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ABSTRACT

The influences of stresses/strains on critical current (I_c) in REBCO high temperature superconducting (HTS) tapes wound onto a TORT (tape on round tube) cable were investigated.

Firstly, the HTS tapes were helically wound on copper tubes with various diameters in range of 2.95 - 8 mm, where considerably better results were achieved in case the superconductor layer of tape was positioned during winding to the inner side of the helix. The cables with tape wound on tube with diameter of 6.35 mm were subjected to bending tests with various bending radius in range from 21 to 60.5 mm. The I_c degradation as a function of both tube diameter and bending radius has been studied by measuring current-voltage curve, from which the critical current was determined. The I_c degradation in all samples was confirmed by microstructural investigation of HTS layers using scanning electron microscopy (SEM).

INTRODUCTION

The attempts to deposit the HTS layer of high quality on a round substrate and thus produce a superconducting cable suitable for coil manufacturing did not lead to significant success [1]. Currently, a commercially produced flat HTS tapes in long lengths possess good current transport properties and can be bundled into the superconducting cable. There are several promising concepts published on how to achieve flexible, high-current cables with good prospective of application in fusion reactors, particle accelerators and electrical machines. The different solutions can be summarized into three categories: (1) tapes stacked and transposed according to the Roebel Assembled Coated-Conductor (RACC) technique [2]-[4]; (2) tapes stacked and twisted along the longitudinal direction by the Twisted Stacked-Tape Cable (TSTC) concept [5]-[6]; (3) tapes helically wound on a round former like rod or tube, so called Conductor on Round Core (CORC) [7]-[8] and Tape on Round Tube (TORT) concepts [9], respectively.

The last proposed TORT cable allows circulating of a coolant inside the tube like liquid nitrogen (LN2) and its advantage is that it does not need vacuum in case that some outer thermal isolation (e.g. polyurethane foam) is used. Important step for cable design is the selection of optimal diameter of the metal tube forming the cable core. Too small diameter can mean too high resistance for coolant flow in cable wit length of several tens of meters, and it can also be a reason for mechanical damage of HTS tape resulting in I_c degradation. On the other side, unnecessarily big tube diameter reduces the engineering current density in the coil winding, and contributes to reduction of the cable flexibility. If the TORT cable will be bent into the coil form, the additional mechanical strains are expected leading to further degradation of the wound HTS tapes.

In this work, we studied the effect of cable diameter as well as bending radius reduction on electrical and structural properties of HTS tapes.

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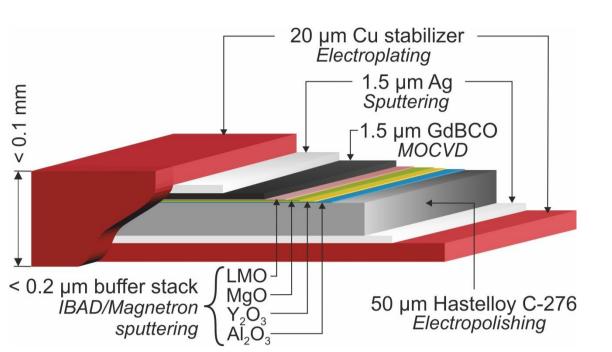
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EFFECT OF MECHANICAL LOADING ON HIGH TEMPERATURE SUPERCONDUCTING TAPES DUE TO WINDING ONTO ROUND CABLES

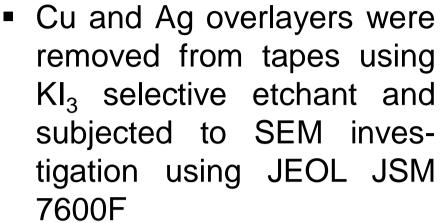
M. Pekarčíková, E. Michalcová, Ľ. Frolek, J. Šouc, P. Gogola, M. Drienovský, M. Skarba, J. Mišík, F. Gömöry

