FCC Week 2019, June 24 – 28, Brussels, Belgium

Development progress in KAT

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Outline

- Introduction
- Development progress of Nb_3Sn strand for FCC
- Additional improvement activities
- Conclusion

Introduction

Conductor development program between CERN and KAT

Mar-2017	Sep-2017	Mar-2018	Mar-2019	Mar-2020	Mar-2021
Contract	Task 1	Task 2	Task 3	Task 4	Task 5

Task 1	Task 2	Task 3	Task 4	Task 5
R&D Design	Billet design Manufacturing plan	Sample supplement (2km – 3 Types)	Sample supplement (5km – 1 Type)	Sample supplement (20km – 1 Type)
Cost estimation	Cost estimation	Cost estimation	Cost estimation	Cost estimation
Bimonthly report Task report	Bimonthly report Task report	Bimonthly report Task report	Bimonthly report Task report	Bimonthly report Task report

Final target

- ✓ Diameter : < 1mm
- ✓ Cu/NCu : ~ 1
- ✓ Deff : < 50 μm
- ✓ RRR ≥ 150
- ✓ Jc ≥ 1,500 A/mm^2

- Collaboration agreement between CERN and KAT was established in Mar-2017.
- KAT is currently approaching the end of Task 3.
- Delivery of 6km sample is in progress.

Local collaboration for Nb_3Sn development

Kiswire KAT
- Strand design and manufacture
- Project management

KITECH
- Hydrostatic extrusion process

Item	Specification
Extrusion load	6 MN
Working extrusion pressure	1 GPa
Container bore diameter	90 mm
Container type	Wire-wound
Maximum billet diameter	80 mm
Maximum billet length	350 mm
Maximum stem speed	50 mm/sec
Main hydraulic power	345 kW

NFRI
- Wire design consultation
- Strain performance test

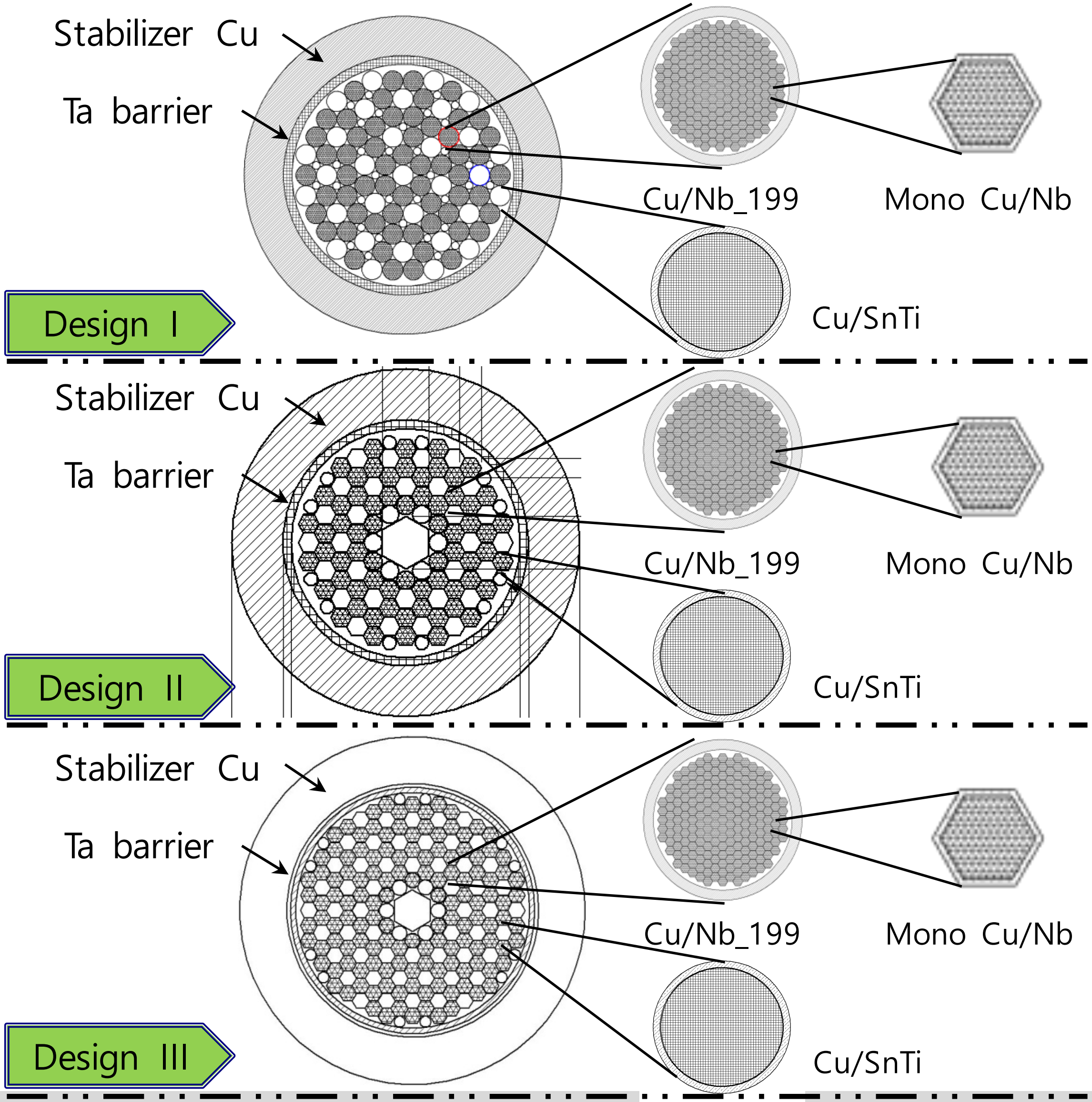
RIST
- Low temperature test at 16T, 4.2K

