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【4MO1-06】
New Nb_3Al superconducting wires with Ta-Ni interfilament matrix

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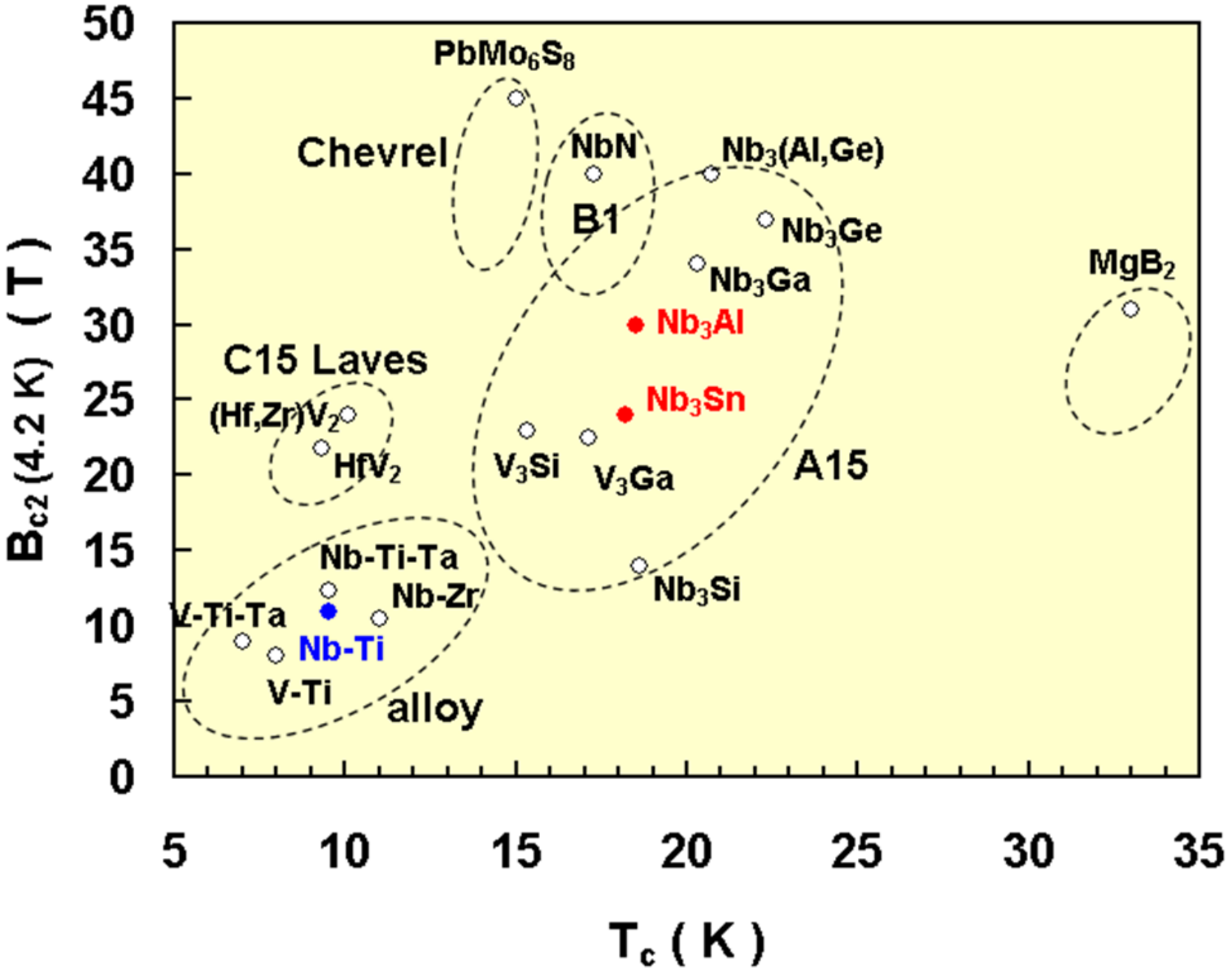
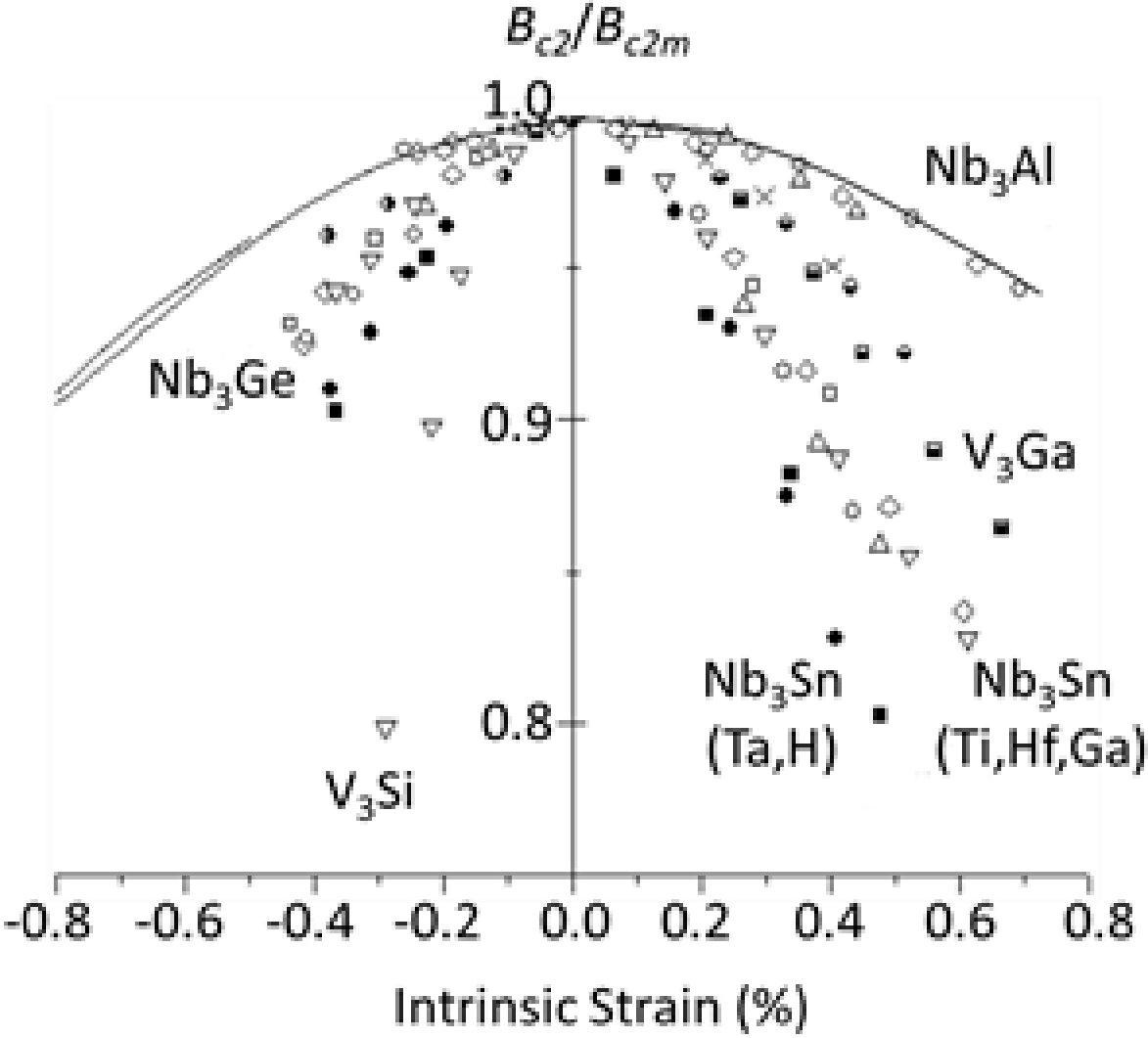
Kiyosumi Tsuchiya (KEK)

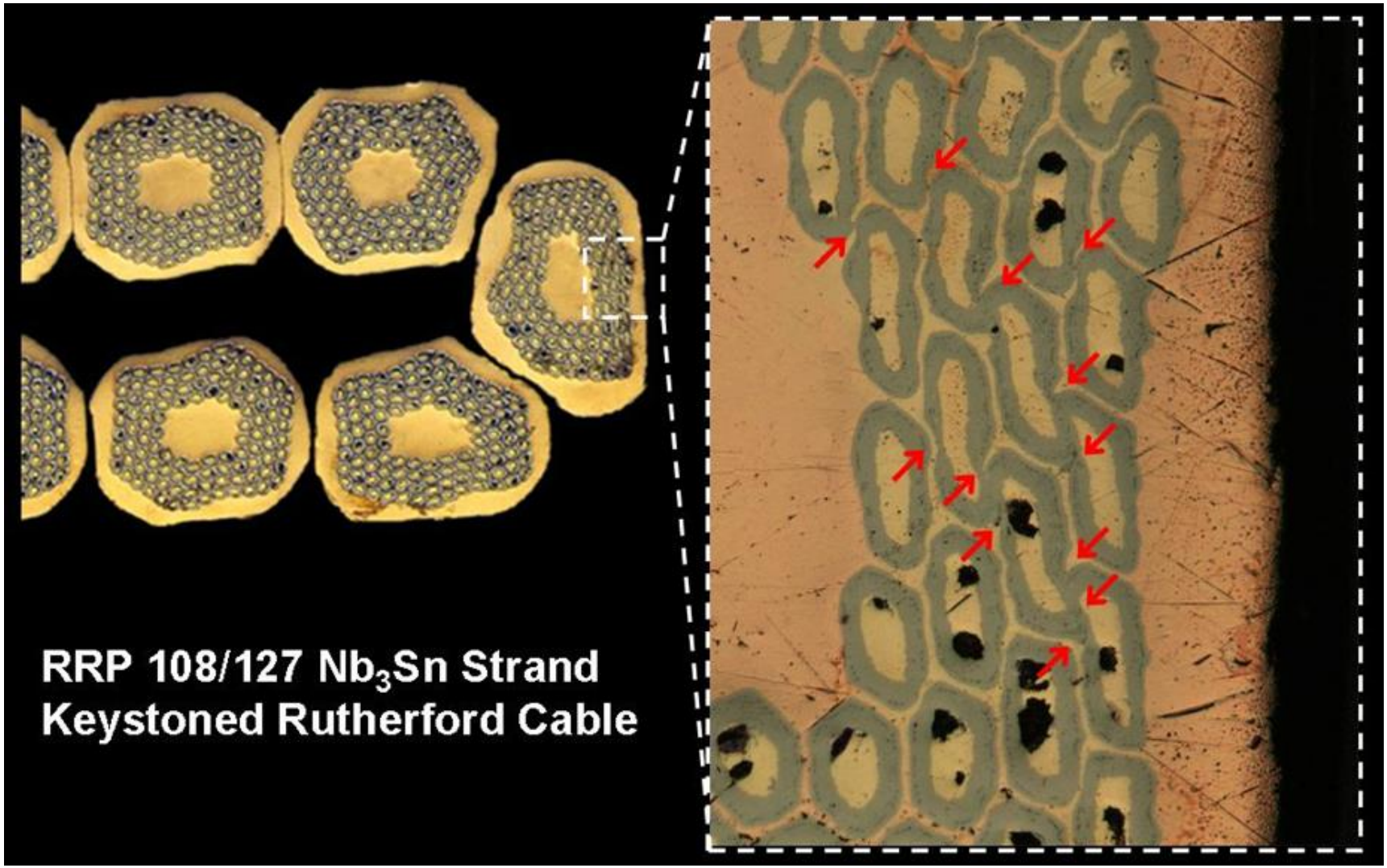
Nb_3Al : 30 T of B_{c2} (4.2K)



