FURUKAWA ELECTRIC

FURUKAWA ELECTRIC GROUP

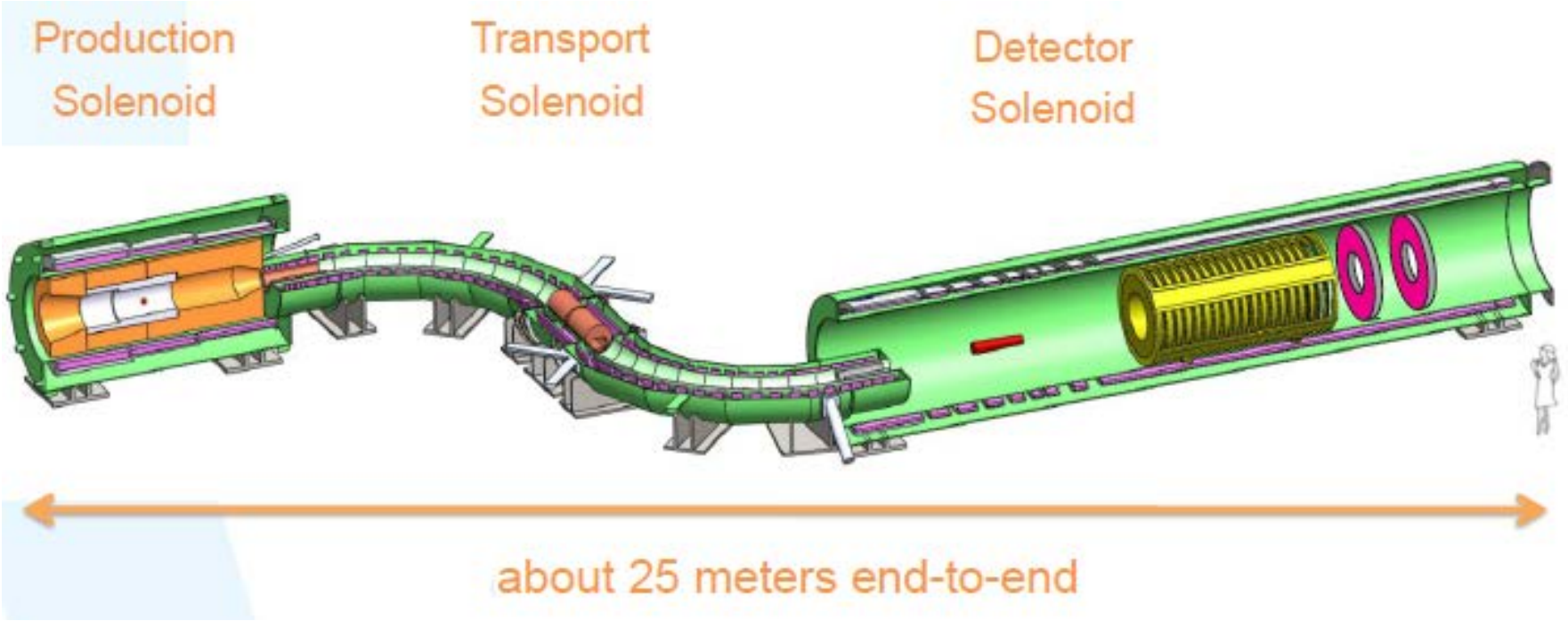
Results of R&D and production on two types of High purity Aluminum stabilized Superconducting cable

Kota Katayama, Keisuke Kitazato, Hirokazu Tsubouchi, Akira Takagi,
Ricardo Tanaka and Joao Shigueoka

Contents

FURUKAWA ELECTRIC

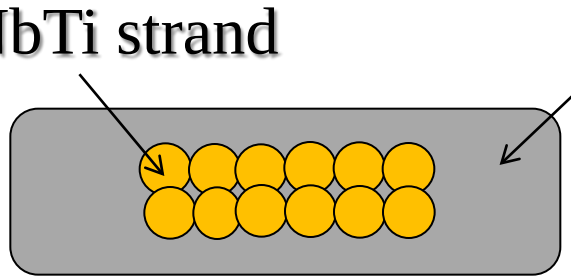
1. Introduction



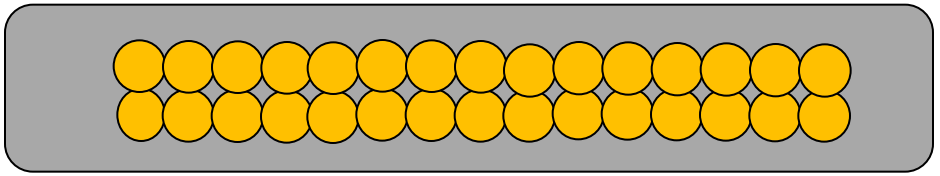
Refer to【Doug Glenzinski, Fermilab PAC, Jan 22-24 2014】

The superconducting cable is used for Production solenoid, Transport solenoid and Detector solenoid in Mu2e project

1. Introduction



Cross-section of DS1 cable



Cross-section of PS cable

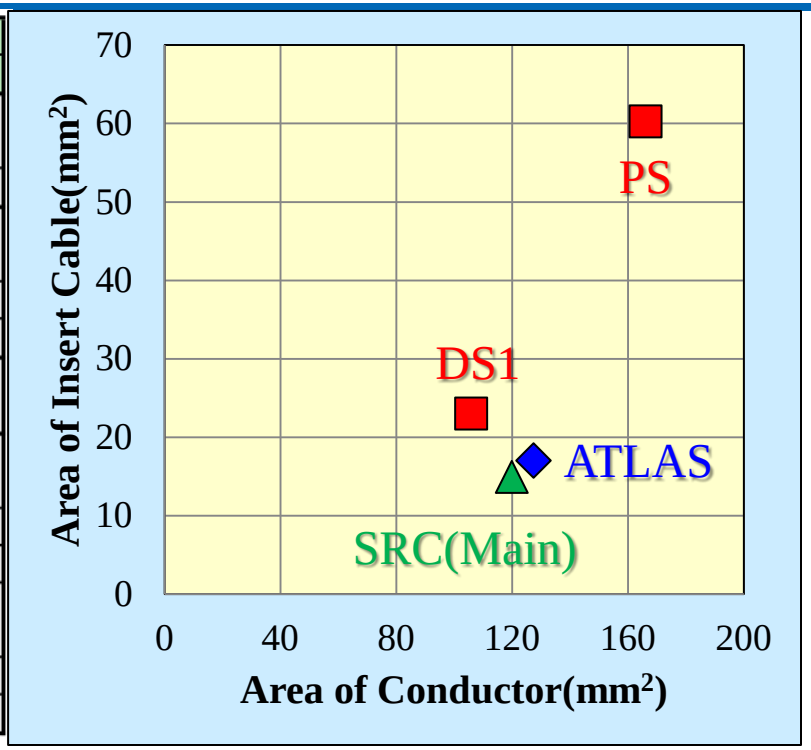
Specification for DS1 & PS conductor

Parameters	Unit	Value：DS1	Value：PS
Aluminum		5N	5N-0.1wt%Ni
Number of strands		12	30
Cable width at 293K	mm	20.1±0.1	30.1±0.1
Cable thickness at 293K	mm	5.27±0.03	5.52±0.03
Cable critical current at 5T, 4.2K	kA	＞23.9	＞66.25
Copper RRR		＞80	＞100
Aluminum RRR		＞800	＞500
0.2% yield strength of Al at 4.2K/293K	MPa	≧40/30	≧80/60
Shear strength of Al-Cu bond at 293K	MPa	≧20	≧40

