Direct slice Nb R&D for SRF cavities at KEK

Takeshi DOHMAE

2023/Nov./20

The 11th IHEP-KEK SCRF Collaboration Meeting

Current KEK activities on direct slice Nb

KEK is now working on two main topics about direct slice niobium.

1. Investigation on large grain (LG) niobium
   - ✓ KEK had produced totally 14 cavities including 1-cell, 3-cell and 9-cell 1.3 GHz cavity.
   - ✓ In current 3 years, we fabricated four 3-cell cavities and two 9-cell cavities with new LG materials from ULVAC.
   - ✓ One 9-cell cavity was jacketed and tested in horizontal cryostat.
2. Investigation on medium grain (MG) niobium
   - ✓ KEK had newly started investigation on MG niobium.
   - ✓ Two 1-cell cavities were fabricated and tested.
   - ✓ Mechanical testing on MG is on going.
   - ✓ Fabrication of 9-cell cavity is on going.

Nb production

Melting

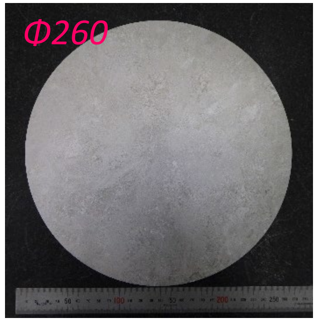
Nb ingot

Forging

Rolling

Large Grain (LG) Nb

Medium Grain (MG) Nb



Fine Grain (FG) Nb

	Grain size	Formability	Mechanical properties	Cost
FG	Small (< 0.1mm)/uniform	Good	Uniform	-
MG	Medium (< 5mm)/almost uniform	Good	Almost uniform	Lower
LG	Large (1cm～15cm)/not uniform	Bad/Large distortion	Non uniform	Lowest

Study on LG

Lists of cavities

Cavity	RRR	Supplier	Shape	cell	Ta
R1	496	TD	Tesla-Like	1	Lo-Ta
R5	107	CBMM	Tesla-Like	1	Hi-Ta
R11	270	CBMM	Tesla	1	Hi-Ta
R10/R10b	270	CBMM	Tesla-Like	3	Hi-Ta(1191)
R10 (VT2)	270	CBMM	Tesla-Like	3	Hi-Ta(1191)
R16/R16b	497	Silmet→ULVAC	Tesla	3	Lo-Ta(20)
R17/R17b	408	CBMM→ULVAC	Tesla	3	Hi-Ta
KEK-2	496	TD	Tesla-Like	9	Lo-Ta
KEK-4/5	270	CBMM	Tesla	9	Hi-Ta
KEK-7	408	CBMM→ULVAC	Tesla	9	Hi-Ta

※LG with low Ta is more expensive since removing Ta from Nb needs special chemical procedure.
High Ta LG is more cost effective.

Lists of cavities

Cavity	RRR	Supplier	Shape	cell	Ta
R1	496	TD	Tesla-Like	1	Lo-Ta
R5	107	CBMM	Tesla-Like	1	Hi-Ta
R11	270	CBMM	Tesla	1	Hi-Ta
R10/R10b	270	CBMM	Tesla-Like	3	Hi-Ta(1191)
R10 (VT2)	270	CBMM	Tesla-Like	3	Hi-Ta(1191)
R16/R16b	497	Silmet→ULVAC	Tesla	3	Lo-Ta(20)
R17/R17b	408	CBMM→ULVAC	Tesla	3	Hi-Ta
KEK-2	496	TD	Tesla-Like	9	Lo-Ta
KEK-4/5	270	CBMM	Tesla	9	Hi-Ta
KEK-7	408	CBMM→ULVAC	Tesla	9	Hi-Ta

New (R16/R16b, R17/R17b)

New (KEK-7)

※LG with low Ta is more expensive since removing Ta from Nb needs special chemical procedure.
High Ta LG is more cost effective.

