Preparation and Properties of YBCO-PE Composites

[1]A. Cigáň, [1]J. Polovková, [2]I. Krupa, [1]A. Koňakovský, [1]J. Maňka

[1]Department of Magnetometry, Institute of Measurement Science
Slovak Academy of Sciences, Dúbravská cesta 9, 841 04 Bratislava, Slovakia
[2]Department of Special Polymers and Biopolymers, Polymer Institute
Slovak Academy of Sciences, Dúbravská cesta 9, 842 36 Bratislava, Slovakia
E-mail: julia.polovkova@savba.sk

Abstract. *Composite samples consisting of YBCO superconductor and low-density polyethylene have been prepared. The standard resistance four-point method and contactless induction method based on Meissner-Ochsenfeld effect were used for characterizing transition properties, e.g. critical temperature of sintered YBCO precursor and composite samples, respectively. In all composite samples, no decrease of the critical temperature of YBCO precursor filler was observed.*

Keywords: High temperature superconductor, YBCO, polyethylene (PE), composite, magnetization, critical temperature

1. Introduction

It has been more than twenty years since a new class of high temperature superconductors, HTS, has been discovered in ceramic materials containing $Cu\text{-}O_2$ layers. Today, many interesting future industrial applications are already being laboratory prepared and tested, such as superconducting conductors, motors, and generators with high power and torque at smaller dimensions, superconducting fault-current limiters, superconducting magnets, superconducting energy storage systems (rotation, magnetic), superconducting levitation transportations, bearings, etc. [1-3]. On the other side, HTS show poor mechanic properties as low fracture toughness and high brittleness as well as chemical instability under ambient conditions, generally. So, more different routes as to improve the properties are being found. One of them is using polymers. Composites, where a superconductor serves as a filler of polymer matrix, represent more frequently studied compositions. The $YBa_2Cu_3O_y$ (YBCO) superconductor is the most frequently used superconducting filler in the superconductor-polymer (S-P) composites [4-6]. This is a result of its relatively good phase stability and good control of processing conditions. In addition, many different polymer agents were studied in S-P composites, e.g., PVC, PVB, PVA, PA, PPS, epoxy resins, etc., [7-9]. However, with respect to the preservation of superconducting properties of the S-P composites, it is important to use polymer agents or components with relatively low processing temperature, e.g., melting, curing, and decomposition temperatures.

In this paper, we present the preparation and properties of a composite superconducting material containing $YBa_2Cu_3O_y$ and low-density polyethylene using the solid-state reaction method of syntheses of YBCO precursor and contactless induction method of measurement of superconducting properties of composites. The induction method is more suitable for the composites that consist of electrically insulated superconducting grains.

2. Subject and Methods

Superconducting precursors with the nominal composition $YBa_2Cu_3O_{7-\delta}$ have been prepared by the standard solid-state reaction method from Y_2O_3, CuO oxides and $BaCO_3$. The powder mixture in appropriate weight amounts has been homogenized in an agate mortar and calcined in air at 915 °C for 24 h. The obtained precursors have again been homogenized in the agate mortar, pressed into pellets (with the diameter of 12 mm) under the pressure of 200 MPa and sintered in flowing oxygen (10 ml/min) at 1007 °C for 24 h; then cooled to 520 °C and held at this temperature for 24 h, and thereafter cooled in a furnace to the room temperature. As polymer matrix, we used the low density polyethylene Bralen RA 2-19 product of Slovnaft Petrochemicals, Ltd., Bratislava, Slovakia. (MFI = 1.7 g/10 min., density = 0.916 g cm^{-3}, particle size < 50 μm, specific enthalpy of melting = 109.8 J g^{-1}, melting temperature = 107 °C). The superconducting and PE powder precursors have been homogenized in an agate mortar and the mix of powders was used to obtain (1-*x*) wt. % $YBa_2Cu_3O_{7-\delta}$ +*x* wt. % PE composite samples, by hot pressing at temperature 130 °C under the pressure of 3 MPa for 3 minute. The samples in the form of the pellets of the diameter of about 12 mm and of the thickness of 1 mm had mass from 0.13 to 0.34g depending on the content of superconductor. The content of YBCO in composite changed from 30 to 85 % of the sample weight.