We developed aluminum stabilized superconducting cable for Production solenoid and Detector solenoid(1)

1. Introduction

	SRC	ATLAS	Mu2e	
	Main		DS1	PS
【Strand】 Diameter	1.25	1.22mm	1.466mm	1.466mm
Cu to Superconductor ratio	1.05	0.9	0.9	0.9
【Cable】 Number of strands	10	12	12	30
Thickness	2.35mm	2.30mm	2.63mm	2.63mm
Width	6.35mm	7.40mm	8.74mm	22.90mm
【Aluminum】 Additive	Zn 190ppm	Ni 1000ppm	-	Ni 1000ppm
【Conductor】 Thickness	8.0mm	4.2/4.3mm	5.27mm	5.52mm
Width	15.0mm	30.0mm	20.1mm	30.1mm
Al/NbTi ratio	17.0	15.6	9.0	4.5
Critical current	14,000A (at 4.3K, 6T)	23,000A (at 4.2K, 5T)	23,900A (at 4.2K, 5T)	66,250A (at 4.2K, 5T)
Aluminum RRR	707	490	800	500
0.2% yield strength of Al	49MPa	79MPa	30MPa	60MPa



For Al-stabilized conductor in Mu2e project

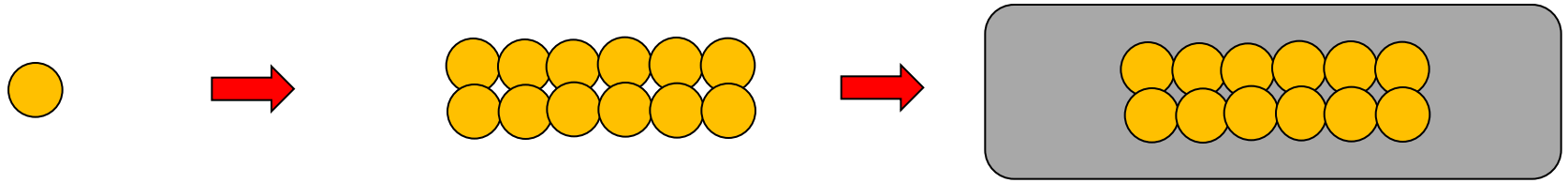
- High critical current
- Bigger size (Rutherford cable , Al-stabilized conductor)
- Low Al/NbTi ratio

We have performed integrated development from strand through cable to conductor

1. Introduction

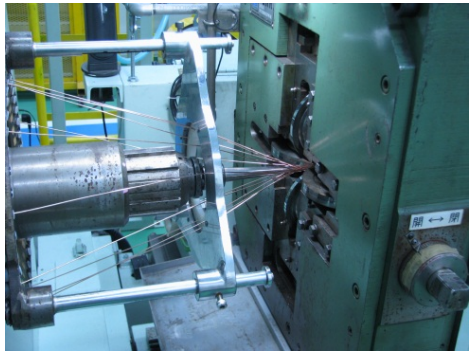
FURUKAWA ELECTRIC

Production process

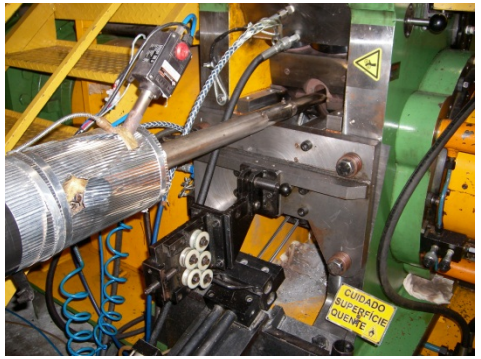


NbTi strand

Rutherford cable



Conforming & Cold work

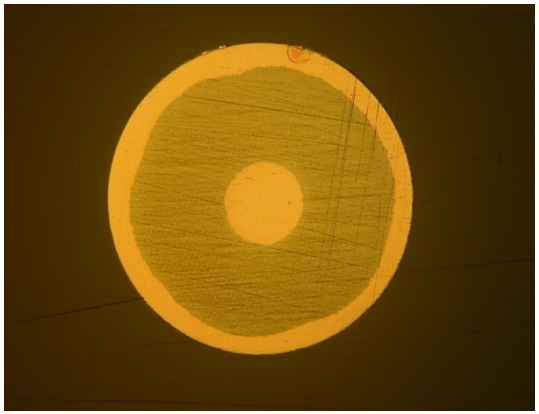


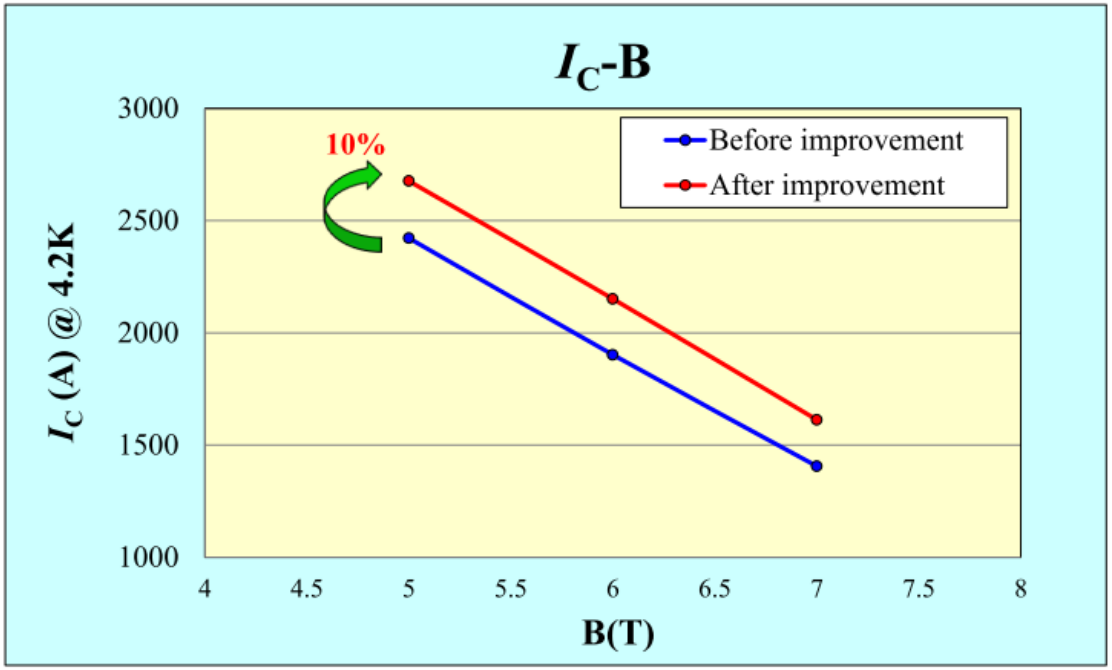
2. R&D production for DS1 & PS conductor

