Comparison of Cavity Fabrication and Performances Between Fine Grains, Large Grains and Seamless Cavities

2015/9/17

SRF2015, Canada, Whistler

High Energy Accelerator Research Organization (KEK)

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CFF / Machine shop

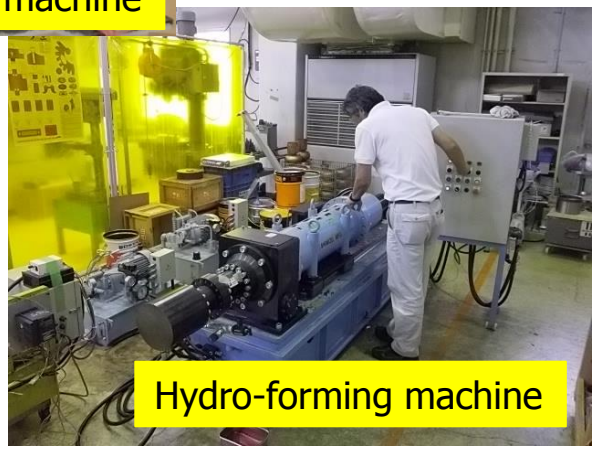
- KEK-CFF/Machine shop has a series of machines, which are needed to produce EBW cavities and hydro-formed seamless cavities

Servo press machine


CP area

CNC vertical lathe

EBW machine (new)


Hydro-forming machine

Tensile testing machine


EBW machine

Motivation of study

- To learn cavity fabrication procedures for different Nb materials and also different fabrication methods.
  - Material: Fine grain Nb, Large grain Nb
  - Method: EBW, Hydroforming
- To investigate merit/demerit and which are important points for cavity fabrication.
- To compare cavity performances between these cavities

Cavity type	Nb Material	Vendors	Cavity name
Fine grain single cell cavity	Fine grain Nb sheet	Tokyo Denkai	R-2
		ULVAC	R-4
Large grain single cell cavity	Sliced Nb ingot (Large grain)	Tokyo Denkai	R-1
		CBMM(low RRR)	R-5
Seamless single cell cavity	Fine grain Nb tube	Wah Chang	W-1
		ULVAC	U-4

THPB030: Fabrication and Evaluation of Low RRR Large Grain 1-Cell Cavity (Shimizu-san)
THPB041: Hydroforming SRF Cavities from Seamless Niobium Tubes (Yamanaka-san)


R-1 (Large Grain, Tokyo Denkai)


W-1 (Seamless, Wah Chang)


R-5 (Large Grain, CBMM)


U-4 (Seamless, ULVAC)


R-2 (Fine Grain, Tokyo Denkai)

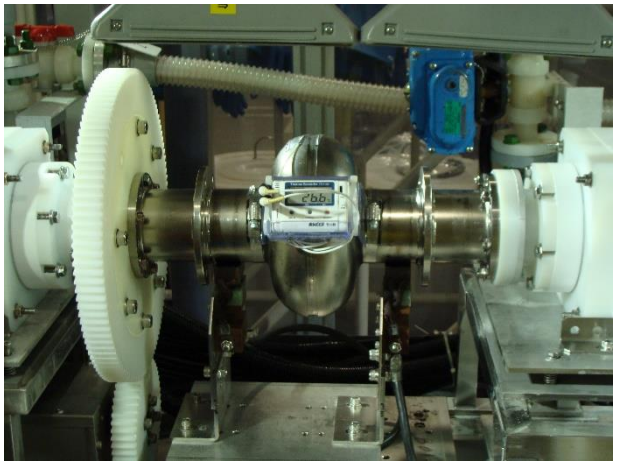

R-4 (Fine Grain, ULVAC)

