Present Status of Nb_3Al Development at KEK

in collaboration with NIMS

K. Tsuchiya

KEK

Outline

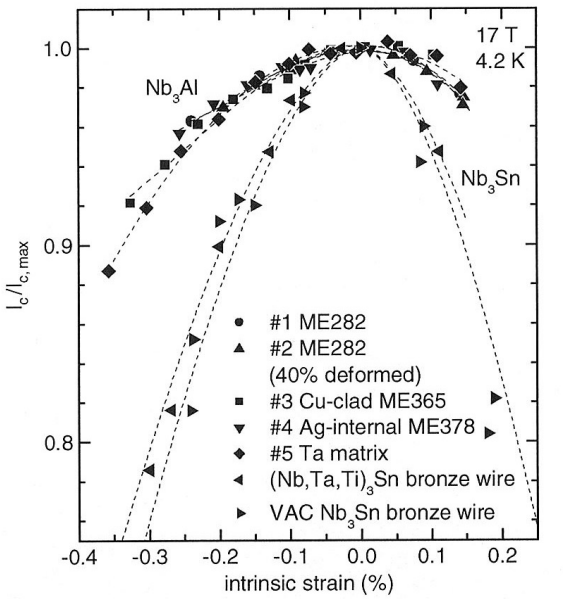
- Introduction
- Experience of billets fabrication (Hitachi Cable)
- Fabricated wires during past several years
- Electroplating technique
- Ic measurement method
- Study of Ta-matrix wire (ME476)
- K2 (ME492) and K1(ME493) wire
- Summary

Introduction (1/3)

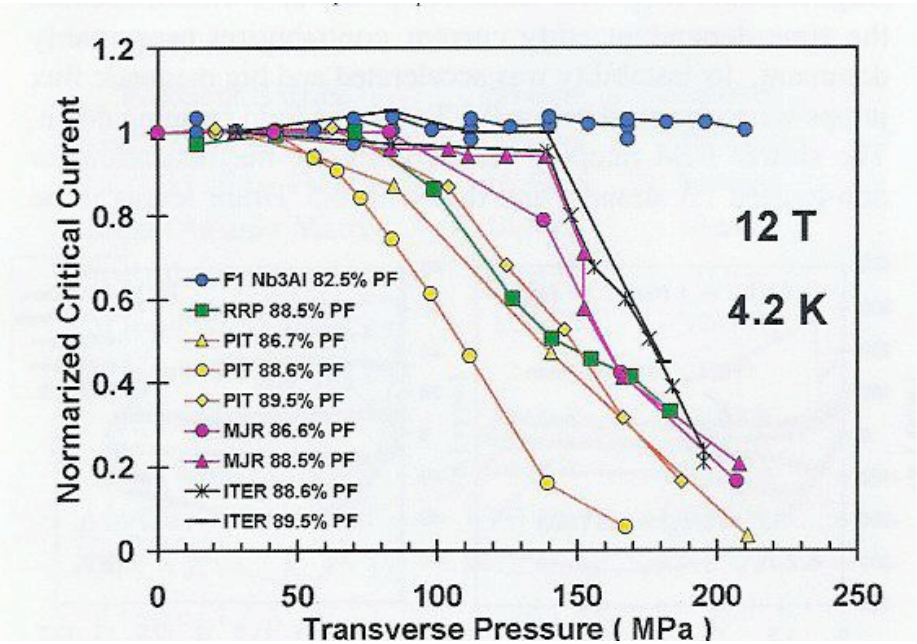
- Nb_3Al has a great potential for high-field application

  Compared with Nb_3Sn, it has a better strain tolerance.

---> it might be a promising candidate for use in future accelerator magnets (~15 T)



Supercond. Sci. Technol. 18 (2005) p. 284.
by N. Banno et al.



Presented at MT-20
by A. Kikuchi et al.

At 150 MPa, Jc of Nb_3Al shows no degradation, however, Jc of Nb_3Sn(RRP) decreases to ~1/2 of the value at 0 MPa.

Introduction (2/3)

- Items which have required development
  - Non-copper Jc
    At present, Jc of Nb_3Al is rather lower than Nb_3Sn
  - Stabilization method
  - Magnetization
  - Cabling etc.

- Specific target during past three years

  development of Ta-matrix wire and fabrication of cables for small coil
  - Strand development
    - Compared with Nb-matrix wire
      Mechanical properties, non-Cu Jc, magnetization
    - Review of fabrication process
  - Cable development
    - Trial manufacture of the cable

Introduction (3/3)

Mono-filament billet

Jerry-Roll:
Nb+Al sheets, Nb or Ta core

Extrusion and drawing

Multi-filament billet

Extrusion and drawing

Precursor wire (Nb/Al)

Rapid Heating Quenching (RHQ)

(Nb/Al)ss

Strand has no Cu stabilizer

Area reduction

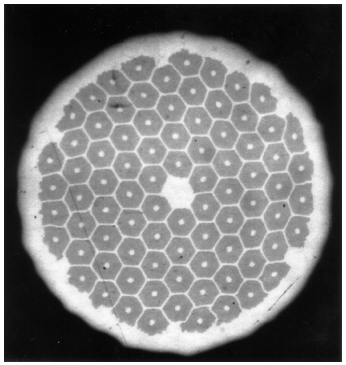
drawing

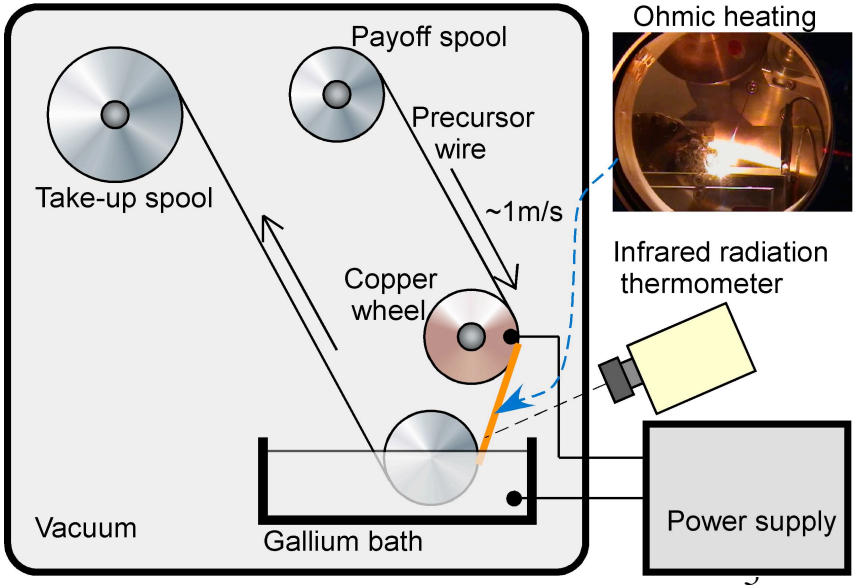
Cu stabilization

electroplating

2^{nd} HT (800℃×10h)