FURUKAWA ELECTRIC

Development of NbTi strand having high I_C

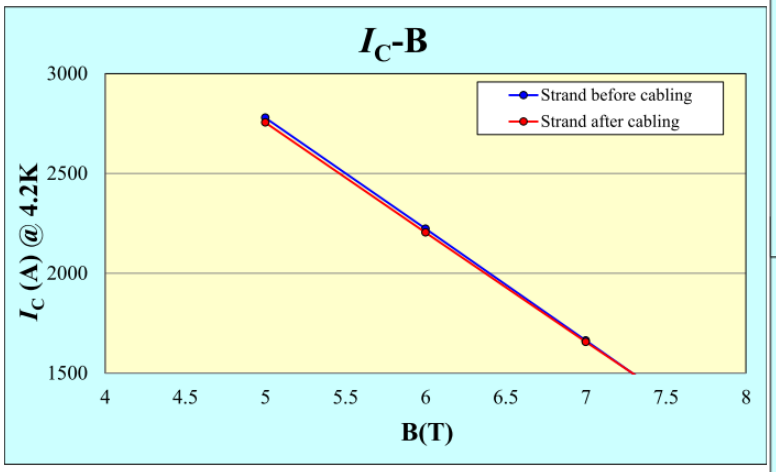
We succeeded in increasing 10% of I_C value by improving heat-treatment process.

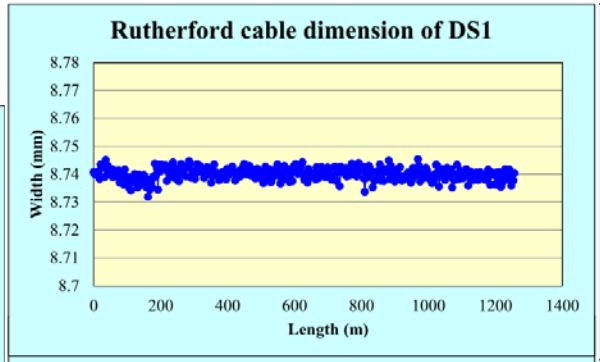


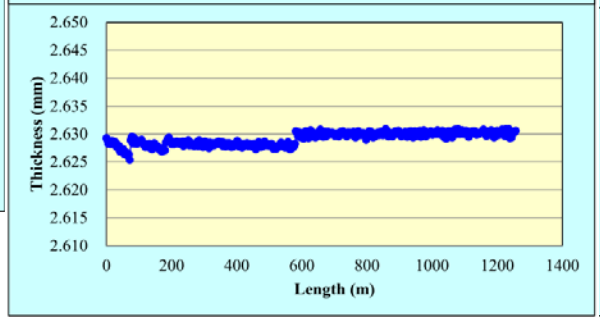


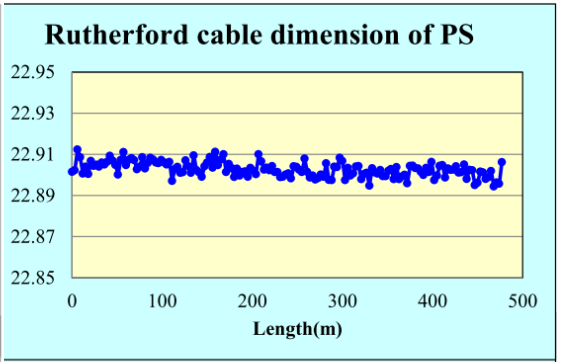
Items	unit	Specification	Result of developed strand
Wire diameter	mm	1.466±0.005	1.467
Twist pitch	mm	30±4	30
Matrix Cu to Superconductor Ratio	-	0.90±0.05	0.95
Critical Current at 4.22K, ρ=1×10-14Ωm – I_C at 5T (A)	A	≧2,350 (DS1) ≧2,480 (PS)	2,676
n value at 5T, 4.22K	-	≧30	46
Residual Resistivity Ration(RRR)	-	≧150	165

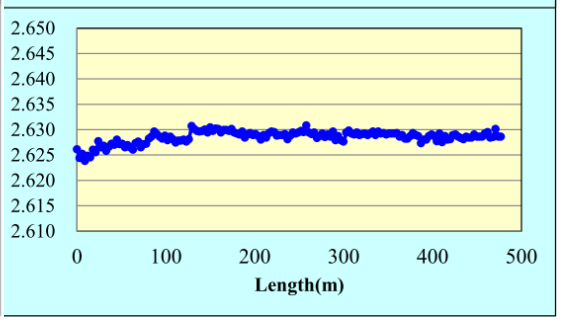
Development of Rutherford cable











By optimizing cabling process,

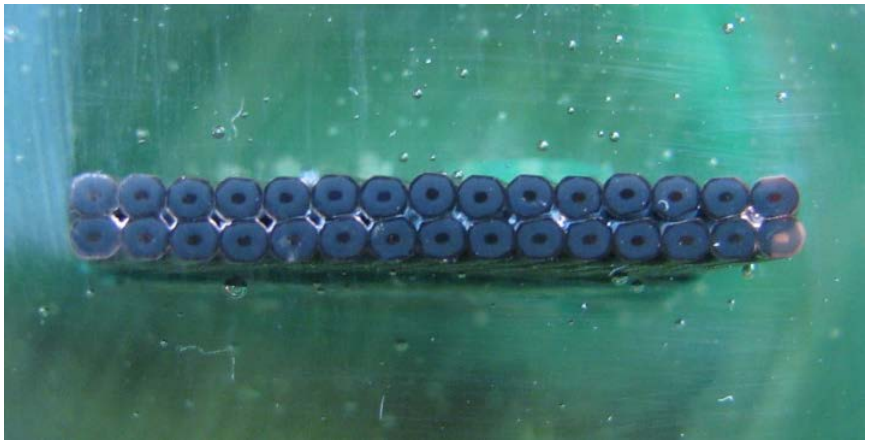
- I_C degradation : < 2%
- High stability in dimension

