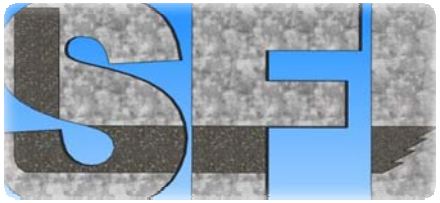

New Directions in Materials Engineering

"Fine-Grain Tube Fabrication via ECAE"

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(2) Texas A&M University, Mech. Engr. Dept., College Station, Texas, 77843-3123

Presentation at U.S. Hydroforming Workshop, Fermi National Accelerator Laboratory, Batavia, Illinois, September 1, 2010

Work sponsored by DOE SBIR program pending Grant 10SC004475

Shear Form, Inc.

- Mission:
  - To sell equipment for equal channel angular extrusion, ECAE process materials, and provide superior fine grain products for challenging applications.
- Staff
  - Dr. K. Ted Hartwig, P.E., President
  - Robert E. Barber, P.E., Vice President
  - Technical Staff
    - Doug Krebs
    - David Foley
    - Nathan Miller

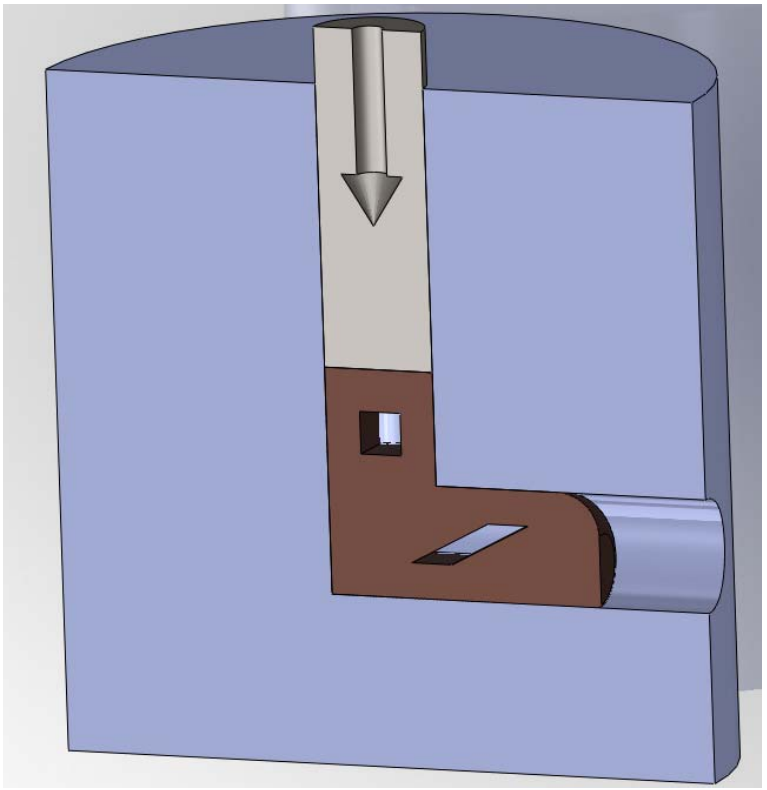
SFI History and Capabilities

- Established 2003
- SBIRs (8 Ph I, 2 Ph II)
- Commercial (9 Projects)
- Collaborations (Wyman-Gordon, HCST, OST, etc.)
- Press, ECAE Tooling (square, round, plate, and tube (R&D))
- Tooling Scale up (R&D)

