Development of Nb_3Sn in Japan

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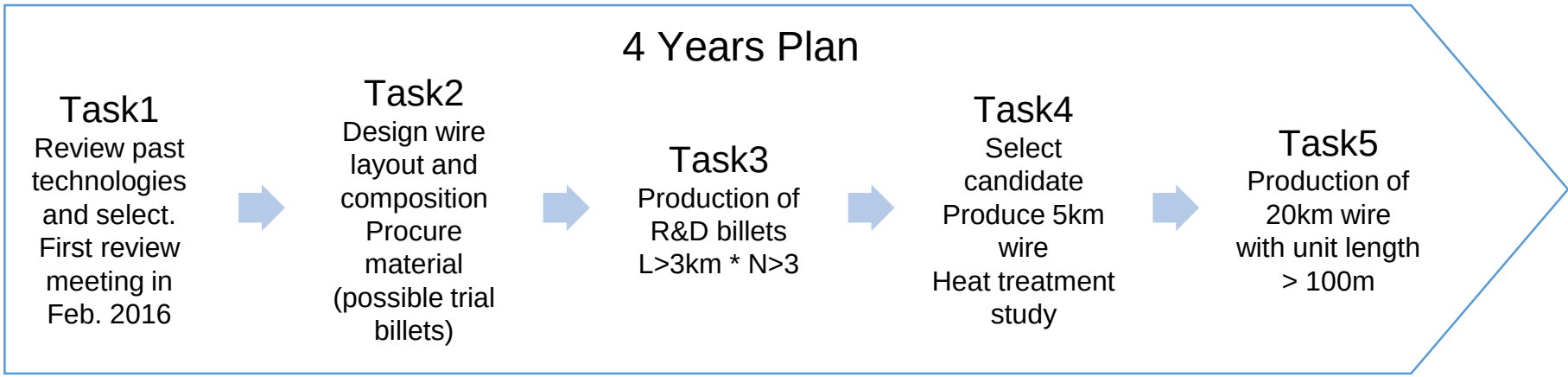
R&D Plan

CERN, KEK and Tohoku & Tokai university have jointly launched a R&D program

- The scope of the program is to develop, produce in representative lengths and characterize Nb_3Sn wire with enhanced characteristics.
- The final goal is to achieve in representative unit lengths of material the development targets defined, on the basis of magnets performance, for the FCC Nb_3Sn conductor: 1500A/mm^2 @ 16T
- Contract with 2 Japanese companies: Task 3; 4 R&D contracts each
  - JASTEC/Kobelco: Distributed Tin (DT) Method
  - Furukawa Electric: Nb Tube Method



Development of DT Nb_3Sn wire for FCC in KSL/JASTEC

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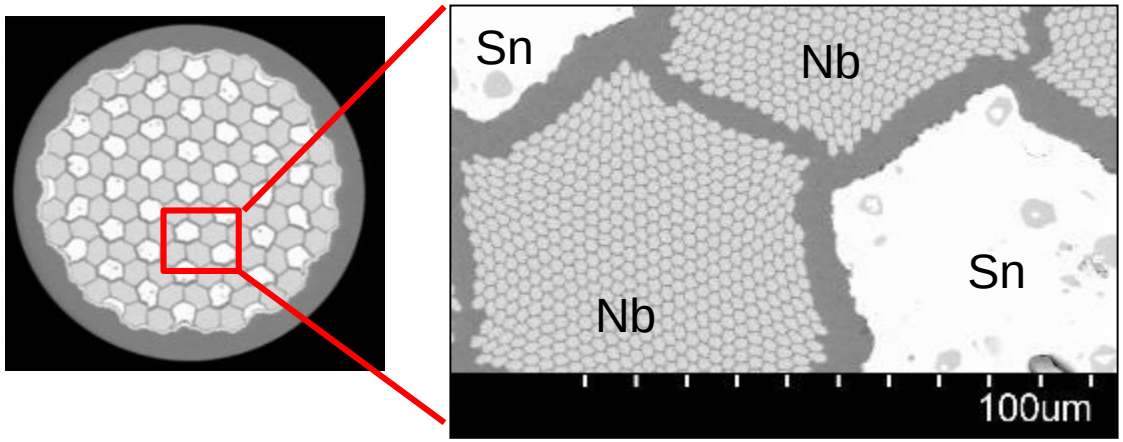
Key factors for higher J_C Nb_3Sn

Confidential

KSL/JASTEC are developing the DT wire for FCC.

