SPOT JOINING OF Si_3N_4 AND SIC CERAMICS USING SELECTIVE AREA LASER DEPOSITION (SALD) TECHNIQUE

Ibrahim M. Ghayad*, Erik Geiss , James E. Crocker, and Harris L. Marcus
Institute of Materials Science, University of Connecticut, Storrs, Connecticut
*Central Metallurgical Research and Development Institute, Cairo, Egypt

Keywords, Silicon Nitride, Silicon Carbide, Laser Spot Joining of Ceramics

Introduction

An important approach to forming difficult and intricate ceramic products is the joining of simple ceramic shapes together to build up to the desired design and hence the economic and technological barriers in manufacturing complex ceramic designs could be avoided. The traditional manner of metal welding by melting the base material is extremely difficult with the typical ceramic high melting temperature or impossible due to thermal decomposition. Brazing of an intermediate material to stick two objects together at a seam also has complications because ceramics are poorly wet by most metals and the resulting operating temperature is lowered (1).

A new, promising manufacturing path involves a gas-phase decomposition approach, known as Selective Area Laser Deposition (SALD) joining. SALD is a gas-phase Solid Free Form (SFF) process in which a specific gas mixture decomposes either thermally or photolytically from the energy input of a laser beam to form a solid reaction product (1,2,3,4). The chemical process is similar to Chemical Vapor Deposition (CVD) but the product is selectively deposited locally under the laser spot, which can be scanned, and therefore controlled.

The present paper focuses on deposition of silicon nitride or silicon carbide filler materials to spot join silicon nitride and silicon carbide ceramic materials. Chemical and structural characterization of joints was performed.

Experimental

The SALD work-station consists of a vacuum chamber, a 150 watt continuous wave Nd:YAG (1.06 micron wavelength) laser beam, an xy table, scanning mirrors, and an optical pyrometer temperature probe. During SALD experiments the surface temperature was measured by an optical pyrometer and was used in a feedback loop to adjust the laser output power to establish the conditions to maintain a constant surface temperature throughout the experiment. These laser power conditions were then used in the spot joining experiments. The laser beam spot size is nominally 1 mm in diameter and approximately Gaussian in shape.

Specimens of fully dense silicon nitride from Norton (NBD 200), 0.8 x 0.8 x 0.2 inch samples were used for joining experiments. Other experiments were carried out using silicon carbide infiltrated Mo powder specimens prepared using the Selective Area Laser Deposition Vapor Infiltration (SALDVI) technique which shares many attributes of SALD. The main difference is that SALDVI uses the pyrolytic products of gas precursor decomposition to infiltrate into layers of powder rather than forming a completely free standing shape associated with SALD (2). The specimens were held together with a clamp (Fig. 1) prior to exposing them to laser. The precursor gases as well as the processing parameters are summarized in Table 1. These conditions were used in the previous work of Shay Harrison (1) for the deposition of SiC and Si_3N_4 whose XRD patterns are shown in Figures 2 and 3. Metallographic cross-sections of the formed joints were investigated using an Environmental Scanning Electron Microscope (ESEM).

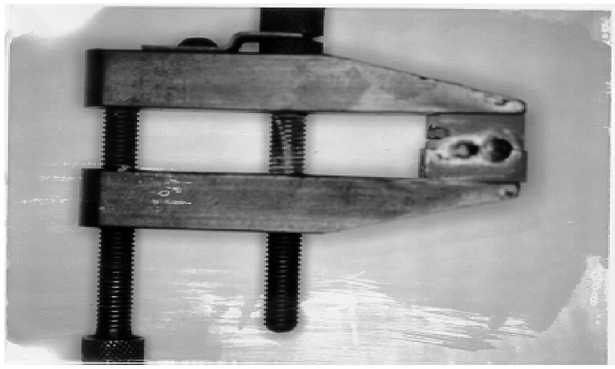


Figure 1: The clamp used to hold the samples.

Table 1: Precursor gases and the processing parameters of experiments

Deposited Material	Gas Precursors	Pressure (torr)	Temperature, °C
Silicon Carbide	Tetramethylsilane (TMS) and H_2	20 TMS and 20 H_2	800-1000
Silicon Nitride	TMS and NH_3	20 TMS and 30 NH_3	900-1100

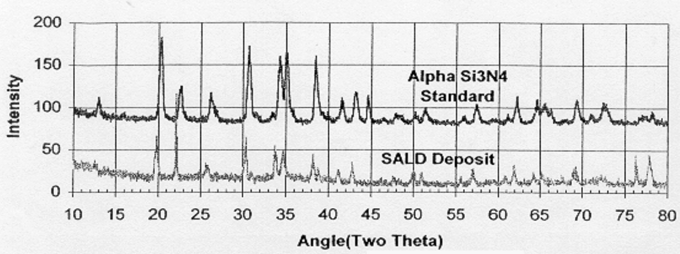


Fig. 2: X-Ray diffraction of SALD Si_3N_4 compared to standard alpha silicon nitride.

