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Reliability Evaluation Procedure of Electromechanical Properties in REBCO CC Tapes Obtained by Uniaxial Tension and Cyclic Tests at 77K

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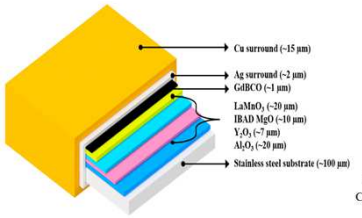
Introduction

- In utilizing 2G CC tapes in superconducting device applications, it has been known that repeated cyclic loading (e.g., cool-down and warm-up variation, Lorentz forces in coils and magnets and alternating centrifugal forces in a motor or generator) may affect the current carrying capacity of the CC tapes, especially during long-term applications.
- It is also known that I_c degradation in REBCO CC tapes is possible under long-term mechanical loads even at the static stress level below the reversible stress limit of the CC tapes. This can be analyzed using a static fatigue test.
- Based on these conditions, the electromechanical fatigue limits obtained by fatigue tests of CC tapes are very important.
- Since the static fatigue behavior of REBCO CC tapes is not yet well understood, the life prediction to a crucial I_c level under given conditions could be an issue in real applications.
- In this study, to ensure the durability of superconducting application devices, the reliability of mechanical and electromechanical properties of CC tapes were evaluated at 77 K using uniaxial tensile and fatigue tests. A newly constructed static fatigue tester was introduced.

Experimental procedure

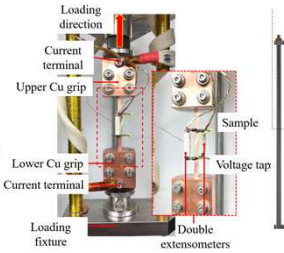
Uniaxial and cyclic testing apparatus

Sample specifications

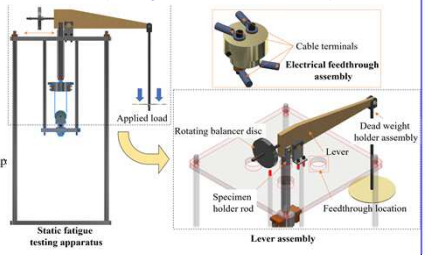


IBAD/$GdBa_2Cu_3O_y$ (*GdBCO*) 4-mm wide CC tape fabricated by the RCE-DR was used

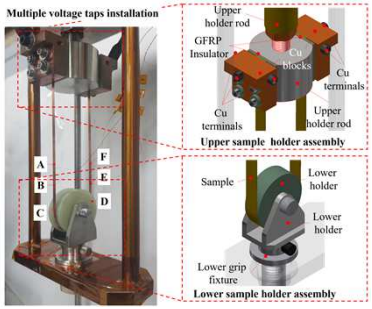
Uniaxial tension test set-up



Static fatigue testing apparatus (Newly constructed at ANU)



Multiple voltage taps installation



Uniaxial tension test

- Shimadzu UTM: 5 kN capacity; Ramp rate: 1 mm/min
- Extensometer: 25 mm Nyilas-type double extensometers
- Sample length: Total length **= 120 mm;** gage part length **= 60 mm**

Fatigue test conditions

- Constant stress amplitude
- Frequency: 10 Hz
- Applied maximum stress (σ_{max}) levels: **determined based on σ_y**
- Stress ratio ($\sigma_{min}/\sigma_{max}$): **R = 0.1**
- Voltage taps separation: **20 mm**
- I_c was measured using the four-probe method with an electron field criterion of 1 μV/cm

Static fatigue test conditions

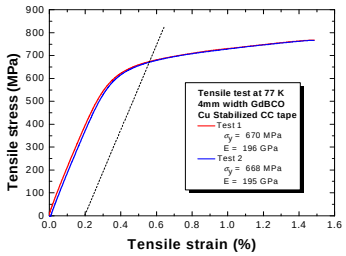
- A lever-type loading device: lever ratio 1:10
- Electrical feedthrough: designed to transmit 1 kA
- I_c measurement: up to 100 hour elapsed time
- GFRP mandrel bending condition: 50 mm dia.
- Multiple voltage taps separations: AB= 25 mm, section BC= 25 mm, round section CD= 90 mm, section DE= 25 mm, and section EF = 25 mm, with **section AF= 190 mm**
- A 450 mm-long CC tape sample was used: Gripping part: 40 mm; Gage length: of 370 mm