Cross-section of DT wire (before Heat treatment)



- Multi Nb module (pure Nb)
- Mono Sn module (Sn-Ti alloy)
- Nb common barrier
- Stabilized Cu outside barrier

For higher Jc…

(1) Improvement of Sn diffusion：Reduction of Sn diffusion distance
(2) Increase of Nb volume fraction：Reduction of useless volume
(3) Ternary additive elements ：Amount and method
(4) Optimization of heat treatment ：Stoichiometry, Refinement

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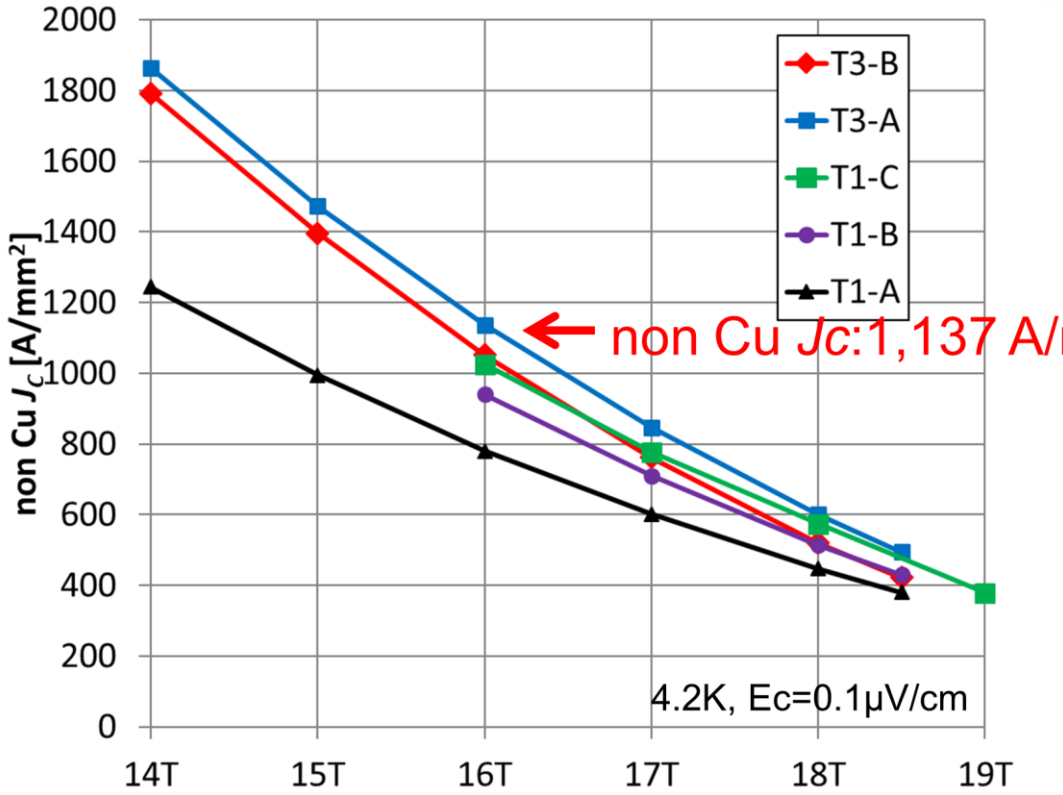
Non Cu J_C *v.s.* B



	T1-A	T1-B	T1-C	T3-A	T3-B
Wire diameter (mm)	0.80	0.74	0.64	0.80	0.80
Sn diffusion distance (μm)	60	58	48	32	32
Ti ratio (wt%)	0.55	0.55	0.55	0.48	0.35
non Cu J_C (A/mm²)@16T	800	930	1025	1137	1032

Non Cu *Jc* of 1,100 A/mm² at 16 T, 4.2 K has been achieved by improving Sn diffusion and optimizing Ti content.

