Supercond. Sci. Technol. **28** (2015) 124001 (8pp) doi:10.1088/0953-2048/28/12/124001

Engineering current density in excess of 200 A mm^{-2} at 20 T in CORC® magnet cables containing RE-$Ba_2Cu_3O_{7-\delta}$ tapes with 38 μm thick substrates

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Received 8 August 2015, revised 7 September 2015
Accepted for publication 24 September 2015
Published 23 October 2015

Abstract

Conductor on round core (CORC®) cables wound from RE-$Ba_2Cu_3O_{7-\delta}$ coated conductors are currently being developed for the next generation of accelerator magnets because of their high flexibility and potential for high engineering current densities J_E. CORC® cables previously reached J_E of 114 A mm^{-2} at 4.2 K and 20 T in a 7.5 mm diameter cable. Accelerator magnets require a current density of at least 300 A mm^{-2} and a cable-bending diameter as small as 40 mm, which has so far not been possible with superconducting tapes made on 50 μm thick substrates. CORC® cables made from thinner substrates could have significantly increased J_E with greater flexibility as we here demonstrate with a CORC® cable made of tapes with 38 μm thick substrates. A custom cable machine produced higher cable quality and better retention of tape performance compared to previous cables that were wound by hand. The thinner substrate showed an almost twofold increase in engineering current density from 114 A mm^{-2} to 216.8 A mm^{-2} at 4.2 K and 20 T, at a reduction in cable diameter from 7.5 mm to 6.0 mm. The results clearly demonstrate that winding CORC® cables from tapes with thinner substrates is a straightforward method for raising their current density and one that shows great promise for use in accelerator magnets.

Keywords: high-temperature superconductors, magnet cable, coated conductors, CORC cable

1. Introduction

High-field magnets that operate at magnetic fields exceeding 20 T, or at temperatures significantly above the boiling temperature of liquid helium, require the use of high-temperature superconductors (HTS). Several HTS materials are being explored for potential use in high-field magnets, including Bi-2212 [1], Bi-2223 [2, 3], and RE-$Ba_2Cu_3O_{7-\delta}$ (REBCO) coated conductors [4–6]. A suitable HTS conductor could enable the next generation of accelerator magnets, more powerful science magnets, and much more compact fusion energy magnets that could be demountable to allow easier access to the fusion chamber.

High-field magnets require high winding currents, high mechanical strength and in some cases very high engineering current densities J_E and small winding diameters. REBCO coated conductors have a potential for use in high-field magnets because of their high strength, great stability and high winding current density. Large magnets require cables with multi-kiloampere capability and several approaches to bundle REBCO coated conductors into high-current magnet cables have been developed. These include the Roebel bar, in which wide REBCO coated conductors are patterned and assembled into rectangular structures [7–9], the twisted stacked-tape cable [10, 11] and its several variations [12, 13] and the conductor on round core (CORC®) cables in which multiple layers of REBCO tapes are wound in a helical fashion onto a small round former [14–16].

Only Roebel and CORC® cables have the potential for use in accelerator magnets which in most cases require tight bending diameters between 30 and 40 mm. The flexibility of cables wound from flat tapes depends largely on the ability of the tapes to slide inside the cable during bending. Such sliding of the tapes from the compressive to the tensile side of the cable bend prevents overstressing of the tapes. The smallest bending diameter that the cable can potentially survive depends on the diameter of the cable and the transposition length of the tapes in the cable. To reduce ac losses, the transposition length, or pitch of the tapes in the cable, should be smaller than the diameter over which the cable is bent. The very short twist pitch of 10–20 mm possible in CORC® cables make them the most flexible HTS magnet cable available, potentially allowing for cable bending diameters as small as 40 mm, as is required for accelerator magnets. Unlike CORC® cables that can be bend in any direction, rectangular Roebel cables have anisotropic flexibility. While they are relatively flexible in the out-of-plane direction, they are much less flexible when bent in any other direction.

REBCO coated conductors experience anisotropic performance when it comes to magnetic field orientation. At 4.2 K, anisotropic pinning in REBCO coated conductors results in the highest critical current I_c when the field is applied in-plane and it is lowest when the magnetic field is oriented perpendicular to the tape plane. Because of the partly transposed nature of the helical winding in a CORC® cable, the strands experience all field directions along their length. As a result, the in-field performance of CORC® cables is isotropic and is determined by the field orientation at which pinning is weakest [16]. On the other hand, tapes in Roebel cables are stacked in a parallel fashion. This allows for a higher in-field performance, as long as the field is always applied parallel to the tapes in the Roebel cable, an extremely hard situation to arrange in a real magnet. The current density in CORC® cables is limited primarily by the non-superconducting core on which the tapes are wound, which generally occupies between 25% and 50% of the cable cross-section. Thus a path to raising J_E of CORC® is to reduce the core diameter by using more flexible tapes with thinner substrates.

