Recent progress of REBCO coated conductors at Fujikura

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A part of this work has been commissioned by
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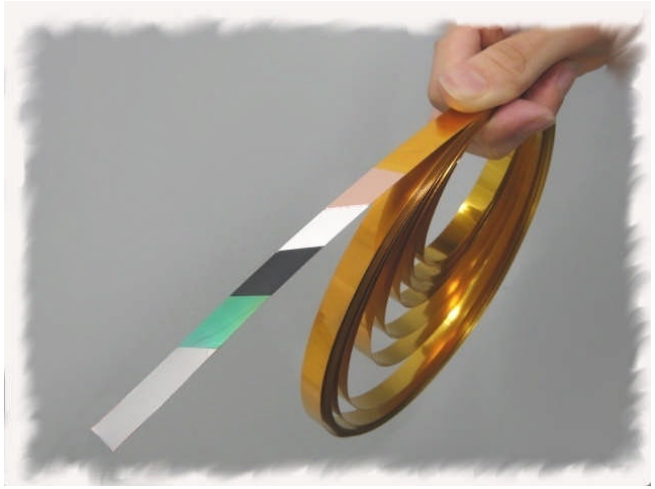
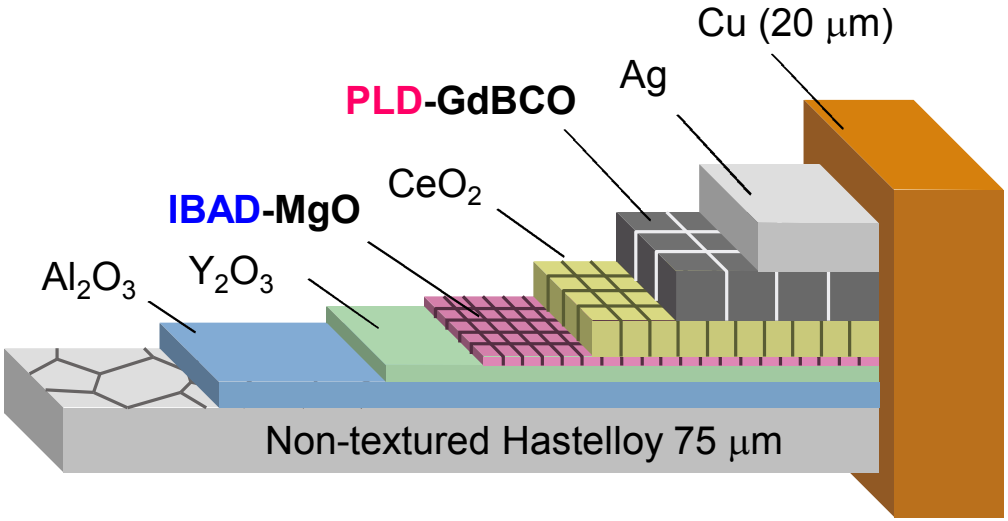
Outline

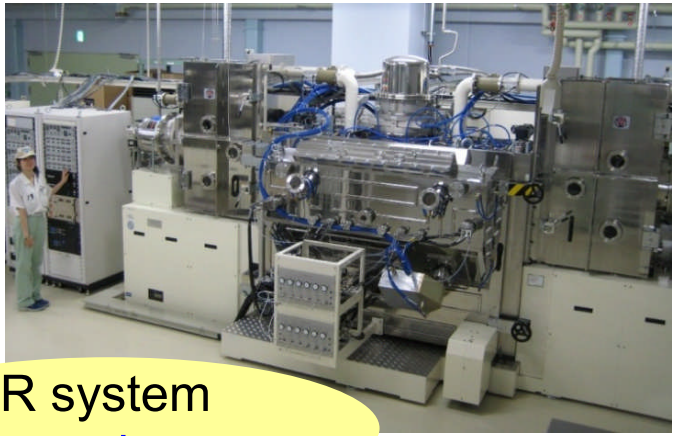
- Introduction
- Characteristics of Fujikura's REBCO coated conductors
- Recent progress of REBCO coated conductors at Fujikura
- Summary

Fujikura's REBCO coated conductor (IBAD / PLD)





Ion Beam Assisted Deposition (IBAD)



R-to-R system
with large ion source

Pulsed Laser Deposition (PLD)

R-to-R system
with hot-wall heating

Fujikura's REBCO coated conductors

Typical Specification

Item	Width [mm]*	Thickness [mm]*	Substrate [μm]	Stabilizer [μm]	Critical Current (I_c) [A] (@77K, S.F.)
FYSC-SCH04	4	0.13	75	20 x 2	≧165
FYSC-SCH12	12	0.13	75	20 x 2	≧550

* Dimensions do not include thickness of insulating tapes.

