Investigation of the Tape Shaped RHQT-Processed Nb_3Al Conductors

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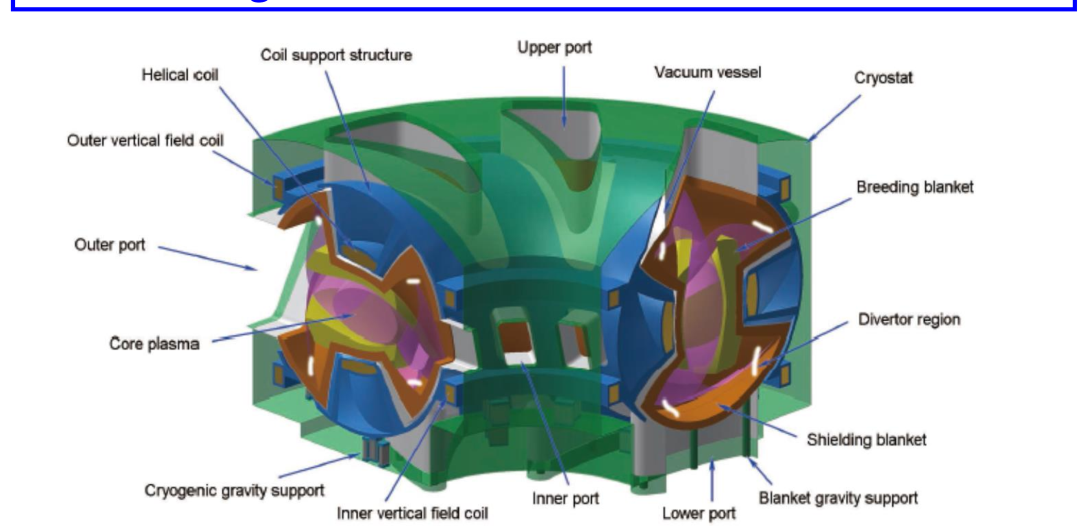
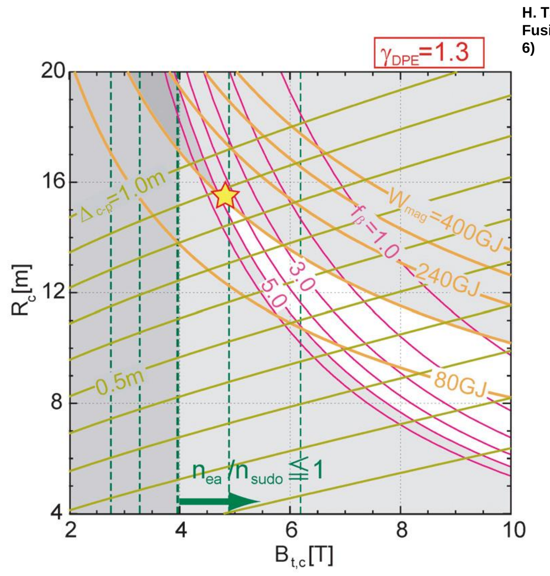
1. Background

Final Target : Helical DEMO Reactor FFHR-d1



H. Tamura, et. al., "Design Status of the Structural Components of the Helical Fusion Reactor FFHR-d1", Plasma and Fusion Research, Vol. 11 (2016) 2405061(1-6)

