Fabrication and Testing of ILC Cavities Produced from Seamless Nb Tubes

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LARGE SAMPLES

Rationale and Approach, for Seamless ILC 1.3 GHz SRF Cavities

Advantages of seamless tube cavity production

- No RRR degradation in the welding seam
- No pits associated with the HAZ
- No weld contamination
- Lower production costs in large production runs
- Less scatter in performance compared to welded cavities (in theory)

Historical Approaches for Seamless Niobium Tube:

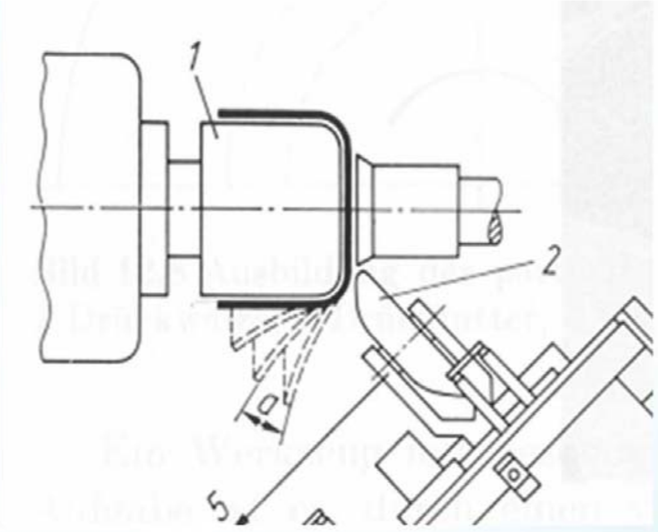
- Drawing or Spinning from sheet and flow forming (DESY)
    - Extrusions were not adequate due to large grain size
- Spinning directly to cavity shape (INFN)
- Heavily deformed and recrystallized *fine-grain* billet, Back extrusion, forward extrusion and flow-forming (BL/AWC)

INFN, DESY: Tube Making from sheet

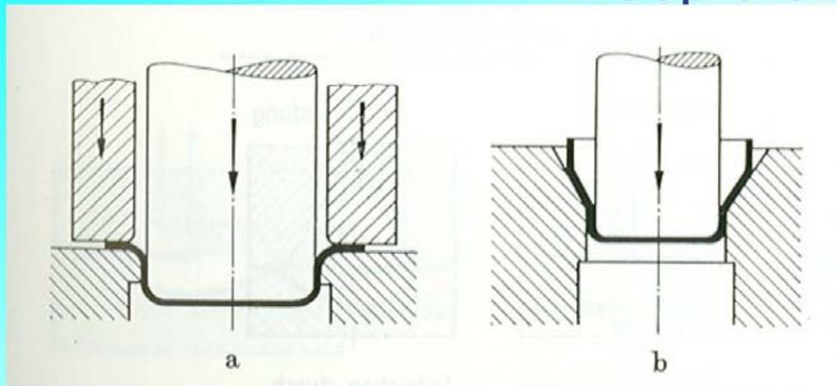
Successful fabrication of tube and hydroformed cavities

Tube is good for 3-cells

- Spinning



- Deep drawing



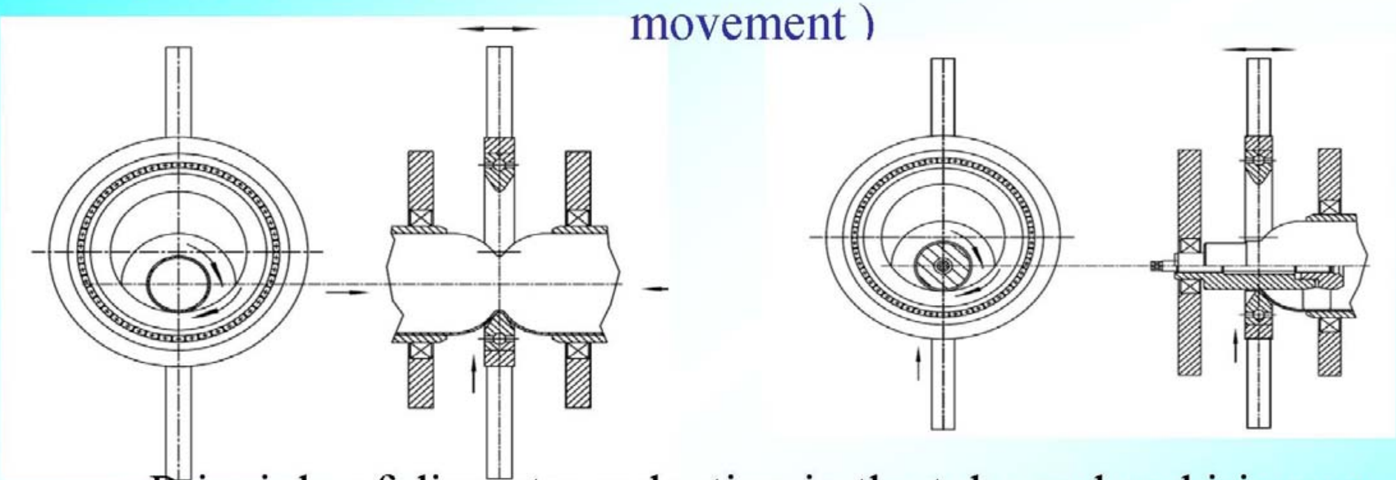
Principle of deep drawing; a-first step, b-second and further steps