Fine grain cavity(1) – Fabrication

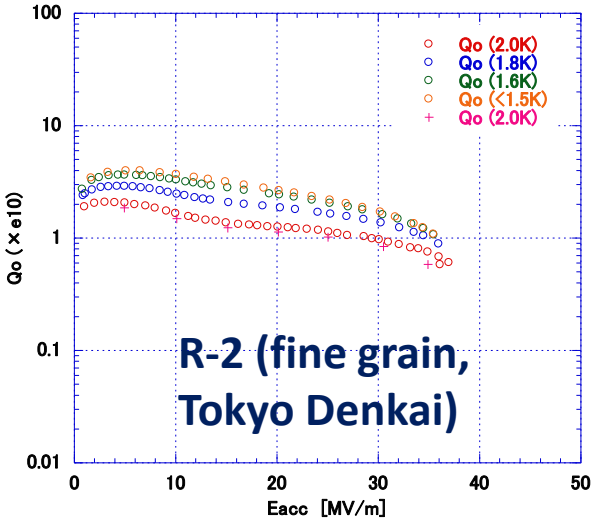
Fine grain cavity – Surface treatment and VT

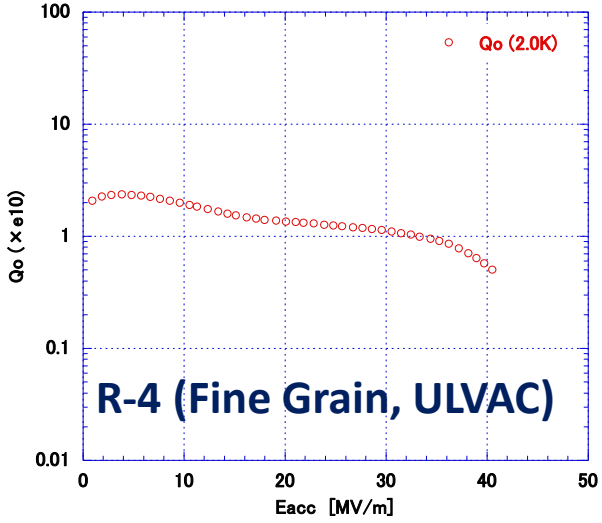
Typical process:

-- EP-1 (～100um), HPR
-- Annealing (750 C, 3hours)
-- EP-2 (～20um), HPR, Assembly
-- Baking (140 C, 48hours)
-- Vertical test



Vertical test results

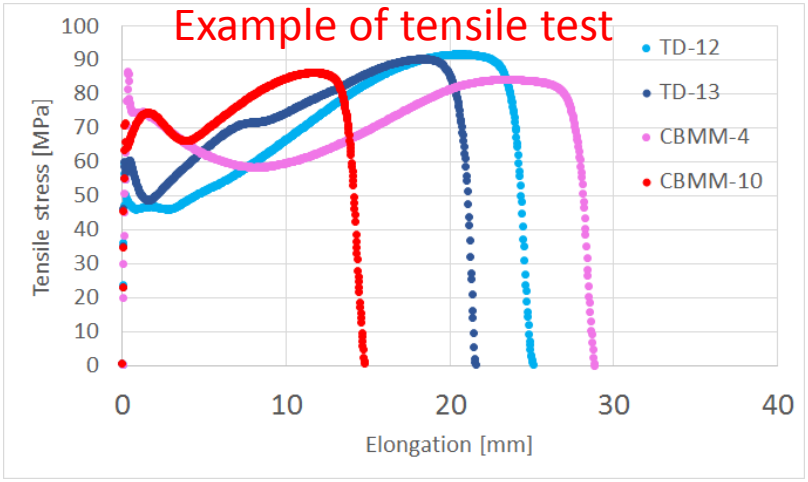




- Fine grain cavities were fabricated by nominal way, i.e. EBW.
- Both cavities show good performances.

