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RESEARCH ON PROPERTIES OF MULTI-CORE SUPERCONDUCTING WIRES MADE FROM MATERIALS BASED ON MAGNESIUM AND BORON (MgB_2)

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The article presents the results of laboratory research on the production of multi-core superconducting wires. Multicore wires containing boron and magnesium powders in a copper matrix were obtained in the drawing process combined with intermediate heat treatment. The wires contains powder cores were sintered under high isostatic pressure to produce the MgB_2 superconducting phase. The critical temperature for the composite's superconducting state was determined. The macrostructure and energy dispersion (EDX) analysis of multi-core wires was also presented.

Keywords: magnesium diboride, composite multi-core superconducting wires, sintering under high pressure conditions, drawing of powder composites, X-ray research

INTRODUCTION

The unique structural properties of MgB_2 related to the high critical temperature of transition to superconductivity (T_c = 39 K) along with high critical current densities (J_c > 100 A/mm^2) were the reason why it became a part of a modern superconducting materials from 2001 [1]. The compound is usually produced in-situ or ex-situ, however, in both cases extremely high chemical purity of substrates and appropriately selected matrix material in which the powder is placed is necessary to obtain wires with superconducting properties. The most popular technology of producing MgB_2 based wires is Powder In Tube method [2-4] which is obtained by placing fine powder in-situ or ex-situ in a tubular metal matrix. The wire being a result of a deformation process is being subjected to heat treatment which synthesizes magnesium and boron into MgB_2 phase in-situ and in the case of ex-situ method combine the grains of the ground MgB_2 powder [5]. Local overheating of superconducting wires during operation may lead to transition the core into the state of normal conductivity. Electrical current while transferred rapidly generates heat which may damage the wire, thus the matrix of superconducting wires must produce low amounts of heat and be able to quickly remove it which is why the chosen materials are usually copper, Monel or GlideCop [6-9]. As magnesium and boron highly react with e.g. copper, when producing superconducting wires in-situ a protective barrier must be introduced between the powder core and the coating and since niobium is chemically inert to magnesium and boron it may be used. However, new technologies of superconducting wires manufacturing as a protective barrier between high quality Mg+B powder (in-situ) being the main superconductive phase after sintering and coating material (e.g. copper) use ground reacted MgB_2 phase powder (ex-situ) [8]. A small volume of ex-situ powder will create chemical compounds with the coating material, however, its much larger amount after sintering process shall show superconductivity.

EXPERIMENTAL DETAILS

The obtaining of superconducting core was based on an idea of two layers (in-situ and ex-situ) compositions of magnesium-boron powders in a copper coating as presented at Figure 1.

In the central wire part a high-quality powders of Mg and B of appropriate stoichiometry in the in-situ form were placed. Directly around the core in order to block reactivity of copper and magnesium ex-situ ground, reacted MgB_2 phase with the grain size of up to 20 mm was used. The outer layer was the copper matrix due to its high thermal and electrical conductivity. Inside of the copper tube of 28 mm diameter with a wall thickness of 5 mm a two layer charge was composed of Mg+B powders in two forms: the in-situ core (the main powder of the best quality used to form MgB_2 superconducting phase with high transmission parameters) and

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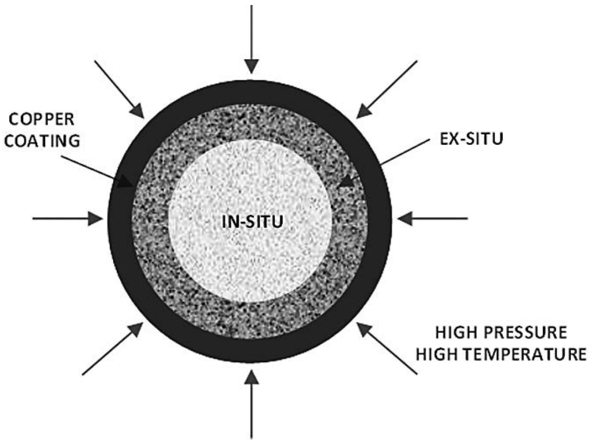

Figure 1 Two layer (in-situ and ex-situ) composition of Mg+B powders in a copper coating subjected to sintering and high pressure to obtain superconducting wire with MgB_2 phase

the ex-situ middle layer (a fine ground reacted powder containing MgB_2 phase) which shall function as a protective chemical barrier. The charge material for the drawing process was prepared in the moisture-free glov-box chamber with protective argon atmosphere and under reduced pressure. Wires with powder cores were produced with Powder In Tube method of drawing and compacting using a bench drawing machine with a constant elongation coefficient of 1,2. Throughout the process sintered carbide dies were used to diameter 3 mm and further polycrystalline diamond dies were used. The drawing process was conducted with intermediate annealing at 200 °C for 1 hour each 4 drawing operations in a protective atmosphere of argon in order to increase the ductility of the material. A single core wire with a diameter of 1,3 mm was used to produce a 6 wire composition with a central copper wire of the same diameter and placed in a copper tube of a diameter of 8 mm and wall thickness of 2 mm. The multi-core wire formed in this a way was further drawn in analogical conditions (constant elongation coefficient of 1,2) to a final diameter of 0,82 mm with intermediate annealing in corresponding conditions (200 °C, 1 hour, each 4 drawing operations with protective argon atmosphere) to increase the ductility of the wire. Further research was conducted on multi-core wires with diameter of 1 and 0,82 mm.

