Characterization of the Electromechanical Delamination Strength of REBCO Coated Conductor Tapes under Transverse Loading

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Introduction

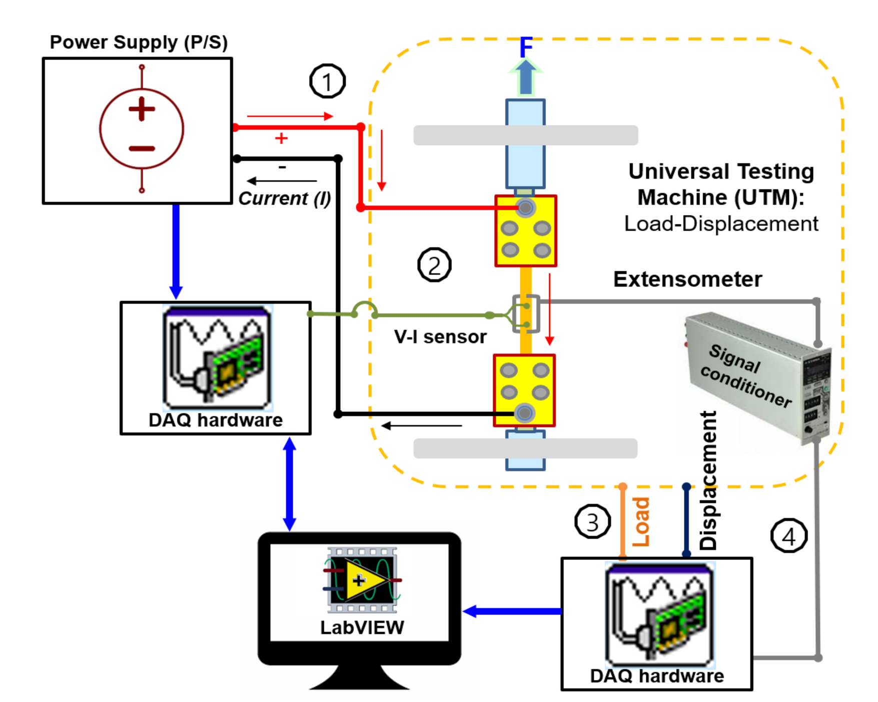
❖ In most application of coated conductors (CC) tapes, particularly in wet wound coils, CC tapes are subjected to different kinds of stresses which inevitably degrades their transport properties.
❖ These covers hoop stress that acts along the length-wise of the tape, and the Lorentz force enforcing perpendicular to the surface of the tape. CC tape is known to have a multilayered structure, from that, the latter is a common cause of the structural delamination and/or ballooning phenomena that often takes place in the interlayers of the CC tape.
❖ In addition, the difference in the coefficient of thermal expansion (CTE) of each layer of the CC tape, the bobbin, and the impregnating materials is the main reason for the occurrence of delamination in CC tape when it is subjected to thermal cycling often experienced during its actual operation. In the design of degradation-free superconducting coils, characterization of the mechanical and electromechanical delamination behaviors including the mechanism becomes critical.
❖ In this study, a transverse tensile test was conducted by anvil-test method at 77 K using a wider upper anvil size that covers the entire width of the 4-mm CC tape. This allows us to include the slit edge effect in the 4 mm wide CC in characterizing the delamination behavior. In the case of the electromechanical delamination characterization, our newly developed critical current, I_c measurement system apply current continuously while being subjected to transverse loading at a constant crosshead speed of 0.5 mm/min.

