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A possibility of using mechanical alloying for developing metal matrix composites with light-weight reinforcements

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Abstract

A new type of metal matrix composite (MMC) with light-weight reinforcements from 10 types of boron–hydrogen compounds was prepared using the method of mechanical alloying. The boron–hydrogen compounds had a decomposition temperature higher than 500 °C and a density of 1.3–2.5 g/cm^3. The initial size of particles was 50–500 μm. Aluminum and copper were used as the matrix materials. The reinforcements were 20–40 vol. % of the MMC. Mechanical alloying followed by compaction can yield a good-quality bulk material of reduced density.

Keywords: Metals; Mechanical alloying; Scanning electron microscopy (SEM)

1. Introduction

Reducing weight while preserving strength of materials is an important issue, as it allows for saving on energy costs. This is especially obvious in the automotive industry.

We developed a new composite material using boron–hydrogen or boron–halogen compounds [1,2] as reinforcing particles (density, 1.3 g/cm^3 up to 2.5 g/cm^3). A boron compound is a tetrahydro- or tetrahalogen–borate anion of the general formula $Cat_2B_nX_m$, where Cat is a metal cation or onium cation, B is boron, X is hydrogen or halogen, n = 10–12, m = 10–12, at m not greater than n. We studied the compounds whose decomposition temperature is higher than 500 °C.

2. Experimental procedure

Aluminum or copper was used for the matrix. The boron compounds were as follows: $Cs_2B_{10}H_{10}$, $[Me_2NH_2]_2B_{10}H_{10}$, $[Ph_4P]_2B_{10}H_{10}$, $[Et_3NH]_2B_{10}Cl_{10}$, $Cs_2B_{12}H_{12}$, $[Et_3NH]_2B_{12}H_{12}$, $[Bu_3NH]_2B_{12}H_{12}$, $[Bu_4N]_2B_{12}H_{12}$, $[Ph_4P]_2B_{12}H_{12}$ and $((C_2H_5)_3NH)[CuB_{10}H_{10}]$.

Composite materials were produced by mechanical alloying in a Gefest-11-3 planetary mill equipped with drums with quasi-cylindrical milling bodies. Energy efficiency of this mill reaches 10 kW/dm and exceeds that of gravitation ball mills by 2 or 3 orders of magnitude. The impact of large inertial forces on the milling bodies and treated material considerably reduces the milling time.

As the drums in this mill are intensively cooled and lubricated with flowing water, activation of processed material is considerably increased due to the slowdown of the recovery processes and inhibition of phase transformations.

Initial material for the matrix was chip scrap preliminarily ground for 2 min. The size of powders of the matrix alloys after preliminary grinding was 0.5–3 mm.

After preliminary grinding, portions of ground powders were prepared (160 g per drum) to produce dispersion-strengthened composite material. The portions were annealed in a vacuum drying chamber at a temperature of 110 °C to remove moisture. The reinforcing particles made up 10 to 20 vol. %.

Material was treated in a planetary mill in an argon atmosphere. For this treatment, the drums were pre-evacuated for 30 min to rule out the oxidation, and were filled with argon on a specially designed setup. The times of treatment of the powder mixtures in the planetary mill varied from 30 to 120 min.

Granules produced by mechanical alloying were compacted on a 40-tonne press, followed by heat treatment in a vacuum furnace.

3. Results and discussion

Material was studied both in the initial state and at all stages of treatment. The appearance of boron compounds is shown in

