EFDA WORKPROGRAMME 2011

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 Dublin on the 23rd June 2010 the EFDA Steering Committee approved the EFDA 2011 Workprogramme, including the tasks identified below. This Call for Participation covers the activities of the 2011-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

Structural materials have been recognized as one of the key issues in development of fusion power plant and are becoming highly relevant in design and construction of DEMO reactor. Among the candidate materials for the First Wall, Tritium-Breeding Blanket and the Divertor of a Fusion Reactor, the SiC-based composites have been identified to offer promising solutions for the structural parts in fusion reactor in-vessel components, but unfortunately they are the least developed among the candidate materials. This remains true even after a certain period of investigations that was in line with a minor effort on development of a suitable new material observed in the materials science community and in literature

SiC is considered in the context of Fusion reactors for at least five reasons:

- it is a material able to sustain very high temperatures
- its constituents, carbon and silicon, are light and as such less detrimental to the plasma
- it is the only non – magnetic material among the candidates
- its thermal conductivity is reasonably good.
- Low neutron activation

However, the thermal conductivity degrades under irradiation, which is a consequence of the deep modification of the microstructure

The main issues remained were unacceptable final porosity and gas permeability as well as insufficient thermal conductivity at high temperatures. While the latter partly proceeds from the intrinsic properties of the composite, the porosity that additionally contribute to the limited thermal conductivity, mostly results from the manufacturing technique.

An Ad-hoc meeting "*SiC for fusion – present status and road-map for future*" was organised in Garching, Germany from 7th to 8th of May 2009 to evaluate the current status and to set a vision of the future development and possibilities for Silicon Carbide continuous fibres based composite materials regarding the technology application and products.

The main conclusions of this MAT-SiCSiC meeting are given hereafter:

- SiC_f/SiC composite is the only ***non magnetic*** material susceptible to comply with structural application within fusion environment, i. e. being a potential Low nuclear Activation (LA) material, having heat resistance up to at least 1000 ^{0}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), TBB and D are of shell type, which require a ***3D SiC_f/SiC composites with high thermal conductivity and mechanical strength normal to the thickness***.
- This implies the need for ***dense cubic β-SiC matrix*** beyond the possibility of the present industrial processes such as Chemical Vapor Infiltration (CVI) or Polymer Infiltration Pyrolisis (PIP). High density will also contribute to the tightness concerning the LiPb.
- Due to radiation effects, ***dense β-SiC matrix*** will most probably ***not be sufficient to obtain thermal conductivity as high as 20 W/m/K after irradiation***. Therefore, using ***fibres with a core in W metal*** is proposed to improve conductivity, with a limit to be determined from the neutronics, in order to avoid detrimental effects of too a high neutron absorption.
- Radiation effects, especially mastering the ***point defect swelling*** and associated ***loss of thermal conductivity*** within the range from ~300 to 1000 ^{0}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.

During this meeting the target materials properties were also agreed (table 1)

Operating temperature limit max. allowed T	300-1000 C 1200 C
Thermal conductivity at 1000 C	> 20 W/mK
Stability at high temperature (embrittlement, creep)	!
Tritium retention	no
Thermal shock resistance	(100K/s)
Normal compressive at RT (MPa)	≥420
Normal tensile at RT (MPa)	≥110
Shear strength (MPa) at RT	≥44
Poisson ratio	< 0.2
Strain to failure	>0.4 %
G modulus (GPa)	80/50
Oxygen %	<0.5
Free Si /other metals	Not allowed (Evaporation!!)
Young modulus (GPa)	200-300
% TD (He impermeability)	> 95 % TD (closed porosity)
Swelling	<0.2%
Thermal expansion (%)	< 4.5
Neutron induced activation (specific contact dose)	After 100 year <0.25 mSv/h
Neutron transparency	Higher than steel
Compatibility with other materials (flowing PbLi at 1000 C)	!
Joining ability	!