Nb_3Al

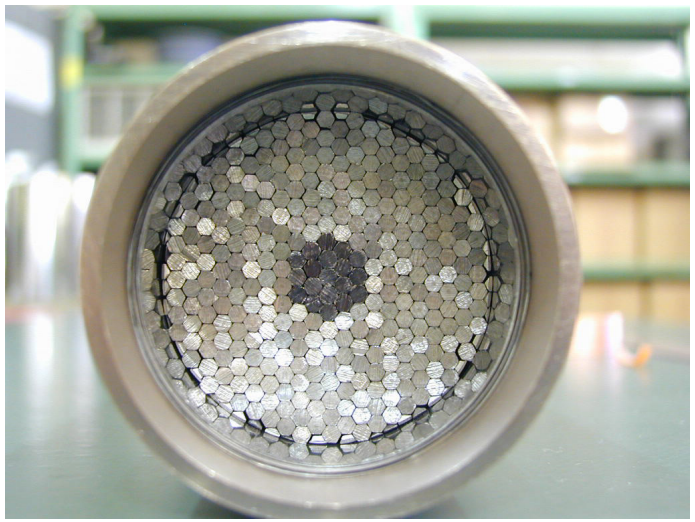




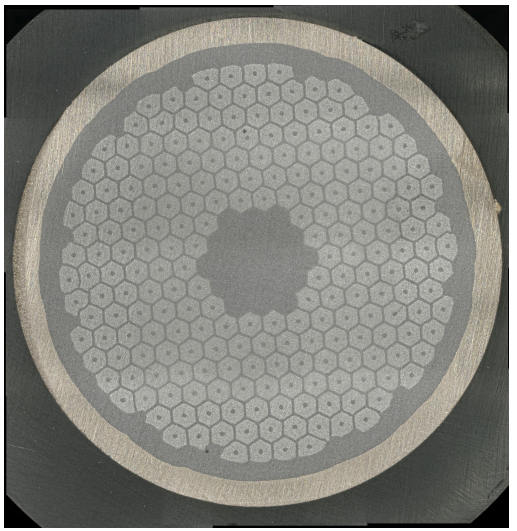
Nb-Al billet fabrication experience

(Hitachi Cable)

Billet size		1.35ϕ wire length	Num. billet by 2005	Num. billet by 2008
samll size	~30 mm ϕ	~50 m	many	
middle size	~70 mm ϕ	~300 m	~30	~10
large size	~150 mm ϕ	~2500 m	3	



middle size billet



cross section of the wire

Manufactured Nb-Al strands for KEK

	2003		2005		2006	2006		2007		2007		2008	2008
線材 No.	M21-3		ME451		ME458	ME476		ME492		ME493		ME502	ME501
Matrix material	Nb		Nb		Nb	Ta		Ta		Ta		Ta	Ta
Core material	Nb, Nb		Nb, Nb		Nb, Nb	Ta, Ta		Ta, Ta		Nb, Nb		Nb, Ta	Nb, Nb
Matrix ratio	0.8		0.69		0.79	0.8		0.8		0.8		0.95	0.8
Num of filam	144		294		546	222		222		222		222(241)	294(313)
Frequency of wire breaking			3		3+crack	2		7		4			
RHQ													
Wire dia (mm)	0.8		1.35		1.35	1.35		1.35		1.35		1.35	1.35
Filam dia (μm)	51		62.7		44.2	69		69.8		69.8		66	60
Barrier thick(μm)	4.6		6.4		4.4	8		8		8		11	8
Twist pitch (mm)	32		55		0	54		0		0		54	54
RHQ I (A)	80.6	80.6	228	228	222	226	226		202				
AR ratio (%)		32		52 72			45		72		66.2		
wire dia (w/o Cu)		0.66		0.94 0.72			1.00		0.715		0.785		
wire dia (with Cu)							1.40		1.00		1.00		
filament dia (μm)		34.7		44 33			38		37		40.6		
barrier thick (μm)		3.1		4.5 3.4			4.4		4.2		4.7		
twist pitch (mm)							98		45		45		
non-Cu Jc (A/mm2)													
@ 10T w/o AR	1602												
@ 15T	661		630		430	623							
@ 10T with AR		2176		1720					1776		1669		
@ 12T with AR		1663		1302					1320		1230		
@ 15T with AR		1032		949 817			807		785		718		

Electroplating technique

KEK

1) Strike plating of thin Ni on the surface
2) Electroplating of thick copper
3) Heat treatment for stabilize the bonding

electroplating speed: ~1.5 m/h

(Cu thickness of ~0.17 mm)

NIMS

1) Ion-plating of thin Cu
2) High speed electroplating of thick copper
3) Heat treatment for stabilizing the bonding

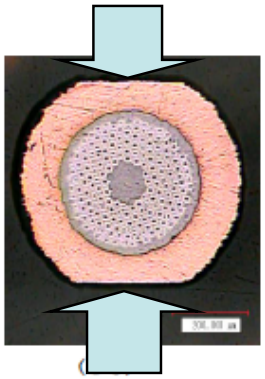
ion-plating speed: 120 m/h

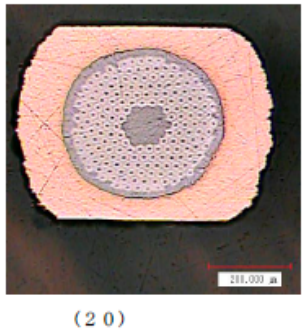
electroplating speed: ~6 m/h

Copper Stabilizer

Mechanical Bonding Strength test

Rolling





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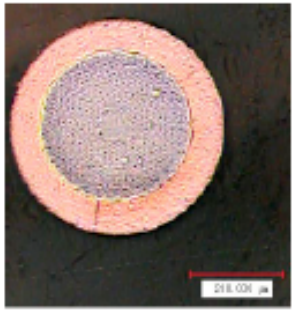
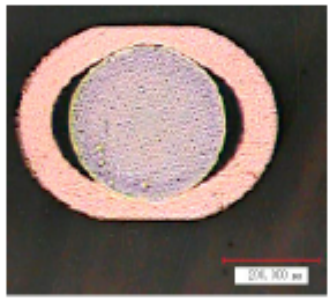
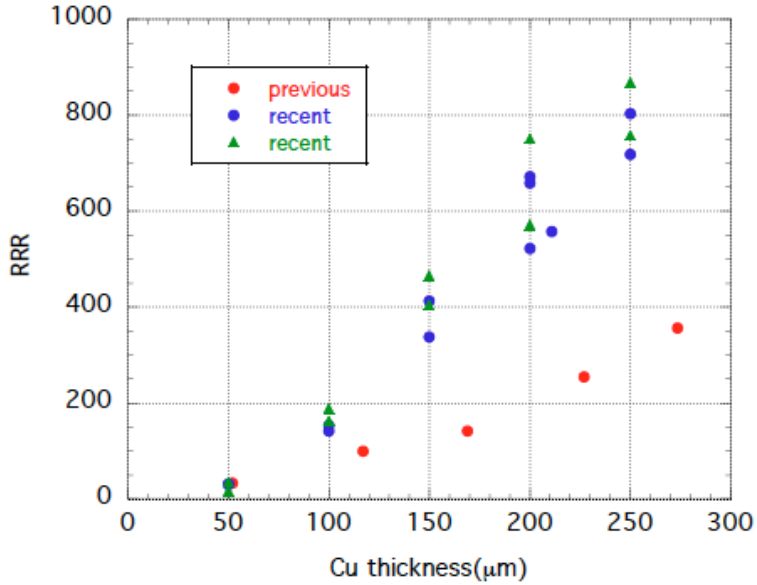
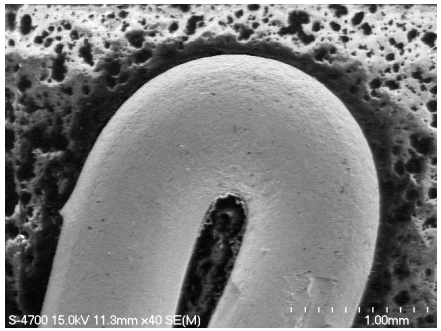