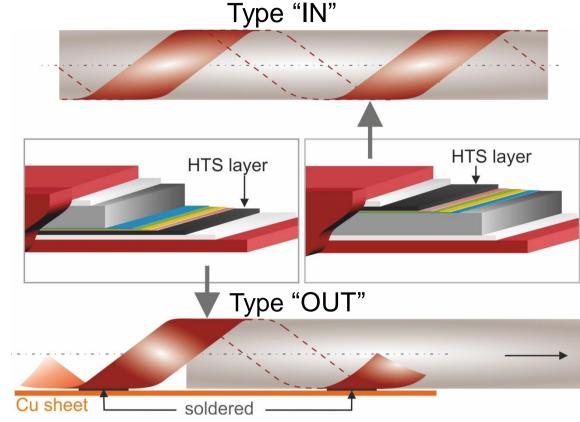
EXPERIMENTAL

EXPERIMENTAL MATERIAL



- HTS tape SCS4050-AP from one batch with width of 4 mm manufactured by SuperPower
- $I_{C_0} = 99.1 \text{ A} \pm 1.7 \text{ A}$
- $n_0 = 27.0 \pm 0.9$
- measured in LN2 bath by four probe method at an electric field criterion of 1µV/cm
- the tapes of type "OUT" had to be additionally soldered to Cu sheet in order to fix the spiral position with following extraction of tube





PREPARATION OF SAMPLES

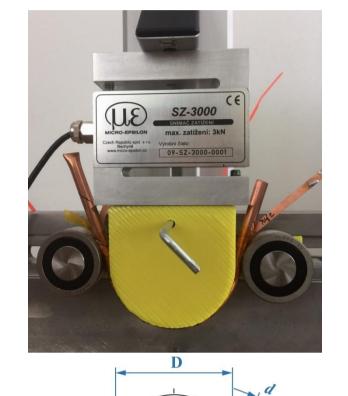
A. WINDING OF HTS TAPE ON TUBE WITH VARIOUS **DIAMETERS**

Outer diameter of tube [mm]	Number of wound tapes	Helix angle [°]	Helix pitch [mm]
8	4	47	22
7.1	4	41	24
6.15	4	37	27
5.95	3	44	16
5	3	35	18
4.15	2	47	9
3.2	2	43	9.5
2.95	2	40	10

- the tapes helically wound on Cu tubes with various outer diameters and parameters shown in the table left
- single layer cable arrangement
- two kinds of winding performed for all tube diameters (type "IN" and type "OUT")
- the I_c of wound HTS tapes was measured after winding in order to obtain a normalized critical current, I_c/I_c

BENDING OF ROUND HTS CABLES

only)



single layer arrangement

tapes were fixed on Cu tubes in spiral winding using a Kapton tape

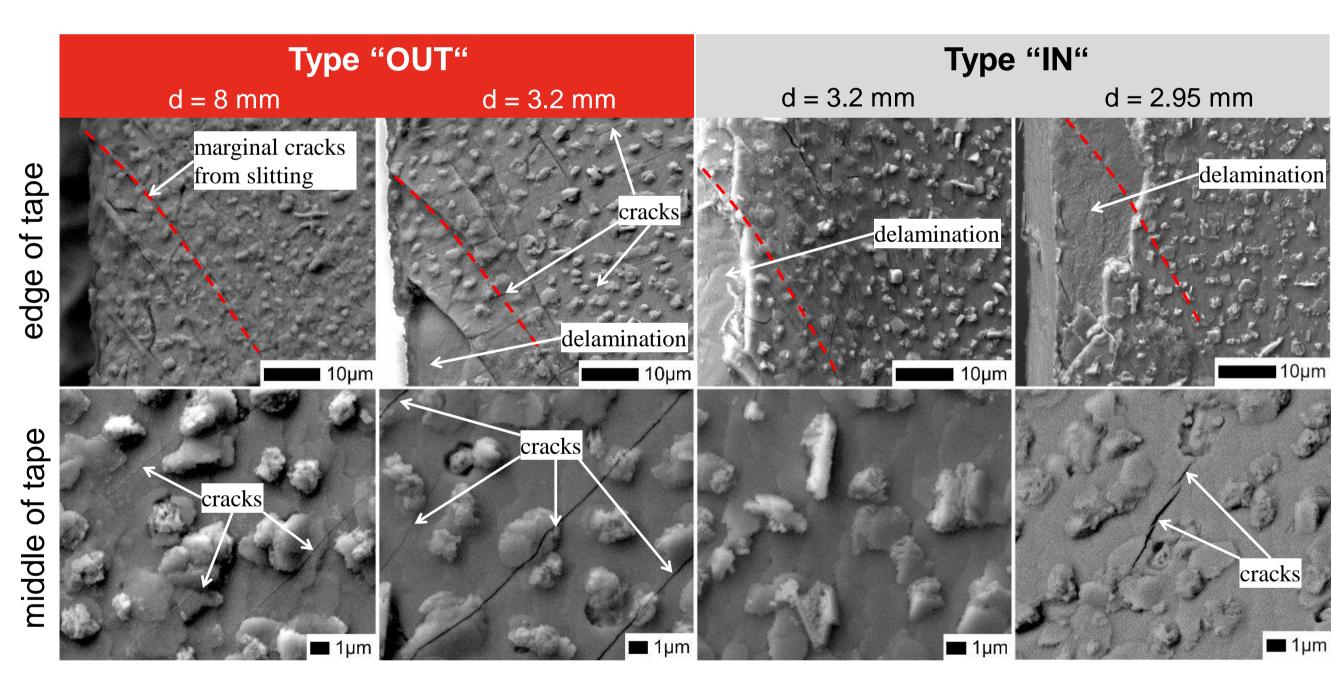
cables prepared by winding on annealed Cu