An engineering current density of 114 A mm^{-2} at 20 T was previously achieved in a 7.5 mm diameter CORC® cable wound from 52 coated conductors [16], a value insufficient for use in accelerator magnets. Moreover, the 7.5 mm cable diameter did not allow for bending to diameters of much less than 100 mm without significant mechanical degradation of the tapes in the cable. Although J_E could be increased by winding additional tapes onto the cable, this would only increase the cable diameter and reduce its flexibility. In this paper, we investigate a method to raise J_E at 20 T to exceed 200 A mm^{-2}, while improving the cable flexibility through a reduction in the cable diameter, by winding the CORC® cables from tapes with thinner substrates. In addition, a custom-manufactured cable machine is used for CORC® cable winding, allowing for an improved cable quality and longer cable lengths compared to hand-wound cables. The thinner substrates reduce the winding strain of the superconducting film, allowing the use of smaller formers in the cable, thus significantly reducing the cable diameter and raising J_E.

2. Experiment

All superconducting tapes used in this paper were obtained commercially from SuperPower Inc. and consisted of ceramic buffer layers deposited on either 38 μm or 50 μm thick Hastelloy C-276 substrates. The 1.0–1.2 μm thick REBCO layer was deposited on top of the buffer layers by metal-organic chemical-vapor deposition (MOCVD) [17, 18]. The superconducting tapes contained a Zr doping of 7.5% to enhance the pinning properties at low temperature and high magnetic field. Grain alignment was introduced into the MgO buffer layer with ion beam assisted deposition (IBAD). A silver cap layer, 2–3 μm thick, was deposited on top of the REBCO layer for electrical and thermal stability. The coated conductors were then slit from a 12 mm wide tape to their final width of 4 mm. They were surround-plated with 5 μm of copper for electrical and thermal stability, which is the minimum thickness to ensure full coverage of the silver cap layer without the silver cap layer being absorbed into any solder layer while making current junctions. The critical current of these 4 mm wide tapes ranged from about 100 A to about 140 A at 77 K in self-field, depending on the tape batch.

2.1. Sub-scale CORC® cable construction

The superconducting layer of the tapes is wound so that it faces the inside of the bend, thereby putting the superconducting layer into axial compression. REBCO coated conductors can experience a significantly higher axial strain in compression compared to tension before irreversible degradation in I_c occurs [14, 19]. The minimum allowable former diameter before irreversible degradation depends mainly on the thickness of the substrate. The maximum strain in the superconducting film when wound into a CORC® cable is given by:

$$\varepsilon = \frac{-t}{d}. \quad (1)$$

Here, t is the thickness of the substrate on which the YBCO layer is deposited and d is the diameter of the former. Thus thinner substrates allow for a smaller former for the cable.

The former diameter at which irreversible degradation of tapes with 38 μm and 50 μm substrates occurs was determined by winding single coated conductors onto several formers with a diameter ranging from 2.4 mm to 4.8 mm and measuring their critical current at 76 K. The angle at which the coated conductors were wound onto the former was chosen to be close to 45° to ensure a minimum reversible

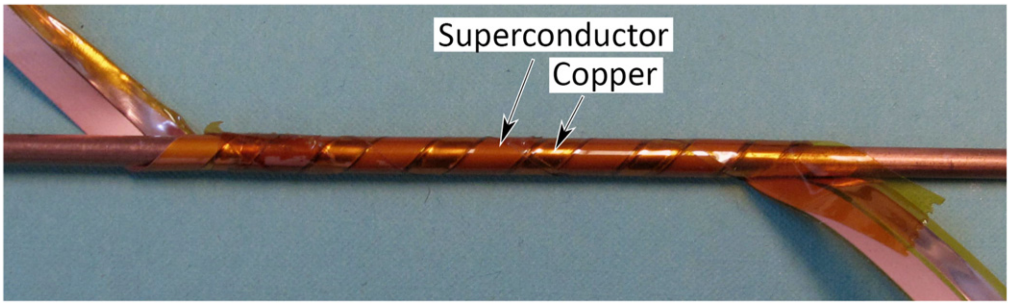

Figure 1. A 4 mm wide superconducting tape wound onto a 3.2 mm diameter former. A 3 mm wide copper tape is wound in parallel to the superconducting tape to ensure a constant winding angle close to 45°.

