Springback, Formability and Stress in Niobium SRF Cavities

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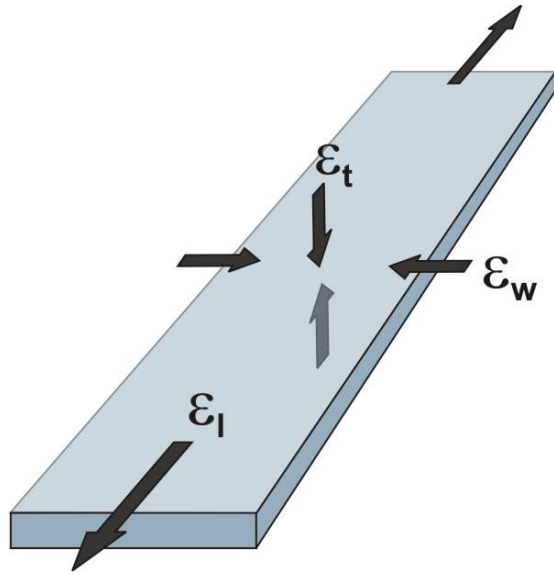
Formability

- Capacity to accumulate high levels of bi-axial strains

Potential Problems with SCs:

- Anisotropy of the r-factor (resistance to thinning) ,Yield stress
- Anisotropic strain hardening
- Variations for a given cavity AND between cavities made from differently oriented SCs.
- grain boundaries
- insufficient strength



Springback

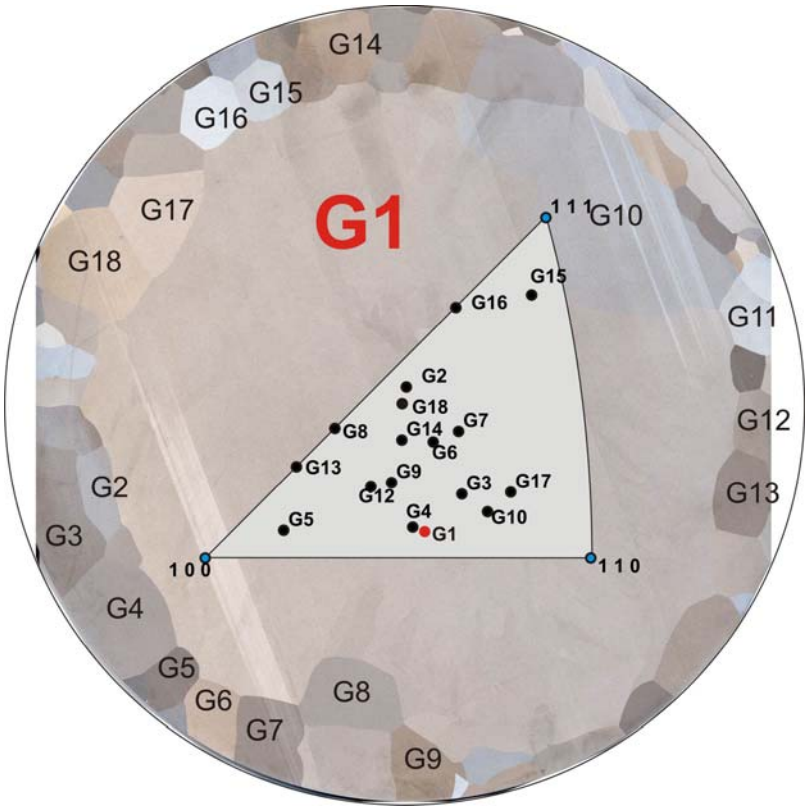
- The shape change of the cavity after releasing the stamping tool.
  - Depends on:
    - Residual Stresses from stamping
    - Thickness
    - Elastic Modulus
    - Shape of the Part
- By itself and for a uniform material, springback is not a problem and it is compensated for by a redesign of the stamping tool. The open question is how the orientation of the SC affects springback.

