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Title: FUNCTIONALLY GRADED BORON CARBIDE

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FUNCTIONALLY GRADED BORON CARBIDE

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ABSTRACT

Fabrication techniques were developed for producing graded porosity B_4C, and for producing aluminum-B_4C and epoxy-B_4C functionally graded materials. The key fabrication aspect was obtaining the graded porosity B_4C. The feasibility of producing graded porosity B_4C using a grading of carbon densification aid produced from a gradient of furfuryl alcohol carbon precursor was demonstrated. This approach is quite promising, but it was not optimized in the present investigation. Graded porosity B_4C materials were produced by a layering approach using different size distributions of B_4C powders in the green state, and then densifying the layered assembly by hot pressing at 1900 °C. The hardness of uninfiltrated graded B_4C, aluminum infiltrated B_4C, and epoxy infiltrated B_4C was observed to be similar.

INTRODUCTION

Lightweight body armor is important for the protection of U.S. soldiers in the field. Advanced body armor must satisfy a number of factors:

- Ballistic performance: It must defeat the specified threat in accordance with standards developed by the military and the National Institute of Justice (NIJ).
- Weight: Additional weight carried by the soldier should be minimized. At least a 40% reduction from the present weight at the same or greater threat level.
- Multi-hit capability: Ability of the armor to defeat multiple hits within an approximately 5 cm spacing of hits.
- Articulation: Comfort and ability to conform to body shape and movement.
- Heat load: Removal of body heat during periods of high stress or activity.
- Multi-threat capability: Provide protection from additional threats such as sharp penetrators.

- Protection of extremities: The armor should protect as much of the soldier as possible, including neck and extremities.
- Blunt trauma: A specification that the deflection of the back of the armor not exceed 44 mm. This requirement prevents damage to internal organs and is a major design requirement.
- Cost: For special military applications, cost is not an important factor compared to the value of the soldier, but in most cases cost is important.

The present top-of-the-line body armor vests are the Army PASGT and the Ranger vests. The Ranger vest is capable of defeating an NIJ Level III threat (high powered rifle, 7.62 NATO metal jacket (<2750 ft/s), 5.56 NATO metal jacket, 12 gauge shotgun rifled slug), but only with the use of Al_2O_3 ceramic plate inserts and a vest areal density of greater than 6 pounds/square foot. At the current time, there is no body armor system capable of defeating NIJ Level IV threats, namely armor piercing rifle fire (.30 caliber armor piercing, <2850 ft/s).

The objective of the present work was to develop materials for an FGM-based armor concept, where a hard ceramic front face would transition gradually to an energy absorbing metal or polymer back face. In this concept, the hard ceramic face would blunt the projectile threat, while the tough back face would allow for energy absorption and shrapnel containment.

MATERIALS

The materials chosen for the FGM-based armor were the following. Boron carbide (B_4C) was chosen as the ceramic material since it is very lightweight (density 2.52 gm/cm^3) and very hard (hardness of 30 GPa) (1). Commercial B_4C powders were obtained from the ESK Corporation. Aluminum was chosen as the metal material because of its light weight, and because of previous work on Al-B_4C cermets (2). A Ciba Geigy 0510 epoxy was chosen as the polymer material, due to its low viscosity and good wetting behavior with B_4C (3).

GRADED POROSITY B_4C

The key to producing boron carbide-to-aluminum and boron carbide-to-polymer FGM materials is the production of graded porosity B_4C microstructures. Two approaches were examined: 1) Densification aid gradients; 2) Green density gradients. These approaches were selected because they were considered to be cost effective and commercially viable.

Densification Aid Gradients

Carbon is the major densification aid for B_4C. A carbon addition level of approximately 6 wt.% is indicated to be optimum for maximizing the sintered density, for sintering temperatures in the range of 2170-2270 °C (4). Furfuryl alcohol ($C_5H_7O_2$) was chosen as the source for the addition of carbon to the B_4C powders (5). Furfuryl alcohol is a liquid at room temperature and uniformly coats fine B_4C powder particles. This material decomposes to nanosize carbon when heated to 850 °C, producing a 40 wt.% carbon yield. It can be diluted with acetone.

