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Development of a Simple Measurement System for the Evaluation of Electromechanical Performance of REBCO Coated Conductor Tapes

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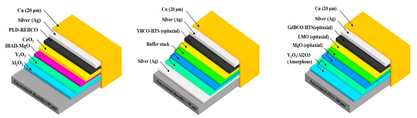
Introduction

- The superior electromechanical properties (EMP) of REBCO coated conductor (CC) tapes made them enabled to be utilized in a wide range of practical superconducting applications such as coils, magnets, and electric devices.
- Moreover, understanding of the I_c degradation behaviors of the CC tapes at the low magnetic field will provide an effective information in predicting the I_c behaviors at operating conditions of a high magnetic field and low temperature.
- The design data such as irreversible stress and strain limits for I_c degradation will further improve the design reliability of superconducting devices. However, since lots of time and effort are required to obtain the EMP data, it is necessary to develop a simple measuring system.
- In this study, the EMPs of REBCO CC tape under low magnetic field conditions were evaluated using our recently developed easy-to-use measurement system that can continuously measure variations in I_c while applying a load or deformation.

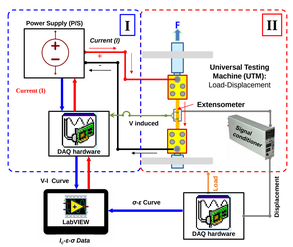
Experimental procedure

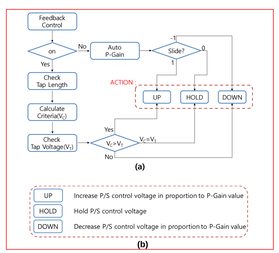
Sample specifications: Commercially available CC tapes



Fabrication process	IBAD/RCE-DR (Sample 1)	IBAD/MOCVD (Sample 2)	IBAD/PLD (Sample 3)
Structure	Ag/**GdBCO**/LaMnO$_3$/ IBAD-MgO/ Y_2O_3/Al_2O_3/ Stainless steel	Ag/**YBCO**/LaMO Homo-epi MgO/ IBAD MgO/Hastelloy	Ag/**GdBCO**/ MgO/Hastelloy
REBCO film thickness	~ 1 μm	~1.6 μm	~2 μm
Critical current, I_c	~250 A	~110 A	~170 A
Dimension, t x w (mm)	0.130 mm × 4.05 mm	0.085 mm x 4.01 mm	0.100 mm x 4.04 mm
Substrate thickness	~100 μm	~50 μm	~50 μm
Stabilizer/technique	Cu-electroplated	Cu-electroplated	Cu-electroplated
Manufacturer	SuNAM.	SuperPower	Fujikura

Schematics of new continuous I_c measurement system for EMP evaluation of CC tapes

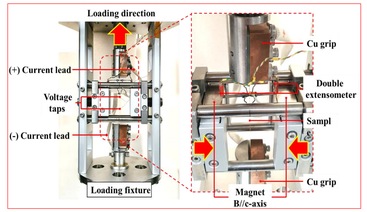




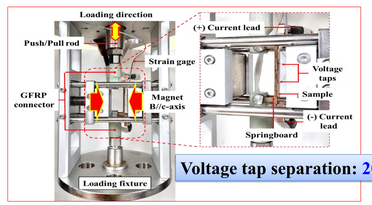
- It can **simultaneously evaluate the mechanical** and **electromechanical properties** of the CC tapes.