Table 1: Target materials properties

The objective of the present programme is to develop a reference SiC- based composite which accomplishes all requirements listed in table 1, focusing mainly on porosity, gas permeability and thermal conductivity at high temperature.

Objectives of the Work Programme 2011

The MAT-SiCSiC research areal is organised in four main activities:

- Definition of a fabrication route for an optimised SiC –based composite
  The priority issue: Definition of a fabrication route and preliminary manufacturing trials to be able to produce a dense, SiC-based composite with closed porosity using elements with low neutron activation and potentially low irradiation effects
- Optimization of Thermal conductivity of SiC - fibre composite
  The priority issue: To be able to reach working temperatures around 1200 °C
- Understanding basic defect formation mechanisms in SiC
  The priority issue: Parametric study of the impact of a selection of most common effects; and an assessment of the He production in SiC under irradiation must be done.
- Radiation effects in EU reference SiC_f/SiC and 3D WSiC_f/SiC composites.
  The priority issue: FURIOSO irradiation evaluation

Definition of a fabrication route for an optimised SiC –based composite. The goal of this activity is the development of a manufacturing technique, by combination of various processes, for infiltration of the 3D fibre perform that would enable radical improvement in densification (decrease porosity)

Optimization of Thermal conductivity of SiC-composite.. The goal of this activity is to increase the thermal conductivity of the composite by incorporation of high conductivity fibres with tungsten core or Carbon nanotubes.

Understanding basic defect formation mechanisms in SiC. The goal of this activity is to identify the mechanisms contributing to microstructural modifications and formation of dislocation loops and swelling. It is also relevant the study of the impact of a selection of point defects on the thermal conductivity. An assessment of the He production in SiC under irradiation must be done.

Radiation effects in EU reference SiC_f/SiC and 3D W-SiC_f/SiC composites. The goal of this activity is the assessment of 2D and 3D EU reference specimens irradiated in FURIOSO.

3. Work Description and Breakdown

3.1 Work Breakdown:

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

Table 2: WP-11: Objectives, milestones, deliverables for 2011.

Objectives	Milestones	Deliverables
Activity 1: Definition of a fabrication route and preliminary manufacturing trials for an optimised SiC –based composite	**12-2011:** Definition of a fabrication route and preliminary manufacturing trials for producing the infiltration of 3D fibre perform with no open porosity	**12-2011**: Report on fabrication route for a high density SiC matrix
Activity 2: Optimization of Thermal conductivity of the SiC-based composite	**12-2011**: Fabrication of SiC- based composite incorporating X-fibres with high thermal conductivity	**12-2011:** Report on Fabrication of SiC- based composite with X-fibres with high thermal conductivity
	12-2011: Industrial contract for 3D fabric with X- fibres through the thickness	**12-2011:** Report on industrial collaboration to fabricate high thermal conductivity fibres
Activity 3: Understanding basic defect formation mechanisms in SiC	**12-2011**: Identification of mechanisms contributing to microstructural modifications and formation of dislocation loops and swelling	**12-2011:** Report on : identification of mechanisms contributing to microstructural modifications and formation of dislocation loops and swelling
	12-2011: Study of the impact of a selection of point defects on the thermal conductivity	**12-2011:** Report on study of the impact of a selection of point defects on the thermal conductivity
	12-2011: Calculation of He production in SiC during neutron irradiation	**12-2011:** Report on Calculation of He production in SiC during neutron irradiation
Activity 4: Radiation effects in EU reference SiCf/SiC and 3D W-SiCf/SiC composites	**12-2011:** Assessment of 2D and 3D EU reference specimens irradiated in FURIOSO.	**12-2011:** Report 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 (0.75PPY, 80 k€), since it has to be a collaborative work between materials scientists & engineers and designers.

Activities	Human Resources (ppy)	Other Expenditures (k€)
Production of a dense, SiC-based composite with closed porosity using elements with low neutron activation and potentially low irradiation effects	1.65	20
Optimization of Thermal conductivity of SiC-based composite	1.40	20
TOTAL	3.05	40

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 in the IDM database.

5. Association Proposal

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