The critical temperature $T_c(R=0)$ of the precursor YBCO samples was determined by the standard resistance four-point method and the transition width ΔT_c was characterized by the 10-90 % criterion. Another contactless electromagnetic induction method based on Meissner effect was used for the measurement of transition properties of the S-P composite samples. The method using a change of the mutual inductance of two coils separated by a sample is based on the Meissner-Ochsenfeld effect - exclusion of the magnetic field from the interior of superconductor resulting in changes of induced voltage (U_1) in the secondary coil [10]. AC volume and mass magnetization (M and M_m) characteristics were measured in detail by a compensation method using the second-order SQUID gradiometer [11]. All magnetization characteristics were measured at 77.3 K after the zero-field cooling in applied magnetization field H_a with the frequency of 0.1 Hz and amplitude ranging from 10^{-1} to 10^5 Am^{-1}. H_a was parallel to the axis of the sample. The superconducting precursor for the composite was prepared by powdering of the $YBa_2Cu_3O_{7-\delta}$ sintered samples.

3. Results

Typical dependence of the electrical resistance (*R*) vs. temperature (*T*) of a precursor sintered sample before powdering in the range of transition into the superconducting state is in Fig.1.

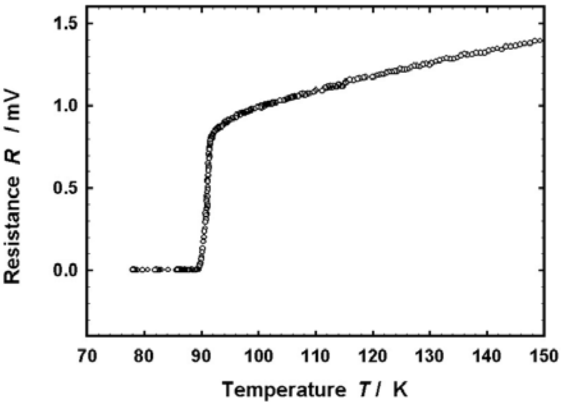

Fig. 1. *R* vs. *T* dependence of the $YBa_2Cu_3O_{7-\delta}$ precursor sintered sample before powdering.

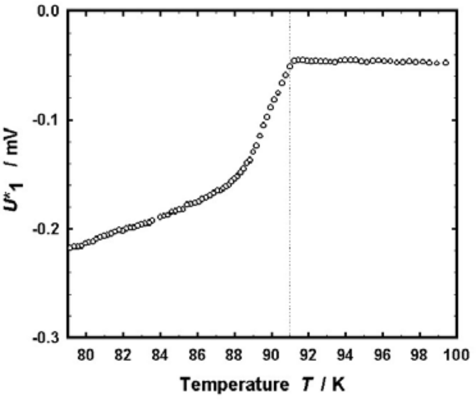

Fig.2. U^*_1 vs. *T* dependence of YBCO-PE composite sample with 60 wt. % of YBCO powder at frequency of 1008 Hz near the transition into the superconducting state.

From measured data, values of the critical temperature Tc(R=0) ~ 91 K and the transition width ΔTc ~ 1.3 K can be determined.

The dependence of the induced voltage U*1 vs. T of composite sample with 60 wt.% of YBCO powder is shown in Fig. 2. The symbol * denotes that an effect of background (a sample-free probe) was subtracted from measured data. The characteristic temperature Tcon determined from the onset of a diamagnetic behaviour (decrease in the induced voltage U*1) is usually used as critical temperature in case of induction method. So, Tcon is about 91 K for all composite samples.

The volume magnetization M versus applied field Ha dependences of YBa2Cu3O7+δ precursor sample before powdering and composite sample consisting of 85 wt. % YBa2Cu3O7+δ and 15 wt. % polyethylene powders for the low amplitude of Ha are in Fig.3.