Test setups for EMP evaluation

Uniaxial tensile testing apparatus

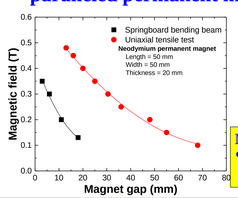


Springboard bending beam testing apparatus



Voltage tap separation: 20 mm

Magnetic field intensity applied to the CC using paralleled permanent magnets

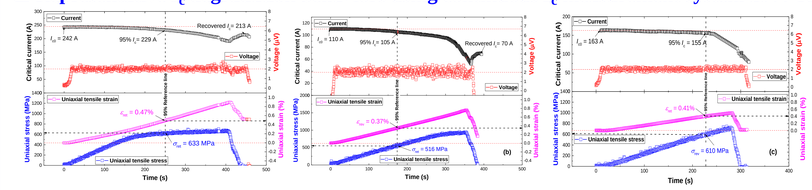


Specifications:
- **Neodymium permanent magnet:** L*W*H = 50*50*20 (mm)
- **Hall probe sensor:** Arepoc: HHP-NP type,

Magnetic field applied adjustment
- By changing the gap between the permanent magnets

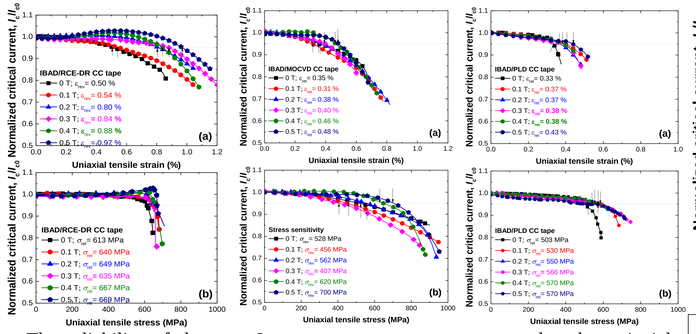
Results and Discussion

Representative I_c degradation behaviors using continuous I_c measurement system at 77 K



- All **pertinent curves** viewed and monitored on a single panel in LabVIEW making it **simpler** and **more efficient.**
- Using this system, a **short CC sample** is **challenged in the same way as superconducting cable**, **coils,** and **magnets** utilized in actual operations.

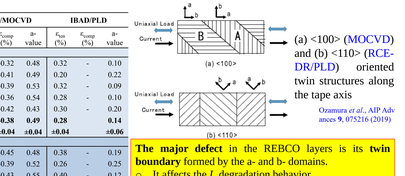
I_c/I_{c0}-ε/σ relationship under magnetic field (*B*//c) of commercially available REBCO CC tapes by uniaxial tensile test at 77 K



- The reliability of the new I_c measurement system was tested under uniaxial tensile test method using 3 different REBCO CC tapes. As a result, RCE-DR CC tape exhibited the highest reversible strain limits obtained by 95 % I_{c0} retention criterion.
- The EMP of the samples significantly increased with increasing applied magnetic field. The differences in I_c degradation behaviors were due to its fabrication process resulting to a unique grain boundary for each CC tapes.

I_c/I_{c0}-ε/σ relationship under magnetic field (*B*//c) of commercially available REBCO CC tapes by springboard bending beam at 77 K