＜Schematic of 2G HTS wire (FYSC-SCH04)＞

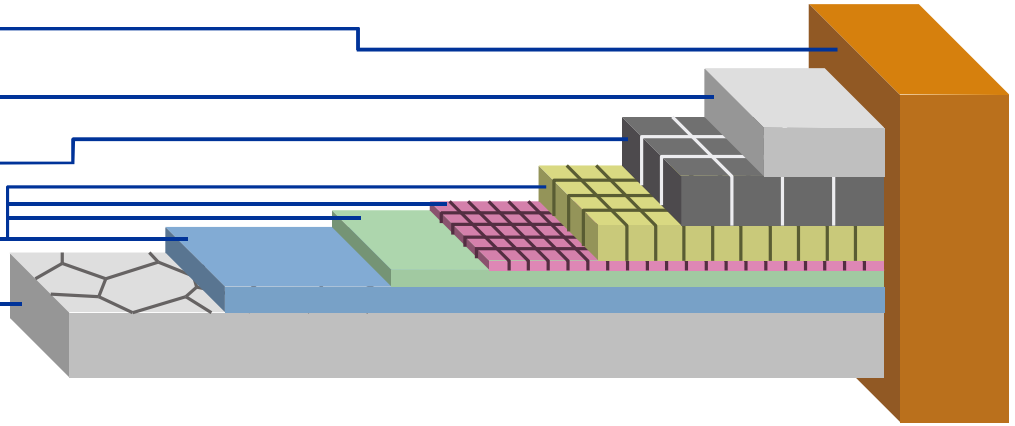
Stabilizer [Copper plate] 20μm

Protection layer [Ag] 2μm~

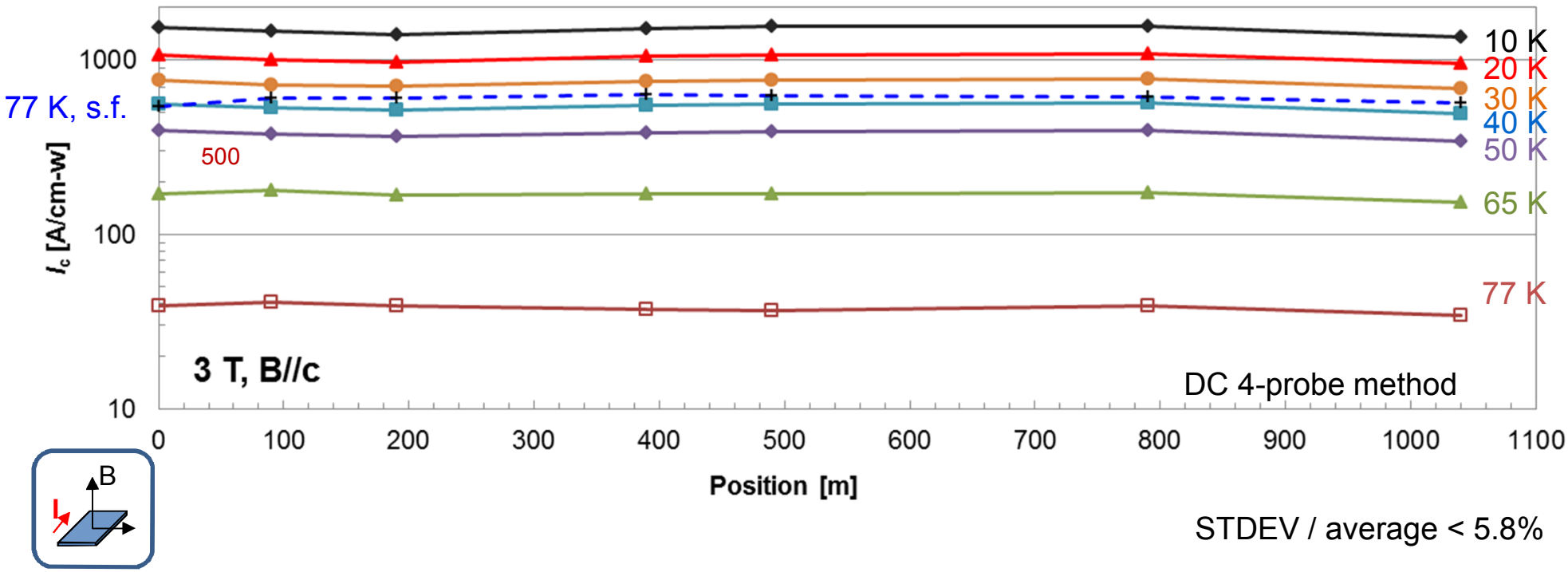
Superconducting layer [$GdBa_2Cu_3O_x$] ~2μm

Buffer layer [MgO, etc.] ~0.7μm

Substrate [Hastelloy®] 75μm



In-field I_c distribution in a 1 km long demo sample at 3 T, 10-77 K

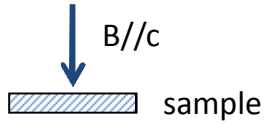


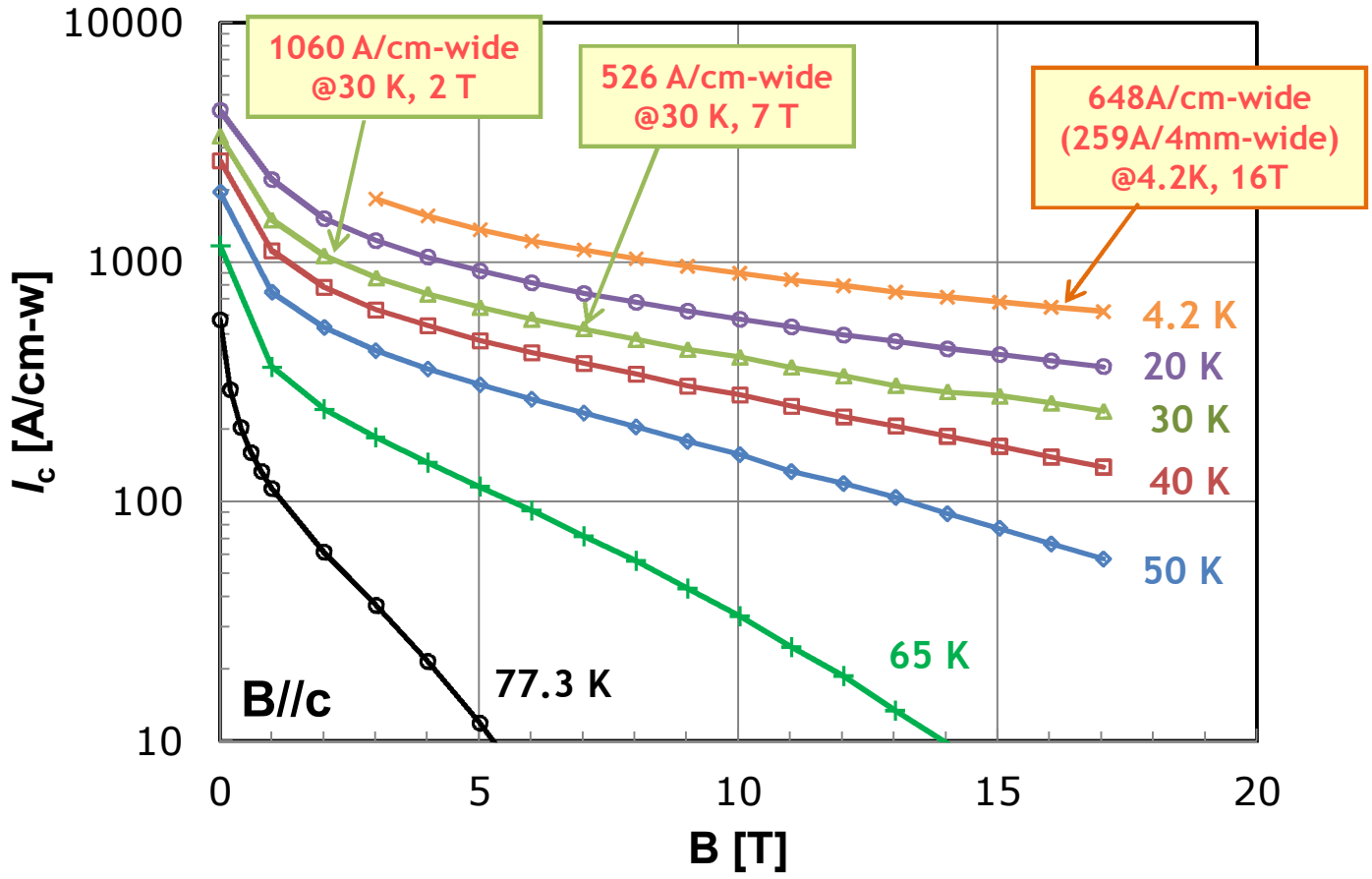
STDEV / average < 5.8%

Uniform in-field I_c in wide range of temperatures are observed

Typical In-field I_c of a production wire

- Example data of typical production wire
- Sample : Ic = 573 A@77K,s.f. (cm-w)



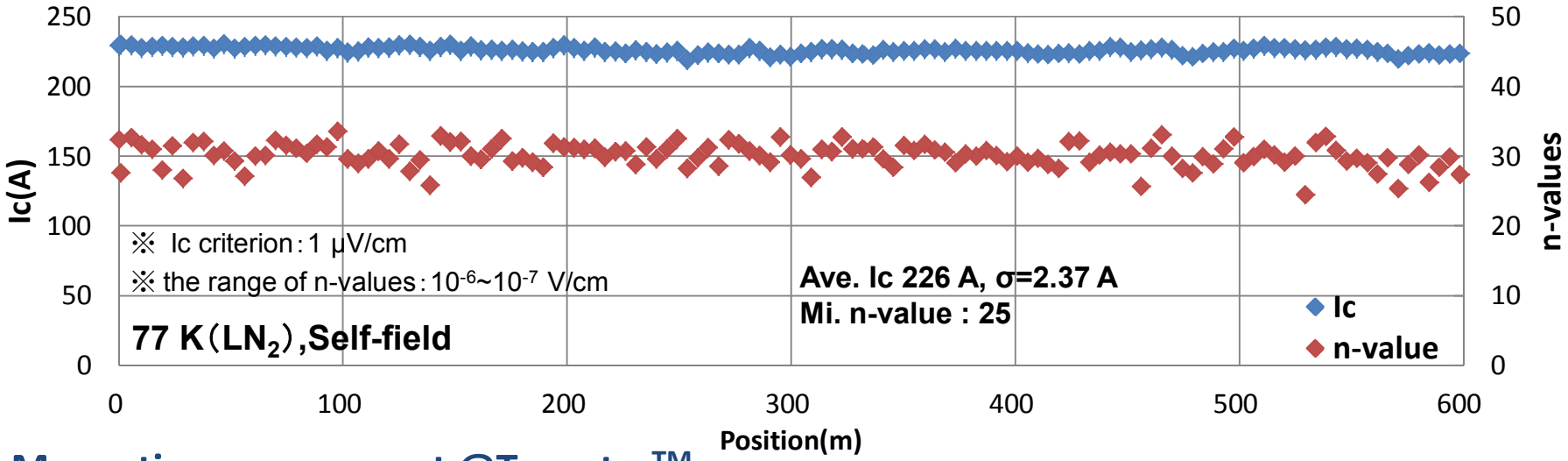


* This work includes some data measured at High Field Laboratory for Superconducting Materials, Institute for Materials Research, Tohoku University.