  Standard deviation : Width 0.002 , Thickness 0.001 (DS1:1257m)

  Width 0.004 , Thickness 0.001 (PS:477m)

2. R&D production for DS1 & PS conductor

Cross section of DS1 Rutherford cable



Cross section of PS Rutherford cable

Items	unit	Specification		Result of developed DS1 Rutherford cable	Result of developed PS Rutherford cable
		DS1	PS		
Number of strabds	-	12	30	12	30
Cable width	mm	8.74±0.01	22.90±0.02	8.74 (Average)	22.90 (Average)
Cable thickness	mm	2.63±0.01	2.63±0.01	2.63 (Average)	2.63 (Average)
Lay direction	-	Right	Right	Right	Right
Critical Current at 4.22K, ρ=1×10-14Ωm – I_C at 5T (A)	A	≧26,790	≧69,737	33,066	80,987
Residual Resistance Ratio(RRR)	-	≧60	≧60	87	92
Transposition angle	degree	Approx. 12	Approx. 12	10	13
Residual twist	degree	＜45	＜45	5	5

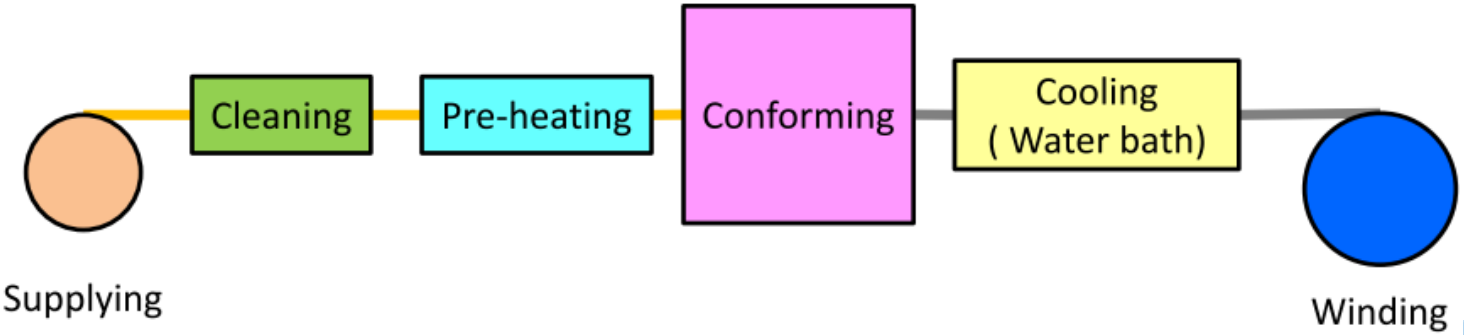
2. R&D production for DS1 & PS conductor

FURUKAWA ELECTRIC

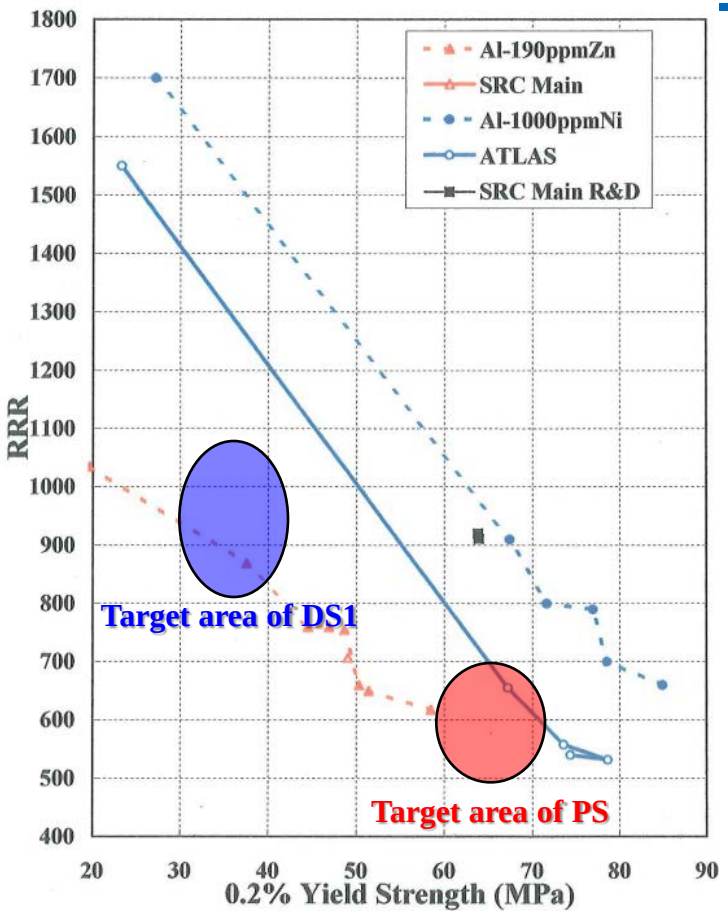
Conforming & Cold work process at FISA (Brazil)