Table 1. Parameters of the various single-tape CORC® cables investigated.

Former diameter (mm)	Gap (mm)	α (°)	ε (%) (38 μm)	ε (%) (50 μm)
2.4	1.5	46.84	−1.58	
3.2	3	44.13	−1.19	−1.56
4	5	45.74	−0.95	−1.25
4.8	7	46.84	−0.79	−1.04

degradation in I_c which occurs when strains along both a and b directions are balanced. Previous studies showed that the reversible strain effect is negligible when the strain is applied along the [110] orientation of the superconducting film, which occurs at 45° to the tape axis in REBCO films manufactured by IBAD–MOCVD [20, 21]. Any decrease in I_c measured while the REBCO coated conductor is wound onto the former is thus caused by permanent damage to the superconducting film, while the absence of any damage should result in close to 100% retention in I_c of the conductor. A single copper tape was wound in parallel to the single superconducting tape in each cable to ensure a constant winding pitch and thus winding angle along the cable length (see figure 1). The width of the copper tapes was chosen such that the winding angle α is close to 45° according to the following relation:

$$\alpha = \sin^{-1}\left(\frac{n(w+g)}{d\pi}\right). \tag{2}$$

Here n is the number of tapes wound in one layer (1 in this case), w is the width of the superconducting tape (4 mm), and g is the width of the copper tape wound in between the superconducting tape.

Table 1 lists the parameters of the various single-tape CORC® cables containing formers of different diameter. Copper tapes with widths ranging from 1.5 mm to 7 mm were available for winding in parallel to the superconducting tapes, which resulted in the winding angles being very close to 45°, with a maximum deviation of less than 2° as listed in table 1. The maximum winding strain in the superconducting film is also listed in table 1 for each former diameter for both tape substrate thicknesses. Strains varied from −0.79% (38 μm substrate on 4.8 mm core diameter) to −1.58% strain for the 38 μm substrate would on a 2.4 mm diameter core.

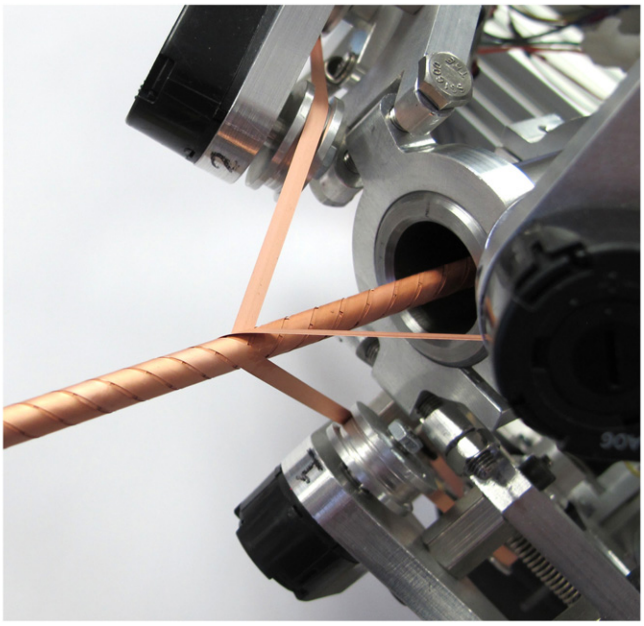

Figure 2. Three 4 mm wide tapes being wound into a single CORC® cable layer.

2.2. 50-tape CORC® cable construction

A CORC® cable containing 50 tapes with 38 μm thick substrates in 23 layers was wound on a solid copper former with a custom cable machine (see figure 2) that allowed winding with accurate control of tape tension, winding angle and gap spacing between the tapes. The copper former was not insulated, allowing for current sharing between the tapes and the former. The tapes available from the manufacturer were only 4 mm wide, which did not allow the use of formers with a diameter smaller than 3.45 mm. Smaller formers require tapes of 2 mm and 3 mm width to avoid large gap spacing between them. Winding 50 tapes into 23 layers yielded a cable diameter of 6.0 mm, including a 0.05 mm thick polyester heat shrink tube that was applied to the outside of the cable for insulation (see figure 3). The winding angle of the tapes in this cable ranged from 35° to about 54.3°, resulting in a

Figure 3. The CORC® cable containing tapes with 38 μm thick substrates. The 6 mm diameter cable contains 50 tapes wound in 23 layers.