376 Ton, 40” stroke, instrumented hydraulic press

ECAE Description

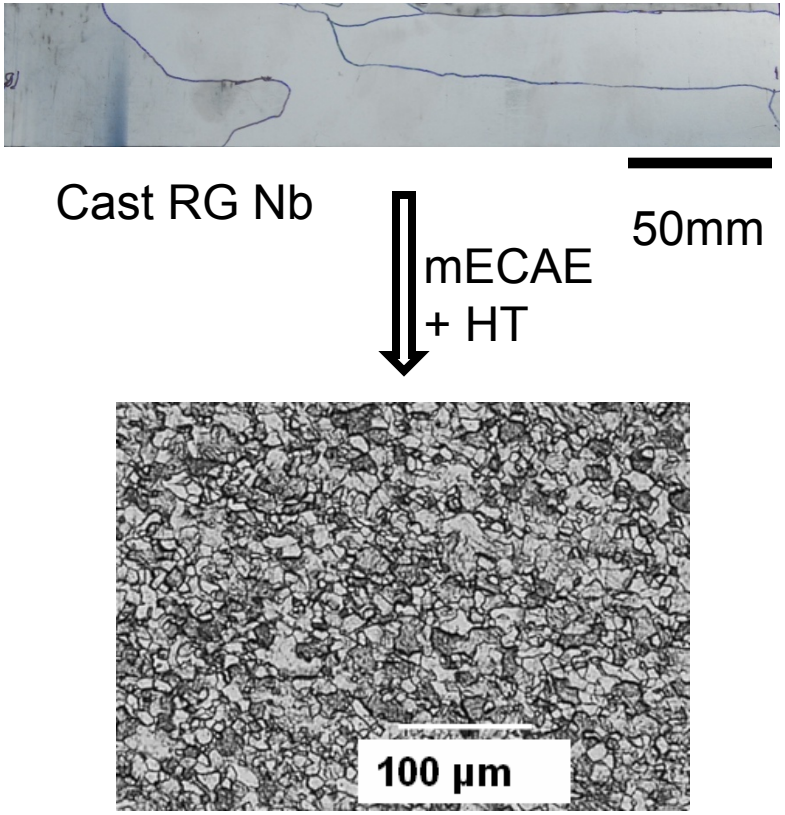
- Concept
  - Intersecting channels
  - Simple Shear Deformation
- Results
  - Uniform Deformation
  - Grain refinement
- Benefits
  - Fine grains
  - Uniformity
  - Some texture control



Opportunity to Improve Nb Tube Hydroformability

ECAE improves Nb microstructure in solid bars and sheet. Why not in Nb tubes?

- Microstructure Improvement
  - Long range and through thickness uniformity
  - Small grain size
  - Some texture control
- Less Expensive SRF Cavity manufacture?



(Pending) SBIR Phase I Project

- "Fine grain Nb Tube for SRF Cavities"
- Proof of Concept Experiments
  - 25-50 mm diameter tube
  - ECAE RRR Nb
  - Material characterizations
- Expectations
  - Control over microstructure
  - Improved mechanical properties
  - Technically feasible and scalable (Phase II)

Hydroforming Material Requirements

- **Desired characteristics of materials for hydroforming**
- **(From "Hydroforming for Advanced Manufacturing", Ch1, Introduction to the state of the art of hydroforming, Ed M.Koc)**

- High and uniform elongation
- High strain hardening exponent (n)
- Low anisotropy (Anisotropy coefficient R)
- Good surface quality.
- Close dimensional tolerances (thickness, diameter etc)
- Burr free edges.

$$\sigma = K\varepsilon^{n} \qquad R = \frac{\ln(\frac{w_o}{w_f})}{\ln(\frac{t_o}{t_f})}$$

For an assessment of tube formability

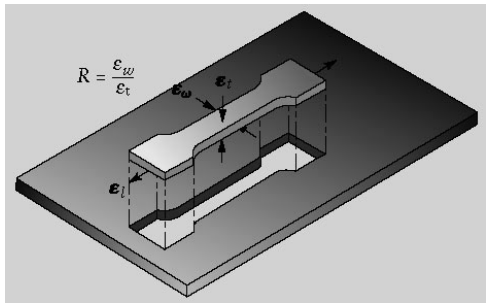
(From "Hydroforming for Advanced Manufacturing", Ch6, Design and modeling of parts, process and tooling in hydroforming)

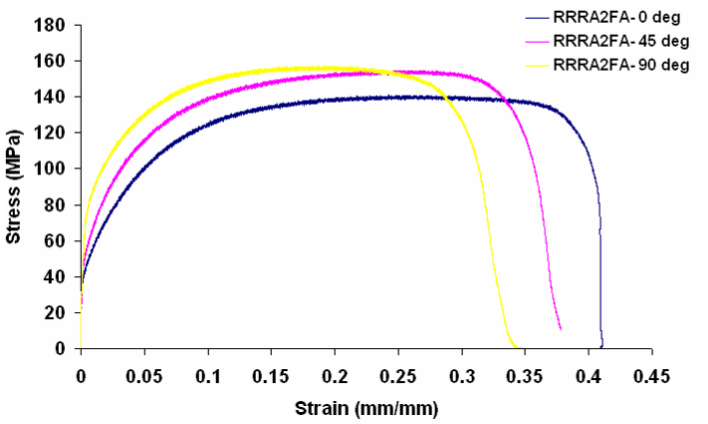
Formability	Poor	Average	Good
n	<0.14	0.14-0.2	>0.2
R	<<1	~1	>>1

Uniformity of strain distribution improves with increase in n value.
Uniformity in thickness distribution improves with R value.