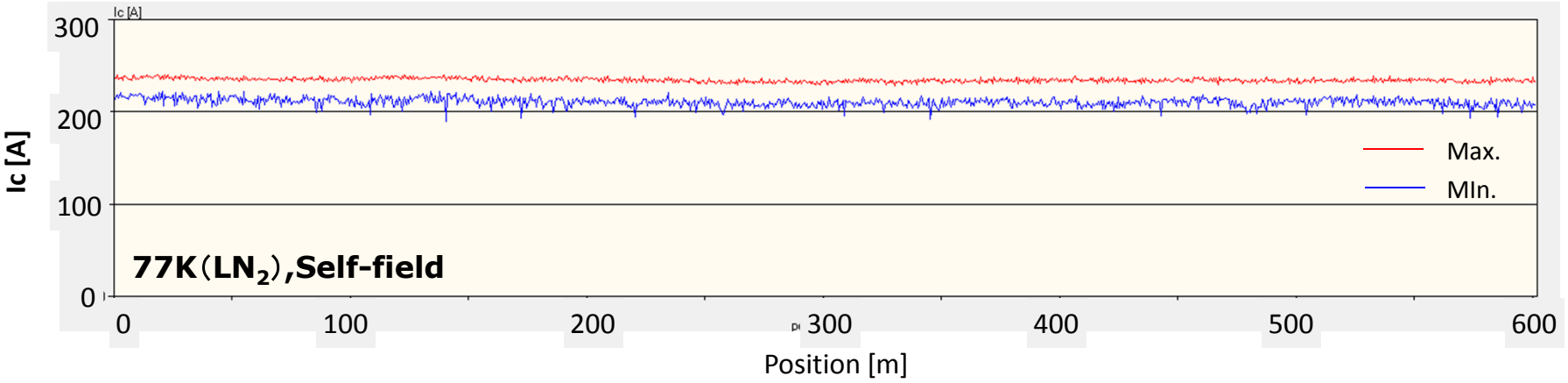
Example data of longitudinal I_c distribution

a production wire of 4 mm-wide

- **4-terminal method current conduction measurement at every 4.7 m**



- **Magnetic measurement @Tapestar™**



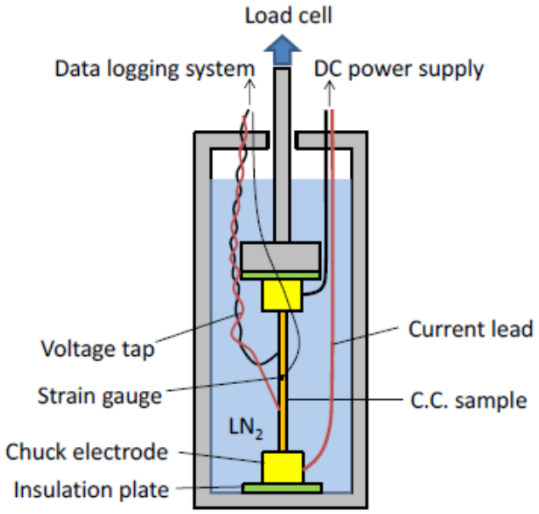
quite uniform I_c with 600m length are obtained

Evaluation of tensile characteristics of divided 4 mm-wide

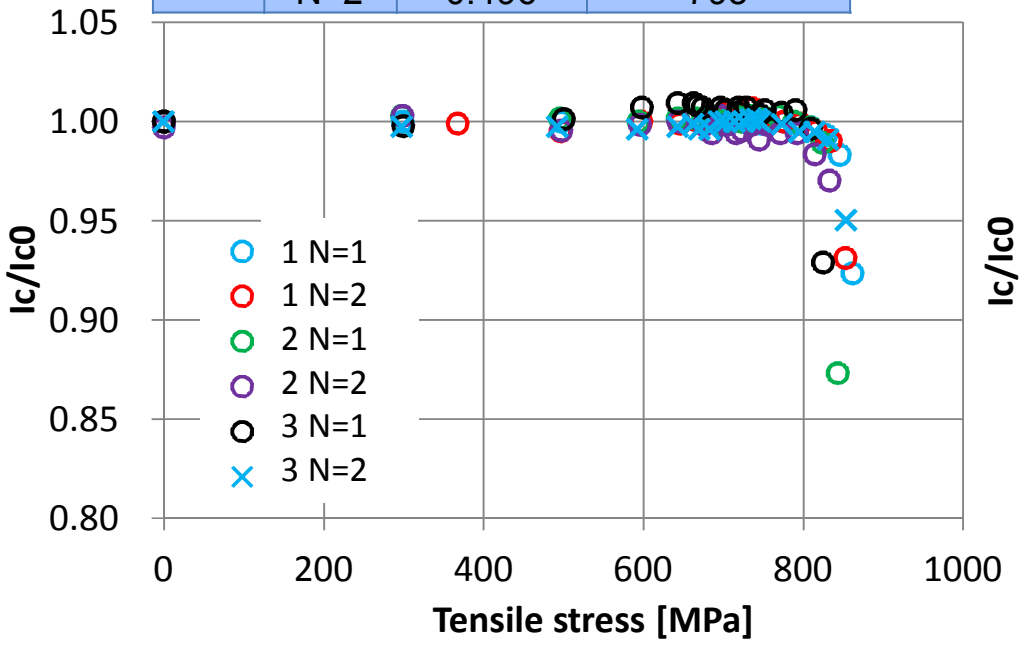
Tensile characteristics of 3 parts of 4 mm-wide conductors divided from 12 mm-wide coated conductor in LN2

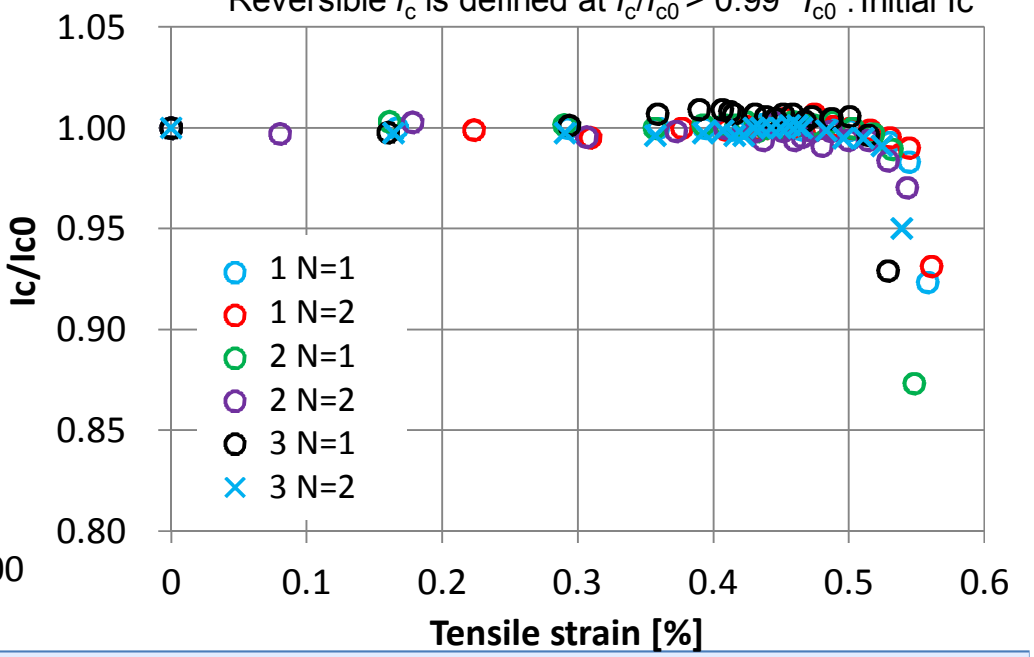
samples		reversible I_c	
		Strain [%]	Stress[MPa]
1	N=1	0.523	820
	N=2	0.513	817
2	N=1	0.521	813
	N=2	0.497	768
3	N=1	0.514	810
	N=2	0.496	795

