Reversible I_c Degradation Behaviour in REBCO Coated Conductor Tapes under Transverse Stress*

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Introduction

- 2G REBCO coated conductor (CC) tapes gained its popularity in electric applications such as motor and generators, power cables, and especially coils due to its superior characteristics and performance.
- In coil applications, the CC tapes might experience several factors that might limit its performance possibly damage its integrity through the delamination of its layers.
- Large Lorentz force, CTE mismatch of constituent layers, screening current and other fabrication related reasons produce excessive transverse stresses.
- As reported elsewhere, the critical current, I_c of impregnated coil was completely degraded due to the delamination of the CC tape's layer.
- Therefore, in coil design, mechanical and electromechanical delamination strength of the CC tape should be enough to withstand these threatening factors for the optimum design.

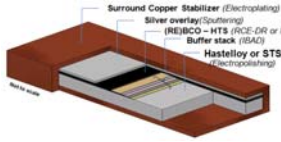
Objectives

- To investigate the mechanical and electromechanical properties of GdBCO CC tape adopting stainless steel (STS) substrate under transverse load using anvil test.
- To examine the reversible I_c degradation behaviors under transverse stress.
- To investigate delamination mechanism of the CC tape under transverse loading.

Sample and methodology

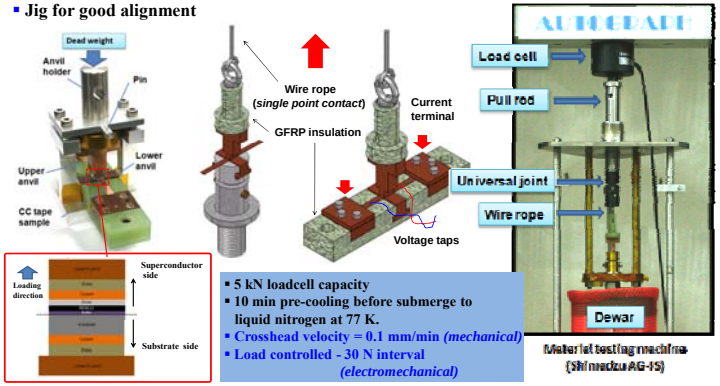
Specifications and properties of GdBCO CC tape sample

Fabrication process	Reactive Co-evaporation by Deposition and Reaction (RCE-DR)
Conducting film	GdBCO(1-2 μm)
Substrate	Stainless steel (~104 μm)
I_c, A	> 220
Dimension, t x w	0.135 x **4.06** (slit)
Stabilizer	Electroplated Copper (15 μm)
Manufacturer	SuNAM



Setup for mechanical and electromechanical delamination test

- Jig for good alignment



- 5 kN loadcell capacity
- 10 min pre-cooling before submerge to liquid nitrogen at 77 K.
- Crosshead velocity = 0.1 mm/min *(mechanical)*
- Load controlled - 30 N interval *(electromechanical)*

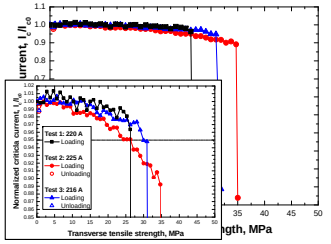
Material testing machine (Shimadzu AG-IS)

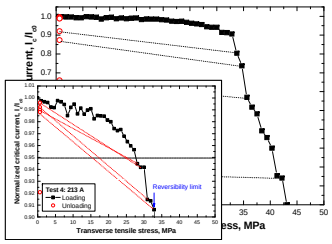
- Soldering was done using the 4 x 8 mm upper anvil at 120°C~ 130°C with an In-Bi solder (*melting point of 70.9 °C*).
- Voltage tap separation of 2 cm and voltage tap criterion for I_c measurement of 1 μV/cm was adopted.

Results and Discussion

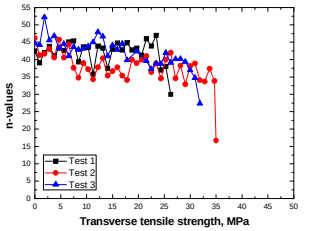
Critical current, I_c degradation behavior

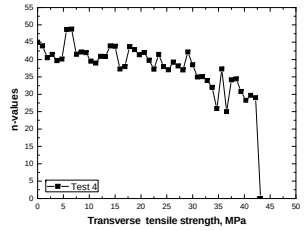
- Reversible I_c until delamination
- Irreversible I_c before complete delamination