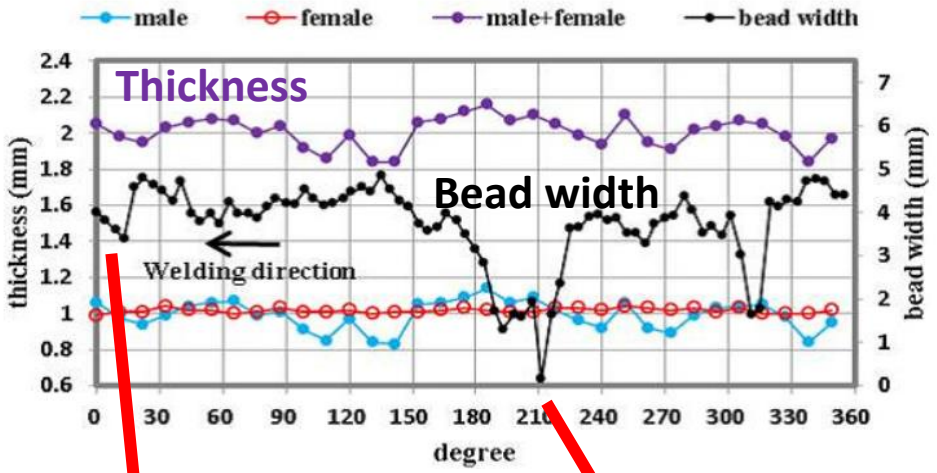
Large grain cavity(1) – Large grain Nb disks

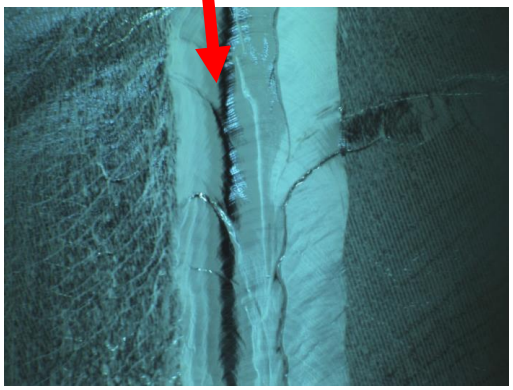
- Use two types of large grain Nb disks
  - Tokyo Denkai (high-RRR ~400)
  - CBMM (low-RRR ～100, with large Ta contents)

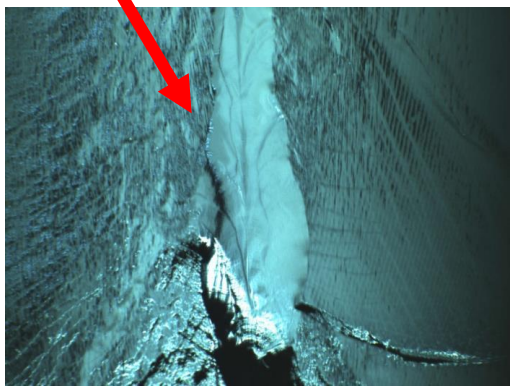


	H	C	O	N	Fe	Si	Ta	RRR
LG (TD)	< 5	< 10	< 10	< 10	< 10	< 10	80	**390**
FG (TD)	< 10	40	100	40	20	20	700	**258**
LG (CBMM)	< 10	< 30	< 30	10	3	20	1034	**100**

Large grain cavity(2) – Deformation

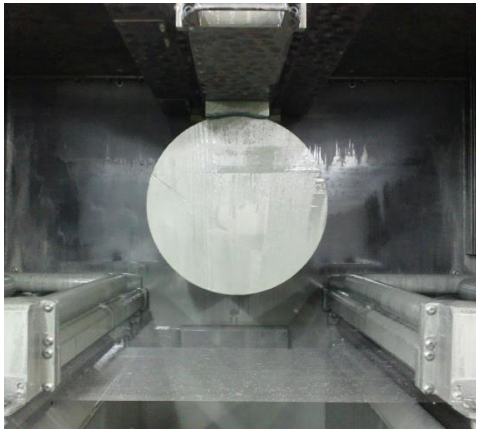




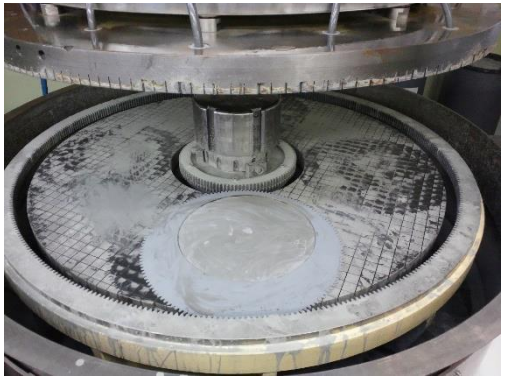


- Deformation around grain boundary give non-uniform thickness distributions around equator region.
- For Tokyo-Denkai cavity, only one side is machined before EBW.
- This thickness variation leads to unstable EBW beads.
- Thickness control is essential.