Springback in the cup/slit ring test

Residual Stress from Forming

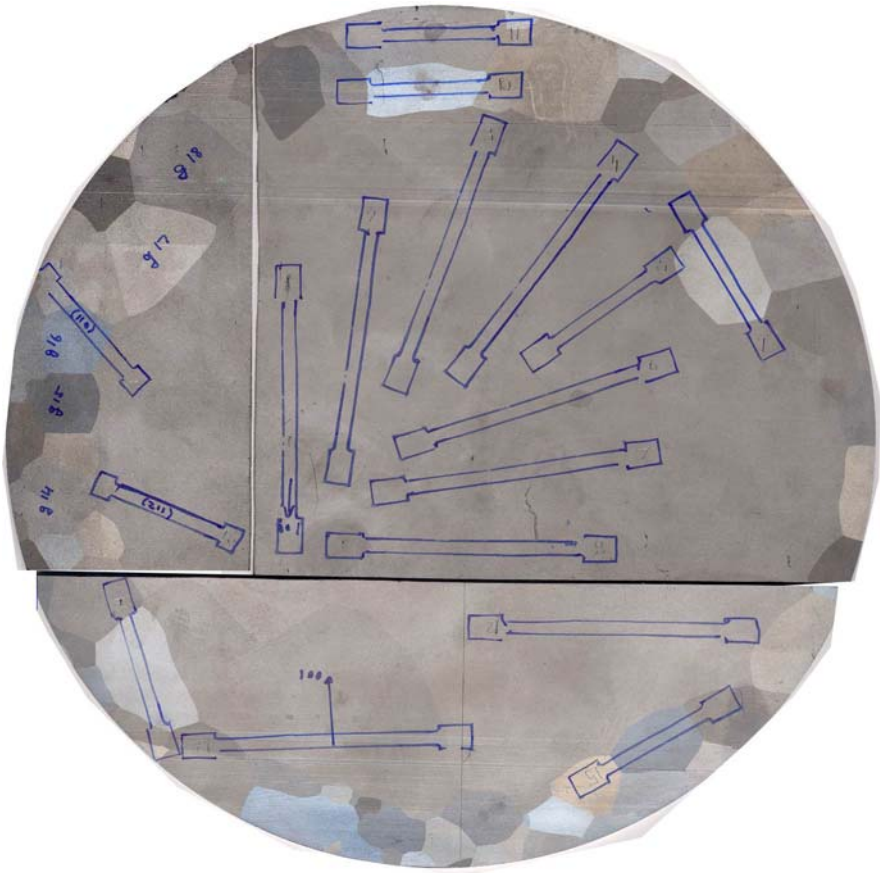
- Originate from bending/unbending processes during forming
- Potential for out-of-spec shape distortion of the cavity depending on orientation
- For a given cavity geometry, stresses depend on:
  - Yield stress, accumulated strain, hardening exponent, orientation of SC