Item	Specification
Maximum field	18 Tesla
Temperature range	1.7 ~ 300K
Magnet bore size	52 mm
Sample space	37mm
Field center(from top flange)	1496mm

POSTECH
- Thermodynamic simulation of reaction

Development progress

Design summary for FCC



✓ Designed parameters

Parameter	Unit	Design I	Design II	Design III
Diameter	mm	1.0	1.0	1.0
Cu/N-Cu		1.0	1.0	1.0
No. Filaments	ea	11,940	13,134	26,268
Dia. Filament	㎛	4.0	3.7	2.7
Dia. Sub't	㎛	68	57	44
Cu fraction	%	35.5	35.8	36.9

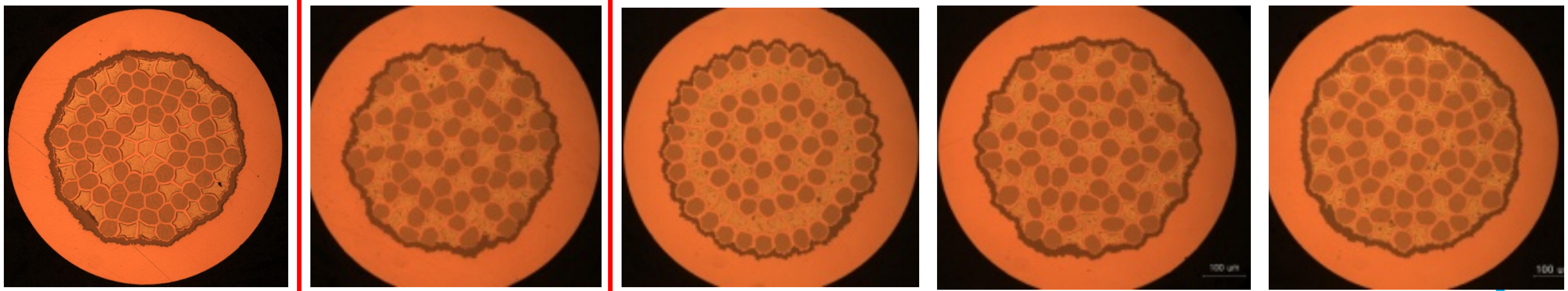
✓ Estimation of performance

Parameter	Unit	Design I	Design II	Design III
Mono Ic	A	0.0344	0.0315	0.0176
Ic	A	411	414	462
Jc	A/㎟	1,047	1,055	1,207

