PII: S0272-8842(96)00014-4

Ceramics International 23 (1997) 149–152

0272-8842/97 $17.00+.00

The Fabrication of Boron Carbide–Aluminium Composites by Explosive Consolidation

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(Received 13 September 1995; accepted 28 November 1995)

Abstract: The technique of explosive consolidation was used to prepare cermets of boron carbide with aluminium and 7075 aluminium alloy. Compacts were produced by application of 10–12 GPa pressure which was induced by explosive detonation. The compacts obtained exhibit high hardness-increasing with an increase in the boron-carbide content, integrity and close to theorical density. Hardness, fracture toughness and flexural strengths of the composites produced indicate extensive shock hardening of the metal (or alloy) matrix during consolidation. © 1997 Elsevier Science Limited and Techna S.r.l.

1 INTRODUCTION

Composites of boron and aluminium offer the attractive combinations of high hardness and toughness in a lightweight structure and have potential for a variety of engineering applications. Their fabrication techniques which retain the key engineering properties of the components therefore assume significance. Compactness by explosive consolidation is an important technique in this context.[1] Explosive consolidation involves the use of detonation-induced shock waves travelling through an encased powder (or mixture of powders) to bring about their densification into a monolithic solid piece. Explosive consolidation of powder has unique advantages over static compaction and subsequent heat treatment.[1,2] They include: (i) possibility of achieving densities approaching theoretical levels without the need for subsequent heat treatment; (ii) elevated temperature compaction for grain size tailoring or synthesis of a compound or alloy from the elemental components; (iii) removal of stoichiometry limitations leading to the formation of unique alloy compositions with special properties; and (iv) possibility of tailoring detonation induced pressure and temperature to introduce or to totally abviate reaction within the constituent powders. Among these many features of explosive consolidation, high density and no reactivity were desired in the production of boron carbide–aluminium composites.

2 EXPERIMENTAL

The starting materials used were boron carbide (98% B_4C and 2% C, approximately 50 μm in size) and either pure aluminium (99.8% Al, commercial powder; approximately 50 μm in size) or 7075 aluminium alloy (5.5% Zn, 2.5% Mg and 1.5% Cu, atomized, approximately 50 μm in size). The B_4C contents of the composites were 30, 50 and 80 volume percent in the aluminium matrix, and 0, 40 and 60 volume percent in the 7075 aluminium alloy matrix. The consolidations were made in axisymmetric assemblies[2] with the application of 10–12 GPa pressure. The basic requirements for the axisymmetric consolidation are a metal container to hold the powder mixture to be compacted surrounded by explosive utilized for the intended pressurization. A metal container having diameter of 5 cm, height of 20 cm and thickness of 0.6 cm was used in experiments. The outer part containing explosive was 30 cm in diameter and 50 cm in height. Detonation of explosive results in a shock wave travelling down the length of metal tube and the consequent consolidation of the powder mixture by kinetic energy imparted by the shrinking container. Composite samples (1×4×0.5 cm dimension) thus obtained were characterized by microhardness, three point bend testing for flexural strength and fracture toughness and density measurements. The force applied on samples in three point bending tests were in the direction of shock propagation. Densities were measured hydrostatically, with a Sartorius 6080 balance.

3 RESULTS AND DISCUSSIONS

All data relating to the present experiments are summarized in Table 1. Four sets of experiments were conducted, three with pure aluminium as the matrix of the composite and in the fourth one the 7075 aluminium alloy was used.

The density of all consolidated samples is quite good and the tendency exhibited is a decrease with increase in ceramic content. Although this decrease is not extensive, it is a consistent behaviour for all sets of experiments performed. The trend results from the possibility that in these cold compaction experiments (ambient temperature) the ceramic (B_4C) did not, as would be expected, exhibit any plastic flow that is required for mechanical attachment. Thus, the higher the ceramic content, the lower was the amount of flow obtained for fuller densification.