Successful tube fabrication by collaboration of Fa. Bravo and INFN Legnaro

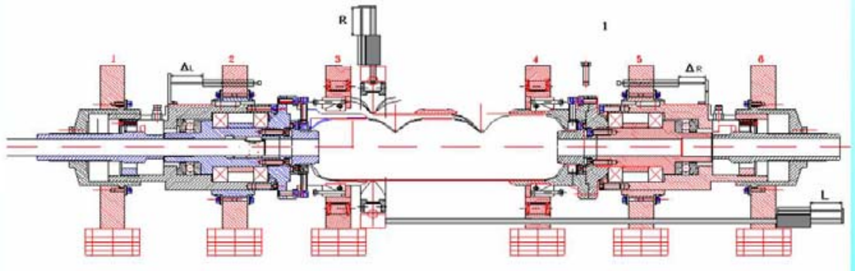
W. Singer, DESY

DESY: Necking by Profile Ring

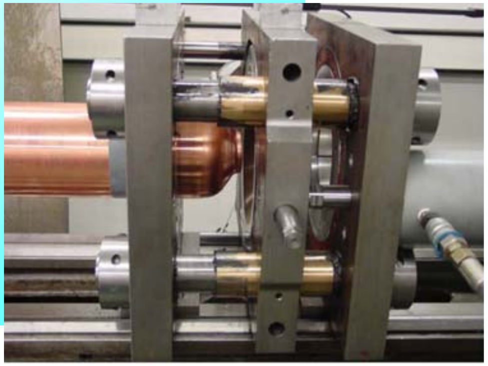
Improvement of the necking procedure and development of DESY necking equipment provided the success (combination of radial and axial movement)