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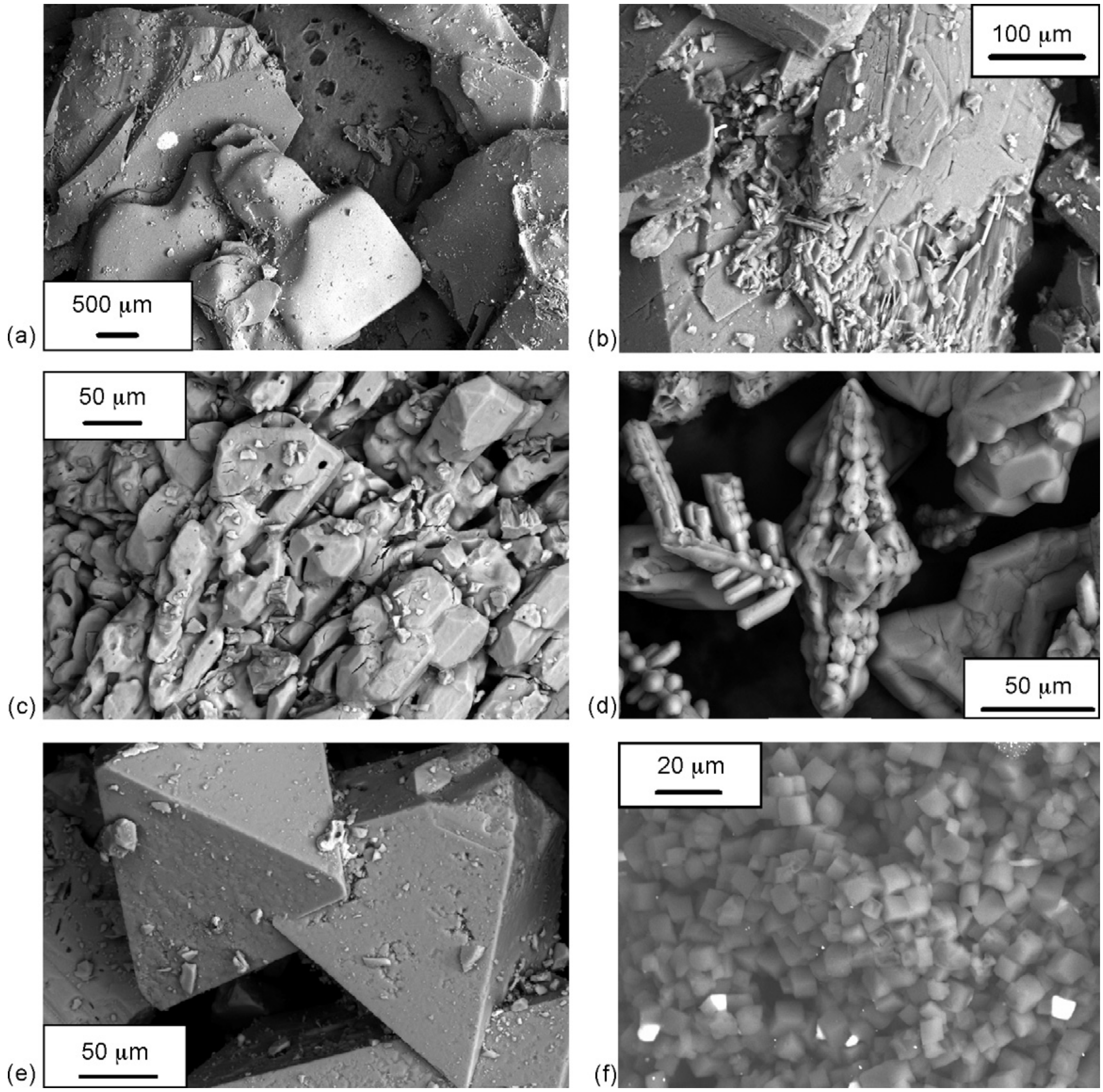

Fig. 1. Appearance of the boron compounds used: (a) $Cs_2B_{10}H_{10}$, (b) $[Me_2NH_2]_2B_{10}H_{10}$, (c) $[Ph_4P]_2B_{10}H_{10}$, (d) $[Et_3NH]_2B_{10}Cl_{10}$, (e) $Cs_2B_{12}H_{12}$, and (f) $[Et_3NH]_2B_{12}H_{12}$.

Fig. 1. Fig. 2 shows the shape of the appearance of the particles under a transmission electron microscope and presents characteristic electron diffraction patterns.

The figures show that the shape and size of boron compounds can be the most diverse, but they have one characteristic in common. All large crystals are not monolythic material, but consist of smaller particles. These fine particles were studied on a Nanoscan scanning probe microscope-nanoindenter to determine the properties of a particle on the nanoscale level [3]. The scanning window was 4.9 μm × 4.9 μm × 0.3 μm. Fig. 3 presents the testing results. It is seen that even fine particles are not homogeneous, and look rather like agglomerates of even finer particles.

To choose the mechanical alloying modes, one should know the hardness indices of the initial materials. The hardness of the initial materials was measured on a Nanoscan scanning probe microscope-indenter. The hardness of boron compounds was lower than that of the metal components. There is information in the literature on the mechanical alloying of materials with significant difference in the hardness of processed components [4].

Mechanical alloying was performed in accordance with the above method. The granules obtained were studied using a scanning microscope. The appearance of the granules is shown in Fig. 4. After their treatment in a planetary mill, the granules can have different shapes. Incorporation of boron compounds into the metal is made difficult owing to the fact that the hardness of the boron compound is smaller than that of the metal used. For better mixing, metal particles were used as chips but not as spherical particles. During the milling, the chips are comminuted and bent. In the process, particles of a boron compound get into the metal. However, in mill treatment up to 120 min, a large amount of the boron compound still remains on the surface of the metal particles. This complicates the process of com-