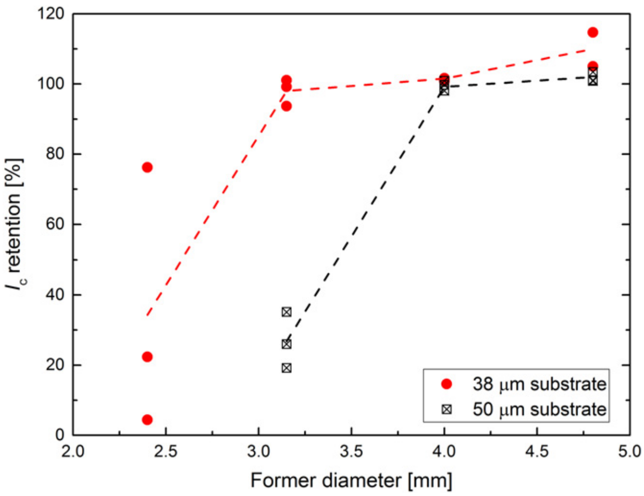

Figure 4. Retention of I_c of tapes made on 38 μm and 50 μm thick substrates, measured at 76 K in Boulder, Colorado, after being wound at an angle of about 45° on formers with various diameters. The dashed lines are a guide to the eye.

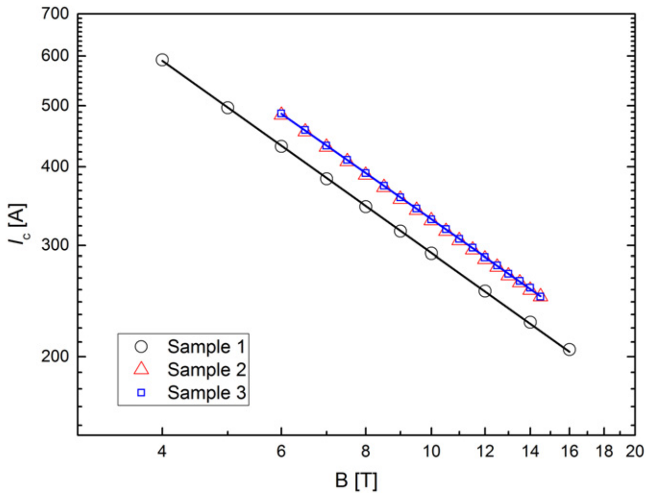

Figure 5. Critical current as a function of magnetic field of three REBCO coated conductors measured at 4.2 K with the magnetic field applied perpendicular to the wide side of the tape. The straight solid lines are fits to the data on a full logarithmic scale according to equation (3).

winding efficiency due to the helical nature of the wind ranging from 1.21 to 1.75. The total winding efficiency (defined by the 142 m of tape needed to wind the 50-strand, 2 m long CORC® cable) was 1.42.

3. Results

3.1. Effect of former diameter on tape I_c

The retention in I_c of the single 4 mm wide tapes with 38 μm and 50 μm thick substrates reported in table 1 wound at an angle of about 45° on formers of different diameters is shown in figure 4. Degradation of I_c occurred only on formers with diameters of less than 3.2 mm for the 38 μm thick substrate and 4.0 mm for the 50 μm thick substrate. Three samples of each configuration were measured to obtain good statistics. Tapes containing a 50 μm thick substrate showed a significant reduction in I_c when wound on a 3.2 mm diameter former, while I_c of tapes with 38 μm thick substrates remained within a few percent of it is original value. Only when tapes with 38 μm substrates were wound on a 2.4 mm diameter former did I_c degrade significantly.

Table 1 lists the maximum axial strain experienced by the superconducting film of the two types of tapes when wound on formers with different diameters. The maximum strain was oriented normal to the former axis and within a few degrees from the [110] orientation of the superconducting film, because of the winding angle of the tapes being close to 45°. At a former diameter of 4.0 mm, the maximum strain experienced by the superconducting film deposited on a 50 μm thick substrate was -1.25%, while it was -0.95% when the film was deposited on a 38 μm thick substrate. I_c of the tapes remains unchanged, even at these relatively large compressive strains, because the strain is oriented along [110] where the reversible strain effect is almost zero. The critical current decreased abruptly and irreversibly when the axial strain exceeded a value of between -1.25% and -1.56%, which occurred at a former diameter between 3.2 mm and 4.0 mm for tapes with a 50 μm thick substrate, and at a former diameter between 3.2 mm and 2.4 mm for tapes with a 38 μm thick substrate. These results confirm that tapes with 38 μm thick substrates can be wound into CORC® cables containing smaller formers without experiencing irreversible degradation compared to tapes with 50 μm thick substrates.