Test #	IBAD/RCE-DR ε_{Ic} (%)	IBAD/RCE-DR ε_{comp} (%)	IBAD/RCE-DR a-/c value	IBAD/MOCVD ε_{Ic} (%)	IBAD/MOCVD ε_{comp} (%)	IBAD/MOCVD a- value	IBAD/PLD ε_{Ic} (%)	IBAD/PLD ε_{comp} (%)	IBAD/PLD a- value
0.1 T									
Test 1	0.40	-	0.20	-0.32	0.48	0.32	-		0.10
Test 2	0.39	-	0.21	0.25	-0.41	0.49	0.20	-	0.22
Test 3	0.41	-	0.14	0.26	-0.39	0.53	0.32	-	0.09
Test 4	0.40	-	0.17	0.28	-0.36	0.54	0.28	-	0.10
Test 5	0.42	-	0.21	0.30	-0.42	0.43	0.30	-	0.20
Mean	**0.40**		**0.19**	**0.27**	**-0.38**	**0.49**	**0.28**		**0.14**
SD	**±0.01**		**±0.02**	**±0.02**	**±0.04**	**±0.04**	**±0.04**		**±0.06**
0.2 T									
Test 1	0.50	-	0.17	0.26	-0.45	0.48	0.38	-	0.19
Test 2	0.50	-	0.25	0.25	-0.39	0.52	0.26	-	0.25
Test 3	0.51	-	0.11	0.25	-0.43	0.55	0.40	-	0.12
Test 4	0.52	-	0.23	0.23	-0.43	0.50	0.34	-	0.20
Test 5	0.50	-	0.17	0.28	-0.35	0.54	0.25	-	0.19
Mean	**0.51**	-	**0.19**	**0.25**	**-0.41**	**0.51**	**0.33**	-	**0.19**
SD	**±0.008**	-	**±0.05**	**±0.02**	**±0.04**	**±0.03**	**±0.06**	-	**±0.04**
0.3 T									
Test 1	0.74	-	0.19	0.24	-0.36	0.55	0.26	-	0.22
Test 2	0.73	-	0.22	0.26	-0.41	0.53	0.25	-	0.24
Test 3	0.61	-	0.21	0.30	-0.41	0.45	0.30	-	0.12
Test 4	0.71	-	0.11	0.28	-0.40	0.48	0.29	-	0.11
Test 5	0.72	-	0.10	0.30	-0.57	0.51	0.31	-	0.25
Mean	**0.70**	-	**0.17**	**0.28**	**-0.43**	**0.50**	**0.28**	-	**0.19**
SD	**±0.04**	-	**±0.05**	**±0.02**	**±0.07**	**±0.04**	**±0.02**	-	**±0.06**

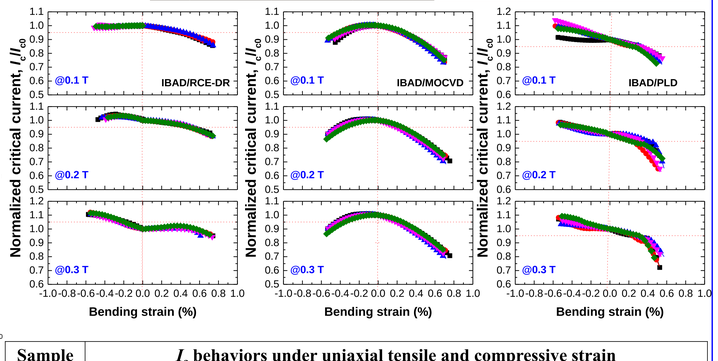


(a) <100> (MOCVD) and (b) <110> (RCE-DR/PLD) oriented twin structures along the tape axis

Ozumura *et al.*, AIP Advances **9**, 075216 (2019)

The major defect in the REBCO layers is its **twin boundary** formed by the a- and b- domains.
- It affects the I_c degradation behavior.
  - ✓ <100> - the twin boundaries are tilted 45° with respect to the direction of the uniaxial strain. ***(Inverted-parabolic behavior or more sensitive to applied strain)***
  - ✓ <110> - the twin boundaries are formed perpendicular to the axis of the tape ***(almost linear Ic degradation behavior or less sensitive to applied strain)***

Such differences in twin boundaries directly affects the strain dependence of I_c occurs in each CC tape.



Sample	I_c behaviors under uniaxial tensile and compressive strain
RCE-DR	✓I_c degradation behavior is almost linear from compressive to tensile strain region with a less sensitive behavior which became significant with the increase of *B*.
MOCVD	✓The parabolic I_c degradation behavior can be attributed by the twin boundaries of the REBCO film regardless of the applied magnetic field at both strain regions.
PLD	✓ I_c degradation behavior is almost linear over the strain range from tensile to compressive. Upon reaching ~0.40% which is the strain just before the I_c starts to drop abruptly due to the fracture of the brittle REBCO layer.

Conclusions

- From a practical viewpoint, the **usefulness and applicability of the new I_c measuring system** which were assessed for three types of practical REBCO CC tapes under two loading modes: uniaxial tension and bending via a springboard bending beam. We showed that this new measuring system can evaluate the EMPs of CC tapes simply and elaborately by measuring variations in I_c while continuously applying loads or deformations.

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