Principle of diameter reduction in the tube end and iris area

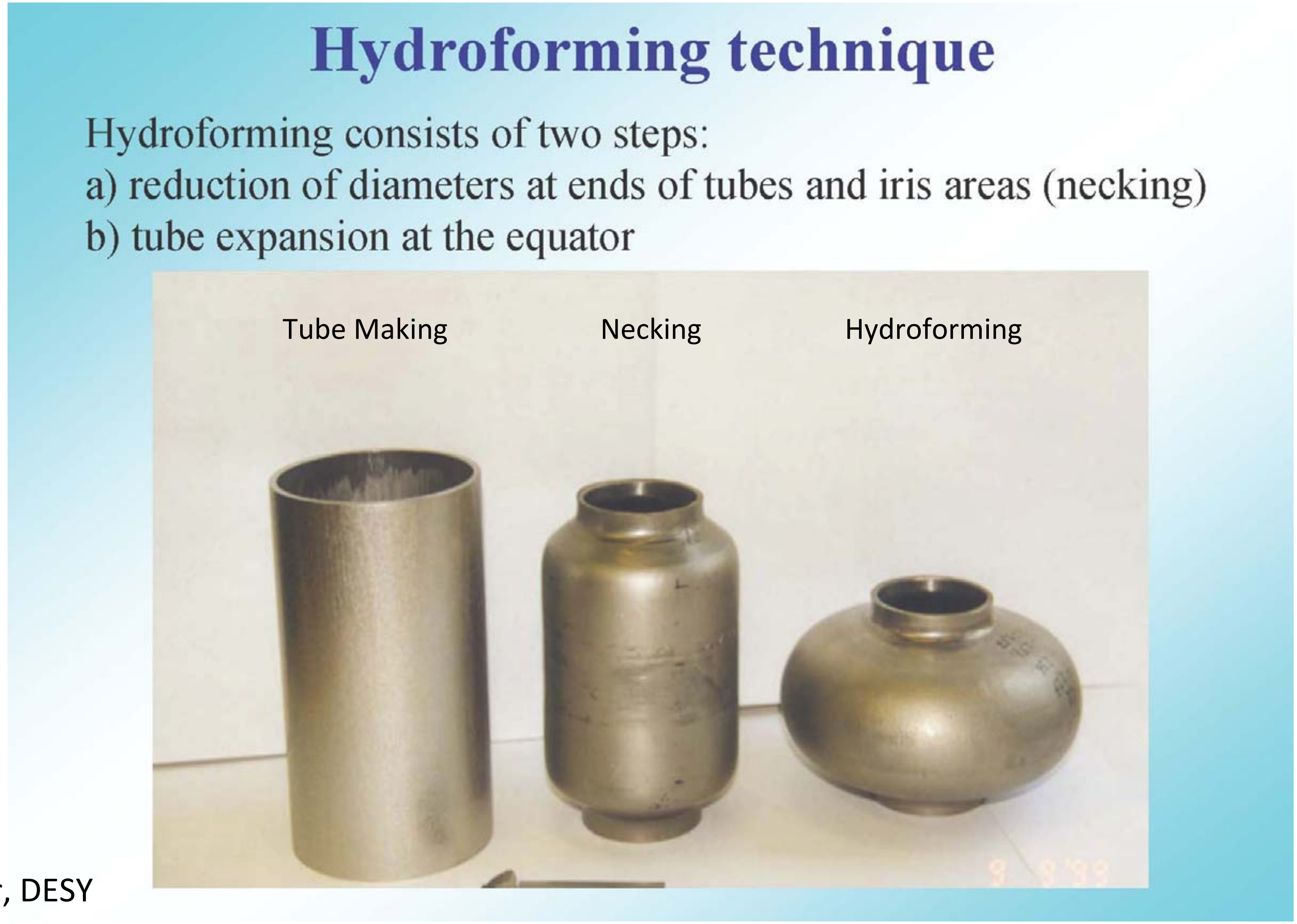


Principle of DESY necking equipment



W. Singer, DESY

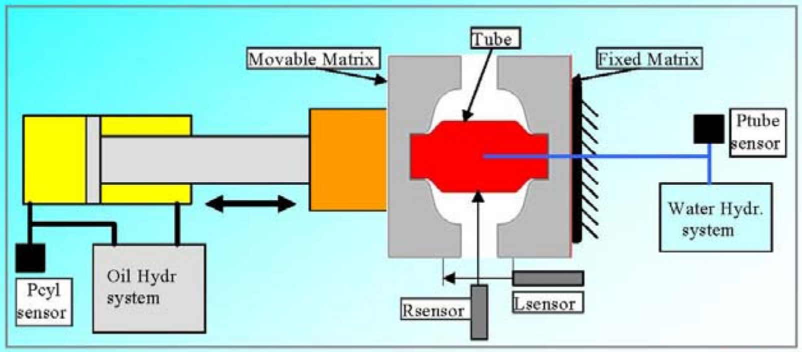
DESY: Hydroforming



W. Singer, DESY

DESY: Hydroforming

Principle of hydroforming



W. Singer, DESY

DESY hydroforming machine

- Designed and build in Russia (INR, Troitsk)
- Equipped with hydraulic systems and software at DESY
- From dimension is in position to produce only units of 3 cells

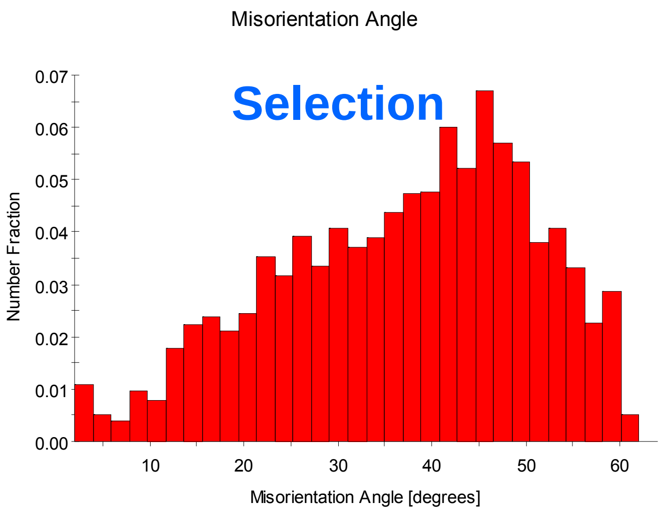
Method Used for this Program: Extruded Tube

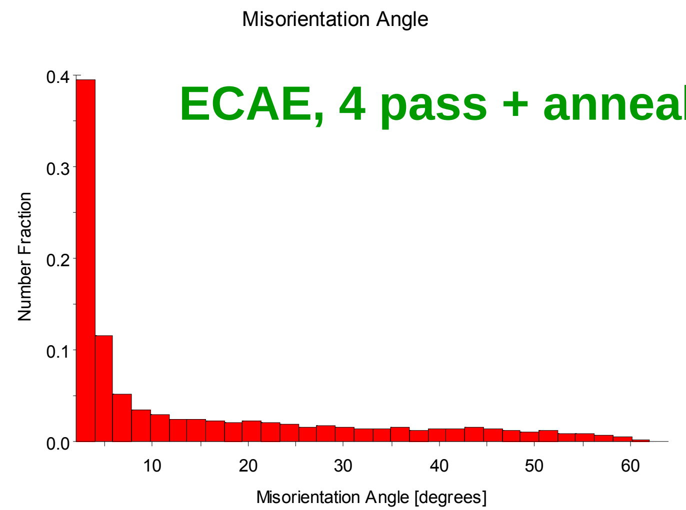
Advantages:

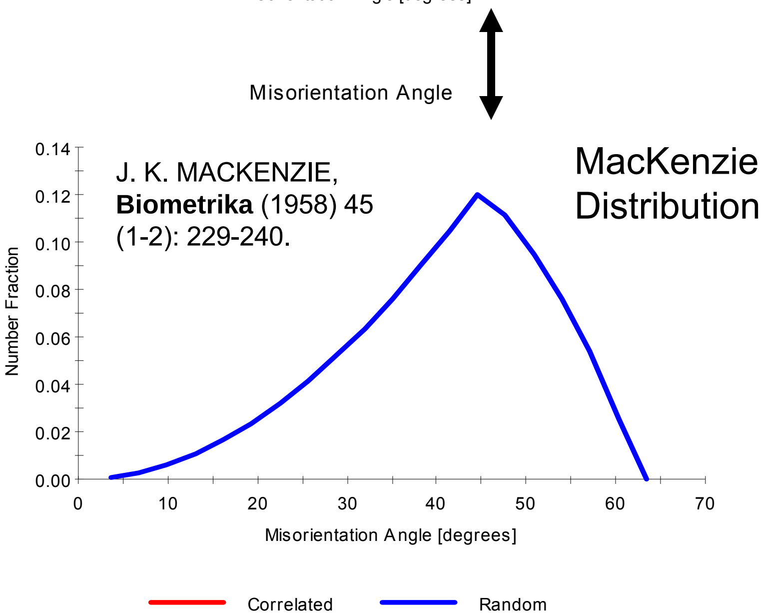
- The metal is exposed to steady-state conditions for most of the extrusion length.
- If a fine grained, randomly oriented starting microstructure is used, then the extrusion axisymmetric stress state should result in axisymmetric microstructure and properties.
- The initial concept, “Production of Seamless Superconducting Radio Frequency Cavities from Ultra-fine Grained Niobium” was intended to produce a microstructure with a grain size of between 100 and 1000 nm. *Luckily, that didn’t work.*
- A billet was produced with a grain size of 11 μm.

Experimental Billet Results

Two of the processes considered, and the resulting grain boundary misorientations, recrystallization fractions and grain sizes







Parameter	BL / AWC Selection	ECAE
Grain size, μm	11	15
ODF max.	7.3	19
% Rx	96	7.0
% lagb	7.8	64

Tube Making

- 6.5” billet, with fine grains and a random grain orientation was then processed to tube:
  - back extrusion
  - forward extrusion
  - flow forming
- Expected grain size to be maintained through subsequent processing.

Flow Forming

Dynamic Flowform - Flowforming - Reverse Flowforming

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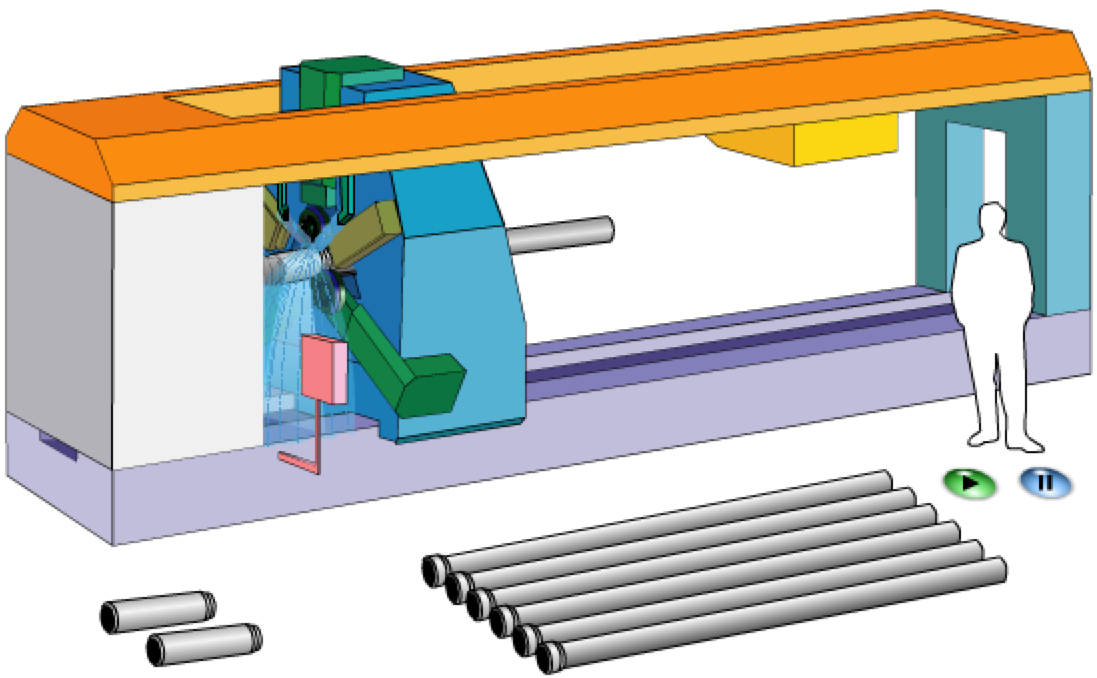
Methods – Reverse Flowforming