Experimental procedure

❖ Sample specifications

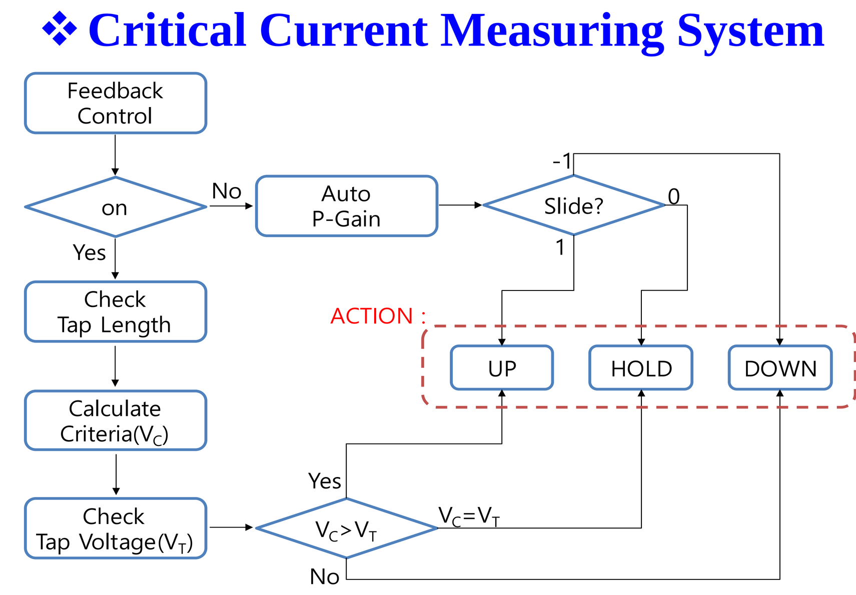
Fabrication process	IBAD/RCE-DR (Sample 1)	IBAD/MOCVD (Sample 2)	IBAD/PLD (Sample 3)
	Ag/GdBCO/LaMnO$_3$/ IBAD-MgO/Y$_2$O$_3$/Al$_2$O$_3$/ Stainless steel	Ag/YBCO/LaMO Homo-epi MgO/IBAD MgO/Hastelloy	Ag/GdBCO/EuBCO/ MgO/Hastelloy
REBCO film thickness	~ 1.5 µm	~1.6 µm	~4.5 µm
Critical current, I_c	~270 A	~110 A	~250 A
Dimension, t x w	0.134 mm x 4.05 mm	0.085 mm x 4.06 mm	0.100 mm x 4.04 mm
Substrate/ thickness	~100 µm	~50 µm	~50 µm
Stabilizer/technique	Cu electroplated, surround (~15 µm)	Cu electroplated, surround (~20 µm)	Cu electroplated, surround (~20 µm)

❖ System diagram for continuously measuring I_c

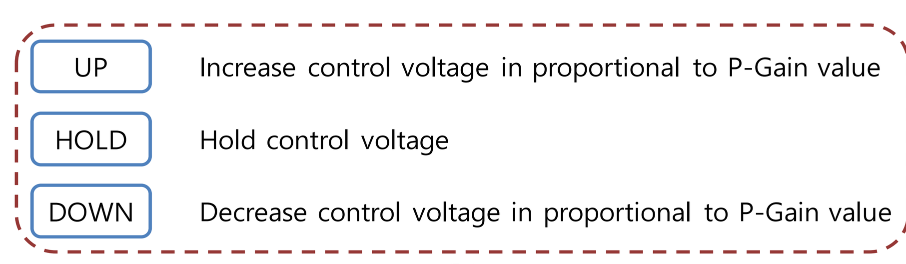


①, the power supply converts AC to DC. ②, I_c in the sample is measured. ③, the load-displacement signal from UTM was obtained. ④, sample strain is measured through extensometer.