Development progress

Optimization of design I (91 Modules)

- Samples having various structures were produced and tested.
- Nb/SnTi volume ratio explored from 1.37 to 1.85.
- Position of Nb multi and SnTi mono is very important parameters to decide Jc performance.

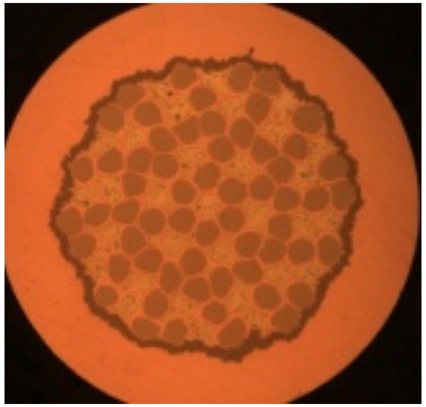


Nb 199 x	56	60	60	60	66
Nb/SnTi	1.37	1.85	1.47	1.47	1.69
Jc@16T	932	1,027	895	956	985
Deff	Not meas.	103.4	126.1	95.0	75.3

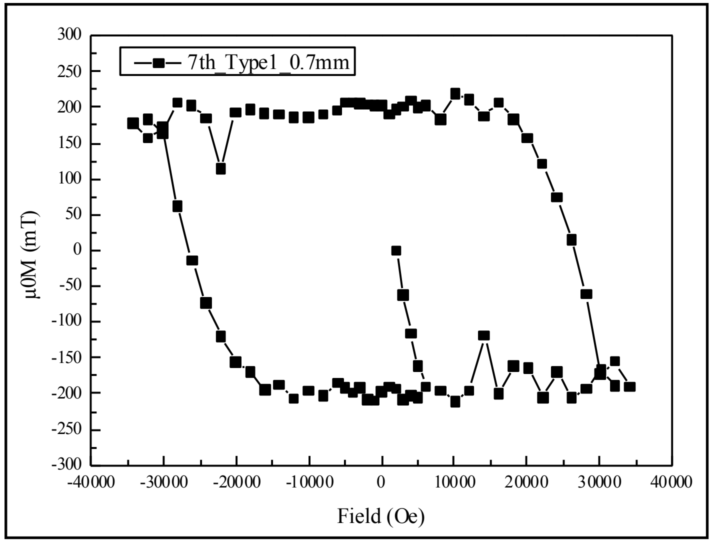
Development progress

Optimization of design I (91 Modules)

- Opportunities of this design :
  1) relatively large effective diameter(~160㎛@ϕ1mm, ~ 100 ㎛@ϕ0.7mm)
  2) Limitation of the final filament diameter : ~ 4 ㎛
  3) Low Ti content in Nb_3Sn filament : < 1.2 at.% (Typical value of ITER strand ~ 1.8 at.%)