To produce functionally graded porosity in B_4C, the approach adopted was to start with a 50% dense cold pressed powder disc (31.8 mm diameter x 6.35 mm thick), and then paint furfuryl alcohol layers on one side of the disc, using a simple paint brushing technique. The furfuryl alcohol would then penetrate the cold pressed disc in a graded manner, leading to a gradient in carbon content. B_4C discs coated in this manner were heat treated to carbonize the furfuryl alcohol (5), then hot pressed in graphite dies at 1900 °C and 20 MPa for one hour in an argon atmosphere, to densify the B_4C.

The feasibility of this approach was demonstrated, in that a B_4C pellet with 25% porosity on the painted face and 37% porosity on the unpainted face was produced. Thus, the furfuryl alcohol painting approach was promising. However, for programmatic reasons, it was not possible to optimize this approach to achieve a larger porosity gradient. Optimization of the furfuryl alcohol approach would require applying the furfuryl alcohol in a more controlled manner than hand painting, so that the graded carbon concentrations obtained from its decomposition would be reproducible and better characterized.

Green Density Gradients

Three different grades of ESK commercial B_4C powders were used in the investigation. F400 powder had an average particle size of approximately 30 μm. F1200 powder had an average particle size of approximately 5 μm. 3000F powder had an average particle size of approximately 0.5 μm.

These B_4C powders were employed to produce layered green density materials. Discs were prepared with five 1 mm thick layers of the following powders: 3000F, 3000F/F1200, F1200, F1200/F400, F400. The mixed-powder layers were a 50-50 wt.% mixture. The above five powder configurations were hand-layered in a graphite hot pressing die, and then hot pressed at 1900 °C and 20 MPa for one hour in argon, to densify the layered assembly.

B_4C graded porosity microstructures obtained in this manner are shown in Figure 1. The percent densities of the various layers are: 3000F, 96%; 3000F/F1200, 90%; F1200, 87%; F1200/F400, 66%; F400, 49%. Thus, a substantial porosity gradient was achieved by this approach. Ultrasonic vibration of the green density layers for 30 seconds was effective in grading some of the layer boundaries, particularly at the lower density regions.