❖ Critical Current Measuring System



(a)

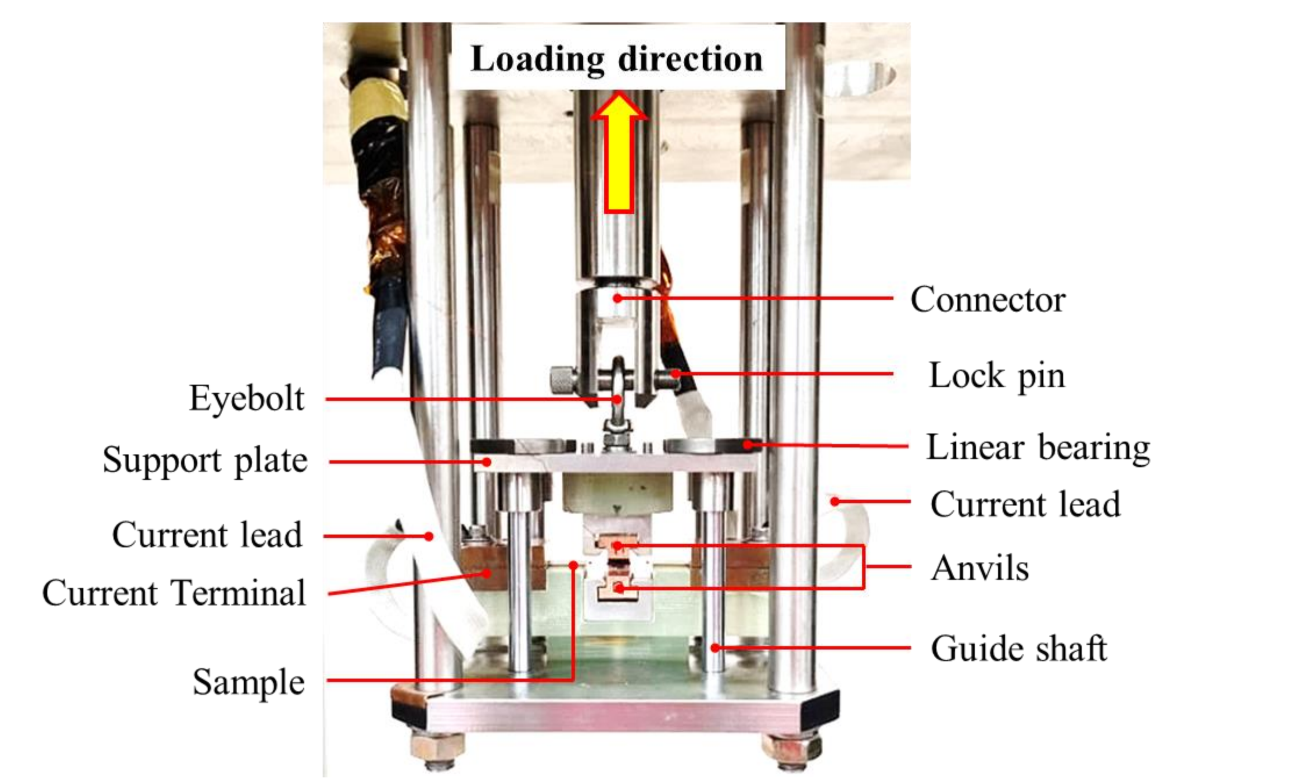


(b)

Block diagram of (a) feedback control, and (b) action control of the continuous I_c measurement system.

➢ Figure (a) shows schematic diagram of the feedback control that controls the flow of the current, the auto P-gain (Sweep rate of the voltage) and the voltage limit that corresponds to the voltage tap length.
➢ The tap voltage (V_T) which was determined by the voltage tap separation of the sample becomes equal to the critical voltage (V_C) when the I_c reaches the V_T.

