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The fabrication of boron carbide compacts by explosive consolidation

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The fabrication of boron carbide compacts by explosive consolidation

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Abstract. This paper presents experiments on explosive compaction of boron carbide powder and modeling of the stress state behind the shock front at shock loading. The aim of this study was to obtain a durable low-porosity compact sample. The explosive compaction technology is used in this problem because the boron carbide is an extremely hard and refractory material. Therefore, its compaction by traditional methods requires special equipment and considerable expenses.

1. Introduction

Boron carbide (B_4C) is the most preferable material for many high technology manufacturing applications due to the unique combination of its properties such as high hardness, low density, high melting point, high Young's modulus, chemical inertness, high neutron capture cross-section, and superior thermoelectric properties. Boron carbide (also known as the black diamond) is the third hardest material after diamond and cubic boron nitride. Its high hardness makes it suitable material for the abrasive powder used for grinding, polishing and water jet cutting of metals and ceramic materials. Therefore, study of the conditions for obtaining strong low porosity compacts based on boron carbide is an urgent task.

2. Experimental study of the structure of compacts

There were used two schemes of explosive loading: plane wave one (figure 1) and one of the powder compaction in an oblique shock wave (figure 2). The experiments employed boron carbide powder with a grain size of 60 μm and a bulk density of 1.3 g/cm^3.

In the scheme of the plane shock loading, impactor 5 (figure 1), which is a steel plate 2 mm thick, was thrown under the influence of detonation products of the explosive (RDX) onto the surface of the container with the powder. The parameters of throwing the plate and shock pressure in the powder were calculated according to [1, 2]. In this scheme, the pressure behind the shock front in the powder was estimated as 11 ± 1 GPa. After loading, the sample was sintered at a temperature 1000 °C for 3 hours. Then, the structure of the sample was studied with scanning electron microscope LEO-420. Structural studies have shown that the samples obtained by the method described above contain macrocracks and consist of particles of boron carbide with size of 1 mm (figure 3). This result can be explained by the fact that after passage

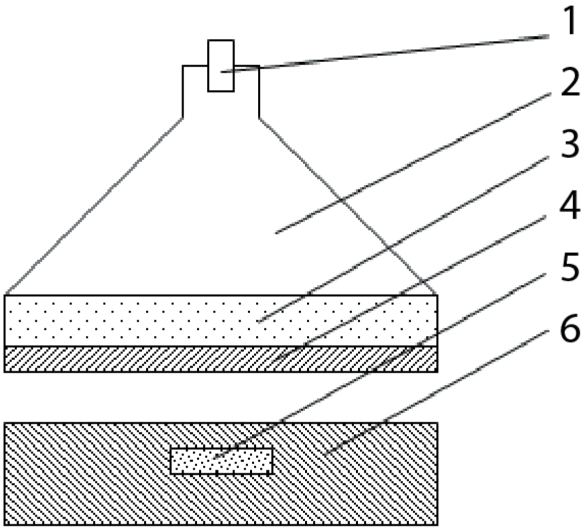

Figure 1. Scheme of the plane shock loading. 1—detonator, 2—plane wave generator, 3—explosive, 4—impactor, 5—copper container with the powder, 6—container.

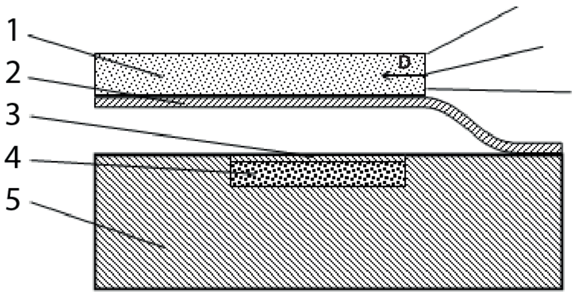

Figure 2. Scheme of the oblique shock wave. 1—explosive, 2—thrown plate, 3—cover; 4—powder, 5—container.