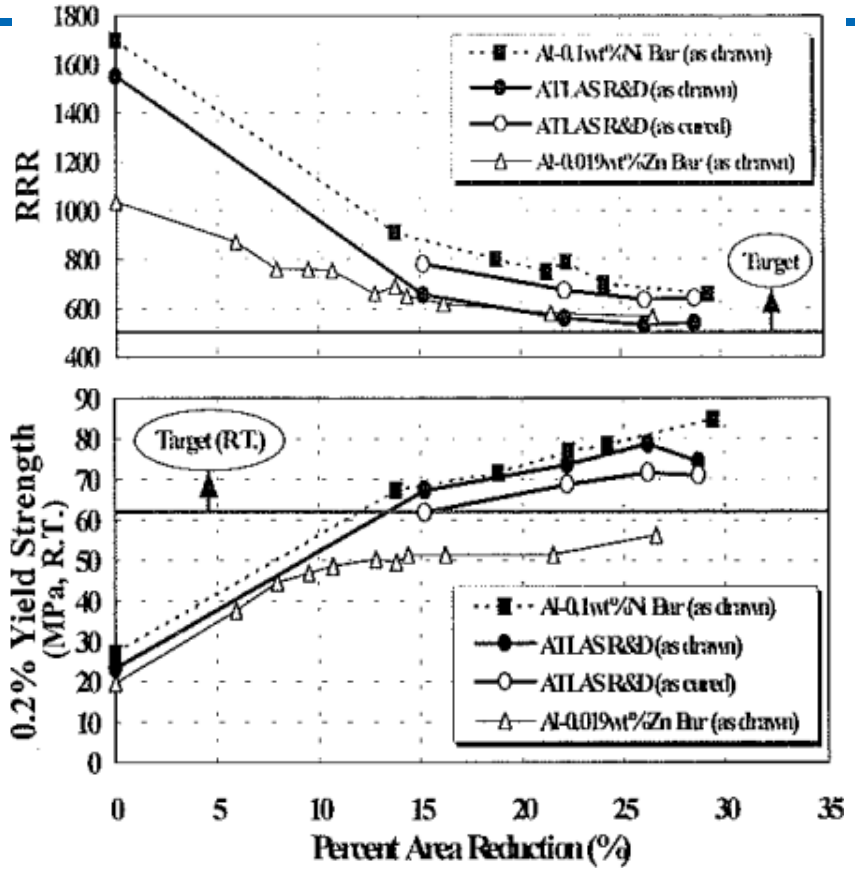
FURUKAWA

FURUKAWA ELECTRIC GROUP



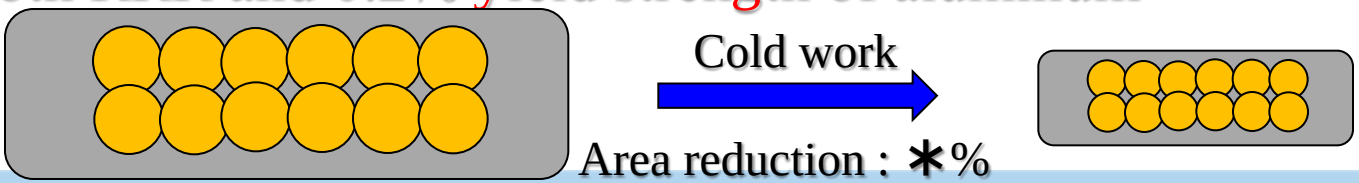
2. R&D production for DS1 & PS conductor





Refer to【K. Wada *et al.*, *IEEE Trans. Appl. Supercond.*, Vol.10, No.1, pp.373-376 2000】

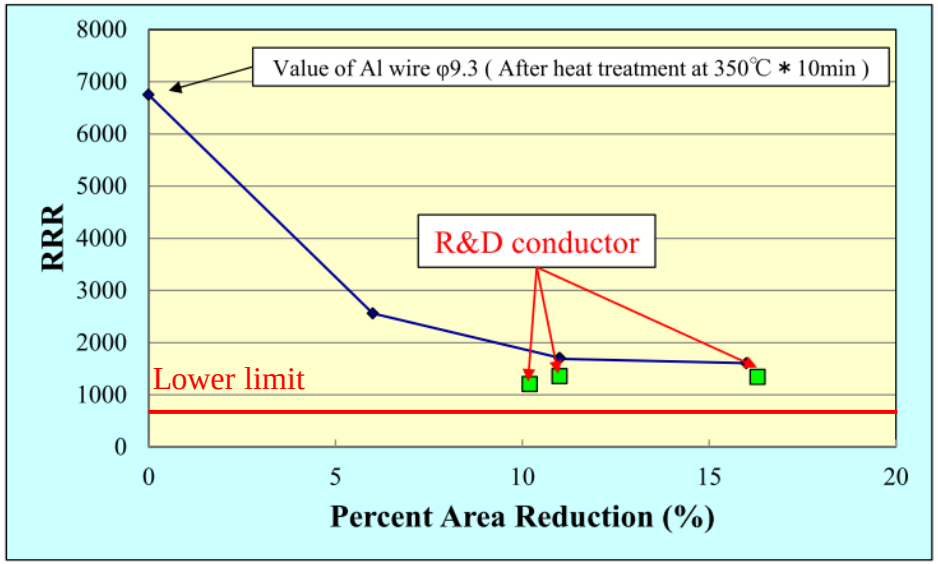
We must control the area reduction of cold work in order to satisfy both RRR and 0.2% yield strength of aluminum

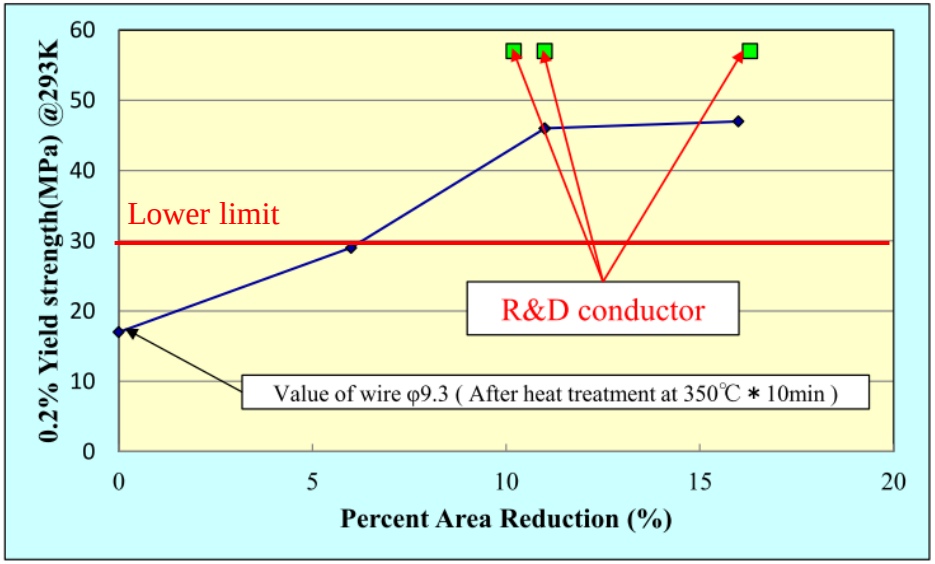


2. R&D production for DS1 & PS conductor

FURUKAWA ELECTRIC

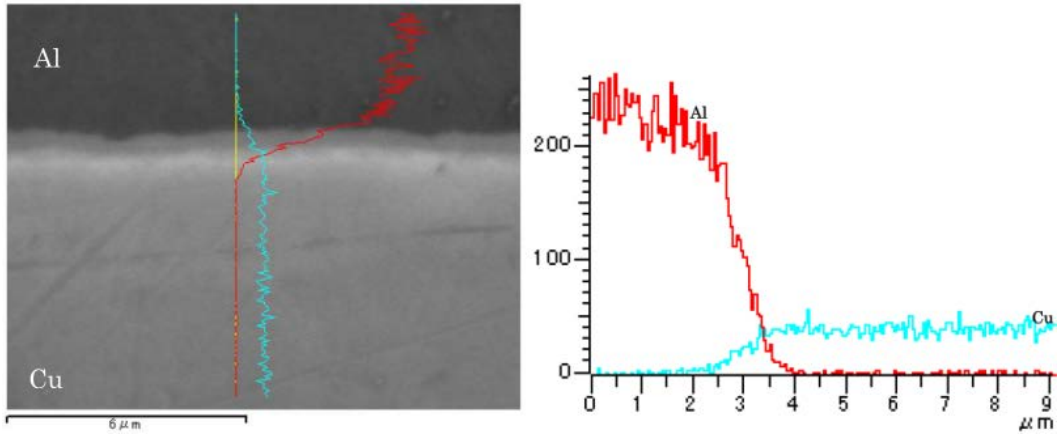
DS1 conductor





Relationship between Al-RRR or Al-0.2% yield strength and area reduction of DS1 conductor

