IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), April 2016.
This plenary presentation C38 was given at ACASC 2015 (The 8th Asian Conference on Applied Superconductivity and Cryogenics).

DI-BSCCO

DI-BSCCO® TypeHT-NX

The strongest and practical Bi2223 wire

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Outline

1. Introduction of lineup of DI-BSCCO
2. Background to develop stronger Type HT
3. Transport and mechanical properties
4. Discussion on practicability
5. Summary

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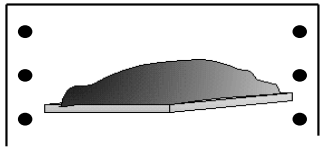
Fabrication process of DI-BSCCO wire

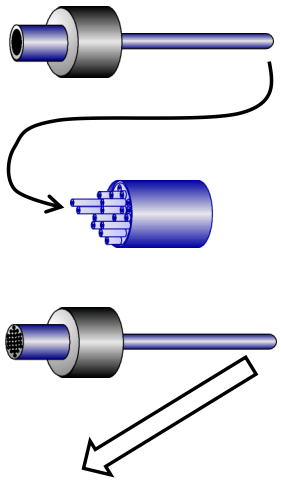
Based on well-known PIT (Powder in Tube) method.

1. Mix & Calcine starting materials

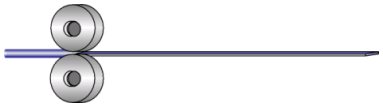


2. Pack into Ag tube

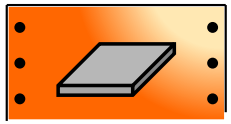
3. Drawing



4. Rolling

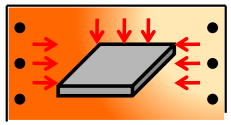


5. Sintering

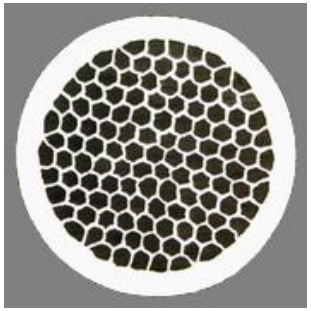


6. Rolling

7. CT-OP® Sintering



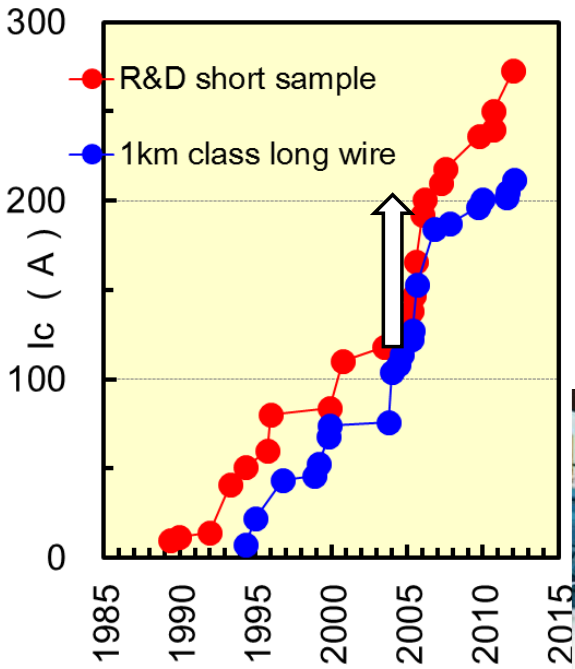
~30MPa



DI-BSCCO® is multi-filament superconducting tape.
Maximum length is up to 2km!

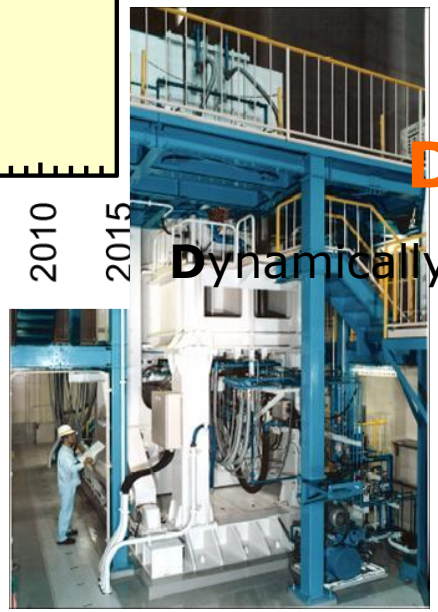
DI-BSCCO

CT-OP(Controlled Over Pressure) technique



High density wire given by CT-OP®
ensures essential properties
as industrial products

- **High and uniform I_c**
- **High mechanical strength**



DI-BSCCO

Dynamically **I**nnovated **BSCCO** wire

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DI-BSCCO

Lineup of DI-BSCCO

Specifications of long-seller commercial products

	Type H High Current Density	Type HT-SS (Stainless Steel) Tough wire	Type HT-CA (Copper Alloy) Tough wire	Type G Ag-Au sheath
Width	4.3 ±0.2 mm	4.5±0.1 mm	4.5±0.1 mm	4.3 ±0.2 mm
Thickness	0.23 ±0.01 mm	0.29±0.02 mm	0.34±0.02 mm	0.23 ±0.01 mm
I_c (77K,Self Field)	180 A ~ 200 A	180 ~ 200 A	180 ~ 200 A	180 A ~ 200 A
Je (77K, Self Field)	180 ~ 200 A/mm^2	140 ~ 150 A/mm^2	120 ~ 130 A/mm^2	180 ~ 200 A/mm^2
Critical Tensile Stress(77K)	130 MPa	270 MPa	250 MPa	130 MPa