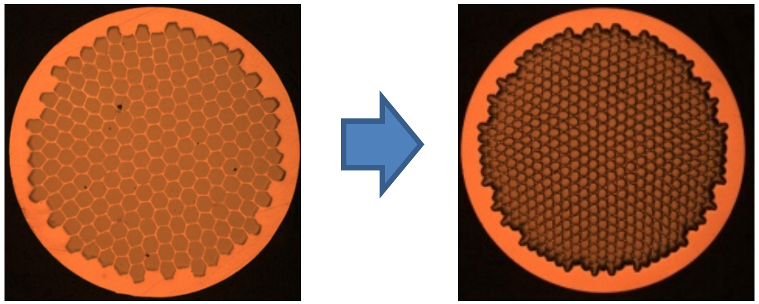


Dia. 0.7mm
Jc 1,027 A/㎟@16T
Deff : 103 ㎛

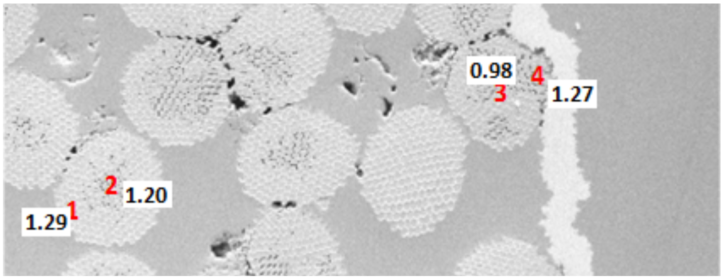


1) Relatively large effective diameter

2) Increase no. Nb(199 → 499) to decrease filament diameter → Difficult to draw down



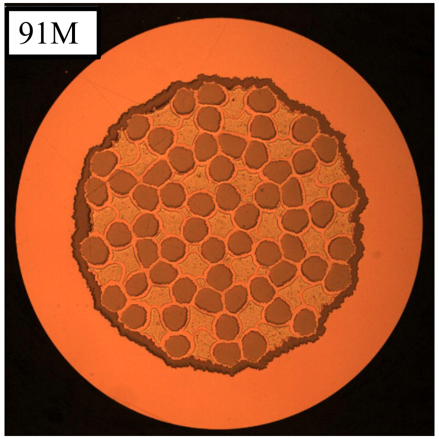
3) Low Ti content and inhomogeneous distribution

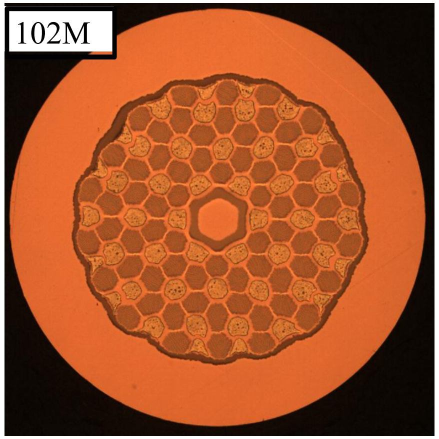


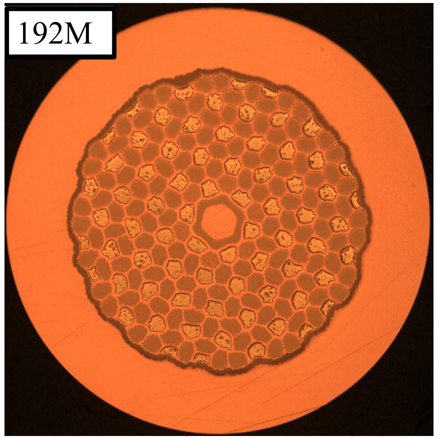
Development progress

Optimization with design II and III

- Next step : To decrease effective diameter, number of restacked modules should be increased.
  (91M → 102M(Design II) → 192M(Design III))
- At this stage, we created a new design using the inner barrier at the core position.
  Purpose of center Cu area → Adjust Nb/SnTi, Improve cold drawing property(Stress distribution)
- Finally, Design III(192M) was adopted as a main structure for 6km deliverable samples.