Sintering of the selected wires with powder cores under high isostatic pressure (HIP – Hot Isostatic Pressing) was the next stage of the conducted research. The wire samples were sintered at 680 °C under 800 MPa pressure with protective argon atmosphere. The purpose of sintering under high isostatic pressure was the increasing of its transmission properties of superconducting wires as the increase of phase density might significantly increase the electrical and mechanical properties resulting in multiplying the amount of critical wire current in comparison to the Mg + B synthesis at normal pressure. The transition to superconductivity temperature of MgB_2 was determined using 4-point contact method for measuring low resistances with external current source. The measurements were conducted on a single-core and 6-core wires of selected diameters. Microstructural analyses of the wires with superconducting cores using Olympus GX51 light microscope and Hitachi Su70 scanning electron microscope were conducted at selected manufacturing stages. What is more the chemical composition analysis at micro-areas of the obtained wires was performed.

RESULTS AND DISCUSSION

The influence of the temperature on the change in resistance of the tested materials for two electric current intensities (15 mA and 50 mA) was presented at Figure 3 and 4. The visible rapid decrease of electrical resistance of the selected wires was caused due to the reaching the state of superconductivity at the critical temperature T_c by the core material.

The collective results of critical temperature i.e. the transition to superconducting state temperature of the tested materials is presented in Table 1. Depending on the diameter and the current intensity the achievement of a superconducting state was observed in the tem-

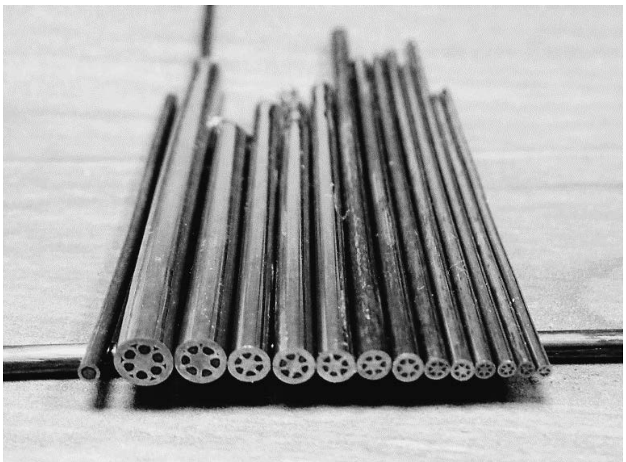

Figure 2 Samples of 6-core wires after various drawing operations

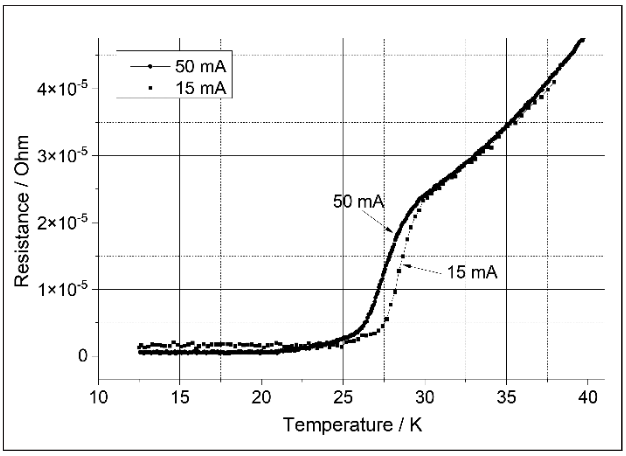

Figure 3 The influence of the temperature and electrical current intensity on the resistance of wire with 1 mm diameter

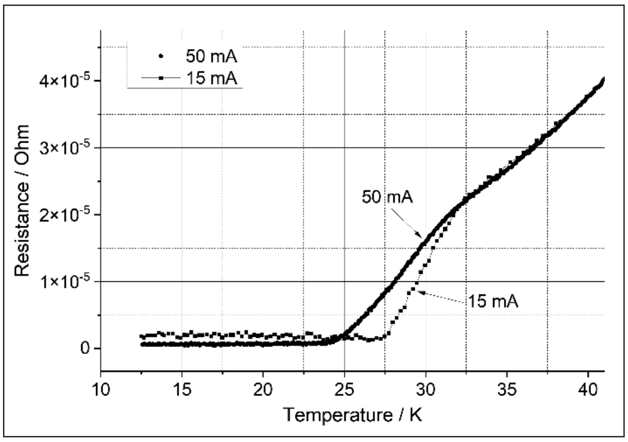

Figure 4 The influence of the temperature and electrical current intensity on the resistance of wire with 0,82 mm diameter