Used for various fields

Used for current lead for SC magnet

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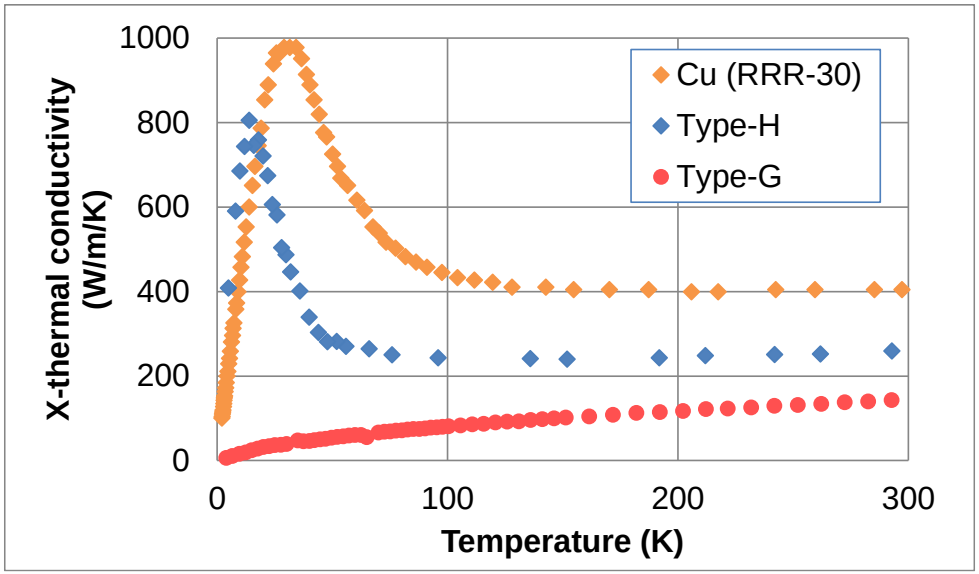
Low thermal conductivity of TypeG wire



Type G wire has very low thermal conductivity keeping large current density as DI-BSCCO.

So, TypeG is widely used for **current lead of SC magnet**.
ITER project, MRI and so on.

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DI-BSCCO

Lineup of DI-BSCCO

Specifications of long-seller commercial products

	Type H High Current Density	Type HT-SS (Stainless Steel) Tough wire	Type HT-CA (Copper Alloy) Tough wire	Type G Ag-Au sheath
Width	4.3 ±0.2 mm	4.5±0.1 mm	4.5±0.1 mm	4.3 ±0.2 mm
Thickness	0.23 ±0.01 mm	0.29±0.02 mm	0.34±0.02 mm	0.23 ±0.01 mm
I_c (77K,Self Field)	180 A ~ 200 A	180 ~ 200 A	180 ~ 200 A	180 A ~ 200 A
Je (77K, Self Field)	180 ~ 200 A/mm^2	140 ~ 150 A/mm^2	120 ~ 130 A/mm^2	180 ~ 200 A/mm^2
Critical Tensile Stress(77K)	130 MPa	270 MPa	250 MPa	130 MPa

difficult to handle

Used for coil

Used for power line cable and coil

Insulated Type H

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Application of HTS wire

DI-BSCCO

Medical and bioscience

MRI
Magnetic resonance imaging

NMR
Nuclear magnetic resonance

HT-CA, SS

Stronger magnetic field!
Large bore!

Power application

SC cable

350m/
Connect to power grid

220kV
FCL

Type H, HT-CA

Applications of DI-BSCCO

Industrial application

Permanent magnet measurement and production

Type H

Large bore!

HT-CA, SS

Si single crys

billet extrusion

Transportation

Ship propulsion

Super car

Type H, HT-CA

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DI-BSCCO

Example of high field application

- Very high field magnet for research 30 – 50T
- High resolution NMR
  Resolution of NMR depends on its field strength.

920MHz
21.6T

1.05GHz
24.7T

High field but small

LTS can not be used in such high field

1.2GHz
28.2T

1.3GHz
30.5T

Large hoop stress!