Nb_3Al : Better Strain Tolerance

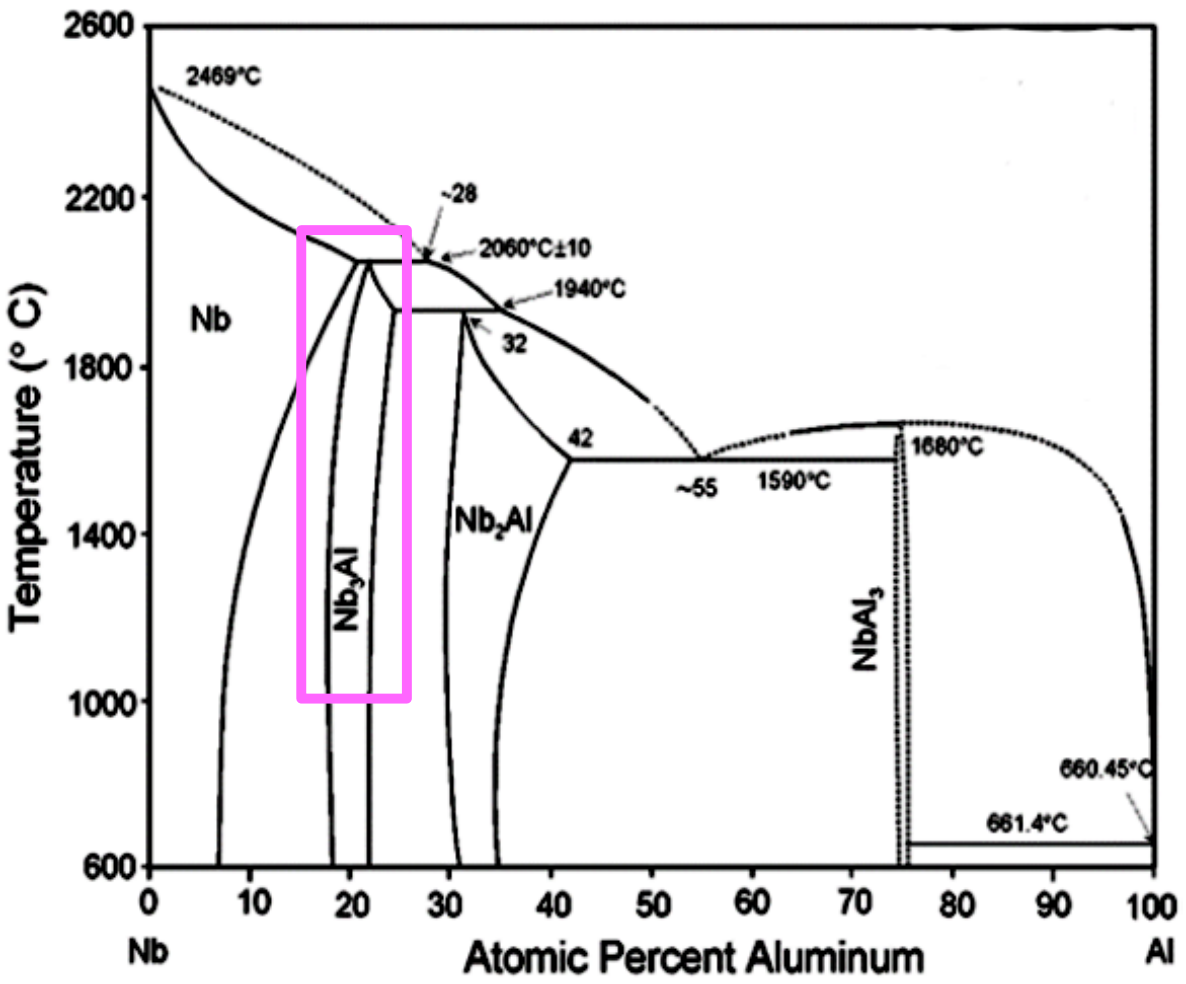


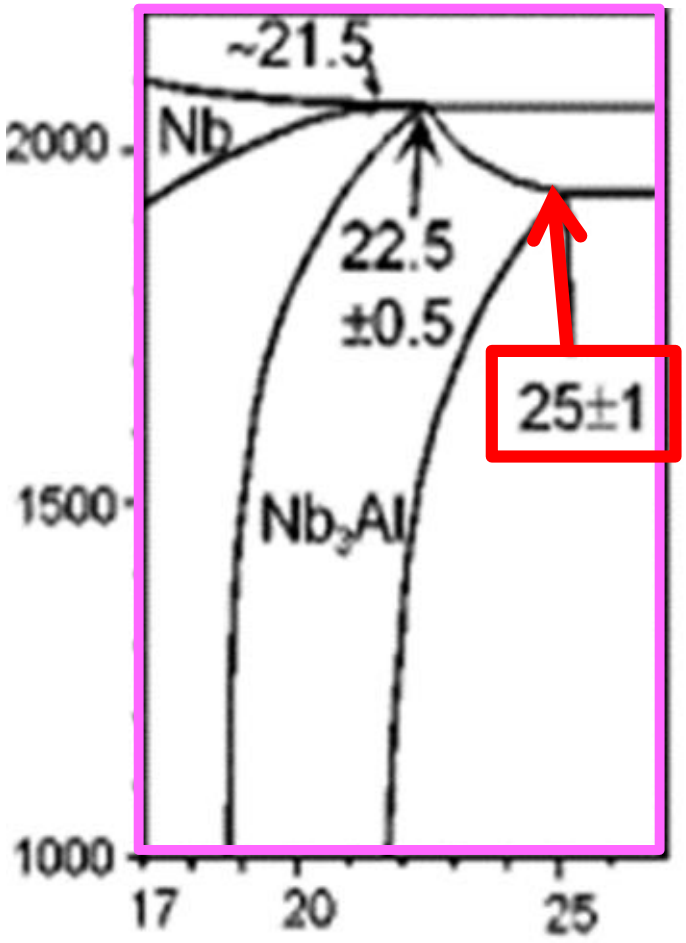
Nb_3Al : No Tin Leakage Problem



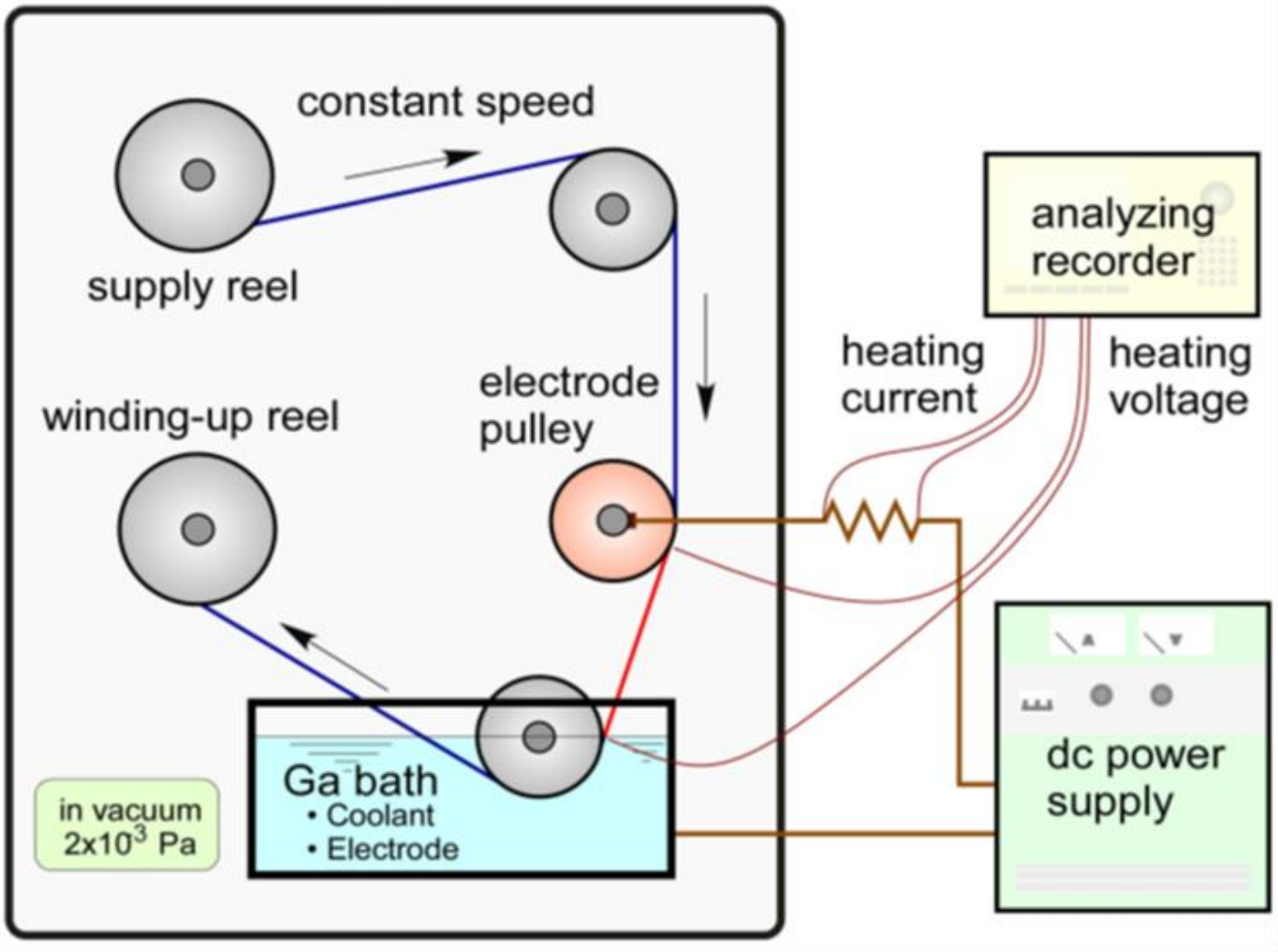
Courtesy by R. Yamada, E. Barzi, A. Zlobin (FNAL)

