EuCARD² Work Package 10

MINUTES

14th June 2013

EuCARD ’13 Workshop - Friday Afternoon session

Technical progress YBCO

1. Alexander Usoskin (Bruker): *Status in 2G technology at BHTS*

Coated conductors from Bruker are made around a 50-100 µm thick stainless steel substrate. Coated conductors are directly produced to their final width (4-12 mm) since slitting may induce degradation. Among the different manufacturing steps, substrate polishing was identified as one of the most critical. Scratches induced during polishing reduce the local I_c of the conductor. If the scratches extend over conductor width, the current percolation path is interrupted. The YSZ buffer layer is deposited by an ABAD machine rated for 2 km batch length of 4mm/12mm wide tapes.

The HTS layer is formed by a multiplume Pulsed Laser Deposition. The I_c of YBCO conductors present saturation for film thickness exceeding 1.5-2 µm. The last step of coated conductor production is the galvanic copper plating (RRR is measured to be 29-39). Thickness of copper plating is in the range 20-80 µm on each sides of conductor. After fabrication, the conductor I_c is measured at 77 K and in self-field over conductor sections of 10 cm (1 µV/cm electric field criterion). Longest ABAD coated conductor manufactured is 200 m long with a 10° texture. This is the longest and the highest quality coated tape ever produced in Europe. The highest I_c achieved (small 4 mm wide sample) is 1925 A in parallel field of 18 T.

The mechanical properties of coated conductors from Bruker are:

- Axial critical stress: 500-650 MPa
- Out of plane minimum bending radius: 6 mm
- In plane minimum bending radius: 500 mm
- Torsion: 30°/cm (4mm wide, 40 N load)

C. Senatore: Can Bruker produce 2 mm wide conductor to set up on the strain sample holder of UniGe? Yes for short length, to be studied for longer one.

2. Wilfred Goldacker (KIT): *Status of RACC- Cables: Roebel Assembled Coated Conductor cable*

Among the different coated conductors (SuperPower, AMSC, Fujikura, Sunam, SuperOx, Bruker and THEVA), KIT has experience for Roebel cable with SuperPower, AMSC and THEVA. The magnetic substrate of AMSC conductor limits it application in accelerator magnets. The standard coated conductors of KIT Roebel cable is SuperPower. A Roebel cable is produced by a mechanical punching of coated conductor to form meander tapes. The two producers of Roebel cable are: KIT (R&D) and IRL- General Cable (commercial). The standard widths of KIT Roebel cables are 4 and 12 mm with transposition pitch in the range 116 to 426 mm. After shaping, meander tapes are hand assembled to form the Roebel cable (5 m). An automated machine is used at IRL, longest length produced is 26 m. Numbers of strands in Roebel cables can be increased by multi fold stacked strands. A 12 mm wide KIT Roebel cable with 45 strands (3-fold stacking of 15 strands) exhibits an I_c of 2.6 kA (77 K s.f).

The experimental devices of the KIT laboratory for experimental characterization of materials and cables are:

- Continuous Bending Strain Rig for coated conductors
- Torsion Bending Strain Rig for coated conductors and Roebel strands
- Continuous Edge Bending Strain Rig for coated conductors, strand or cable
- I_c (ϴ) measurements in JUMBO (10 T/ 100 mm solenoid/ Imax=1.5 kA (4.2 K))
- FBI Test facility: a15 T split pair coil for cable I_c(B,T,σ) measurements

Different pancake and solenoid coils were wound with Roebel cables at KIT. The CERN measurements of I_c at 4.2 K in parallel and perpendicular field are presented for a Roebel cable manufactured at KIT. At 10 T, the cable J_e is 400 A/mm^2 in perpendicular field and above 1000 A/mm^2 in parallel field.

Two more Roebel cables were delivered to CERN and will soon be tested. These cables include additional copper stabilisation. The cables are 2 m long with transposition pitch of 126 mm:

- Cable 1: 9 HTS tapes + 9 Cu tapes
- Cable 2: 16 HTS tapes + 8 Cu tapes

To reduce AC losses in Roebel cables, an option of striated coated conductors is presented.

The potential for 10 kA Roebel cable (20 T, 4 K) is surely a reality, but there are some open questions, such as: saddle bending, stabilisation technique, Lorentz force stress management and availability of material (CC and cable length).