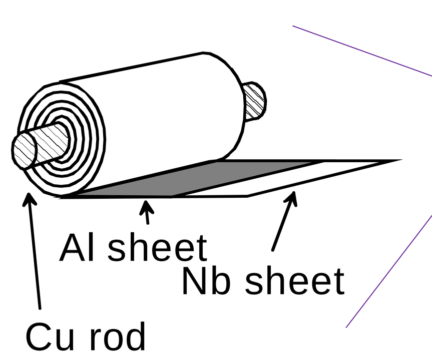


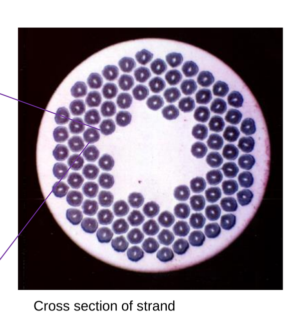
Helical coil major radius R_c [m]	15.6
Plasma major radius R_p [m]	14.4
Helical pitch parameter γ_c	1.25
Plasma volume V_p [m^3]	1878
Helical coil minor radius a_c [m]	3.9
Toroidal field at winding center $B_{t,c}$ [T]	4.7
Magnetic field on axis B_{ax} [T]	5.08
Central electron density n_{e0} [10^{20}m^{-3}]	2.5
Central electron temperature T_{e0} [keV]	10.5
Peak beta value β_0 [%]	10
Fusion power P_{fus} [GW]	3.0
Confinement enhancement factor relative to the experimental data used for DPE γ_{DPE}	1.3
Confinement enhancement factor relative to ISS04v3 scaling $H^{ISS04v3}$	1.19
Helical coil current density j_c [A/mm^2]	25
Maximum magnetic field on helical coil B_{max} [T]	11.9
Minimum distance between the helical coil and the plasma Δ_{c-p} [m]	0.89
Average neutron wall load <Γ_{nw}> [MW/m^2]	1.5

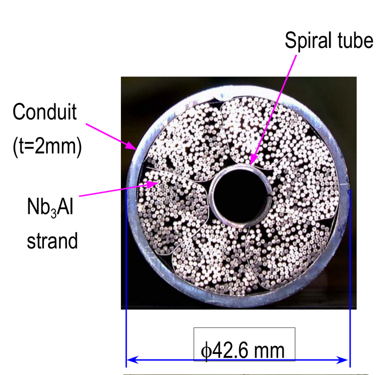
T. Goto, et. al., "Design Window Analysis for the Helical DEMO Reactor FFHR-d1", Plasma and Fusion Research, Vol. 7 (2012) 2405084(1-5)

→ React & Wind method is preferable for a coil fabrication.

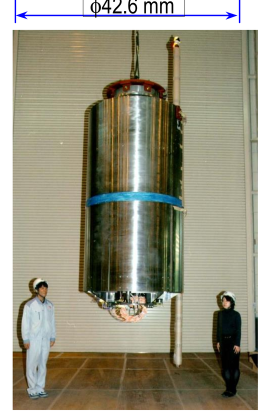
Past Experience: ITER-CS Nb_3Al Model Coil



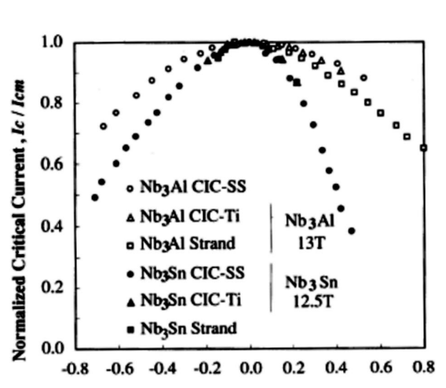


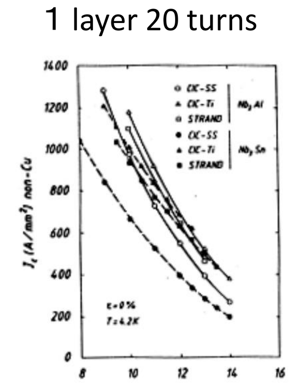


R&W Nb_3Al Insert Coil
Winding Diam.: 1.43m
Bending strain: 0.4%
1 layer 20 turns



