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One Stage Production of Superconducting MgB_2 and Hybrid Power Transmission Lines by the Hot Shock Wave Consolidation Technology

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Abstract

The rapid development of research of the conductors based on superconducting compound MgB_2 makes them a very real prospect for technical applications at temperatures below 30 K.

The technology of development superconductive materials belongs to traditional powder metallurgy: preparing and densification Mg–B powder blends in static conditions with their further sintering processes.

The application of shock wave consolidation technology to fabricate high dense MgB_2 billets with maximal critical temperature T_c = 40K was also used but required a sintering to be applied after a shock wave compression to fabricate high dense MgB_2 billets.

We applied the original hot shock-assisted consolidation method combining a high temperature with the two-stage explosive process without any further sintering which produced superconducting materials with high density and integrity. The consolidation of MgB_2 billets was made at temperatures above the melting point of Mg up to 1000ºC in partially liquid condition of Mg-B blend powders. The influence of isotope B composition on critical temperature and superconductive properties was evaluated as well as the first successful application of this method for production of hybrid power transmission lines for simultaneous transport of hydrogen and electric energy was demonstrated.

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Keywords: superconducting MgB_2, shock-wave consolidation, B isotopes, hybrid energy lines

INTRODUCTION

The rapid development of research of the conductors based on superconducting compound MgB_2 makes them a very real prospect for technical applications at temperatures below 30 K.

Reported achievements of all higher values of the critical current density in wires and tapes at moderate magnetic fields [1,2] lay out a strong hope that soon these conductors may be more economical at helium temperatures than industrial wires and cables based on NbTi and Nb_3Sn.

In the field of applied superconductivity, at temperatures 20–30 K MgB_2 based conductors may seriously push out industrial tape-based high-temperature superconductor (HTSC) materials.

Main way for getting of MgB_2 is a solid-phase synthesis in particular modifications. As example, one of quite fruitful ones is the synthesis under high pressure [3]. As HTSC ceramics, compound MgB_2 is brittle and therefore cannot be directly manufactured in the form of wire or ribbon. The most widely used method now to manufacture conductors based on MgB_2 (as for HTSC ceramics) is the method "powder-in-tube" (PIT) [4]. It is mainly used in two ways: in situ and ex situ. In the in situ PIT method, thoroughly mixed stoichiometric mixture of magnesium and boron powders are pressed into a metallic tube, after which it runs into the wire. Superconducting core of MgB_2 wire is a final result of wire annealing in temperature range, usually, 600-950ºC. In ex situ PIT method, in contrast, a metal tube filled with already provisionally synthesized compound MgB_2 is stretched into the wire. Both options have their advantages and disadvantages.

In work [5], a novel method of photostimulated solid-state synthesis of oxide materials was developed enabling a dramatic increase of the solid-state reaction speed. The rate of solid-state reaction appears to be approximately two orders of magnitude higher compared with ordinary high-temperature solid-state reaction performed in furnace. Experimental results given in [5] provide evidence of the photostimulated nature of performed solid-state reaction and demonstrate the possibility of production of HTSC and CMR oxides by of light that is usually limited by the sample thickness, one could expect that this method could be particularly effective in the preparation of oxide films having a high-technological importance.

The [6] paper presents first results of investigation of properties of superconducting MgB_2 samples, obtained by hot explosive compaction (HEC) method. By this method, similar effect for increasing the speed of solid-state reaction as in case of using the photostimulated solid-state synthesis was obtained. Besides it, due to the high penetrating capability of shock-waves generated by explosion with intensity of compression 10 GPa, this method allows one to fabricate bulk, high-density and long-body cylindrical billets with length near to 200 mm and diameter up to 30 mm. The HECs of cylindrical billets were conducted using half-automatic explosive device created at the Tsulukidze Institute of Mining allowing one to consolidate different composition precursors near the theoretical density within the temperature range 20-1200ºC and with intensity of loading 5-10 GPa.

The described HEC method also allows one to produce multilayer cylindrical tubes (pipes) when gap between the two metallic layers (e.g., Cu) is filled by superconducting MgB_2 composites which could find important applications for production of superconducting cables for simultaneous transport of hydrogen and electrical power in hybrid MgB_2 based electric power transmission lines filled with liquid hydrogen [7].