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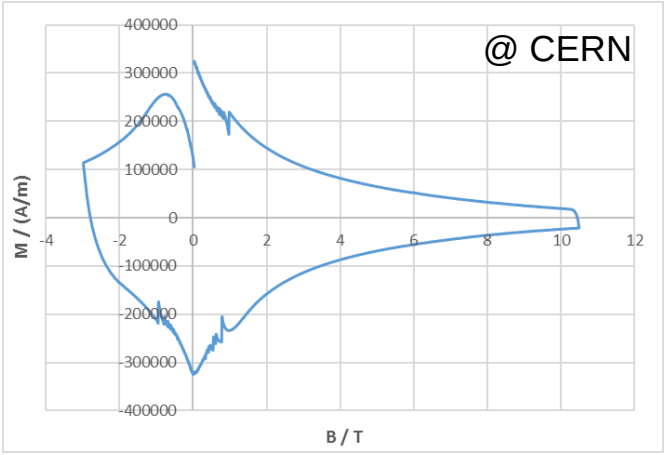
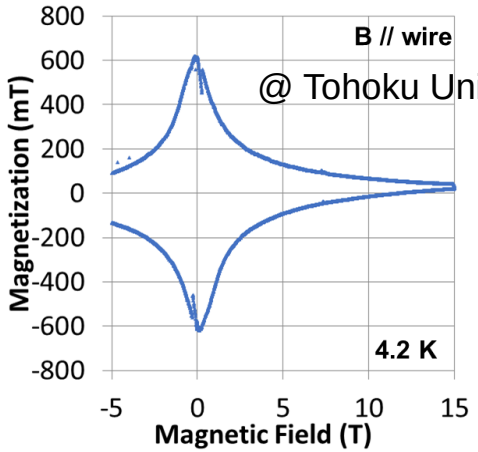
Magnetization characteristics

・For high *Jc* wire (T3-A,B), KSL/JASTEC evaluated magnetization characteristics and changes of *Jc* and RRR after rolling.

・The magnetization were measured at 4.2 K at CERN and Tohoku University, separately.

【Magnetizations of T3-A 】





【Calculated d_{eff} 】

Sample name	T3-A	T3-B
d_{eff} by CERN (μm)	54.5	55.0
d_{eff} by Tohoku Uni. (μm)	35.1	30.6

※Nominal Nb module dia.: 32μm

・There is no large flux jump.
・The calculated d_{eff} (effective filament diameter) were 30 to 60 μm, which was for one or two modules. It is possible to achieve a value close to the current target (≤ 60 μm).

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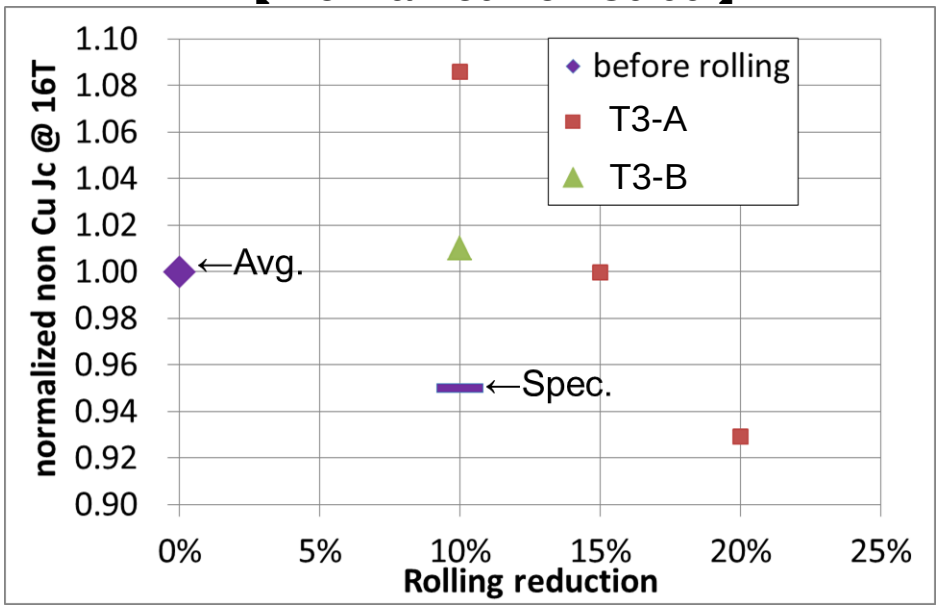
Rolling test (J_C, RRR)

