EFDA WORKPROGRAMME 2009

Call for Participation

Emerging Technologies

Fusion Materials Topical Group

Research Project:
MAT-SiC/SiC: SiC_f/SiC Composite for Structural Application in Fusion Reactor

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1. Introduction

At its meeting in Barcelona on the 8th July 2009 the EFDA Steering Committee approved the EFDA 2010 Work Programme, including the tasks identified below. This Call for Participation covers the activities of the 2010-WP of the MAT-SiCSiC Research Area within the Fusion Materials Topical Group, and will be implemented on the basis of the provisions given in Art. 5 of EFDA Agreement.

2. Objectives

SiC_f/SiC composites are foreseen to be used as structural materials for high temperature advanced tritium-breeding blankets in a Fusion Reactor.

The 2008-2009 WP had the objectives of assessing (i) requirements concerning properties of SiC_f/SiC composites intended to be used as structural material for Tritium Breeding Blanket (TBB) and Divertor (D) of a future fusion reactor, (ii) the parameters controlling physical properties of SiC_f/SiC composites, (iii) effects of irradiation on fundamental physical properties of Silicon Carbide, (iv) alternative concepts involving Silicon Carbide in combination with other materials.

The WP2008 results have been evaluated during the MAT-SiC_f/SiC Monitoring Meeting in Garching on the 7th and 8th of May 2009.

Long term Objectives

The main conclusions of this MAT-SiCSiC meeting, together with the associated long term objectives, are given below:

- SiC_f/SiC composite is the only ***non-magnetic*** material capable of complying with the requirements for structural application within fusion environment, i.e. being a potential Low nuclear Activation (LA) material, having heat resistance up to at least 1000°C and radiation resistant strength properties, as a result of the neutron irradiations conducted so far.
- The geometries of the structure foreseen for the First Wall (FW), Test Blanket Modules (TBB) and Divertor (D) are of shell type, which require ***3D SiC_f/SiC composites with high thermal conductivity and mechanical strength in the direction normal to the surface***.
- This implies the need for ***dense cubic β-SiC matrix*** beyond the possibility of the present industrial processes such as Chemical Vapour Infiltration (CVI) or Polymer Infiltration Pyrolisis (PIP). High density will also prevent infiltration of LiPb coolant into the material.
- Due to radiation effects, ***dense β-SiC matrix*** will most probably ***not be sufficient to achieve thermal conductivity as high as 20 W/m/K after irradiation***. Therefore, using ***fibres with a core made of W metal*** is proposed to improve conductivity, with a limit on the possible volume fraction of tungsten to be determined from the neutronics, in order to avoid the undesirable high rates of absorption of fusion neutrons in the structure.
- Radiation effects, especially controlling the ***point defect swelling*** and associated ***loss of thermal conductivity*** within the temperature range between ~300 to 1000°C, remains an open issue as well as the transition temperature to (i) amorphisation regime at low temperature & (ii) void swelling at high temperature, in presence of dpa and He (& H), which need experimental data and understanding.

- The mechanical properties of SiC_f/SiC is a domain that remains to be documented, especially the irradiation creep, which will be the predominant deformation mechanism in the range of operating conditions.

Objectives of the Work Programme 2010

According to the long term objectives, the MAT-SiCSiC Research Area is structured according to three research and development lines:

(i) Optimisation of β-SiC-coated W-fibres.
(ii) Development of a dense β-SiC matrix in 3D perform.
(iii) Radiation effects in EU reference SiC_f/SiC and 3D $WSiC_f$/SiC composites.

The objectives for WP-2010 are given below with the expected deliverables and requested resources under baseline and priority support.

(i) Optimisation of β-SiC-coated W fibres.