Need High Temperature Heat Treatment at 2,000°C for Stoichiometry



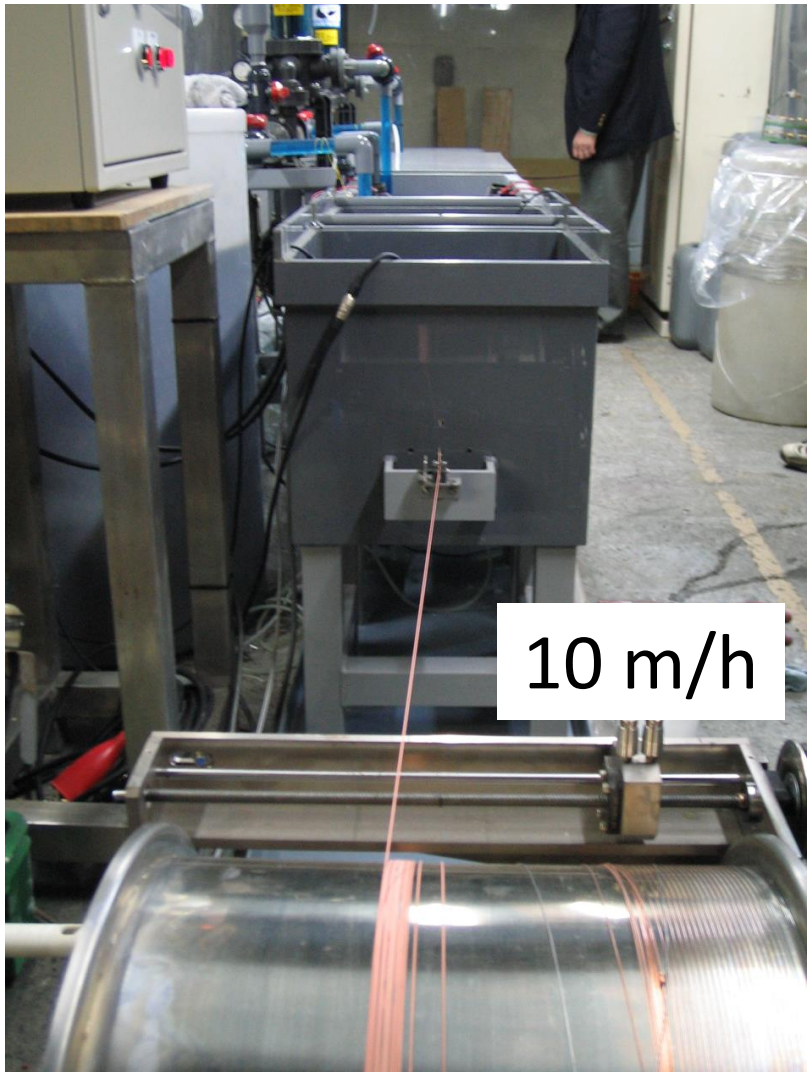


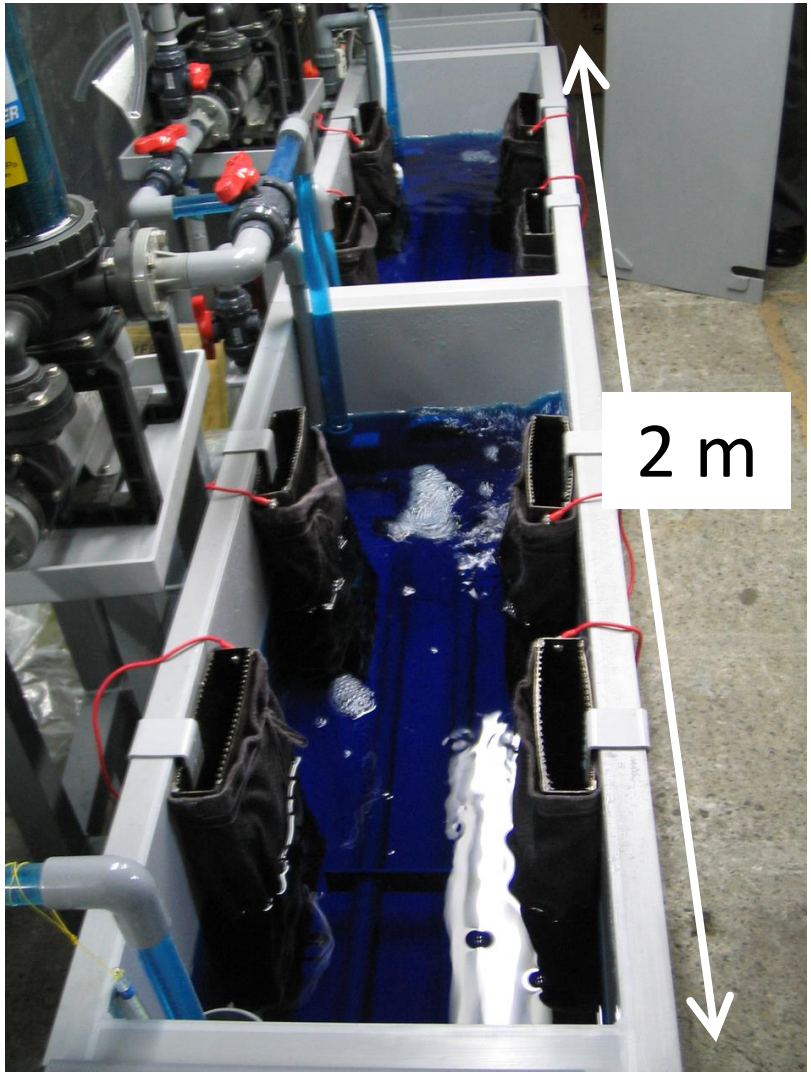
NIMS Method (1994)
(Rapid Heating/Quenching)



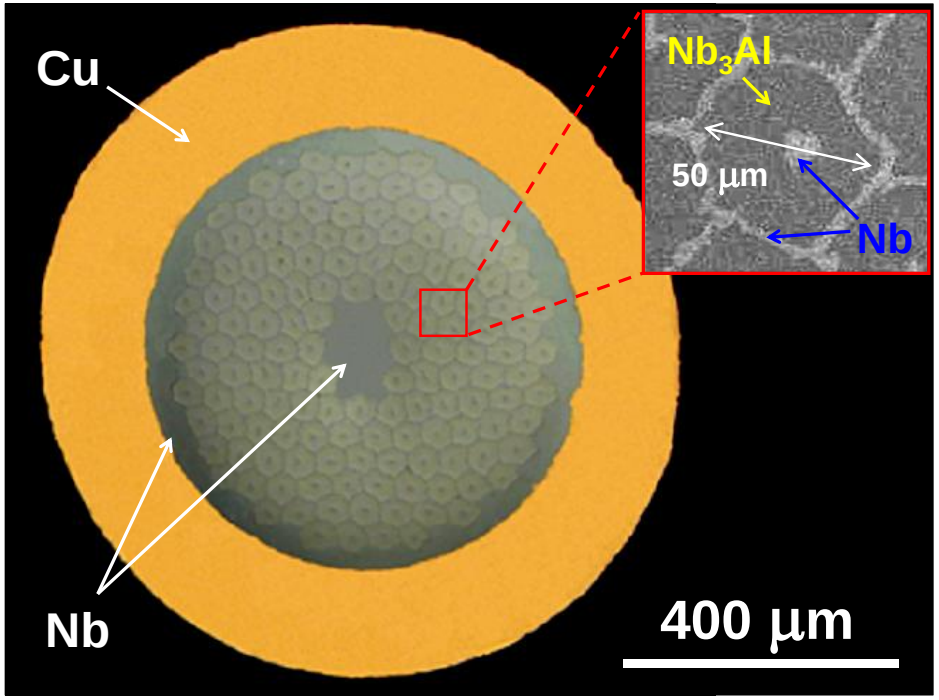
Cu Stabilizer Fabrication

Reel to Reel High Speed Cu electroplating





1 km Long 1 mm diameter Nb_3Al Strand with Cu stabilizer (2006)



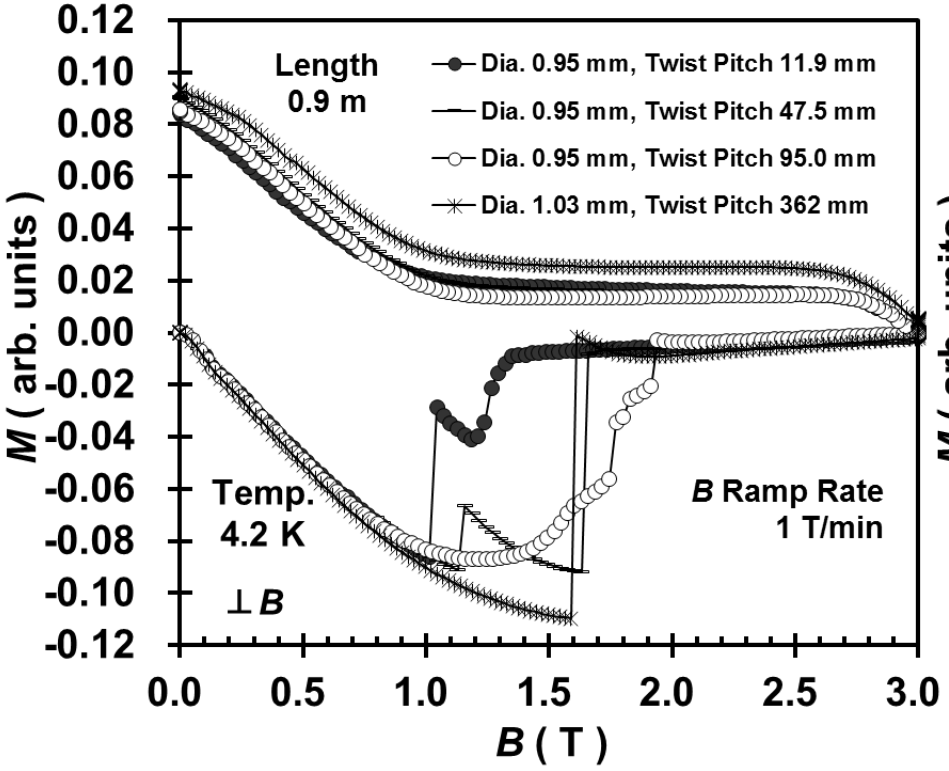
1.2 km

Nb interfilament matrix

Good Cold-Drawability, No Wire-Breakage

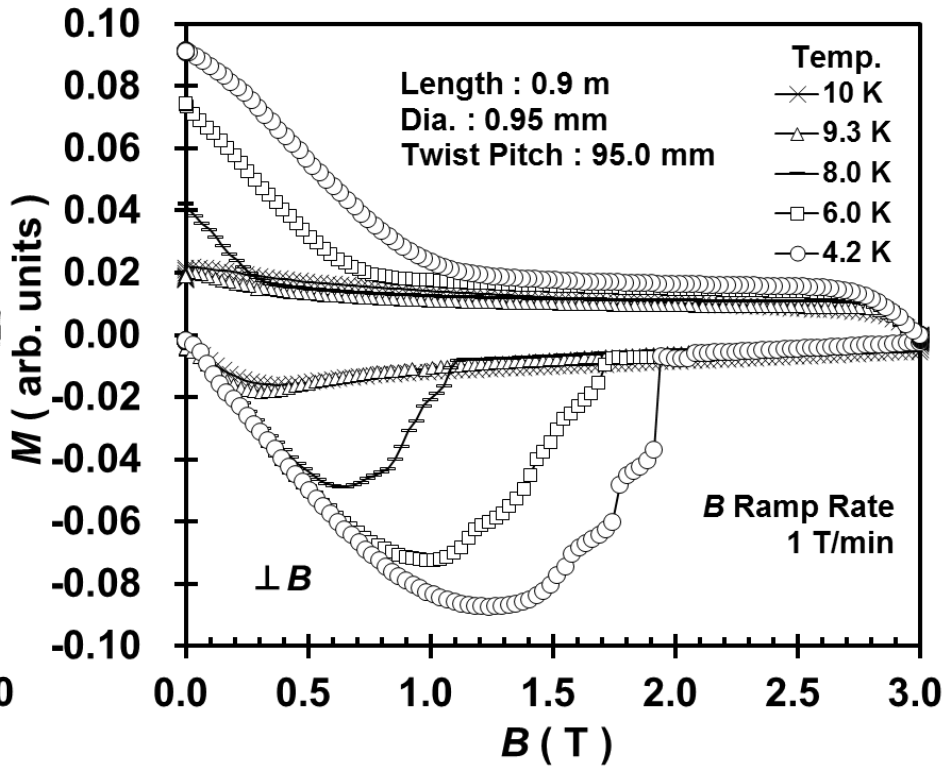
Magnetic Instability at Low Fields and 4.2 K

(a) Twist Pitch Dependence



No correlation with twist pitch at 4.2 K

(b) Temperature Dependence

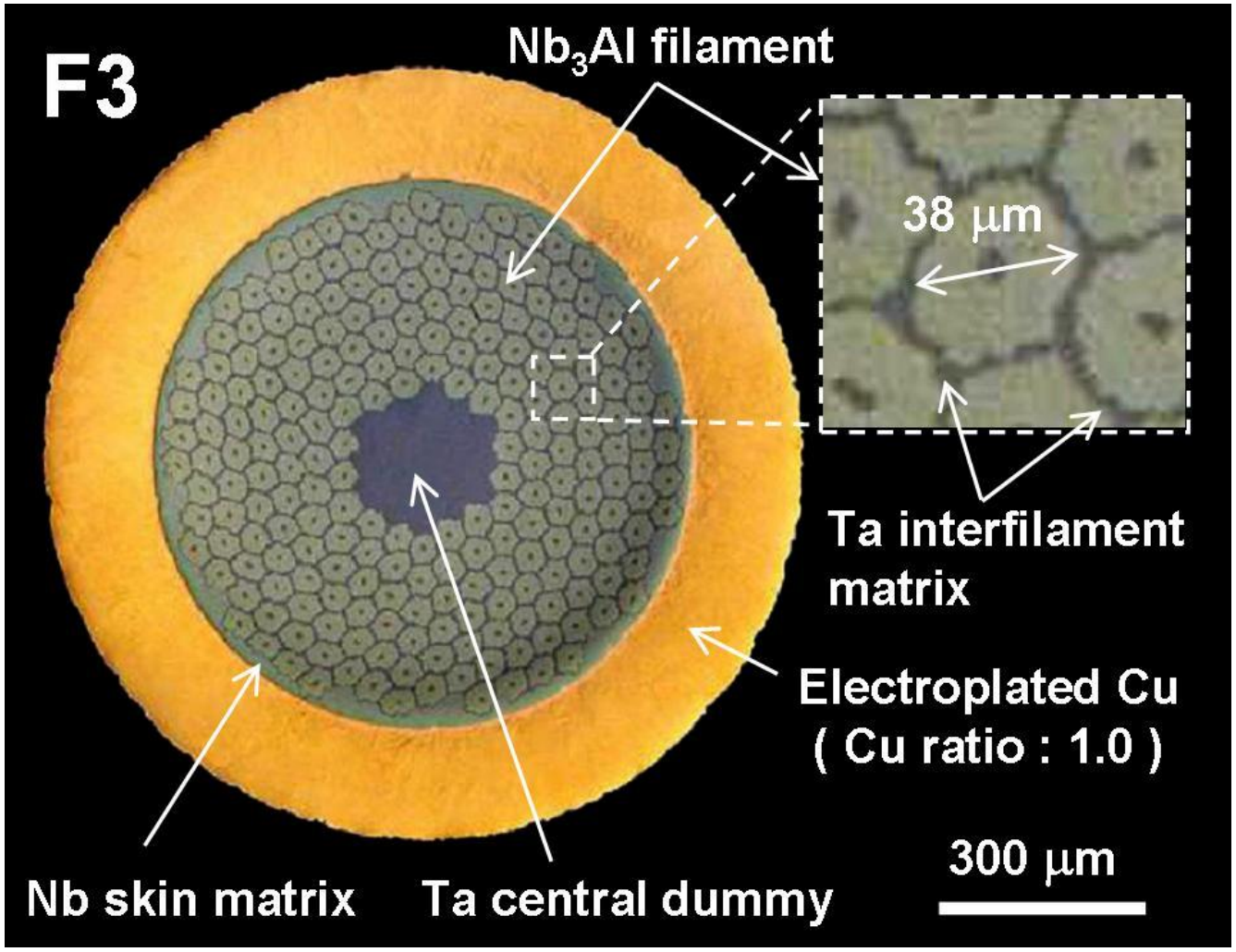


Suppressed with increasing temperature

Niobium and Tantalum

		Niobium (Nb)	Tantalum (Ta)
Purity (wt.%)		99.8~99.9	~99.9
Physical Properties	Category of Superconductivity	Type II	Type I
	Critical Temperature, Tc (K)	9.2	4.48
	Critcal Field, Bc (4.2 K) (T)	0.35	0.01
	Melting Point (°C)	2,477	3,017
	Crystal Structure	body-centered cubic	body-centered cubic
	Magnetism	Paramagnetism	Paramagnetism
	Density (g/cm^3)	8.57	16.7
	Coefficient of Thermal Expansion (μm/m·K)	7.3	6.3
	Thermal Conductivity (300 K) (W/m·K)	53.7	57.5
Mechanical Properties	Vicker's Hardness, Hv (300 K)	~60	~80
	Young's Modulus (300 K) (GPa)	105	186
	Poisson's Ratio (300 K)	0.40	0.34
	Tensile Strength (300 K) (MPa)	~ 180	~ 220
	Elongation (300 K) (%)	~ 25	~ 25