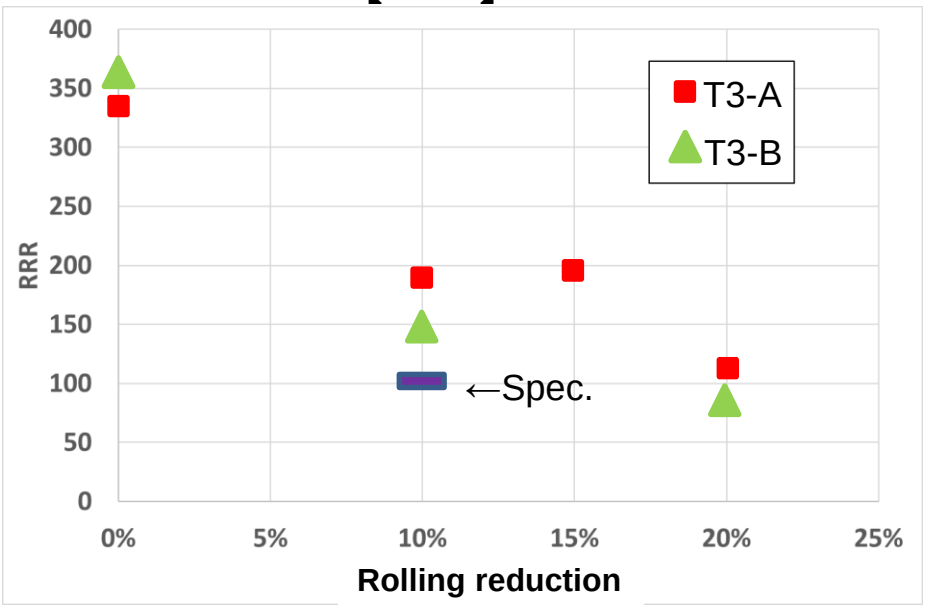
Required specifications for FCC wire (16 T dipole mag.)

After 10 % rolling : 1) I_C (J_C) > 95 % for round wires, and 2) *RRR* > 100.

【 Normalized non Cu *Jc* 】



【RRR】



・Both J_C and RRR after rolling meet the specifications.

・From the SEM images of cross section, at any rolling reduction level, the deformation of Nb/Sn modules were only partial.

Also at 10% reduction, there was no Nb barrier break.

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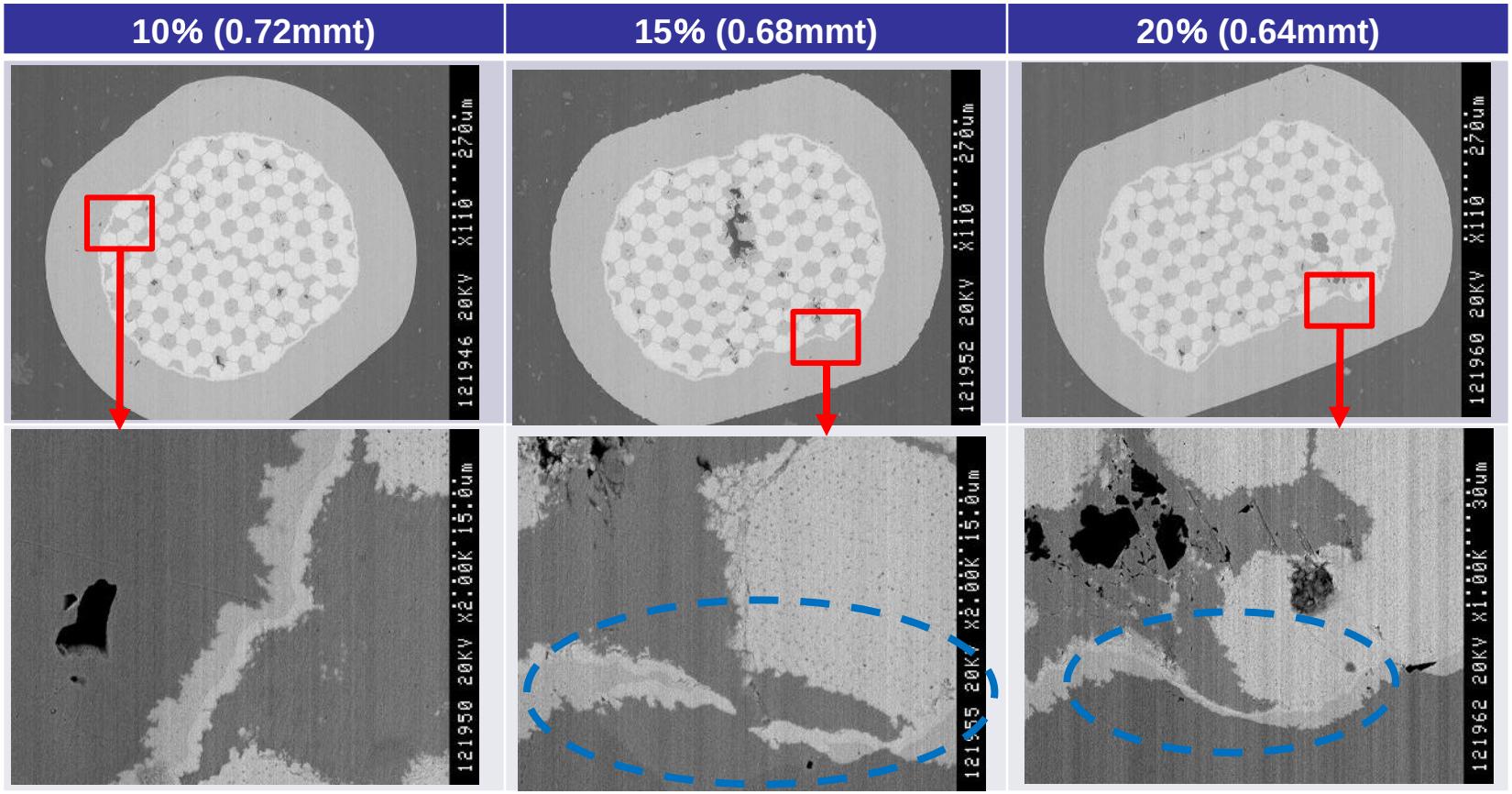
Cross section of T3-A after rolling (after heat treatment)



