A NEW APPROACH TO JOINING OF SILICON CARBIDE-BASED MATERIALS FOR HIGH TEMPERATURE APPLICATIONS

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Ceramic joining is recognized as one of the enabling technologies for the application of silicon carbide-based materials in a number of high temperature applications. An affordable, robust technique for the joining of silicon carbide-based ceramics has been developed. This technique is capable of producing joints with tailorable thickness and composition. Microstructure and mechanical properties of reaction formed joints in a reaction bonded silicon carbide have been reported. These joints maintain their mechanical strengths at high temperatures (up to 1350°C) in air. This technique is capable of joining large and complex shaped ceramic components.

1. INTRODUCTION

Silicon carbide-based ceramic materials are either being used or are under active consideration for use in a number of high temperature applications in aerospace and ground-based systems [1-2]. The interest in these materials is due to their good mechanical properties, high thermal conductivity, and good oxidation and thermal shock resistance. The engineering design often requires fabrication of complex shaped silicon carbide-based ceramic components which are quite expensive. In many instances, it is much more economical to build up complex shapes by joining together geometrically simple shapes. However, the joints must have good mechanical strength and environmental stability comparable to the bulk materials, and the joints must retain their structural integrity at high temperatures. In addition, the joining technique should be robust, practical, and reliable.

Overviews of various joining techniques for monolithic ceramics, i.e., mechanical fastening, adhesive bonding, welding, brazing, and soldering have been provided in recent publications [1-8]. The majority of the techniques used today are based on the joining of monolithic ceramics with metals either by diffusion bonding, metal brazing, brazing with oxides and oxynitrides, or diffusion welding. These techniques require either high temperatures for processing or hot pressing. The joints produced by these techniques have different thermal expansion coefficients than the parent materials, which contributes to stress concentration in the joint area. Normally, the use temperatures for these joints are around 700 °C.

Ceramic joint interlayers have been developed as a means of obtaining high temperature joints in silicon carbide-based ceramic materials. These joint interlayers have been produced via pre-ceramic polymers, in-situ displacement reactions, and tape casting/reaction bonding techniques [8]. Joints produced by the pre-ceramic polymer approach exhibit large amounts of porosity and poor mechanical properties. On the other hand, hot pressing or high temperature fixtures are needed for in-situ displacement reactions and reaction bonding techniques. Due to the equipment required, these techniques are not well suited for joining large or complex shaped components.

The reaction forming technique reported here is unique in terms of producing joints with tailorable microstructures. The formation of joints by this approach is attractive since the thermomechanical properties of the joint interlayer can be tailored to be very close to those of the silicon carbide base materials. In addition, high temperature fixturing is not needed to hold the parts at the infiltration temperature. A variety of silicon carbide-based ceramics and fiber reinforced composites have been joined using this approach [9-15].

In this paper, the microstructure and mechanical properties of reaction formed joints in a reaction bonded silicon carbide material (Cerastar RB-SiC) have been discussed. The room and high temperature mechanical behavior of as received Cerastar RB-SiC material has been presented, too, for comparison.

2. EXPERIMENTAL PROCEDURES

The Cerastar reaction bonded silicon carbide (Cerastar RB-SiC) materials used in this study were obtained from Carborundum Co., Gardener, MA. Appropriate size pieces were cut from the large plates and as machined surfaces were used for joining. Before joining, these pieces were cleaned in acetone and dried.

Details of the reaction forming method for the joining of silion carbide-based ceramics and fiber reinforced composites have been discussed in earlier publications [9-15]. The joining steps include the application of a carbonaceous mixture in the joint area and curing at 110-120°C for 10 to 20 minutes in a fixture. Silicon or a silicon-alloy in tape, paste, or slurry form is applied around the joint region and heated up to 1250-1425°C (depending on the composition of the infiltrant) for 5 to 10 minutes. The molten silicon or silicon-alloy reacts with carbon to form silicon carbide with controllable amounts of silicon and other phases as determined by the alloy composition. Joint thickness can be readily controlled in this process by controlling the fixturing force during the curing step.

Flexure bars were machined from the joined pieces, with joints in the middle of the flexure bars. Four-point flexural strength testing was carried out using MIL-STD-1942 (MR) configuration B specimens with 20 mm inner and 40 mm outer spans. Flexure tests were conducted at room temperature, 800, 1200, and 1350°C in air. At least six to nine specimens were tested at room temperature, and four specimens were tested at each high temperature. After testing, fracture surfaces were examined by optical and scanning electron microscopy to identify the failure origins.

3. RESULTS AND DISCUSSION

An optical micrograph of joined Cerastar RB-SiC material with a ~ 25 μm thick reaction formed joint is shown in Fig. 1. This micrograph shows a non-uniform distribution of coarse and fine silicon carbide grains (grey) and a silicon phase (white) in the base material. The joint contains silicon carbide and silicon phase. Reaction formed joints with different thicknesses have been fabricated using this process. The joint thickness and composition have a strong influence on both the room and high temperature properties of the joined materials.