The condition which meets the specification of DS1 conductor was determined

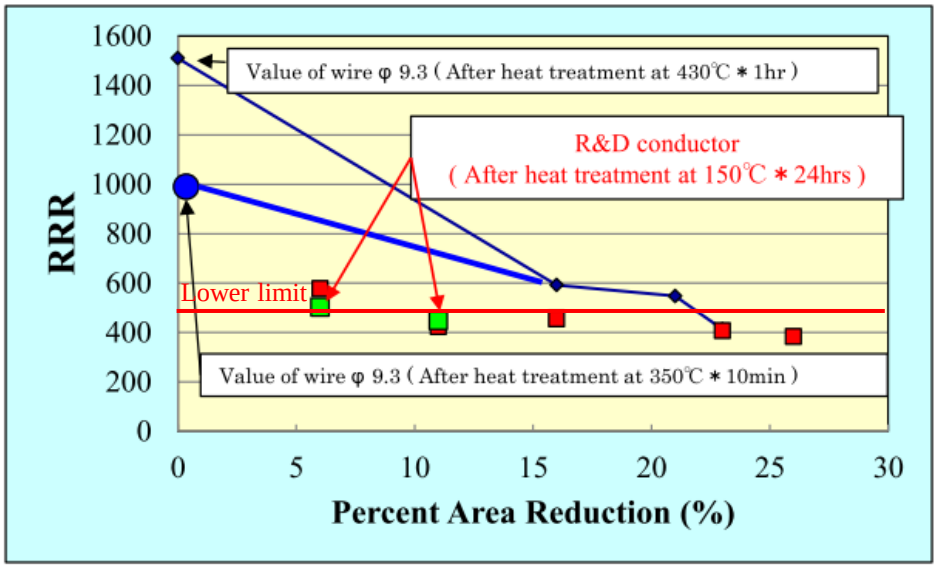


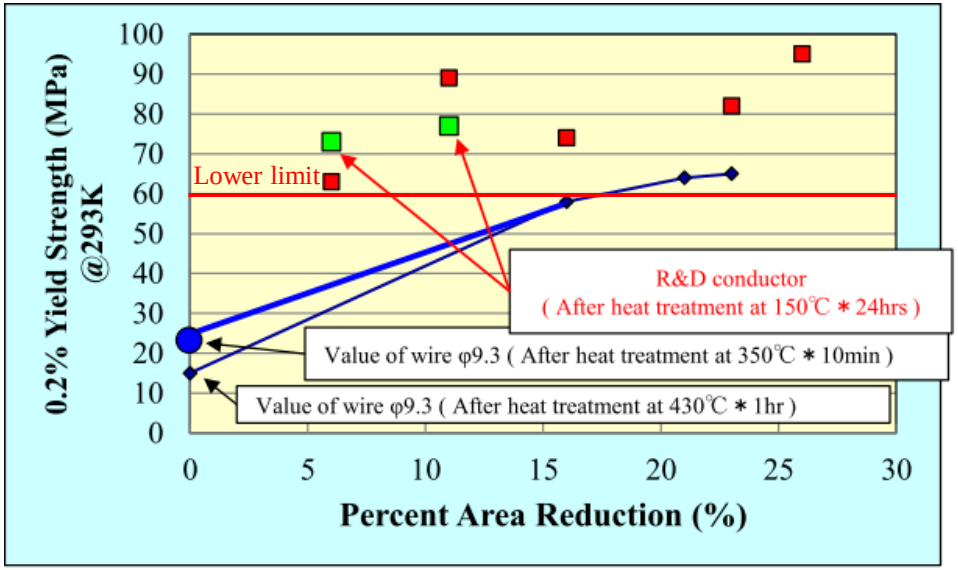
The results of SEM and EDX observation of DS1

2. R&D production for DS1 & PS conductor

FURUKAWA ELECTRIC

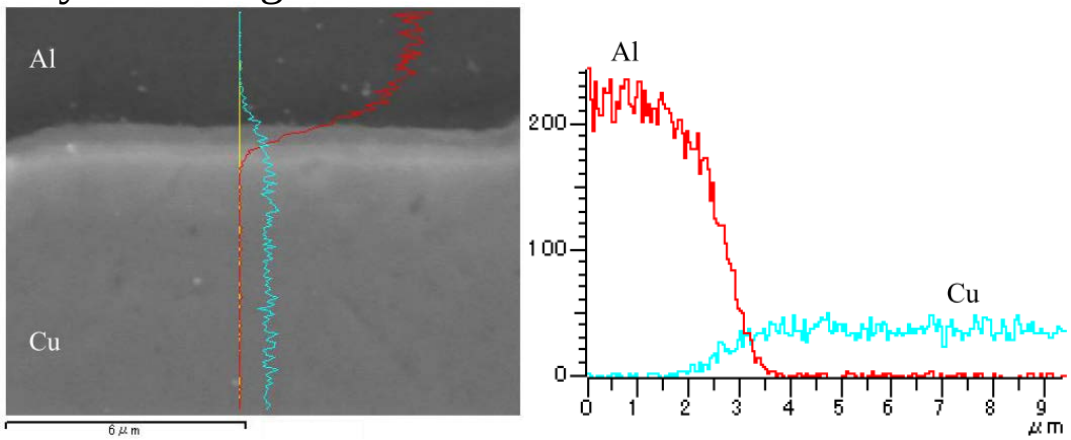
PS conductor





Relationship between Al-RRR or Al-0.2% yield strength and area reduction of PS conductor