Reverse Flowforming is utilized to produce a component with two open (unrestricted) ends such as a tube. Once the preform is placed on the mandrel, it is pushed all the way to the left side against

Tubes

5 tubes ordered:

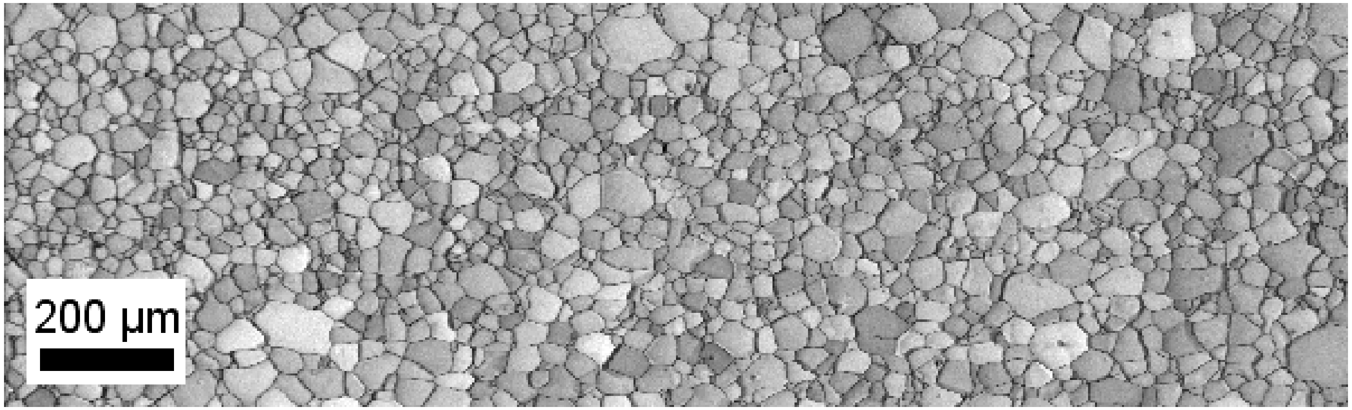
Two extrusions, B1 and B2

Final tube making step (flow forming) *experimental*

First tube of each extrusion used variable reduction

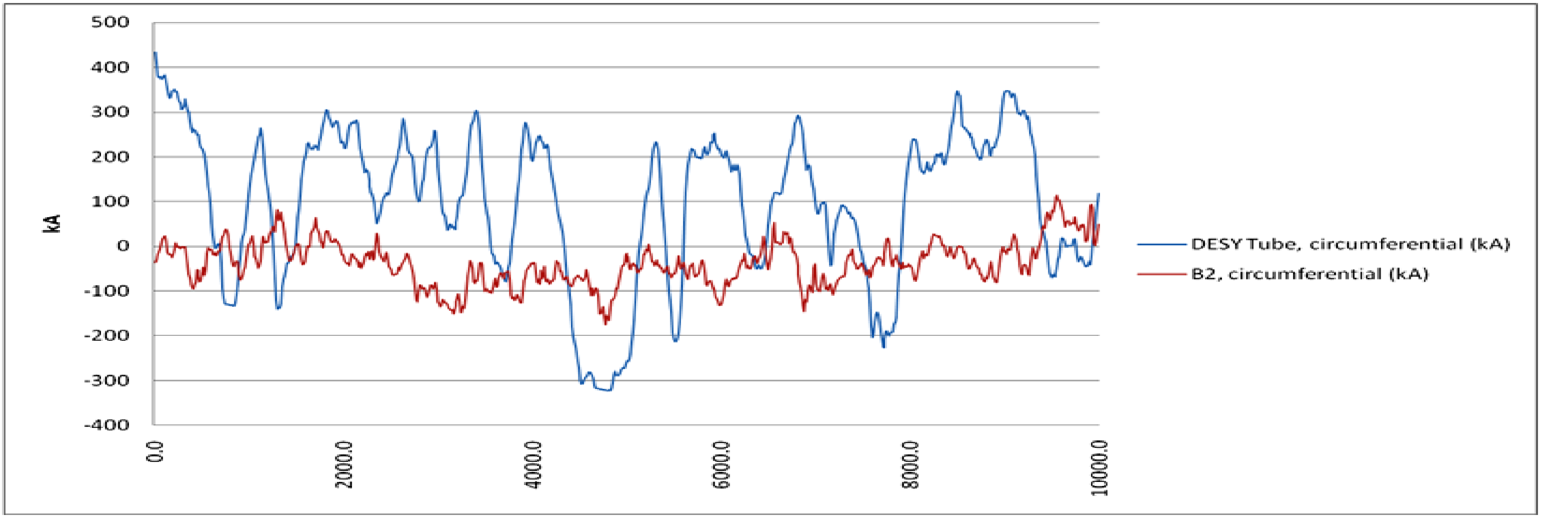
Tube microstructure

EBSD Image Quality Map



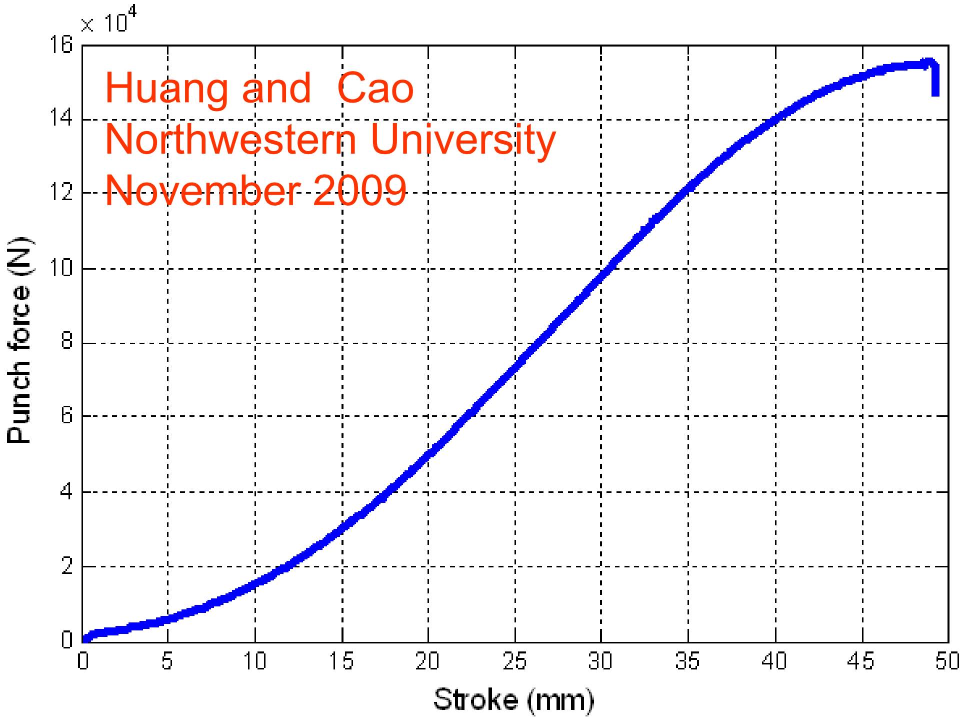
