# Diffusion Bonding of Boron Carbide to Boron Carbide Using Cu Interlayer

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## ABSTRACT

Carbide ceramics have found many industrial applications. Among them is boron carbide ($B_4C$). This material due to its unique properties such as hardness, low density, chemical inertness, and neutron absorption is the most suitable candidate for many advanced applications. However, in many cases boron carbide has to be joined to itself or to metals. The objective of the present study was to join $B_4C$ to $B_4C$ using diffusion bonding method. For this purpose, a copper foil was used as a metallic interlayer to assist bonding process. Copper, due to its properties such as ductility, low melting point, and high diffusivity is one of the most commonly used metals in this field. It was revealed that Cu penetrates into the porosity of the base material. The shear strength of the joints was measured. The highest value obtained was about 170 MPa.

**KEYWORDS**: Boron Carbide, Diffusion Bonding, Joining, Interlayer, Cu.

## 1. INTRODUCTION

Increasing demand for high performance materials in many industries has lead to the use of modern ceramics such as boron carbide ($B_4C$). This material processes unique properties such as high hardness and melting point, excellent resistance to wear and corrosion, low density, and high cross section for neutron absorption. Due to these properties, this material has a potential use in strategic industries [1-3]. However, in many cases boron carbide has either to be joined to itself or to supporting metallic members.

There are varieties of methods available for joining of ceramics, which can be divided into two major groups; liquid phase joining and solid state bonding. Each method has its advantages and limitations. Although liquid phase joining such as brazing or soldering has widely been used for this purpose, but there are problems associated with this technique. Non-wetting of ceramics by most of the commercially available filler metals and coefficient of thermal expansion mismatch between ceramics and filler metals are some of these problems [4, 5].

Although solid state methods such as diffusion bonding can produce high-quality joints, however they are limited to joining of parts with simple geometry and also require more expensive equipments compare to other joining techniques.

The principal objective of the present investigation was to join $B_4C$ to $B_4C$ for low temperature applications. A diffusion bonding process was selected for this purpose. In order to perform the process at low temperatures, a Cu interlayer was placed between the pieces to be joined. Pervious studies have shown that copper interacts with boron carbide [5, 6].

## 2. EXPERIMENTS

The materials used in this study consisted of boron carbide as the base material and high-purity Cu foil. The $B_4C$ bodies were made in house using a high-purity $B_4C$ powder mixed with 15wt% high-purity $TiB_2$ powder as sintering aid. The mixture was then cold pressed in a cylindrical mould. The green samples were sintered at 2150$^{o}$C for 1hr using a microprocessor controlled graphite element furnace under Ar atmosphere. Before bonding, the surfaces to be joined were ground using diamond abrasive wheel and polished down to 1μm finish by diamond paste. The polished surfaces of $B_4C$ pieces and the Cu foil were thoroughly degreased before bonding process. The Cu interlayer was placed between the $B_4C$ pieces and the assembly was hot pressed under a pressure of 50 MPa in an Ar atmosphere. The joining process was carried out at three different temperatures of 800, 850, and 900$^{o}$C for different holding times of 15 to 45 minutes. The bonded samples were then prepared for microstructural examinations and strength measurement. The microstructure of the joints area was observed using a scanning electron microscope (Camscan model MV2300) equipped with an energy dispersive spectroscopy (EDS) system. The strength of the bonded samples was measured using shear testing method using a universal testing machine (MTS 30/MH) under a cross-head speed of 0.5 mm/min.

## 3-EXPERIMENTAL RESULTS

Figure 1 illustrates a SEM micrograph of the joint area of the samples bonded at 900$^{o}$C for 45 minutes. The first thing to be noticed in this figure is high porosity of the $B_4C$ body which is due to the sintering temperature being not high enough to achieve a dense body. As can be seen from Figure 1 the Cu interlayer has perfectly bonded to the ceramic surfaces at both sides of the joint assembly. Figure 1 can be divided into three distinct zones. Zone 1 is boron carbide, zone 2 is the area in which Cu has penetrated into the porosity of the base material, and zone 3 is Cu interlayer. As can be seen, the thickness of the primary Cu foil has reduced from 100 μm to 50 μm which indicates high penetration of Cu into the ceramic. Under this bonding conditions, the dept of the penetration was measured to be about 15 μm. The main reason for this phenomenon is that under applied pressure at bonding temperature the Cu interlayer undergoes viscose flow and penetrates into the interconnected pores of the ceramic body. This will results in a good bonding between these two materials.