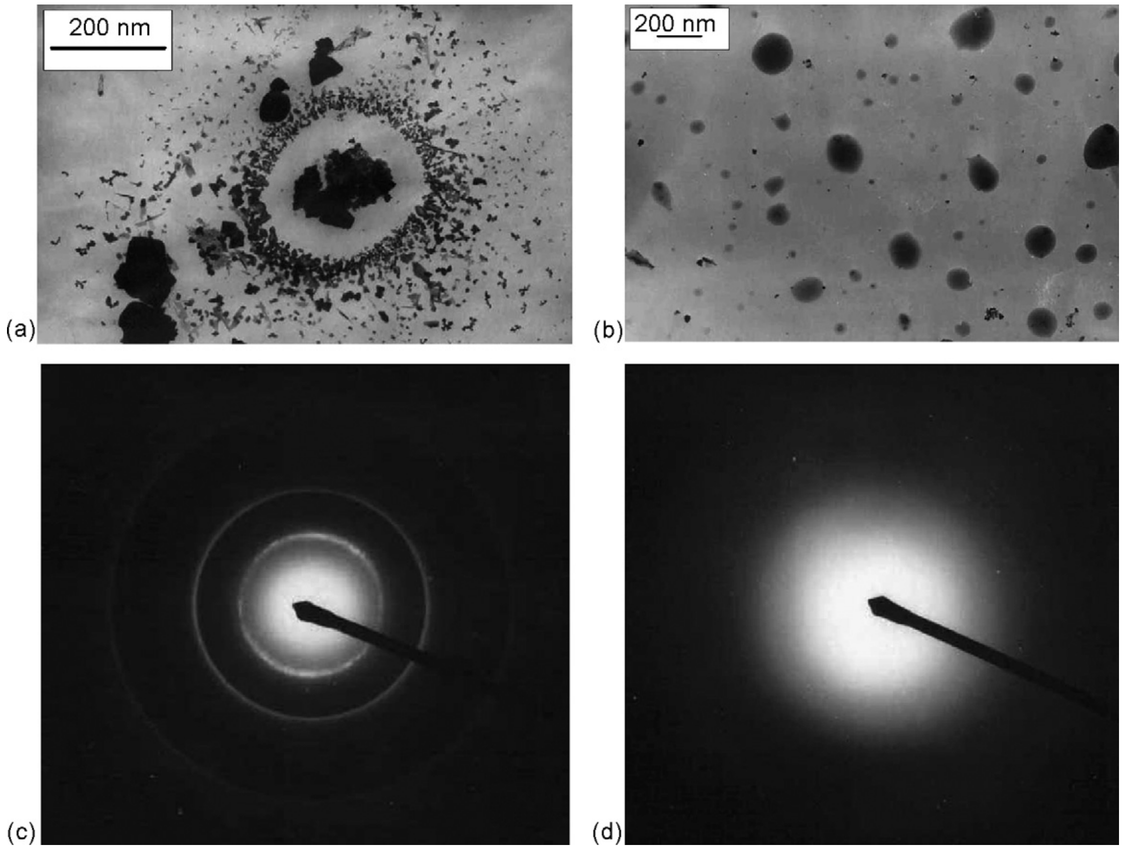

Fig. 2. Structure of the boron–hydrogen using a transmission microscope. (a) and (b) Appearance of particles of the boron-hydrogen compounds; (c) and (d) characteristic electron diffraction patterns. (a) $Cs_2B_{10}H_{10}$, (b) $Cs_2B_{12}H_{12}$, (c) $[Ph_4P]_2B_{12}H_{12}$, and (d) $[Bu_4N]_2B_{12}H_{12}$.

paction. Attempts at compacting the granules by cold pressing gave no positive results. Therefore, further studies were conducted with the view of: (1) improving the compaction process and (2) improving the mechanical alloying process in planetary mills.

Addition of some amount of powder from the matrix material and the use of special tools to increase the shearing deformations yielded a compacted material.

On the other hand, addition of some amount of hard particles of boron carbide or silicon carbide enabled a much better