RRR of electroplated copper





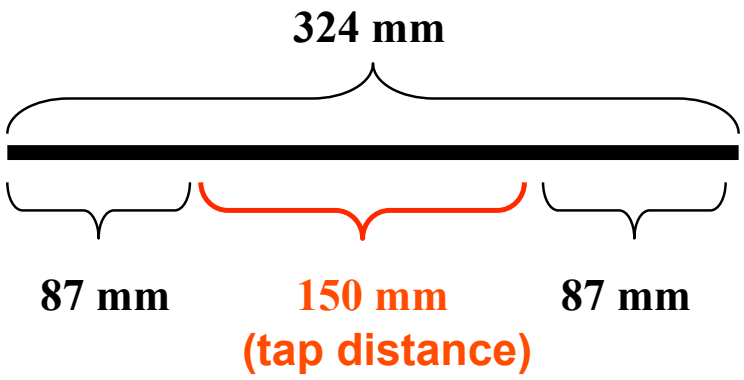
Bent wire to see the folds and projections of Cu stabilizer

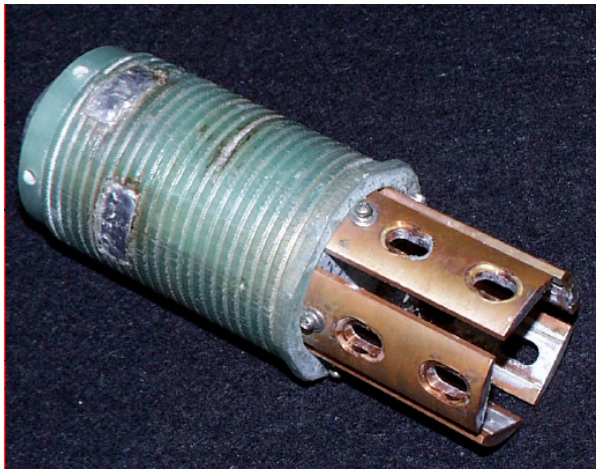
Ic measurement method

- sample preparation

  800℃x 10 hour HT

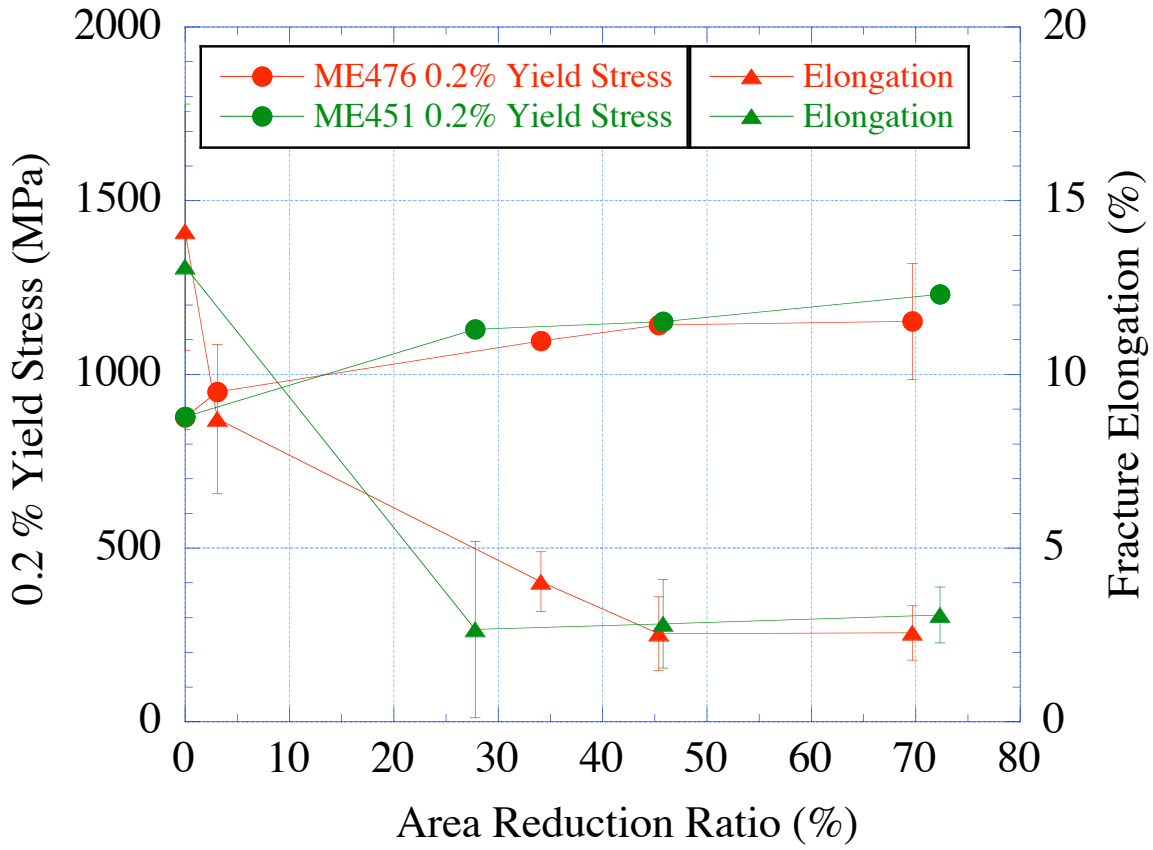
- Ic measurement
  - sample length: ~300 mm
  - Ic criterion : 20 μV/m
  - n-value : 10~40 μV/m





Study of Ta-matrix wire (ME476)