Ta Matrix Nb_3Al Strand (F3)



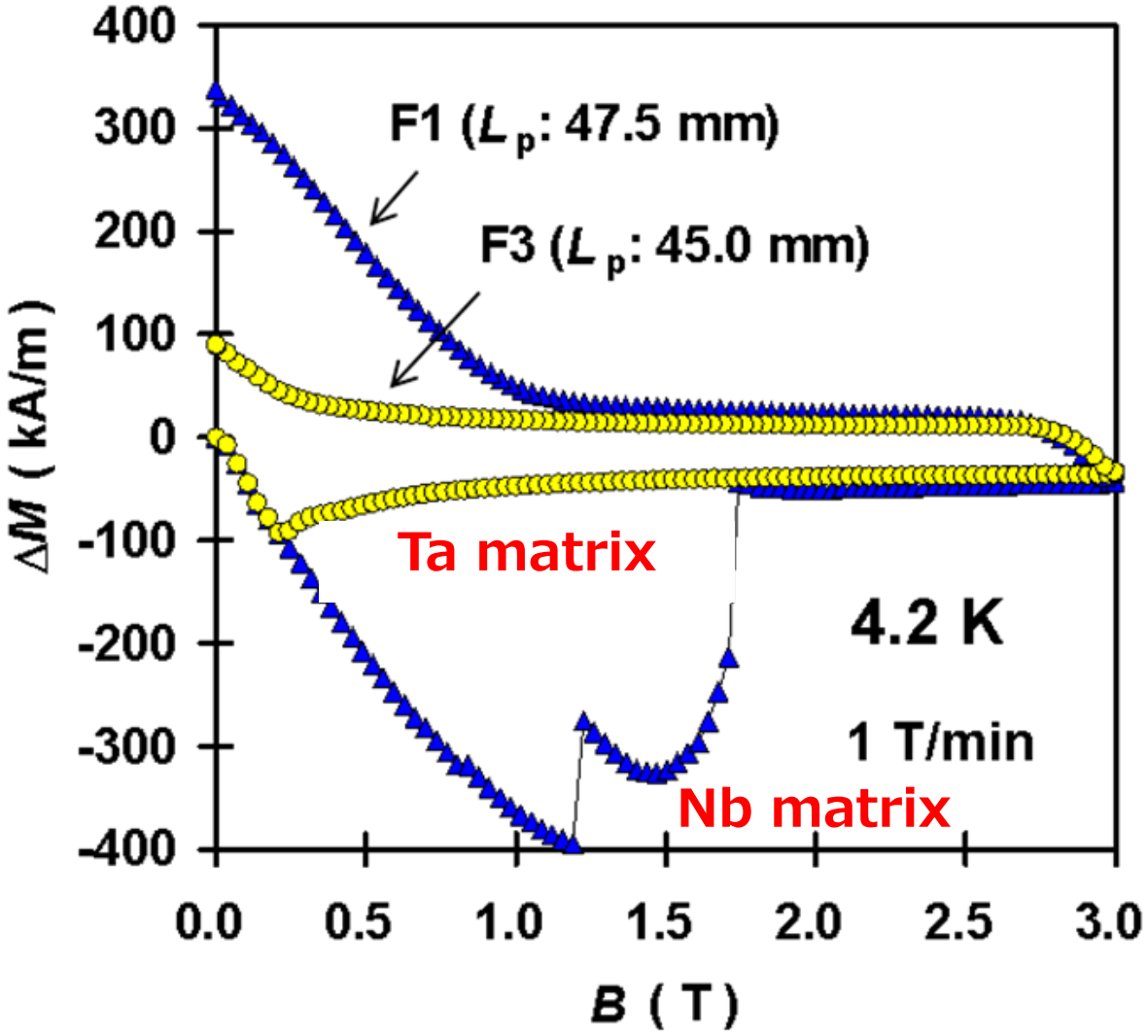
Ta matrix

Cu/non-Cu ratio = 1.0

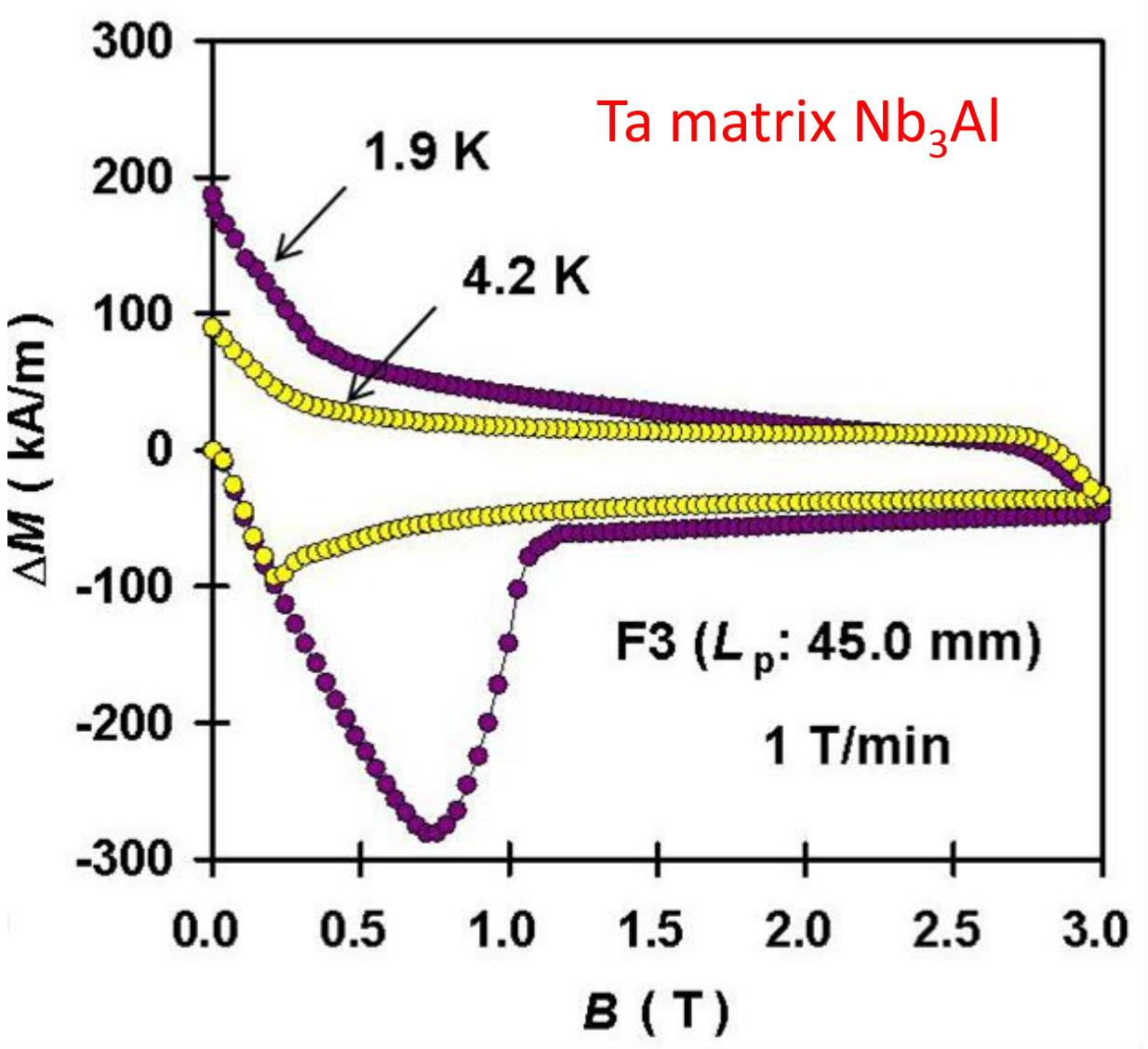
222 Subelements

Deff 38 μm

Suppression of Low Field Instability at 4.2 K on Ta matrix Nb_3Al Strand



Magnetic Anomaly in Low Fields at 1.9 K

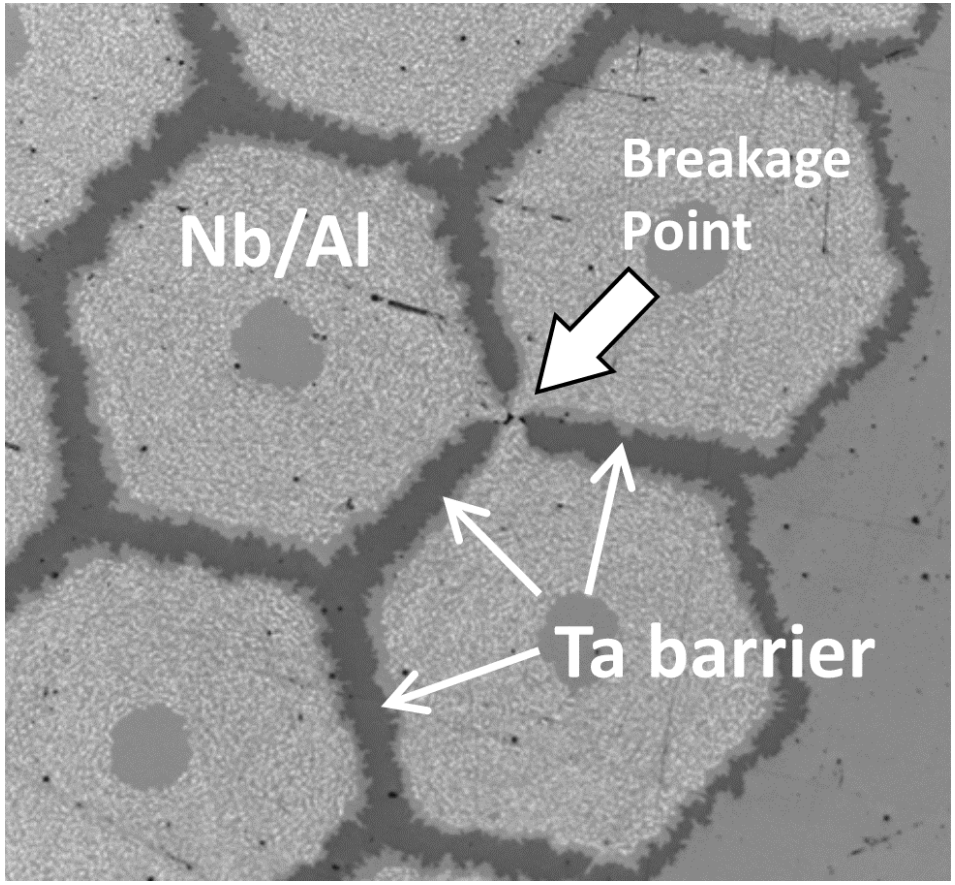


General Specification and Performance of Ta matrix Nb_3Al strand

Strand Dia. (with Cu)	1.00 mm
Strand Dia. (w/o Cu)	0.70 mm
No. of Subelements	222
No. of Total Subelements	222 + 19
Physical Filament Dia.	38 μm
Cu/Non-Cu ratio	1.0

I_c (4.2 K, 12 T)	581.3 A
I_c (4.2 K, 15 T)	343.0 A
non-Cu J_c(4.2 K,12 T)	1,481 A/mm^2
non-Cu J_c(4.2 K,15 T)	874 A/mm^2
n value (4.2 K,12T /15 T)	49.9 / 40.3
RRR (20K/300K)	80-170
Low Field Instability (4.2K)	None

Bottleneck for Mass Production



Wire-Breakages always happened from Ta interfilament matrix, when the wire diameter was reduced under 2-3 mm.