Tube or Sheet	Grain Size, µm, based on 10° boundary	ODF Maximum Intensity	% Rx
Sheet	25	14	92
DESY Extruded + flow-formed	50	33	75
Spun-from-Plate + flow-formed, large grain area	500	15	90
BL/AWC Extruded + flow-formed	**14**	**7**	**90**

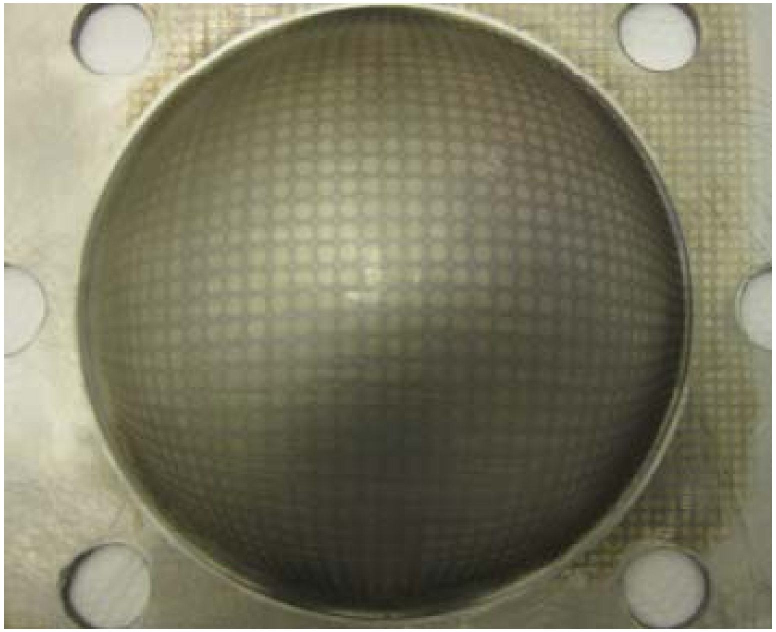
Surface Roughness
Why fine grain is better



Dektak Profilometer data for DESY coarse-grained tube (blue) and BL/AWC fine-grained tube (red); 1kA = 0.1mm; from tensile samples near fracture. Peak to peak for AWC/BLLC tube (25) μm; for DESY coarse-grained tube (75 μm) over a length of 1 mm.