Materials Testing for Formability

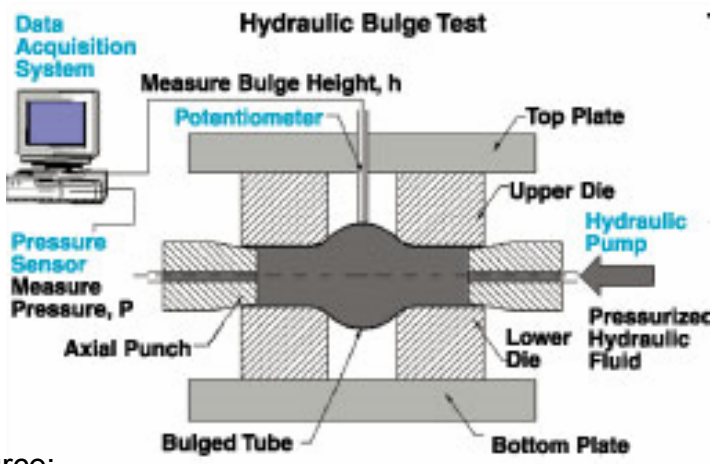
Tensile



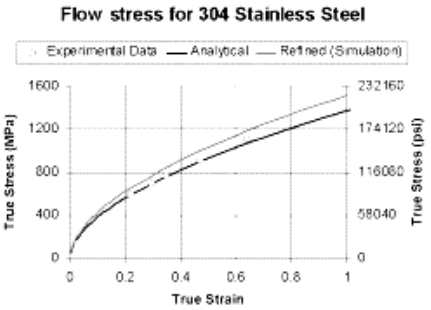


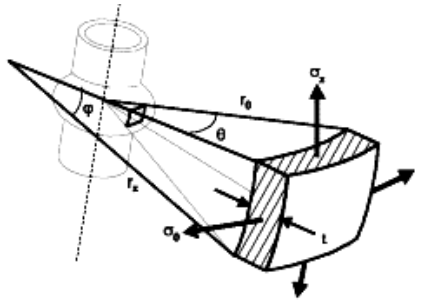
$$\bar{R} = \frac{R_o + 2R_{45} + R_{90}}{4}$$

Bulge



Source:
http://nsmwww.eng.ohiostate.edu/R_D_Update_Bulge_Test
Ohio State University, ERC,NSM Center.