Speculations

- Tantalum sheet may have reached its plastic deformation limit in the present precursor drawing.
- The appropriate softy Nickel sheet may help the plastic deformation of rather harder Tantalum sheet.
- Tantalum has large solubility limit of Nickel at high temperature of 2,000^{o}C.
- Tantalum and Nickel sheets can make a Ta-Ni alloy matrix through the RHQ treatment of 2,000^{o}C, as well as making Nb-Al supersaturated solid solution filaments.
- Nickel may degrade the superconductivity of Tantalum, and may separate superconducting filament couppling at 1.9 K in low field.
- Ta-Ni alloy will be a solid solution strengthening alloy, and those matrix probably acts as an additional reinforcement of Nb_3Al strand.

General Ta Matrix Jelly-Rolled Subelement

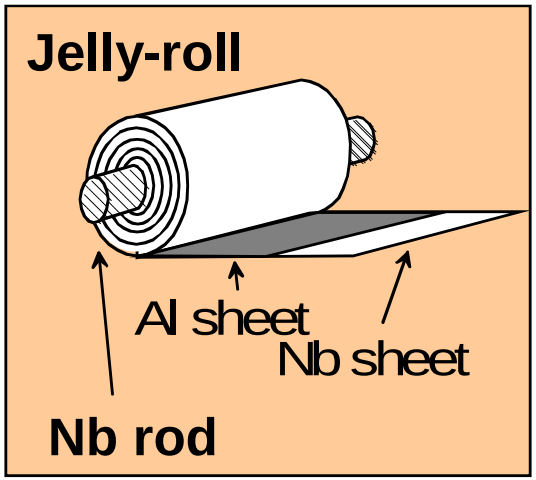
Nb sheet (t0.1 mm) — Al sheet (t0.03 mm) — Nb rod — Ta sheet (t0.1 mm)

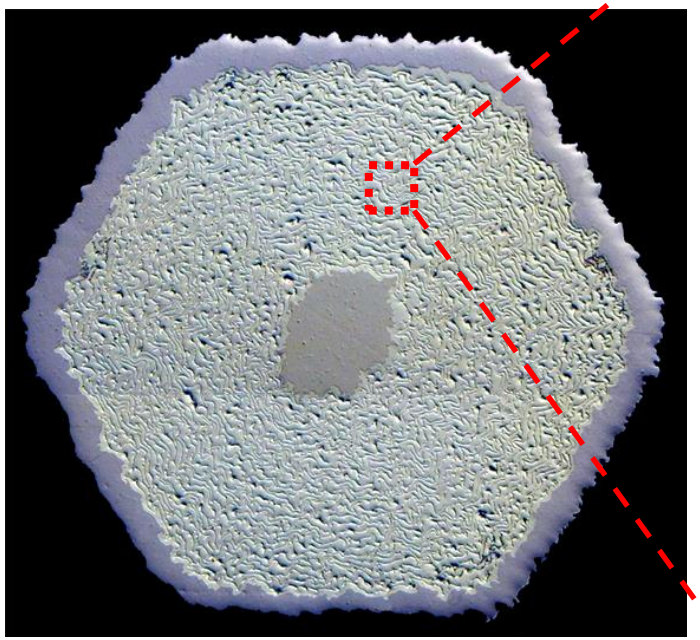
Jelly-Rolling — Cu pipe

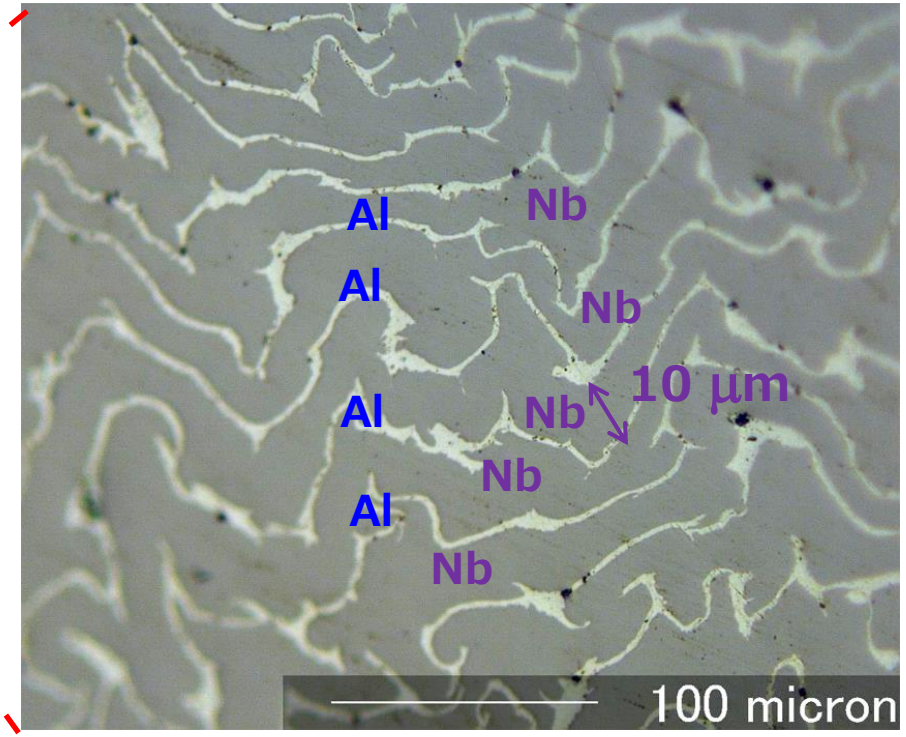
Hydrostatic Extrusion (R.T.)

Die Drawing (R.T.)

Cu Etching Off







New Jelly-Rolled Subelement

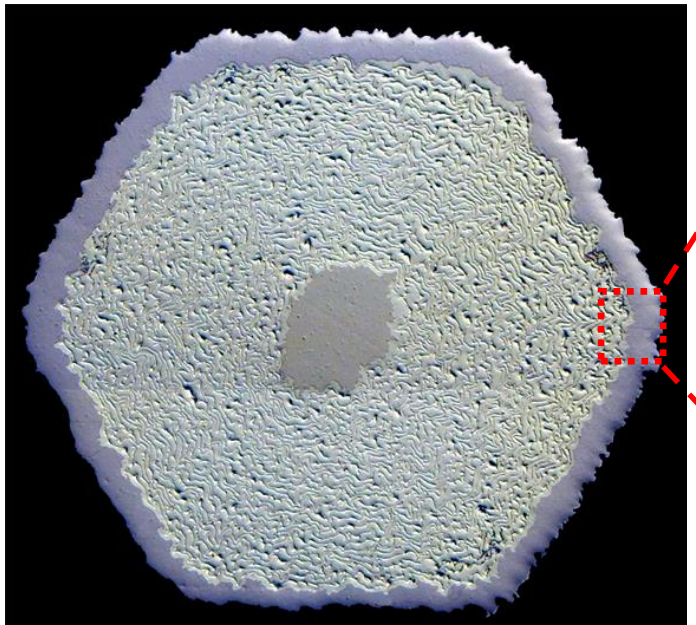
Nb sheet (t0.1 mm) — Al sheet (t0.03 mm) — Nb rod — Ta sheet (t0.1 mm) — Ni sheet (t0.03 mm)

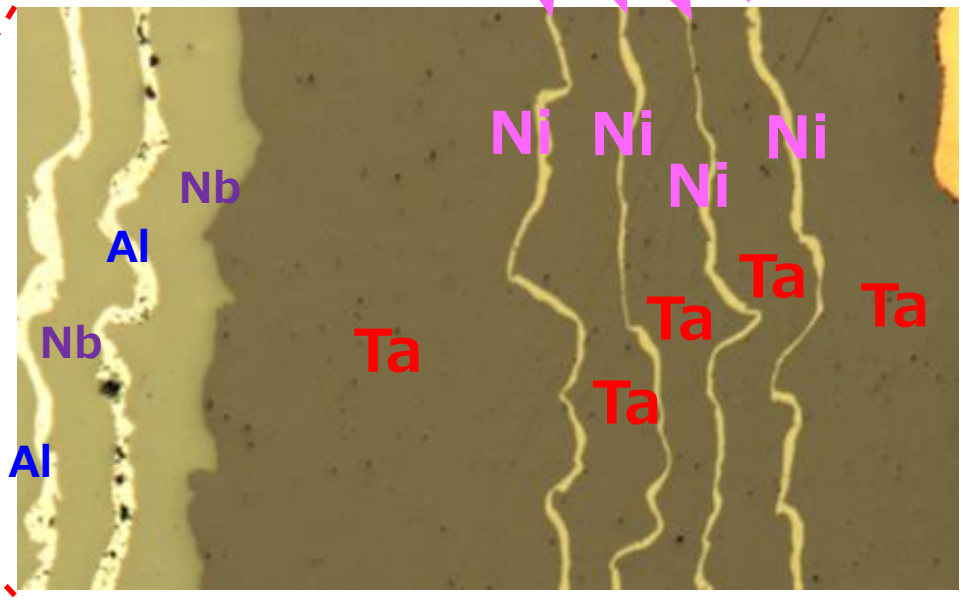
Jelly-Rolling — Cu pipe

Hydrostatic Extrusion (R.T.)

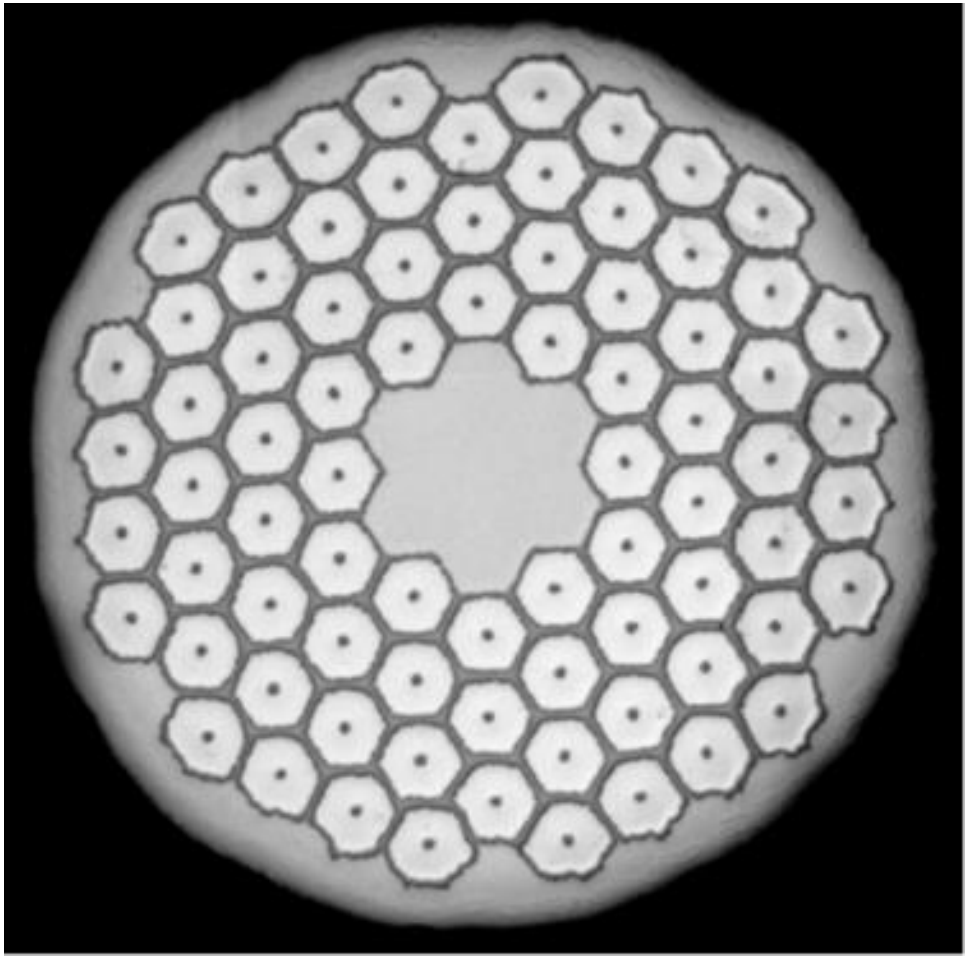
Die Drawing (R.T.)