tube with diameter of 6.35 mm (for type "IN"

- bending to various bending radii 21, 31, 41, 50.5, and 60.5 mm using an universal testing machine UMZ-3K at room temperature
- the speed of upper mandrel during loading 20 mm/min
- the deformation of tape finished when the bending angle α approximately 140° was achieved
- the electrical measurements performed after winding of tape on tube, and after bending of the cable

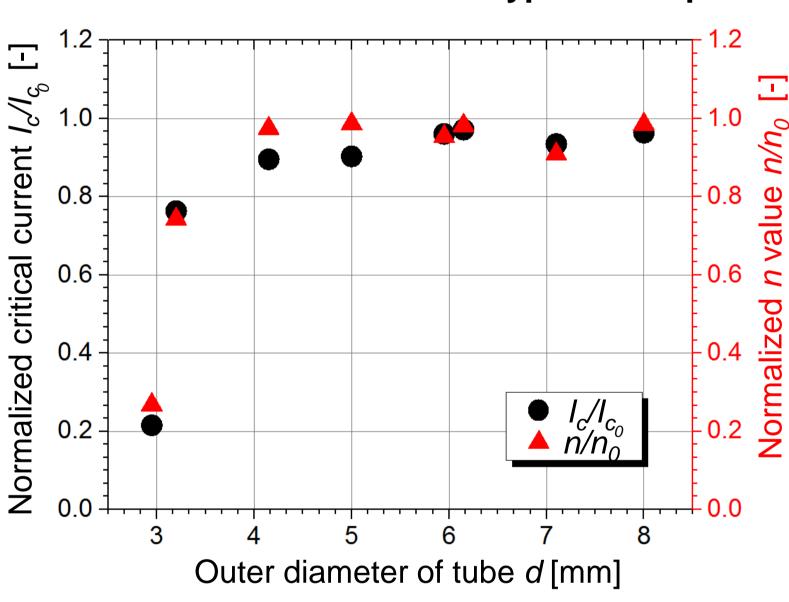
RESULTS

A. WINDING OF HTS TAPE ON TUBE WITH VARIOUS DIAMETERS



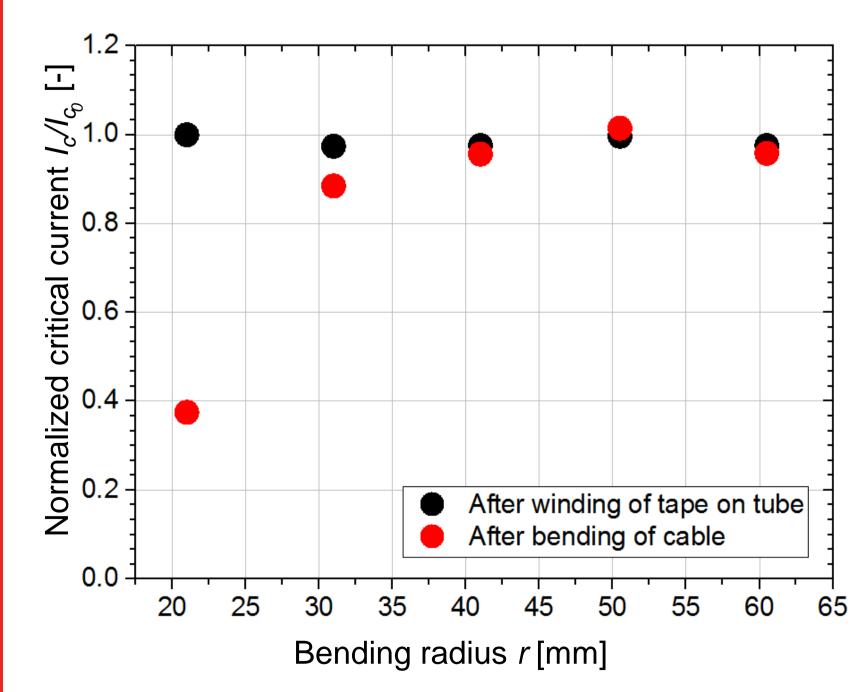
- marginal cracks existing in "as delivered tape" did not continue to spread during winding, even the tape was wound on smallest diameter of tube
- crack formation occurred in all type "OUT" samples because of tensile stress distribution
- no visible cracks in type "IN" samples besides the tape with smallest diameter of tube