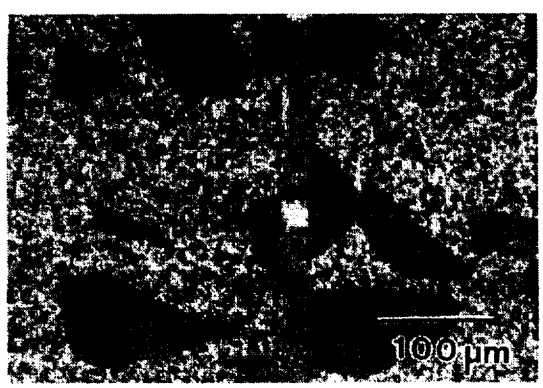

Fig. 1: Microstructure of reaction formed joints in Cerastar RB-SiC material (joint thickness ~25 μm).

The room and high temperature flexural strengths of the as-received and joined Cerastar RB-SiC materials are shown in Fig. 2. The average room temperature strengths of as-received and joined specimens were 157±11 MPa and 212±10 MPa, respectively. The flexural strength of as-received bars increases at high temperatures. Healing of machining flaws is one possible explanation. The flexural strengths of joined bars are comparable to those of as-received materials at high temperatures. In the joined bars, fracture always occurs away from the joint regions. The fracture origins appear to be inhomogeneities inside the parent material. SEM examination of fracture surfaces indicates that the inhomogeneous silicon distribution and porosity are the most common fracture origins.

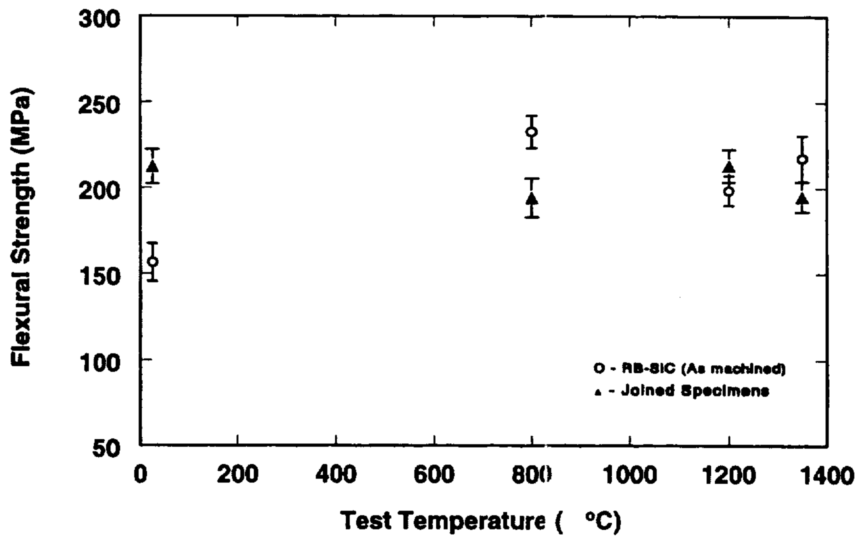

Fig. 2: Flexural strengths of as-received and joined Cerastar RB-SiC at room and high temperatures.

This joining approach has been used to join a wide variety of silicon carbide-based materials in different sizes and shapes as shown in Fig. 3. There is a potential to extend this joining approach to the repair of silicon carbide components in service.

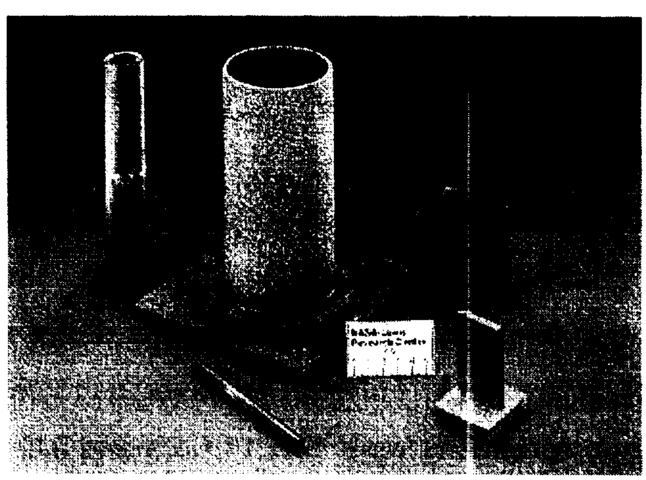

Fig. 3: Photograph showing joined monolithic silicon carbide pieces.

4. CONCLUSIONS

It has been demonstrated that the reaction forming approach can be used to produce strong joints in commercially available reaction bonded silicon carbide-based materials. These joints maintain their strength at temperatures up to 1350°C in air. The joining technology is affordable and robust and it can be used for the joining of large and complex shaped components.

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