Cu Etching Off





Multifilamentary Precursor

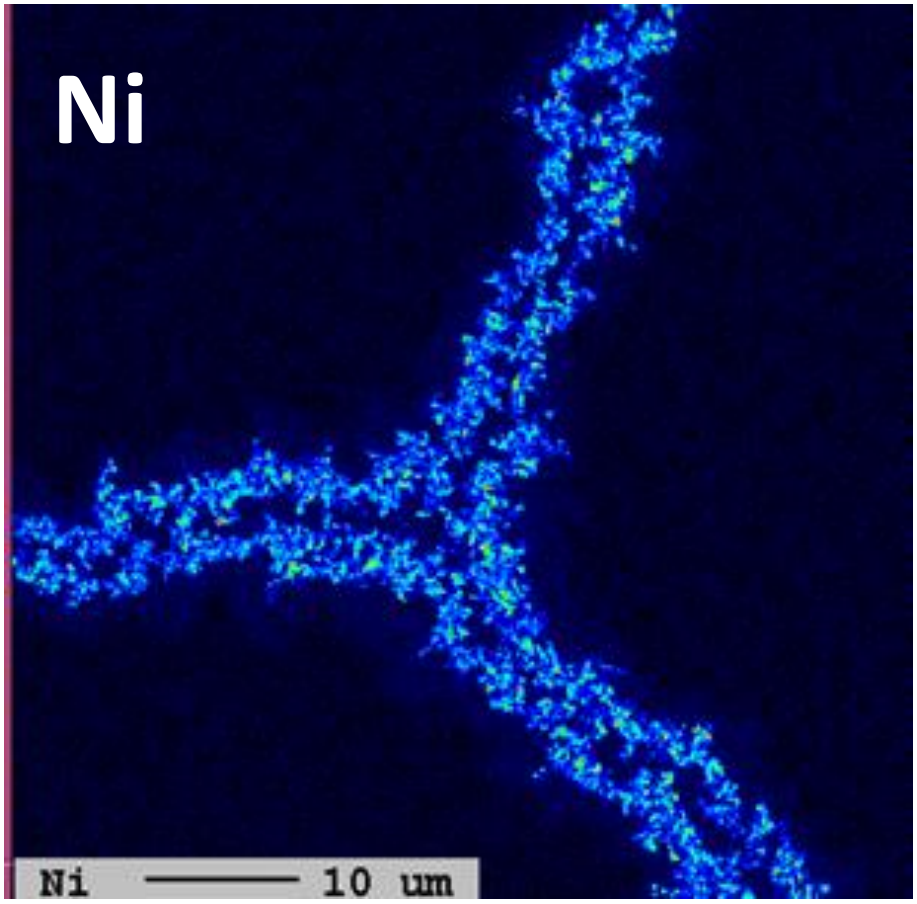


Outer dia. (w/o Cu) : 1.0 mm
JR Filament Dia. : 88 μm
Num. of Filament : 78
Filament/Matrix ratio : 0.8
Central Dummy : Nb
Outermost Matrix : Nb
Interfilament Matrix : Ta/Ni
Wire-Breakage : 1 time
(at φ 2mm)

The Nickel sheet may improve the drawability of Ta matrix precursor, but the wire-breakage still happens a few times. The problem is not completely solved yet.
New Tantalum having excellent cold-workability is still required.

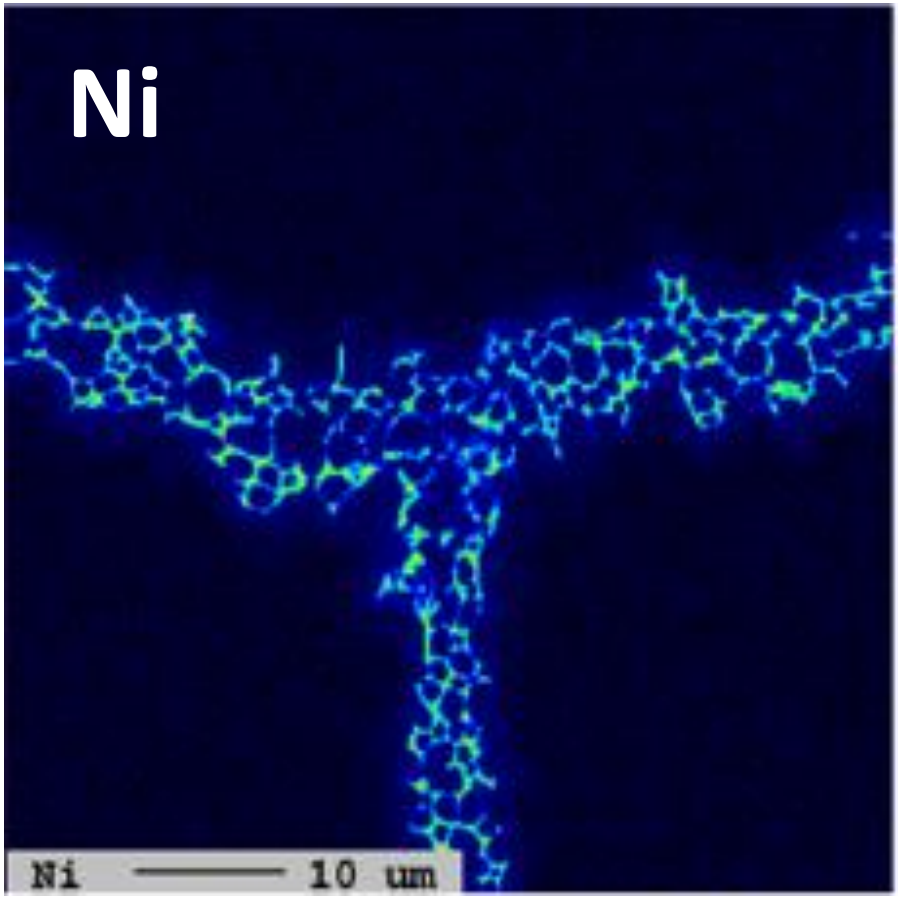
Nickel Mapping at Interfilament Matrix

(a) Before RHQ (after drawing)



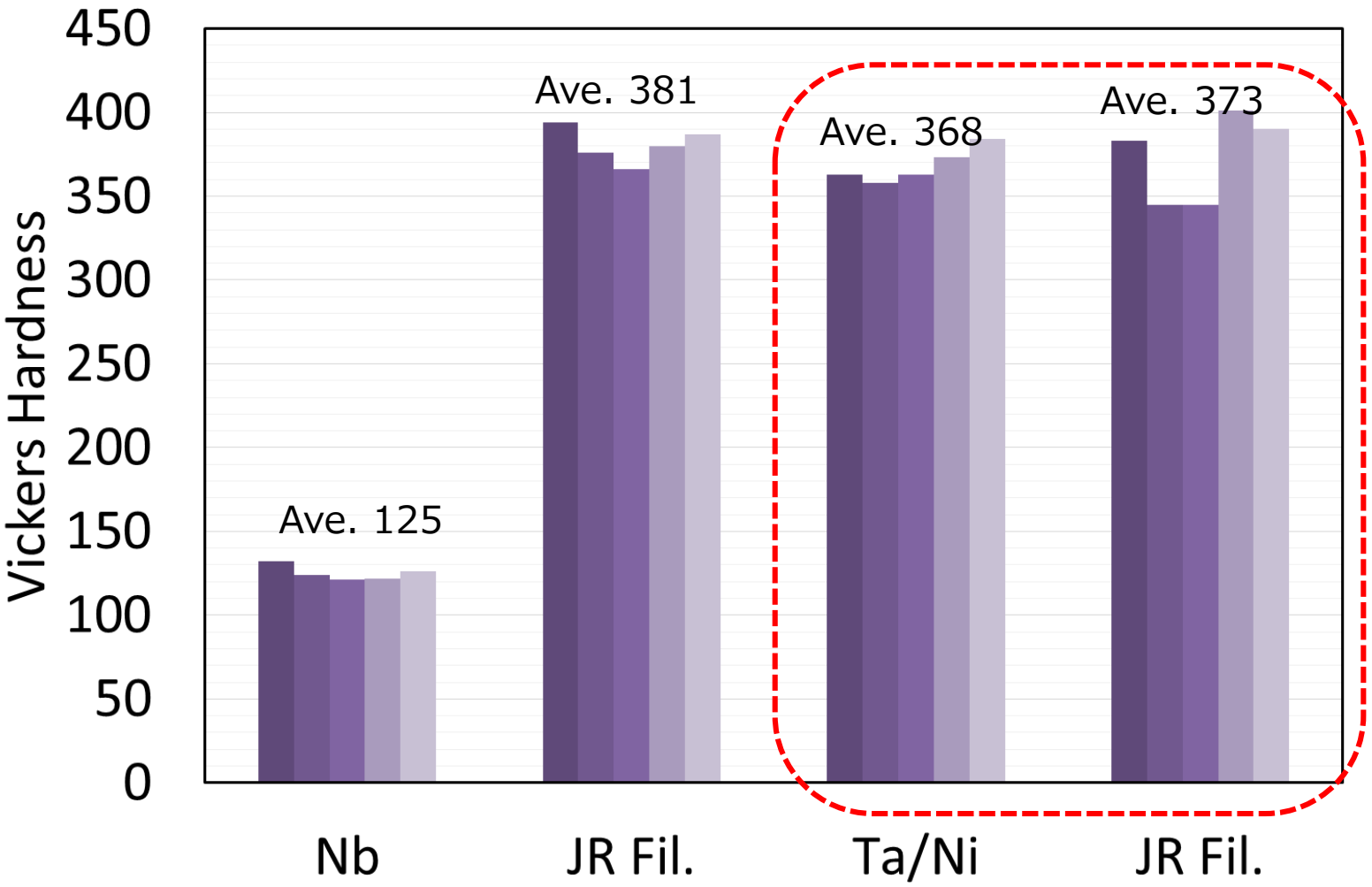
Mechanically mixed with Ta

(b) After RHQ of 2,000°C



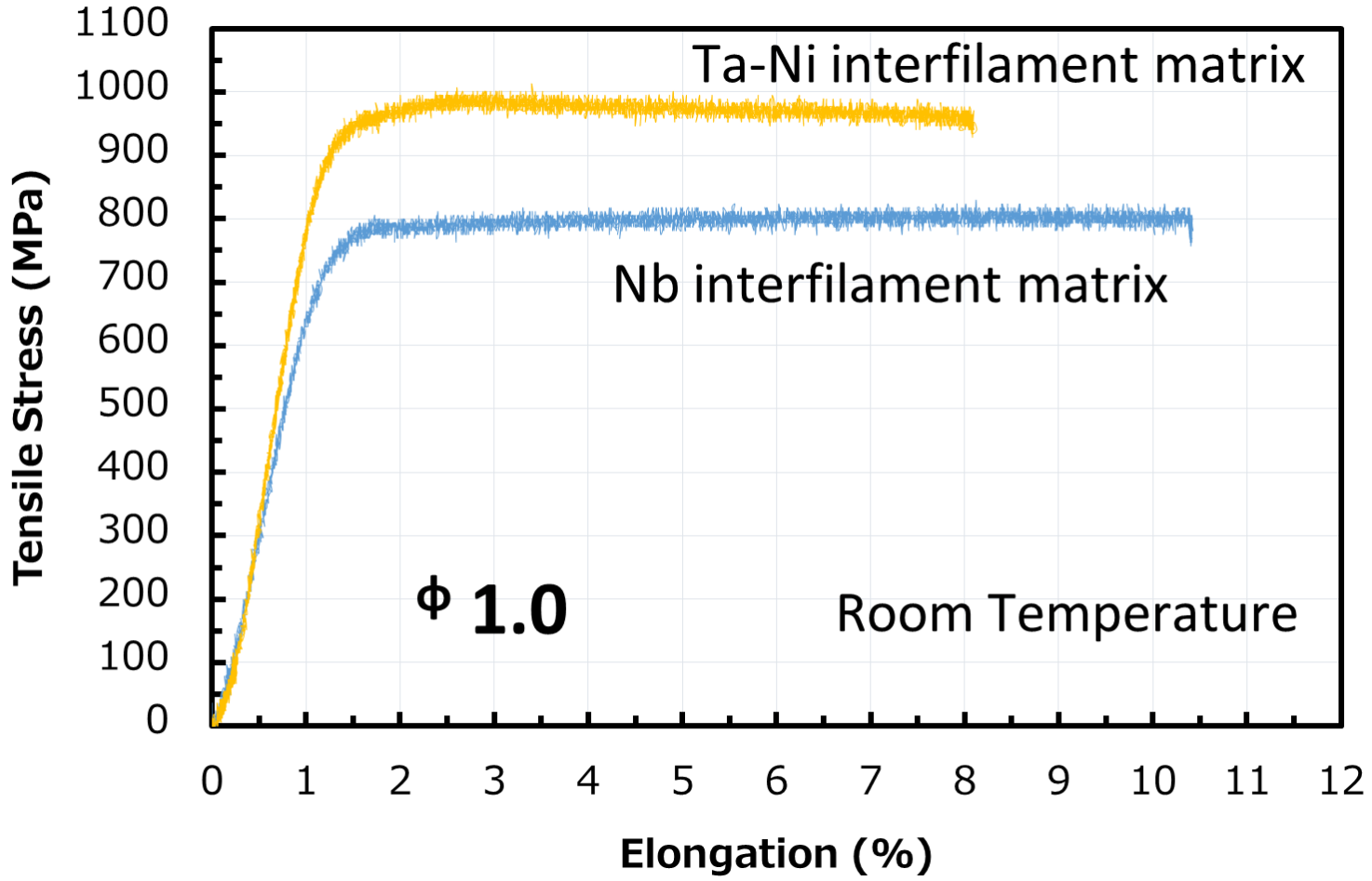
Locally reacted with Ta and distributed in a mesh pattern

Hardness of Interfilament Matrix and Jelly-Rolled Filament (Nb-Al Supersaturated Solid Solution)



Hardness of Ta-Ni interfilament matrix and JR filament are well-balanced.