Explosive consolidation occurs with the radial pressure waves, produced by the detonating explosive, introducing a densification based on an initial jetting that cleans the particle surfaces from adhered impurities (e.g. oxides) followed by joint mechanical flow of material on particle surfaces that afford the mechanical locking. No melting is necessary and thus this is the only means of achieving powder based compacts wherein no diffusion takes place (when done at ambient temperature and detonation geometry tailored for this purpose). In the present system, diffusion would have lead to brittle aluminium carbide formation at the B_4C/aluminium interfaces and a mechanical polish would have easily torn the B_4C particles

Table 1. Experimental data on the fabrication of aluminium–boron carbide compacts by explosive consolidation

Run no.	Composition (vol%)		Theoretical density (%)	Hardness Rockwell B	Flexure strength (MPa)	Fracture toughness (MPa $m^{1/2}$)
	B_4C	Al				
1	30	70	97.4	66.5	1.251	0.940
	50	50	94.0	82.7	1.225	0.664
	80	20	86.1	90.2	0.926	0.413
2	30	70	97.4	65.6	1.470	0.630
	50	50	93.2	78.8	1.452	0.628
	80	20	87.2	96.3	0.326	0.111
3	30	70	98.6	75.7	4.596	1.928
	50	50	93.9	79.1	3.042	1.399
	70	30	90.6	92.4	1.544	0.633
4	00	100*	99.8	32.5	15.215	7.991
	40	60*	94.6	92.3	9.756	0.324
	60	40*	88.6	99.1	0.378	0.268

*Al 7075.

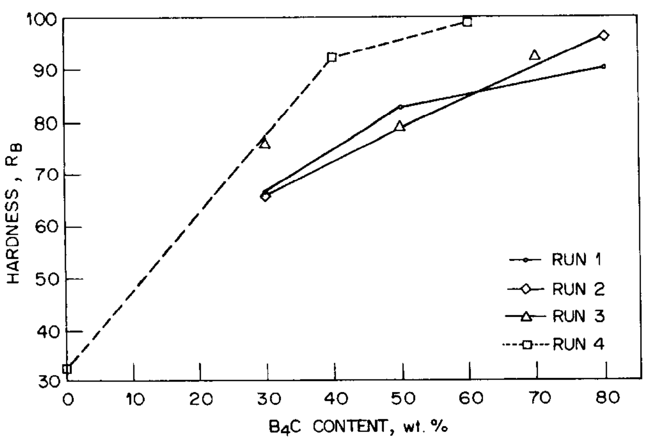

Fig. 1. Hardness as a function of boron carbide content in consolidated composites.

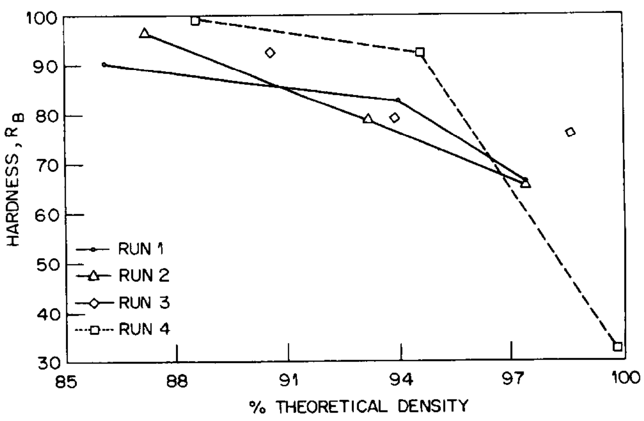

Fig. 2. Hardness as a function of density of compacts.

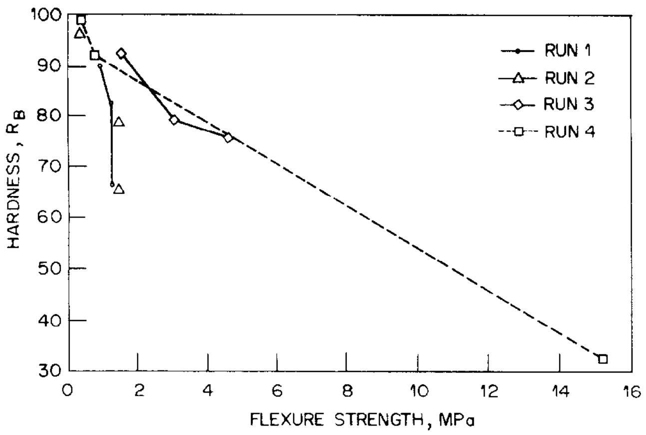

Fig. 3. The relation between hardness and flexure strength of compacts.