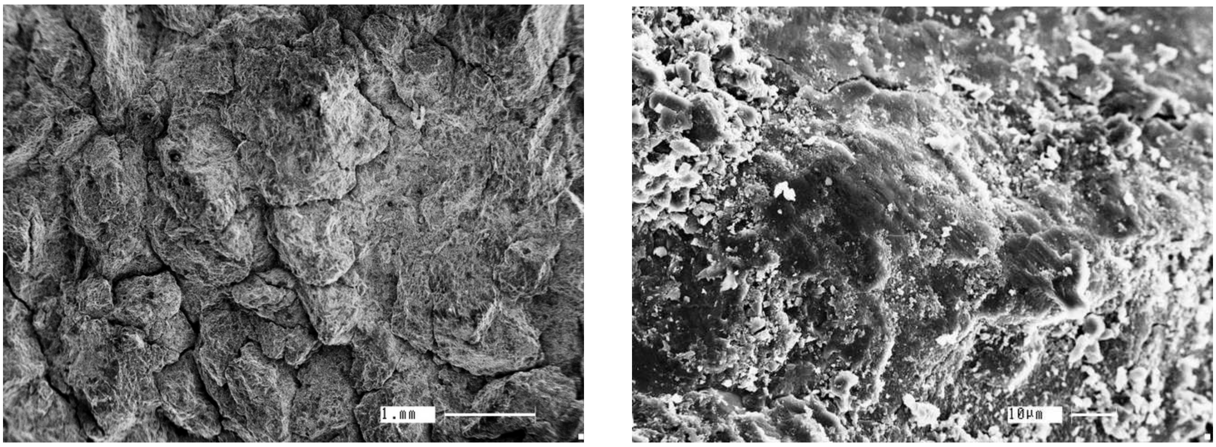

Figure 3. Structure of the compact after the plane shock loading.

of the shock wave, the powder is compacted, but the bond between the particles does not occur. Therefore, there is a destruction of the sample into fragments under the influence of tensile stresses in the decompression wave, and the subsequent sintering does not form a monolithic sample.

At the compaction in the scheme with oblique shock wave (figure 2) the powder were contained in a cavity between steel plates. By detonating the explosive, shock waves were generated in the metal plate 2 mm thick and transmitted to the powder, thereby compacting it. The explosive was ammonite, thickness of the charge was 20 mm, and the detonation velocity was 3200 ± 100 m/s. The pressure in the powder of boron carbide in this scheme was ≈ 2.5 GPa. In this arrangement, pressing the powder occurs during the passage of oblique shock wave and is characterized by larger values of the shear deformation as compared to the plane shock loading, which leads to

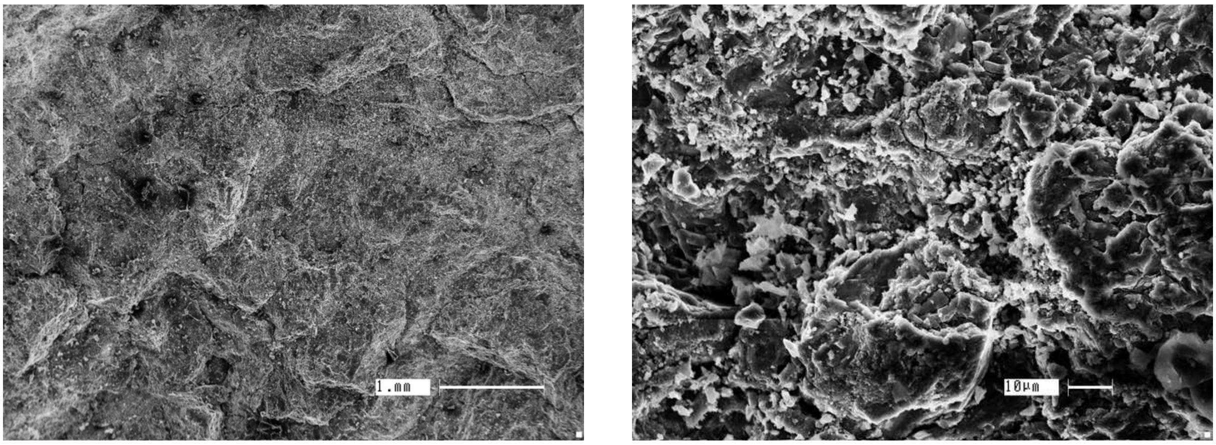

Figure 4. Structure of the compact after compaction in oblique shock wave.