4mm { 1 : one edge side
4mm { 2 : center side
4mm { 3 : the other edge side



* Reversible I_c is defined at $I_c/I_{c0} > 0.99$ I_{c0} : Initial Ic





Each divided 4 mm-wide conductors have shown equivalent tensile characteristics in LN2

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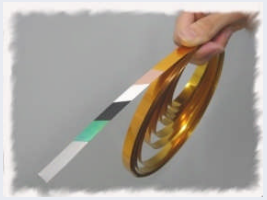
Abstract of 2G HTS development program in Japan(FY2016~)

NEDO started a new program of 2G HTS wires with the aim of promoting rapid commercialization, from FY2016.

Cat.	Development Items		Institutions	Target	'16	'17	'18	'19	'20
HTS Power Cable systems	(1) Electric HTS Power Cable systems	AC	TEPCO Sumitomo Furukawa Maekawa	- Ensuring essential safety functions - Recovery methods - Refrigerators	Ensuring safety functions		Standards for design		
		DC	Isikari Association	- Standards for design/operations	Standards for design				
	(2) Railway HTS Power Cable systems	—	RTRI	- 2km refrigerator systems	Development of small scale refrigerator		Verifications of a 2km refrigerator system		
HTS Magnet Systems	(3) HTS highly stable magnet system for MRI	—	Mitsubishi Electric AIST	- Half-scale 3T MRI systems	Development of a half-scale 3T HTS-MRI system			Development of a half-scale 5T HTS-MRI system	
		joints	AIST etc.	- superconducting joints	Development of superconducting joints				
	(4) 2G HTS wires 	—	Fujikura	- In-field Ic and uniformity improvement - Evaluation of reliability of wires	In-field Ic improvement Uniformity Improvement				
		—	Fujikura	- High productivity	High productivity				

Development of 2G HTS wire to improve the in-field I_c with high productivity

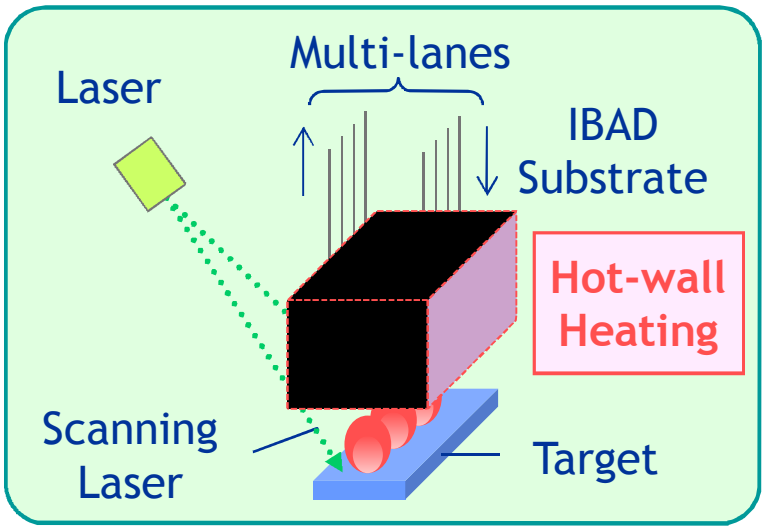
2G HTS development program in NEDO project (~FY2018)

Program of 2G HTS wires with the aim of promoting rapid commercialization

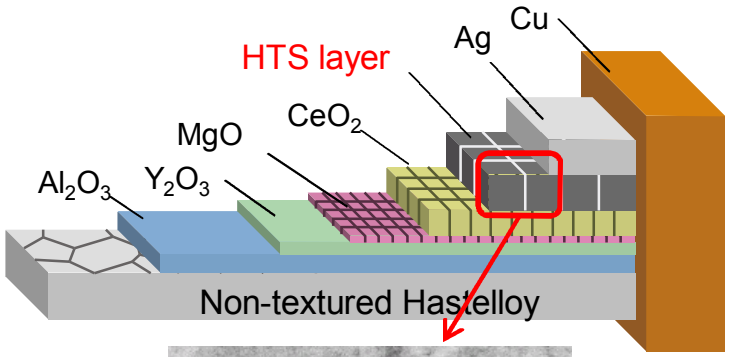
Challenges	Current level	Target
(1) Improvement of current density of 2G HTS wires 	Je=250A/mm^2 @30K, 7T	Je > 400A/mm^2 @30K,7T (with insulation) with high productivity
(2) Improvement of uniformity and Evaluation of reliability of 2G HTS wires 	reduced rate of Ic < 0.15 at 300m	reduced rate of Ic < 0.15 at 1km
(3) Development of low AC loss 2G HTS wires 	fabrication technology of 100μm-wide multi filament Striated 440μm-wide SC layer	Loss Simulation AC loss < 1/10

Improvement of in-field I_c with artificial pinning

Improvement of in-field I_c of 2G HTS wire will be applied introducing artificial pinning techniques in HTS layer