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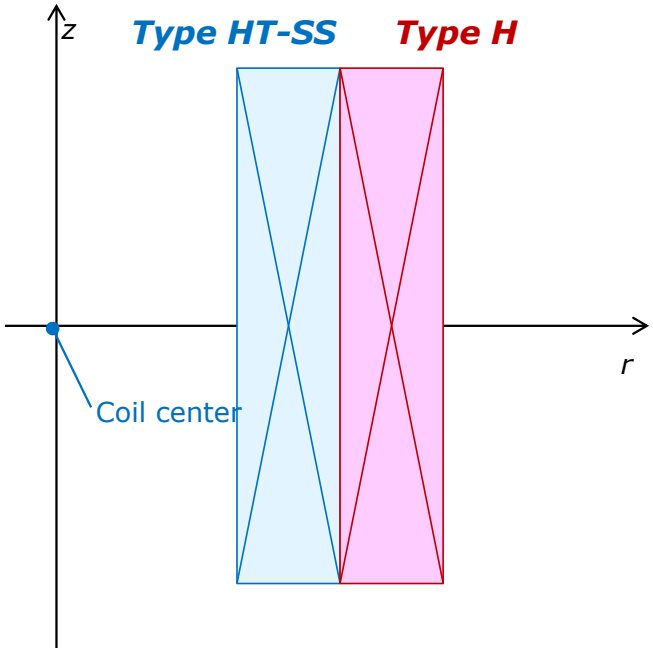
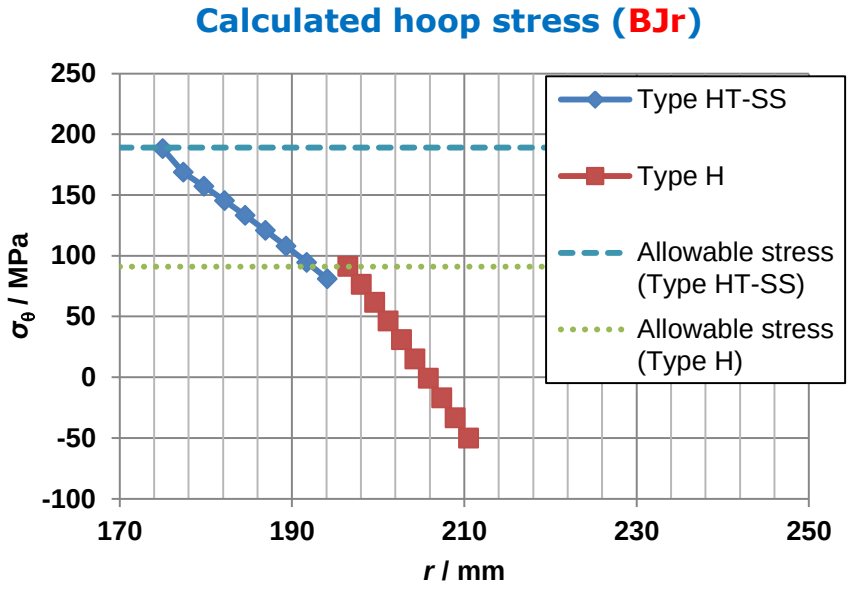
DI-BSCCO

A design of large bore magnet

5T φ300





In case of ID 300 coil, hoops stress will be about 200MPa.
So we can't design it only with Type H wire.
We can achieve it by use of Type HT-SS (or –CA) wire.

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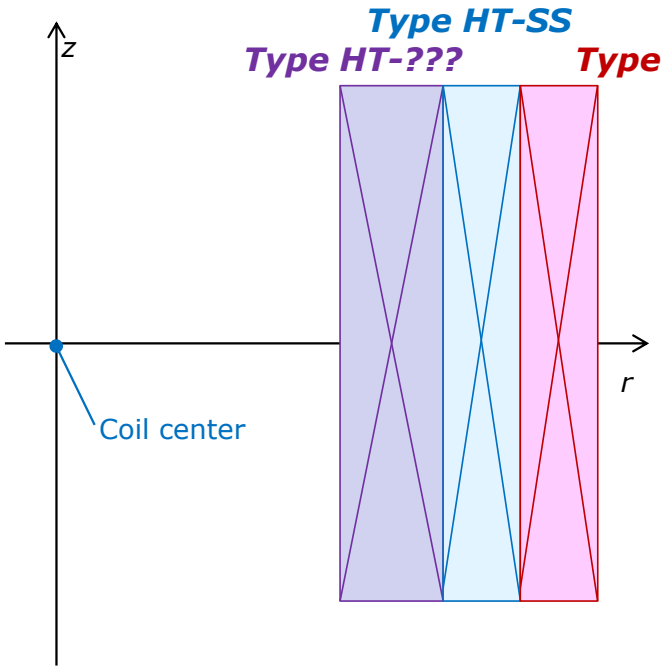
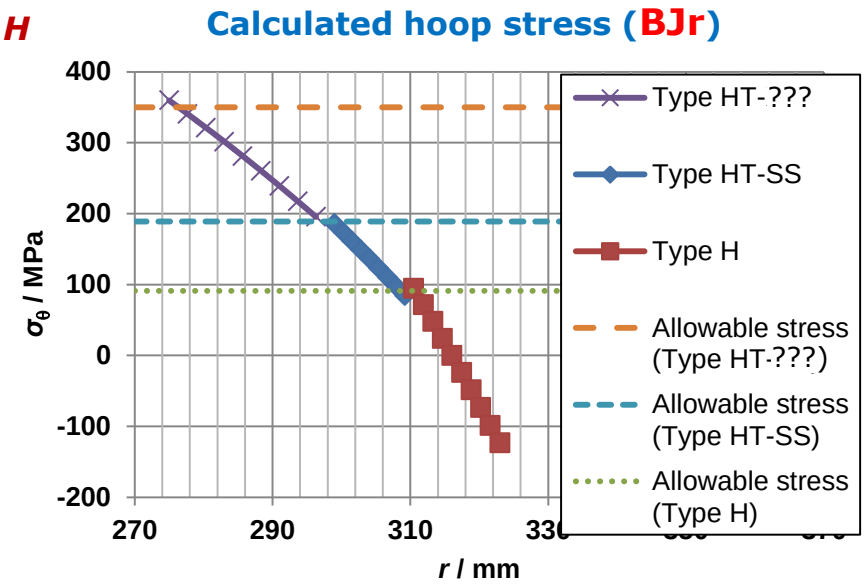
A design of larger bore magnet

5T φ500





In case of ID 500 coil, hoops stress will exceed 300MPa.
So we can't design it even with Type HT-SS wire.
To get such larger bore, we need much stronger wire.

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Demand for stronger Type HT

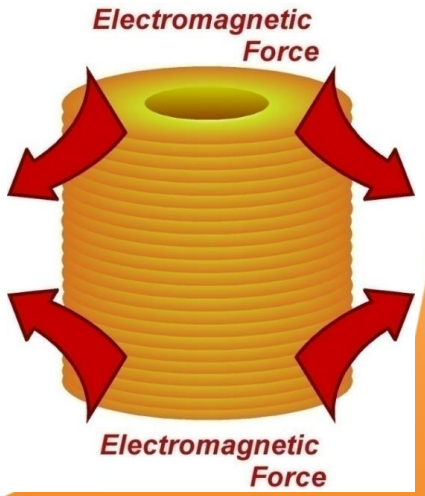
In the field of application where HTS is needed,
stronger magnetic field and/or large bore is required.
For example, over 30T magnet, smaller 1.3Hz NMR, large bore magnet and so on.