・At any rolling reduction, the deformation of the Nb / Sn modules were only partial.
・At 15 and 20% of rolling reduction, there were Nb barrier breaks,
but at 10% reduction, there was no Nb barrier break.

Current Results and Next steps

- KSL/JASTEC have achieved non Cu *Jc* @16T 1,100 A/mm^2, by improving Sn diffusion and optimize Ti content. These wires also showed reasonable results in d_{eff} and rolling test

- We will investigate the followings to overcome the provisional *Jc* target of 1,200A/mm^2:

(1) Increase of Nb area ratio
(2) Control of ternary additive element
(3) Further refinement of Nb_3Sn grain by controlling heat-treatment condition
(4) Artificial Pinning Center (APC)

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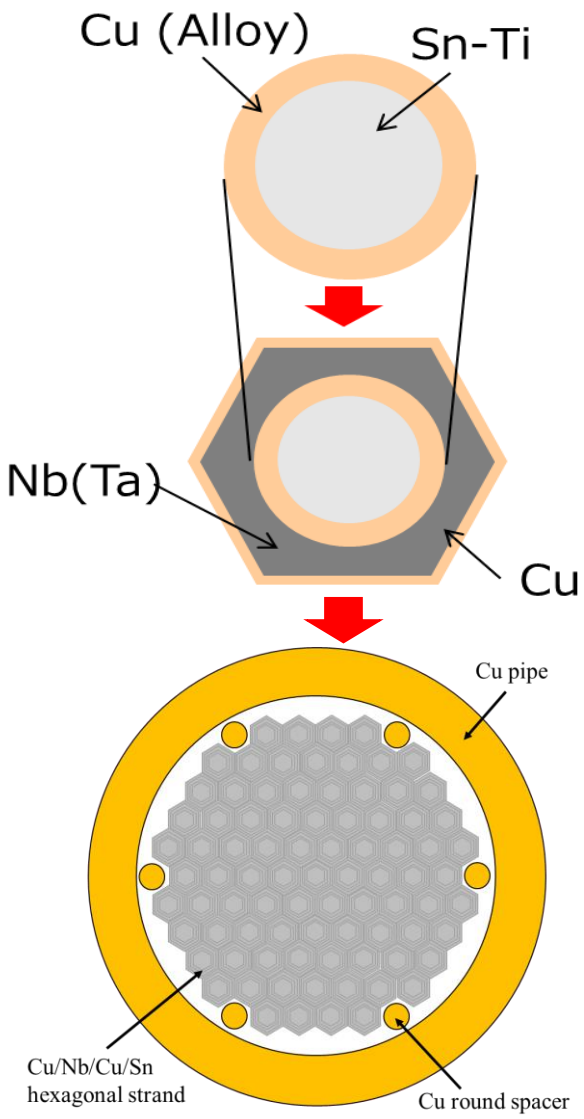
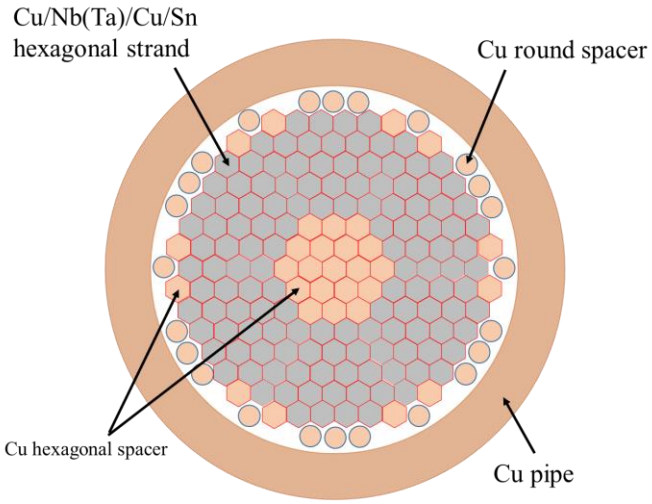
Materials for the FCC Week 2019

Wire Design of Nb tube type Nb_3Sn wire

Items	Wire A	Wire B	Wire C	Wire D
No. of Filament	85	132		
Filament Material	Nb			Nb-7.5wt%Ta
Nb/Sn ratio	~2.1		~3.3	
Filament Dia. (at φ0.83)	64 mm	45 mm		
Cu/non-Cu ratio	~1	~1.6		
Nb pretreatment(℃)	1,150		850	