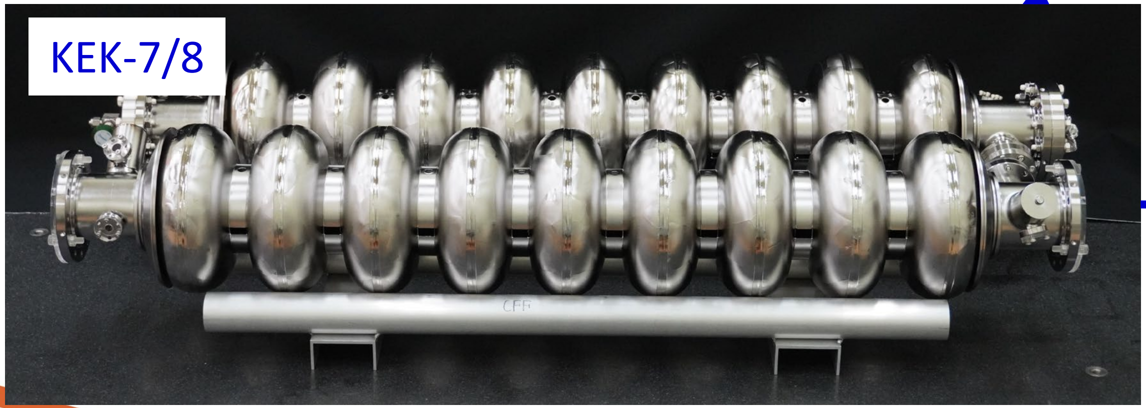
Investigation strategy 2

New challenge by ULVAC. **They melted only one time and got high RRR.**

Silmet→ULVAC; high-RRR, low-Ta

CBMM→ULVAC; high-RRR, high-Ta

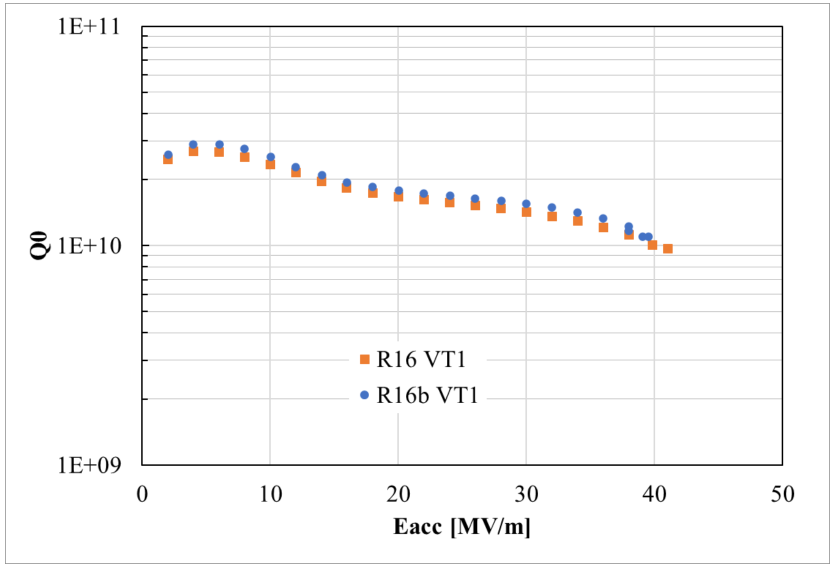
Extend to 9-cell



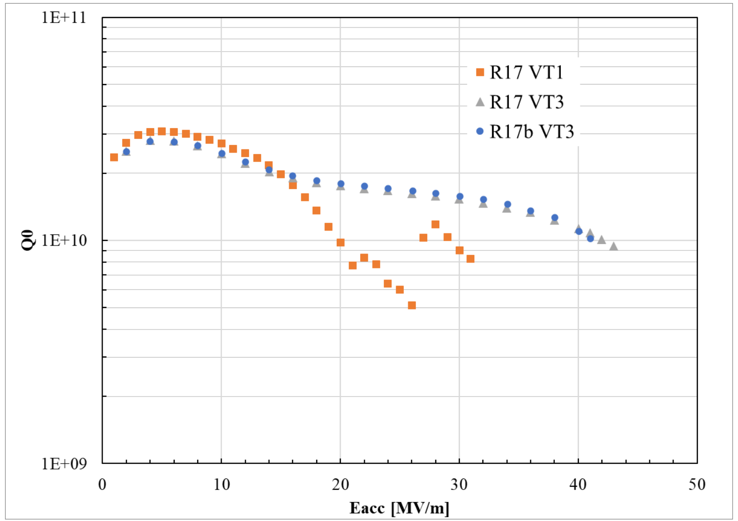
Aiming cost reduction 2 (reduce melting)