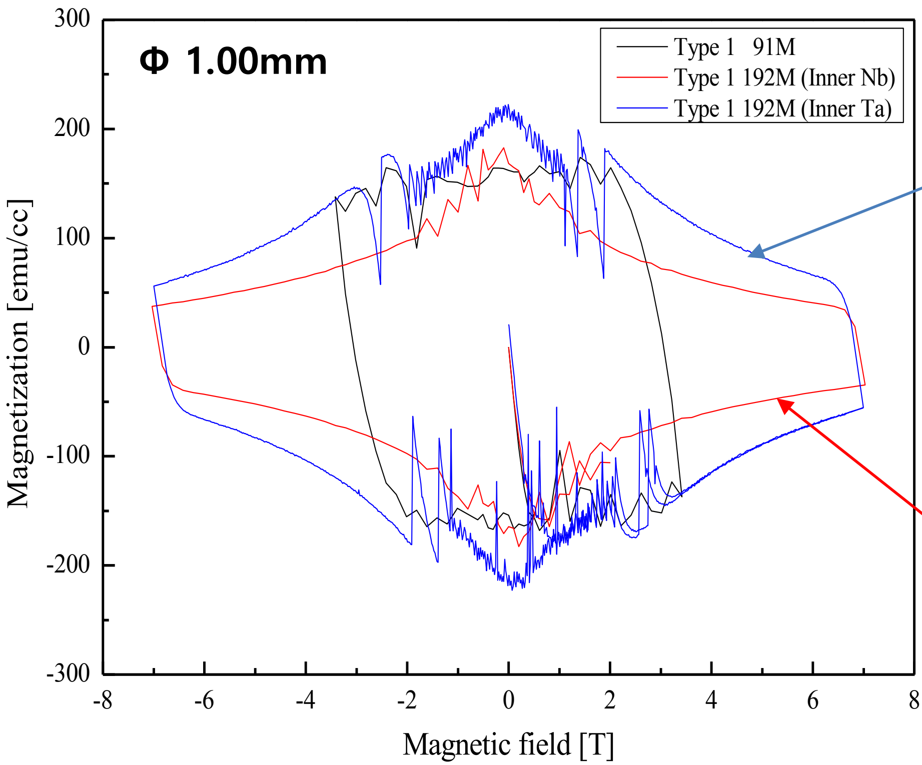


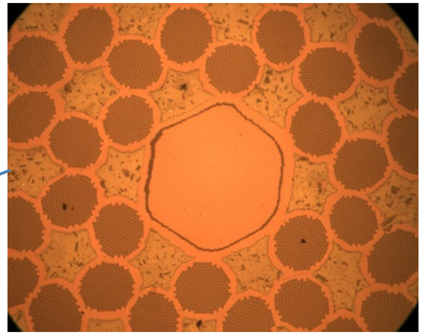
Diameter[mm]	1.0	1.0	1.0
Filament dia.[μm]	4.0	3.7	2.7
Nb/Sn vol. ratio	1.85	1.34	1.76
Volume fraction of Mat. Cu	35.5%	35.8%	35.9%
No. Nb module	60 EA	66 EA	132 EA

Development progress

Optimization with design II and III

- Inner barrier material decision : Nb vs <u>Ta</u> → The use of Ta showed <u>unstable magnetization properties.</u>
- Higher Jc was achieved with Nb inner barrier samples(995.3 A/㎟@ϕ1mm, 1,080 A/㎟@ϕ0.7mm).