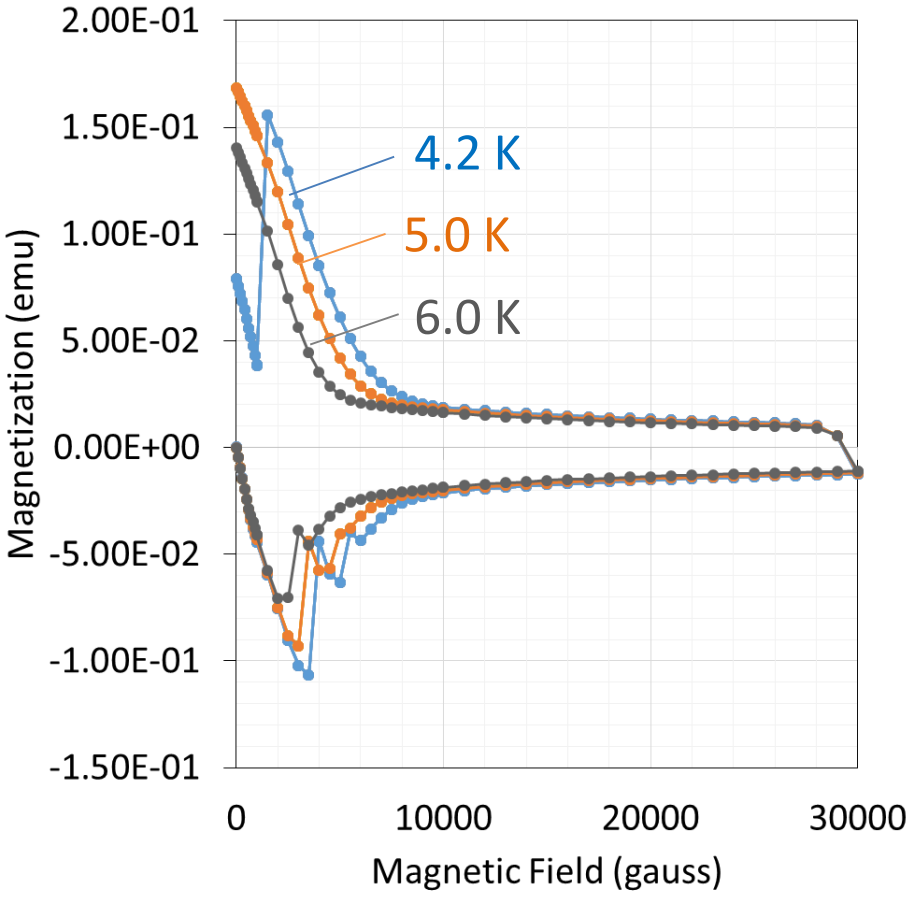
Tensile Test (at R.T.) of 1.0 mm strand
after RHQ (Nb-Al Supersaturated Solid Solution)



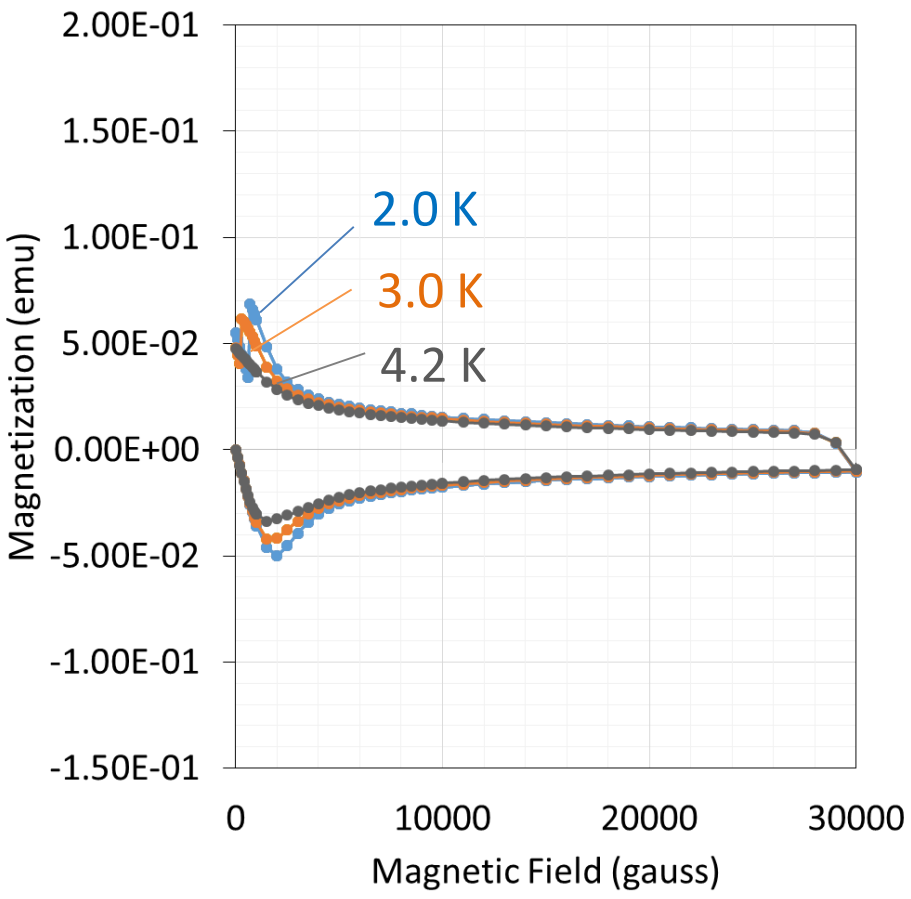
The maximum tensile strength reaches 1,000 MPa at room temperature.
Ta-Ni interfilament matrix acts as an additional reinforcement for the Nb_3Al strand.