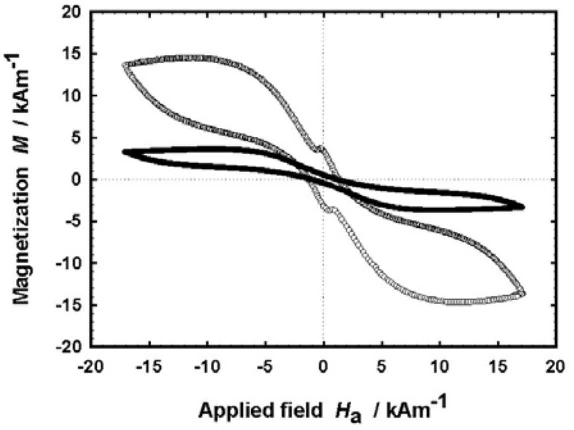

Fig. 3. M vs. H_a dependences of $YBa_2Cu_3O_{7+\delta}$ precursor sample before powdering (○) and composite sample consisting of 85 wt. % $YBa_2Cu_3O_{7+\delta}$ and 15 wt. % polyethylene powders (●).

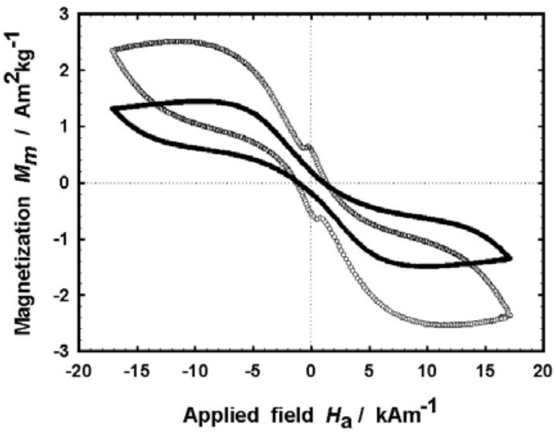

Fig. 4. M_m vs. H_a dependences of $YBa_2Cu_3O_{7+\delta}$ precursor sample before powdering (○) and composite sample consisting of 85 wt. % $YBa_2Cu_3O_{7+\delta}$ and 15 wt. % polyethylene powders (●).

The difference between sample magnetization curves can be ascribed to inter-grain junctions and to different YBCO content. The magnetization peak nearly at zero field of YBCO precursor sample before powdering results from intergrain junctions, whereas the composite samples show no peak. From this, it could be inferred that superconducting grains in the composite sample are not significantly electrically connected. The rate of grain junction magnetization contribution of the samples can be inferred from Fig. 4, where the mass magnetization Mm vs. Ha dependences of the samples are shown. Nevertheless, different sizes or morphology of grains in the two samples could also play some role.

Mass magnetization Mm vs. applied field Ha composite samples with 30, 40, 60, 75, and 85 wt. % of YBCO are illustrated in Fig. 5. It can be seen that the graphs are nearly the same.

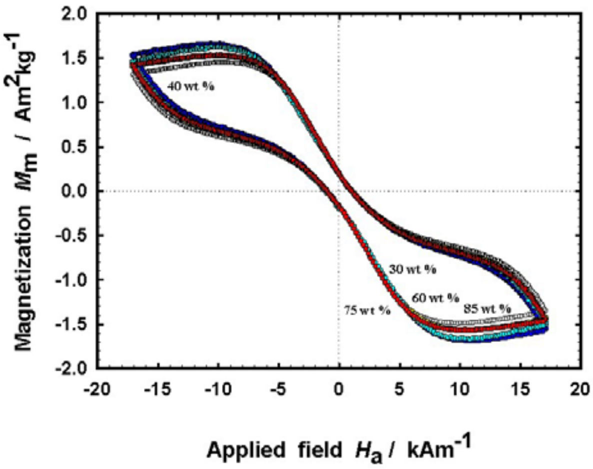

Fig. 5. M_m vs H_a dependences of composite $YBa_2Cu_3O_{7+\delta}$ superconductor-polyethylene samples with 30, 50, 80, and 85 wt. % content of YBCO.