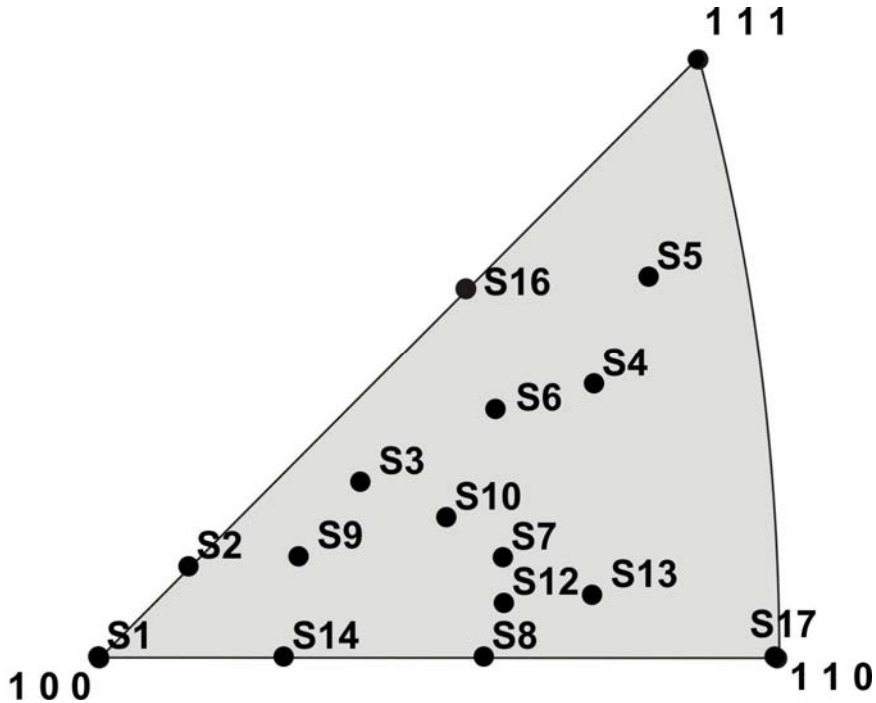
Formability: SC Orientations



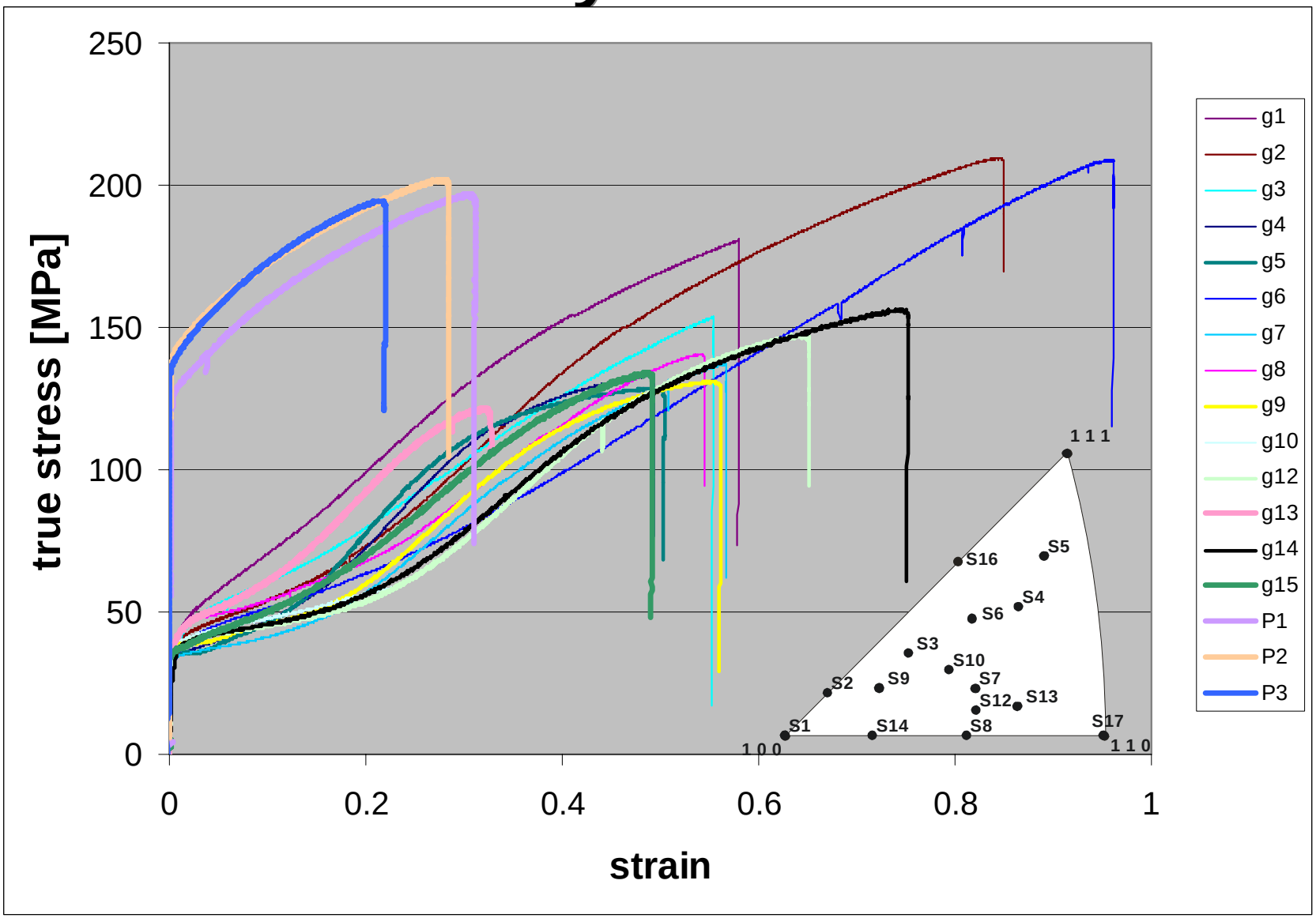
- Measured by X-ray diffraction
- Distribution of grain orientations appears to be random with no SAGB found
- Consequences of wide range of orientations:
  - Strain localization at grain boundaries
  - Potential for out-of-spec local thinning