In this work we present new results on the influence of isotope B composition on critical temperature and superconductive properties of consolidated MgB_2 billets. Besides it, the first successful application of this method for production of hybrid power transmission lines for simultaneous transport of hydrogen and electric energy was demonstrated.

EXPERIMENTAL RESULTS AND THEIR DISCUSSION

The novelty of proposed nonconventional approach relies on the fact that the consolidation of solid high-dense, long-body cylindrical MgB_2 billets from submicrometer-sized Mg and B powder blends is performed in two stages:

1. At the first stage, a preliminary explosive compression of the precursors is carried out at room temperature with a loading intensity of 5-10 GPa to increase the initial density and to activate surfaces in the powder blend.

2. At the second stage, the same already predensified cylindrical sample is reloaded by a primary explosive shock wave with a loading intensity of 10 GPa, but at temperatures about 1000ºC.

The experimental set-up is presented in Fig.1.

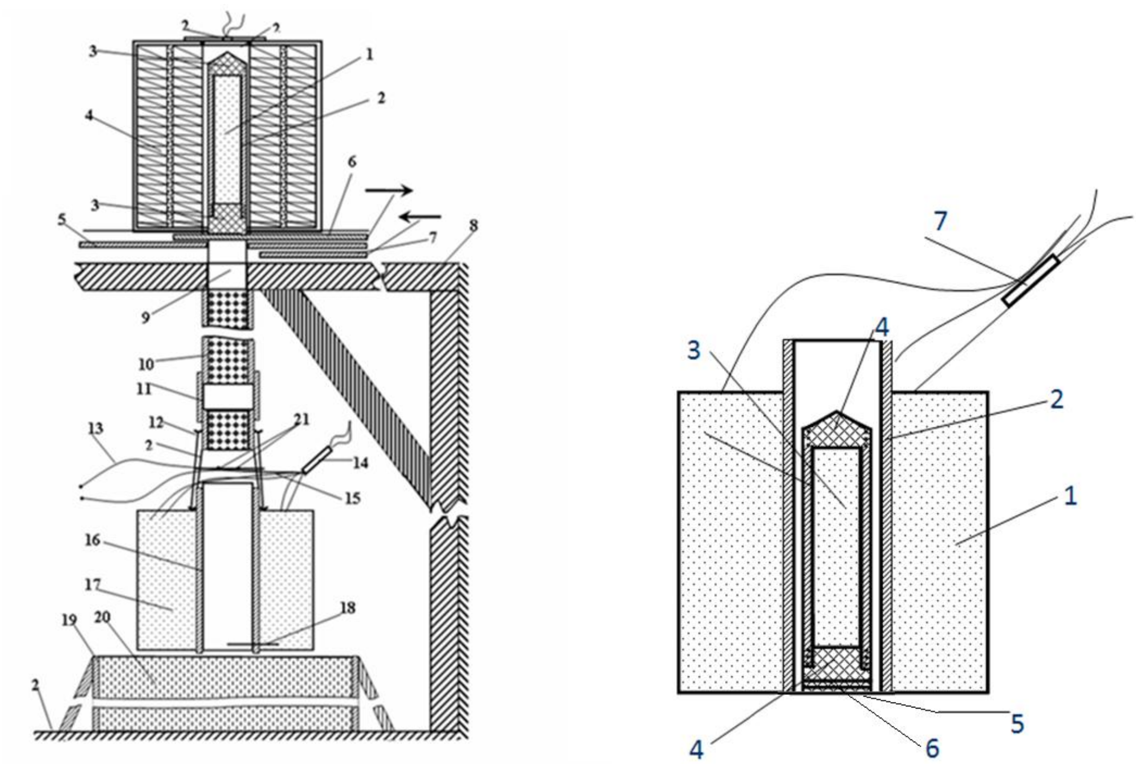

Figure 1: Set-up of HEC device.