LG from ULVAC. **Only 1 melting**

Silmet→ULVAC; high-RRR, low-Ta
RRR:498



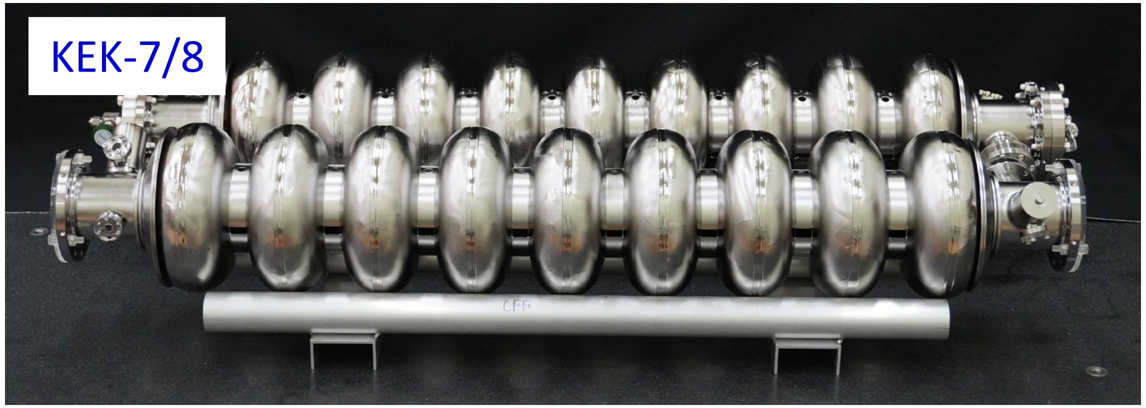
CBMM→ULVAC; high-RRR, high-Ta
RRR: 408

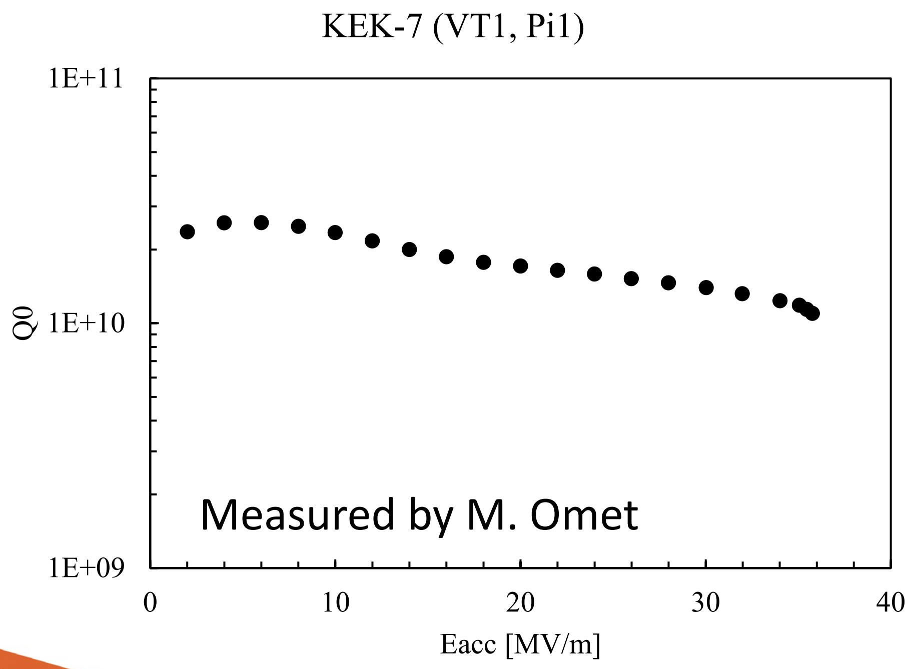


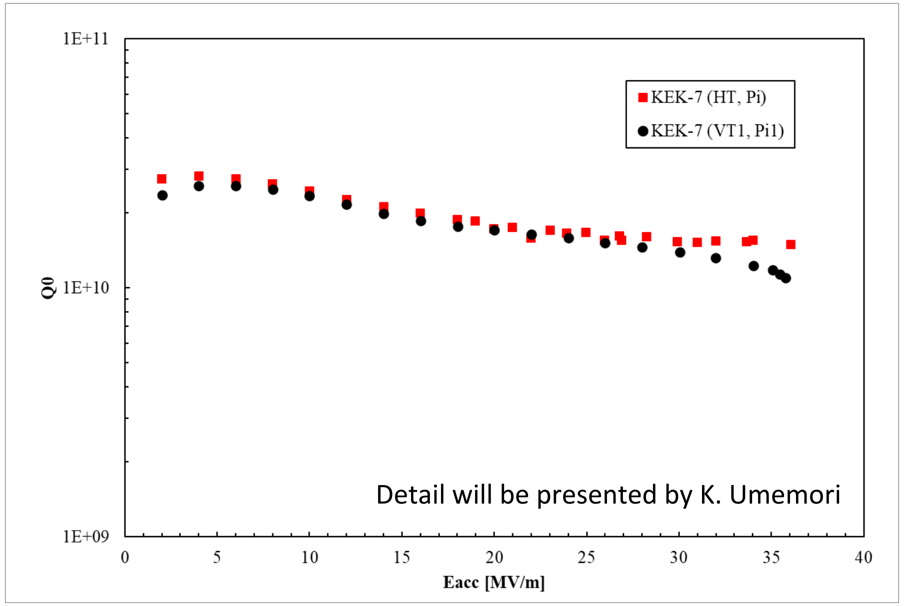
Measured by Araki-san

Aiming cost reduction3

CBMM→ULVAC; high-RRR, high-Ta
RRR: 408







KEK-7 was successfully jacketed

Study on MG

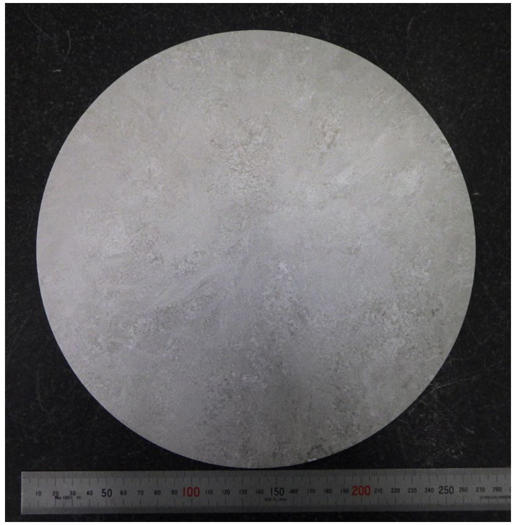
Medium grain (MG niobium)

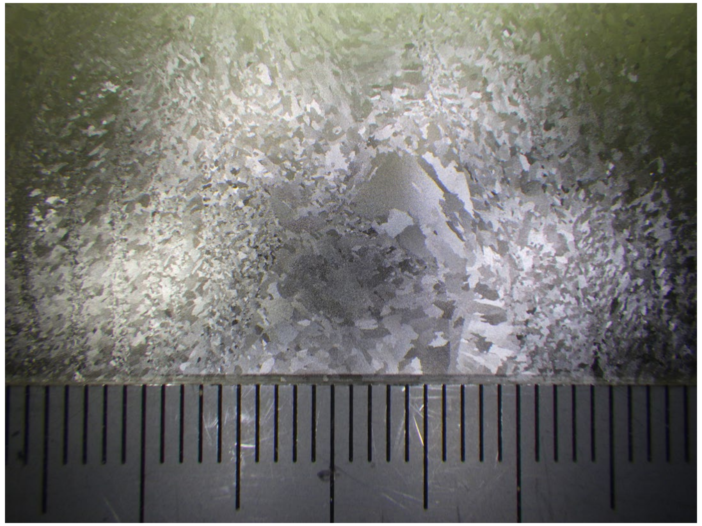
MG production

1. Forge Nb ingot to “billet”
2. Slice billet into discs

Grain size: few μm – 5mm

MG disc





Mechanical Properties [1]

		MG	LG	FG
Room temperature	Tensile strength (σ) [MPa]	123 (5)	84 (3.2)	157
	0.2% proof strength [MPa]	39 (2)	65	44
	Elongation [%]	25 (3)	75	37
LHe temperature	Tensile strength (σ) [MPa]	651 (60)	611 (132.4)	832
	0.2% proof strength [MPa]	283 (34)	-	516
	Elongation [%]	7.5 (1)	6	7

MG w annealing (800Cx3h)

[1]A. Kumar, et al., “Development of the Directly-Sliced Niobium Material for High Performance SRF Cavity”, SRF2023