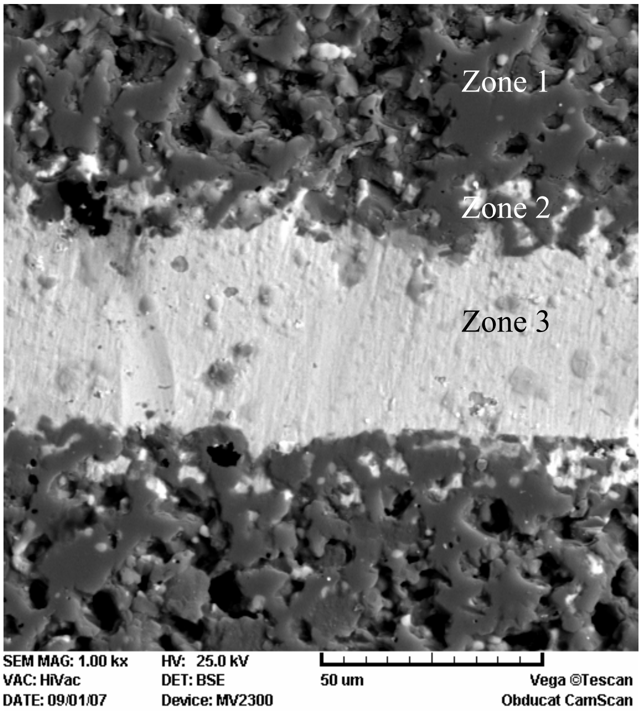

Figure 1. SEM image of the cross section of a sample bonded at $900^{o}$C for 45 minutes.

The result of line scan analysis across the joint area in Fig. 1 is presented in Figure 2. From the figure, it is evident that the Cu interlayer has penetrated into the porosity of the base material. Some Ti has been detected within the interlayer indicating diffusion of this element from $TiB_2$ content of the ceramic into the Cu interlayer.

Figure 3 illustrates SEM micrographs of the cross-section of three samples bonded at different temperatures of 850, 900, and $950^{o}$C for a constant bonding time of 45 minutes. The figure clearly shows that by increasing the bonding temperature the penetration of Cu has consequently increased from almost 5 to 15 μm. This obviously shows the effect of bonding temperature on depth of the penetration.

Table 1 presents the thickness of the penetrated layer under different bonding conditions. The data given in this table emphasizes on the effectiveness of bonding time and temperature on the thickness of the penetrated layer. It also shows that due to the penetration of Cu, even at $850^{o}$C and for the shortest time of 15 minutes, bonding may occur between theses two materials. The table indicates that $850^{o}$C is the lowest necessary temperature for bonding to occur between these materials under the applied pressure.

The strength of the samples was measured using shear testing method. The highest strength achieved was about 170 MPa which belongs to the sample bonded at $950^{o}$C for 45 minutes. This strength value is almost the same as the strength of the base ceramic member. Whereas, the sample bonded at $850^{o}$C for 15 min showed the lowest strength of about 80