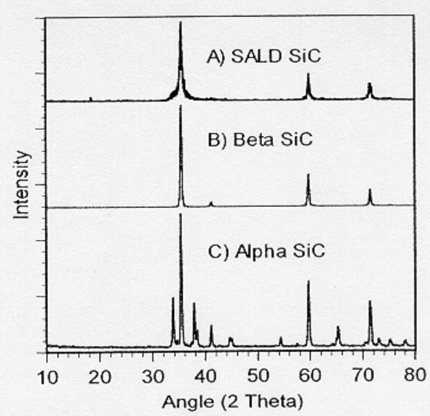


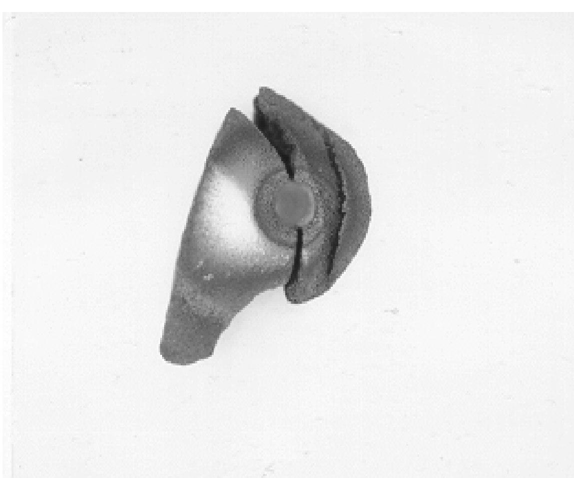
Fig. 3: X-Ray diffraction of SALD SiC compared to commercial alpha and beta SiC

Results

Specimens of SALDVI silicon carbide/Mo composite were held together and exposed to the laser under conditions of silicon carbide deposition. A tight spot joint (Fig. 4) was formed through the deposition of silicon carbide.

Figure 4: SiC joint formed over SiC/Mo composite sample.

When thin specimens of fully dense silicon nitride materials were exposed to the laser a successful spot joint was formed under the conditions of either silicon carbide or silicon nitride deposition (Figs. 5, 6). Thick fully dense silicon nitride samples were exposed to the laser under the above experimental conditions. Unfortunately no joining could be obtained with these specimens. Deposition occurred on one side of the joint but not the other. Several experiments were carried out with exposing the samples to the laser in different geometries without forming a spot joint.



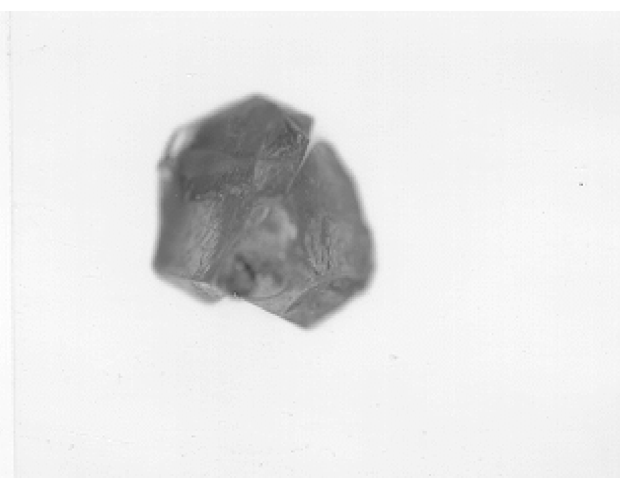


Figure 5: SiC joint formed over Si_3N_4 samples. Figure 6: Si_3N_4 joint formed over Si_3N_4 samples.

The microstructures of the silicon carbide and silicon nitride spot joints, as well as the silicon nitride substrate, are shown in Figures 7, 8, and 9.

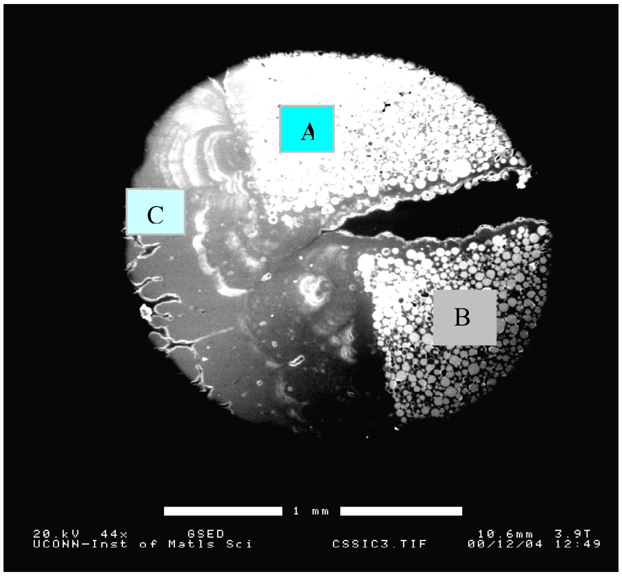


Fig. 7: A cross section of SiC joint over SiC/Mo composite.
A, B: Substrate C: Deposit