Industry has developed silicon carbide fibres grown onto a tungsten core, which exhibit high strength and Young's modulus similar to that of SiC. The diameter for the fibres fabricated so far (TISCS Sigma™ for instance) is in the range of ~100 micrometers, which might make it difficult to easily weave the pre-forms. It has to be noted that on the presently fabricated fibres the diameter of the W core is ~15 micrometers for a fibre of ~100 micrometers in diameter. We assume in the following that the fabrication process can be optimised to end up with a ~10 micrometer fibre of W coated by β-SiC, which should be suitable to be woven with SiC fibres in a 3D perform (see activity b below).

The objectives of this task are the following:

- Develop process fabrication fibres of ~10 micrometer diameter made basically of tungsten coated with β-SiC by extrapolating the present fabrication process.
- Evaluate the stability of the interface between W & β-SiC up to 1500°C, compatible with the fabrication process of a dense matrix such as Slovenian Infiltration & Transient Eutectic (SITE). If required, select a diffusion barrier and test its effectiveness.
- Fabricate a first set of W-fibre coated with β-SiC.

The activity under the first and the third bullet above has to be carried out within one of the Industrial Companies presently involved in the fabrication W-core SiC fibres. The second point is to be carried out in an Association with close collaboration with the industrial company to assure the compatibility with the fabrication process.

In all these tasks particular care will be taken to avoid introducing chemical elements, which could impair the low activation (LA) properties of pure Silicon Carbide.

(ii) Development of a dense β-SiC matrix in 3D preform

The objective is to develop, by combining various processes, a fabrication route for producing dense β-SiC matrix beyond the capability of CVI & PIP industrial processes.

After coating the pre-form fibres with a thin interlayer of pyrolitic carbon the pre-form will be infiltrated using ceramics method such as SITE or hybrid methods including liquid impregnation, the process being ended via sintering or hot – pressing.

(iii) Radiation effects in EU reference SiC_f/SiC and 3D $WSiC_f$/SiC composites

Three programmatic lines have been identified.

- **The regime of point defect swelling:**

Point Defect swelling is controlled by point defects accumulation. It saturates under pure dpa regime once quasi-stationary microstructure has been established. It may depend on the impurity content and may not saturate if He and H are also produced, like in the fusion environment.
The objective is to study, using multiple ion beam irradiation, under dpa, dpa & He, dpa & He & H, the effects of point defect swelling for:

A. the present β-SiC fibres, β-SiC matrix and pyrolithic carbon interphase, especially for the 2D and 3D reference samples,
B. β-SiC matrix obtained by various fabrication processes developed under Activity (iii).
C. The β-SiC-coated W fibres as soon as they are available, including the behaviour of the interface between W and β-SiC.

In addition, due to the well established fact that electronic excitations heal damage at low temperatures, in this way preventing the amorphisation of a semiconducting material, a dedicated study will be performed of the role of high electronic stopping power effects on point defect induced swelling. Specifically, this will involve the comparison of radiation effects introduced by electron, ion (varying energies) and additional X-ray irradiation.

- **Modelling radiation effects:**

From the 2008 Work-Programme, it appears that physically based kinetic modelling of radiation induced microstructure is still out of reach, due to the complex configuration of defects and their electrical charges. Conversely the calculation of the impact of well identified defects on the thermal conductivity is feasible. The objective of the WP 2010 will be a parametric study of the impact of the most common defects on thermal conductivity.

- **Mechanical properties:**

The primary objective is the experimental characterisation of irradiation creep of SiC_f/SiC composites, since it is the dominant deformation mechanism in the TBB SiC_f/SiC structure at low primary stresses. Taking irradiation creep into account is important for calculating the relaxation of significant secondary thermal stresses. The methodological approach remains of multi-scale type, considering the fibre, the bundle also called mini-components and then the composite itself.

The objective for WP2010 should be the irradiation creep testing of the present fibre Nicalon and Tyrano S, and a switch to the SiC-Coated W-fibres, as soon as they are available in the second half of 2011.

Modelling plasticity of SiC_f/SiC composite will not be pursued as an objective non-specific for fusion applications, conversely to the fuel element of GenIV He-cooled reactor, where mechanical interaction between a non creeping fuel and the SiC_f/SiC cladding will impose high stress and overall plasticity of SiC_f/SiC cladding.