3.2. High-field performance of single coated conductors

The critical current of three coated conductors with 38 μm thick substrates coming from the same batch was measured at both 77 K in self-field and at 4.2 K as a function of magnetic field applied perpendicular to the tape surface. The critical current at 77 K in self-field ranged from 120.2 A to 126.7 A depending on the sample. The magnetic field dependence of the critical current measured at 4.2 K was similar for all three tapes, as is shown in figure 5, and can be described by a power-law function of the form:

$$I_c(B) = I_c(0)B^{-p}, \qquad (3)$$

with $p = 0.754$ and 0.762 depending on the sample. The excellent power law fit to the data in figure 5 allows us to

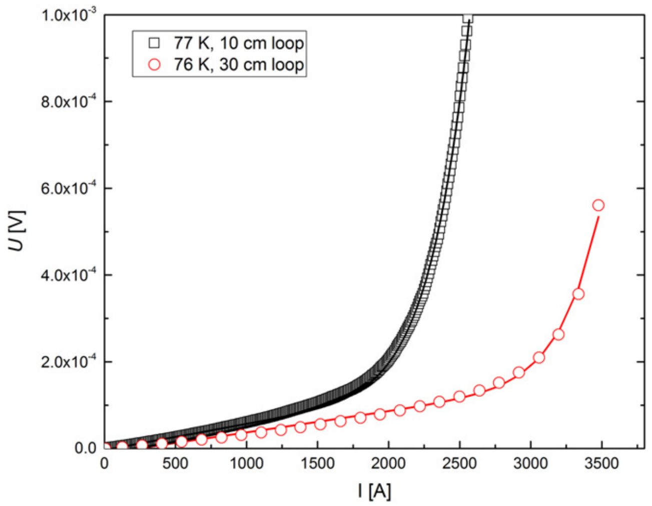

Figure 6. Voltage versus current of the CORC® cable wound from 50 tapes with 38 μm substrates, measured at 76 K while bent into a 30 cm diameter loop. Also included are later data taken at 77 K after the cable was bent into a 10 cm diameter loop. The solid lines are the fit to the data according to equation (4).

estimate the critical current of the tapes at higher magnetic fields, which is expected to be between 194.7 A and 221 A at 17 T and between 172.5 A and 195.8 A at 20 T. The critical current values of the three tapes at 4.2 K, extrapolated to 17 T using equation (3), often called the lift factor, was between 1.62 and 1.74 times I_c at 77 K in self-field, depending on the tape.

3.3. 50-tape CORC® cable performance in liquid nitrogen

The initial performance verification of a high-J_E CORC® cable was performed by measuring its performance in liquid nitrogen and compare the cable I_c to that of the sum of individual tape I_cs as reported by the manufacturer. The in-field cable performance at 4.2 K can then be estimated using the lift factor obtained on select tapes, as described in section 3.2. The results outlined in this section, in combination with the cable measurements performed at high field described in the next section, will show that this approach may work on single tapes, but may not be as straightforward for cables with a high tape count. The remnant intrinsic strain effect of the tapes in the cable, in combination with difficulties injecting high currents into the cable that are operated close to the critical temperature T_c may lower the cable performance in liquid nitrogen. Such lower performance at liquid nitrogen temperatures may be incorrectly blamed on tape degradation during cabling. The performance reduction caused by the remnant reversible strain effect and the current injection may become insignificant when the cable is operated at a temperature far below T_c.

The voltage versus current characteristics of the CORC® cable containing 50 tapes with 38 μm thick substrates, as described in section 2.2, were measured at 76 K, which is the boiling temperature of liquid nitrogen at an altitude of 1655 m in Boulder, Colorado, after the cable was bent into a 30 cm diameter loop to fit the cryostat (see figure 6). Because voltage readings taken on single strands in the cable have proven to be unreliable when the current distribution in the cable is inhomogeneous [22], a pair of voltage contacts located on the outside of the cable terminations was used to measure the cable voltage during I_c testing. These voltage contacts measured the voltage resulting from the superconducting transition of the cable and the voltage caused by the contact resistance between the terminals and the tapes in the cable. The critical current and total contact resistance R of the cable was calculated using the following equation:

$$U = IR + U_c\left(\frac{I}{I_c}\right)^n + U_0. \tag{4}$$

Here, U_c is the voltage at which the critical current is defined, $1 \times 10^{-4}\ \mathrm{V\ m^{-1}}$ times the voltage contact length and U_0 is the inductive offset voltage. The voltage contact length was measured along the length of the tapes in the outer layer of the cable and was 2.2 m.