4. Conclusions

We developed a technique of the preparation of a composite material consisting of ceramic high temperature superconductor YBCO and the low-density polyethylene. All the prepared composite samples show superconducting properties with critical temperature about 91 K. Based on results of detailed magnetization and inductive measurements, it can be inferred that the presented technique of the preparation has no degradation effect on basic superconducting properties. Moreover, the superconducting intergrain junctions effects have not been observed for composite samples, even for the sample with the highest YBCO content. Magnetization measurements suggest possible applications of the composites materials, such as electro-magnetic shielding, or protection of superconductors against moisture or chemical agents. In addition, to conserve superconducting properties of $YBa_2Cu_3O_{7-\delta}$ ceramics, no antioxidant organic compound has to be added in the initial mixture of superconductor and PE.

Acknowledgements

This work was supported by the Slovak Grant Agency for Science, projects VEGA No. 2/7083/27 and No. 2/6114/26.

References

[1] Chen M, Donzel L, Lakner M, Paul W. High temperature superconductors for power applications. *J. European Ceram. Soc.* 24: 1815-1822, 2004.

[2] HAUGHT d, Daley J, Bakke P, Marchionimi B. Overview of the U.S. Department of Energy (DOE) High-Temperature Superconductivity Program for Large-Scale Applications. *Int. J. Appl. Ceram. Technol.*, 4: 197-202, 2007.

[3] Lee K, Kim B, Ko J, Jeong S, Lee S. Advanced design and experiment of a small-sized flywheel energy storage system using a high-temperature superconductor bearing. *Supercond. Sci. Technol.*, 20: 634-639, 2007.

[4] Bhadrakumari S, Predeep P. High-T_c superconductor/linear low density polyethylene (LLDPE) composite materials for diamagnetic applications. *Supercond. Sci. Technol.,* 19: 808-812, 2006.

[5] Bhadrakumari S, Predeep P. PTCR Characteristics in $YBa_2Cu_3O_{7-x}$-Linear Low Density Poyethylene (LLDPE) Composite Materials. *J. Supercond. Nov. Magn.*, 21: 313-316, 2008.

[6] Acosta JL, Moure C, Duran P. High T_c superconductor polymer composites based on $YBa_2Cu_3O_{7-x}$. *J. Mater. Sci.,* 30: 2888-2894, 1995.

[7] Namadneh I, Abdullah I, Halin SA, Abd-Shukor R. Dynamic magnetic propreties of superconductor/polymer NdBCO/PVC composites.*J.Mater.Sci.Lett.,* 21:1615-1617,2002

[8] Davtyan SP, Tonoyan AO, Hayrapetyan SM, Manukyan LS. A note on the peculiarities of producing of high-temperature super-conducting polymer-caramic composites. *J. Mater. Proces. Technol.*, 160:306-312, 2005.

[9] Bhadrakumari S, Predeep P, Sheela A. Magnetic levitation force measurement on HTSC ceramic/thermoplastic polymer composites. *Comp. Sci. Technolog.,* 68: 3230-3233, 2008.

[10] Koňakovský A, Cigáň A, Maňka J, Bartkoviak J. Automatic Apparatus for Simultaneous Measurement of Resistance and Inductance Temperature Transition Dependences of Superconductors. In Measurement Science Review: journal published by the Institute Measurement Science, Slovak Academy of Sciences. ISSN 1335-8871, 2008, vol. 8, sec. 3, No. 6, p. 158-160. (http://www.measurement.sk/)

[11] Zrubec V, Cigáň A, Maňka J. Simplified fast method for magnetic characteristics measurement of the HT_c superconducting materials. *Physica C*, 223: 90, 1994.