- **Neutron irradiation:**

An assessment of the test of the SiC_f/SiC specimens in their initial conditions and after irradiation in FURIOSO will have to be made, as well as the results obtained in the above programme lines, to decide on a neutron irradiation programme.

3. Work Description and Breakdown

3.1 Work Breakdown:

The breakdown of the work and the main deliverables are given below.

Activity (i): Optimisation of β-SiC coated W-fibres		
Objectives	***Milestones***	***Deliverables***
Developing β-SiC W-fibres with ~10 mm diameter	**2010**: Optimising fabrication route of β-SiC W-fibres of ~10 micrometer diameter including a diffusion barrier between W and SiC for temperature up to 1500 °C	**2010**: Report on fabrication route of diameter β-SiC coated W-fibres of ~10 micrometers.

Activity (ii): Development of a dense β-SiC matrix in a 3D preform		
Objectives	***Milestones***	***Deliverables***
Developing ceramics and hybrid impregnation route of 3D perform for high density	**2010**: Optimisation of ceramics route based on SITE. Exploration of hybrid fabrication route including liquid impregnation	**2010**: Report on ceramics fabrication route performance

Activity (iii): Radiation effects in EU reference SiC/SiC and 3d WSiC/SiC composites		
Objectives	***Milestones***	***Deliverables***

Point defect swelling	**2010**: Point defect swelling of β-SiC matrix and SiC fibres versus temperature: dpa and dpa + He regime.	**2010**: Report of point defect swelling of SiC matrix and fibres under dpa and dpa+He regime
	2010: Point defect swelling under high electronic stopping power	**2010**: Interim report on Point defect swelling under high electronic stopping power
Modelling Radiation Effects Modelling	**2010**: Calculation of the impact of a selection of point defects on the thermal conductivity	**2010**: Interim report on the effects of the main point defects on thermal conductivity
Mechanical properties	**2010**: Irradiation creep of present β-SiC fibres (tyrano & High Nicalon-S). Starting experiment on β-SiC coated W fibres	**2010**: Interim report on the irradiation creep of present β-SiC fibres
Neutron Irradiation	**2010**: Assessment 2D and 3D EU reference specimens irradiated in FURIOSO	**2010**: Interim report on FURIOSO specimens testing before and after irradiation

Priority Support

All tasks are under baseline support except the ones shown in the table proposed under Priority Support (1PPY, 150 k€), since it has to be a collaborative work between materials scientists & engineers and designers.

Activities	PPY	Other expenditure	Comments
	2010	**2010**	
Development of a dense b-SiC matrix in 3D preform	0.75	20	(i) Fabrication route development. (ii) Purchase 3D SiC fibres preform.
Optimization of β-SiC coated W-fibres		50	
Manufacture a dense β-SiC matrix with 3D preform	0.25	50	
Point defect swelling under dpa+He+H		30	
Total	**1**	**150**	

3.2 JET related activities

Non-applicable

3.3 Publications

Non-applicable

4. Scientific and Technical Reports

4.1 Progress reports

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

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

The progress of tasks undertaken under Priority Support and the status of deliverables will be reported separately to the EFDA Leader. A final report (and intermediate reports indicating any substantial progress in the achievement of deliverables, if requested by the EFDA Leader) shall be prepared by the Task Coordinator and submitted to the EFDA Leader. These reports shall include specific sub-sections for each of the Associations involved. They shall document the degree to which the deliverables outlined have been achieved, and shall include a breakdown of expenditure for each Association. The EURATOM financial contribution will be made after approval by the EFDA Leader of these reports.

4.3 Milestones.

The results obtained within the MAT-SiCSiC Research Area will be presented by the principal investigators and reviewed during joint monitoring meetings held once 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 Responsible Officer of the Topical Group for approval and uploading the IDM database.

5. Association Proposal

The Associations are requested to complete the Association Response via ECoM system.