

JOINING SiC/SiC COMPOSITES FOR FUSION APPLICATIONS¹ – C. H. Henager, Jr. (Pacific Northwest National Laboratory², Richland, WA 99336, USA)

OBJECTIVE

This work updates joining results on SiC-based materials using solid state displacement reactions between Si and TiC powders.

SUMMARY

The use of SiC composites in fusion environments may require joining of plates using non-mechanical joints, such as reactive joining or brazing. One promising joining method is the use of solid-state displacement reactions between Si and TiC to produce $Ti_3SiC_2 + SiC$. Such joints, while stronger than the SiC-composite interlaminar shear strength, which is a critical metric for joint performance, requires pressure and bonding at elevated temperatures. We are exploring the processing envelope for this joint in advance of the US-Japan TITAN collaboration so that we can produce viable joints to undergo irradiation studies in HFIR. Joining pressure appears to require almost 30 MPa at 1673K in order to produce strong and dense joints.

PROGRESS AND STATUS

Introduction

SiC is an excellent material for fusion reactor environments, including first wall plasma facing materials and breeder-blanket modules. It is low-activation, temperature-resistant, and radiation damage tolerant compared to most materials. In the form of woven or braided composites with high-strength SiC fibers it has the requisite mechanical, thermal, and electrical properties to be a useful and versatile material system for fusion applications, especially since microstructural tailoring during processing allows control over the physical properties of interest [1-7]. However, it is difficult to mechanically join large sections of such materials using conventional fasteners so the analog of welding is being pursued for these ceramic materials [2, 6, 8-15]. Such methods include metallic brazes [9, 16], glass ceramics [8, 17], preceramic polymers [15], and displacement reactions [2]. This paper reports on the current status of SiC and SiC-composite joining for fusion applications based on displacement reactions between Si and TiC. This has been used to produce bulk composite material consisting of SiC- Ti_3SiC_2 , with small amounts of TiC determined by the phase equilibria conditions [18].

Experimental Procedure

Joints are made using a tape cast powder consisting of mixtures of TiC and Si powders, which were 99.99% purity having average diameters less than 45 μm with a TiC:Si ratio of 3:2. Tapes were about 200 μm thick and were cut to shape and applied between two Hexaloy SiC coupons cut to a rectangular parallelepiped shape 20mm x 4mm x 2mm in size. Joints were formed by heating the coupon sandwiches in argon to 1673K at 10K/min and holding for 2 hours at 30 MPa applied pressure. These joints were dense and approximately 12 μm thick. Joints made at lower temperatures and using less pressure were not fully dense and were approximately 100 μm thick. Binder burnout in air at 600K followed by heating in argon resulted in oxidation of the TiC and Si powders, which retarded the displacement reaction progress and prevented the desired phase formation. No joint strength data were generated yet.

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Results

Figure 1 shows an optical micrograph of a joint processed at 1673K for 2 hours. The joint is dense and 12 μm thick, which is in the target range of less than 20 μm in thickness to minimize joint volume fraction. Figure 2 is a scanning electron micrograph of a region of a joint processed at 1573K that shows the resulting microstructure of the joint as a result of the displacement reaction. The dark needles are SiC and the gray matrix is the Ti_3SiC_2 phase. This is the target microstructure for this work where the SiC needle phase reinforces the Ti_3SiC_2 matrix phase in an interpenetrating manner. Figure 3 shows the entire joint as processed at 1573K and 30 MPa, which illustrates the need to process the joint at higher temperatures to ensure the proper joint density, such as that shown in Figure 1.

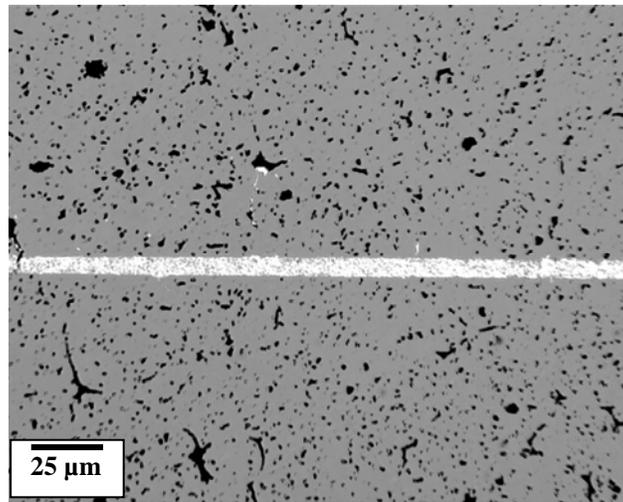


Figure 1. Optical micrograph of $\text{Ti}_3\text{SiC}_2+\text{SiC}$ joint between Hexaloy SiC coupons.

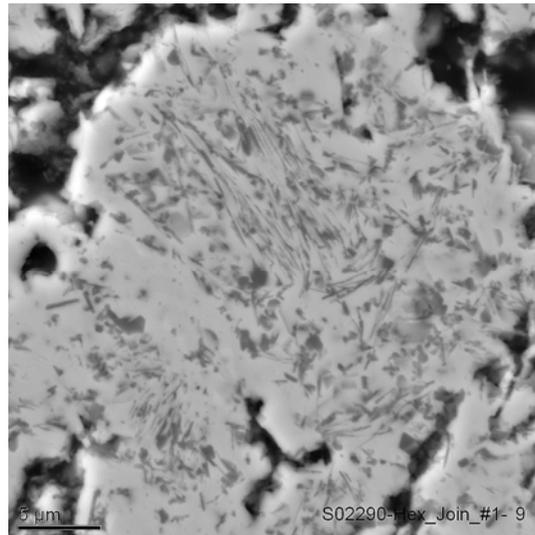


Figure 2. Scanning electron micrograph of a region of a $\text{Ti}_3\text{SiC}_2+\text{SiC}$ joint between Hexaloy SiC coupons showing the desired microstructure that develops during the displacement reaction between $\text{TiC} + \text{Si}$.

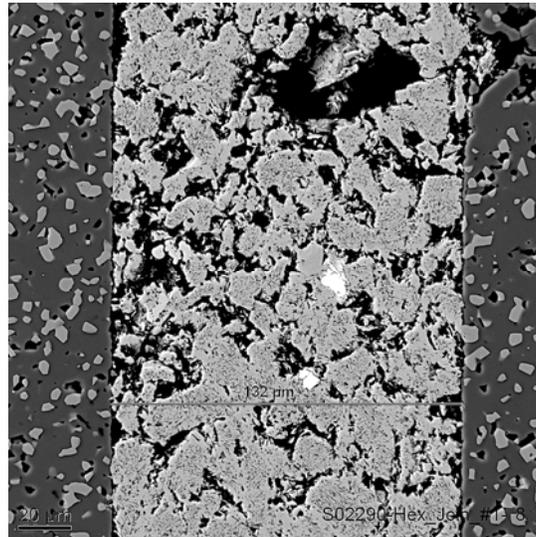


Figure 3. Scanning electron micrograph of a $\text{Ti}_3\text{SiC}_2+\text{SiC}$ joint between Hexaloy SiC coupons processed at 1573K showing the an undesirable amount of joint porosity and thickness exceeding 100 μm .

Conclusions

Solid-state reaction joining was partially optimized by processing tape cast TiC+Si joints in argon at 1673K and 30 MPa bonding pressure using Hexaloy SiC coupons. Joints with desirable microstructures and thicknesses have been obtained. Further work is underway to refine these parameters, such as reducing the pressure but still retain full joint density.

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