Wire A

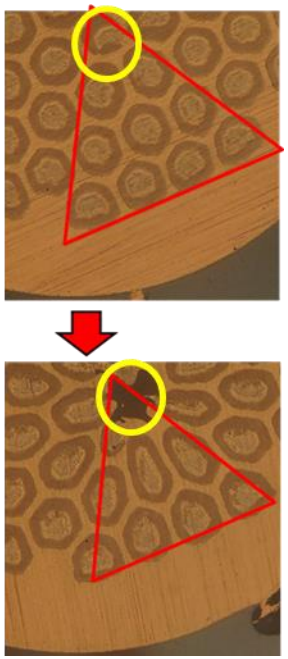


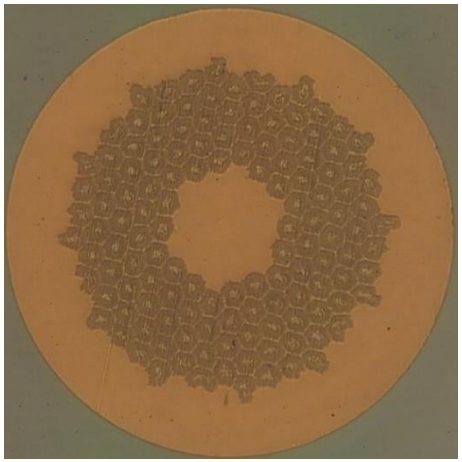
Wire B~D

Drastic improvement of wire workability

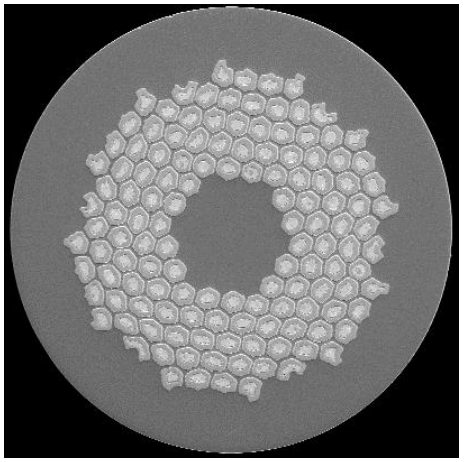
Wire A , φ4.8 mm

Improvement of production process

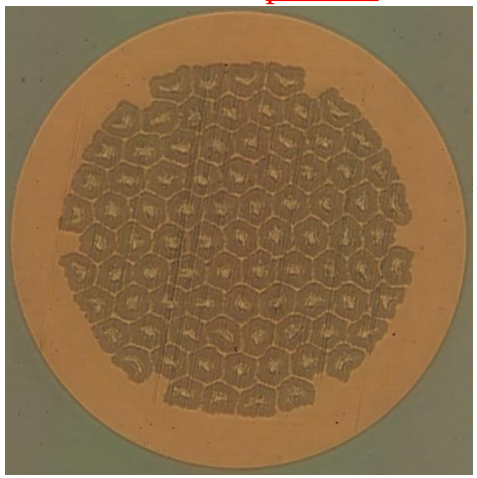




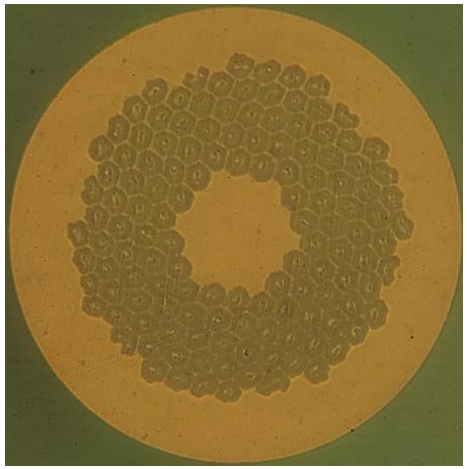
Wire B , φ0.83 mm



Wire C , φ0.83 mm