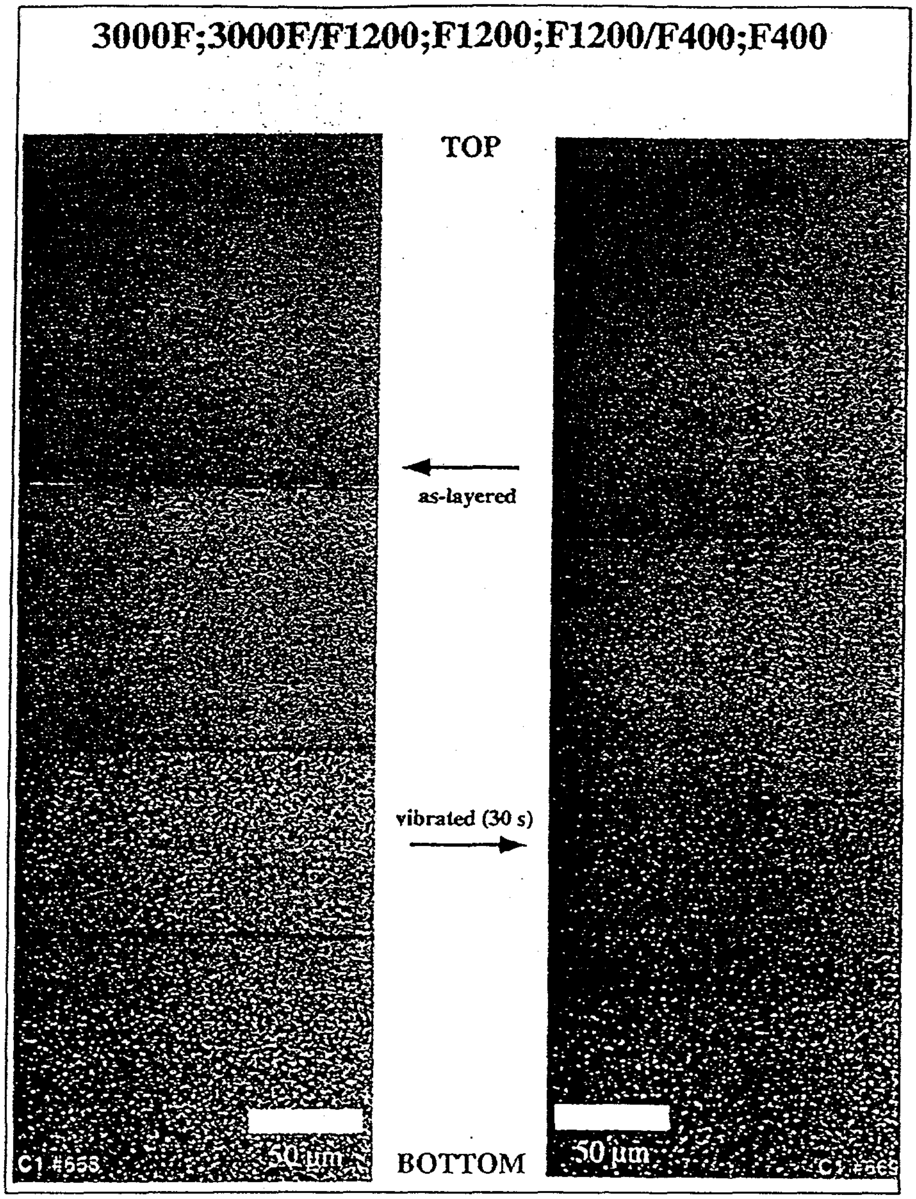


Figure 1: Graded porosity B_4C microstructures derived from the layering of B_4C powders. Microstructures for both as-layered and vibrated are shown.

INFILTRATION OF GRADED POROSITY B_4C

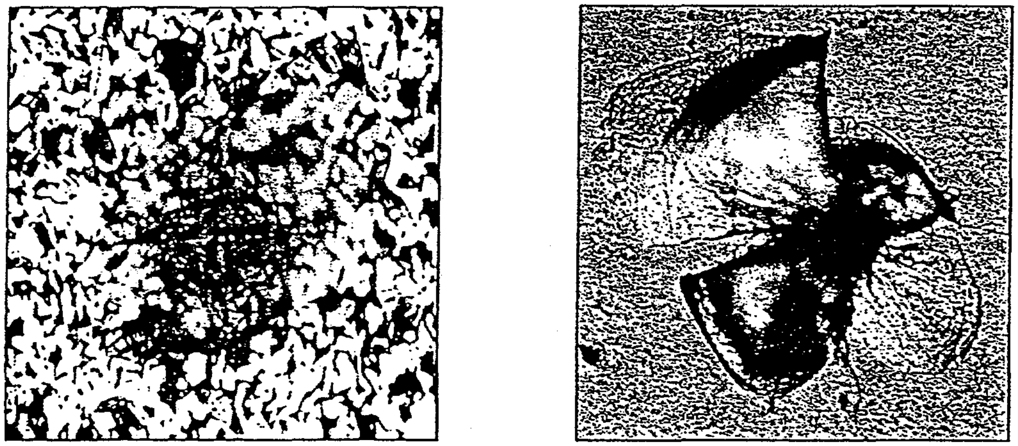
Molten aluminum infiltration of the graded porosity B_4C materials shown in Figure 1 was performed by the heating of pieces of aluminum stacked above the graded porosity B_4C pellet. The infiltration was performed by rapidly heating to

1300 °C in vacuum, then immediately cooling. The temperature of 1300 °C was chosen because previous work (2) indicated very low wetting contact angles for aluminum on B_4C at this temperature. The short time was chosen to minimize the formation of reaction phases between the aluminum and the B_4C (2).

Epoxy infiltration into the graded porosity B_4C materials of Figure 1 was performed at room temperature under vacuum conditions. In this case, the graded porosity disc was immersed in the epoxy under vacuum, until the epoxy material hardened.

PROPERTIES OF FGM B_4C MATERIALS

The microhardness behavior of the graded porosity B_4C and of the B_4C-aluminum and B_4C-epoxy FGM materials was examined. Figure 2 shows 10 kg Vickers microhardness indentations in the 49% dense layer and the 96% dense layer of the graded porosity B_4C.



49 % dense 96% dense

Figure 2: 10 kg Vickers indentations in porous and dense layers of graded porosity B_4C.

The 49% dense layer exhibits little cracking near the indentation, probably due to densification processes under the indentation. In contrast, the 96% dense B_4C layer shows a highly brittle indentation, with extensive lateral cracking.

A comparison of uninfiltrated, aluminum infiltrated, and epoxy infiltrated B_4C is shown in Figure 3. Plastic deformation of the aluminum in the aluminum infiltrated FGM is clearly evident in the light aluminum phase at the indentation. The epoxy infiltrated indentation is similar in appearance to the uninfiltrated indentation.