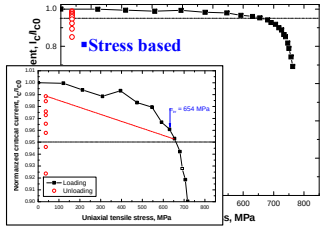
- N-values

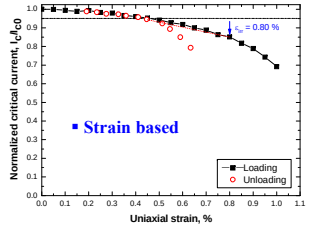




- CC tapes with stainless steel substrate exhibited both abrupt & gradual I_c degradation behaviors.
- Test 1, Test 2, Test 3 and Test 4 exhibited electromechanical delamination strength of 26.5 MPa, 35 MPa , 32 MPa and 43 MPa, respectively with an average value of 34.1 MPa.
- Tests 1 (*abrupt I_c degradation*), 2 & 3 (*gradual I_c degradation*) showed reversible I_c (*= or above 99% I_c retention*) when unloaded to 20 N until the delamination occurred.
- Test 4 (*gradual I_c degradation*), however, there existed a reversible stress limit I_c (*below 99 % I_c retention*) of 32.5 MPa when unloaded to 20 N before complete delamination occurred.
- The n value-transverse stress relation showed a good correlation with the I_c behavior under transverse tensile stress for each test.

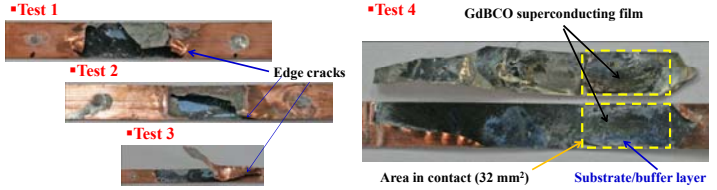
- Comparison of I_c degradation behavior under uniaxial loading





- When compared, the behavior under transverse stress with the one under uniaxial loading, the GdBCO CC tapes with STS substrate exhibited similar I_c degradation behavior.
- Under uniaxial tensile loading, the Cu-stabilized CC tape with stainless steel substrate exhibited a reversible I_c stress limit (*stress where I_c is above 99% I_{c0}*) at 654 MPa.

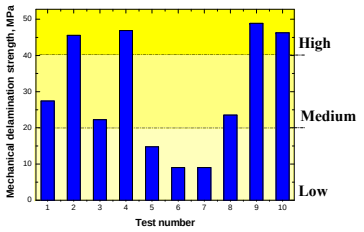
Morphologies of CC tape

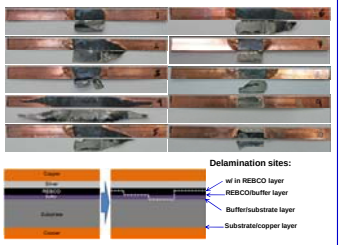


- Morphologies of delaminated CC tape under electromechanical delamination testing showed good correlation with the I_c degradation behavior.
- Test 4 was delaminated mostly within the GdBCO superconducting layer where in this case the I_c degraded in a gradual manner presenting a high electromechanical delamination strength.

Mechanical delamination strength & morphologies

- Mechanical delamination strength of CC tapes
- Morphologies of delaminated CC tapes





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- Exhibited wide scattering of mechanical delamination strength over the three levels classified (9 MPa ~ 49 MPa).
- The Cu-stabilized GdBCO CC tapes with stainless steel substrate had almost similar values in both mechanical and electromechanical delamination strength.
- CC tapes with low and medium mechanical delamination strength were mostly delaminated between the GdBCO/Ag interface, while high ones mostly delaminated between substrate/buffer, buffer/GdBCO interfaces and within the GdBCO superconducting film itself.

Conclusions

- RCE-DR processed GdBCO CC tape with stainless steel substrate exhibited both abrupt and gradual I_c degradation behavior under transverse loading.
- Under transverse tensile, I_c of CC tape showed reversible degradation behavior similar with the one under uniaxial tensile loading.
- RCE-DR GdBCO CC tapes with stainless steel substrate showed almost similar mechanical and electromechanical delamination strength, which are different from the Hastelloy substrate case.
- Exhibited multiple delamination sites and resulted to variation in mechanical delamination strength obtained, CC tape with low mechanical delamination strength mostly delaminates between the GdBCO/Ag interface while CC tape with high mechanical delamination strength mostly exhibits delamination between substrate/buffer, buffer/GdBCO interfaces and within the GdBCO coating film itself.

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