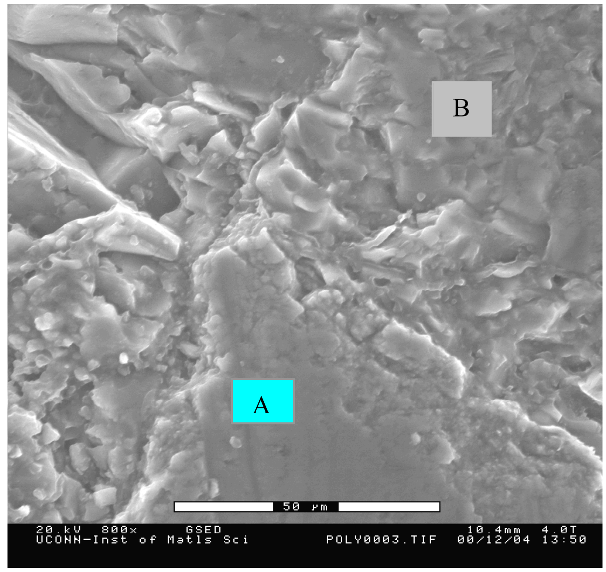


Fig. 8: Si_3N_4 deposition over Si_3N_4 substrate.
A: Substrate B: Deposit

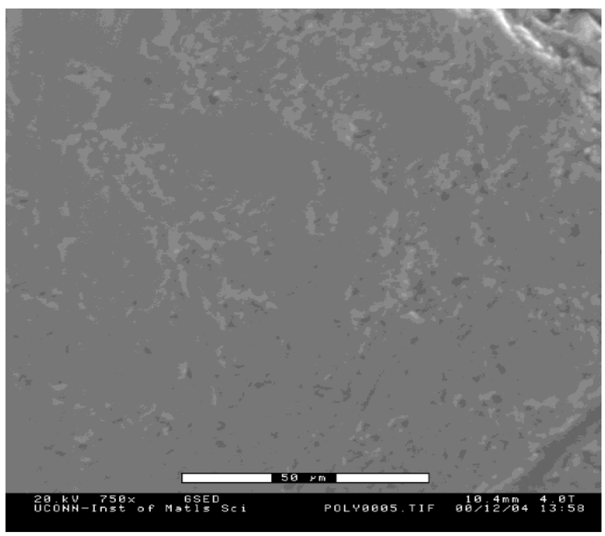


Fig. 9: Microstructure of Si_3N_4 substrate

Discussion

The results of this study demonstrate that spot joining of silicon nitride and silicon carbide using the SALD joining process is possible. A question that arose is; why did the thin specimens spot join while the thicker specimens did not? The answer to this question is related to the thermal conductivity of the sample and the available laser power. The heat sink and resulting thermal gradient of the thinner specimens is much smaller than that of thicker specimens. The laser was able to uniformly heat the thinner specimens effectively, allowing deposition to occur on both sides of the joint at the same time with same deposition rate leading to a successful joint. For the thicker specimens, heating and therefore deposition occurred preferentially on one side resulting in a poor spot joint.

Future work will concentrate on the formation of a complete joint between silicon nitride flat samples and silicon nitride tubes. Other factors that influence joining will be studied, including the laser scan speed and laser wavelength.

Conclusions

1. Spot joints were obtained for the thin fully dense silicon nitride samples and for SALDVI silicon carbide samples.
2. The factors that affect the successful spot joining process are the laser power, the thermal conductivity of the substrate, and the substrate size.

References:

1. Selective Area Laser Deposition (SALD) Joining of Silicon Carbide With Silicon Carbide Filler, Shay L. Harrison, Ph.D. Dissertation, 1999.

2. In Situ Thermocouples in Macro-Components Fabricated Using SALD and SALDVI Techniques, I. Evaluation of Processing Parameters, Lianchao Sun, Kevin J. Jakubenas, James E. Crocker, Shay Harrison, Leon L. Shaw, and Harris L. Marcus, Materials and Manufacturing Processes, vol. 13, No. 6, p 859-882, 1998.

3. In Situ Thermocouples in Macro-Components Fabricated Using SALD and SALDVI Techniques, II. Evaluation of Processing Parameters, Lianchao Sun, Kevin J. Jakubenas, James E. Crocker, Shay Harrison, Leon L. Shaw, and Harris L. Marcus, Materials and Manufacturing Processes, vol. 13, No. 6, p 883-907, 1998.

4. Gas-Phase Solid Freeform Fabrication of SiC Ceramics Using SALDVI, James E. Crocker, Leon L. Shaw, and Harris L. Marcus, Solid Freeform Fabrication Symposium Proceedings 2000, p 168-175.