Table 1 **Critical temperature, i.e. transition to superconducting state measurements results**

Sample	Critical temperature value T_c, K	
	I=50 mA	I=15 mA
6-core wire; diameter 1 mm	25	26
6-core wire; diameter 0,82 mm	24	27

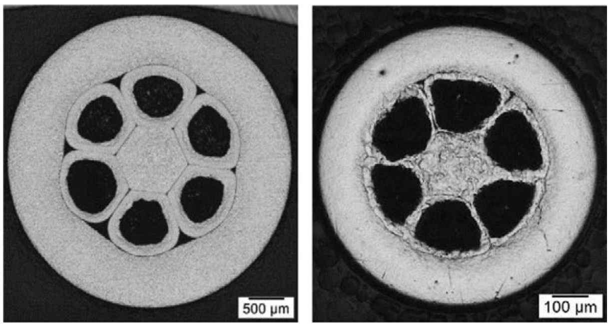

Figure 5 Macrostructure of the cross-section of a six-core wire: at initial compacting stage (left) and after the final stage of drawing for a diameter of 0,82 mm (right)

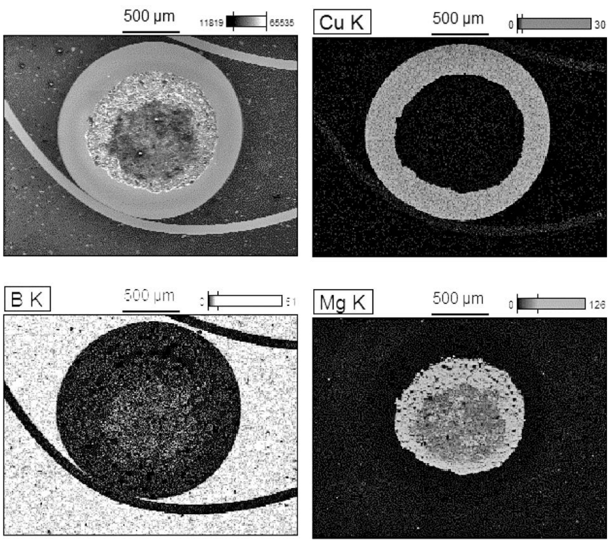

Figure 6 Energy dispersion (EDX) analysis of element distribution of a single-core MgB2 wire with a diameter of 1,3 mm

perature range of 24 - 27 K. A smoother course of the curve (Figure 4) may result from too intense thinning of the walls of individual inner wires (cores) or their possible local breakage. The macrostructure of the cross-section of a 6-core wire at the initial stage of wire compaction with a diameter of 1,3 mm and after final drawing operation at the diameter of 0,82 mm was presented at Figure 5. The significant thinning of the walls of the powder cores coatings is visible.

The EDX analysis of element distribution of the obtained wires was presented at Figure 6 - 7. The former shows the behaviour after the drawing process of a two-layer composition of in-situ and ex-situ Mg and B powders. The latter shows the element distribution among the single wire core after the sintering process in high isostatic pressure conditions with clearly visible areas of the MgB_2 phase obtained from in-situ powder and intermediate ex-situ protective layer.

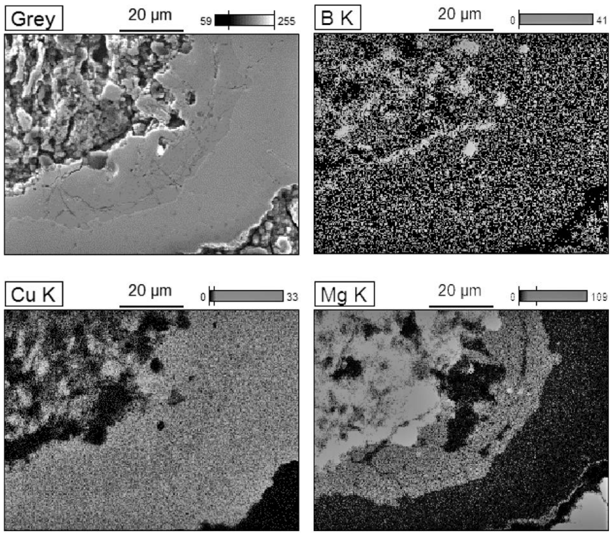

Figure 7 EDX analysis of element distribution of a 6-core MgB2 wire with a diameter of 0,82 mm

CONCLUSIONS

The conducted sintering process at high pressure conditions of multi-core wires made of Mg and B powders resulted in obtaining superconducting MgB_2 phase. The transition to superconducting state temperature of the produced wires ranges from 24 and 27 K. The MgB_2 superconducting wires are a chemically simple material with very high prospective of practical applications and are a serious alternative for currently used low-temperature NbTi and Nb3Sn materials. Magnesium and boron based multi-core wires may have numerous advanced applications in modern technologies, e.g. the construction of SFCL (Superconducting Fault Current Limiter) or SMES (Superconducting Magnetic Energy Storage).

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Note: The translator responsible for English language: Paweł Strzępek, Kraków, Poland