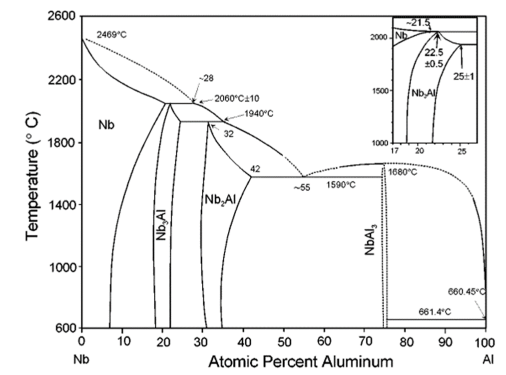
13T-46kA
Nb_3Al insert coil

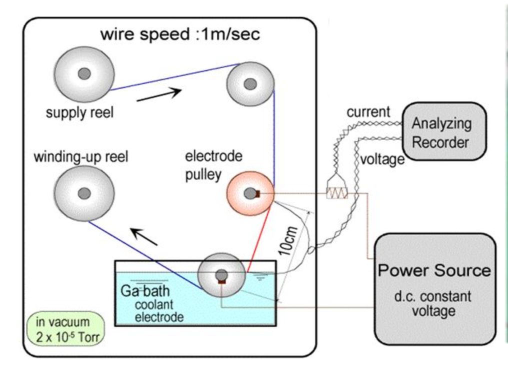


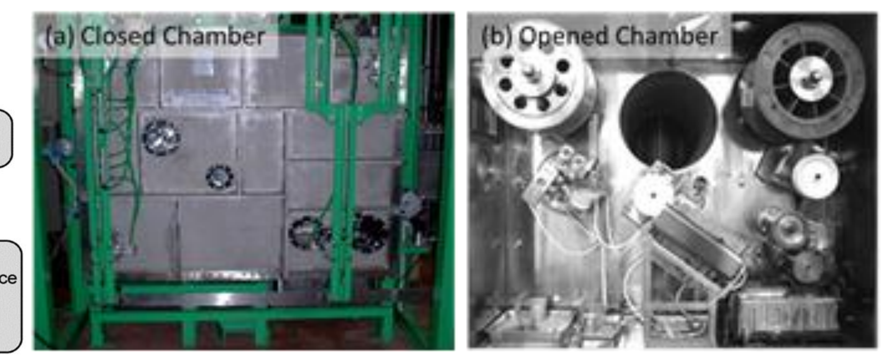


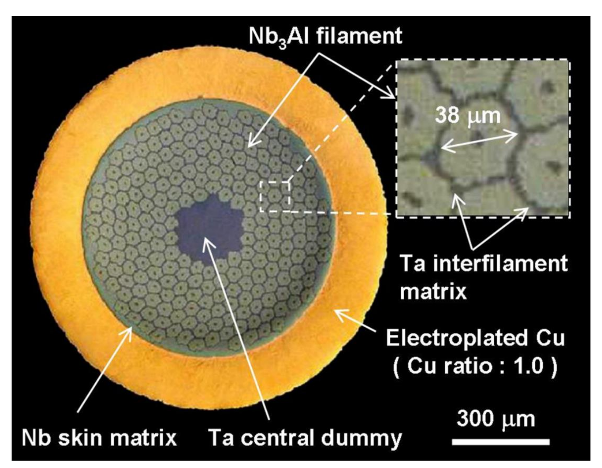
→ Nb_3Al wires are promising for React & Wind method.

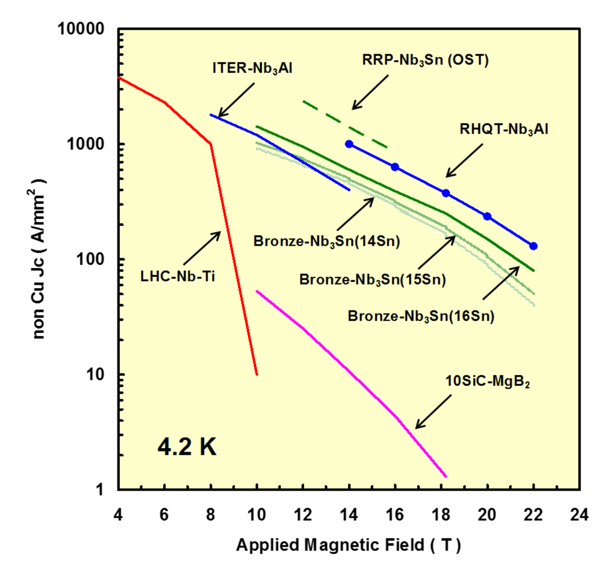
2. Rapid Heating/Quenching & Transformation (RHQT) Nb_3Al