General conditions

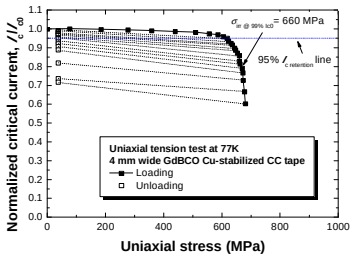
- CC tape samples were cooled for about 5 min and held for 10 min before starting the I_c measurement.
- $In_{52}Sn_{48}$ solder was used to attach the voltage taps to the CC sample

Results and Discussion

Stress-strain curves at 77 K



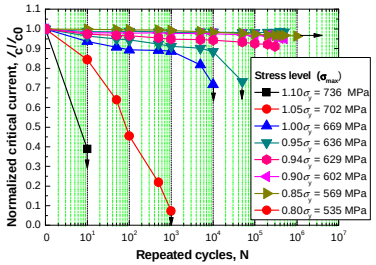
Electromechanical properties at 77 K



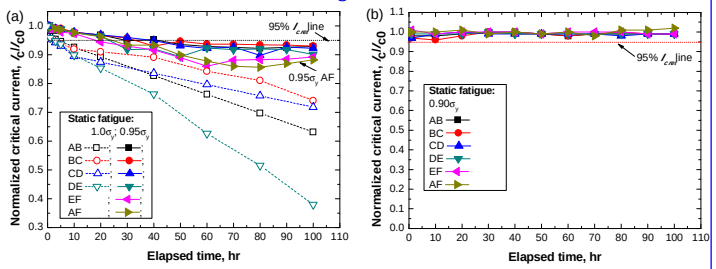
❑ Relationship between characteristic properties obtained by uniaxial tension tests

- **σ_y (0.2% offset strain):** 669 MPa
- Stress-strain curves are used to determine the stress levels since I_c degradation of CC tapes is closely related to the onset of plastic deformation
- **Irreversible stress limit (σ_{irr}):** 99% I_{c0} recovery criterion = 660 MPa
- The obtained electromechanical stress limit, σ_{irr} conformed well to the mechanical yield strength σ_y obtained from the stress-strain curves

High cycle fatigue test results



Static fatigue test results



❑ Characteristic properties evaluated by fatigue tests

- **Mechanical and electrical fatigue limits:** σ_{max} level where mechanical and electrical failure did not occur up to 10^6 cycles
- Number of cycles where the I_c starts to degrade varied with the applied σ_{max} level

❑ I_c degradation behavior: high-cycle fatigue

- ✓ **$\sigma_{max} \leq 0.90\sigma_y$**: no I_c degradation up to 10^6
- ✓ **σ_{max} of $0.91\sigma_y$-$0.94\sigma_y$**: gradual I_c degra; crack propagated slowly then accele with repeated cycles
- ✓ **$\sigma_{max} = 0.95\sigma_y$**: gradual I_c degradation occurred; fatigue life=5 x 10^4 cycles
- ✓ **$\sigma_{max} > 0.95\sigma_y$:** I_c degraded significantly after 10 cycles with a very short fatigue life

❑ I_c degradation behavior: static-fatigue

- ✓ **$\sigma_{max} = 0.90\sigma_y$**: no I_c degradation up to 100 hr
- ✓ **$\sigma_{max} = 0.95\sigma_y$:** I_c started to degradation significantly after 30 hr
- ✓ **$\sigma_{max} = 1.0\sigma_y$:** I_c degraded sharply after a static load was applied
- ✓ I_c degradation along the Section AF occurred most significantly as σ_{max} level increased

Conclusions

- A reliability evaluation test procedure for REBCO CC tapes based on mechanical and electromechanical properties was established.
- The interactions between mechanical and electromechanical properties were obtained and showed consistent results.
- As the σ_{max} level increases, both the repeated cycles for high-cycle fatigue and the time for static-fatigue to bring noticeable I_c degradation decreased significantly. A constructed static fatigue tester provided meaningful results in the reliability assessment of CC tapes.
- By further efforts, essential long-term reliability of CC tapes could be achieved by optimizing the evaluated test conditions.

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