According to equation (4) applied to the 30 cm bend diameter case, the critical current calculated from the voltage contacts located on the terminals was 3337 A, and the n-value was 13.3. The contact resistance was relatively constant up to a cable current at which the superconducting transition occurred, as can be seen from the close match between the data and fit of equation (4), indicating a relatively uniform current distribution in the cable. The contact resistance for both terminals together was 48.9 nΩ as measured with the voltage contacts located on the terminals.

Figure 6 also shows the voltage versus current characteristic of the cable measured at 77 K, after the cable had been bent to a diameter of 10 cm to fit the high-field magnet sample holder. The critical current was reduced by about one third to only 2 226 A. The critical current at 77 K compared to 76 K was much lower than expected, based on the typical reduction of about 15% in I_c when the temperature is increased by 1 K. Although the cable was wound into the 10 cm diameter loop required to fit the sample holder, it was flexible enough that no significant degradation due to bending was expected.

The much lower cable I_c of 3 337 A measured at 76 K and 2 226 A measured at 77 K, compared to the expected I_c of 6 050 A at 77 K, suggest a tape degradation of 45% due to cabling and an additional degradation of 20% due to bending of the cable from a 30 cm diameter loop to a 10 cm diameter loop. Based on these measurements, the lift factor of between 1.62 and 1.74 as determined in section 3.2 would predict a cable I_c at 4.2 K and 17 T of between 3606 A and 3873 A. The actual cable performance is much higher, as will be shown in the next section, which suggests that the limited cable performance in liquid nitrogen is not caused by tape degradation, but by other factors that play an important role near T_c, such as the remnant reversible strain effect and heating at and propagating from the terminals.

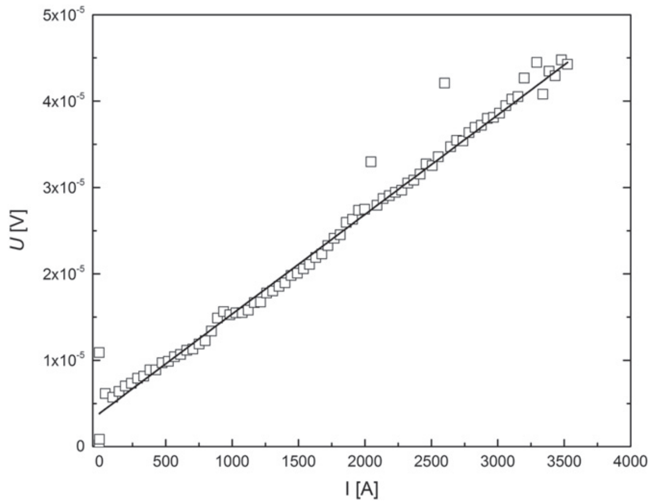

Figure 7. Voltage versus current characteristic of the 50-tape CORC® cable containing tapes with 38 μm thick substrates, measured at 4.2 K in a background field of 17 T. The solid line is a fit to the data. The test was incomplete due to failure of the voltage contacts before current sharing occurred at I_c.

3.4. 50-tape CORC® cable performance at high magnetic fields

The same CORC® cable containing 50 tapes was tested in liquid helium at the NHMFL in the large-bore Bitter magnet. Figure 7 shows the voltage versus current characteristic of the cable at 17 T and 4.2 K up to a current of about 3500 A at which point the voltage contacts of the cable broke. The voltage contacts, co-wound around the cable to reduce the inductive voltage from the Bitter magnet, were cut when the sample current was inadvertently run in the opposite direction. As a consequence, the Lorenz force was directed radially inwards instead of outwards. Because the sample was not supported sufficiently to counter this force, it was able to move, cutting the voltage wires. The contact resistance of both terminals together, as determined from the slope of the curve, was 11.6 nΩ, which is about 25% of that measured in liquid nitrogen due to the lower resistance of the copper and solder at 4.2 K. The completely Ohmic characteristic of figure 7 indicates that the cable never reached the current sharing regime that defines I_c up to a current of about 3500 A.