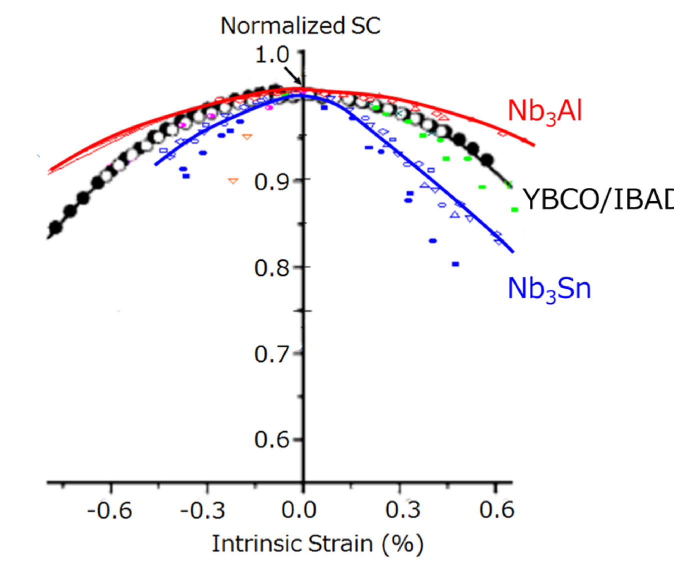






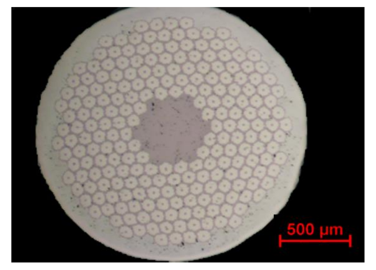




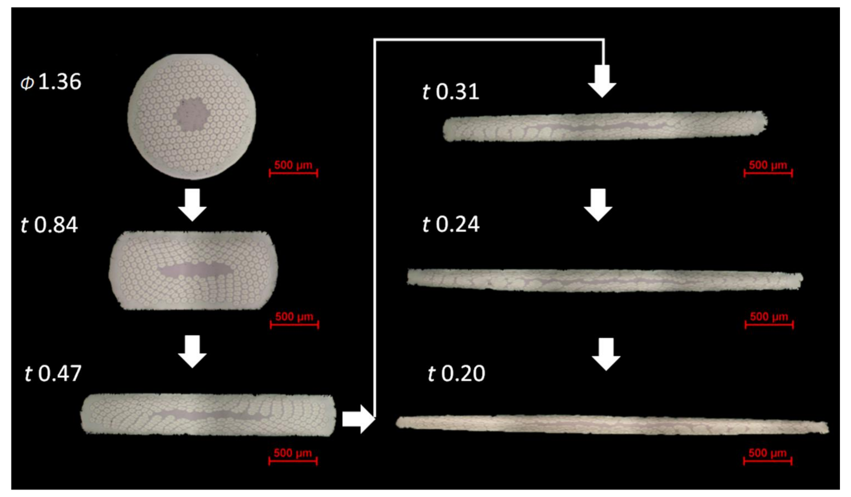


→ Ductile Nb-25%Al solid solution were synthesized after the RHQ.
→ Cu stabilizer was fabricated after the RHQ by a reel to reel electroplating.
→ The RHQT-Nb_3Al shows much larger J_c (4.2 K, 12 T) than the diffusion processed Nb_3Al. (800 A/mm^2 →1,600 A/mm^2)