- **Uniformity of mechanical property from MG is much better than that of LG.**

  → Large advantage on high pressure gas regulation
- **Two single cell cavities were fabricated using these MG discs.**

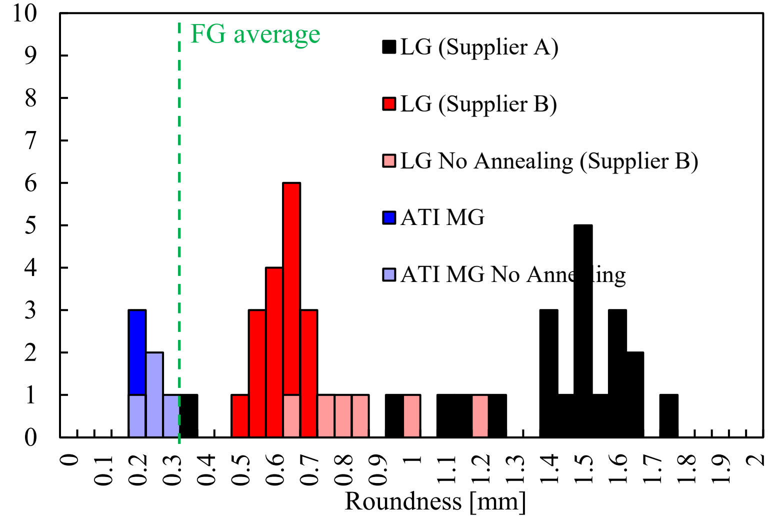
Manufacture of cavity

Formability
Cracked at iris after forming half-cell.
Similar crack happen with LG discs.
This issue was solved optimizing diameter of hole made on disc before forming.

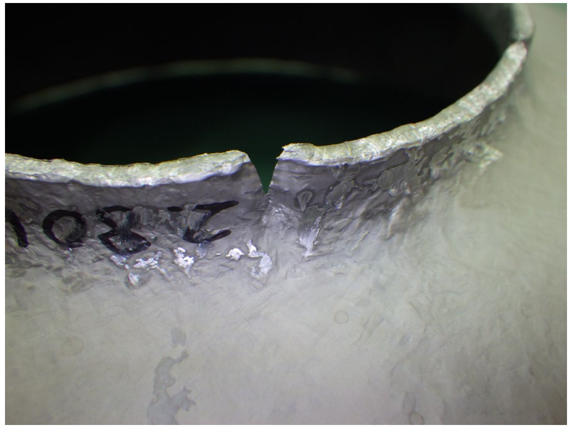
Shape accuracy
Difference between design shape and real shape is less than 0.5mm.
Roundness at equator is similar to that of FG.

Surface roughness
Surface of half cell is rough after forming.
Ra 2.5-5.7μm, Rz 11-28μm

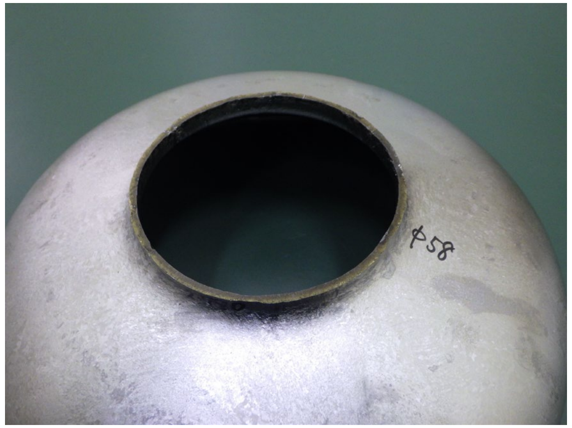
Roundness distribution



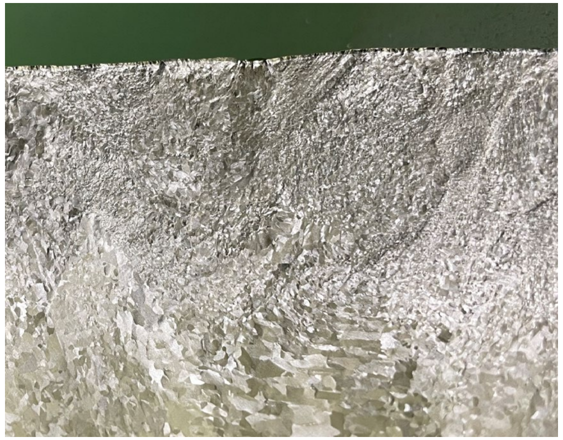
Cracked iris



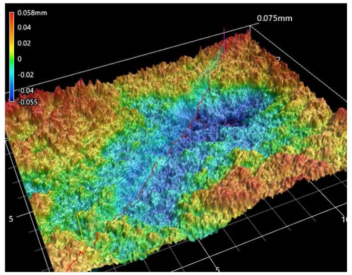
Successfully formed iris
after improving the fabrication process



Inner surface around equator



3D data of surface

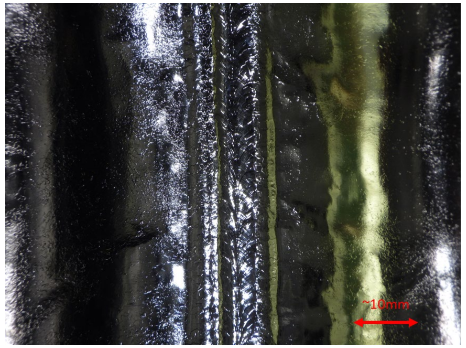


Performance of MG cavities

Fabricated cavities

Equator of R18 was mechanically polished before welding.