Electrical measurements of type "IN" tapes

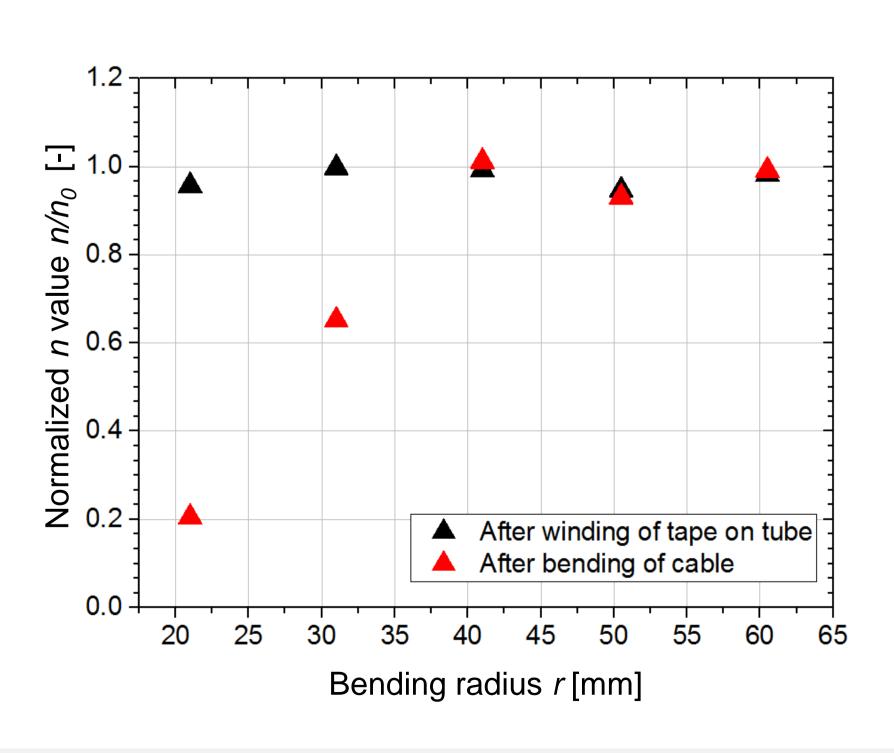


- I_c decrease up to 10 A due to winding the HTS tape on round former with diameter up o 4.15 mm
- 2 x higher I_c decrease for the case of the tape wound on 3.2 mm diameter, and significant I_c decrease for case of tape wound on 2.95 mm

B. BENDING OF ROUND HTS CABLES



- very low I_c and n value degradation due to winding of all tested tapes
- approximately the same I_c and *n* value degradation due to cable bending for tapes tubes with onto diameters above 41 mm
- smaller radii than 31 mm led to significant I_c and n value degradation
- n value more sensitive on the bending load of HTS cables than I_c



SUMMARY

- The winding process did not cause further spreading of marginal cracks formed during the tape slitting. • The position of HTS layer in the helix arrangement has significant influence on I_c degradation and therefore should be located at the inner site of the helix, where more advantageous compressive stresses are acting. This arrangement allows to wind HTS tape on tubes with outer diameter up to 4.15 mm without significant I_c degradation.
- The cable flexibility was demonstrated by bending a 6.35 mm diameter cable over a radius as small as 41 mm radius, which did not reduce the I_c of more than 2 A. Smaller bending radii than 31 mm are not recommended for a coil manufacturing.



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