Formability Test





Limiting dome height test from flattened tube. 100mm hemispherical dome, 5mm/min

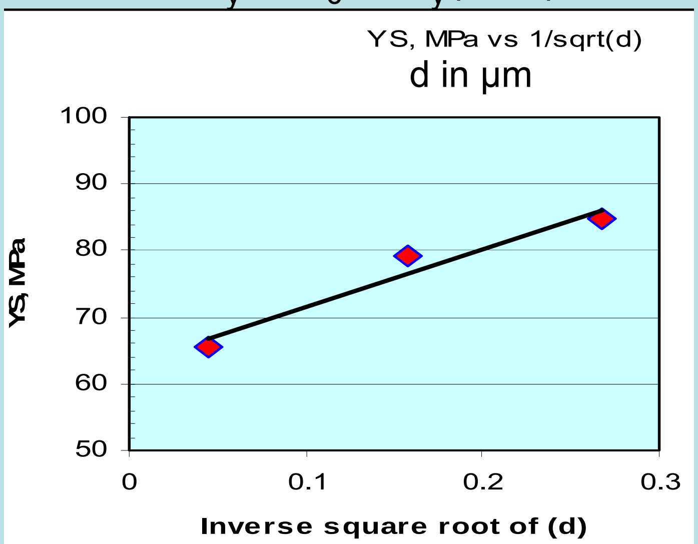
Grain size optimum?

Smoother surface vs. lower ductility

Nb

Hall-Petch Plot

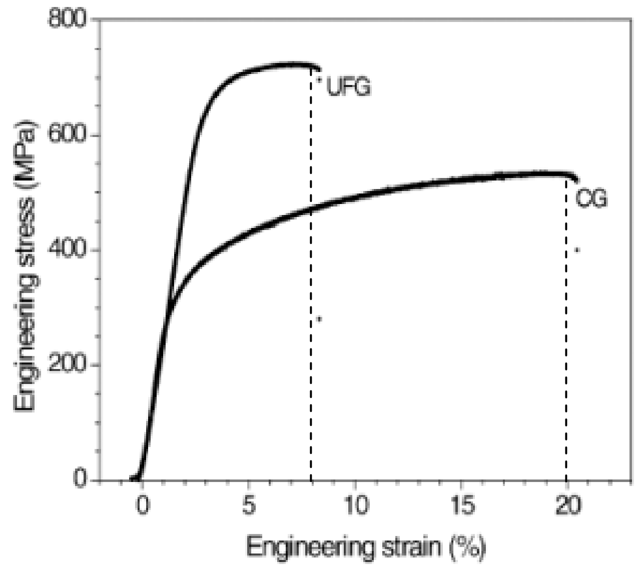
$\sigma_y = \sigma_0 + K_y(d^{-1/2})$



Coarse vs fine grain Nb tube
YS vs inverse sq rt grain size

for 100 nm, YS = 338 MPa

7075 Al

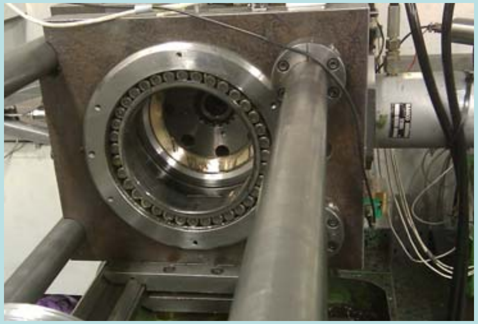


AA7075

Zhao et al Act mater; 52 (2004) 4859

BL/AWC Tube Forming at DESY

Spinning



Spinning of irises

Hydroforming

First Stage

Final Hydroforming Stage

Second Stage

BL/AWC/Fermi Hydroforming Results at DESY

Assembly of BL/AWC 9-cell (best 3)

Welded at JLab, stiffener rings
BCP, no leaks warm or cold

SRF Testing

Peter Kneisel

Jefferson Lab

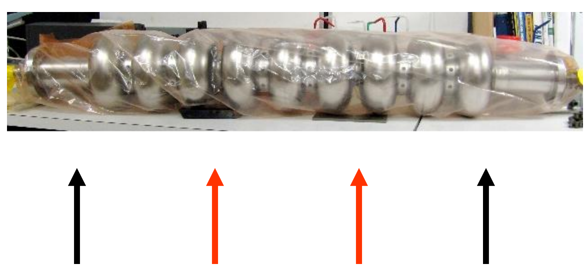
Testing has begun on:

- **the 3, 3-cell hydroformed cavities selected by Waldemar Singer for assembly**
- **a 2-cell piece made from surplus tube**

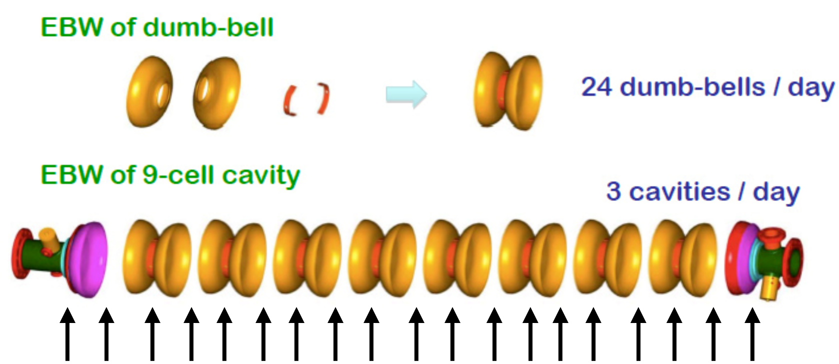
9-cell test results to-date

- Field emission limited, ~ 16 MV/m
- Problem with roughness of welds at two iris welds.