improved bond between the compacted particles, as well as allows one to save the compacted material from breaking in the unloading wave. However, the pressure in the powder of boron carbide in this scheme is insufficient for its pressing to a density of the monolith. Moreover, after loading, the samples had no mechanical strength. After the explosive loading, the sample was also sintered for 3 hours at temperature 1000 °C. The density of the sample after the heat treatment was 2.05 ± 0.05 g/cm^3 ($\approx 80\%$ of the monolith). The microstructure of the compact is shown in figure 4.

Comparison of structures of the compacts obtained by the different schemes (figures 3 and 4) shows that the sample compressed in oblique shock wave has more pores, but fewer defects on the macro level. Figure 4 shows that during the compaction, the particles of boron carbide are crushed, and the powder is thereby compacted. Bonds between the particles occur only during sintering.

3. The calculation results and discussion

For the numerical simulation of the propagation of shock waves, a complete system of equations of deformation of the porous elastic-plastic material was solved [3]. The methods of numerical modeling of explosive loading of porous materials are described in detail in [4, 5]. In this paper, we used the few-parameter equation of state adequately describing the physics of collision at high pressures and temperatures [6–8], which made it possible to carry out calculations of shock-wave processes with a minimal number of physical parameters as the initial data. The geometrical dimensions and the values of the physical parameters correspond to the experimental data mentioned above.

With the results obtained in [6, 7] the Hugoniot for boron carbide have been constructed (figure 5). The presented comparison of the results obtained in this study with known experimental data [9–16] shows that the error in calculating of the parameters of the Hugoniot does not exceed 5–10%.

Joint theoretical and experimental studies have allowed to implement an approach that uses mathematical and physical simulation of shock-wave loading of powdered materials. The Hugoniot of the boron carbide has been constructed. Thus, using the technology of explosive compaction, compact samples of boron carbide are obtained. On the basis of experimental and numerical studies of shock waves propagation, the optimum parameters of dynamic compaction of boron carbide are determined in order to maximize the density and the conservation of the ready samples after loading.

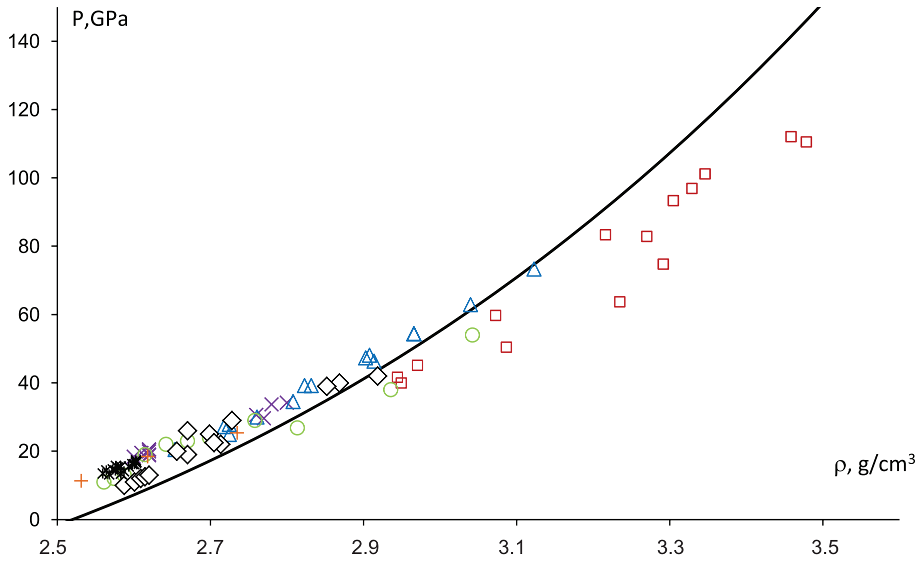

Figure 5. The Hugoniot for boron carbide. Experimental data: ◊—[9], ○—[10, 11], □—[12], ×—[13], △—[14], +—[15], ∗—[16].

Acknowledgments
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