Progress in Development and Fabrication of YBCO-Coated Conductors at EHTS-Bruker

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Abstract - **An overview of recent technical progress in development of YBCO-coated conductor (CC) at EHTS-Bruker is provided. Technological route employed for tape fabrication is based on alternating ion-beam-assisted deposition and high-rate pulsed laser deposition, which were shown earlier to be cost-effective. Following this route, 100m length of YBCO tape was continuously produced with a critical current of 253 A/cm-width. Production equipment with much higher processing speed has been developed and will be installed soon. Galvanic plating of CC with Cu allowed us to improve significantly mechanical and electrical parameters of CCs, reducing, for instance, critical bending radius to 6mm.**

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I. INTRODUCTION

This report provides a brief overview of recent results, current status and outlook for the development of $YBa_2Cu_3O_7$ (YBCO) coated conductor (CC) at European High Temperature Superconductors GmbH & Co. KG (EHTS).

Generally, EHTS develops a technological route that is based on (i) alternating beam assisted deposition (ABAD) [1] and (ii) high-rate pulsed laser deposition (HRPLD) [2]. Another important constituent of this technology is (iii) employment of stainless steel as a substrate, instead of Hastelloy or other expensive alloy. As we have demonstrated earlier [3], this route exhibits a high potential for lowering production costs of HTS coated conductors.

II. CONDUCTOR DESIGN

A non-magnetic CrNi stainless steel tape, 0.1 mm thick, is employed as a substrate for coated conductors. Prior to deposition of the layer structure the substrates in unit lengths up to 120 m were polished in order to reduce the surface roughness to 2-3 nm.

The used type of stainless steel exhibits favourable mechanical properties, with, *e.g.*, a stress threshold of ~650 MPa. Improved mechanical behaviour of YBCO coated conductors may be achieved merely due to this enhanced substrate stability. Prior to YBCO deposition the stainless steel tapes are coated with yttria-stabilized zirconia bi-axially textured buffer layer using a novel “alternating beam assisted deposition” (ABAD) technique [1]. After deposition of 70nm thick CeO_2 cap layer onto YSZ, YBCO films were deposited employing a high-rate pulsed laser deposition (HRPLD). At the last processing step, the CC tapes were coated with thin shunt layer of silver or gold, 0.2 µm thick, and with a 20 to 40 µm thick copper shunt layer.

III. LONG LENGTHS OF COATED CONDUCTOR

We continuously fabricated 100m length of YBCO tape. The continuing development of sophisticated ABAD and HRPLD technology allowed us to attain an average critical current of 253 A per cm width in self field. The measurement of the critical current, I_c, has been performed on 5m-sections, demonstrating the very high homogeneity of the product with a standard deviation of approximately 2.5% only (see histogram of Fig. 1).

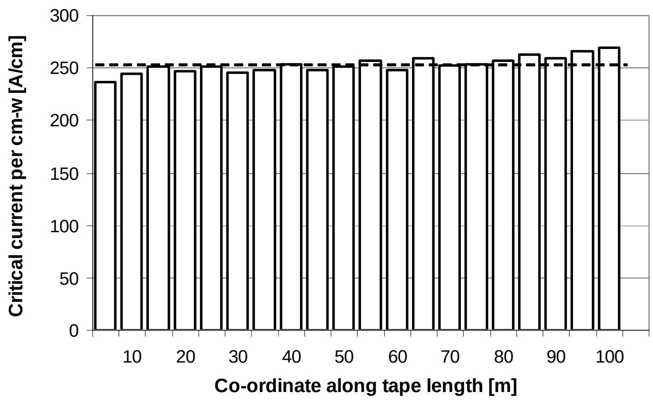

Fig. 1. Critical current measured in sections of 100m long YBCO coated conductor. Measurements performed at 77K in self field.

Currently, EHTS is fabricating more than 2000m of YBCO tape sections for the European power cable project Super 3C (EC Framework 6, Project No. 502615). In this batch, we are expecting to improve further the homogeneity and reproducibility of the ABAD-PLD technology. The next goal is fabrication of 300m unit lengths carrying a critical current of 350 Amps per cm width in aiming at the future use in electrical machines and electric power infrastructure. To fulfill this goal, new PLD deposition equipment with 8 to 9 time higher throughput was recently developed. Presently, the equipment is being manufactured. Installation of it is scheduled for December 2007. Eventually, it should permit us to increase the YBCO deposition speed to 75 m/hour and extend the production capacity to approximately 500 km per year, with batch lengths up to 2000m. The new deposition machine will also accommodate a wider variety of CC widths, from 3 to 500 mm.

Scaling up of the ABAD equipment represents the major task in achieving high throughput, since the ABAD presently creates a “bottle neck” in the tape fabrication. Nowadays, the ABAD setup is capable of processing speed of only 3 to 4 m/hour. At the beginning of 2008, this rate will be increased in the new deposition installation to about 35m/hour. Discrepancy between production speeds of PLD and ABAD can be avoided either though employment of 2 ABAD units per 1 PLD unit or by a further scaling up of the ABAD system. The route to follow will be determined by the market demand for CC.

Before June 2007, the bi-axial texturing based on ABAD technique exhibited relatively poor yield, of ~30%, caused mainly by too complicated manual control procedure of processing runs. Introduction of a newly developed process controller, which simultaneously controls translation speed of the tape, operational status of ion sources and gas flows, resulted in increase of this yield to >90%. It was very impressive to observe that the quality and reproducibility of the buffer layers were also improved. This was confirmed by (i) X-ray phi-scan measurements of YSZ in-plane texture that presently yields a FWHM value of <11° and (ii) by measurements of critical currents in YBCO films deposited onto short pieces of buffered tapes.