3. Form Change from Round Wire to Tape for Minimizing of Bending Strain



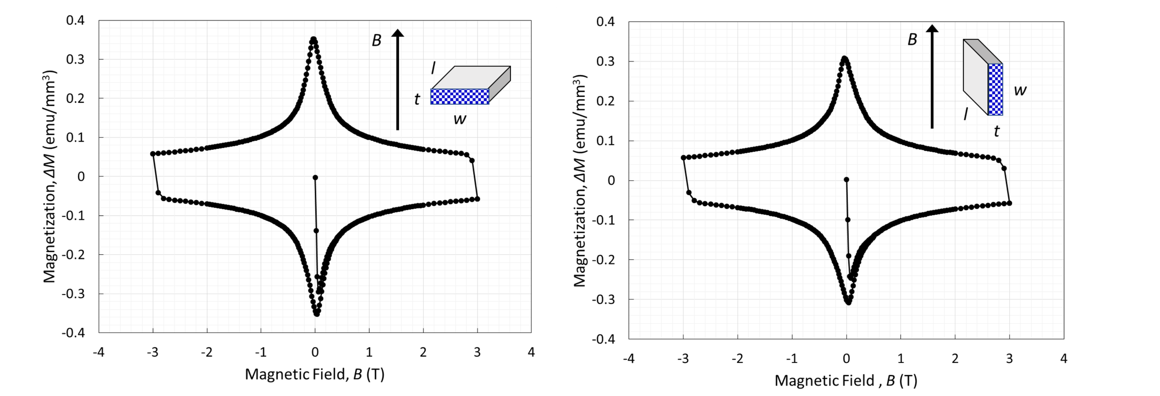
Wire dia. (ave.)	1.36 mm
Filament dia. (ave.)	80μm
Interfilament matrix	Ta
matrix/filament ratio	0.8
Nominal Al thickness	170 nm
Num. of Filament	222



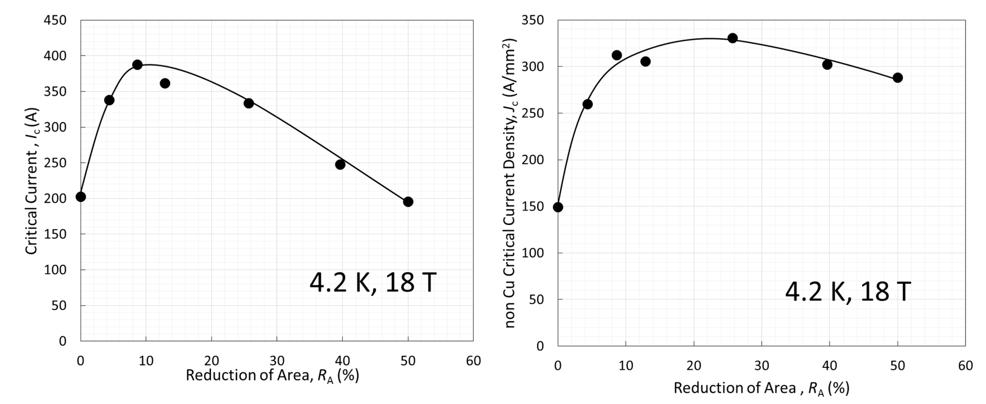
→ Ductile Nb-25%Al solid solution wire could be rolled to tape at room temperature.
→ Final thickness of the RHQT-Nb_3Al multifilamenry tape is about 0.2 mm. Its width is 4.6 mm.
→ The RHQT-Nb_3Al multifilamenry tape is much improved mechanical flexibility.

