CARE NED Work Package 3

Report on SMI Cable production and performance

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Abstract

In the framework of CARE-NED project, CERN placed a contract with ShapeMetal Innovation (SMI) in the Netherlands for the development and the fabrication of a Nb3Sn conductor. The targeted conductor is a Rutherford-type cable made of a few dozens of Nb3Sn high performance superconducting strands. Cabling that was performed at both Lawrence Berkeley National Laboratory (LBNL) and CERN is presented here, together with the critical current and RRR measurements on extracted strands that followed.

Acknowledgements

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395)

1. Introduction

In the framework of CARE-NED project, CERN placed a contract with ShapeMetal Innovation (SMI) in the Netherlands for the development and the fabrication of a Nb_3Sn conductor. The targeted conductor is a Rutherford-type cable made of a few dozens of Nb_3Sn high performance superconducting strands. The cabling ability is a crucial issue since even a good Nb_3Sn strand can be damaged during cabling due to the deformations that can induce cracks in filaments and thus impede both the critical current and RRR performance of the conductor.
Cabling that was performed at both Lawrence Berkeley National Laboratory (LBNL) and CERN is presented here, together with the critical current and RRR measurements on extracted strands that followed.

2. Cabling trials at LBNL

2.1 Cabling description

During its R&D phase, SMI successfully developed a Powder-In-Tube (PIT) strand, B215, with good performance in terms of critical current density (~ 2500 A/mm^2 in the non-copper part at 4.2 K and 12 T when reacted during 84 h at 675 ^{o}C as recommended by the firm) and fine filaments (~ 50 µm). The B215 strand was produced in a single length of 950 m, almost fully sent to LBNL for cabling trials. Four short cable lengths made of 40 strands were manufactured with slightly different dimensions, in June 2007. Two views of the cable C are shown in Figures 1 and 2.

Figure 1: a cross-section view of LBNL cable (length C)

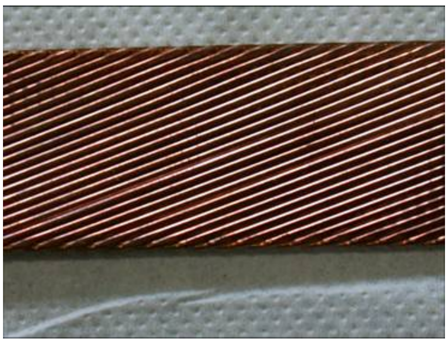

Figure 2: a general view of LBNL cable (C)

The cable C, 2.8 m long, was selected by CERN for the degradation measurements. The main parameters of this cable are summarized in Table 1, together with the parameter ranges for all the four cable lengths. This cable presents a filling ratio of ~ 84 %. Strands at both edges of the cable C do not present sheared or broken filaments, thus indicating a fair mechanical behavior during the cabling process, as can be seen in Figure 3.

Parameter	All cable lengths	Cable C
Finished length [m]	1.8-2.8	2.8
Mid-thickness [mm]	2.285-2.317	2.317
Width [mm]	26.922-26.988	26.978
Keystone angle [º]	0.392-0.415	0.394
Pitch length [mm]	150-191	150

Table 1: the main parameters of cable C and their ranges for all the four cables produced at LBNL.

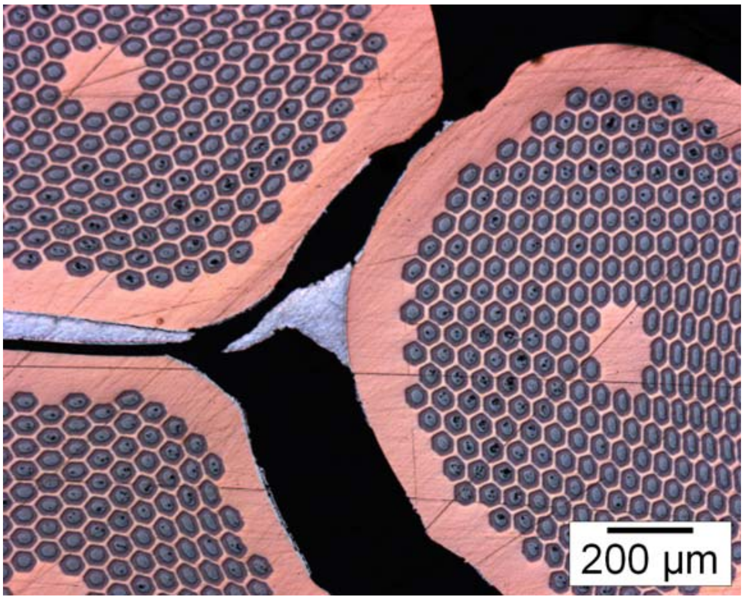

Figure 3: A cross-section of Cable C thin edge (only slightly deformed filaments)

2.2 Cabling degradation versus heat treatment schedule

Degradation measurements were performed at CERN, INFN/Milano and University of Twente by means of strands extracted from LBNL cable C, for which both I_c and RRR were measured and compared to those of virgin strands. The critical current degradation due to cabling is summarized in Table 2, together with RRR values for both virgin and extracted strands.