BHO doping by hot-wall PLD system



< STEM image >

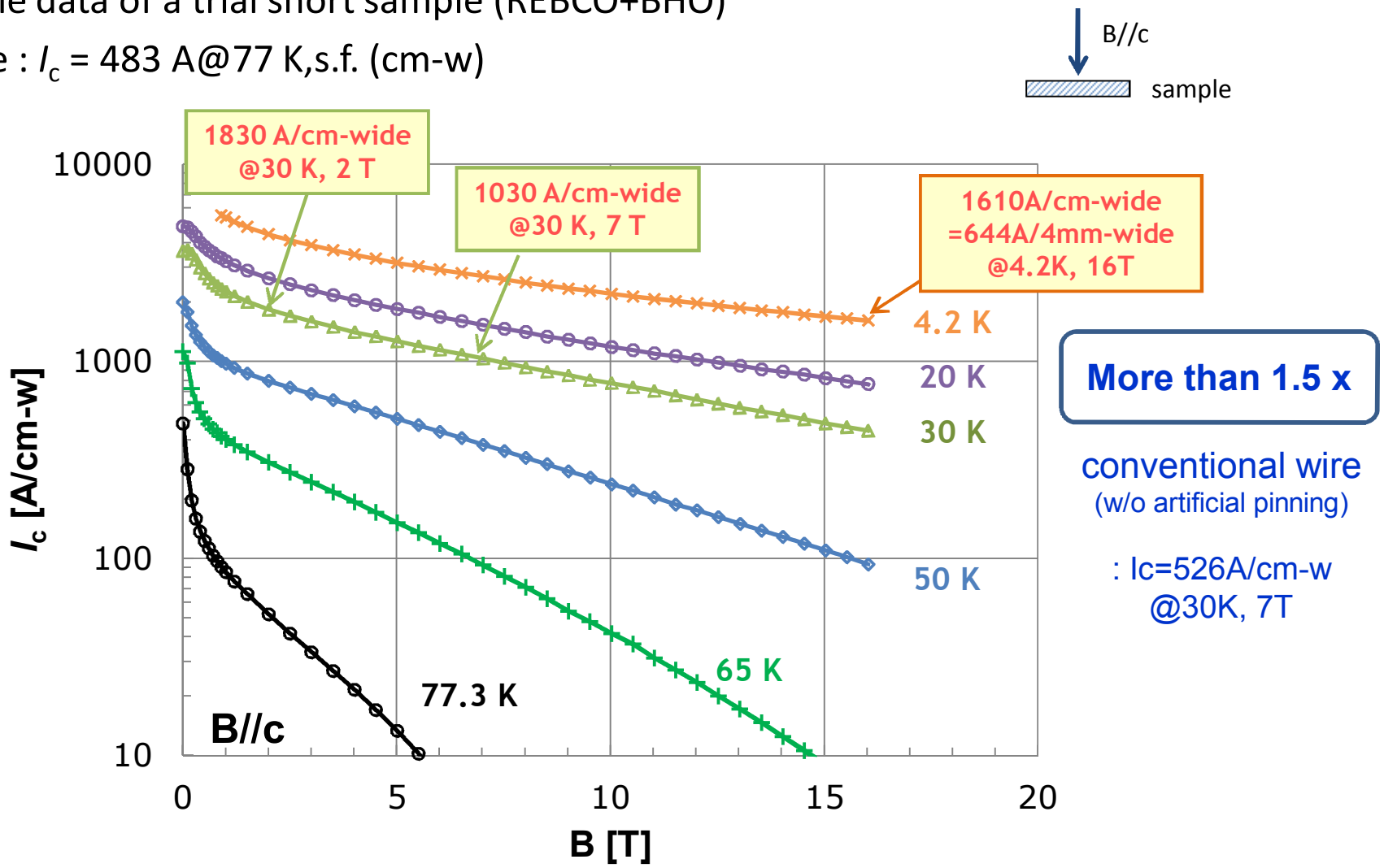
Typical dimensions of nano-rods

- **Length : ~100 nm**
- **Diameter : 3~5 nm**
- **Distance between rods : 10~30 nm**

Rod-shaped precipitates were observed

Example data of in-field I_c with artificial pinning (B//c)

- Example data of a trial short sample (REBCO+BHO)
- Sample : I_c = 483 A@77 K,s.f. (cm-w)



More than 1.5 x

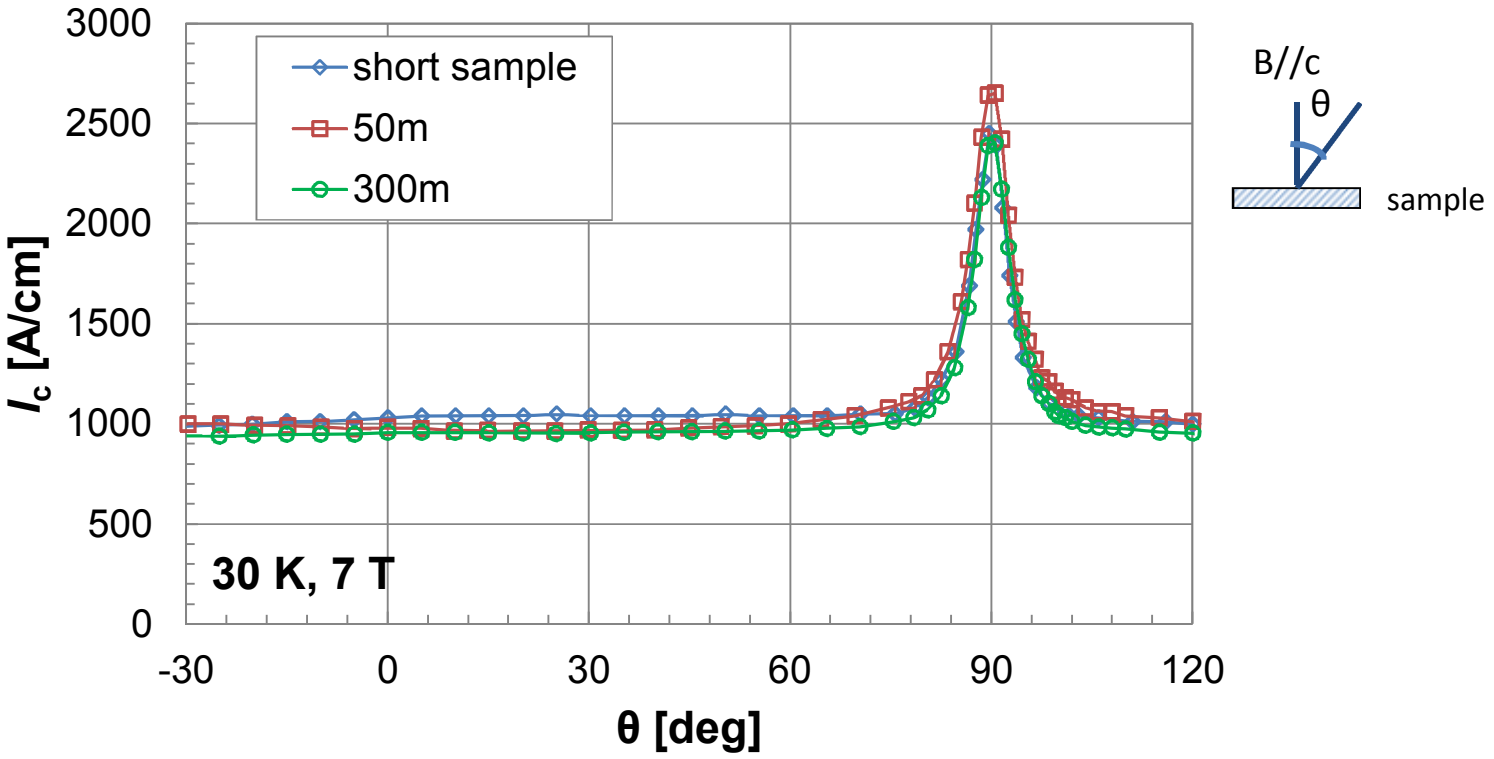
conventional wire
(w/o artificial pinning)

: Ic=526A/cm-w
@30K, 7T

Evaluation of reproducibility of I_c-B-θ characteristics

Focus on evaluating the reproducibility of in-field I_c and I_c-B-θ characteristics of coated conductors

- Example data of trial samples with artificial pinning (REBCO+BHO)



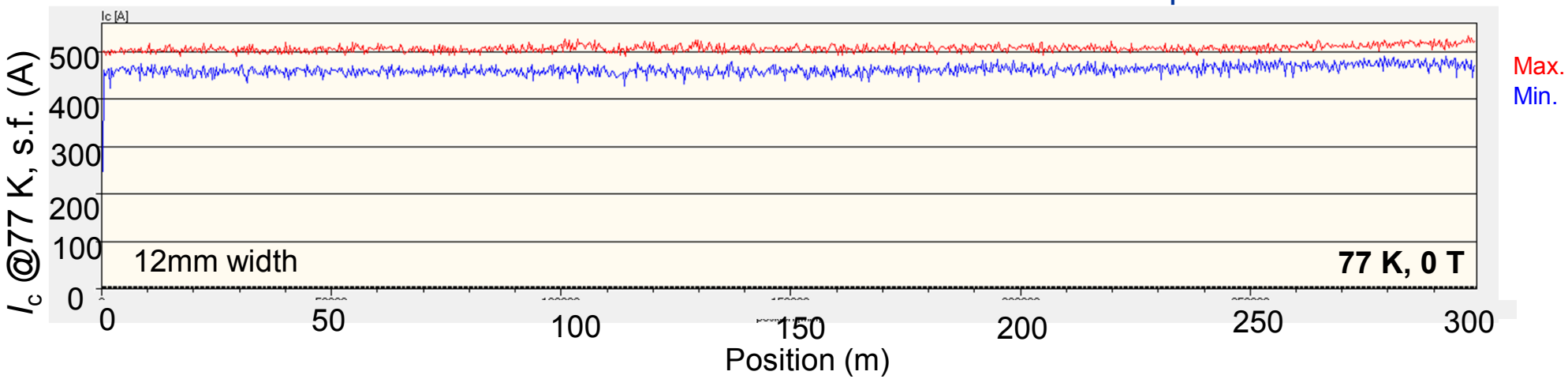
Good reproducibility of I_c-B-θ characteristics are obtained

Reproducibility will be evaluated with optimization of deposition conditions and thickness, etc.