Inner surface after 100 µm EP

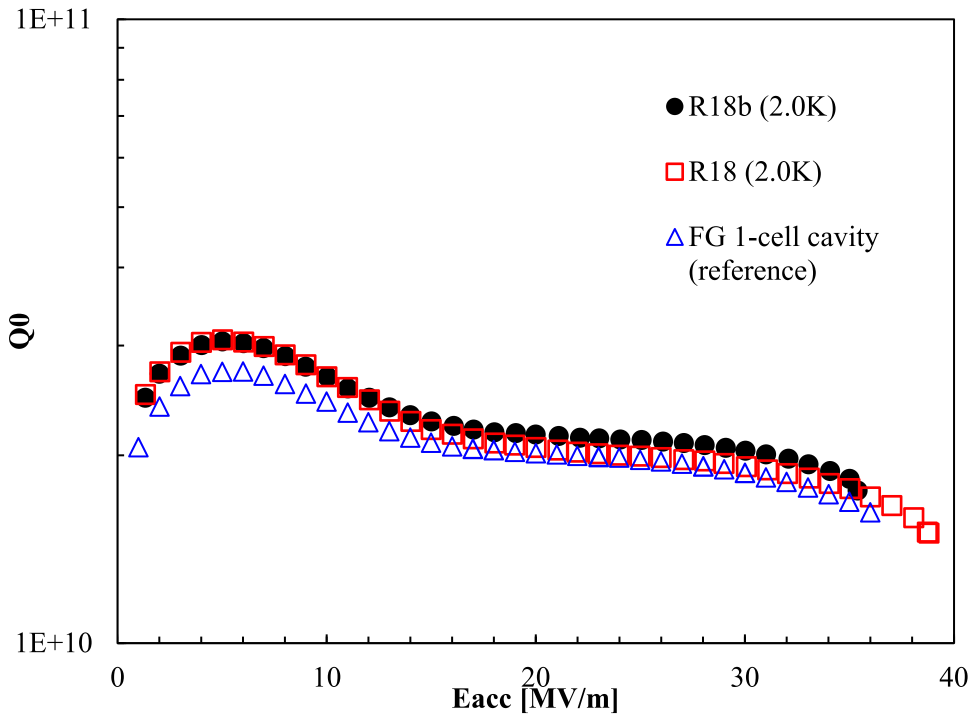


	Ra [µm]	Rz [µm]
Disc	0.7	-
Formed	2.6 ~ 5.7	11 ~ 28
Polished	2.6 ~ 3.7	2.6 ~ 11
EP (100µm)	1.1 ~ 1.5	3.4 ~ 6.7

Surface roughness

Surface treatment menu

1. Initial electropolishing of 100 µm
2. Annealing at 800 ℃ × 3 hours in a vacuum furnace
3. Second electropolishing of 20 µm
4. High pressure rinsing with ultra-pure water
5. Baking at 120 ℃ × 48 hours

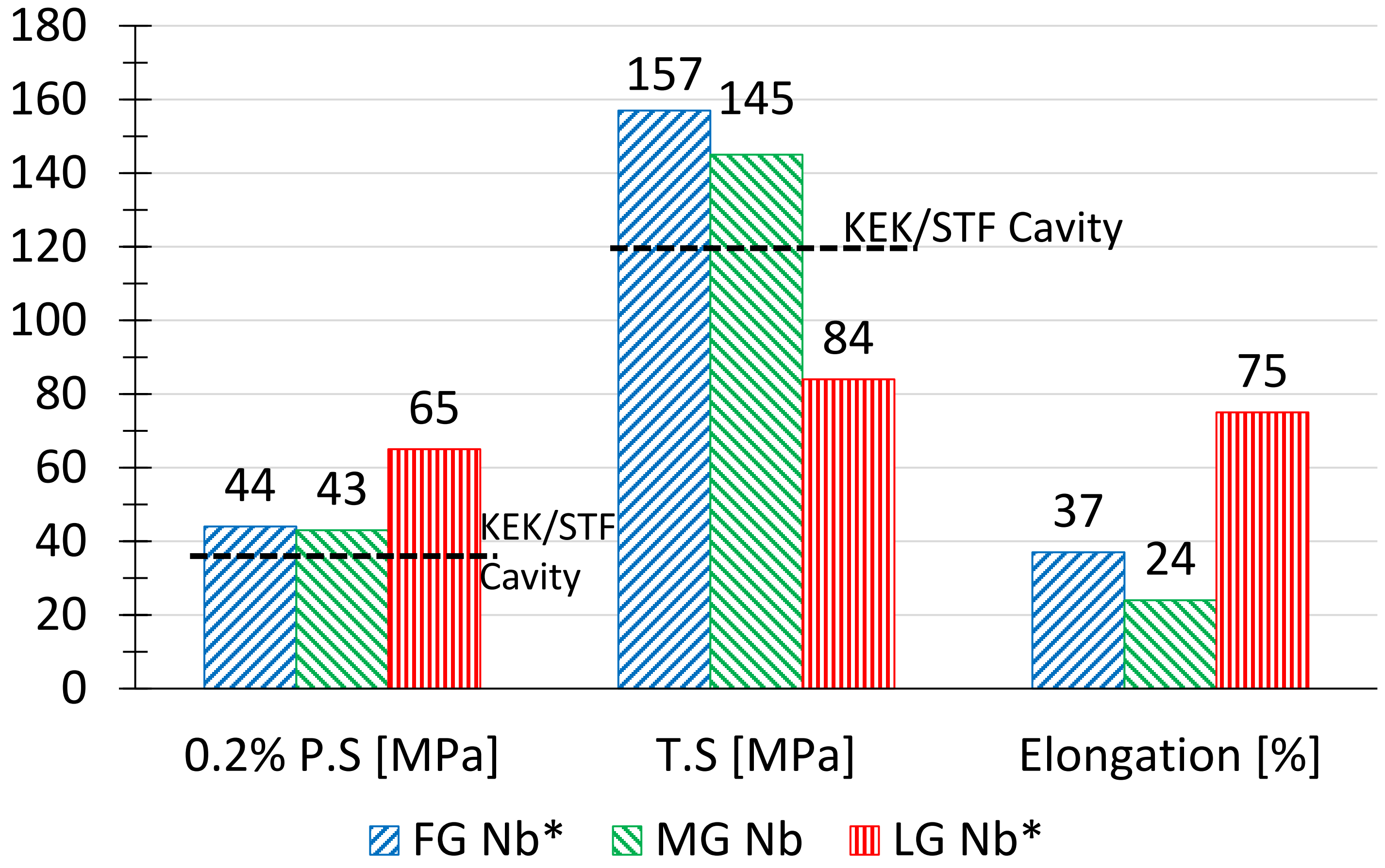


Mechanical testing of MG is now on going.