❖ Electromechanical test setup of CC tape under transverse tensile load at 77 K



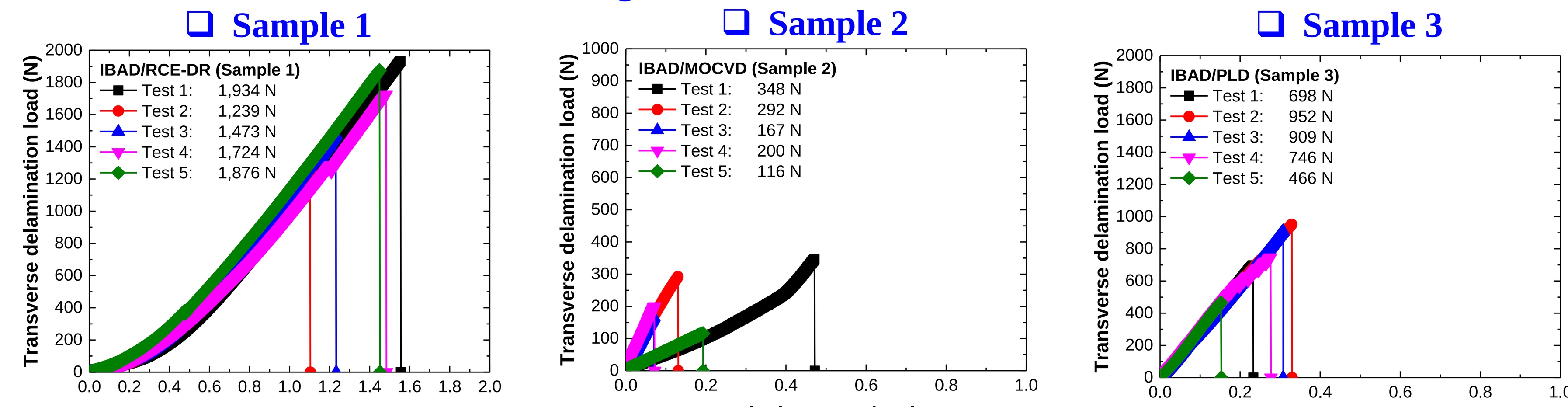
For the mechanical and electromechanical delamination test, the CC tapes were cut into 50 mm and 100 mm length, respectively.

➢ In this study, we used 4.5 mm x 8 mm upper anvils which cover the whole width of the CC tapes representing the actual condition on the superconducting coil application.
➢ The CC tape sample was carefully soldered to the upper and lower copper anvils using an In-Bi solder at a soldering temperature of 110–120 °C with. a flux ($ZnCl_2$) that administer even distribution of solder during soldering.
➢ The setup provides equal distribution of the load along the surface of the CC tape with the help of the linear bearings and guide shafts. This setup maintains a good load-axis alignment during testing.

Results and Discussion

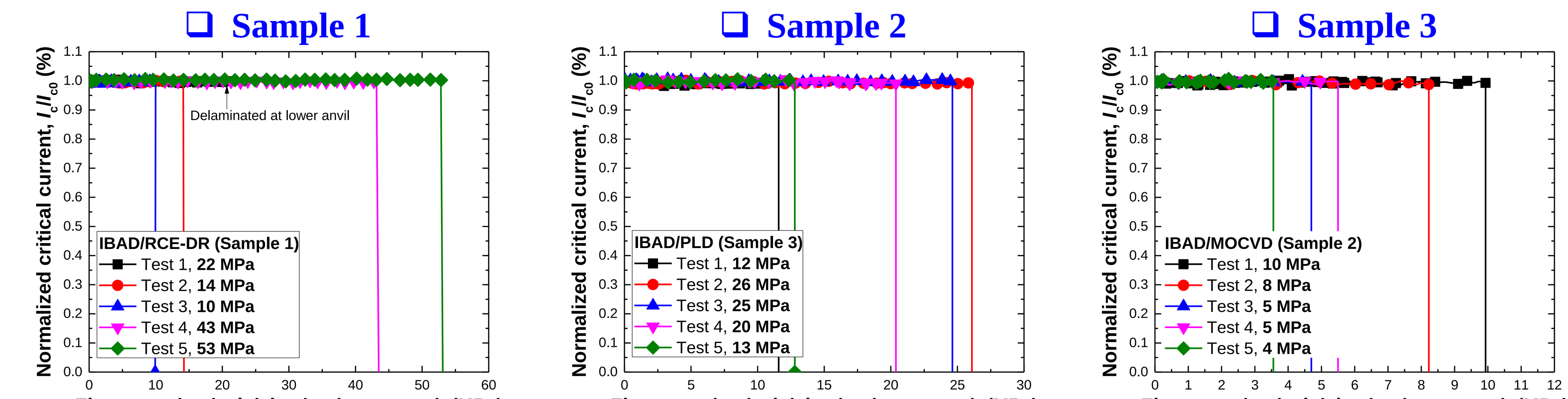
❖ Mechanical delamination strength at 77 K