Wire A , φ0.83 mm



Wire D , φ0.83 mm

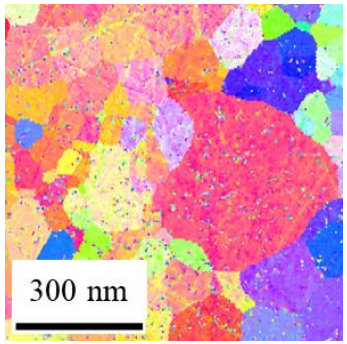
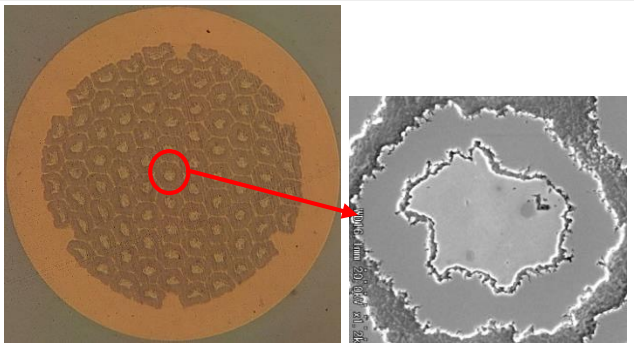
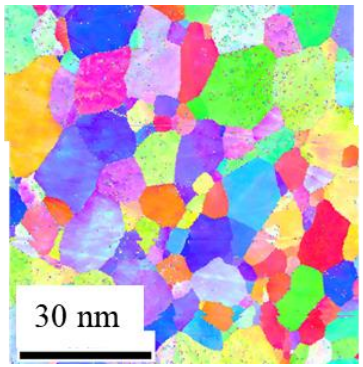
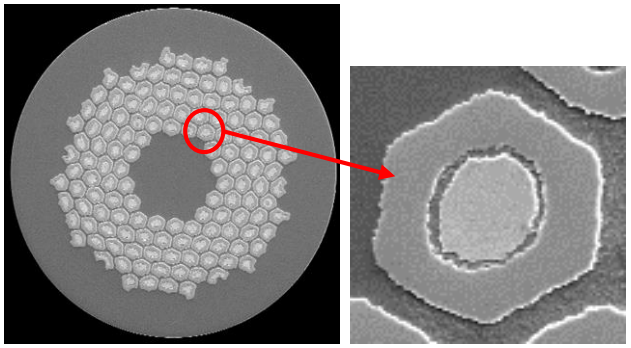
✓Some improvements were conducted for wire workability.

- material pretreatment
- Cleaning method of strands
- drawing parameter

✓Wire drawing is succeeded to φ0.83 mm.