4. Superconducting Properties of RHQT-Nb_3Al Tape

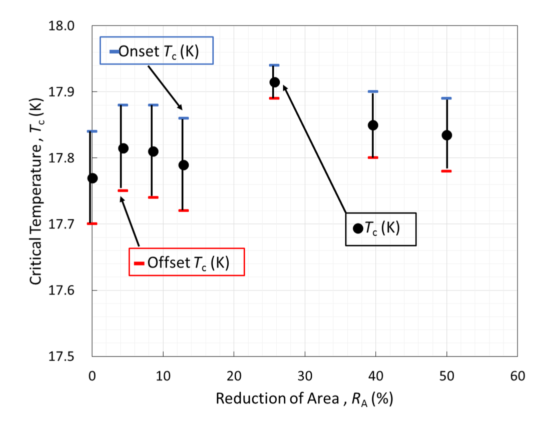
Low Field Instability & Anisotropy



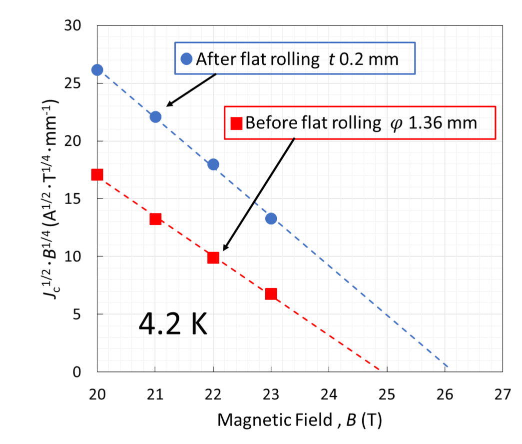
Transport I_c & non Cu J_c at 4.2 K



T_c



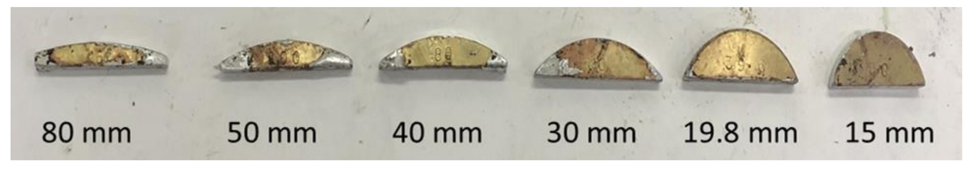
B_{c2} (4.2K)



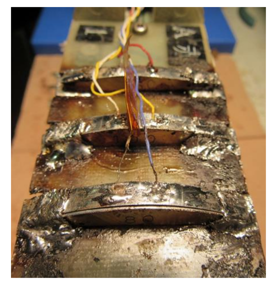
→ The RHQT-Nb_3Al tape does not show both low field instability and anisotropy.
→ Ic at 4.2 K and 18 T became double by the reduction of area (R_A) of 10 %. Then, it gradually decreased with increasing R_A.
→ Non Cu J_c increase with increasing the reduction of area up to 25 %.
→ B_{c2} (4.2 K) apparently increased by a form changing from wire to tape, and T_c slightly increased.

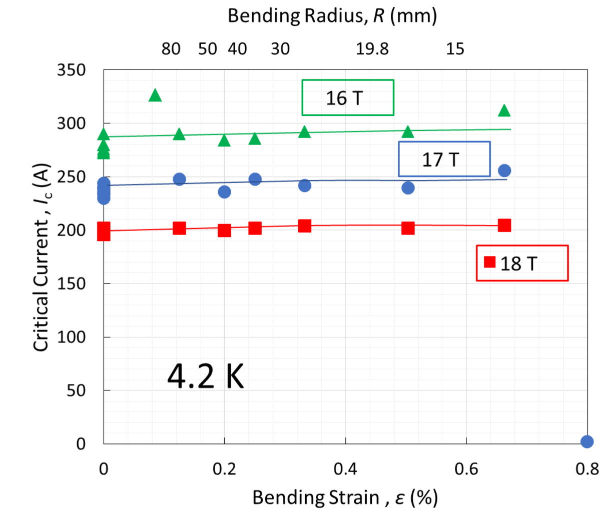
5. Relationship Between I_C and Bending Strain on RHQT-Nb_3Al Tape

Brass fixtures for keeping bending with different radius.



