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Multicore MgB_2 wires made by hydrostatic extrusion

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Seven-filament MgB_2/Fe and MgB_2/Nb/Cu wires have been made by in situ process using hydrostatic extrusion, drawing and two-axial drawing deformation into the wire size of $1.1 \times 1.1\ mm^2$. The conductors were sintered at 650 °C/0.5 h and studied in terms of field-dependent transport critical current density and thermal stability. XRD, SEM and EDX analysis were applied for structural characterization. Transport current property and compositional/structural differences are compared and discussed in connection to used powders and metallic materials.

1. Introduction

MgB_2 composite wires are still intensively studied and developed [1–5]. Mostly used technique is 'in situ' powder-in-tube (PIT) process. Up to now, different sheath materials have been tested. Relatively 'low-cost' Fe, Ni and Fe-alloy sheaths are not chemically inert and reactions of iron and nickel with boron and magnesium degrade the wire properties [3–5]. Therefore, more expensive metals as niobium and tantalum have been used in order to avoid chemical reactions [5]. Variable deforming techniques, rotary swaging, drawing and rolling are mostly used for PIT process. Each technique influences directly the density and uniformity of Mg–B filaments and conversion to well connected MgB_2. Analogical to low temperature superconductors, extrusion can be applied as initial deformation for scaling up the PIT process allowing long length production. Pachla et al. have tested the application of hydrostatic extrusion for single-core ex situ and in situ wires [6,7]. Recently, also multi-filament iron sheathed SiC doped MgB_2 wires have been produced by hydrostatic extrusion and high current densities were measured for 60 μm filaments [8].

The aim of this work is to present the current densities and thermal stability related to the structure of seven-filament MgB_2 wires in different powders and sheath materials made by combination of hydrostatic extrusion and rolling.

2. Experimental

Seven-filament in situ wire (7A) was prepared using the powders from *Alfa Aesar*: Mg (99%, ~20 μm particle size) and low purity B (90%, ~1 μm) mixed with 7 wt.% of nano-size SiC (~20 nm). Seven wholes were pre-drilled into pure iron rod of 13 mm in outer diameter. After filling the holes with Mg–B–SiC mixture the composite was electron beam sealed in a vacuum. Several hydrostatic extrusion (HE) passes were applied to reduce the wire diameter to 2.5 mm. HE wire was further deformed by two-axial rolling (TAR) to square cross-section of $1.14 \times 1.14\ mm^2$ and fill factor FF = 22%.

The wire (7B) was made using the same Mg powder, but with higher purity boron (99%) mixed with 10 wt.% of SiC and filled into seven wholes drilled into niobium rod of 13 mm. HE wire 4.16 mm was drawn (D) to 2.2 mm and then two-axially rolled to 1.1×1.1 mm with FF = 13%.

Fig. 1 shows the final cross-sections of as-deformed wire 7A (a) [8], billet components of 7B (b) and the final size of wire 7B (c). The

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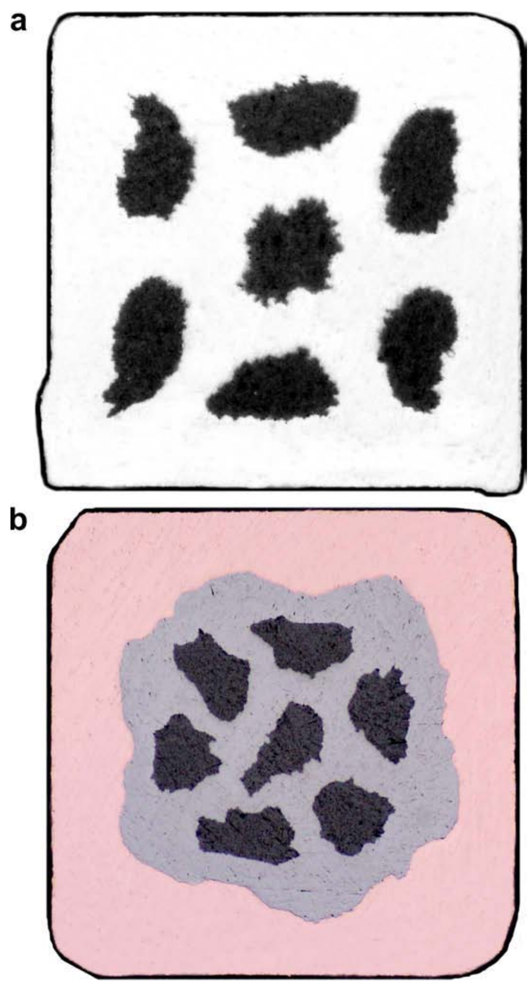

Fig. 1. The cross-section of seven-filament wires: (a) wire 7A – MgB_2/Fe of $1.14 \times 1.14\ mm^2$ (shown also in [8]) and (b) wire 7B – MgB_2/Nb/Cu of $1.1 \times 1.1\ mm^2$.