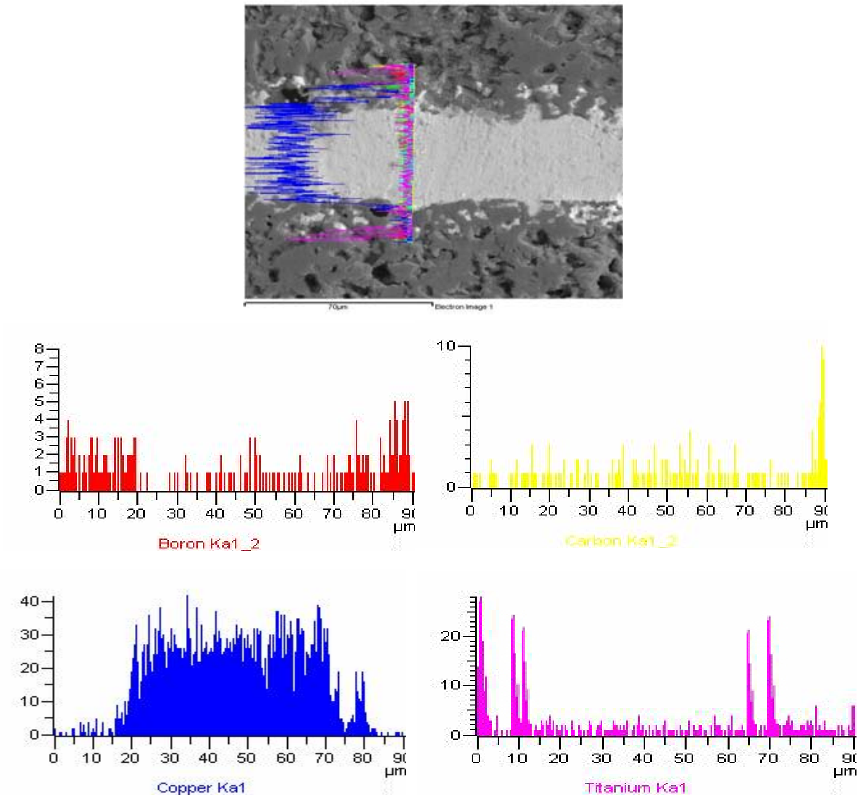

Figure 2. Line analysis from the area given in Fig. 1.

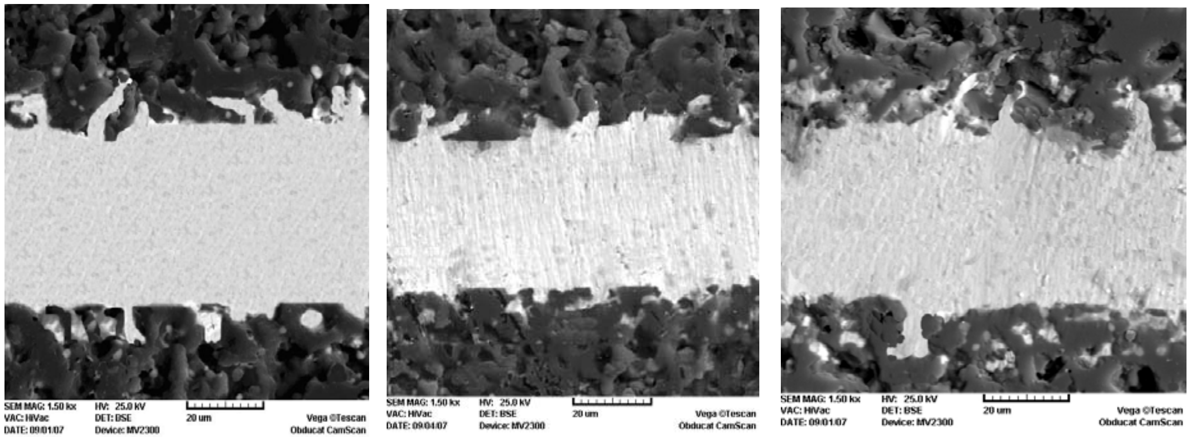

Figure 3. SEM images of the cross section of three samples bonded at (a) 850, (b) 900, and (c) 950°C for 45 minutes.

| Thickness of the penetrated layer (μm) | Time (min) | Temperature | Sample |
|---|---|---|---|
| 0 | 15 | 800 | 1 |
| 0 | 30 | | 2 |
| 0 | 45 | | 3 |
| 3 | 15 | 850 | 4 |
| 4 | 30 | | 5 |
| 6 | 45 | | 6 |
| 4 | 15 | 900 | 7 |
| 7 | 30 | | 8 |
| 8 | 45 | | 9 |
| 6 | 15 | 950 | 10 |
| 11 | 30 | | 11 |
| 14 | 45 | | 12 |

Table 1. Thickness of the penetrated layer at different bonding conditions.

MPa which is steel high enough for this joint to be used for low temperature applications. These results again emphasize on the effect of bonding time and temperature on the joint strength in the current system.

## 4- CONCLUSIONS

- Utilizing solid state technique, simple-shape boron carbide pieces can be joined to itself using a Cu interlayer.
- Bonding occurred mainly due to the penetration of Cu into the porosity of the ceramic body close to the interface.
- Increasing in bonding temperature and time resulted in an increase in depth of penetration of Cu and hence joint strength.
- The highest strength value obtained was about 170 MPa which is among the highest previously reported values for ceramic joints.

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