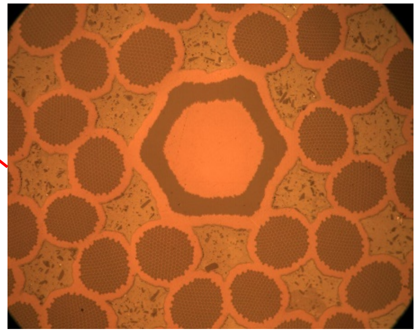




Ta inner barrier
Jc 909 A/㎟, Deff 134 ㎛

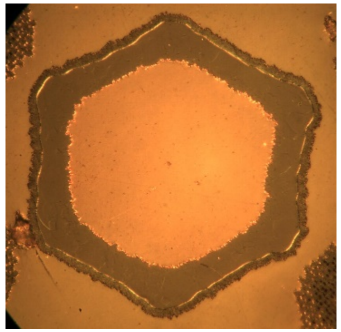
HT

RRR 128



Nb inner barrier
Jc 995.3 A/㎟, Deff 69.2 ㎛

HT



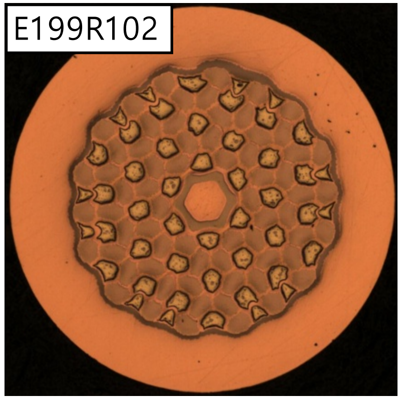
RRR 180

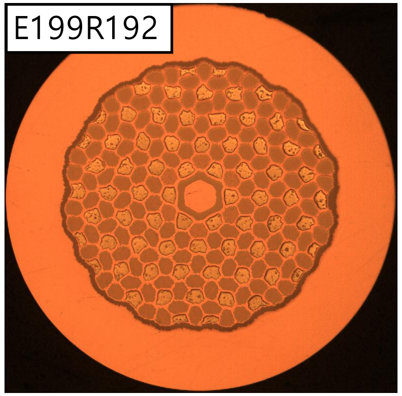
Development progress

6km sample delivery for Task III

- 6km samples were manufactured and being delivered to CERN.
- Minimum piece length was 100m and maximum piece length was 752m.
- Totally, 9 restacking billets were assembled with short length(1M) → increase variation

Billet No.	Dia. (㎜)	No. Nb filament	Sub't dia.	Vol.% in matrix			Nb/SnTi	Filament Dia. (㎛)
				Cu	Nb	SnTi		
E199R102-1	1.004	13,134	55.5	40.5	33.5	26.0	1.29	3.42
E199R192-1	1.004	26,268	45.3	36.8	42.1	21.2	1.99	2.86
E199R192-2	1.004	26,268	43.8	34.3	40.9	24.8	1.64	2.66
E199R192-3	1.004	26,268	44.4	37.3	40.3	22.4	1.80	2.56
E199R192-4	1.004	26,268	43.2	36.9	38.0	25.1	1.52	2.59
E199R192-5	1.004	26,268	43.6	33.7	41.7	24.6	1.69	2.76
E199R192-6	1.004	26,268	44.9	33.6	42.3	24.2	1.75	2.88
E199R192-7	1.004	26,268	44.1	33.5	42.8	23.7	1.80	2.78
E199R192-8	1.004	26,268	44.2	32.3	43.5	24.2	1.80	2.84