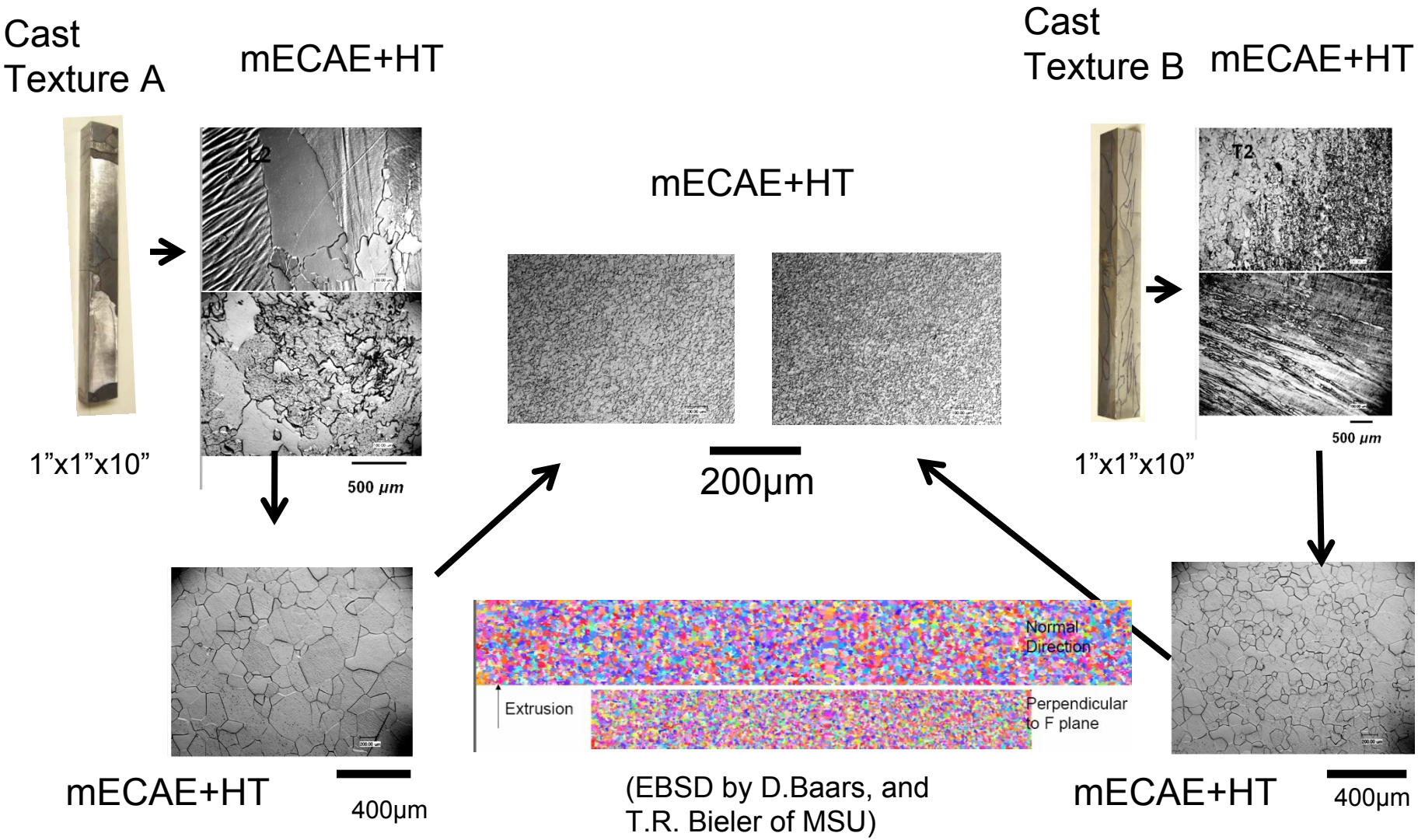




Source:Koc, M. and Altan, T. " An overall review of the Tube Hydroforming Technology," J.M.P.T., 108(2001), p. 384.

Nb Microstructural Refinement

(and convergence to long range uniformity)

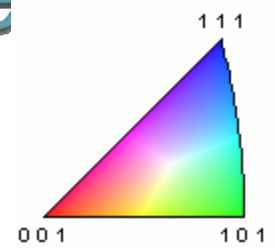


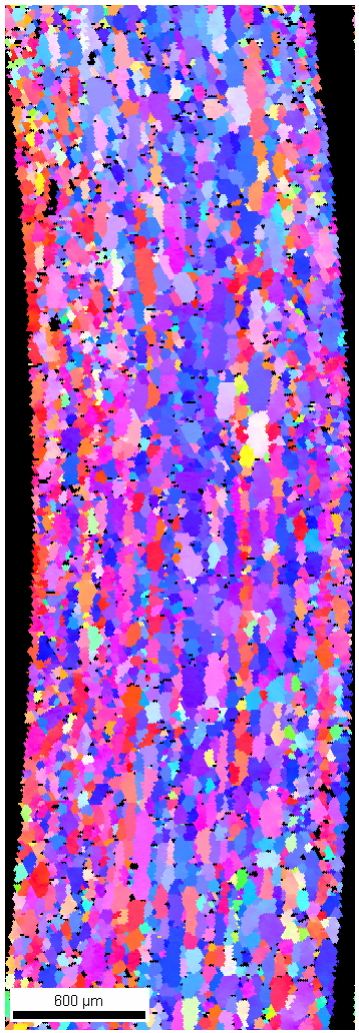
Microstructure in RRR Nb Tube

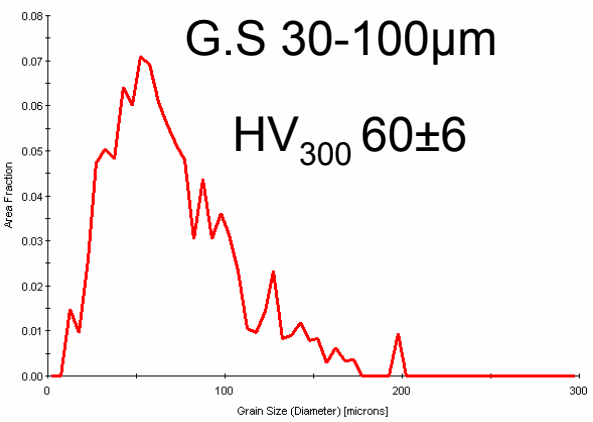
Tube cross-section (microstructure of rolled sheet material)

