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Status of the European R&D activities on SiC_f /SiC composites for fusion reactors

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Abstract

Silicon carbide composites are a candidate for fusion reactors structural material because of their low activation and after heat properties and good mechanical properties at elevated temperatures. These materials, to be more suitable with their use for fusion energy production, need a strong R&D effort in order to solve some critical issues such as thermal conductivity and radiation stability, hermeticity, chemical compatibility with the fusion environment, the capability to be formed in complex geometries, the joining process and long production time. Constant progress in the fibre quality and matrix–fibre interfaces contribute to support the use of SiC_f/SiC composites as structural material for fusion application. This paper presents an overview of the current status of the European R&D activities on SiC_f/SiC composites focussing on reactor design studies, composites manufacturing, material characterisation in particular after irradiation, chemical compatibility with different blanket environments and development of joining techniques. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The final goal of the Fusion Technology Programme is power generation under attractive economical and environmental conditions. In this pursuit the use of structural low activation materials (LAM) is fundamental as their use will reduce the risk related to accidents, will facilitate maintenance operations and will simplify decommissioning and waste management.

Among LAMs, the SiC_f/SiC composites are the leading candidates as structural material for fusion reactors due to their good mechanical properties at high temperature, low chemical sputtering, good resistance to oxidation at high temperature (≤ 1000°C) and very low short and medium term activation [1].

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The SiC_f/SiC composites have been conceived and developed mainly for aerospace applications. The optimisation of such material for fusion needs a strong coordination of R&D efforts among research institutes, including participation of industry through all the development stages.

The development of more advanced fibres and the enhancement of composites processing methods as well as alternative solutions for fibre–matrix interphase lead to improved thermo-mechanical characteristics at elevated temperatures. Nevertheless critical issues related to the nuclear environment are still present; these issues are mainly connected to the fibres and matrix stability under neutron irradiation, to the poor thermal properties and to the residual porosity. In parallel, technology issues must be addressed, e.g. joining methodology and definition of design criteria.

In parallel to the manufacturing development and materials characterisation, fusion reactors design studies using SiC_f/SiC composites as structural material have been undertaken. These studies, relying on currently available materials data, provide also guidelines for improvements of ceramic composites, ranking the priorities of future developments.

The present overview reports the main achievements of the European R&D activities on SiC_f/SiC composites. A description of the design study of a SiC_f/SiC composites blanket which uses liquid lithium lead as coolant is discussed. Advances in manufacturing routes dealing with chemical vapour infiltration (CVI) and polymeric infiltration and pyrolysis (PIP) are also presented including recent results on joining and coating techniques. Studies on radiation effects on thermal conductivity and mechanical properties including irradiation creep and compatibility with some solid breeders for long exposure time (10 000 h) are also reported.

2. Design

The use of SiC_f/SiC composite as structural material for fusion power reactor has been proposed by different institutions by means of various design studies which differ on the assumed safety strategy [2–4]. Within the EU the TAURO blanket concept [4] has been proposed by the Commissariat a l'Energie Atomique (CEA). In this concept the chosen safety strategy is based on the minimisation of the energy available within the reactor so that the amount of radioactive material released, in case of severe accident, can be limited. This passive safety concept, which has to be applied to all in-vessel components, leads to the use of low pressure coolants with reduced chemical reactivity in air. Liquid Pb–17Li is the most promising candidate. The main objectives of the TAURO Study were to find a credible alternative to existing high-pressure He-cooled blanket designs, to develop models and design criteria adapted to ceramic matrix composites (CMC) structural materials, to determine the main issues for a self cooled Pb–17Li using SiC_f/SiC materials and to evaluate the limit for fusion application of the existing industrial SiC_f/SiC composites.

The TAURO design is based on the reactor specifications defined for the SEAFP Study [5]: 3 GW of fusion power, neutron and heat wall loading of, respectively, 2 and 0.5 MW m^{-2} and 5 years of full power continuous operation. The SEAFP conceptual reactor has 16 toroidal field coils and 48 outboard and 32 inboard segments (about 10 m high).

The TAURO blanket consists essentially of a SiC_f/SiC box containing the Pb–17Li which works as coolant, tritium breeder, neutron multiplier and tritium carrier. The maximum velocity of Pb–17Li is about 1 m s^{-1} in the channel located just behind the FW. The design is based on the assumption, to be experimentally verified, that the SiC_f/SiC has enough low electrical conductivity to avoid large magneto-hydro-dynamic (MHD) induced pressure drops. Recent studies carried out at JRC Ispra [6] indicate, for commercially available SiC_f/SiC composites, a measured electrical conductivity ranging from 350 $(\Omega m)^{-1}$ at 200°C to 550 $(\Omega m)^{-1}$ at 1000°C. Therefore, the item need further investigations taking into account that the neutron irradiation tends to increase the electrical conductivity, being the design reference value 500 $(\Omega m)^{-1}$.