As shown by Table 1, except for the standard heat treatment (84 h at 675 ^oC) for which a substantial I_c degradation (10 % - 13 %) is observed, the various reaction schedules considered provide similar and fairly acceptable degradation levels of several % (up to 8 %). One should mention that this degradation is less than the 10 % specified level. As an example, for extracted strands reacted during 320 h at 625 ^oC, the non-copper critical current measured at Nijmegen (the Netherlands) exceeds 1400 A/mm^2 and is thus suitable for a 15 T dipole magnet.

From RRR point of view, the heat treatment schedule of 320 h at 625 ^oC, for which an I_c enhancement of ~ 10 % was observed on virgin strands, appears to be, as well, the most favorable with RRR values of ~ 220 (virgin strands) and ~ 130 (extracted strands).

HT	I_c degradation (ext. from cable C)	RRR, virgin	RRR, ext.
675 ^oC/84h	10-13 %	70-80	30-60
650 ^oC/120h	4-8 %	100-143	~ 100
625 ^oC/320h	4-6 %	~ 220	~ 130
625 ^oC/400h	3-7 %	~ 120	54-93

Table 2: critical current degradation and RRR values as a function of heat treatment

3. Cabling at CERN: SMC cable

A Setic cabling machine, used at Brugg Cables AG for the fabrication of the LHC MQM and MQY quadrupole superconducting cables and allowing for the fabrication of Rutherford cables containing up to 40 strands, was brought back to CERN in 2006. By means of this machine, a Nb_3Sn cable made of PIT strands was produced for the Short Model Coil (SMC) program. The SMC project is a collaboration between STFC/RAL, CEA/Saclay and CERN for manufacturing and testing LBNL-type racetrack coils wound on the basis of NED sub-cables.

The SMC cable was successfully fabricated in early September 2008 with B228 and B230 strands, which were received at CERN as a part of the final NED strand delivery. It is a 14-strand rectangular cable, including 6 strands from B228 wire and 8 strands from B230 strand. It is ~ 135 m long and is thus sufficient for the winding of 1.5 SMC coils (i.e. 3 poles). The SMC cable dimensions are very close to specifications and they are summarized in Table 3.

Dimensions	Thickness [mm]	Width [mm]	Angle [^{o}]
Achieved	2.201	9.675	0.15
Nominal	2.200 ± 0.005	9.700 0/– 0.01	0 ± 0.05

Table 3: SMC Nb3Sn cable dimensions

Numerous cross-sections of the SMC cable were observed at the beginning and the end of the cabling; neither broken nor sheared filaments were found. However, degradation measurements were quite disappointing. Indeed, at the end of the cabling, five strands were extracted from the cable together with the corresponding adjacent virgin sample. In such a way, a direct degradation measurement could be performed. For the strands investigated, the critical current degradation due to cabling was found to be between 10 % and 17 % for a heat treatment schedule of 120 h at 650 ^oC. This degradation level is substantial and has to be compared to 4 % to 8 % range observed for LBNL cable extracted strands. One should mention that both cables have quite similar cabling parameters like cable filling ratio or deformation parameters. Moreover, the extracted sample with 17 % degradation was dismounted from the barrel and its copper completely etched by means of nitric acid; no broken filaments were observed. The cable transposition pitch (80 mm for the SMC and 150 mm for the LBNL cable) could be the main factor explaining the degradation discrepancy between both cables. Indeed, due to smaller pitch, the ratio of SMC strand which is deformed following the cabling is more than twice as compared to LBNL cable.

4. Conclusions and perspectives

The Powder-In-Tube strand was used to fabricate Rutherford-type cables at both LBNL and CERN. For the same heat treatment schedule (120 h at 650 ^oC), critical current degradation

measurements showed a more significant degradation for the Short Model Coil cable made at CERN (between 10 % and 17 %) as compared to that of LBNL (up to 8 %). This is despite no broken filaments observed and cabling parameters similar in both cases. This issue is currently under investigation at CERN. A new SMC cable was fabricated at CERN by varying cable dimensions and transposition pitch. Degradation measurements will be performed in early 2009 on strands extracted from this cable.
Last but not least, a SMC cable sample was heat treated, soldered and impregnated; its critical current will be shortly measured at FRESCA station at CERN. This would allow for a direct assessment of the cabling impact on conductor electrical properties.