Mechanical properties

Room Temperature Property Comparison

Slide by A. Kumar (SRF2023)



- MG Nb closer to FG Nb than LG Nb at room temperature.
- Elongation is lower than FG Nb but fine for HPGS
- High elongation necessary for press forming of half cells.

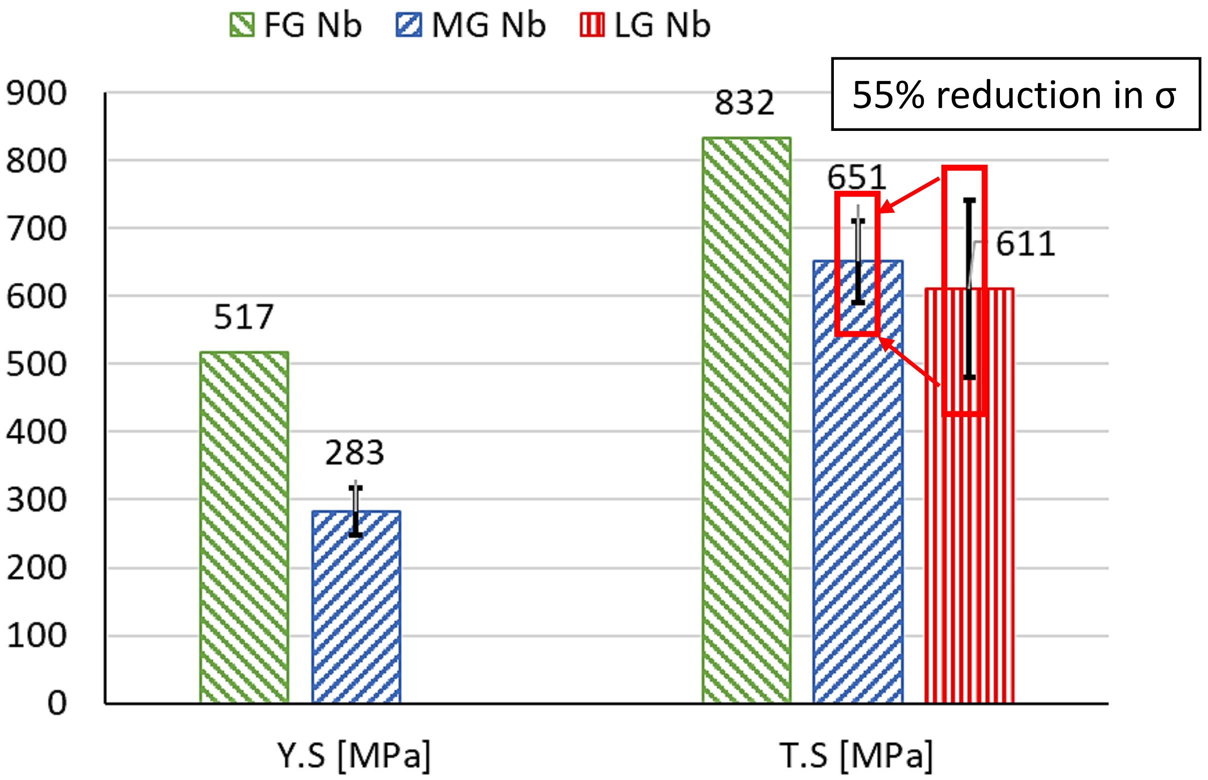
Mechanical strength of MG-Nb achieved the criteria of HPGS regulation for KEK/STF-Cavity

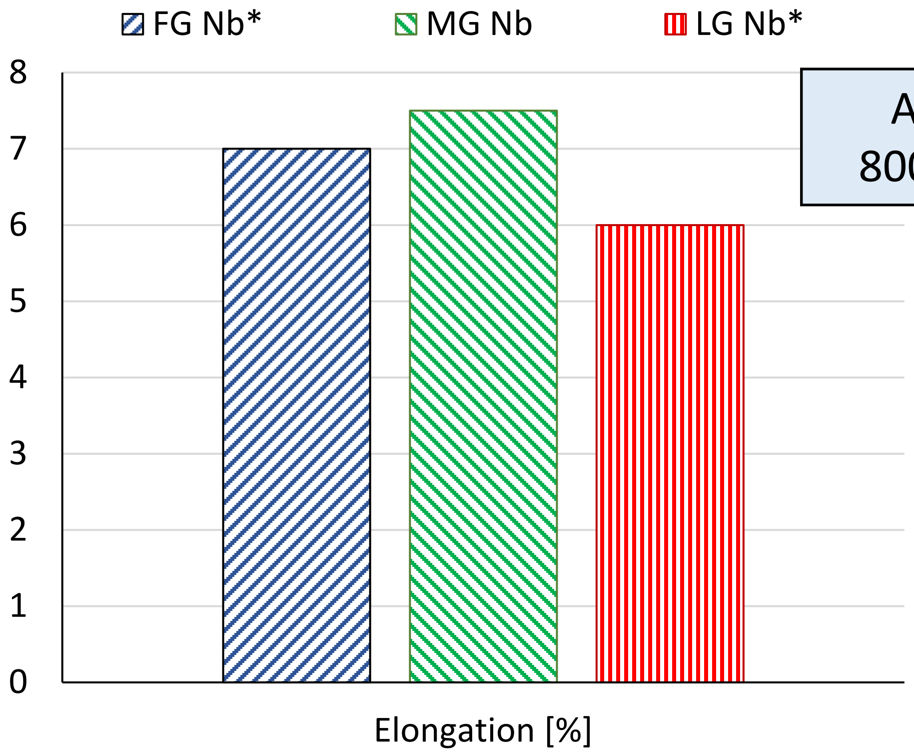
MG Nb data: A. Kumar et al. (July 2021), SRF2021 MOPCAV004