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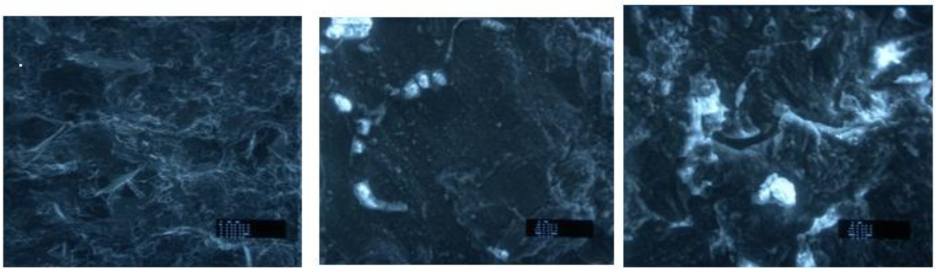
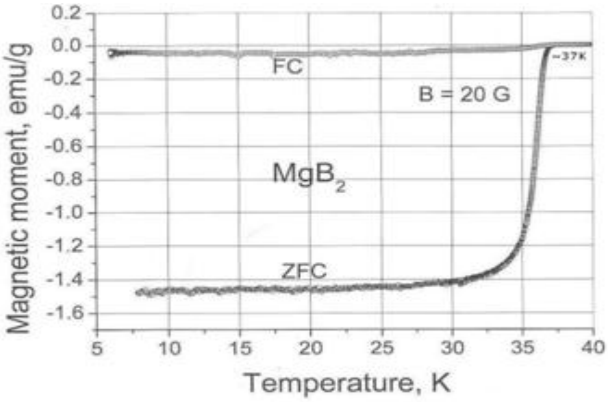
1. consolidating powder material; 2. Cylindrical Steel container, 3. Plugs of steel container, 4. Heating wires of furnace, 5. Opening and closing movement of furnace, 6. Opening sheet of furnace, 7. Closing sheet of furnace, 8. Basic construction of HEC device, 9. Feeding steel tube for samples. 10. Movement tube for heated container, 11. Connecting tube from rub, 12. Accessory for fixing explosive charge, 13. Circle fixing passing of steel container. 14. El. Detonator, 15. Detonating cord, 16. Flying tube for HEC, 17. Explosive charge, 18. Lowest level of steel container, 19.Bottom fixing and stopping steel container, 20. Send.

The first successful HEC of Mg-B powder blends was performed at temperature 1000°C, with above the melting point of Mg phase at loading intensity 10 GPa providing critical temperature of superconductive transition T_c near 37 K, Fig. 2b.



(a)



(b)

Figure 2.a- Traces of oxidation are observed on the microstructures (light places). **b-** Magnetic moment temperature dependence measurements in zero-field-cooled (ZFC) and field-cooled (FC) modes, showing the superconducting transition at temperature near 37 K [6].

The mentioned confirms the important role of temperature in formation of superconductive MgB_2 phase in the whole volume of the sample and corresponds with literature data, where only after sintering processes above 900°C the formation of MgB_2 phase with T_c =40 K there took place. The difference of Tc between the HEC and sintered MgB_2 composites may be explained with a rest of nonreacted Mg and B phases or existing of some oxides in precursors Fig. 2a.

The mentioned could be checked by increasing HEC temperature or application of further sintering processes. The careful selection of initial Mg and B phases is important too and in case of consolidation Mg-B precursors with the abovementioned corrections the chance to increase T_c in the HEC samples essentially increases.

In Fig. 3, the views of MgB_2 billets in steel jackets after the previous densification (Fig. 4a) and after the HEC procedure (Fig. 3b) are shown.

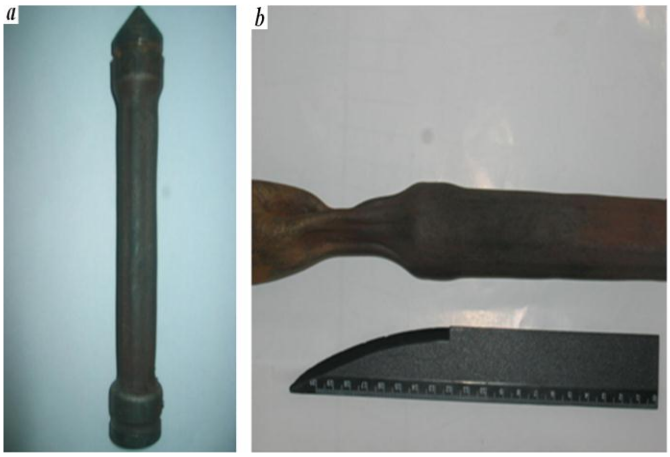


Figure 3: Views of billets before (**a)** and after the HEC procedure at 1000 ◦C and loading intensity 10 GPa (**b**)

In further experiments the application of pure Mg and crystalline and amorphous B powder blend prevented the formation of MgO in HEC billets and increased T_c of the obtained MgB_2 composites up to 38.5 K, Fig. 4, in case of pure amorphous boron powder without any post-sintering of obtained samples.