The condition which meets the specification of PS conductor was determined



The results of SEM and EDX observation of PS

2. R&D production for DS1 & PS conductor

FURUKAWA ELECTRIC

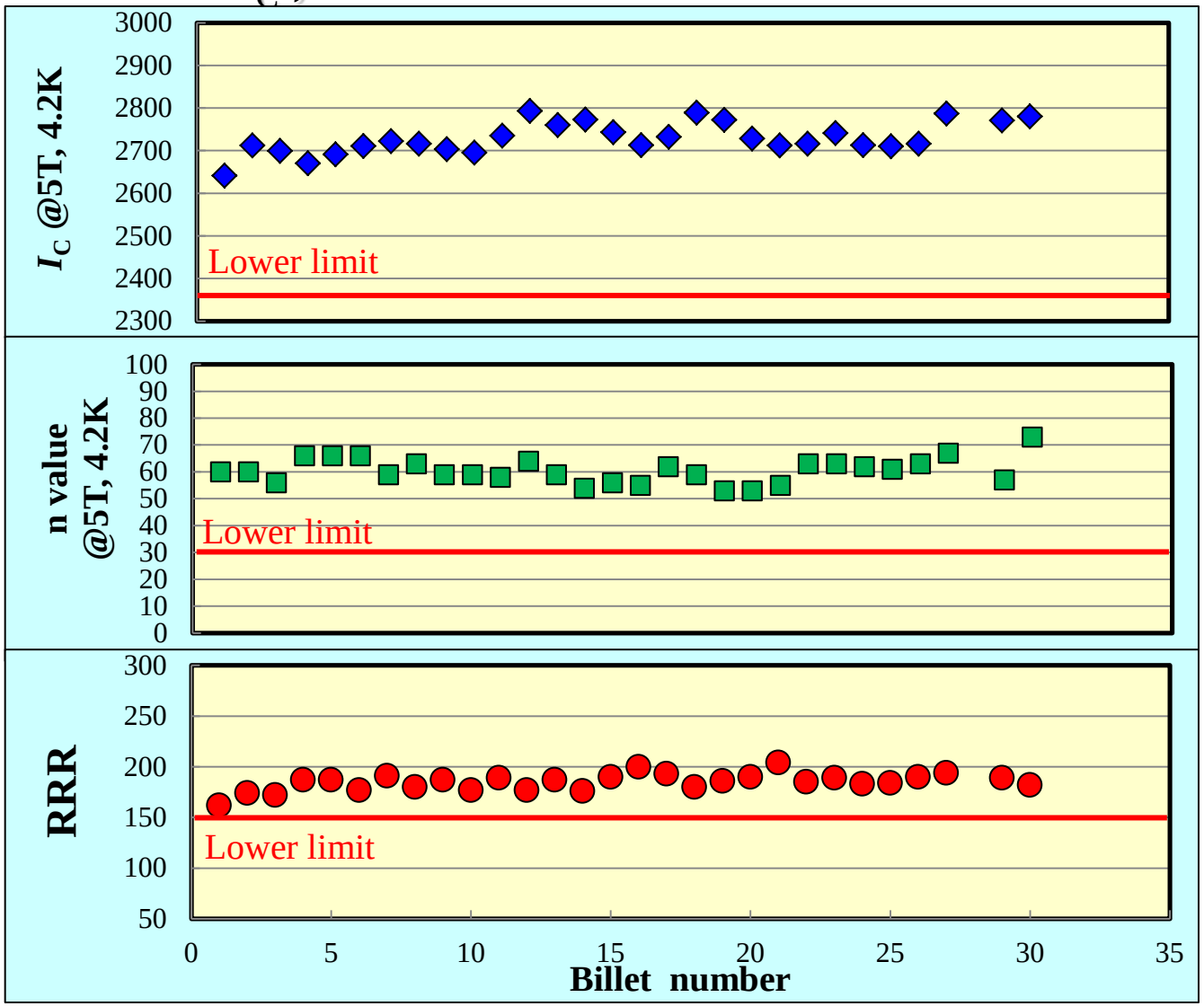
Items	unit	Specification		Result of developed DS1 conductor	Result of developed PS conductor
		DS1	PS		
Cable width	mm	20.1±0.1	30.1±0.1	20.1 (Average)	-
Cable thickness	mm	5.27±0.03	5.52±0.03	5.27 (Average)	-
Critical Current at 4.22K, ρ=1×10-14Ωm – I_C at 5T (A)	A	≧23,900	≧66,250	28,236	74,460
Aluminum RRR	-	≧800	≧500	1,205	502
0.2% yield strength of Al at 293K	MPa	≧30	≧60	57	73
Shear strength of Al-Cu bond at 293K	MPa	≧20	≧40	42	-

- We succeeded in developing the DS1 conductor
- We succeeded in finding the process condition for PS conductor

