

Characterization of silicon carbide joints fabricated using SiC particulate-reinforced Ag–Cu–Ti alloys

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Abstract

CVD silicon carbide was brazed to itself using two Ag–Cu–Ti braze alloys reinforced with SiC particulates to control braze thermal expansion and enhance joint strength. Powders of the braze alloys, Ticusil (composition in wt%: Ag–26.7Cu–4.5Ti, T_L : 900 °C) and Cusil-ABA (Ag–35.3Cu–1.75Ti, T_L : 815 °C) were pre-mixed with 5, 10 and 15 wt% SiC particulates (~ 20 – $30\ \mu\text{m}$) using glycerin to create braze pastes that were applied to the surfaces to be joined. Joints were vacuum brazed and examined using optical microscopy (OM), field emission scanning electron microscopy (FESEM), energy dispersive spectroscopy (EDS) and the Knoop hardness test. The SiC particles were randomly distributed in the braze matrix and bonded to it via reaction with the titanium from the braze alloy. Titanium together with Si and C segregated at the particle/braze interface, and promoted nucleation and precipitation of the Cu-rich secondary phase on particle surfaces. The Si–Ti–C-rich reaction layers also formed at the interface between CVD SiC substrate and the braze alloy. The loss of Ti in the reaction with SiC particulates did not impair either the bond quality or the thickness of the reaction layer on the CVD SiC substrate. Microhardness measurements showed that the dispersed SiC particulates lowered the braze hardness by depleting the braze matrix of Ti. Theoretical calculations indicated the CTE of the braze to decrease by nearly 45–60% with the incorporation of about 45 vol% SiC.

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1. Introduction

In monolithic form, silicon carbide ceramics are widely used in a variety of structural, functional and semiconducting applications. However, net-shape ceramic parts are expensive and difficult to fabricate. Therefore, robust joining and integration technology such as brazing attains importance in manufacturing. In addition, like most ceramics, SiC is seldom used in isolation and this requires it to be integrated to diverse materials including metals. For example, there is interest to develop a micro-electro-mechanical system lean direct (fuel) injector for advanced aircraft gas turbine engines [1,2] for which chemical vapor deposited silicon carbide (SiC) ceramics

have to be joined together and also integrated with low-expansion alloys such as kovar [3]. There is thus a critical need to develop and demonstrate promising technology to join SiC to itself and to other materials, particularly metals.

Brazing is simple, cost-effective and proven technology to join ceramics. However, joining and integration technologies for advanced silicon carbide ceramics have not been widely investigated. Prior work on brazing of silicon carbide ceramics to themselves and to metals [3–8] has made use mainly of Ag–Cu–Ti brazes [3,6–8] although Co-base [9,10] and Ni-base [11] brazes also have been used. It has been reported [11] that Ni-base brazes form a Ni–Si liquid with the free silicon in the ceramic substrate, which reacts with the SiC to form deleterious low-melting point phases at the joined interface. Particulate-reinforced brazes also have been successfully used to join both SiC [11,12] and other ceramics [13,14] as well

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as ceramic–matrix composites such as C/SiC [15–17]. SiC has attractive physical and mechanical properties and a moderate CTE ($4.1 \times 10^{-6} \text{ K}^{-1}$) and reinforcing the braze matrix with SiC particulates (SiCp) would permit CTE control for residual stress management besides strengthening the matrix as in a composite. Knowles et al. [12] reported improvements in joint strength in monolithic SiC with 5% SiC ($\sim 5 \text{ }\mu\text{m}$) dispersed in Ag–Cu–Ti brazes to which excess Ti was added to compensate for its loss in reactions due to increased ceramic surface area. Improvements in joint strength have also been observed by Qin and Yu [17] who brazed C/C to Ti–6Al–4V using SiC particulate-reinforced Ag–Cu–Ti alloys, and by Blugan

et al. [13] who joined Si_3N_4 to steel using a Ag–Cu–In–Ti braze reinforced with SiC. Besides particulate-reinforced brazes, short fiber-reinforced Ag–Cu–Ti brazes also have been observed to increase the joint strength of ceramic–matrix composites such as C/SiC [15,16]. Thus, there is considerable interest in using reinforced metallic brazes to join ceramics.