Large grain cavity(4) – Ingot to disk(CBMM)

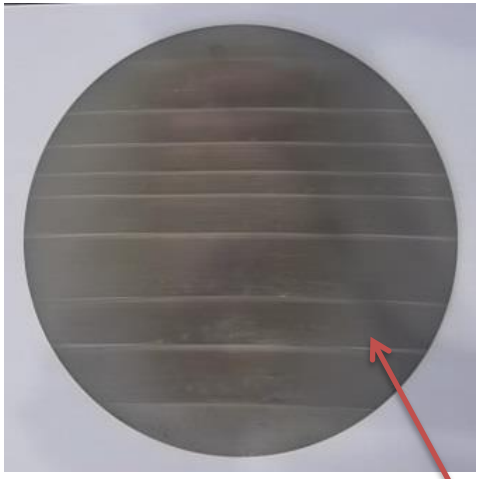


Multi wire-saw

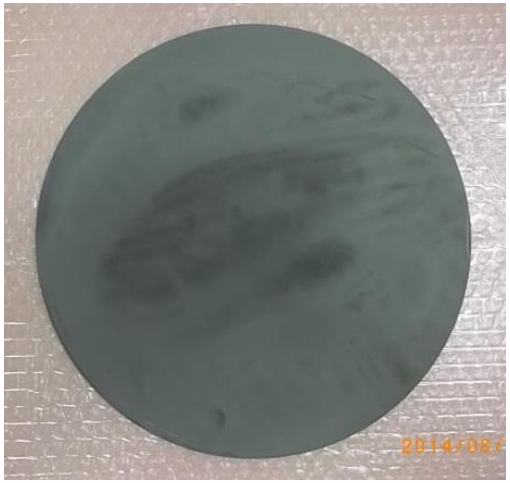


Polishing machine

・Nb ingot was sliced to disk by multi wire-saw.
・Saw-mark appeared on surface → Applied mechanical polishing.
・Then, CP was applied.



