PRESENT STATUS OF SiCf/SiC COMPOSITES AS LOW-ACTIVATION STRUCTURAL MATERIALS OF FUSION REACTOR IN JAPAN

A.Kohyama(1), A.Hasegawa(2), T.Noda(3) and Y.Katoh(1)

(1)Institute of Advanced Energy, Kyoto Univ. Uji, Japan
(2)Dept. of Quantum Science and Energy Engineering, Tohoku Univ., Sendai, Japan
(3)National Research Institute of Metals, Tsukuba, Japan

Abstract

The outline of research subjects on SiCf/SiC composites to apply to the structural components of fusion reactors are described and present status on material development of SiCf/SiC composites in Japan is reviewed. Irradiation experiments of the composites using fission reactors conducted by international collaborations to clarify their radiation response and to optimize the fabrication processes are introduced.

1. INTRODUCTION

Silicon carbide (SiC) fiber reinforced SiC matrix (SiCf/SiC) composites is considered as one of candidate first wall and blanket structural materials of fusion reactors because of low induced activity after the irradiation of fusion neutrons, good fracture resistance, and excellent high temperature mechanical properties[1]. In the fusion reactor systems, nuclear collisions and reactions caused by high-energy neutrons have strong impacts on materials through the production of displacement damage and radioactive elements. Degradation of material performance such as mechanical properties, and thermal properties will be resulted by the production of the damage and transmuted atoms. Based on previous neutron irradiation works, monolithic SiC has high resistance to radiation damage in high temperature region (800-1100C). The temperature dependence of volume change by neutron irradiation and the corresponding defect behavior are summarized in figure 1. Designing operating temperature of fusion reactors with He gas coolant system is in the range of 900-1100C. In this temperature region, radiation damage of SiC is expected to be its minimum. On the other hand monolithic SiC shows brittle fracture behavior, therefore, improved fracture-resistance is required to use SiC as structural material.

In the last decade, continuous SiC fiber reinforced composites have been developed for high temperature applications such as gas-turbine engines. Some of the SiCf/SiC composites exhibited acceptable high-temperature strength and physical properties before irradiation, but severe degradation of mechanical properties were observed after neutron irradiation. The main reason for the property change of composites was debonding between reinforcing fibers and matrix caused by fiber shrinkage [2]. Radiation enhanced crystallization of partly amorphous SiC fibers was responsible for the volume change. Differences of radiation response between fiber and matrix mainly caused by their microstructure and compositions. It is considered that the radiation enhanced recrystallization may be enhanced by extra-carbon and impurity oxygen in the fiber, therefore low oxygen and highly crystallized SiC fibers, which has stoichiometric composition, is expected to have high radiation-resistance. On the other hand, properties of SiCf/SiC composites before and after irradiation are controlled by (1) SiC fiber grade, (2) volume fraction of fiber and fiber texture, (3)SiC matrix and (4) fiber-matrix interface properties. Based on these understandings, development of SiCf/SiC composites for fusion applications is underway to optimize its fabrication conditions in many countries.

In this paper, present status of the research activities of SiC/SiC composites for fusion applications in Japan and their new results are presented, and irradiation programs conducted by international collaborations are introduced.

2. CURRENT RESEARCH ACTIVITIES

The research activities of SiCf/SiC composites for structural materials of fusion reactor collaborate with researchers at universities, national institutes and private companies in Japan are summarized in figure 2. These activities are partly supported by CREST-ACE (Core Research for Evolution Science and Technology, Advanced Material Systems for Energy Conversion) program and JUPITER (Japan-US Program of Irradiation Testing for Fusion Research) program. These activities can be divided into three major tasks; (1) process development of material production in composites material, (2) evaluation and prediction on materials performance under irradiation, (3) design and fabrication of component and material systems.

The first task consists of three sub-tasks; (a) improvement and innovation of SiC fibers, (b) process development of composites production including matrix materials R&D, (c) design and control of interfacial microstructure to optimize materials' performance. In this task, chemical vapor infiltration(CVI) method, polymer impregnation and pyrolysis (PIP) method, and reaction-sintering (RS) process have been used to fabricate composite.

The second task is on (a) mechanical properties, (b)thermal and electrical properties, (c)establishment of evaluation test methodology for SiCf/SiC composite materials and fibers. In this task, suppression of degradation of mechanical property and thermal conductivity by neutron irradiation are emphasized. Effects of transmutation gas such as He are studied in this task.