The sample was warmed up and the voltage contacts were repaired. Unfortunately, the voltage wires could no longer be co-wound with the CORC® cable, resulting in significant noise in the voltage measurement as shown in figure 8. However, the traces were sufficient to clearly identify the resistive transition from which at 17 T a cable critical current of 6966 A and an n-value of 23.2 were deduced. The sample length to determine I_c using equation (4) was taken now to be 1 m, the average length of the tapes located within the uniform high-field region of the magnet. The critical current of 6966 A corresponds to a J_E of 247 A mm^{-2}. The measurement was performed at a current ramp rate of 60 A s^{-1}. The voltage versus current characteristic measured at 12 T is shown in figure 8(b), where I_c was 8815 A. Figure 9 shows the magnetic field dependence of I_c for fields between 11 T and 17 T. Data at lower fields could not be taken because the maximum available sample current of 9600 A was insufficient to reach the superconducting transition of the cable. The critical current was measured again at 17 T after seven measurements that each resulted in a sample quench. The critical current at 17 T after the 7th quench was 6834 A, or within 2% of its original value. Figure 9 includes a fit to the data using a power-law function of equation (3), with $p = 0.72$. Extrapolating the magnetic field dependence of I_c using equation (3) would predict an I_c at 20 T of 6130 A, or a J_E at 20 T of 216.8 A mm^{-2}. The value of $p = 0.72$ as determined from the cable measurement is slightly lower than the value of 0.76 measured on the single tapes. This slight deviation could be caused by variations in in magnetic field dependence over the tape length, a change in magnetic field dependence of I_c of the tapes when experiencing significant winding strain, or the minimum in I_c at 4.2 K and high magnetic field occurring at a field orientation other than perpendicular to the tape plane.

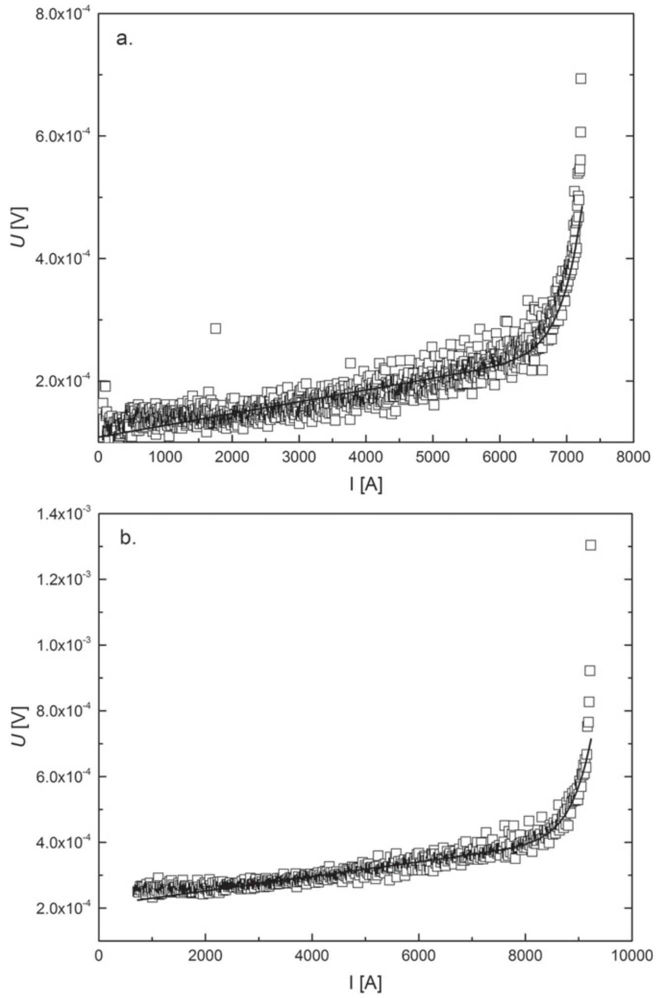

Figure 8. Voltage versus current characteristic of the 50-tape CORC® cable containing tapes with 38 μm thick substrates measured at 4.2 K after the voltage contacts were repaired. (a) In a background field of 17 T at a current ramp rate of 60 A s^{-1}, and (b) measured at 12 T at a current ramp rate of 150 A s^{-1}. The solid lines are a fit to the data using equation (4).