After sliceing to disk

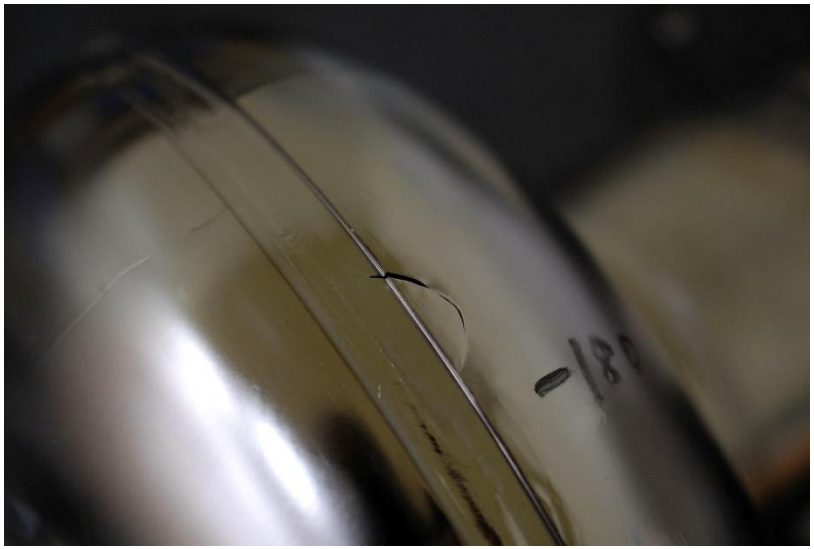


After polishing

After CP

Saw mark

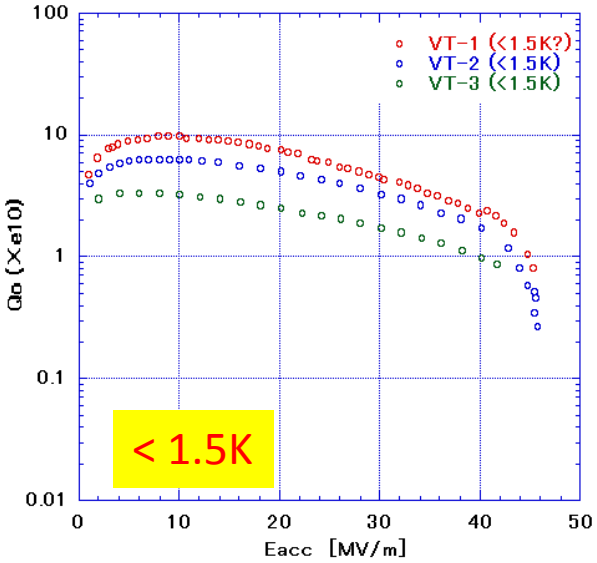
Large grain cavity(5) – CBMM cavity



- Deformations at grain boundary seem to be more severe.
- Cracks are also observed around equator. No vacuum leak.
- Spattering is observed (Only outside?)

Large grain cavity(6) – Vertical tests

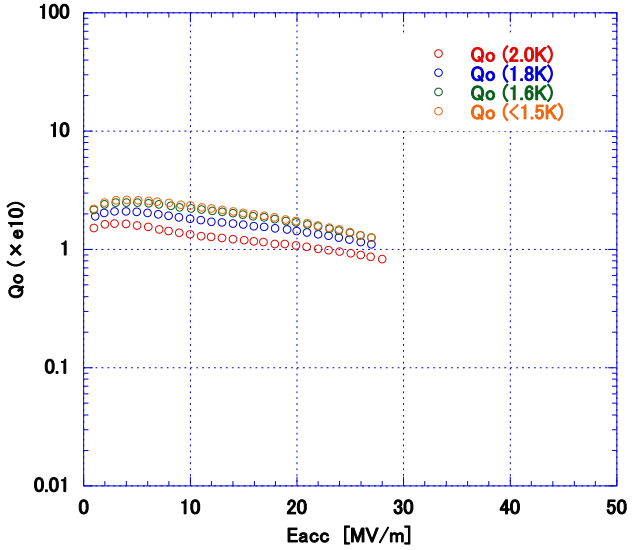
Results for R-1 (LG Tokyo Denkai)

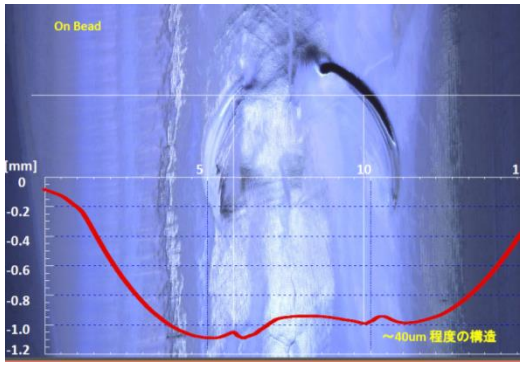


・LG(Tokyo Denkai) showed good Eacc and Q. But, unfortunately, high Q values are not reproduced.

・KEK vertical test system does not seem to be suitable for high-Q measurements.

Results for R-5 (CBMM))

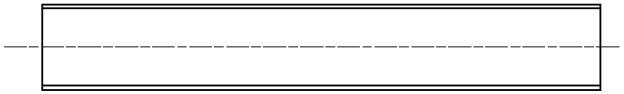




・LG(CBMM) cavity reached 28 MV/m. Eacc is limited by a defect. Have a plan of next VT after local grinding.

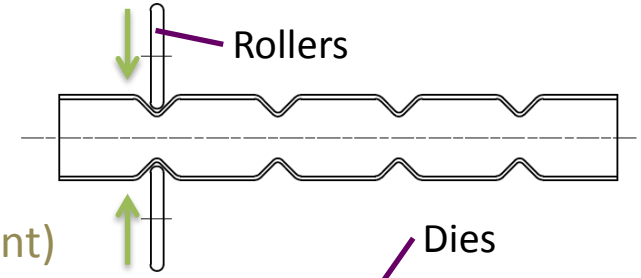
Seamless cavity(1) – fabrication procedure