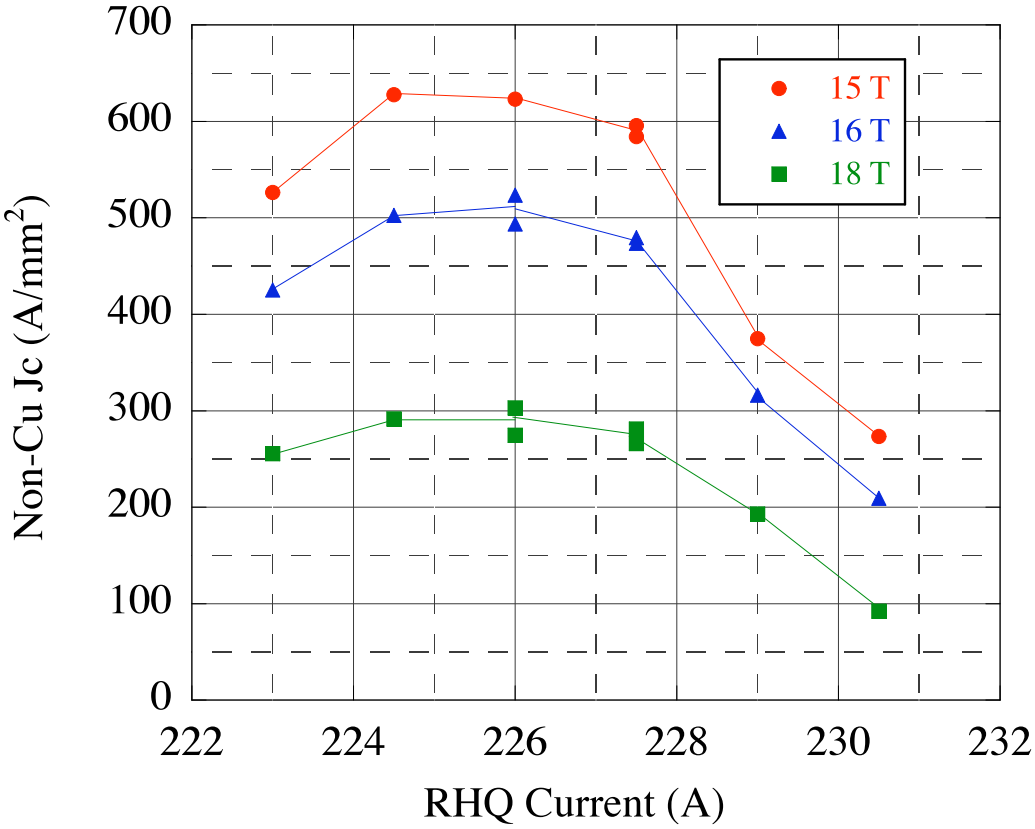
➢ Mechanical properties of the wire aft RHQ process



Difference between Nb- and Ta- matrix is fairly small.

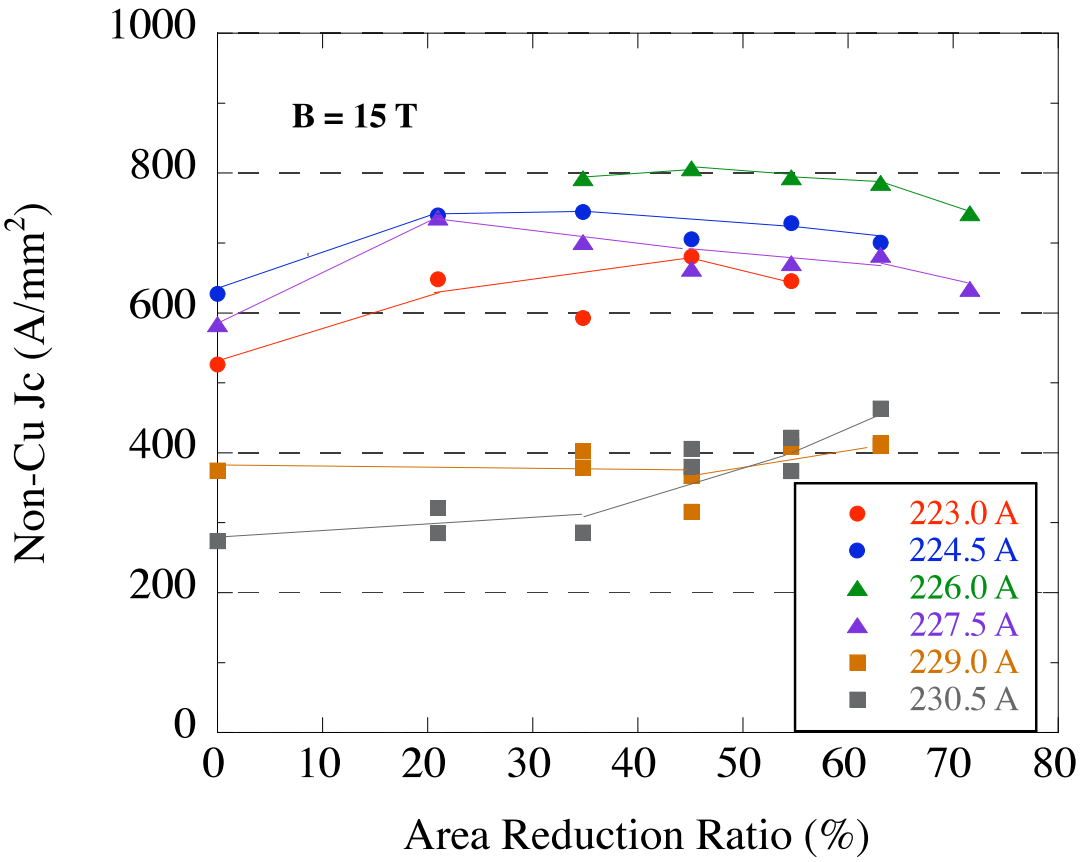
Study of Ta-matrix wire (ME476)

➢ Effect of the RHQ current on non-Cu Jc (wire dia = 1.35 mm)



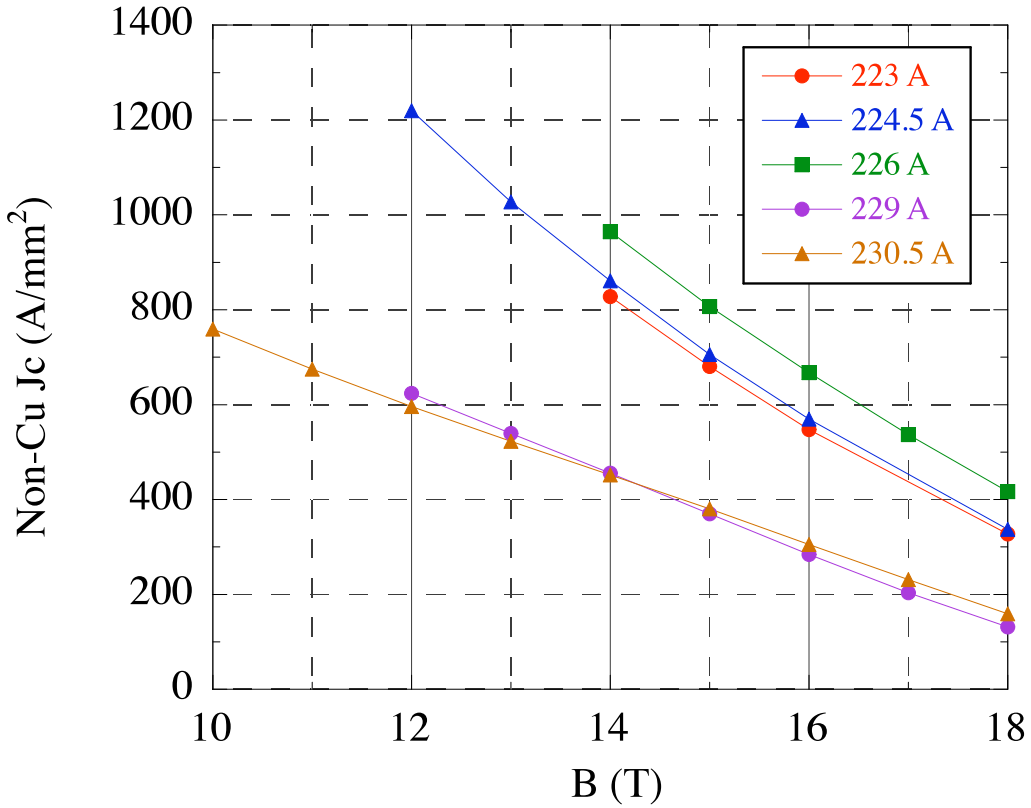
Study of Ta-matrix wire (ME476)