3. Arnaud Badel (INPG): *WP-10 Future magnets Some considerations about HTS conductors for high field inserts*

In his presentation A. Badel compared the advantages and drawbacks of Bi-2212 and YBCO conductors. The work performed in collaboration with Nexans to increase the mechanical properties of Bi-2212 wires is presented. Bi-2212 Nexans wires are included in a 50 µm Inconel

610 shell. Many holes (300 µm) in the shell allow the flow of O_2 during heat treatment. Inconel has a yield stress of 540 MPa, therefore it enhances the critical stress of Bi-2212 conductors from 80 MPa to 200 MPa. Reinforced Bi-2212 strands present no strong I_c degradation.

Coated conductors present a strong I_c anisotropy. At high fields, conductor I_c is much lower in perpendicular field than in parallel one. Therefore YBCO conductor may be oriented in block coils to take advantage of the parallel field. The YBCO conductor of the block EuCARD1 insert is presented. It is made of two 12 mm wide tapes from SuperPower soldered around a copper strip. Cable of EuCARD1 insert consist of two insulated conductors in parallel. Nominal cable current is 2.8 kA at 19 T of central field (13 T from LTS+6 T from HTS). Conductors are transposed between mid-plane pancakes.

The EuCARD1 conductor was measured to present no significant I_c reduction at bending radius of 10 mm.

4. Marc Dhallé (University of Twente): *Role of UT in WP10 & State-of-the-art with CORC for HEP*

Role of UT in WP10

M. Dhallé reminds the role of University of Twente in the EuCARD 2 collaboration: performs AC loss characterization of both wire/tape and cable samples; and contributes to I_c measurements of wires/tapes under longitudinal mechanical stress and of both wires/tape and cables under transverse stress.

The existing infrastructures of Twente University are:

- SC magnetometer
- Packman: axial strain measurement
- Tape contact pressure
- TARSIS: Extension and/or torsion of coated conductor. First tests will be at 77 K, self field, followed by 4.2 K and parallel magnet field.
- Cable I_c & transverse pressure (with S.C. transformer) up to 15 T at 4.2 K. Cyclic transverse stress in the range 10 – 20 MPa
- Quench Analysis sample holder for MQE and V_{NZP} of both wires/tapes

The measurements of MQE and V_{NZP} of YBCO tapes performed by J. Van Nugteren are presented. The order of magnitude of Normal Zone Velocity is about 1-10 cm/s. The normal zone velocity decreases with the temperature at fixed fraction of I_c and increases with the current at fixed temperature.

State-of-the-art with CORC for HEP (D. van der Laan)

A 52 YBCO coated conductors made from 17 layers reach an I_c of 5 kA at 4.2 and 19 T, corresponding to a J_e of 114 A/mm^2. Performances of a CORC cable (26 CC,11 layer, O. D. 6 mm) are strongly reduced by bending to 6 cm diameter. CORC cables present no effect of high current ramp rates.

Technical progress Bi-2212

5. Mark Rikel (Nexans): *BSCCO 2212 precursor at Nexans: Current Status and Further Development within EuCARD2*

The initial state of Bi-2212 precursor predetermines the extent of phase separation during the partial melting step and therefore the final performance of Bi-2212 wires. Minimization of phase separation by:

- choosing proper composition;
- making precursor as close to equilibrium as possible

In Bi-2212 conductors, cations composition and Oxygen content has an impact on conductor performances.

First tasks of Nexans within EUCARD2:

- Production of 10 kg standard Bi-2212 precursor granulate (521-like composition).
- Study the effect of particle size in the granulate on processing BSCCO2212 round wires
- Preliminary studies of Bi-2212 bulk with various Sr/Ca ratio and contents

Major Plans of Nexans within EUCARD2:

- Supplying high-quality precursor to OST
- Optimizing composition including O contents as variable
- Stabilizing the industrial process for optimum composition

6. Daniel .R. Dietderich (LBNL): *LBNL work on Bi-2212 and US-CDP Plans*

D. Dietderich introduced the motivation for development of Bi-2212 wire and magnet technology. A series of Bi-2212 racetrack coils have been tested at 4.2 K at LBNL in the last decade. The best coil generates a field of about 1 T at a cable current of 2.6 kA, which is about 85% of witness sample performance. The pending issues with Bi-2212 leakages have been resolved. The quench protection and the compatibility of materials must be further studied.