Initial tube



ϕ123

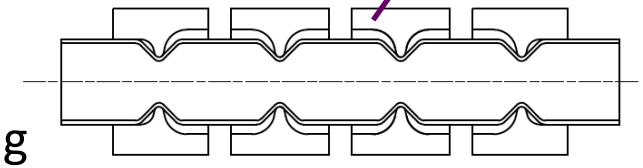
Necking



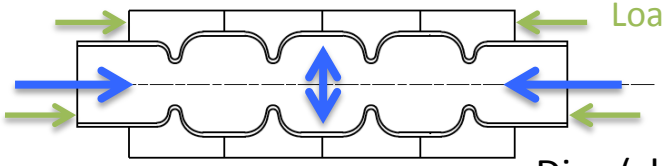
ϕ123 to ϕ70 (Iris)

(Heat treatment)

Hydroforming (1st stage)

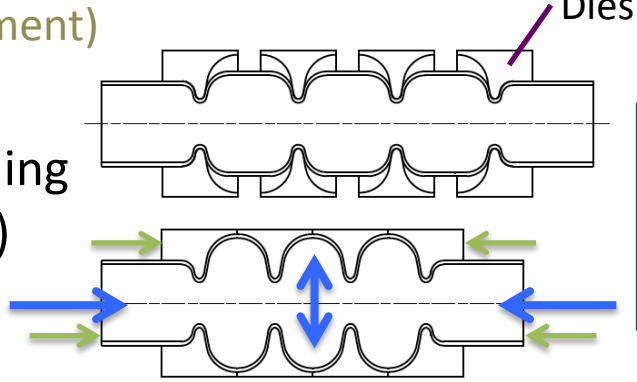


Φ123 to ϕ153

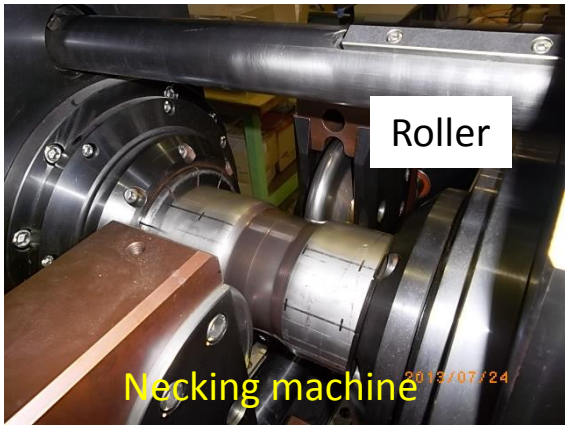


(Heat treatment)

Hydroforming (2nd stage)

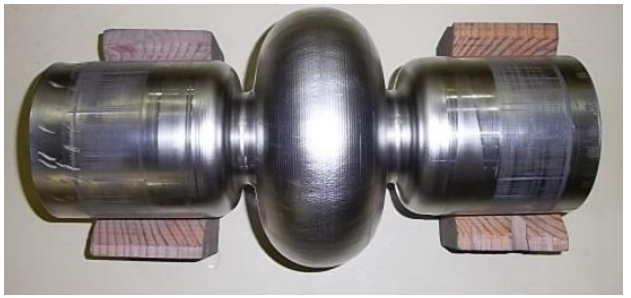


ϕ153 to ϕ205 (Equator)
Total expansion ratio: 67 %



seamless cavity(2) – History, case of Wah Chang

- Received the tube from War-Chang
- Inspection of thickness distribution (Ultrasonic measurement)
- Necking
- Chemical Polishing (CP) and Anneling (750 degree, 3 hr)
- Hydroforming, 1st stage
- Visual inspection
- Light CP and Anneling (750 degree, 3 hr)
- Hydroforming, 2nd stage, interrupt at half
- Visual inspection
- Light CP and Anneling (750 degree, 3 hr)
- Hydroforming, 2nd stage (continue) to finish
- Inspection of thickness distribution (Ultrasonic measurement)
- Finish to cavity
- Inspection inside (Kyoto camera)
- Ship to **FNAL**
- Barrel polishing (~120 µm, mirror finish)
- Ultrasonic cleaning, High pressure rinse
- Ship back to **KEK**
- Leak check
- Inspection of thickness distribution (Ultrasonic measurement)
- Inspection inside (Kyoto camera)
- Electric polishing (EP) (~5 µm) : Pre-EP
- Anneling (750 degree, 3 hr)
- Inspection inside (Kyoto camera)
- EP2 (~15 µm)
- High pressure rinse
- Baking (120 degree, 48 hr)
- Vertical test