➢ Effect of the area reduction ratio on non-Cu Jc



Study of Ta-matrix wire (ME476)

➢ Non-copper Jc of ME476



Non-copper Jc of the samples treated at different RHQ currents

wire dia. = 1.0 mm (AR=45 %)

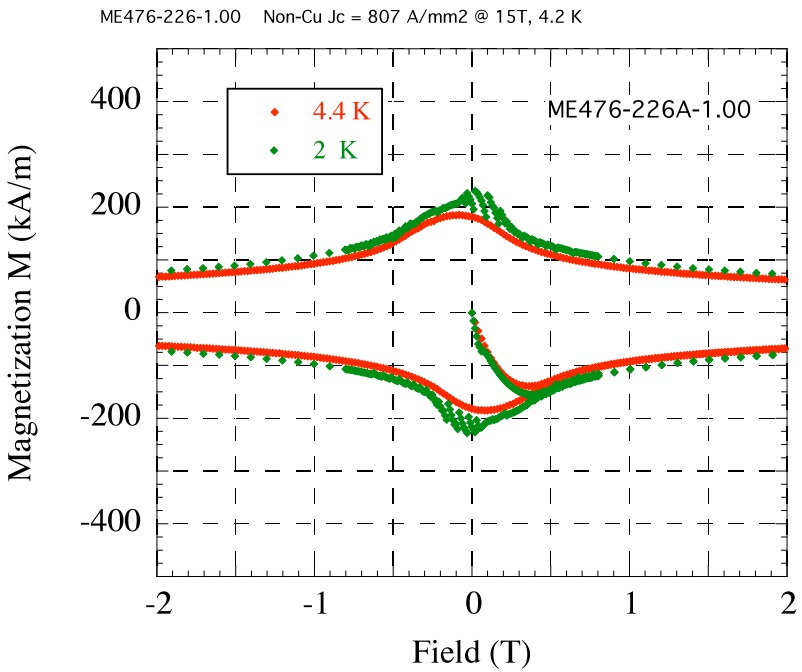
Non-copper Jc @ 15 T

ME476 (Ta)	807 A/mm^2
ME451 (Nb)	946 A/mm^2

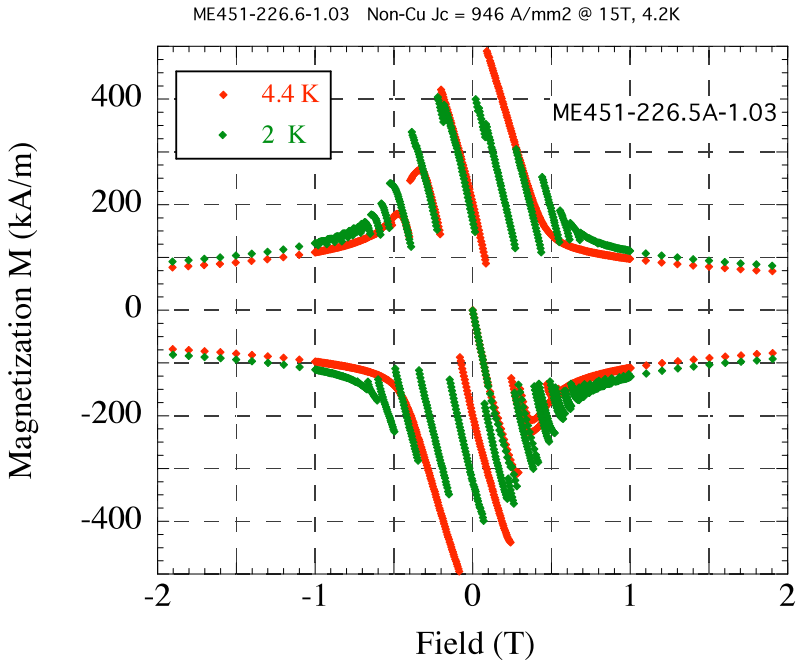
Study of Ta-matrix wire (ME476)

➢ Magnetization (SQUID magnetometer)

Ta-matrix (ME476)



Nb-matrix (ME451)



Study of Ta-matrix (ME476) wire

➢ Summary

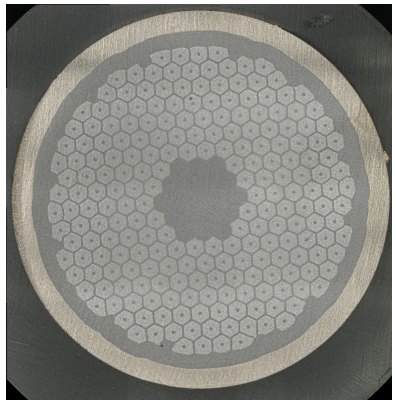
- The difference of the mechanical properties between Ta- and Nb-matrix wires is fairly small.
- The RHQ current to obtain a high Jc is almost the same as that of Nb-matix wire.
- The effect of the area reduction on Jc is also similar to that of Nb-matrix wire. However, the highest Jc seems to be slightly lower than that of the Nb-matrix wire*.
- The low field instability is dramatically improved in Ta-matrix wire.

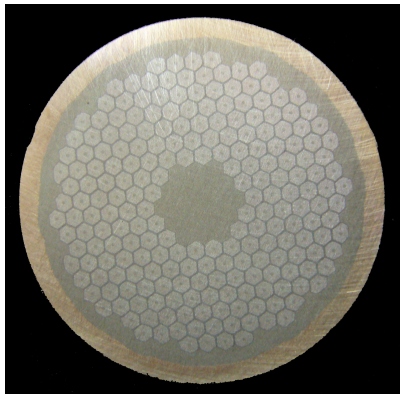
* Recently tried new Ta-matrix wire (restacked method) showed a higher non-Cu Jc (950-1000 A/mm2 @ 15T, 4.2 K) than this ordinal Ta-matrix wire.