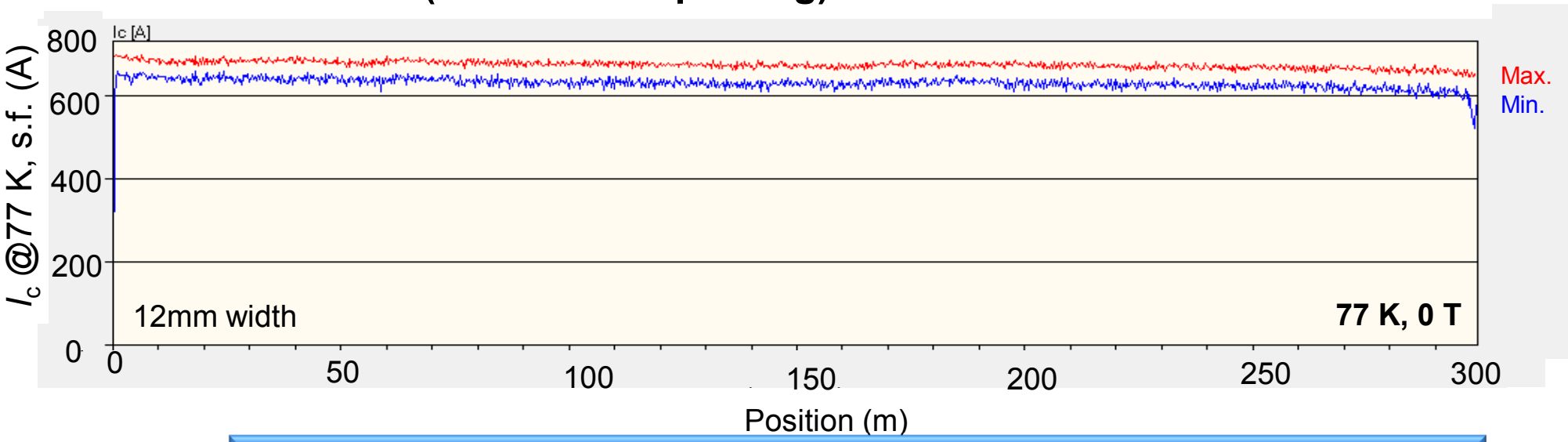
Comparison of uniformity of longitudinal I_c distribution

■ **Artificial pinning wire (REBCO+BHO)**

Tapestar® measurement



■ **Production wire (w/o artificial pinning)**

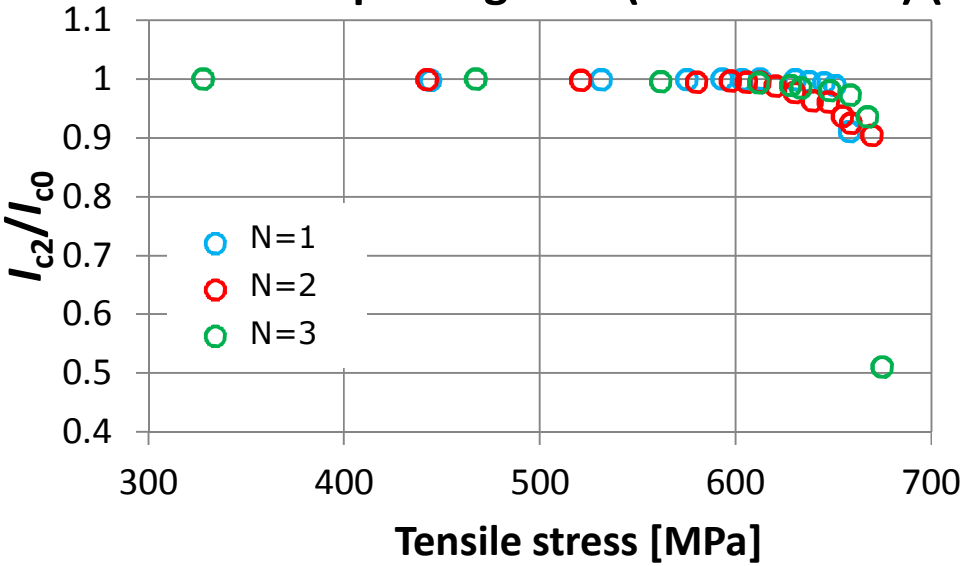


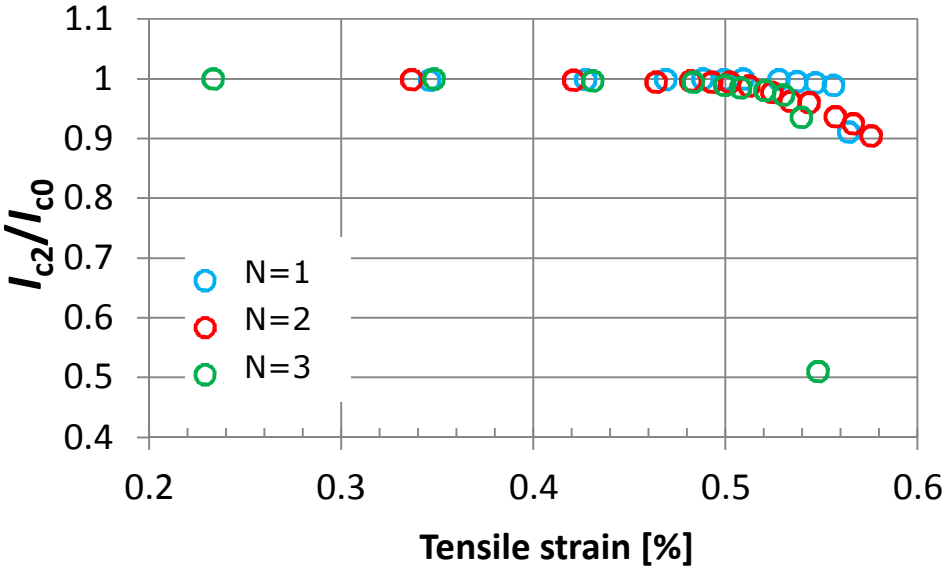
Uniform I_c with 300-m-long artificial pinning wire are obtained

Comparison of tensile characteristics of 4mm-wide wires

■ Artificial pinning wire (REBCO+BHO) (unloading) (with 40μm copper)