If HTS wire will used in such applications,
wires will exposed to large hoop stress.
In such situations, Type HT-SS(CA) wire is no longer strong wire.

So we are developing stronger Type HT wire
whose name is Type HT-NX.

Goal of Type HT-NX :

Critical tensile strength 400 MPa



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DI-BSCCO

Selection of reinforcement material

Demand for reinforcement material.

- ✓ high Modulus
- ✓ high Yield

NX tape		Stainless Steel
Modulus : >200GPa	>	Modulus : 180GPa
Yield : >1800MPa		Yield : 1200MPa

We have investigated adequate thickness from the view point of strength and high J_e.

Finally we have selected **30um** of NX tape.

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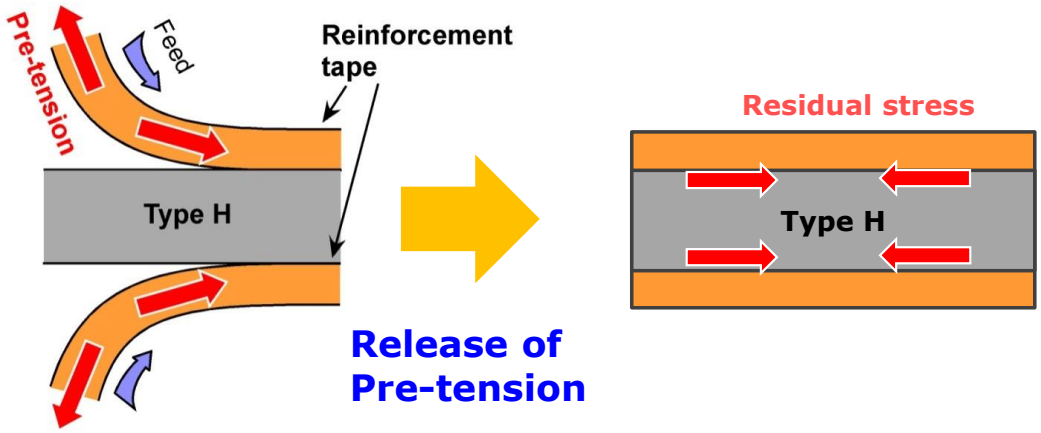
DI-BSCCO

Lamination techniques

Adoption of pre-tension technique.



During lamination : Large tensile stress is applied to NX tape. ⬅ Pre-tension

After lamination : 3 plied wire is released from applied tensile stress.

In the end : Compressive strain is applied to Type H wire.
Type H wire in center has advantage against tensile strain. (minus offset)

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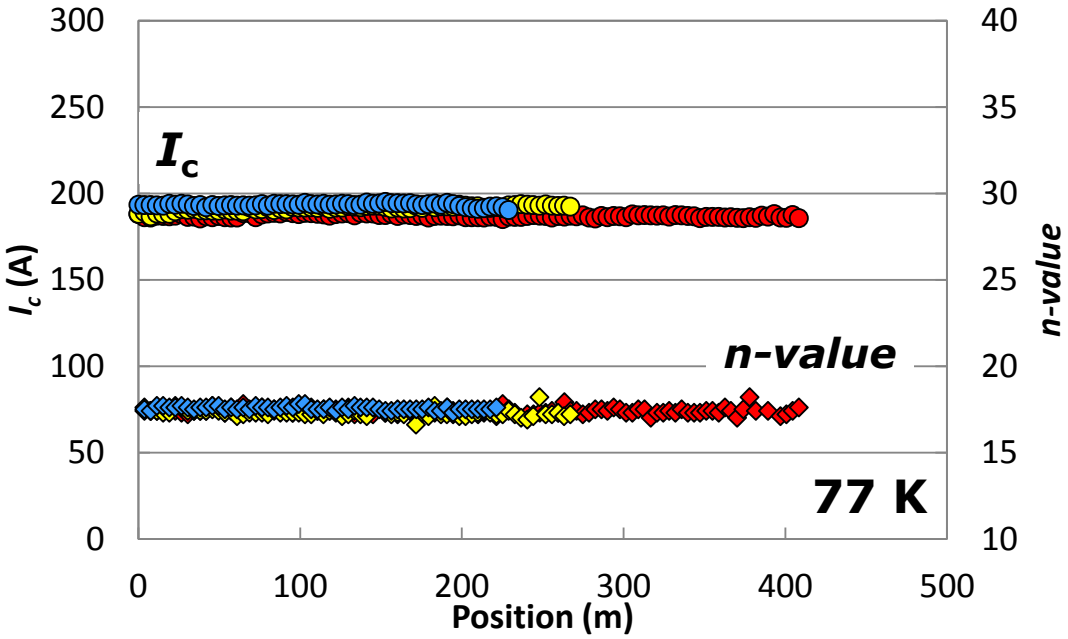
DI-BSCCO

I_c distribution of Type HT-NX



I_c and *n-value* show good uniformity in long length.
Maximum length for shipment is 200m so far.
Our next target for shipment is >500m.
(We will release it in near future)