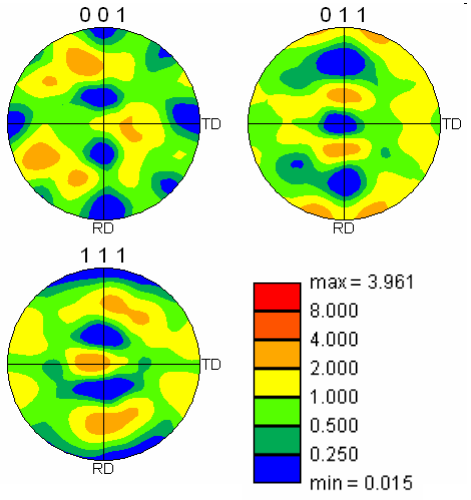
(EBSD by D.Baars, and T.R. Bieler of MSU)

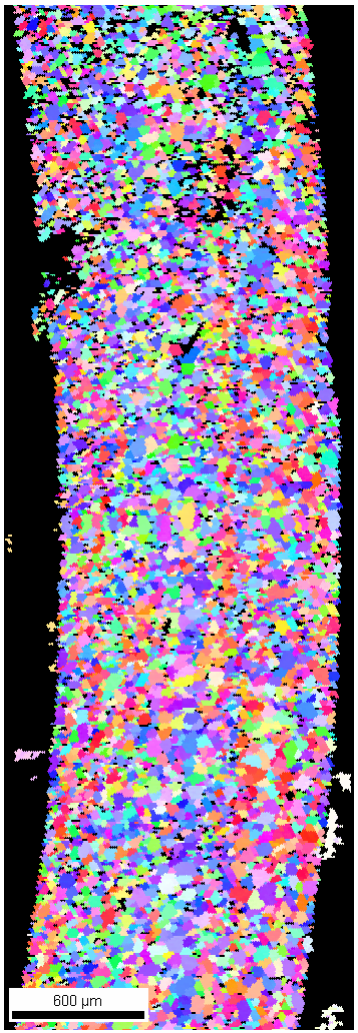
Tube microstructure from ECAE processed tube.(4E+HT 800^{o} C)