Just after forming

Barrel polishing @ FNAL

Ship to FNAL and back to KEK

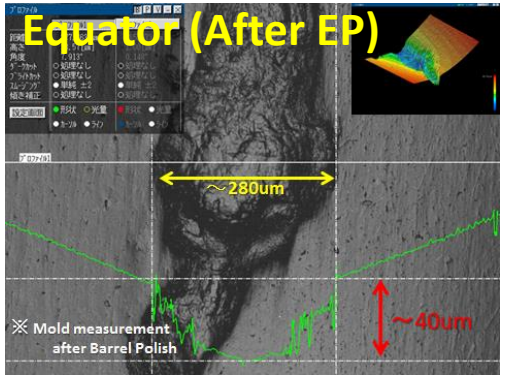
Seamless cavity(3) – Burst

- Hydro-formed cavities sometimes suffered from burst!
- Difficulty comes from rather large expansion ratio at equator region

- Uniform and small grain is essential for uniform expansion.
- Hydro-forming process is divided into two or three steps with annealing to reach final expansion ratio.
- Larger diameter seamless pipe is desirable.

Seamless cavity(3) – Cavity surface

W-1: Wah Chang seamless cavity



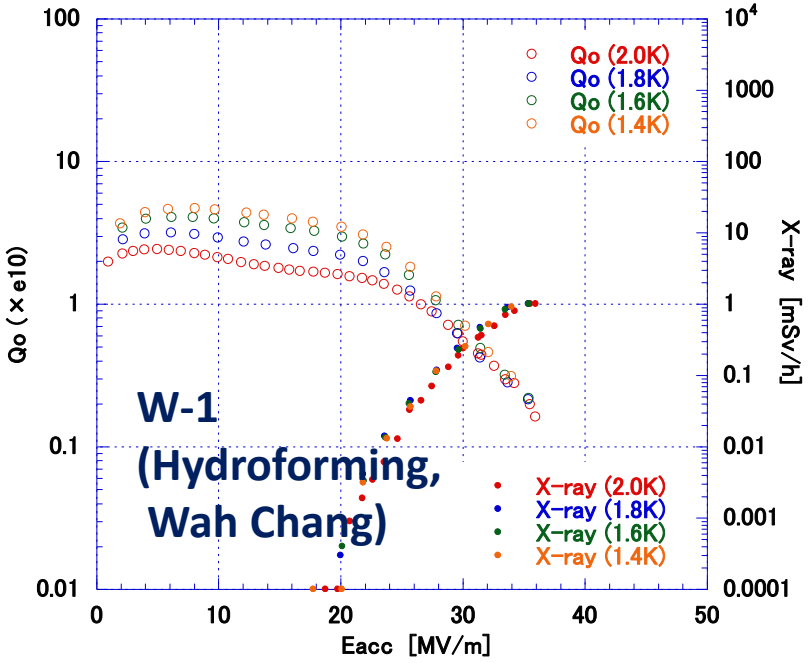
- Equator part have a valley.
- Effect from joint parts of dies.
- Needed rather tough grinding.