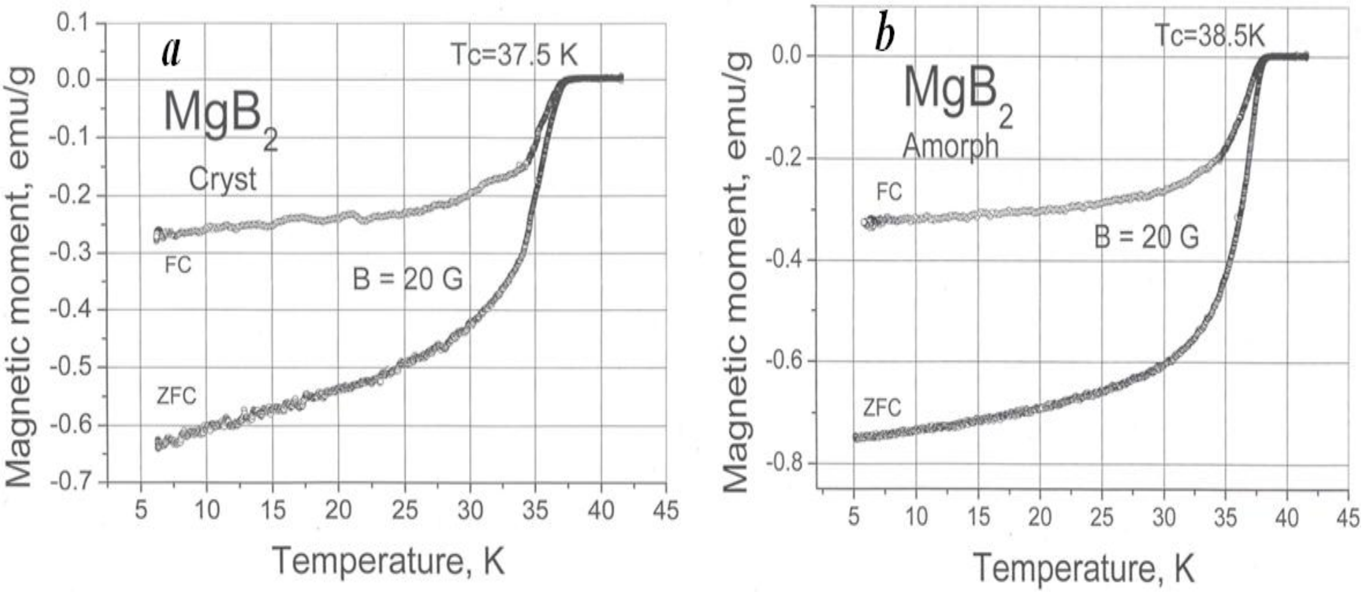


Figure 4: Temperature dependences of the zero-field cooled (ZFC) and field-cooled (FC) magnetic moment for HEC MgB2 composites at 1000 ◦C with intensity of loading 10 GPa in magnetic field 20 Oe

For these samples, traces of oxidation (light places) on microstructures were not observed (Fig. 5.)