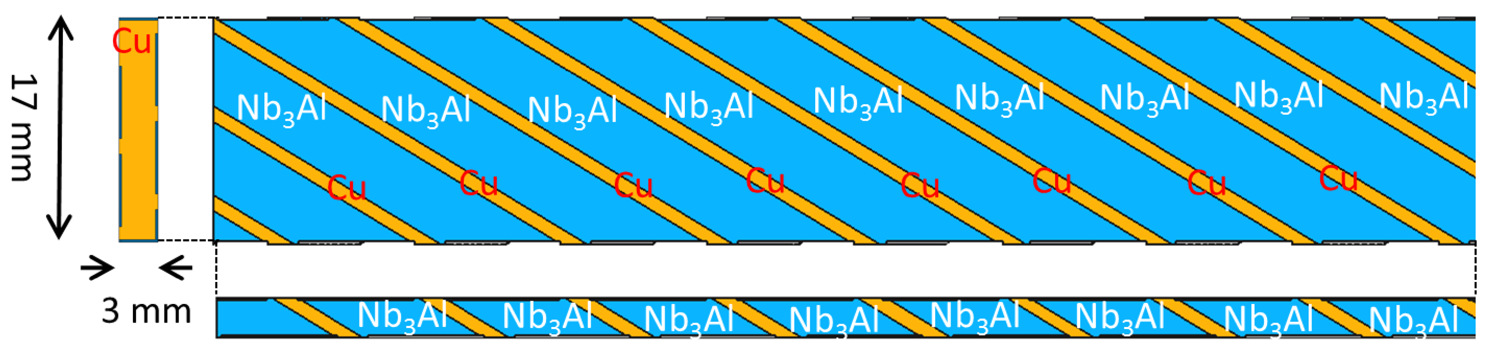
Radius (mm)	Bending Strain (%)
80	0.125
50	0.200
40	0.249
30	0.332
19.8	0.503
15	0.662

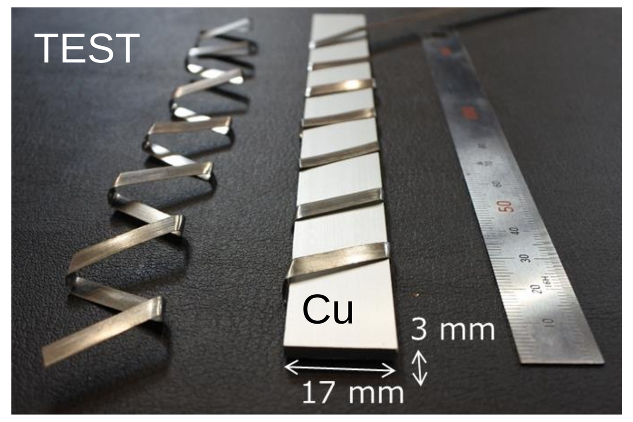




→ The RHQ-Nb_3Al tapes were soldered on the brass fixture having different radius.
→ I_c (4.2 K) were measured by 4 probe method under the magnetic field up to 18 T.
→ I_c (4.2 K) did not change by applying the maximum bending strain up to 0.662.

6. New Cable : Six RHQT-Nb_3Al Tapes around Cu Stabilizer Plate





→ We propose new designed large current capacity cable using the RHQT-Nb_3Al tapes.
→ 0.2 mm thick six RHQT-Nb_3Al tapes are lapped around Cu stabilizer plate with 17 mm in width and 3 mm in thickness.
→ This new cable can be minimized the bending strain, and the Cu electroplating process can be skipped as well.