Magnetic Instability in Low Fields

(a) Nb interfilament matrix

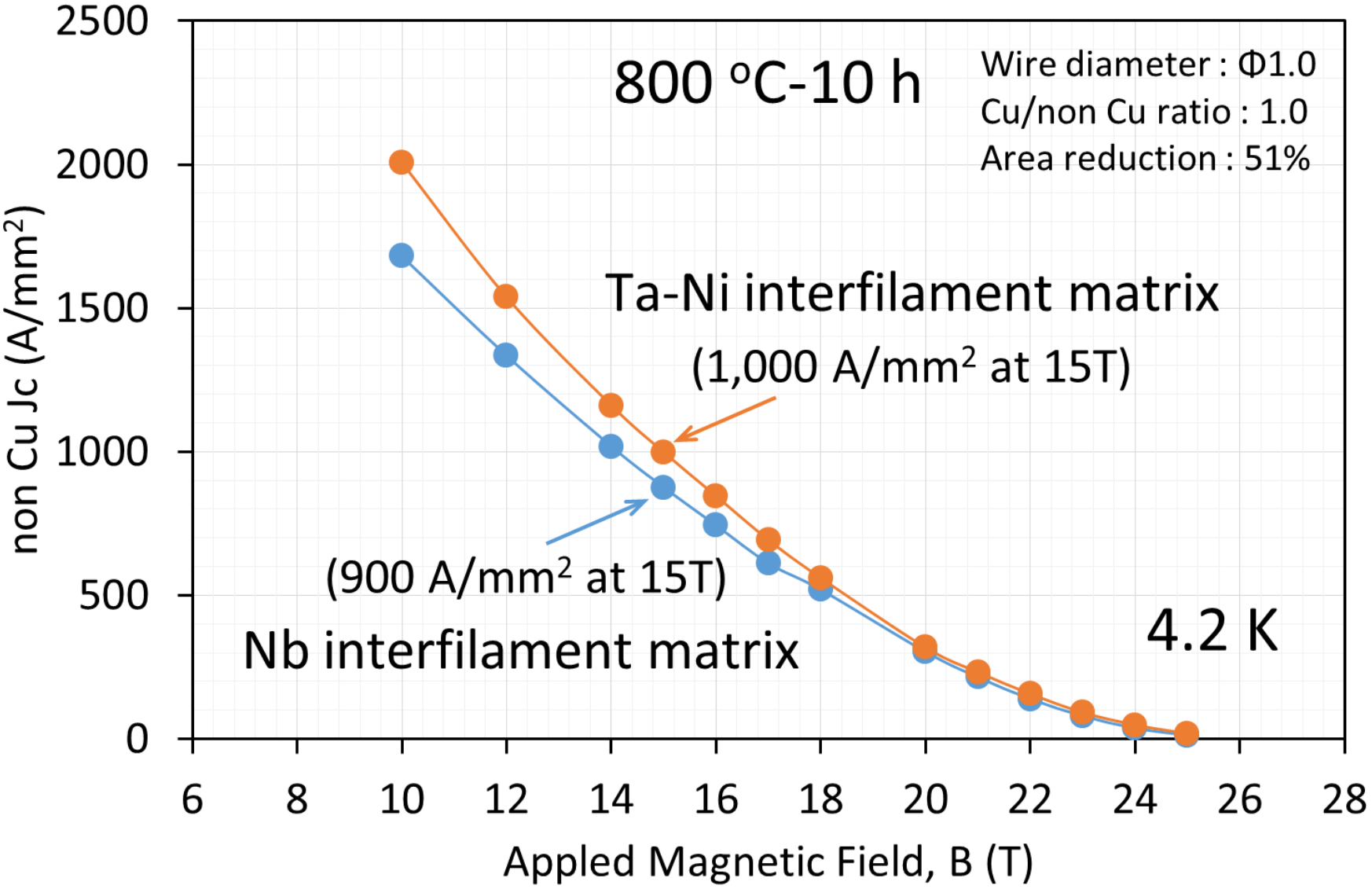


(b) Ta-Ni interfilament matrix

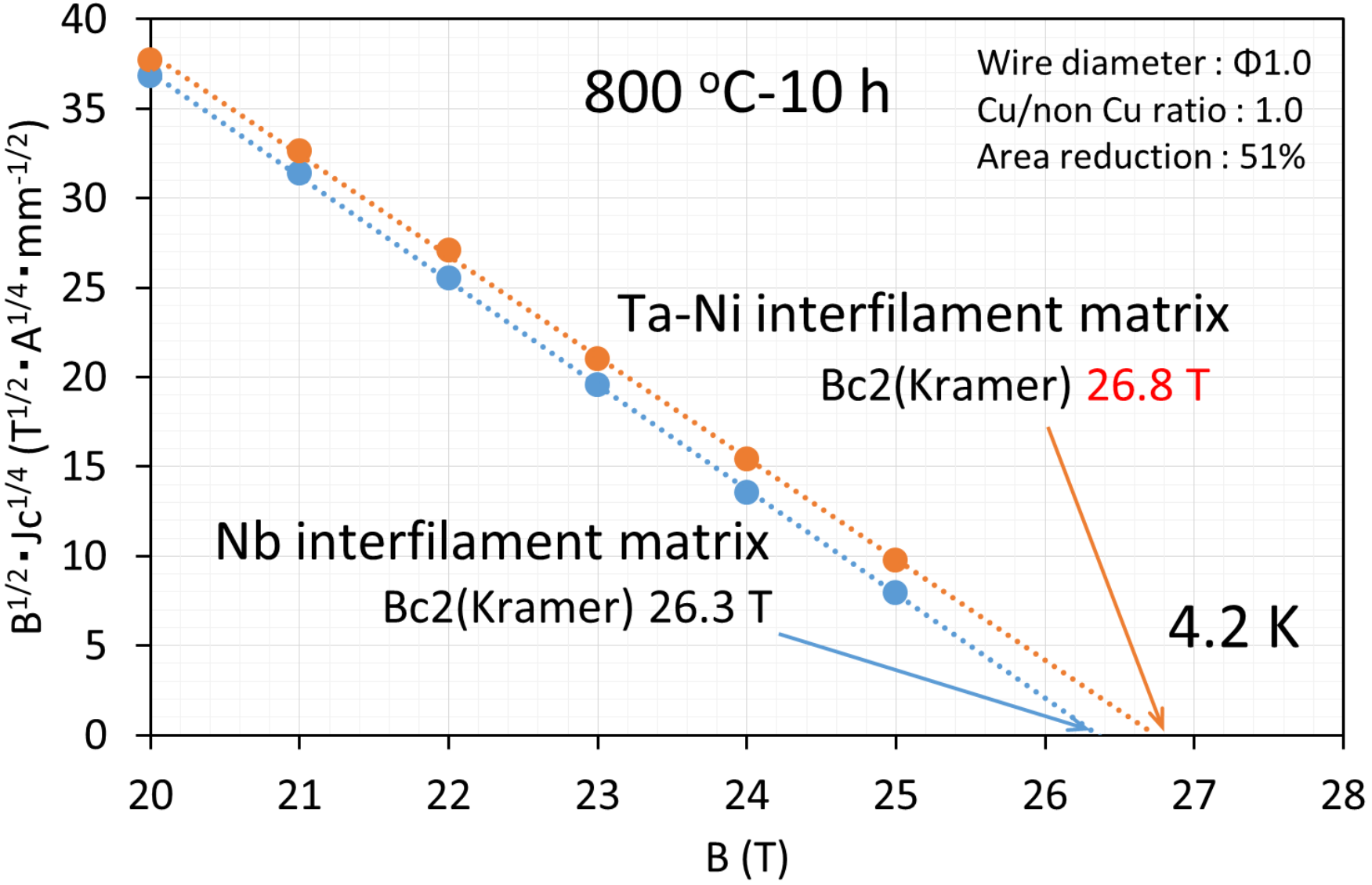


Ta-Ni interfilament matrix apparently improves low field instability at low temperatures.

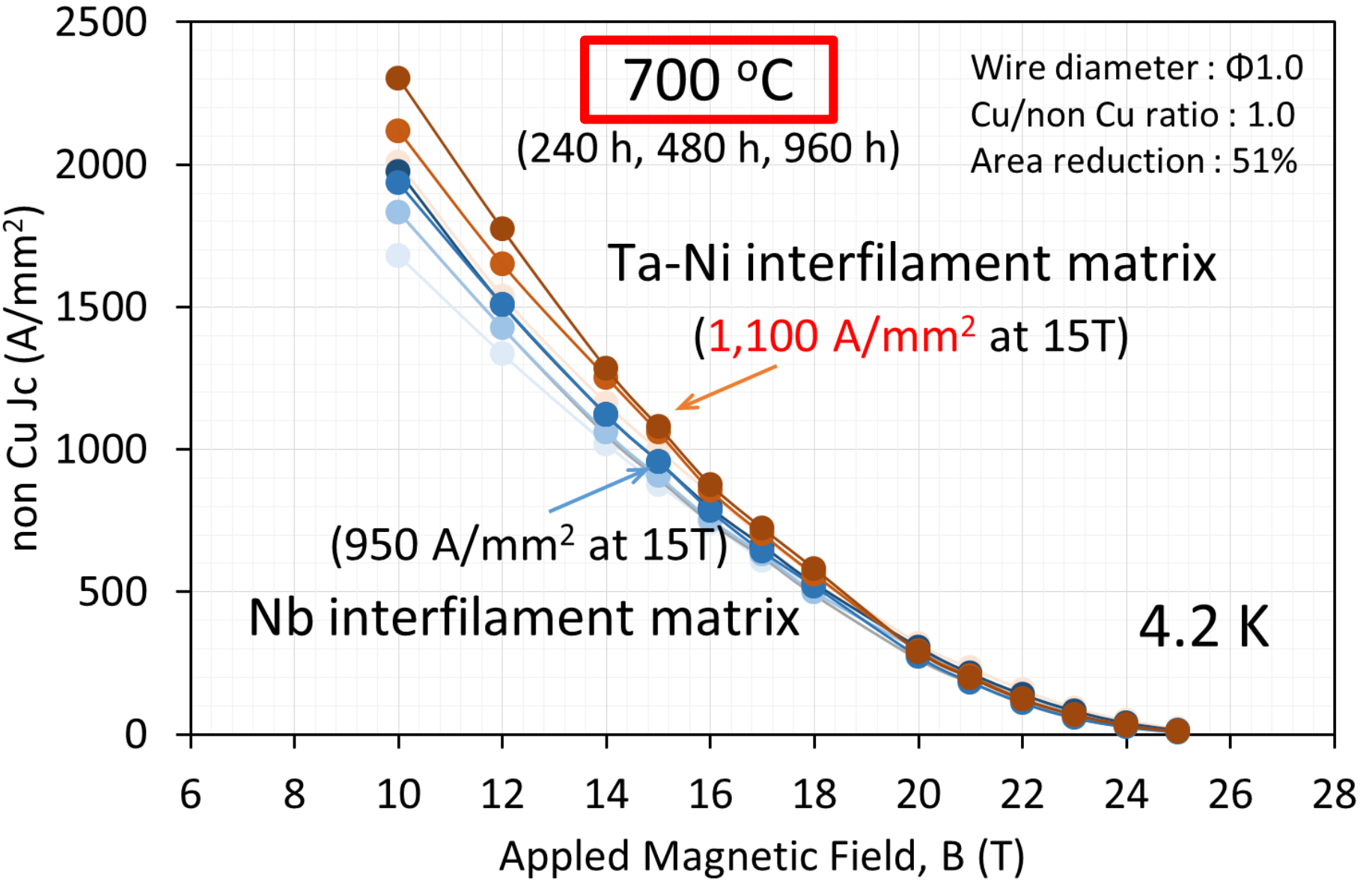
non Cu Jc (4.2 K)


800 °C-10 h
Wire diameter : Φ1.0
Cu/non Cu ratio : 1.0
Area reduction : 51%
Ta-Ni interfilament matrix
(1,000 A/mm² at 15T)
(900 A/mm² at 15T)
Nb interfilament matrix
4.2 K
non Cu Jc (A/mm²)
2500
2000
1500
1000
500
0
6
8
10
12
14
16
18
20
22
24
26
28
Appled Magnetic Field, B (T)

Kramer Extrapolation Bc2 (4.2 K)



Improvement of non Cu Jc

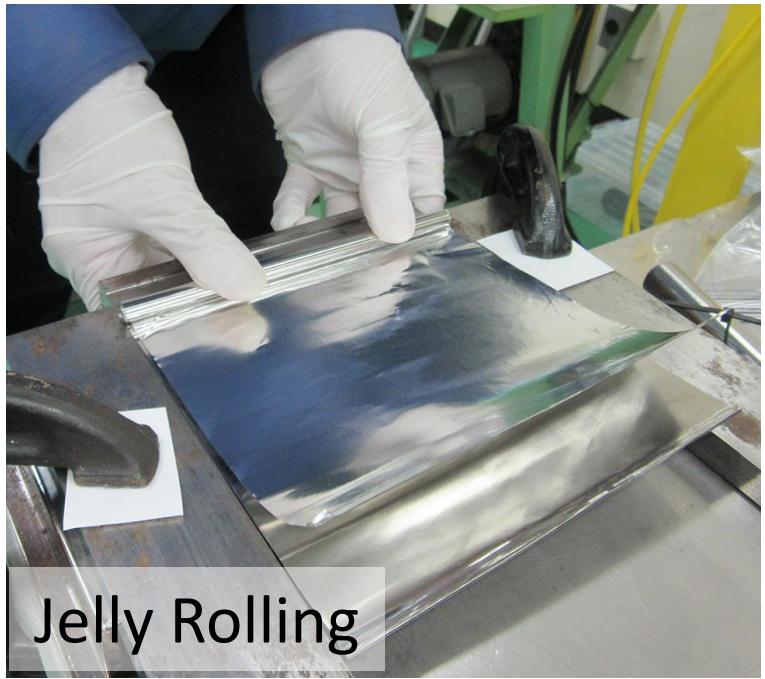


Summary

- Nb_3Al conductor has great potential, such as 30 T of Bc2(4.2 K), excellent strain tolerance and no tin leakage problem.
- Present Tantalum sheet may have reached its plastic deformation limit in the present precursor drawing.
- The Nickel sheet with Tantalum sheet may improve the drawability of Ta matrix precursor, but the wire-breakage still happens a few times. The mass production problem is not completely solved yet.
- Ta-Ni interfilament matrix increases the maximum tensile strength and acts as an additional reinforcement for the Nb_3Al strand.
- Nickel degrades the superconductivity of Tantalum and improves low field instability of Nb_3Al strand at low temperatures.
- 1 mm Nb_3Al strands with Ta-Ni interfilament matrix has 1,100 A/mm^2 of non Cu Jc (4.2 K, 15T) and 26.8 T of Bc2 (4.2 K).

In-House Jelly-Rolled Billet Assembly for 1 km Long Nb_3Al Strand in National Institute for Material Science

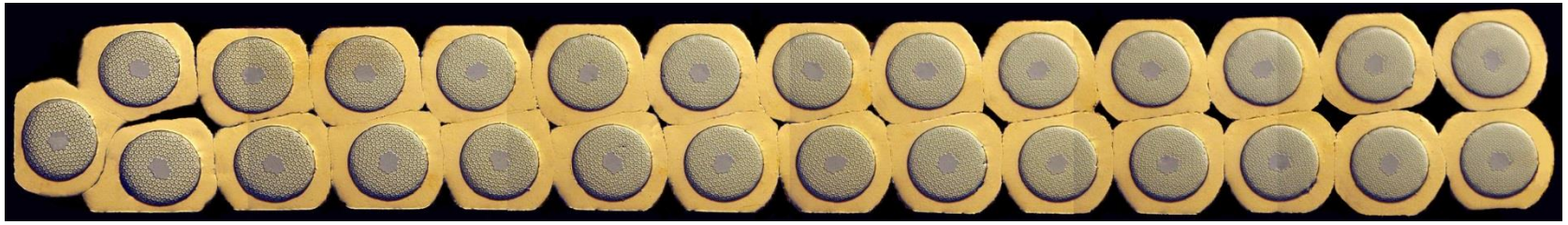
Billet Assembly Room



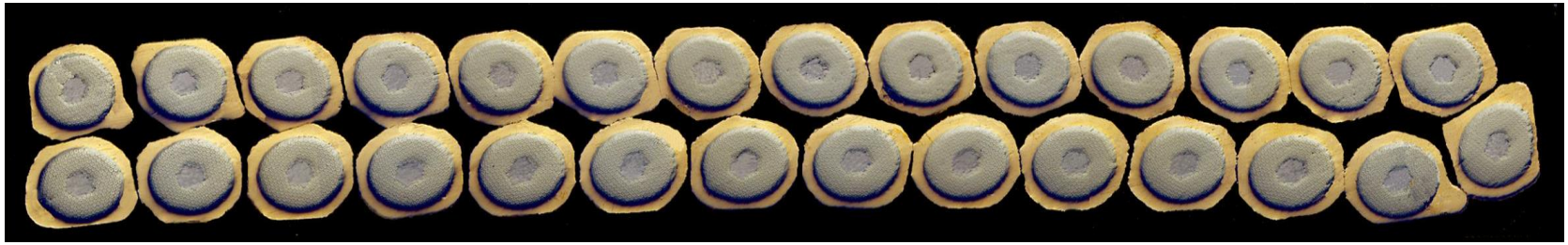
Jelly Rolling

Jelly Rolled Subelement Billet

Nb_3Al Rutherford Cables



- 27 F3 strands, Keystoned, 87% Compaction



- 27 F4 strands, Rectangular, 86.5 % Compaction

Expanded View of Nb_3Al Rutherford Cable