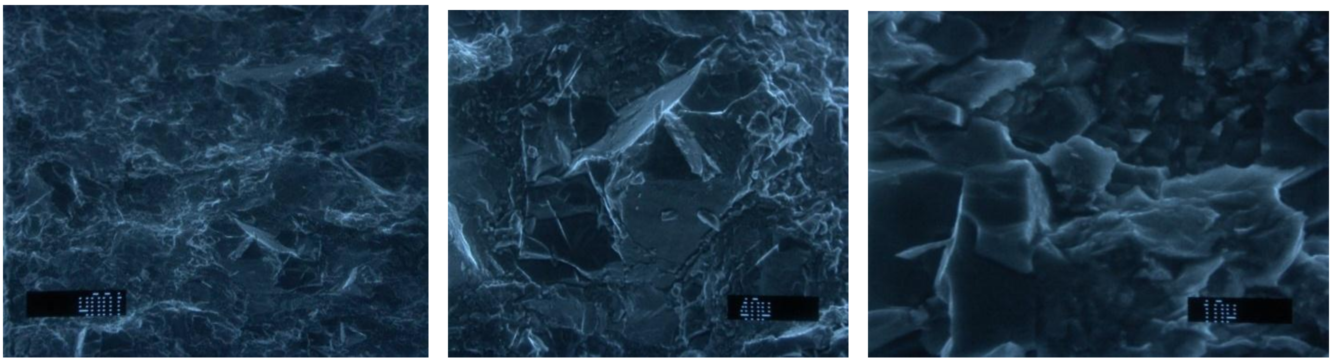


Figure 5: Microstructures of the HEC MgB_2 composites HEC at 1000◦C and loading intensity 10 GPa from pure Mg and B powder blends [6]

The experiments for HEC of precursors were performed under and above the melting point of Mg phase. The consolidation was carried out at 500, 700, 950, and 1000 ˚C temperatures with the loading intensity 10 GPa.

It was experimentally established that the comparatively low-temperature consolidations at 500˚C and 700˚C give no results and obtained compacts have no superconducting properties.

The application of higher temperatures and consolidation at 1000ºC provides formation of MgB_2 composition in the whole volume of HEC billets with maximal value T_c =38.5 K without and further sintering procedure and corresponds to literature with T_c =40 K takes place.

Fig. 6. show the influence of isotopic effect on superconductivity.

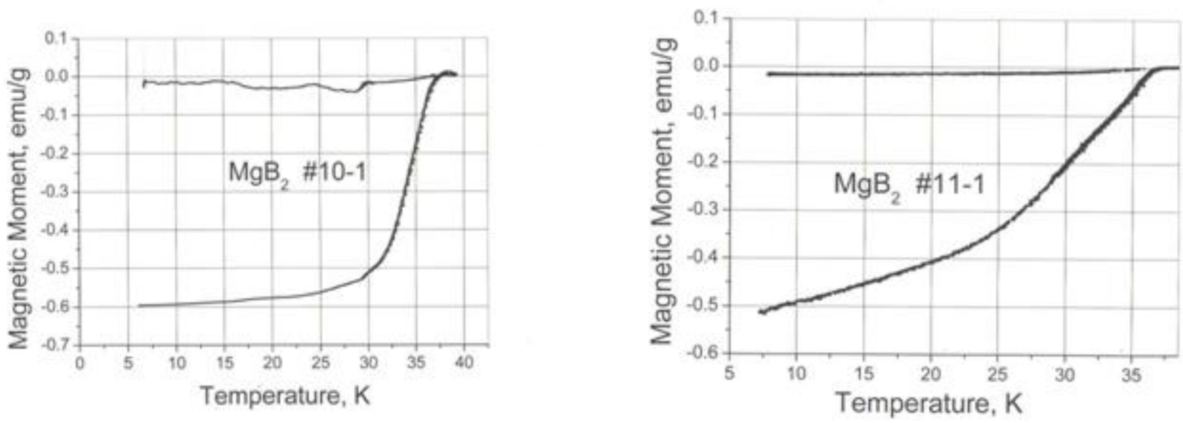


Figure 6: The influence of isotopic effect on superconductivity

The investigation of influence type of boron isotope onto the final superconductive characteristics of magnesium diborides (MgB_2) after the HEC at 1000ºC shows that in contrast to ^{11}B isotope application of ^{10}B isotopes in Mg-B precursors provides increasing of critical temperature on 1K. Such difference may be explained by higher density of ^{10}B in contrast to ^{11}B.

And finally different types of superconducting Cu-MgB_2–Cu tubes for hybrid power transmission lines are demonstrated in Fig. 7.

Figure 7: Cu-MgB_2–Cu superconductive tubes

CONCLUSION

- The liquid phase HEC of Mg-B precursors under the 1000˚C temperature provides formation MgB2 phase in whole volume of billets with maximal Tc=38.5K
- The type of applied B powder has influence on final result of superconductive characteristics MgB2 and in case of amorphous B precursors better results is fixed (38.5K against 37.5K).
- The purity of precursors is important factor and existing of oxygen in the form oxidized phases in precursors leads to reducing Tc and uniformity of HEC billets.

- The isotopic modification of starting boron powders is important too and application of ^{10}B isotope in starting Mg-B precursors provides higher critical temperature in formed MgB_2 composites.

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