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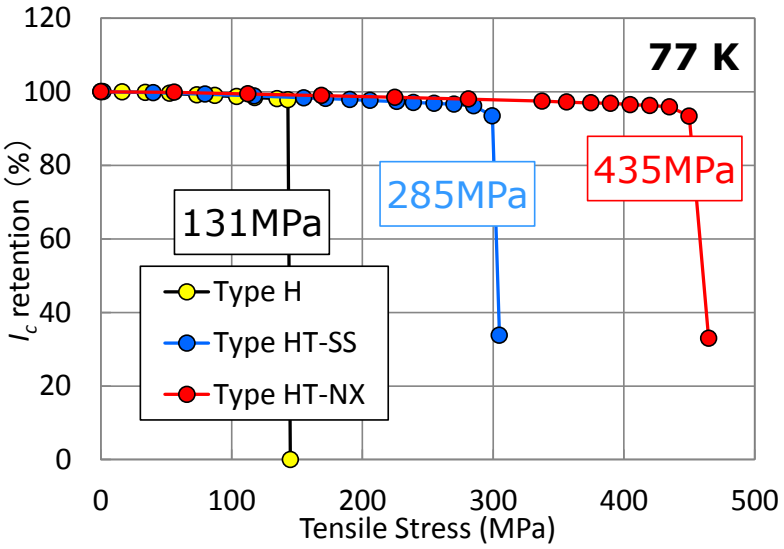
17

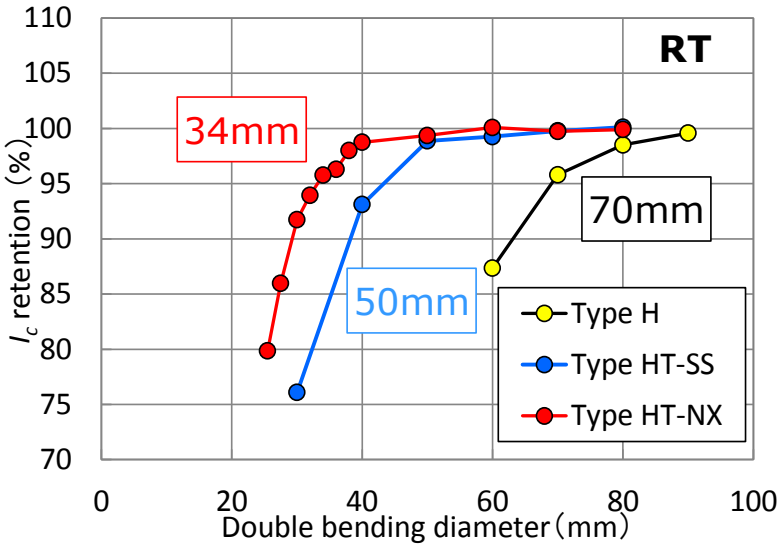
DI-BSCCO

Mechanical properties

Tensile test at 77 K



Bending test at RT



95% Ic retention for each test,

Tensile stress : 435MPa@77K

Bending diameter : 34mm@RT

Bending test at 77K with wire bended is under consideration.

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DI-BSCCO

Can Type HT-NX really be used in practical condition?

To verify practicability of Type HT-NX wire,
we performed various test supposing actual use condition.

- Transport properties at low temperature
  in high magnetic field > 30T
- Reproducibility of mechanical properties at low temperature
- Hoop stress test
  Mechanical stress is applied with wire bended(shape of coil).
  Moreover homogeneity in long length is needed.
- Fatigue test
  Wire must be robust as an industrial material.

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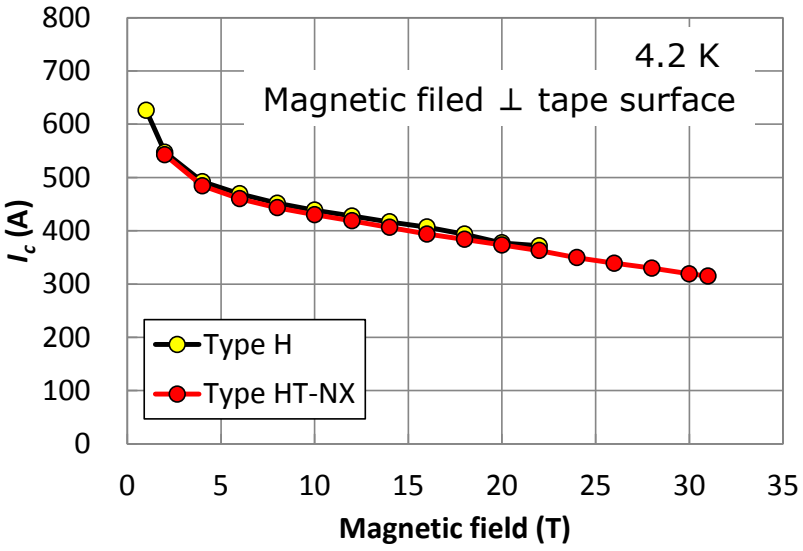
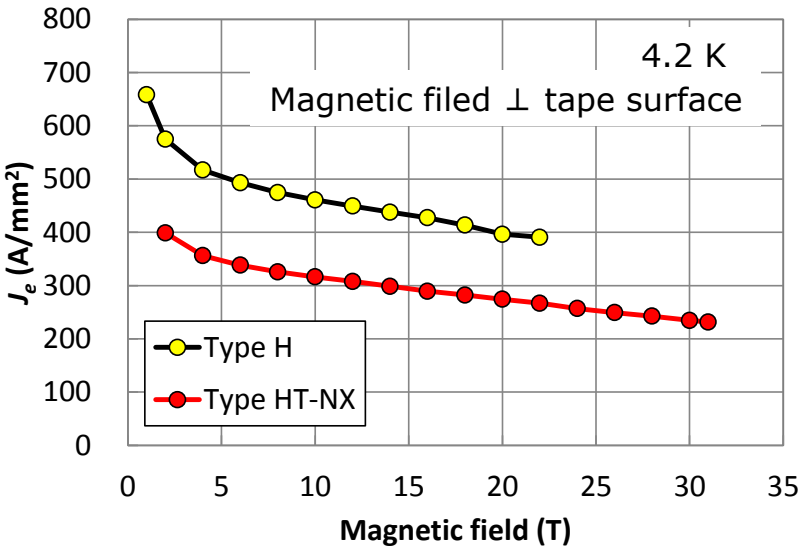
DI-BSCCO