✓The filament diameter is reduced to 45 μm.

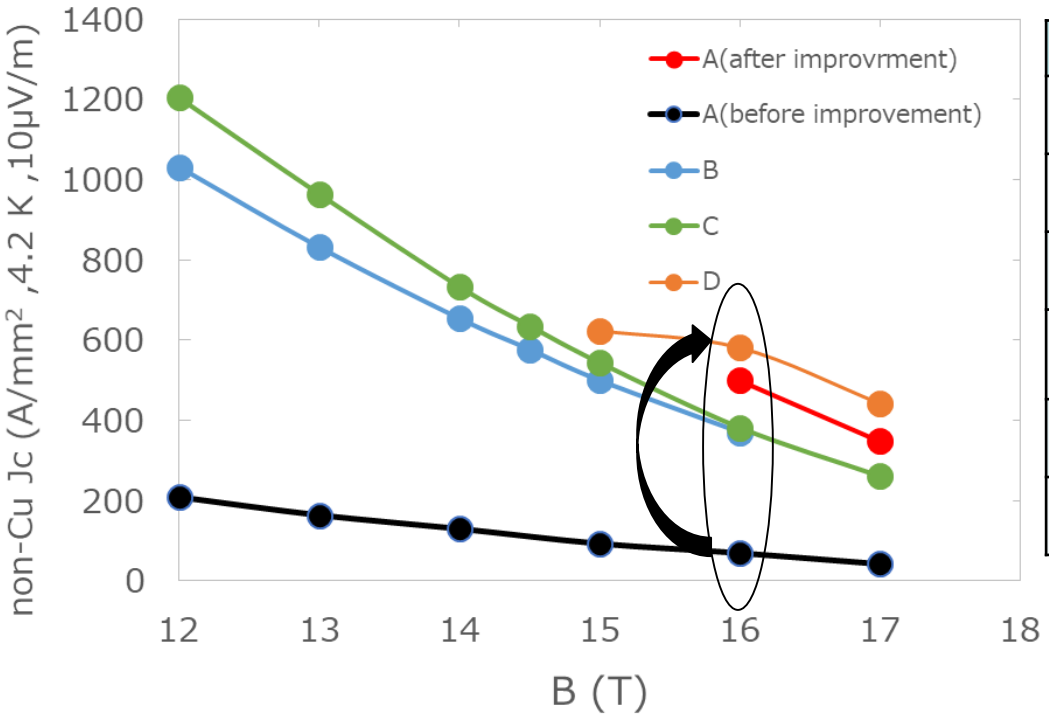
Improvement of filament shape

Wire	Nb tube grain (before drawing)	Filament shape (Cross section)
A		
C		

✓Nb tube grain size greatly affects filament shape.

✓Filament shape is improved by optimization of Nb tube pretreatment.

Non-Cu Jc



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Filament Dia. (at φ0.83)	64 mm	45 mm		
Cu/non-Cu ratio	~1	~1.6		
Nb pretreatment(℃)	1,150			850

✓ Non-Cu Jc of 580 A/mm^2 @16 T was obtained in Wire D.

✓ Some improvements have been conducted for higher non-Cu Jc.
- Optimization of heat-treatment condition
- Nb/Sn ratio in filaments
- Grain size reduction of Nb_3Sn (including APC technique)

Summary

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- ✓ Nb_3Sn wire with 85 or 132 Nb-tube filaments was tried.
- ✓ Multiple wire was drawn to 0.83 mm by improvements for wire workability.
- ✓ Nb pre-treatment optimization give a good influence on the filament shape.
- ✓ Non-Cu Jc of 580 A/mm^2 @16 T was obtained in Wire D.

Summary

- Task 3 almost completed
- Review
  - May 17-24: D. Larbalestier, S. Hopkins, T. Ogitsu
  - Visit JASTEC, Furukawa, and Tohoku Univ.
  - Review R&D plan and discuss new plan
- The R&D work so far
  - 8 R&D contracts: DT reach 1100 A/mm^2, Nb Tube workability improved
- Propose to modify Task 4 and Task 5
  - Task 4: R&D contracts 4 more each for JASTEC and Furukawa
    - With advanced technologies to aim for 1500 A/mm^2
  - Task 5: Produce 5 km x 2 with best conductors