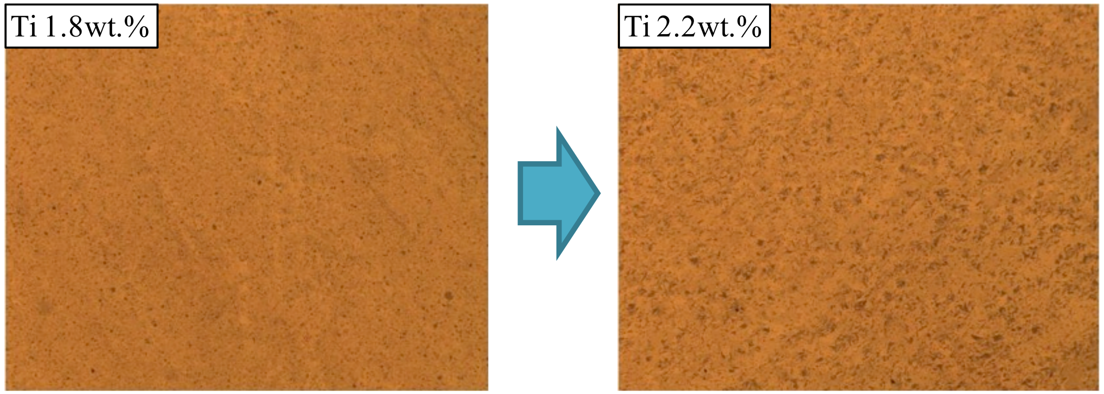




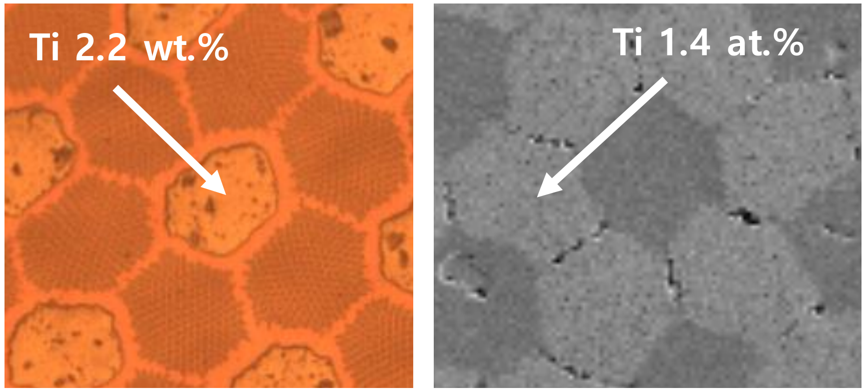
Additional improvement activities

Increasing Ti content in SnTi alloy

- As the Nb volume ratio increased, the Ti content in the Nb_3Sn strand became insufficient.
  → If Nb/SnTi is equal to 1.7 with 34% Cu ratio, the estimated Ti content in Nb_3Sn is 1.2 at.%.
- Increasing Ti content in SnTi alloy(1.8 wt.%) would be required.
  → 2.2 wt.% SnTi alloy was manufactured by ourselves and applied in our strands
- Consequently, the increase of Ti content resulted in Jc degradation from $995A/mm^2$ to $850A/mm^2$.
  → The main causes can be Ti non-uniform distribution and Nb_3Sn diffusion tendency change.