I_c dependency on B at 4.2 K

TypeH Measured by NIMS @ LNCMI/Grenoble

TypeHT-NX Measured by NIMS @ NHMFL/Florida





I_c of Type H and Type HT-NX are same at 4.2K.

New lamination technique don't affects the original Type H's transport property.

J_e at 4.2K keep large value at very high field!
~300 A/mm² at 15T
~235 A/mm² at 30T

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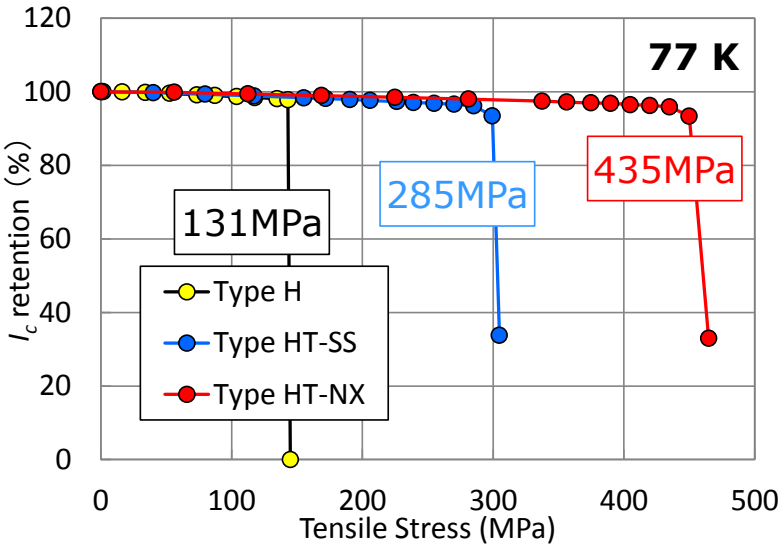
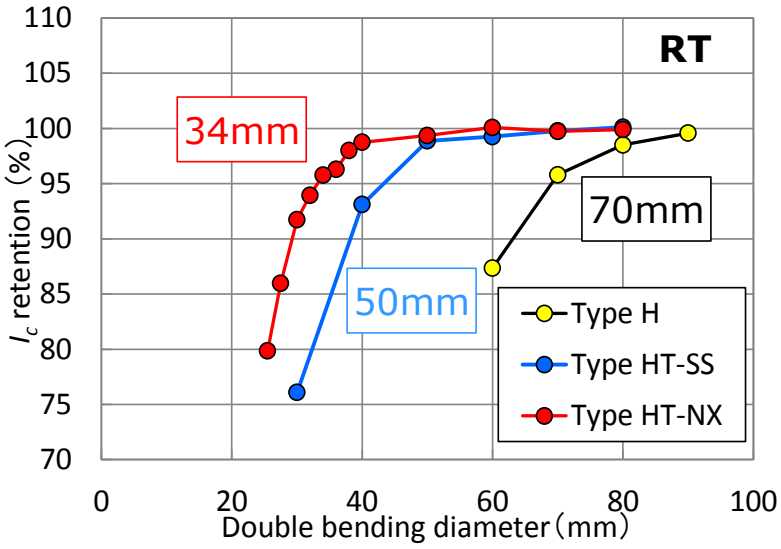
DI-BSCCO

Mechanical properties

Tensile test at 77 K



Bending test at RT



More than 100 wires
have been produced and tested so far.

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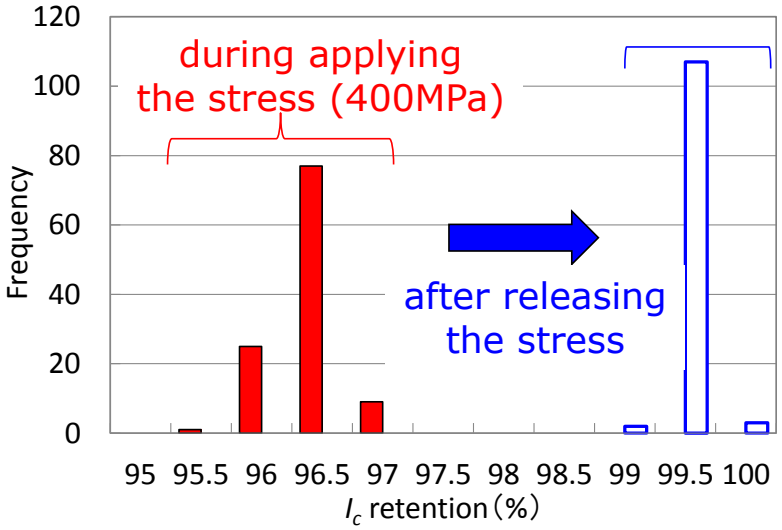
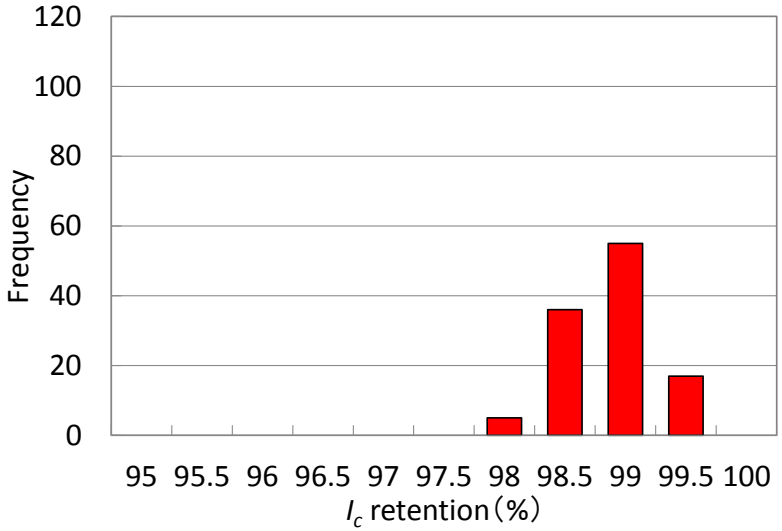
DI-BSCCO