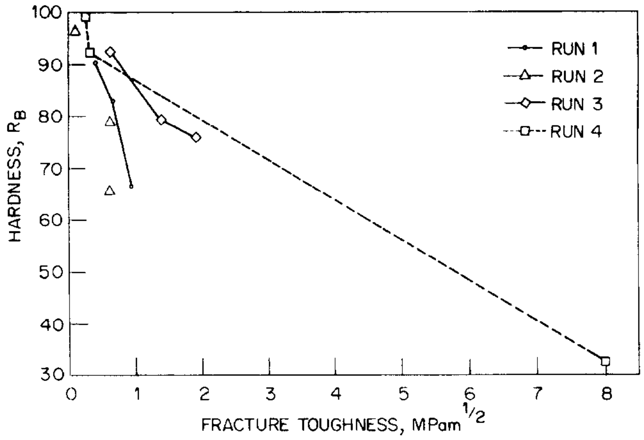

Fig. 4. The relation between hardness and fracture toughness of compacts.

from that surface. On the other hand, it was observed that the ceramic particles are sufficiently well attached to afford cutting through the B_4C particle without dislocating it from the aluminium matrix.

The consistency of values obtained in the densities is repeated, in all four sets of experiments, in the Rockwell B hardness values. Composites containing B_4C powder in the 7075 aluminium alloy matrix exhibit consistently higher hardness values, as would be expected.

The embrittling effect of the increased ceramic content is reflected in the flexure strength values listed in Table 1. A variation exists in the flexural strength between experimental sets 1 and 2 and the values in sets 3 and 4. This possibly results from the fact that an explosion of slower detonation velocity ($V_D = 3400$ m/s) was used in sets 3 and 4, whereas in sets 1 and 2 a faster explosive ($V_D = 6800$ m/s) was used. The faster explosives could have caused microcracking, not visible to SEM scrutiny. This possibility is quite evident in the fracture toughness values listed in the last column of Table 1.

The fracture strength and fracture toughness values could not be compared to those obtained for products of conventional processing since no work on B_4C/aluminium cermets could be found in the open literature. Comparison to SiC/aluminium cermet processing[3] reveals the existence of extensive shock hardening in the present samples.

The correlation of the various parameters in terms of each other and in terms of the B_4C content of the composite are presented in Figs 1–4. The increase in hardness with B_4C content in each set of the composites consolidated is given in Fig. 1. It may be seen from Fig. 2 that a distribution of hardness based on the density of compactness is difficult to make in the present case, as all compacts had high density and the differences from one set to another are minimal. Figure 3 shows hardness plotted against flexural strength and, as indicated earlier, higher hardness, in each set, corresponded to lower flexure strength. This also holds good in Fig. 4, where a plot of hardness values against fracture toughness is shown. The higher hardness values lead to a reduction in toughness, both conforming to the embrittlement of composition with increased B_4C content.

4 CONCLUSIONS

Explosive compaction can be used to produce metal/ceramic composites that exhibit integrity, high density and no reactivity between the constituent powders.

In the B_4C/aluminium compacts prepared by explosive compaction, increased ceramic content leads to higher hardness, lower percent theoretical density, lower flexure strength and fracture toughness. There is a good attachment between the ceramic and metal matrix, a uniform distribution of the ceramic and no microcracking.

ACKNOWLEDGEMENTS

The authors are grateful to Professor O. T. Inal (NM Tech, Socorro, NM, USA) for help in explosive consolidations. The project was supported by UNIDO through the IHRD branch.

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