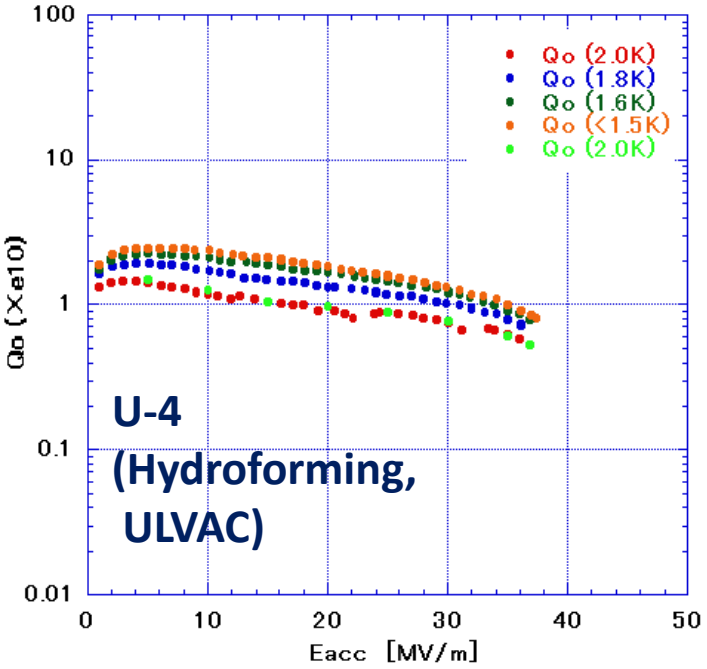
U-4: ULVAC seamless cavity

Surface is rough like orange peel skin.

- Inner surface of seamless cavities become very rough, compared with EBW cavities.
- How to get smooth inner surface? This is big issue for hydro-formed cavity.

Seamless cavity(4) – Vertical test



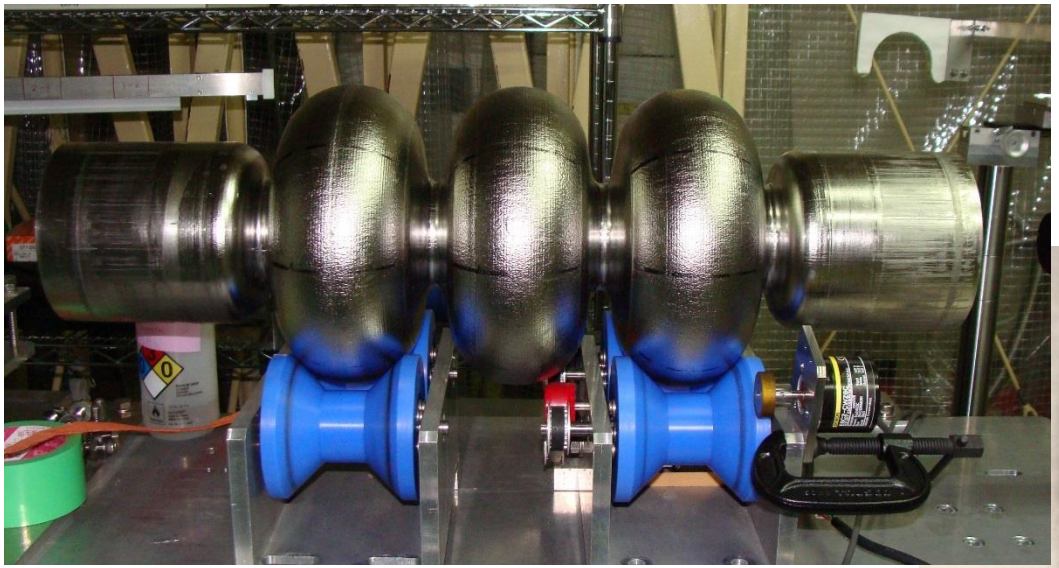


- Seamless cavities reached to more than 35MV/m.
- Relatively high-Q values were obtained for W-1 cavity . Is this due to mirror-finished barrel polishing?
- Field emission above 20MV/m for W-1 cavity come from poor welding part of beampipe.

Seamless cavity(5) – Trial for 3-cell cavities

Recent news

3-cell hydro-formed seamless cavity, from Wah Chang pipe, was successfully produced! Congratulation!



Summary

- We prepared several single-cell cavities to investigate effects of Nb materials; fine grain, large grain(high-RRR and low-RRR).
- Deformation around grain boundaries cause difficulty in LG cavity fabrication, e. g., unstable EBW bead, spattering and cracks around boundaries.
- Vertical test results are fine for both FG/LG cavities.
- Hydroforming of Nb seamless tubes was also tried.
- Several steps of hydro-forming and annealing are needed to avoid bursts.
- Seamless single-cell cavities were successfully fabricated, but the cavity inner surface is rough, leading to a heavy mechanical polishing. A room for improvement?
- After applying barrel polishing, seamless cavity(War-Chang) reached > 35MV/m.