K2(ME492) and K1(ME493) Wires

- Two kinds of Ta-matrix wires were fabricated in 2007, however, the wire breaking happened frequently. K2 (ME492); 7 times
  K1 (ME493); 4 times

K2



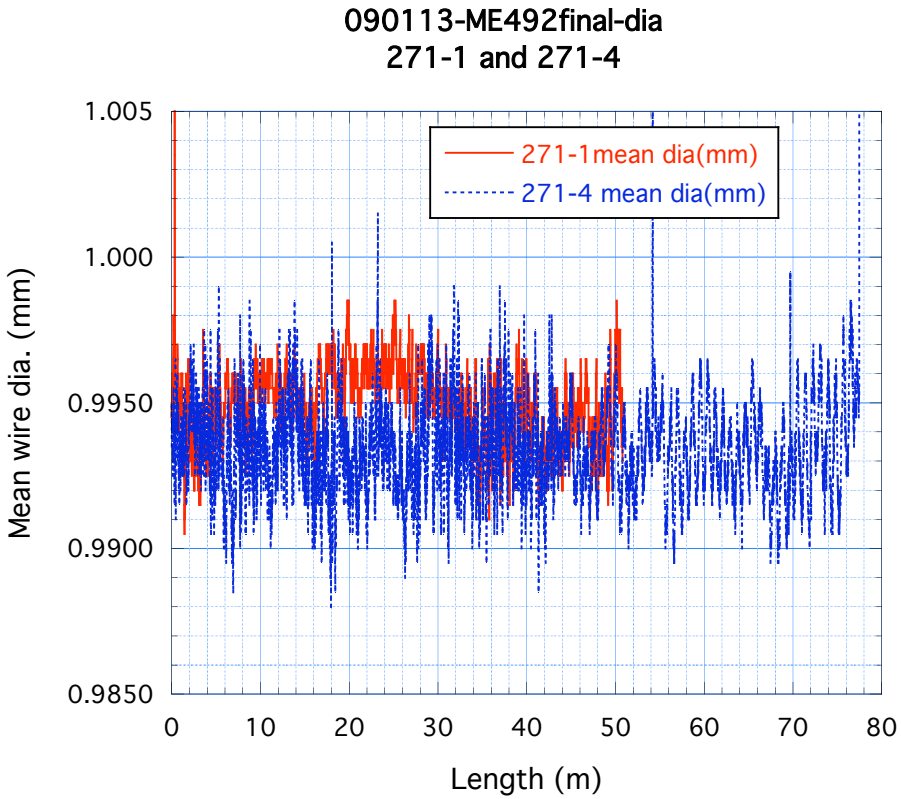


K1

- Also it was rather difficult to perform stable RHQ treatment in K2(ME492) wire.
- Although various trouble happened during the fabrication,
  the following strands could be made.
  K2 (ME492); ~270 m strand with Cu stabilizer
  K1 (ME493); ~700 m strand with Cu stabilizer
- Using these strand, trial fabrication of Rutherford cable was performed
  at Fermilab last February and a 22 m long 28-strand cable was made successfully.

K2 (ME492) Wire

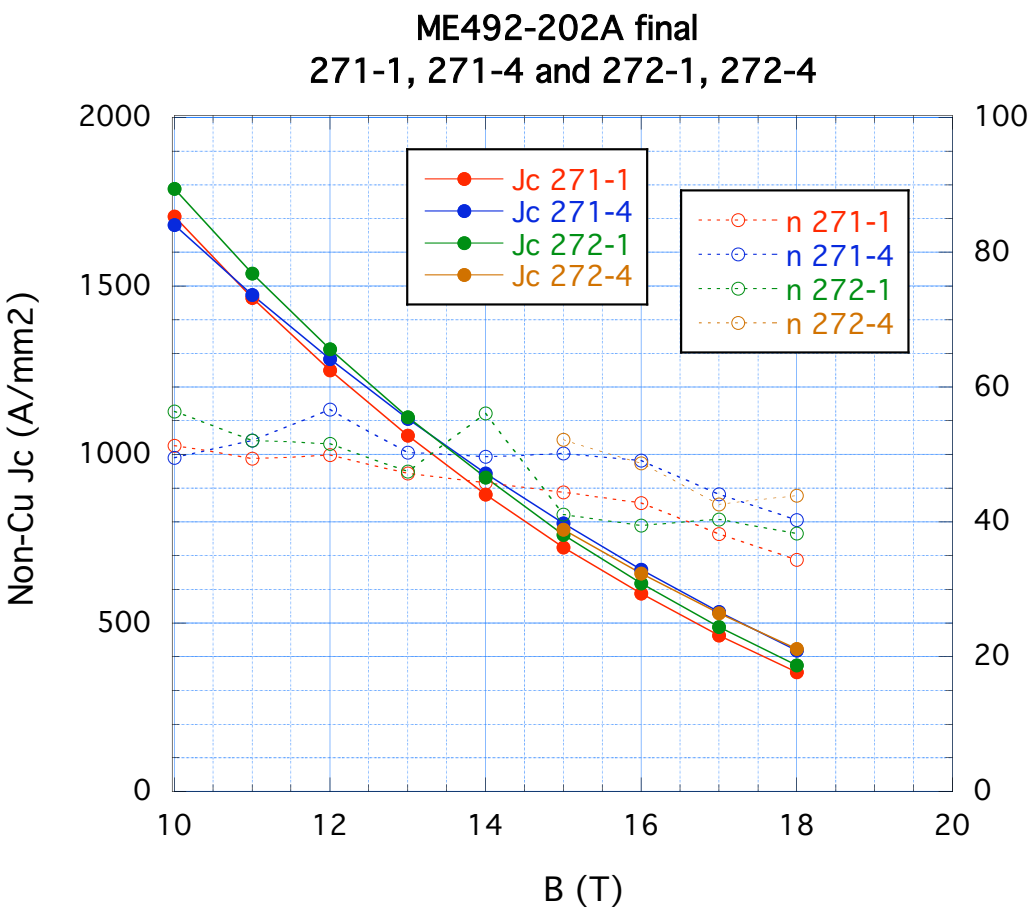
➢ Diameter of K2 (ME492) wire after electroplating