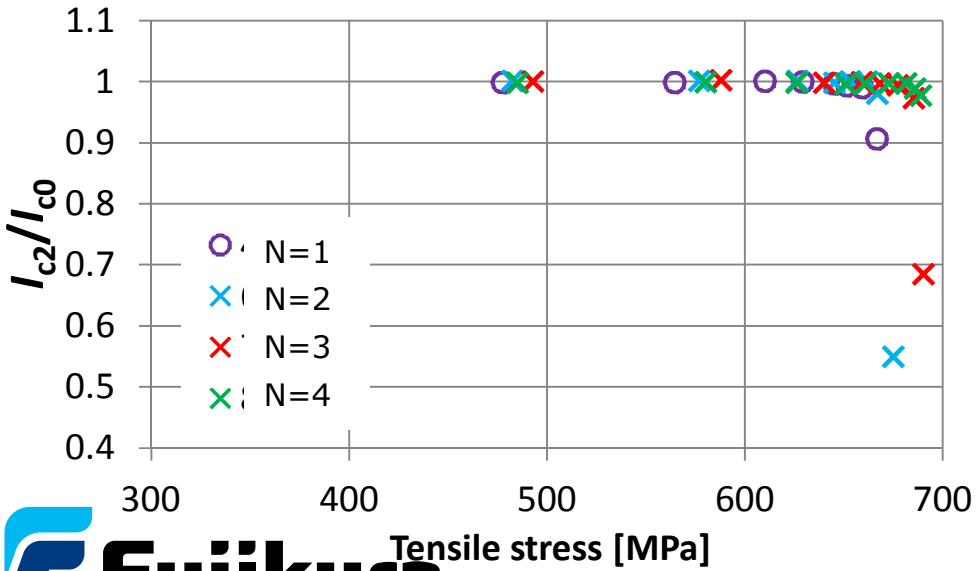
I_{c0} : Initial Ic

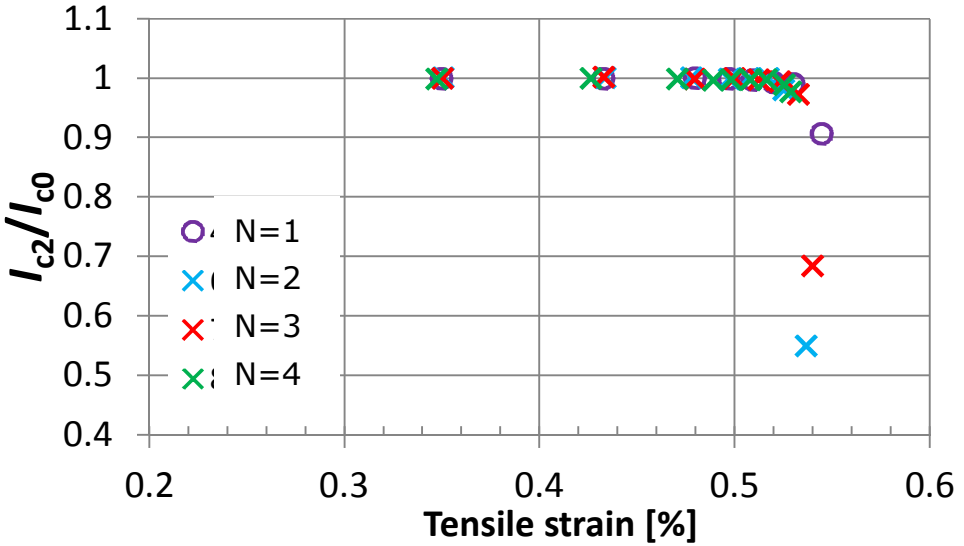




■ Production wire (w/o artificial pinning)(unloading) (with 40μm copper)