With reference to the use of Ag–Cu–Ti brazes reinforced with SiCp to join SiC substrates, only one study by Knowles et al. [12] could be found. In their study, these authors used 30 min brazing time to join SiC; presumably to promote interfacial reactions and bonding. In actual practice, shorter brazing times are generally used; therefore, studying the effect

Table 1
Composition and Selected Properties of Brazes Used.

Braze (composition, wt%)	T_L (°C)	T_S (°C)	E (GPa)	YS (MPa)	UTS (MPa)	CTE ($\times 10^{-6}\text{C}^{-1}$)	% EL	K (W/m K)
Cusil-ABA [®] (Ag–35.3Cu–1.75Ti)	815	780	83	271	346	18.5	42	180
Ticutil [®] (Ag–26.7Cu–4.5Ti)	900	780	85	292	339	18.5	28	219

E : Young’s modulus, YS : yield strength, UTS : tensile strength, CTE : coefficient of thermal expansion, % EL : percent elongation, K : thermal conductivity. Cusil-ABA[®] and Ticutil[®] are active braze alloys from Morgan Advanced Ceramics, Hayward, CA.

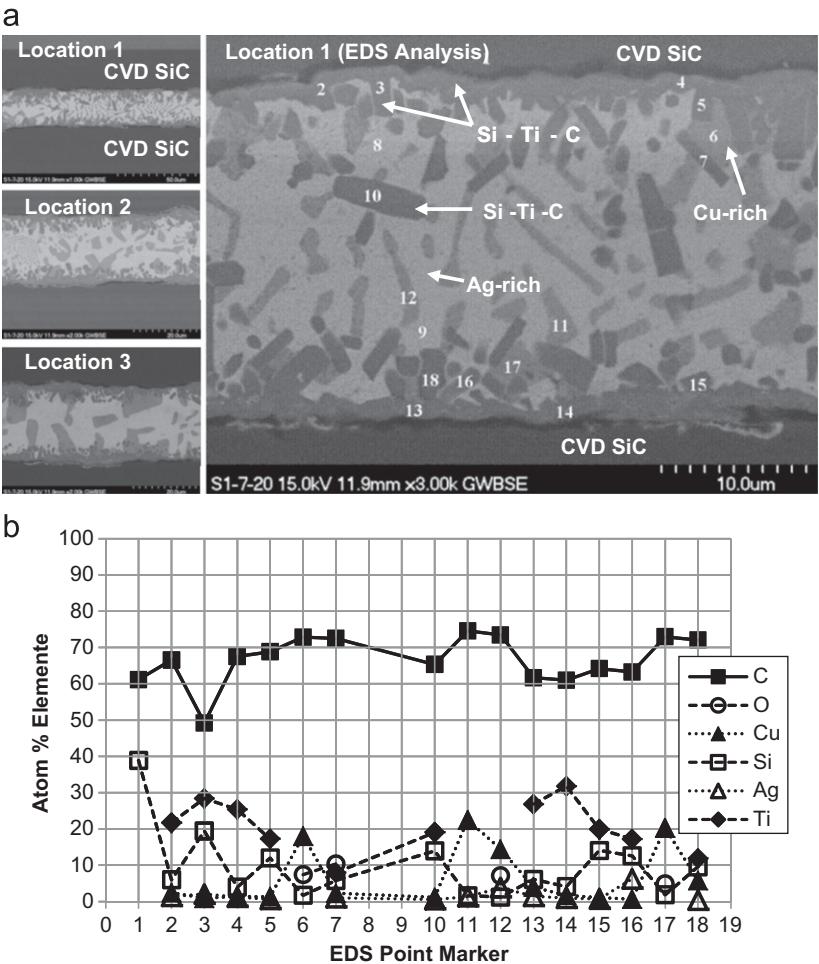


Fig. 1. (a) SEM backscattered electron (BSE) images of different locations of a CVD SiC/Ticutil/CVD SiC joint with 0 wt% SiC particulates, and a higher magnification view of the joint; (b) relative atomic percentages of the alloying elements at point markers in (a). The data at point markers 8 and 9 are not shown owing to a signal access error in EDS.

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