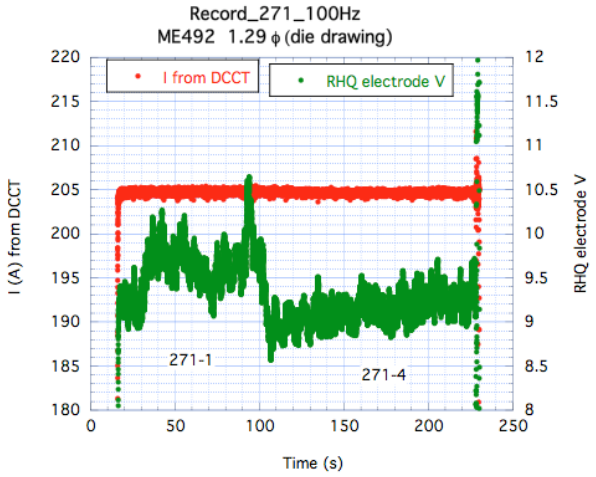


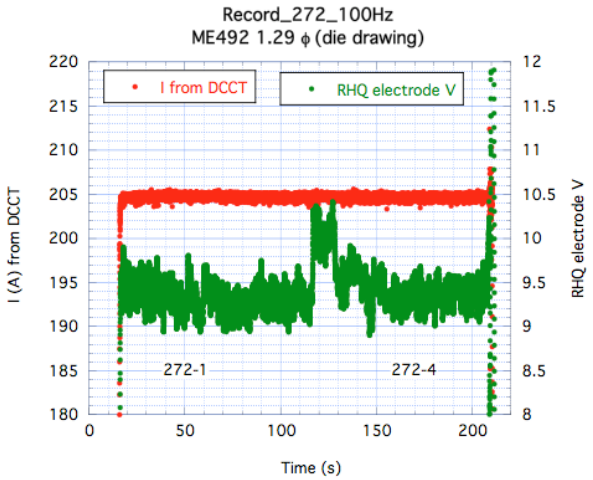
	Length (m)	Mean wire dia. (mm)	σ (mm)
271-1	50	0.995	0.0013
271-4	77	0.993	0.0016
272-1	87	0.995	0.0029
272-4	61	0.996	0.0010

K2 (ME492) Wire

➢ Non-copper Jc and n-value



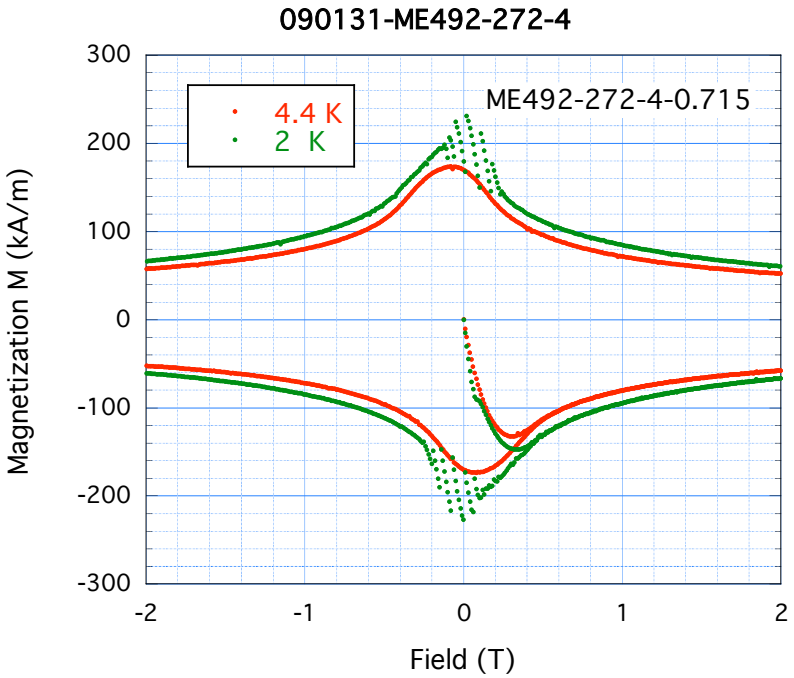




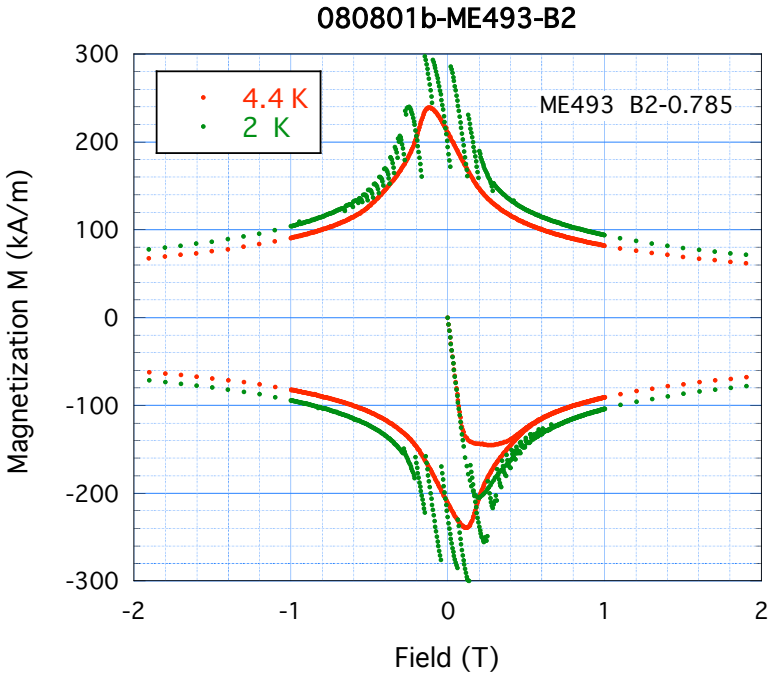
K2(ME492) and K1(ME493) Wires

➢ Magnetization

K2 wire



K1 wire

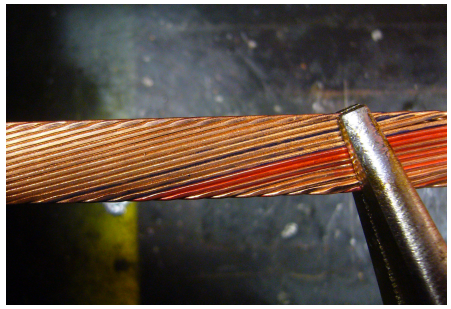


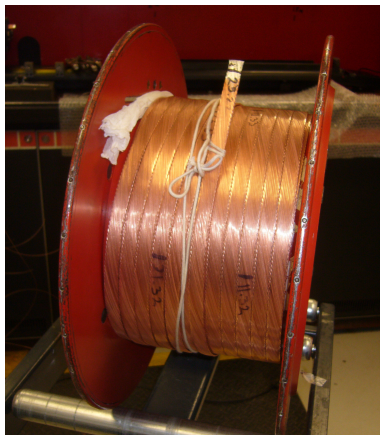
Interfilament matrix :	Ta	Ta
Core of the filament :	Ta	Nb
Central core of wire :	Ta	Nb
Skin of wire :	Ta	Nb