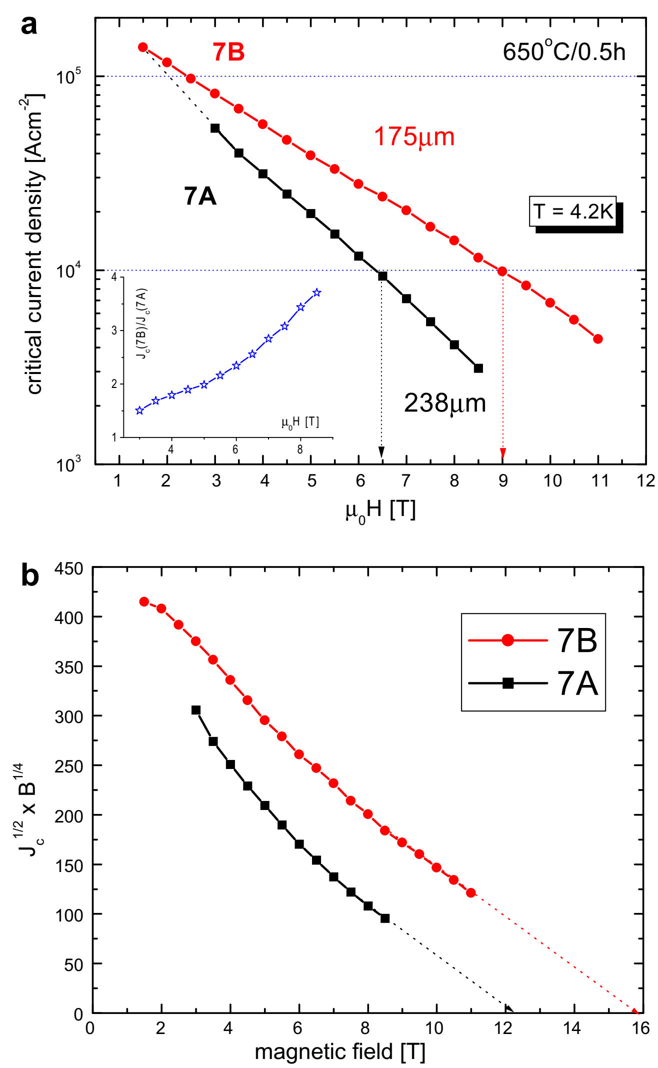

Fig. 2. The transport current densities measured for wires 7A [8] and 7B at 4.2 K (a) and Kramer's plot used for approximately estimation of the upper critical fields (b).

average filament diameter of 238 µm and 175 µm were estimated for 7A and 7B, respectively. Filament uniformity of 7A after HE–TAR deformation is slightly better in comparison to 7B deformed by HE–D–TAR sequence. It was already shown that the uniformity of Nb sheathed single-core MgB_2 is generally worse than for iron sheath [5]. The final sintering was done at 650 °C by 30 min in an argon atmosphere. Transport critical currents (I_c) were measured for 50 mm samples at 4.2 K in variable external magnetic field using the standard electric field criterion of $1\ \mu V\ cm^{-1}$. *I–V* characteristics at constant ramping-up and ramping-down currents (0.33 A/s) were measured up to the voltages of 10^{-3}–10^{-2} V in different external fields 5.5–8.5 T. Filament and filament phase was analyzed by X-ray diffraction (XRD) scans performed on Siemens D500 diffractometer. The structure and element mapping (local and line scans) were investigated by the scanning electron microscope (SEM) LEO 1520 with Gemini column made by Elektronen Mikroskopie GmbH equipped with Link energy dispersive X-ray (EDX) detector made by Oxford Instruments.

3. Results and discussion

3.1. Transport currents

Fig. 2a presents the transport current densities measured for wires 7A [8] and 7B at 4.2 K. While the critical current density level of $10\ kA\ cm^{-2}$ is reached at 6.5 T for 7A, wire 7B shows considerably improved property with $10\ kA\ cm^{-2}$ at 9 T. The insert in Fig. 2 shows the ratio of critical current density of 7B to 7A wire versus field. Despite the smaller filament size of 7B (by 25%) and worse filament uniformity, approximately four times higher J_c(8 T) and less inclined $J_c(\mu_0 H)$ decrease was measured for 7B. It can be attributed to higher phase purity and the absence of chemical reaction at the filament/Nb interface. Comparable J_c improvement (around three times at 8 T) has been observed for rectangular MgB_2 wires using boron purities 90% and 99% and MgB_2 filaments separated by chemically inert Nb and Ti barriers [9]. The insert in Fig. 2 shows the slightly higher ratio of current densities at 8 T: $J_c(7B)/J_c(7A) = 3.5$, which can be attributed to not inert iron sheath reacting with boron giving lower J_c than MgB_2 filaments with 90% boron purity surrounded by niobium [10]. Sudden voltage increase (quench) was observed for 7A below 3 T due to more resistive elements surrounding the MgB_2 filaments – Fe_2B/Fe [10,11]. J_c over $10^5\ A\ cm^{-2}$ (below 2.5 T) was possible measure without quenching for 7B having better thermal stability attributed to Nb/Cu sheath. Fig. 2b shows the Kramer's plot, which was used for approximately estimation of the upper