As we have reported earlier [3] and confirm presently, the industrial production cost limits for HRPLD and ABAD taken together are about 8 Euro per kAm. Moreover, CrNi stainless steel used as a substrate in the CC architecture represents a further cost-effective component, considerably lowering the material costs.

IV. GALVANIC PLATING PROCESS

For galvanic plating, a highly efficient copper (Cu) deposition technology has been developed in cooperation with the Adelwitz Technologiezentrum, GmbH. The Cu layer is well bonded to the YBCO coated conductor (CC) in both mechanical and electrical respects. This results in a low interface resistance (~1μOhmcm^2) to current transfer from the Cu layer to the HTS film. Due to its high conductivity along the HTS tape, the Cu layer efficiently plays the role of a shunt that protects the YBCO superconductor during current overloads. In general, a Cu layer with a thickness of 20 to 40μm improves both the electrical and thermal properties and provides mechanical protection of the YBCO film. In addition, the Cu shunt makes it possible to use standard soldering techniques, which provide an easy way for joining conductors. Thereby, the galvanic Cu deposition process also enables us to use an economical reel-to-reel procedure. A considerable part of the recent progress in the improvement of critical currents in YBCO-coated conductors was achieved by using a relatively thick Cu shunt layer. It not only stabilizes the electrical performance and protects the conductor against over-currents, but, simultaneously, permits to transfer currents *via* joints with a relatively short overlap.

This new step in electrical and mechanical stabilization of coated conductors is providing now a constructive impact on the production of the remaining YBCO coated tapes for the European cable project Super3C.

V. MECHANICAL AND ELECTRICAL PARAMETERS OF CU-STABILIZED COATED CONDUCTORS

Critical axial stress of the CC without Cu plating is mainly determined by stainless steel substrate that fills about 97-98% of CC's cross-section. Thus, the stress threshold in the non-stabilized conductors is practically the same as in stainless steel, *i.e.*, 650-700 MPa. In the Cu-plated coated conductors, cross-sectional fraction of Cu may vary from 20 to 40% what should lead to reduction of the stress threshold from 700 to 600 MPa. Nevertheless, the corresponding tensile force that causes this stress increases by ~15%, as the thickness of the stainless steel substrate is assumed constant. Fig. 2 depicts these dependencies following from FE modeling of the CC architecture. For these calculations we developed and utilized a model based on the Quick Field FE method [4]. Room temperature mechanical parameters as well as negligible effects at all internal interfaces of CC architecture were assumed

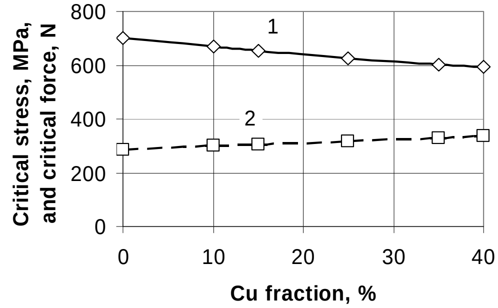

Fig. 2. Dependence of critical axial stress (1) and critical tensile force (2) on cross-sectional fraction of Cu layer. Calculations by FE model;

thickness of stainless steel substrate equals to 0.1 mm.

Furthermore, Cu-stabilized coated conductors exhibit also an improved stability by tape bending. Instead of former critical radii of 7-8 mm in non-stabilized CC-s, Cu plated conductors have critical radii of 6mm for both directions of tape bending [5]. Dependence of critical current in 4-mm- wide coated conductor on bending radius, *R*, is depicted in Fig. 3. It demonstrates that in high quality tape, with I_c = 500 A/cm-w, reduction of I_c does not exceed 5% at the critical radii, of ±6mm ($1/R$=±0.17 mm^{-1}).

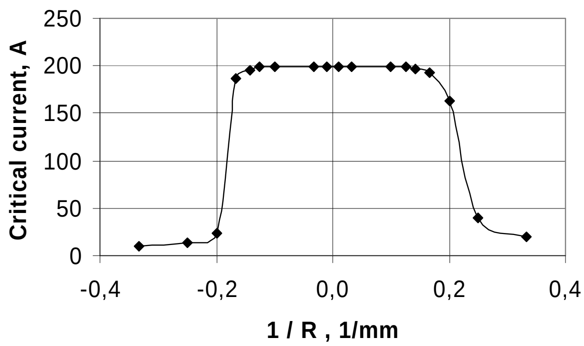

Fig. 3. Dependence of critical current in 4-mm-wide coated conductor on 1/*R*, where *R* denotes bending radius. Measurements performed at 77K and self field. Before bending of the tape (at 1/*R*=0) critical current amounted to 200.2 A, *i.e*., I_c per unit width was 500 A/cm-w. [5]

A short summary of recently attained CC parameters is given in Table I.

Table I. Parameters of Cu-stabilized YBCO-coated Conductors

	Short length (≤10m)	Long length (≥40m)
Critical current, at 77K, SF	500 A/cm-w	253 A/cm-w
Critical bending radius	±6 mm	±6 mm
Axial stress	650 MPa	650 MPa
Stability against over-currents*)	2xI_c during 2 sec *)	2xI_c during 2 sec *)

*) maximal current that can be carried within indicated time without conductor damage.

VI. CONCLUSION

Recent progress in the EHTS development of coated YBCO conductors with Cu stabilization layer resulted in significantly improved mechanical and electrical parameters. With this new degree of conductor stabilization, it is easier to meet requirements of various electrical applications.

ACKNOWLEDGEMENT

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