3. Mass production of DS1 conductor

FURUKAWA ELECTRIC

Production trends on I_C , n value and RRR of NbTi strands in mass production

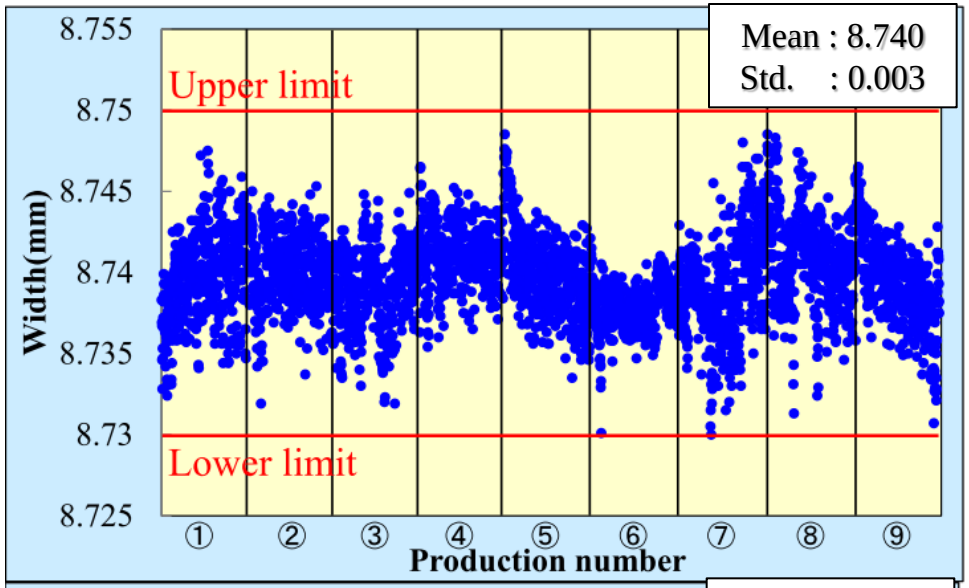


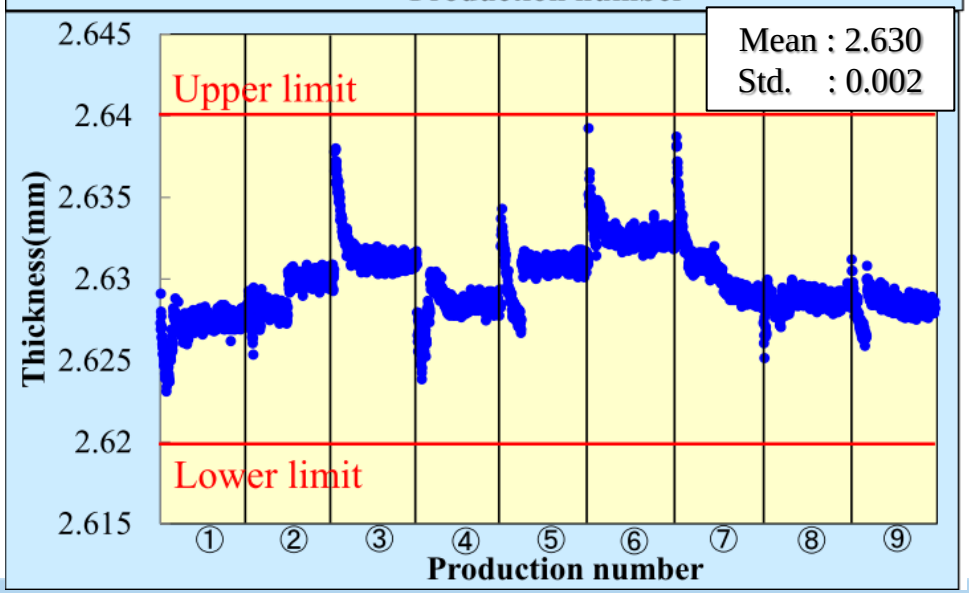
I_C , n value and RRR measured on both side of each billet of NbTi strand for DS1 conductor

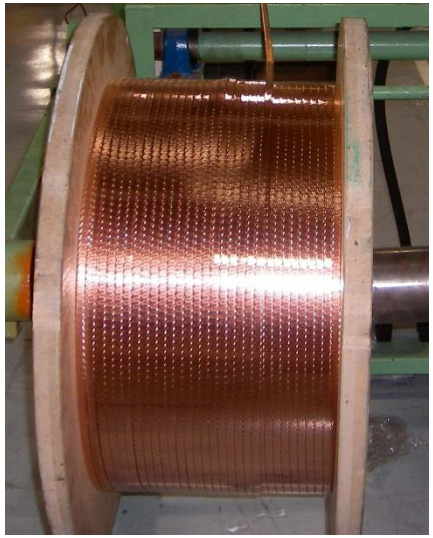
3. Mass production of DS1 conductor

FURUKAWA ELECTRIC

Production results of Rutherford cable

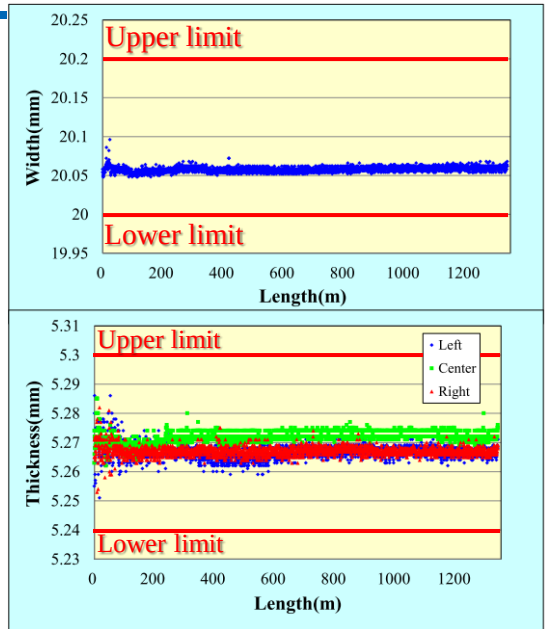


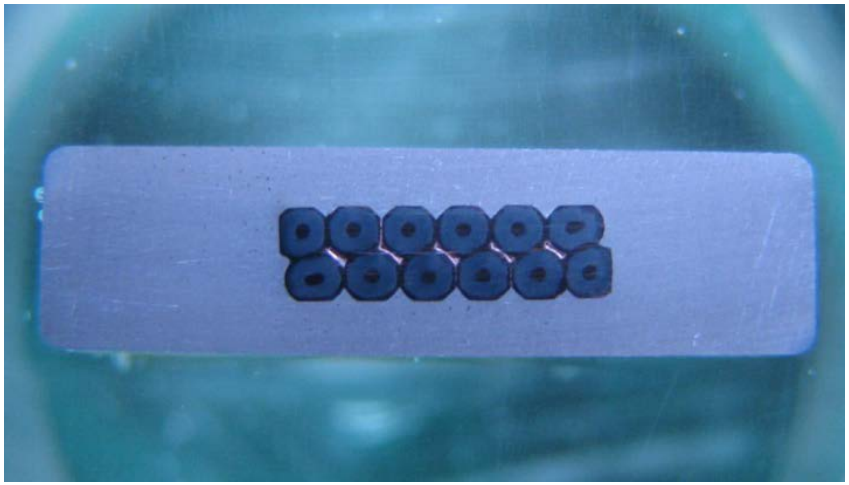




- We produced 9 Rutherford cables for DS1 conductor (Total length : 11,000m)
- The Rutherford cables are high stability in dimension

3. Mass production of DS1 conductor





Production No.	Conductor width(mm) Average	Conductor thickness(mm) Average	Standard dev. Width	Standard dev. Thickness	Al-RRR	Al-0.2% yield strength @293K	Shear strength
1	20.058	5.269	0.003	0.003	1919	56	36
2	20.065	5.274	0.006	0.007	2260	58	39
3	20.078	5.272	0.002	0.004	1819	58	38
4	20.064	5.271	0.004	0.005	2040	55	40
5	20.060	5.268	0.004	0.006	2179	55	40
6	20.068	5.275	0.004	0.007	2137	56	38
7	20.060	5.271	0.003	0.006	1780	54	42
8	20.066	5.274	0.003	0.006	1860	54	37
9	20.060	5.269	0.004	0.005	1665	54	39

➢We succeeded in manufacturing 9 DS1 conductors (9,900m)

4. Summary

FURUKAWA ELECTRIC

- We developed NbTi strand , Rutherford cable and Al-stabilized-conductor for PS and DS1 conductor
- We have successfully manufactured all DS1 conductors (1,100m ✕ 9 length)

※ Testing of final DS1 stabilized cable production lengths is currently ongoing

- We plan to start mass production of PS conductor hereafter (Total length : 14,400m)

Bound to Innovate

FURUKAWA
FURUKAWA ELECTRIC GROUP