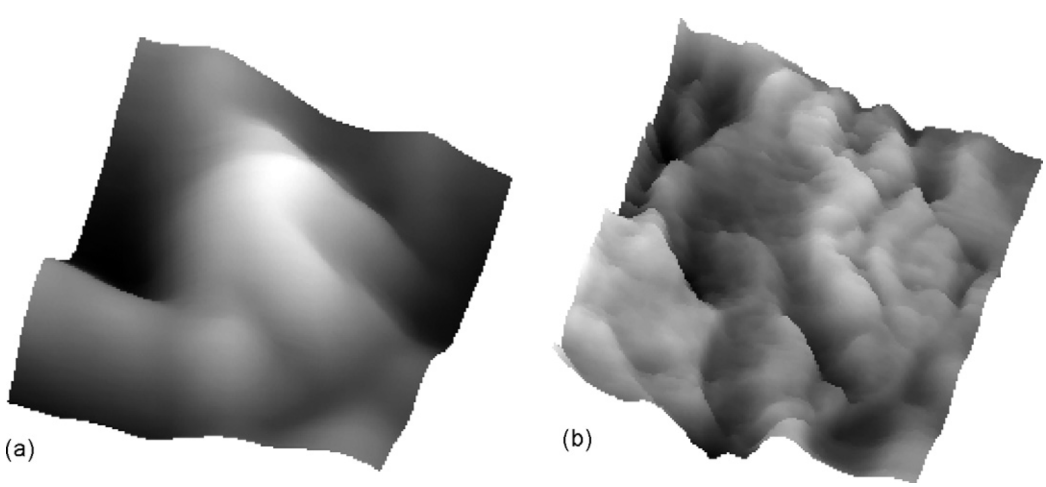

Fig. 3. Scanning a boron-compound particle on a Nanoscan setup: (a) surface relief and (b) elasticity modulus map. The scanning window is $4.9\ \mu m \times 4.9\ \mu m \times 0.3\ \mu m$.

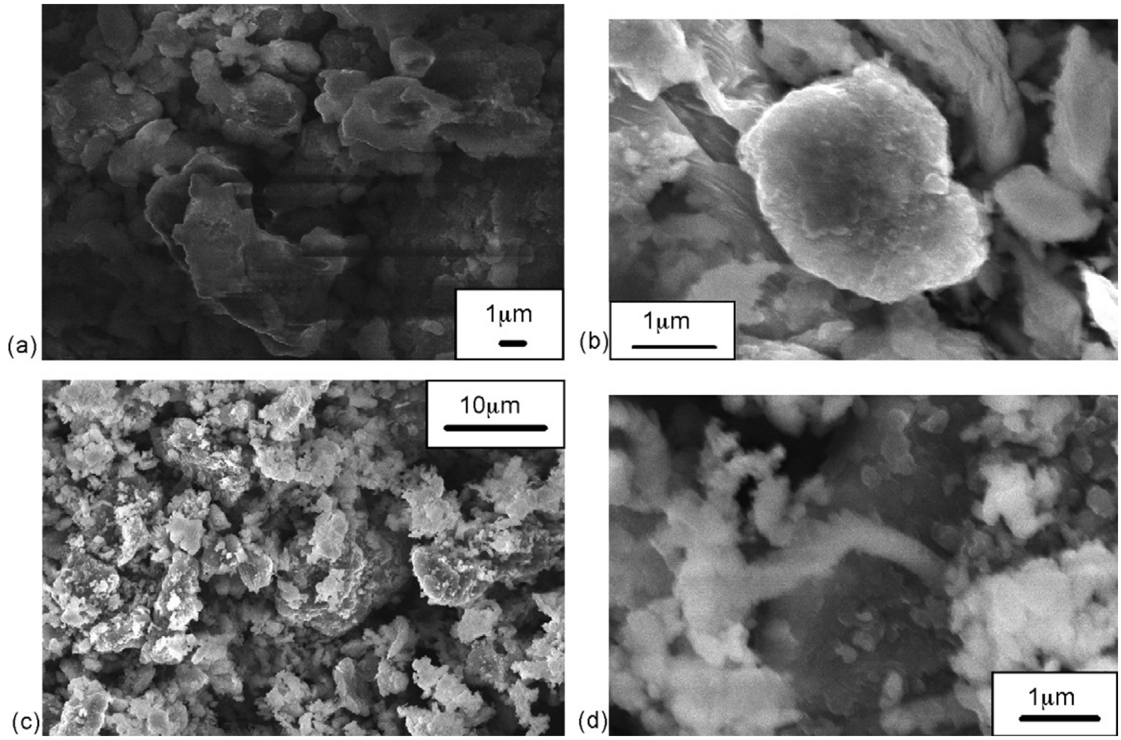

Fig. 4. Appearance of granules after mechanical alloying.

mixing of the composite components. This also contributed to compaction of the material.

4. Conclusion

We have studied the possibility of producing a composite material with reinforcing particles from boron compounds with density of 1.3 g/cm^3 up to 2.5 g/cm^3 for the case of mechanical alloying.

References

[1] E. Malinina, K. Zhizhin, L. Goeva, et al., Closo-Decaborate Anion as a Lidand in Complex of Copper(I), Euroboron II, France, Durham, 2001.
[2] K.Yu. Zhizhin, I.V. Dudenkov, K.A. Solntsev, et al., Russ. J. Inorg. Chem. 45 (12) (2000) 2016.
[3] V. Blank, M. Popov, N. Lvova, et al., J. Mater. Res. 12 (11) (1997) 3109.
[4] J. Kaneko, M. Sugamata, L. Blaz, R. Kamei, Mater. Sci. Forum 396–402 (2002) 161–166.