Reproducibility of mechanical properties

Tensile stress of **400MPa** at 77 K



Bending diameter of **40mm** at RT



This tensile test (recover of I_c after removing stress) means 400MPa stress don't degrade Type HT-NX wire essentially.

All of the more than 100wires passed two tests.

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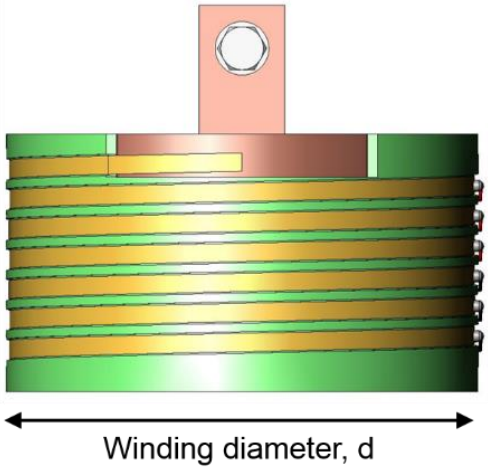
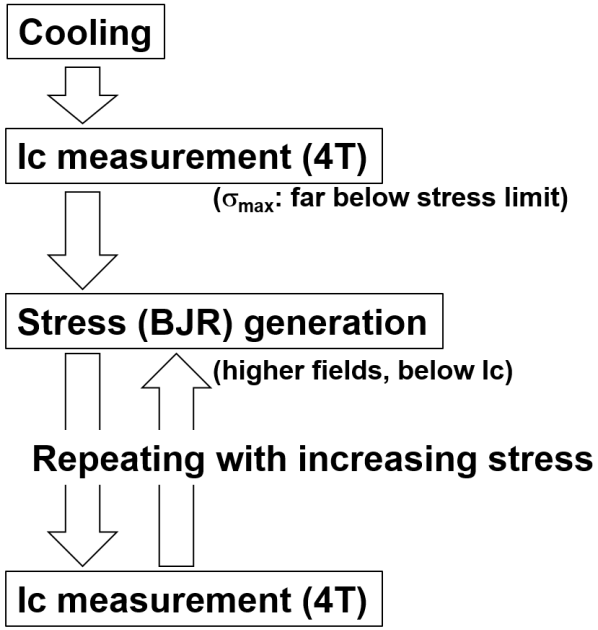
DI-BSCCO

Hoop stress test of Type HT-NX



Using one layer coil specimen,
test was performed in LHe bath.

O.D. = 108 mm
Wire length = 2 m
Voltage tap spacing V1 = **0.340 m**
V2 = **1.021 m**
V3 = **1.701 m**



Y. Miyoshi, H. Kitaguchi, X. Chaud,
F. Debray, G. Nishijima, Y. Tsuchiya,
Supercond. Sci. Technol. 27, 025003, 2014.

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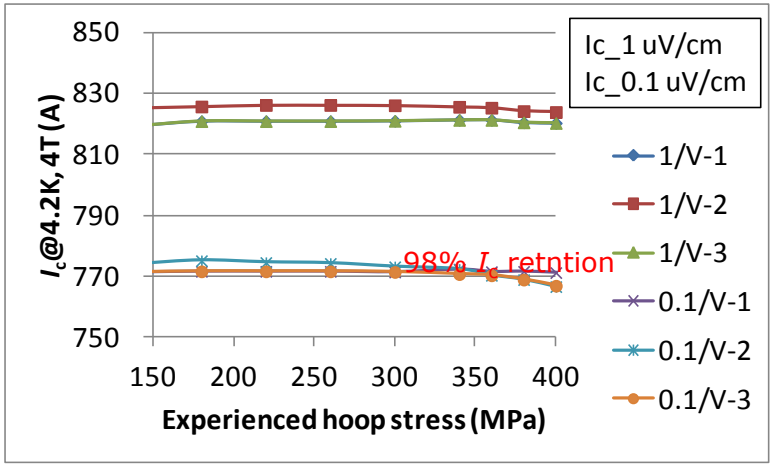
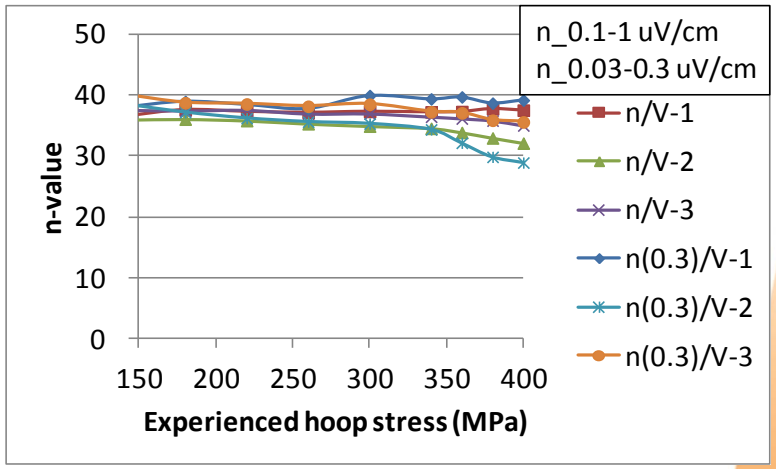
DI-BSCCO