Increase of Ti in the SnTi production step

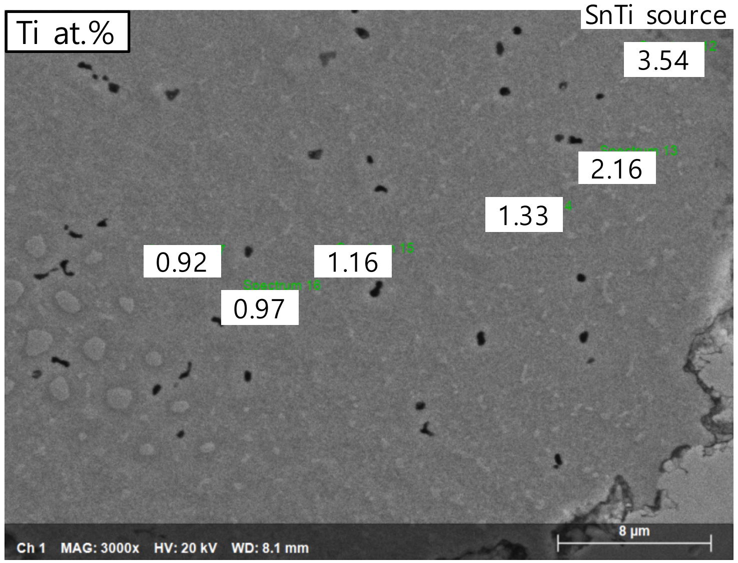


Estimated Ti content in Nb_3Sn after HT

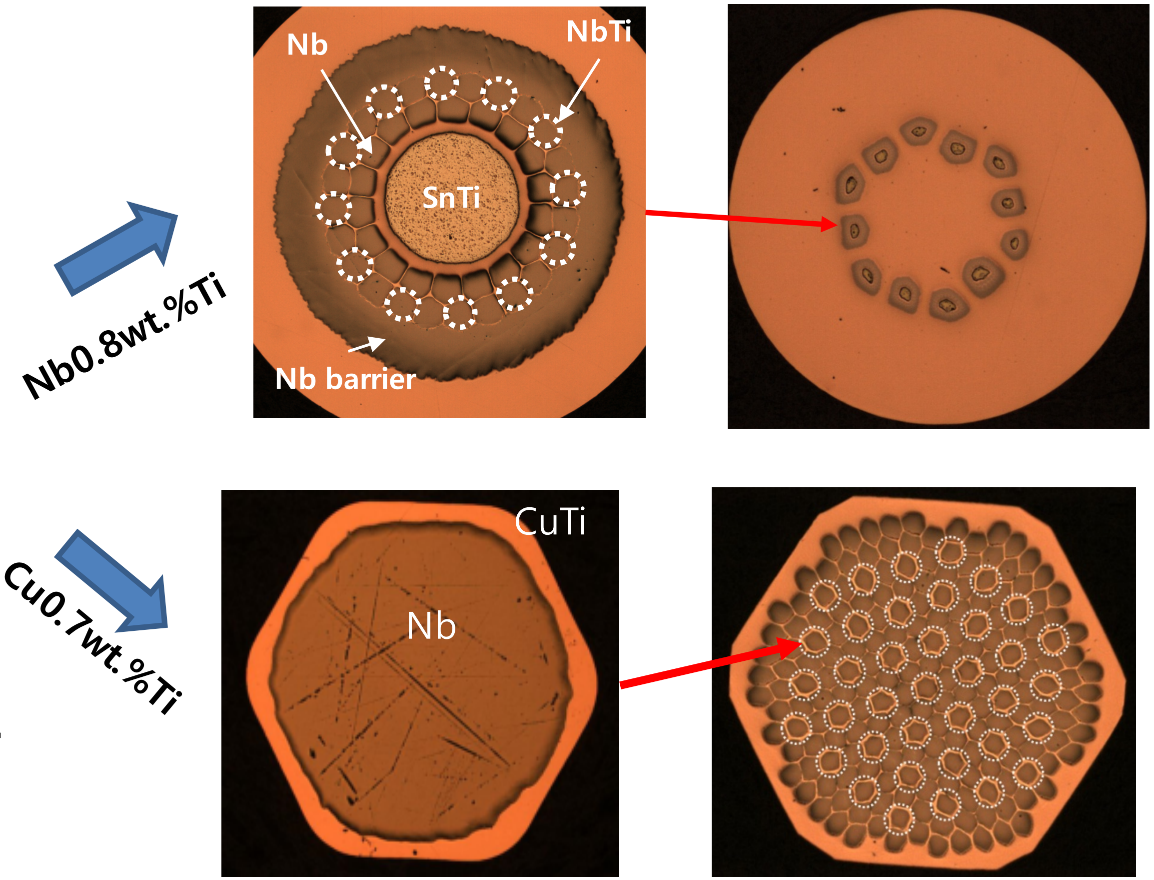
Additional improvement activities

Apply additional Ti source(Nb0.8wt.%Ti, CuTi)

- Non uniform Ti distribution is also considered to be one of the main causes of Jc degradation.
  → Since Ti traveling from SnTi source is very difficult, additional Ti source is required.
- Nb0.8wt.%Ti and Cu0.7wt.%Ti have been applied and evaluation is in progress.



Non uniform Ti distribution after HT



Conclusions

Current status of development

- Various type's strand have been produced and evaluated, and optimization studies on design III(192Module) are in progress.
- A total of 6km strands is being delivered to CERN for the completion of Task III.

For the next steps..

- Further study would be required on increasing Ti content.
- In order to solve non-uniform issue of Ti distribution, the introduction of additional Ti sources(NbTi, CuTi) is under consideration.

Thank you!