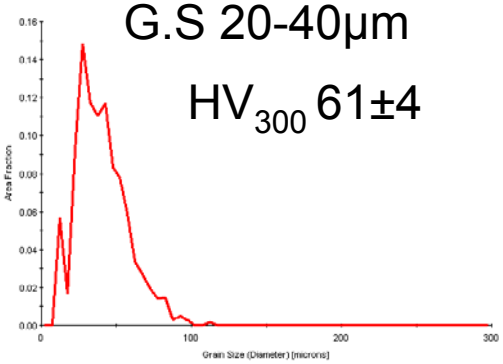


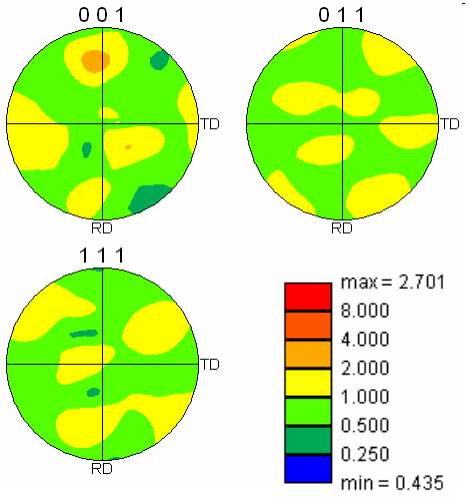






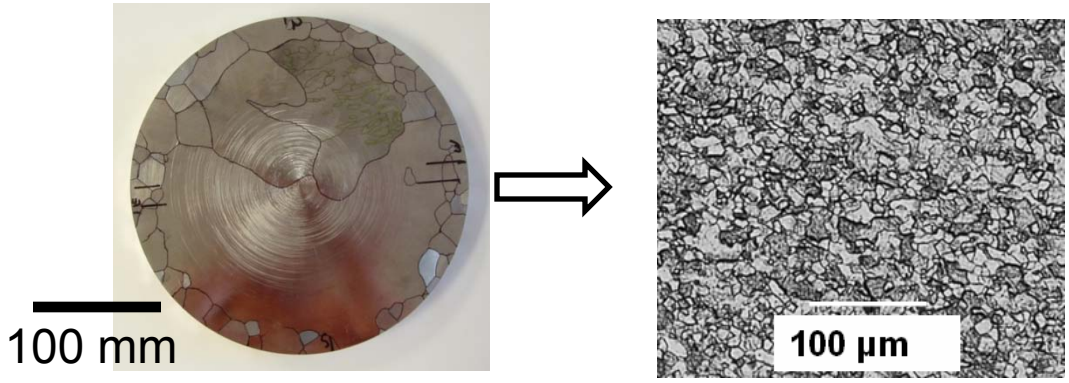




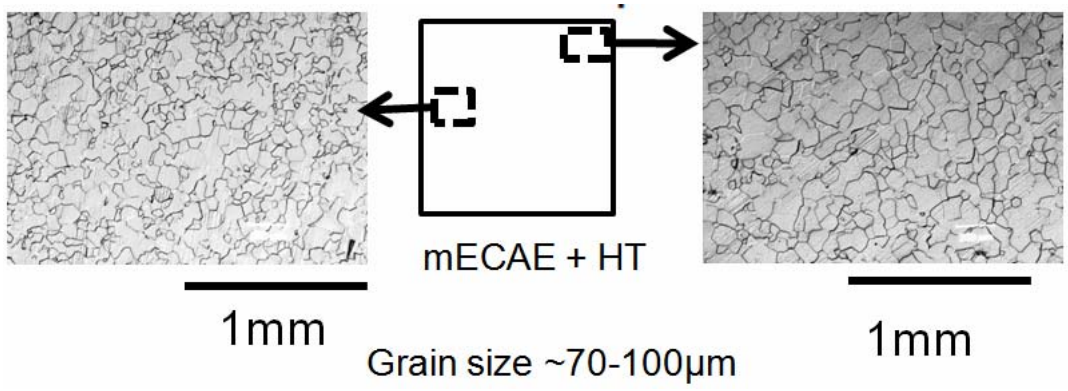


Microstructure Engineering by ECAE

Nb Grain Refinement

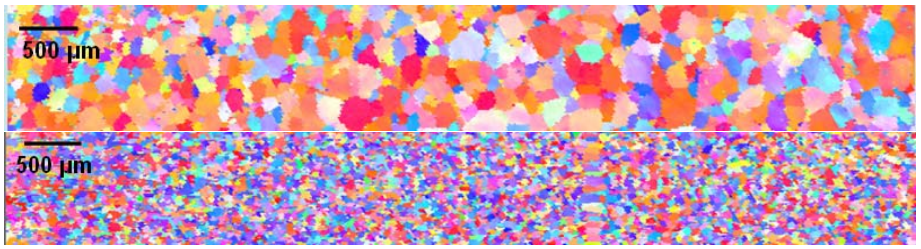


Long Range Uniformity



Texture Options

(EBSD by D.Baars, and T.R. Bieler of MSU)



RRR Nb Tube Microstructure Possibilities via ECAE

Characteristic	Outcome
Grain Refinement	20-50 μm
Texture Alternatives	Weak to moderate Several variations
Long Range Uniform Microstructure	millimeters to meters

Schedule and Challenges

SFI Objective for USHW Challenge

To fabricate several full-scale RRR Nb tubes with a uniform, fine-grain, and well textured microstructure by Summer 2012, suitable for hydroforming into SRF cavity strings, by a method that holds promise for commercial production.

Phase	Challenge	Completion
Lab Scale Test (Ph I)	Tooling Improved Hydroformability	Spring 2010
Prototype Tube (Ph II)	Tooling Manufacture Press Full Scale Hydroforming	Winter 2011 Summer 2012 Summer 2012
Commercialization (Ph III)	Make product for sale	≤ 3 years

Questions?

Thanks for your time…