* FG Nb and LG Nb data is for middle RRR annealed material (M. Yamanaka et al., SRF'21 WEPFDV005).

Low Temperature Property Comparison

Slide by A. Kumar (SRF2023)





Annealed at 800 °C for 3 hrs

- Tensile Strength of MG-Nb at LHe-T is better than LG-Nb, with lower standard deviation.
- No issues with HPGS w.r.t mechanical strength in LHe (800 °C for 3 hrs).

* FG Nb and LG Nb data is for middle RRR annealed material (M. Yamanaka et al., SRF'21 WEPFDV005.

MG Nb data: A. Kumar et al., SRF2021 MOPCAV004

Summary

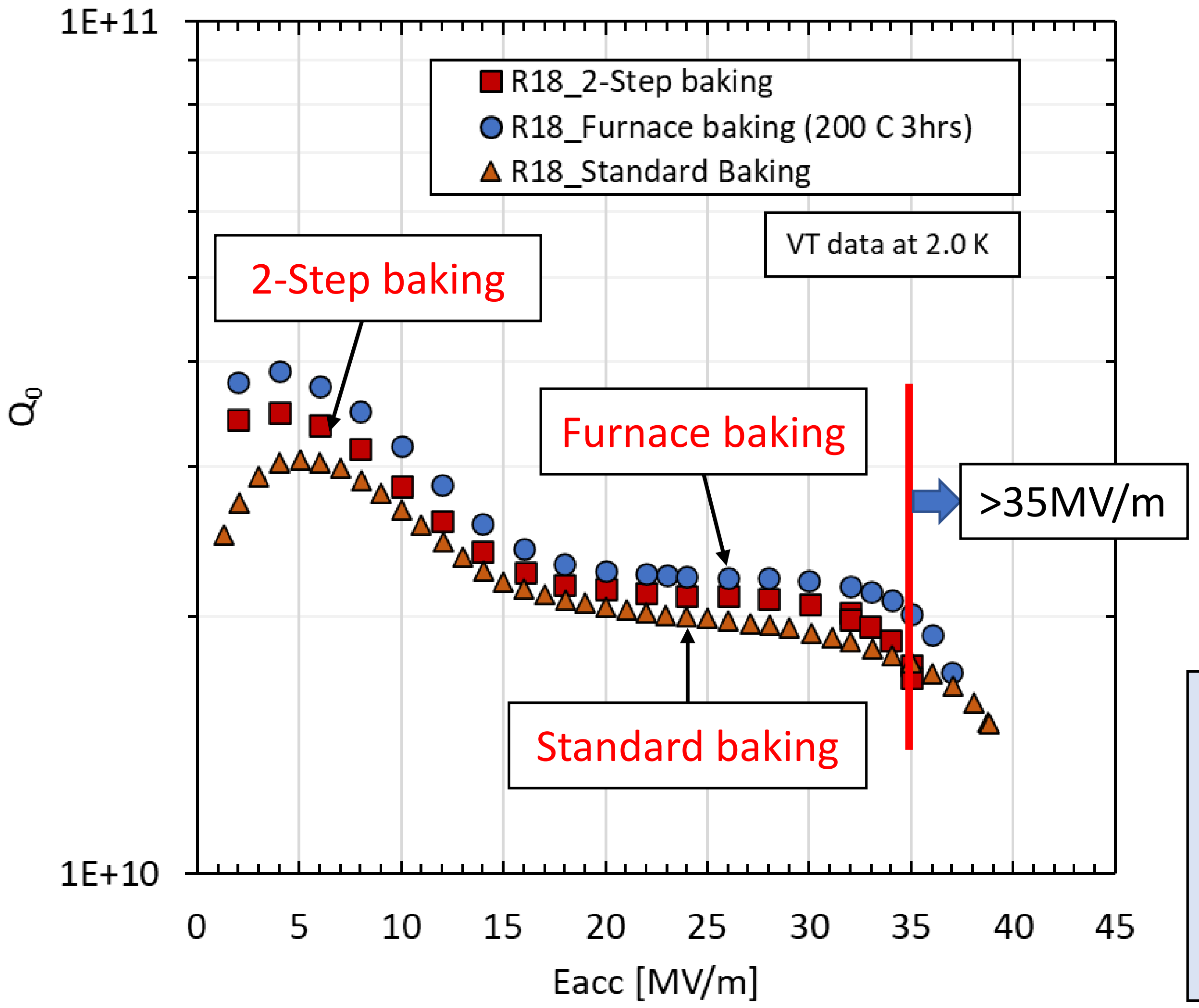
Investigations on direct slice material are on going.

1. Investigation on large grain (LG) niobium
   - ✓ In current 3 years, we fabricated four 3-cell cavities and two 9-cell cavities with new 1 time melted LG materials from ULVAC.
     →All cavities achieved more than 35MV/m
2. Investigation on medium grain (MG) niobium
   - ✓ KEK had newly started investigation on MG niobium.
   - ✓ Two 1-cell cavities were fabricated and tested.
     → Two of them achieved more than 35MV/m.
   - ✓ Mechanical testing on MG is on going.
     → Variation of mechanical strength is smaller than LG.
   - ✓ Fabrication of 9-cell cavity is on going.