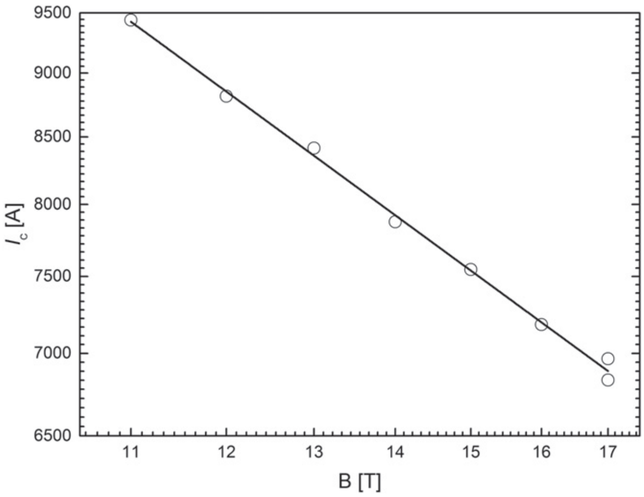

Figure 9. Magnetic field dependence of I_c of the CORC® cable containing tapes with 38 μm thick substrates, measured at 4.2 K. The solid, straight line is a fit to the data on a full-logarithmic scale according to equation (3).

The critical current at 17 T of 6996 A is between 67% and 71% of its expected value, based on the I_c of each tape at 77 K using the lift factor at 4.2 K and 17 T as determined from the short sample measurements (see section 3.2). The lower limit in I_c retention of 67% corresponds to the higher lift factor of 1.74, while the higher limit in I_c retention of 71% corresponds to the lower lift factor of 1.62. The performance of the cable at 4.2 K and 17 T is much higher than what is expected from the cable measurements performed at 76 K and at 77 K (figure 6). A large part of the reduced performance of the cable measured in liquid nitrogen is thus likely due to the remnant reversible strain effect experienced by the tapes in the cable that are not wound at exactly 45° and by heating in the cable terminations at high current.

Heating in the terminals play a much smaller role at 4.2 K when only the middle section of the cable is located in the high magnetic field region of the magnet and the terminations experience a much lower magnetic field. Still, the reversible strain effect may still result in a significant reversible reduction of I_c at 4.2 K and 17 T [23, 24], so it remains unclear what fraction of the 29%–33% performance reduction of the CORC® cable at 4.2 K and 17 T is due to irreversible degradation of the tapes in the cable. Also, the variation in lift factor measured on a limited number of samples results in a relatively large uncertainty in estimated cable I_c at 17 T. The only way to determine the retention in I_c of the tapes wound into a CORC® cable is to measure their I_c after they are extracted from the cable, which we plan to perform in the near future.

4. Conclusion

CORC® cables are one of the most promising high-temperature superconducting cables for use in future accelerator magnets that will operate at fields exceeding 20 T because they are the most flexible cable wound from REBCO coated conductors. The principal disadvantage of CORC® cables so far has been their relatively low engineering current density of a little over 100 A mm^{-2} at 4.2 K and 20 T.

This work shows that a straightforward way to increase the engineering current density of CORC® cables is to wind them from tapes with thinner substrates. Such tapes allow winding on a smaller former, which significantly reduces the cable diameter. Tapes containing 38 μm thick substrates can be wound onto formers with 3.2 mm diameter without experiencing significant degradation, compared to 4 mm in case of tapes containing 50 μm thick substrates. The use of tapes with thinner substrates enabled us to double the engineering current density of CORC® cables to 216.8 A mm^{-2} at 4.2 K and 20 T. The cable diameter was also reduced from 7.5 mm to 6.0 mm, further improving the flexibility of CORC® cables and reducing the minimum allowable cable bending diameter.

The retention in critical current of the tapes in the CORC® cable after being bent to 10 cm diameter and measured at 4.2 K and 17 T was between 67% and 71%, which is an estimate based on limited data measured at high magnetic field on three short samples from one of the tape batches from which the CORC® cable was wound. The estimated performance reduction at 17 T of 29%–33% could be caused by damage to the tapes during cable winding or due to high-field operation. Part of the performance reduction is expected to be reversible and caused by the remnant reversible strain effect in tapes that are not wound at exactly 45°. Further cable optimization could likely reduce the remnant reversible strain effect and increase the I_c retention of the cable.

The results show that the engineering current density of CORC® cables can be increased significantly to make them suitable for use in accelerator magnets by using tapes containing thinner substrates. Future improvements of the in-field performance of REBCO coated conductors by improving their pinning properties and increasing the superconducting layer thickness will further increase the performance of CORC® cables, likely making them the most practical HTS cable for use in accelerator magnets.

Acknowledgments

This work is supported in part by the US Department of Energy, under contract numbers DE-SC0007891 and DE-SC0009545. Work at the National High Magnetic Field Laboratory is supported by the US National Science Foundation under Cooperative Agreement number DMR-1157490 and the State of Florida.

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