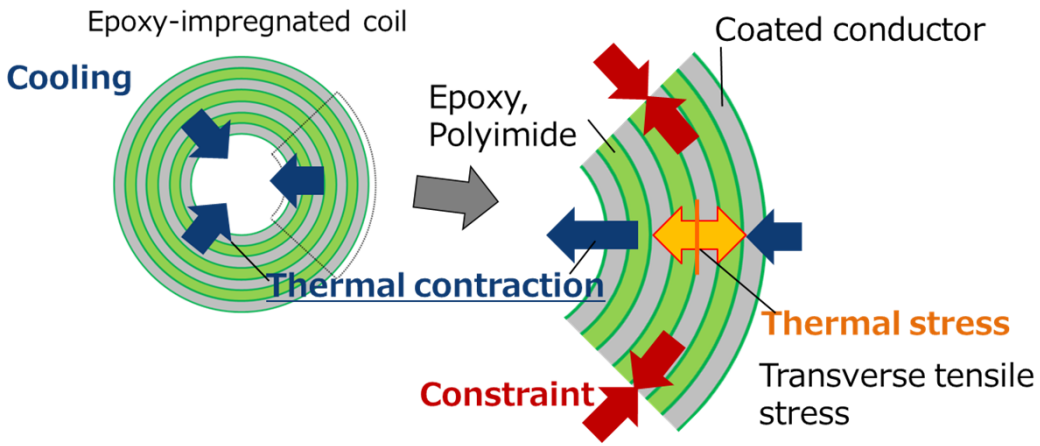
I_{c0} : Initial Ic

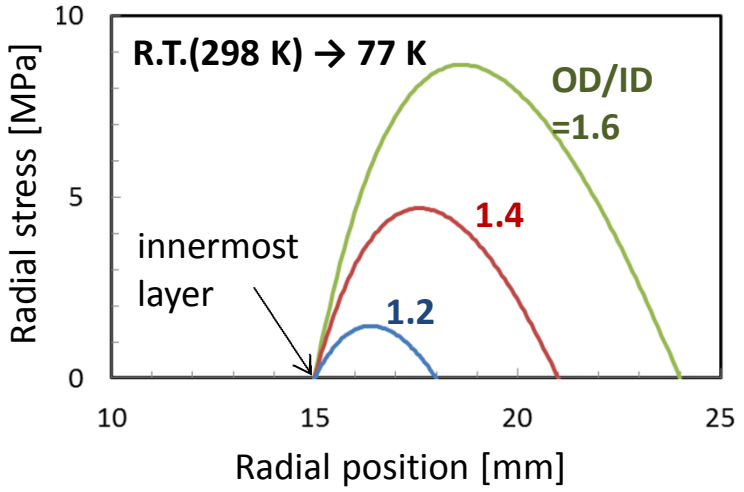


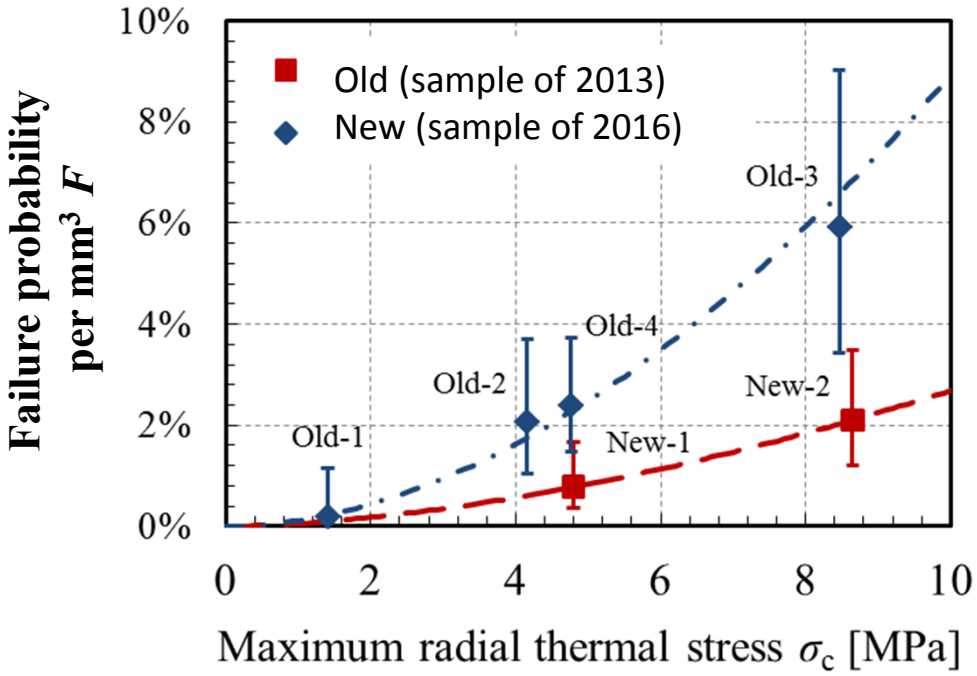


Evaluation of failure probability of delamination

<Delamination stress by thermal stress>





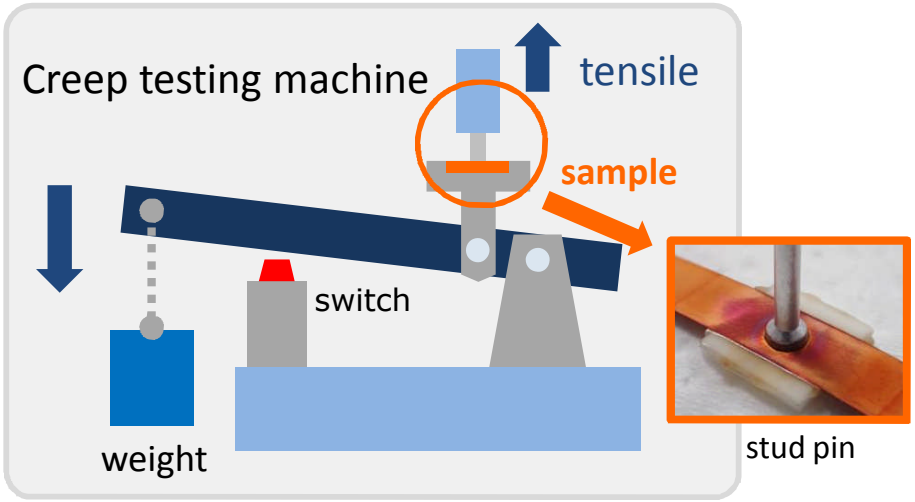


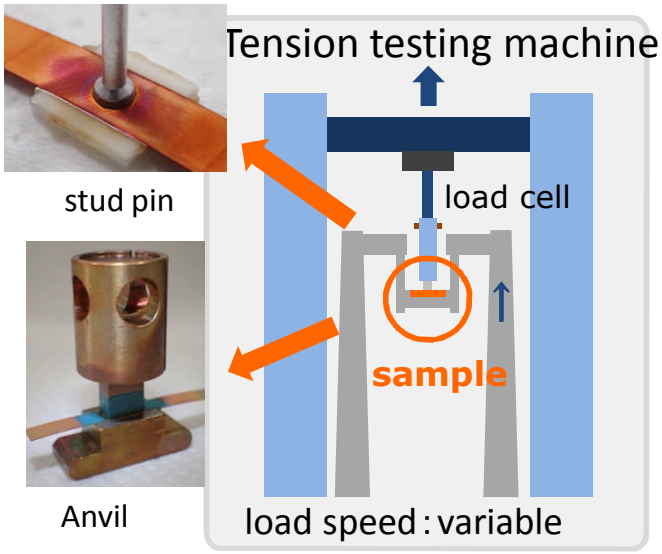
$$F(\sigma_c, V) = 1 - \exp\left[-V_{\mathrm{E}}(m, V)\left(\frac{\sigma_c}{\sigma_0}\right)^m\right]$$

$$V_{\mathrm{E}}(m, V) = \int_V \left(\frac{\sigma(\vec{x})}{\sigma_c}\right)^m \frac{dV}{V_0}$$

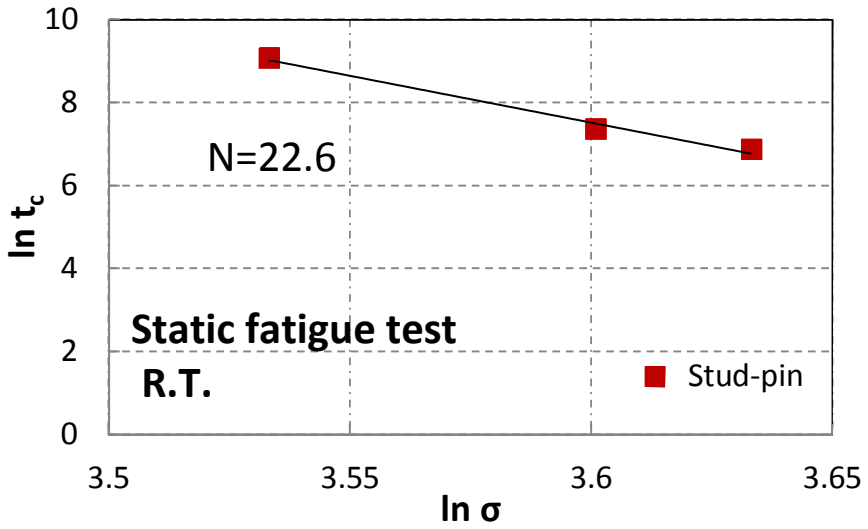
Average delamination stress of 2G HTS tapes have improved by Weibull analysis

Evaluation of static and dynamic fatigue coefficient at R.T.

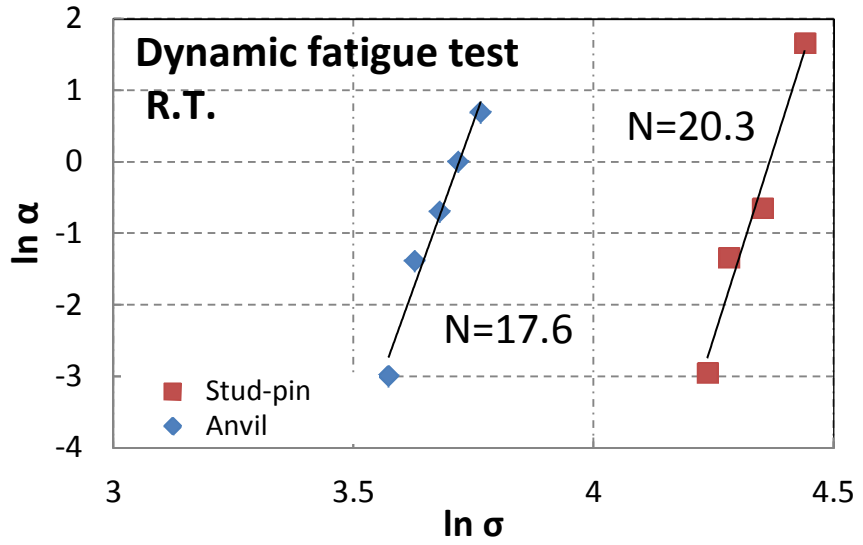




$$\ln t_c = -N \ln \sigma + C'$$



$$\ln \alpha = (N+1) \ln \sigma + C(N)$$



Fatigue coefficient N≒20 are in agreement with general ceramics

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Summary

Evaluation of conventional REBCO coated conductors

- Stabilizer of nominal specification is applied 20μm copper plate
- Uniform I_c with 600m length are obtained from mass-produced conductors without artificial pinning

Recent progress of REBCO coated conductors at Fujikura

- 3-year NEDO program of development of 2G HTS wires, FY2016-2018
- Fujikura has developed REBCO coated conductors with artificial pinning(REBCO+BHO) for Improvement in-field I_c by IBAD/PLD method
- Focus on uniformity and reproducibility for mass-production
- Evaluate Failure probability of delamination stress, static and dynamic fatigue coefficient of conductors, in terms of reliability of conductors

Thank you for your attention

Please visit Fujikura website !!

- Global Site
  http://www.fujikura.com/solutions/superconductingwire/
- Fujikura website
  http://www.fujikura.co.jp/eng/products/new/index.html


Fujikura