiation and helium embrittlement models, and radiation stability of complex alloys. The advanced characterization methods involve applying both *in – situ* and *ex-situ* electron microscopy, advanced TEM, micromechanical tests, SANS, PAS, EELS, and APT.

Priority tasks include:

Exploration of the effect of chemical composition, specifically Cr content, on the swelling of ion irradiated FeCr alloys.

Experimental and modelling investigation of thermal desorption of helium from ferritic materials and refractory alloys.

Quantitative analysis of neutron irradiation induced microstructural defects in reduced activation ferritic/martensitic steels from ARBOR and SPICE irradiations.

Assessment of phase stability and defect microstructure in Fe-based alloys, steels and ODS materials under high-temperature irradiation.

Experimental investigation, linked with dislocation dynamics modelling, of effects of impurity atmospheres on hardening, softening and embrittlement of materials the low- and high-temperature limits.

Experimental and modelling analysis of *in-situ* electron microscope observations of defect accumulation and microstructural development in Fe-based alloys and steels.

JET related activities

Not applicable.

2.4 Scientific and Technical Reports

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Milestones and Deliverables

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The report on the Association activities under Priority Support will be prepared by the Coordinator to be presented to the EFDA Leader at the end of every calendar year.

The final and technical report will be submitted to the EFDA PPPT Responsible Officer for review and final approval and uploading in the IDM database.

References

[1] J.-L. Boutard, M.J. Caturla, S.L. Dudarev, F. Willaime, Strategic Objectives for Radiation Effects Modelling and Experimental Validation 2010-2015, EFDA-D-2D4B78

3. WP12-MAT-ODSFS:

Task Agreement WP12-MAT-01-ODSFS: Nano-structured ODS Ferritic Steel Development

3.1 Introduction

At its 49th meeting in Warsaw on 24-25 October 2011, the EFDA Steering Committee approved the EFDA 2012 Workprogramme, including the tasks identified below. This Task Agreement covers the activities of the MAT-ODSFS Research Project in the Area of Fusion Materials in the PPPT WP 2012 aiming at Nano-structured ODS Ferritic Steel Development, and will be implemented on the basis of the provisions given in Art. 5 of the EFDA Agreement.

3.2 Objectives

The objective of the present programme is to develop ODS ferritic steels with high tensile and creep strength and sufficient ductility and fracture toughness up to about 750°C, as well as good radiation resistance. The strategy for achieving this ambitious objective consists in optimizing the chemical composition and manufacturing conditions at the laboratory scale and, at the same time, launching the fabrication of ODS ferritic steels at semi-industrial or industrial scale. Activities should yield the industrial production of optimized ODS ferritic steels for DEMO-type reactors in about five years from now.

3.3 Work Description and Breakdown

Structure

The Work Programme 2012 is organised along four activities:

- Production and characterization of laboratory scale batches of nano-structured ODSFS.

The priority issue: Identification of an optimal combination of chemical composition, fabrication routes and thermo-mechanical treatment.

- Production and characterization of industrial batches of nano-structured ODSFS.

The priority issue: Production at industrial or semi – industrial scale of the optimised generation of ODSFS with high tensile and creep strength at higher temperatures, sufficient ductility and fracture toughness for DEMO relevant conditions.

- Irradiation and post-irradiation characterization of produced nano-structured ODSFS.

The priority issue: Investigate the effect of dose and temperature on hardening and stability of oxide particles at the grain boundaries.

- State of the art nano – structured ODSFS: Bibliographical review.

The priority issue: Evaluation of the results obtained mostly by USA and Japan in developing this kind of materials

The main objective of these activities is to produce optimized ODSFS material with a well defined chemical composition, fabrication route and a set of thermo-mechanical treatments, with a first delivery foreseen mid 2012.

The strategy for achieving this ambitious objective consists in optimizing the different relevant parameters involved in the production of ODSFS on small scale batches, i. e., laboratory scale, and, at the same time, developing an industrial or semi - industrial route of fabrication for the optimized material.