The transverse stress sensitivity of impregnated Bi-2212 Rutherford cable is presented (measurements from 2001). The cable I_c starts to reduce at 60 MPa. At 160 MPa, the I_c reduction is only 10%. This measurement should be reproduced with over pressure processed cables.

The axial strain sensitivity of Bi-2212 wires reacted under 1 bar and 100 bar is presented. Over pressure processed wire transport 3 times more current but apparently does not present significant improvement in strain tolerance.

The new coil concept Canted Cosine-Theta (CCT) that manages stress is presented.

7. Lance Cooley (FNAL): *Bi-2212 Round Wire R&D at Fermilab*

FNAL is designing a 100 bar-class furnace for reacting Rutherford Bi-2212 cable designed for test in FRESCA at CERN. Long narrow tube in Inconel 625 will fit in regular tube furnace. FRESCA sample that require a 1.5 m uniform hot zone in furnace imply a gas flow, just an over pressure. The insert is designed for pressure of 40 bar, a bore of 32 mm and a length of about 2 m. Challenges of the Bi-2212 samples for FRESCA will be the splices to NbTi cable and the epoxy impregnation.

During heat treatment performed under 1 bar, internal gas pressure drives the creep of silver sheath, causing wire to expand. Expansion is permanent and allows pores to gather into bubbles large enough to obstruct filaments, thereby lowering J_c in long-length wire. Leakage is a natural consequence of the creep rupture of Ag/Mg at the strain of ~3%.

Over-pressure (OP) opposes internal gas pressure during heat treatment and controls creep. If OP is higher than internal gas pressure, Negative creep results – wire densifies.

As an illustration of this, the I_c of a 6+1 Bi-2212 cable is presented as a function of external field for specifics heat treatment. A 10 bar overpressure processing increased the J_c by 4 times, and improved n-values.

To reduce the pressure during heat treatment: the sheath creep of matrix must be reduced and impurities that turn to gas must be removed.

8. Yibing Huang (OST): *Bi-2212 Round Wire Performance Continuous Improvement*

Gas bubbles are limiting the J_e of Bi-2212 wires. Core densification of Bi-2212 wires limits the appearance of large gas bubbles during melt treatment. Densification could be done by wire swaging (J_e= 480 A/mm^2 at 15 T) or by cold isostatic pressing (CIP) (J_e= 470 A/mm^2 at 15 T). Improvement of J_e is also obtained by Over-Pressure (OP) heat treatment. With both process combined (CIP+OP (10 bar)) J_e values of ~550 A/mm^2 at 15 T were achieved on 1 m long closed ends samples. Close ends simulates long length as in a coil. Round Bi-2212 OST wires are available in multiple conductor architectures (0.7-1.5 mm OD) to fit different application requirements of cable and insert coils. Performances of Bi-2212 OST wires continue improving with leakage under control. Bi-2212 OST wire can be twisted down to 12 mm without significant J_e degradation. The filament diameter could be as small as 15 µm. Cluster of filaments are however naturally formed during HT, and an effective filament diameter is not quoted.

The 2009 OST Bi-2212 solenoid generates an additional 2.25 T at 20 T of background field**.** Coil I_c was 77% of short sample I_c, and 85% of witness sample. At 15 T J_e on conductor was ~200 A/mm^2.

B. Bordini: In how many steps is performed the swaging? Only one.

L. Bottura: What is the maximum unit length? No limitations, up to ~1-2 km.

9. David Larbalestier (NHMFL): *The NHMFL Bi-2212 Coil and Conductor Development Program - Presentation to EUCARD 2013*

All prior high J_e wires were short wires allowing internal gas to escape and thus limiting de-densification, wire expansion, but NOT preventing bubble formation. Only external pressure can densify the 2212 and compress bubbles to small volumes.

Earlier Bi-2212 RW Coils at NHMFL : 1.1 T in a 31 T background. J_w=80 A/mm^2. Recent over pressurized Bi-2212 Coil: 2.6 T Field increment achieved in 31.2 T background field (J_w= 187 A/mm^2).

NHMFL workhorse over pressure furnace is 15 cm in length and 25 mm in diameter rated for a maximum pressure of 200 bar. New OP furnaces will increase capacity for moderate sized coils and scientific studies (ID=170 mm L= 50 cm).
Is one powder better than another? For now the answer seems to be that (more recent) Nexans granulate develops higher J_e than (older) Nexans standard fine powder. New powder from Nexans will provide a new test that eliminates powder age as variable.