The third task consists of (a) purification based on the low activation guideline, (b) joining and hermetic coating technique to construct component of reactor, (c) fabrication of large and complex components. Low activation characteristics are the most important technological challenges and selection of low activation elements and elimination of harmful element (to produce high purity SiC or SiC(x), where x is element(s) to improve thermal and electrical properties) are to be extensively carried out. Technological issues predicted in fusion devices are also emphasized in this task. The leak tightness to pressurized coolant of He gas is a major problem in this part.

3. MATERIAL DEVELOPMENT

One important result from this research group is fabrication of new composites that are expected to have higher radiation-damage-resistance. Based on the previous studies, it is expected that high purity and highly crystallized SiC fiber may have high radiation-damage-resistance. In 1998, these fibers can be obtained from Japanese companies, these are Nicalon type-S™ from Nippon Carbon and Tyranno SA™ from Ube Industries Ltd. Development of SiC fibers for even improved radiation stability is being attempted in CREST-ACE program. Fabrication of new composites using these fibers started in summer of 1998. In order to make high-density composites, FCVI(Forced CVI), PIP and RS are used. It is expected that these new composites will appear in late 1998.

Another result from the research activity is fabrication of Japanese reference material of SiCf/SiC composites and their round-robin tests. The composites were 2-dimensional SiCf/SiC composites fabricated by Ube Industries using CVI and PIP methods. Hi-Nicalon™ (Nippon Carbon) which is stable at high temperature and under irradiation conditions compared to conventional SiC fiber such as Nicalon™ was used as SiC fabric materials in the composites. Round-robin test on mechanical properties and thermal properties of composites was carried out by many researchers in Japan.

Using the reference materials and other composites, the following results were obtained. Effects of carbon coating on mechanical properties of SiCf/SiC composites were studied using bend test and ultra-micro-indentation experiments, and microstructural observation was also carried out to clarify fiber coating effect and fracture mechanism of the composites[3-7]. These results suggest that it is possible to control mechanical properties by controlling interfacial shear stress by the coating. Other results were presented in reference [8].

4. IRRADIATION EXPERIMENTS

Neutron irradiation experiments of SiCf/SiC composites at high temperature region are now in progress using JMTR(Japanese Material Testing Reactor) and HFIR (High Flux Isotope Reactor, USA). In HFIR irradiation (800C,10dpa), several types of SiCf/SiC composites using Nicalon type-S or Tyranno SA will be irradiated. Mechanical property and thermal conductivity tests are planned after irradiation. These data will be used to optimize fabrication processes of composites. Fiber irradiation creep test is also planned in the same irradiation cycle in HFIR using BSR(Bend Stress Relaxation) test. The irradiation experiment will start in January 1999. The composite specimens for the irradiation have already been prepared. This program is supported by JUPITER program.

Irradiation creep test of composites using BR-10 in Russia is also planned under Japan-Russia collaboration. In this irradiation, in-reactor creep test using relatively larger size composites is planned to clarify deformation behavior under neutron irradiation environment. This irradiation program is supported by ISTC(International Science and Technology Center).

Effect of transmuted gas element such as helium on bending behavior and microstructural development of SiCf/SiC composites are being carried out using implantation techniques by a cyclotron at Tohoku University[9]. Dual ion beam irradiation using HIT(High-fluence Irradiation Facility of the University of Tokyo) and TIARA(Takasaki Ion accelerators for Advanced Radiation Application, JAERI) are in progress. In addition, new dual-ion beam facility, DuET (Dual-beam for Energy Technology, Kyoto University), with a ultra high temperature environmental cell target is under construction and will be made available for SiCf/SiC fusion irradiation research in 1999.

5. Summary

The outline of research activities on SiCf/SiC composites in Japan to apply to the structural components of fusion reactor is introduced. Development of radiation resistant composites is in progress. Irradiation experiments of the new composites using fission reactors are under way by international collaborations to clarify radiation response of the new composites.