Welding of 3x3 hydroformed cells



Conventional welding of deep drawn cells

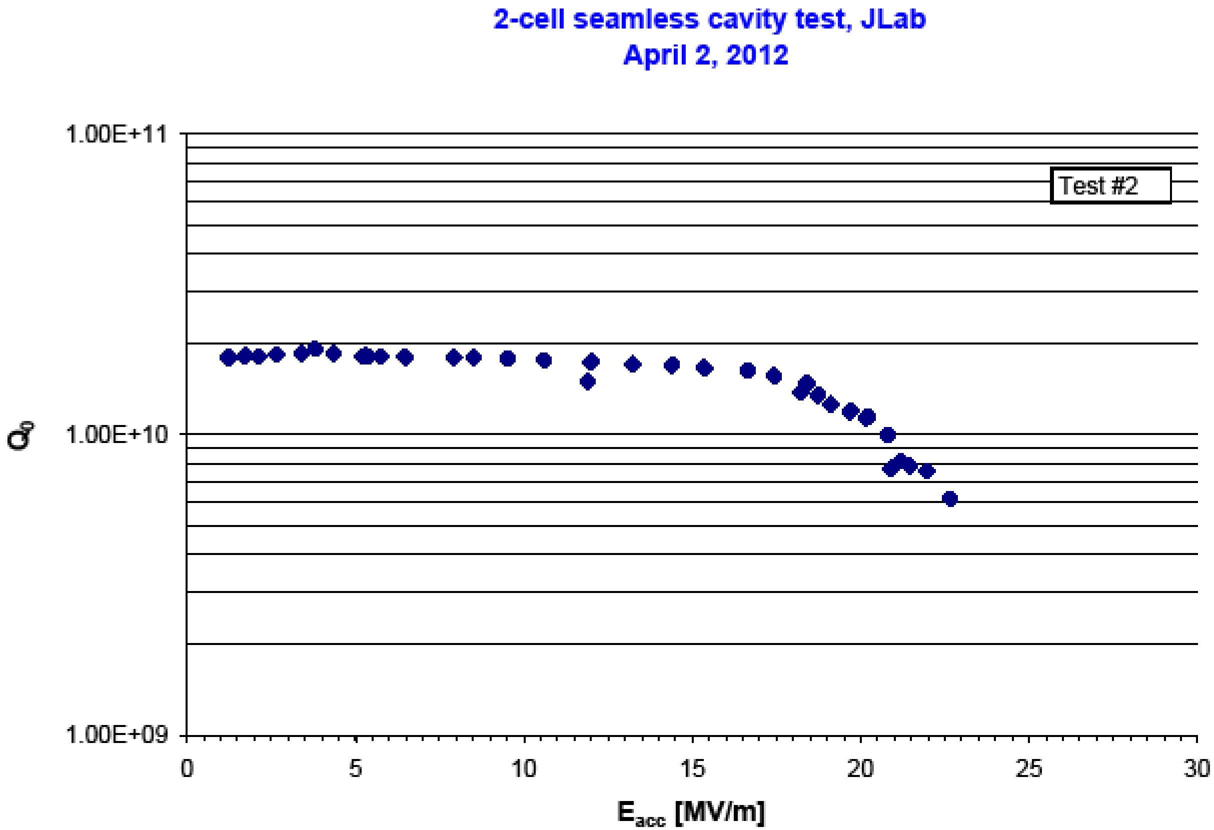


(From Fermilab webpage)

- Similar issue with DESY 3 x 3-cell, even though 3-cells tested at 34 – 36 MV/m
- Grinding and polishing will be used to modify

2-cell test

Welded at JLab



Prepped manually before JLab facility shutdown in Spring 2012
BP, HPR assembly in Class10 clean room
Did not quench at the highest gradient
Limited by Q-drop – will be barrel polished, (EP?) and retested

Conclusions

- Thermomechanical treatment of the RRR niobium billet allows tube making with extrusion processes
- Tube has been formed into ILC cavity shapes, but only in 3-cell sections, due to equipment limitations
- Problems with weld roughness at the 3 x 3-cell junctions have shown field emission and inhibited performance
- A 2-cell section without welds did not quench and was limited by Q-drop
- Smoothing of welds, and further processing and testing is proceeding