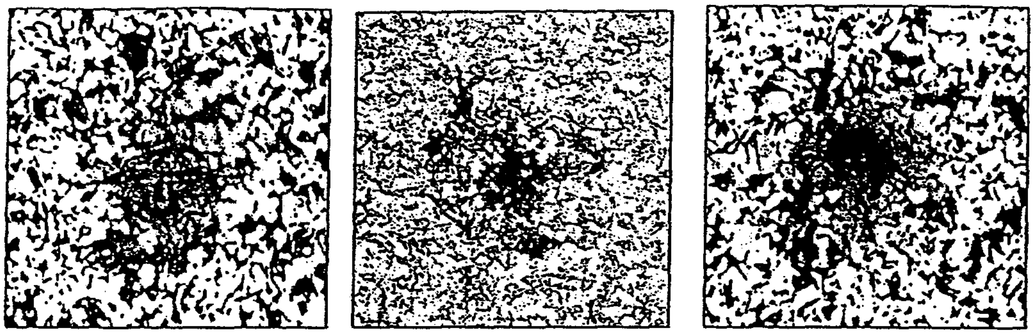


Figure 3: 10 kg Vickers indentations in B_4C region containing 51% porosity in the uninfiltrated condition.

Hardness versus B_4C % density is shown in Figure 4, for the uninfiltrated B_4C, the B_4C-aluminum FGM, and the B_4C-epoxy FGM.

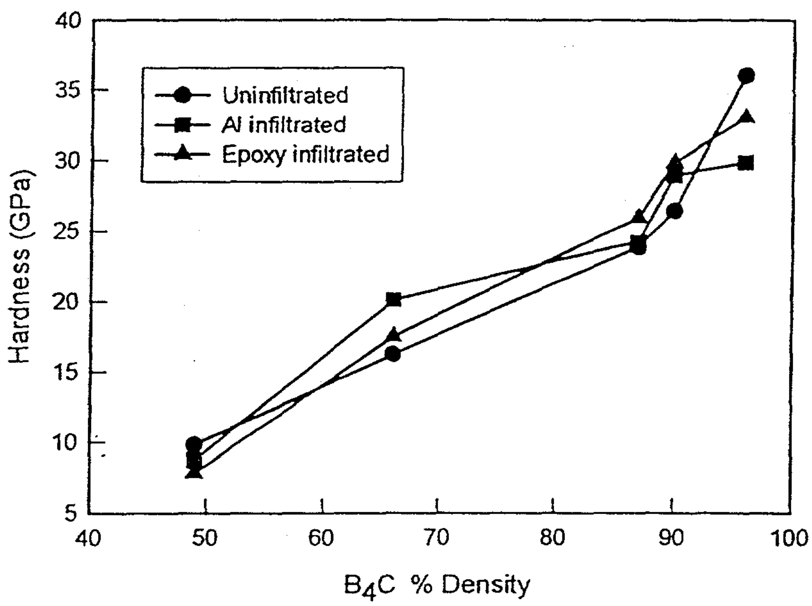


Figure 4: Hardness versus B_4C density for uninfiltrated, aluminum infiltrated, and epoxy infiltrated condition.

The hardness is little affected by infiltration with either the aluminum or the epoxy. This indicates that the B_4C is the only phase controlling the hardness, since it is much harder than either the aluminum or the epoxy. The hardness of 49% dense B_4C is approximately 10 GPa, while that of 96% dense B_4C is approximately 30-35 GPa.

REFERENCES

1. F. Thevenot, "Boron Carbide-A Comprehensive Review", J. European Ceram. Soc., 6, 205-225 (1990).

2. D.C. Halverson, A.J. Pyzik, I.A. Aksay, and W.E. Snowden, "Processing of Boron Carbide-Aluminum Composites", J. Am. Ceram. Soc., 72, 775-780 (1989).

3. D. Hemphill, Los Alamos National Laboratory, private communication.

4. S.L. Dole and S. Prochazka, "Densification and Microstructure Development in Boron Carbide", Proceedings, January 1985 American Ceramic Society Cocoa Beach Meeting, Cocoa Beach, Florida.

5. U.S. Patent No. 3,124,625, H. Sheinberg, J.R. Armstrong, and D.H. Schell, Los Alamos National Laboratory, 10 March 1964.

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