Hoop stress test of Type HT-NX

Measured by NIMS @ LNCMI/Grenoble





Hoop stress test proofed following feature of Type HT-NX.

- ✓ **Homogeneous strength for long length(1.7m)**
- ✓ **Strength with wire bended = the shape of coil**

These are really important in practical use condition!

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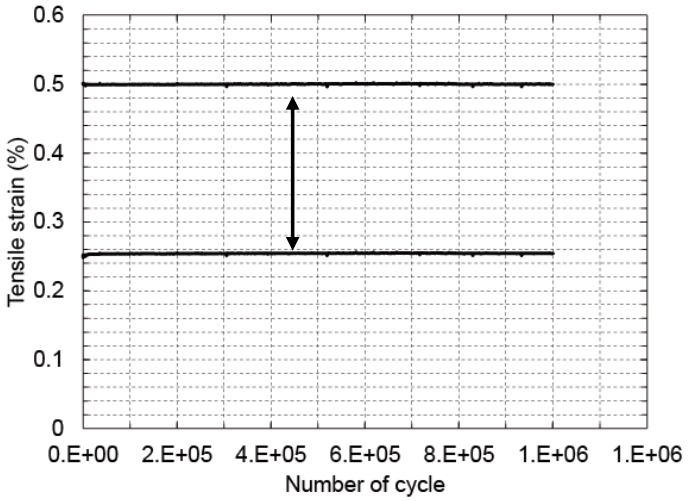
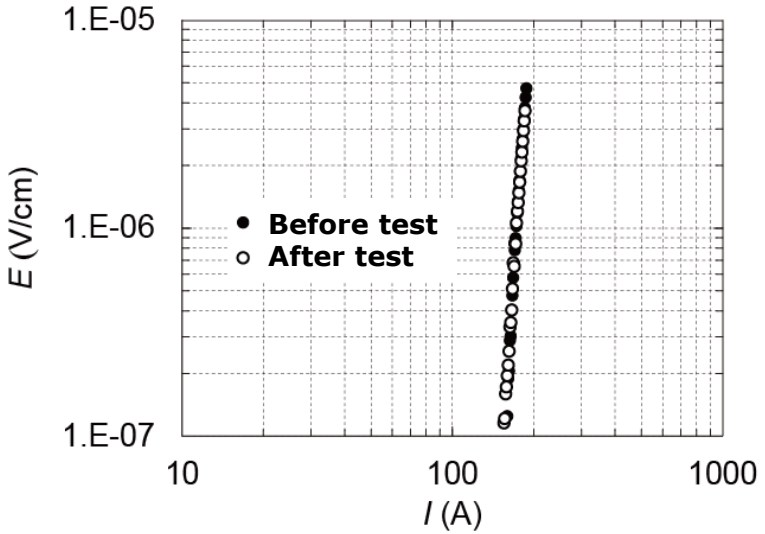
Fatigue test of Type HT-NX

Test condition

Max.Stress: 485MPa
(=Max. Strain: 0.48%)
Min. Stress: 170MPa
Temperature: 77K
Number of Cycles: 1,000,000 cycles

	Before	After
I_c(1mV/cm)	174 A	173 A
I_c(0.1mV/cm)	166 A	165 A





No degradation of I_c and n-value until 10^6 cycles.
Also no degradation of solder

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DI-BSCCO

Summary

Wire Type	Type H Type G	TypeHT	*Type HT-NX*
Status	Commercial	Commercial	Commercial (100-200m)
Reinforcement tape	-	CA/SS	Ni-alloy
Width	4.3 mm	4.5 mm	*4.5* mm
Thickness	0.23 mm	0.34/0.29 mm	*0.31* mm
I_c (77 K, s.f.)	200 A	200 A	200 A
I_c (4.2 K, 17 T)	400 A	400 A	400 A
J_e (4.2 K, 17 T)	400 A/mm^2	260/310 A/mm^2	*290* A/mm^2
Critical Tensile Stress (77 K)	130 MPa	270/250 MPa	*400* MPa
Critical D. B. Diameter (R.T.)	80 mm	60 mm	*40* mm

We have lineup of practical HTS wire for various applications.

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Application of HTS wire

DI-BSCCO

Medical and bioscience

MRI
Magnetic resonance imaging

NMR
Nuclear magnetic resonance

HT-CA, SS
HT-NX

Stronger magnetic field!
Larger bore!

Power application

SC cable

350m/
Connect to power grid

220kV
FCL

Type H, HT-CA

lications of DI-BSCCO

Transportation

Permanent magnet measurement and productio

Type H
HT-CA, SS
HT-NX

Si single crysta

let extrusion

Ship propulsion

Super car

Type H, HT-CA

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DI-BSCCO

Thank you for your attention!

If you need further information,
please contact me
of
check our WEB site.

www.sei.co.jp/super/

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