Summary

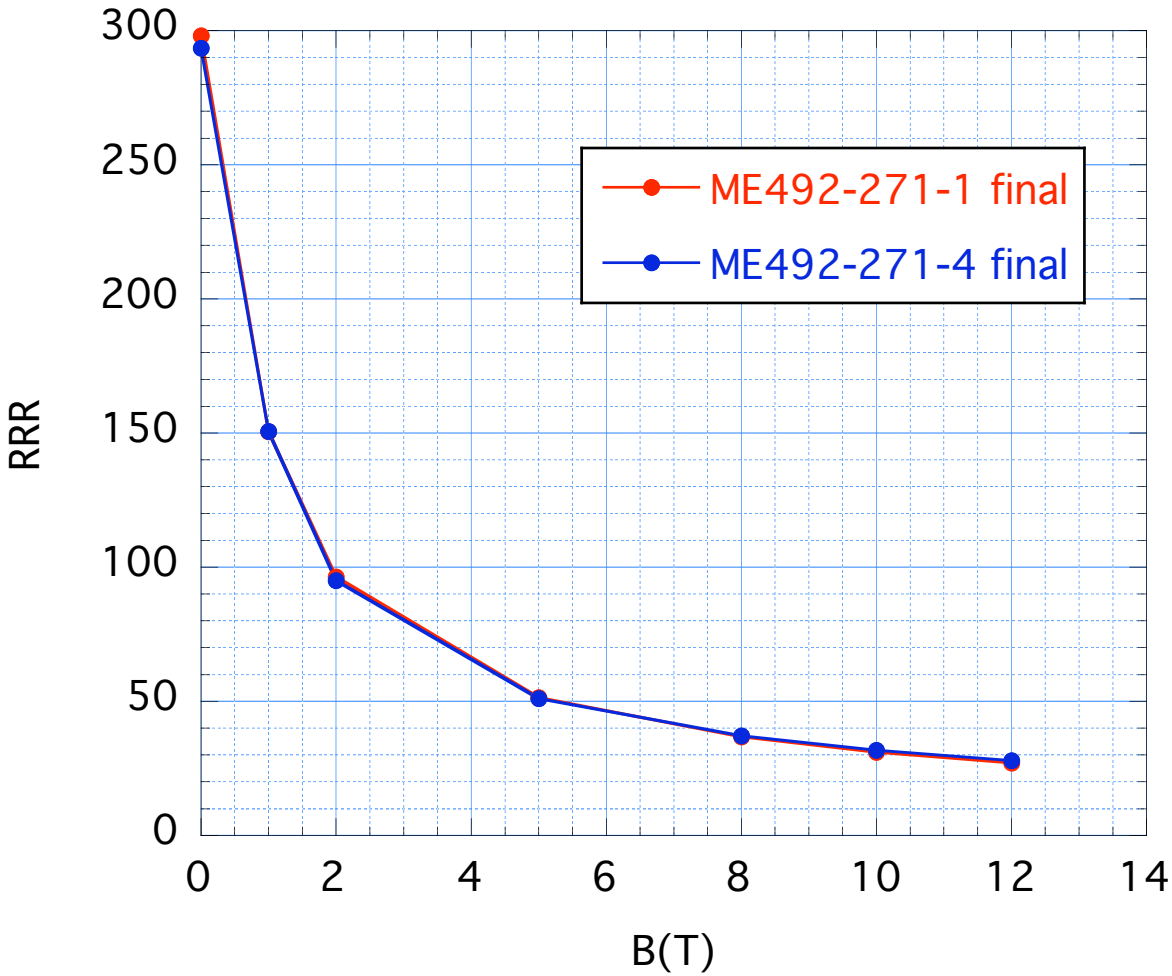
- Fabrication of Ta-matrix wires were performed.
  Their mechanical and SC properties have been studied and compared with those of the Nb-matrix wire.

- Two kinds of Ta-matrix wire were fabricated in 2007. However, wire breaking happened frequently during the fabrication.
  In spite of the trouble, we could make the Rutherford cable at Fermilab.



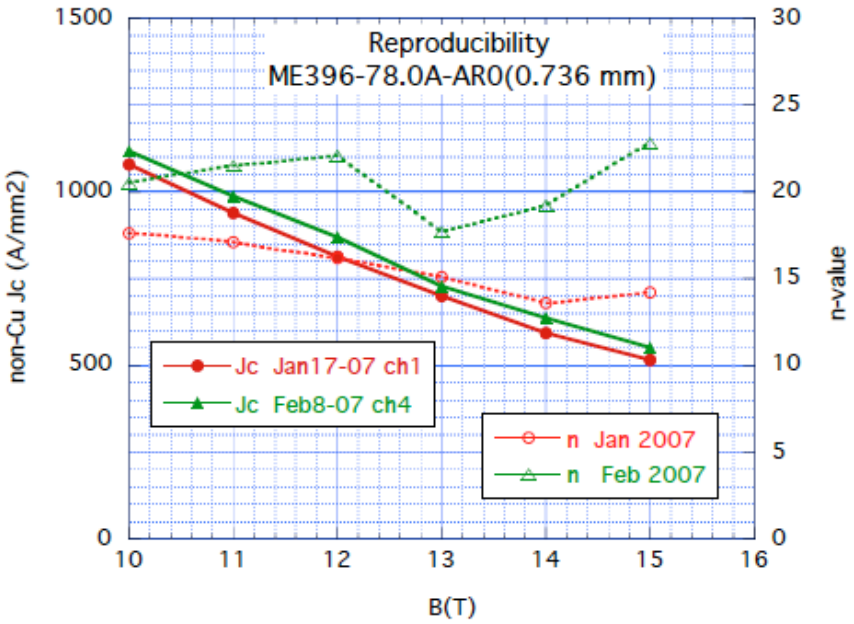


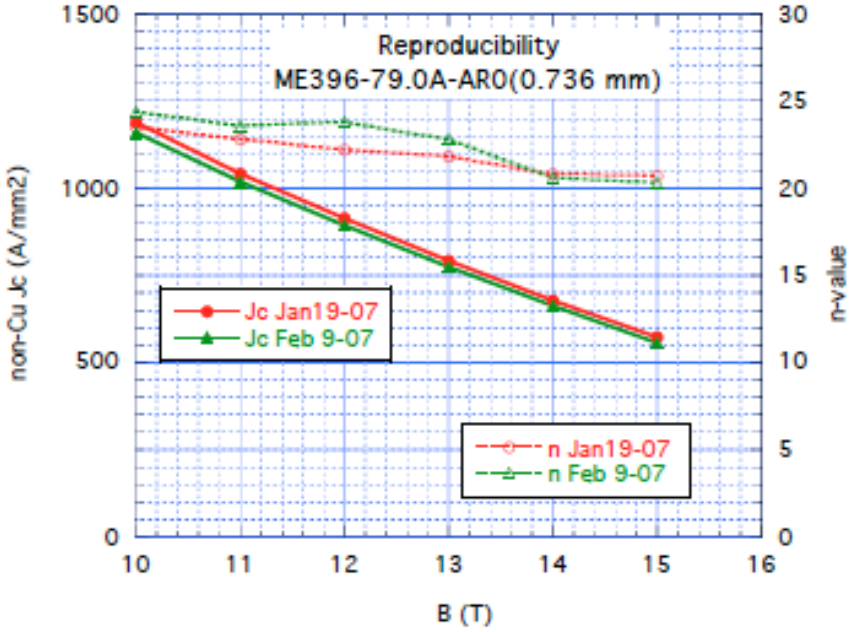
- Items need more improvement
  - reliable precursor fabrication
  - stable RHQ treatment
  - bonding strength of copper stabilizer
  - non-copper Jc


300
250
200
150
100
50
0
RRR
0
2
4
6
8
10
12
14
B(T)
ME492-271-1 final
ME492-271-4 final

Ic measurement method (2/2)

➢ Reproducibility check of Ic and n-value





Ic : ΔIc ~ 6 % (78.0A), ΔIc ~ 2 % (79.0A) @12 T

n-value : Δn=6~8 , Δn=2~3