Work Breakdown

WP12-MAT-01-ODSFS-01

WP12-MAT-ODSFS-01: Production and characterization of laboratory-scale batches of nano-structured ODSFS

This activity is devoted to optimizing the chemical composition and manufacturing conditions involving powder metallurgy, and based on mechanical alloying followed by either hot isostatic pressing (HIPping) or hot extrusion and thermo-mechanical treatments, like cross hot rolling, high speed hot extrusion, etc., in order to obtain a dense population of small nano-clusters and submicrometre grains, both conditions being required for high creep strength and reasonable fracture toughness after irradiation. Small batches up to about 1 kg will be produced at the laboratory scale.

Characterization before irradiation of the produced ODSFS will be done. This includes microstructural investigation and mechanical characterization:

- Microstructural investigation: Optical microscopy, SEM, TEM, APT, SANS, XRD, laser confocal microscopy, chemical analyses, etc.

- Mechanical characterization: Tensile tests, compression tests, fatigue tests, Charpy impact tests, fracture toughness measurements, microhardness measurements, nano-indentation experiments, etc.

WP12-MAT-01-ODSFS-02

WP12-MAT-ODSFS-02: Production and characterization of industrial batches of nano-structured ODSFS

This activity is focused on the fabrication of ODS FS using semi-industrial or industrial scale-methods. Therefore, the goal of this line of work is to probe the feasibility of production of ODSFS in large batches around 5-15 kg.

Following the identification of chemical composition and manufacturing conditions, production of one or several batches and preliminary characterization of the batche(es) in the unirradiated condition have to be carried out. The characterization activities should be comparable to the ones described under the previous line, but should also include creep and ageing experiments as well as analysis of the physical properties (thermal, electrical and magnetic properties).

Priority task: Industrial or semi-industrial scale fabrication of ODSFS

WP12-MAT-01-ODSFS-03

WP12-MAT-ODSFS-03: Irradiation and post-irradiation characterization of produced nano-structured ODSFS

This activity is devoted to acquiring information about the irradiation-induced microstructure, with a focus on the stability of oxide particles, and effects of radiation hardening by performing ion irradiations of the laboratory scale batches in the JANNuS facility in various conditions as well as post-irradiation characterization.

It also includes the definition of irradiation conditions, irradiation experiments (including eventually in-situ TEM) and post-irradiation characterization of the batches. Post-irradiation examination (PIE) will include TEM analyses and hardness measurements.

WP12-MAT-01-ODSFS-04

WP12-MAT-ODSFS-04: State of the art of nano-structured ODSFS: Literature review

This activity is devoted to the evaluation of the available information about nano-structural ODSFS produced in the USA and Japan.

JET related activities

Not applicable

Resources

3.4 Scientific and Technical Reports

Progress Reports

At the end of each calendar year, and at intermediate times where appropriate, the Task Coordinator shall present a report on activities under the Task Agreement to the EFDA Leader for his approval. These reports shall integrate the progress made by each Association on each activity, and they shall indicate the level of achievement of the objectives, the situation of the activities, the allocation of resources and recommendations for the next year when applicable. The EURATOM financial contribution will be made through the usual procedures for baseline support through the Contract of Association.

Report of achievements under Priority Support (final report and, when appropriate, intermediate reports)

Achievement of Priority Support deliverables will be reported separately to the EFDA Leader. A final report (and intermediate reports marking substantial progress in the achievement of deliverables, if the EFDA Leader so requests) shall be prepared by the Task Coordinator and submitted to the EFDA Leader. If part of or all the activities carried out relate to JET, the Associate Leader for JET will be involved in clearing the report. These reports shall include specific sub-sections for each of the Associations involved. They shall document the degree to which the deliverables have been achieved. The EURATOM financial contribution will be made after approval by the EFDA Leader of these reports.

The results obtained within the Research Project Nano-structured ODS Ferritic Steel Development will be presented by the principal investigators and reviewed during joint monitoring meetings held twice a year. On this basis the progress accomplished by the contributing Associations will be reported by the Coordinator to the EFDA Leader.

The report on the Association activities under Priority Support will be prepared by the Coordinator to be presented to the EFDA Leader at the end of every calendar year.

The final and technical report will be submitted to the EFDA PPPT Responsible Officer for review and final approval and uploading in the IDM database.