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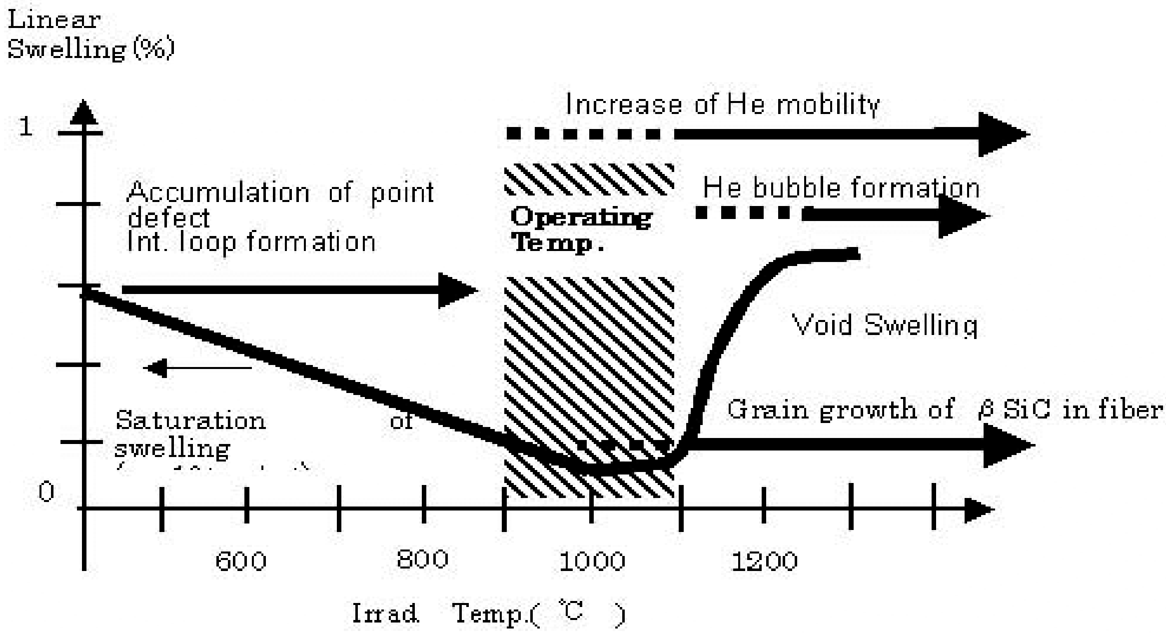

Figure 1 Summary of Irradiation behavior of monolithic SiC and SiC-fiber

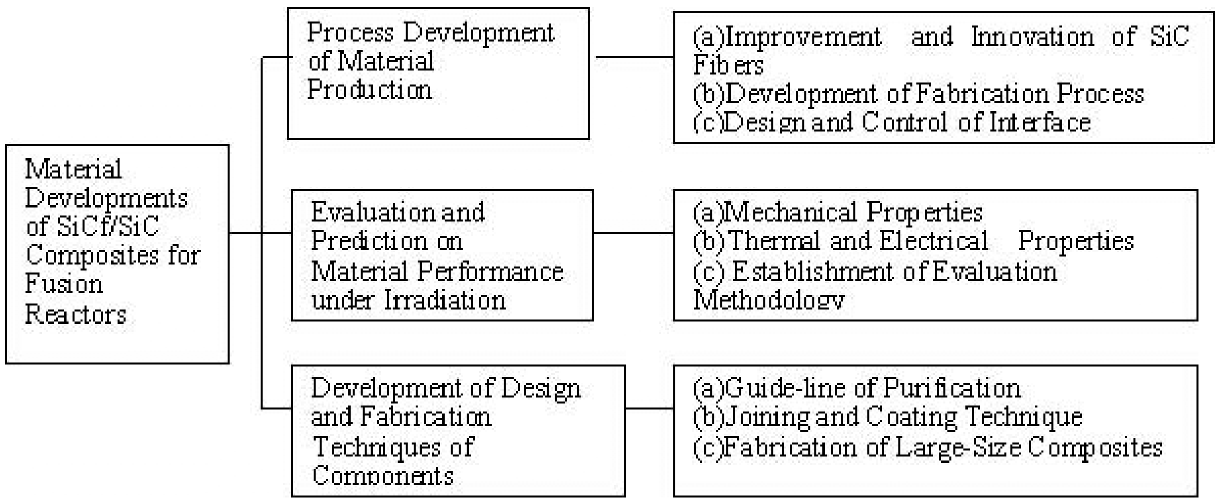

Figure 2 Overview of Research Tasks on SiCf/SiC in Japan