❑ Sample 1 ❑ Sample 2 ❑ Sample 3



❖ Electromechanical delamination strength at 77 K

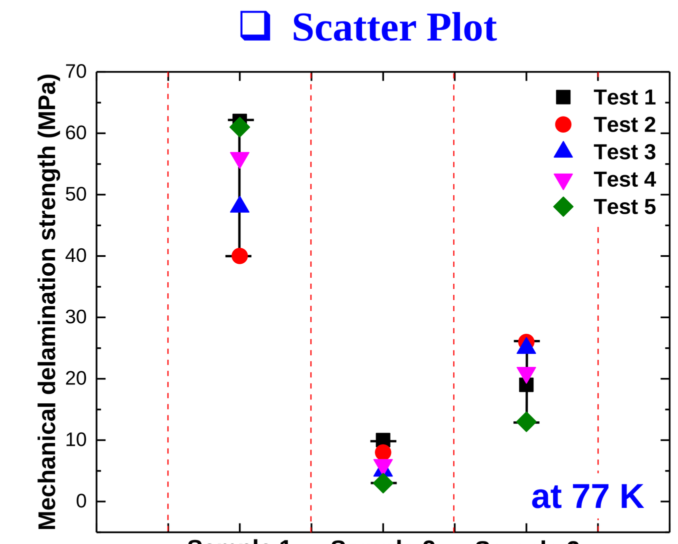
❑ Sample 1 ❑ Sample 2 ❑ Sample 3



These figures illustrate the load-displacement curve at 77 K wherein mechanical delamination strength was derived by dividing the maximum load by the contact area of the upper anvil (4.05 mm x 8 mm).

➢ As a result, sample 1 exhibits the higher mechanical load (~1934 N). Samples 2 and 3 mostly exhibits bulging and detachment on the upper anvil due to poor soldering adhesion.
➢ No significant I_c degradation were observed among the samples, moreover, abrupt Ic drop was observed which is the most common behavior of the I_c degradation when subjected to transverse tensile loading.

❑ Scatter Plot



This figure shows the mechanical delamination strength of the CC tape samples under **large upper anvil (4.5 mm x 8 mm).**

➢ Sample 1 exhibits higher delamination strength among the sample tested at 77 K.
➢ We cannot conclude that sample 1 is superior to other samples because we only did 5 tests for sample 2 and 3, which are mostly detached on the upper anvil due to bad soldering.

❖ Fracture morphology of IBAD/RCE-DR (Test 1)

✓Crack propagated from **the edges of the upper anvil** leaving a large opening revealing the substrate (indicated by the yellow arrow).
✓**Brittle fracture of the Cu-stabilized** due to low temperature caused this kind of delamination.

Conclusions

❖ Electromechanical property measurement were performed using continuous I_c measurement system to check whether the I_c degrades in a significant manner when the current flows through the sample simultaneously with the load being applied.
❖ As a results, the measurement technique was quite effective, however, abrupt I_c degradation was observed through all the samples. This proved that it is not dependent on the fabrication process nor on the method of load application. Sample 1 shows an outstanding mechanical and electromechanical delamination strength among other CC tapes.
❖ This information is necessary in designing coil especially when it is for wet wound coils, wherein epoxy impregnated is inevitable which leads to delamination. More test are required to support the results of Samples 2 and 3.

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