Thank you

MG Nb 1-Cell Cavity High Q-High G Study

Slide by A. Kumar (SRF2023)

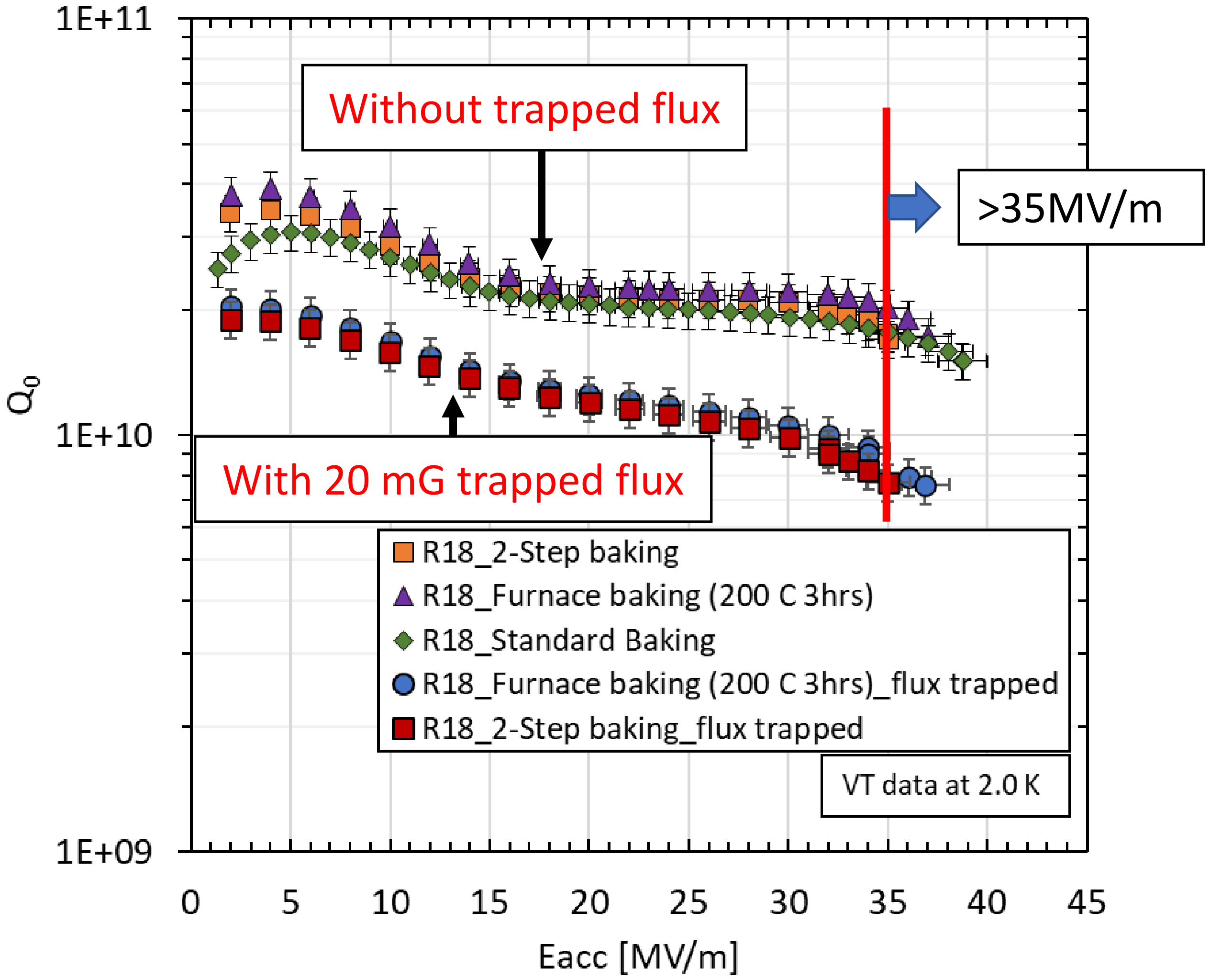


Parameters @ 2.0 K (R18 cavity)	E_{acc} max.	Q_0 @ E_{acc} = 35 MV/m	Q_0 max.
Standard Treatment (120 °C 48h)	38.8 MV/m	1.77E+10	3.06E+10
2-step baking (70°C 4h + 120°C 48h)	35 MV/m	1.75E+10	3.47E+10
Furnace baking (200 °C * 3hrs)	36.3 MV/m	1.87E+10	3.73E+10

- Clears ILC Specification.
- Highest Eacc for Standard surface treatment.
- Q_0 within error range
- No degradation in Eacc after quenching unlike LG Nb cavities.

MG Nb 1-Cell Cavity High Q-High G with Flux Sensitivity Studies

Slide by A. Kumar (SRF2023)



Parameters @ 2.0 K	E_{acc} max.	Q_0 @ E_{acc} = 35 MV/m	Q_0 max.
Standard Treatment (120 °C 48h)	38.8 MV/m	1.77E+10	3.06E+10
2-step baking (70°C 4h + 120°C 48h)	35 MV/m	1.75E+10	3.47E+10
2-step baking Flux Sensitivity test	35 MV/m	7.71E+09	1.89E+10
Furnace baking (200 °C * 3hrs)	36.3 MV/m	1.87E+10	3.73E+10
Furnace baking Flux Sensitivity test	37 MV/m	8.05E+09	2.03E+10

- No degradation in Eacc due to trapped flux.
- Degradation in Q_0 expected due trapped flux.