Formability: Tensile Tests
Orientations

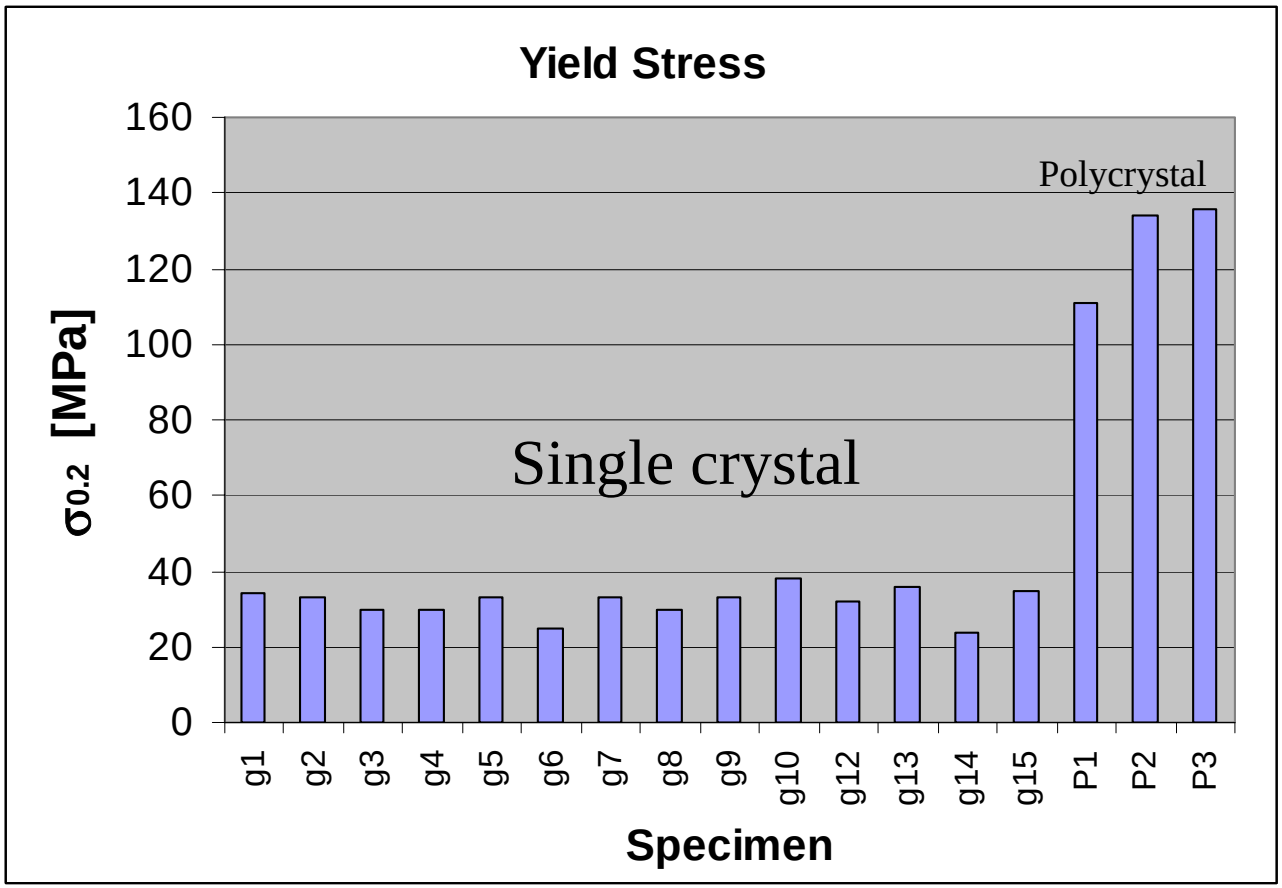




Formability: Tensile Tests

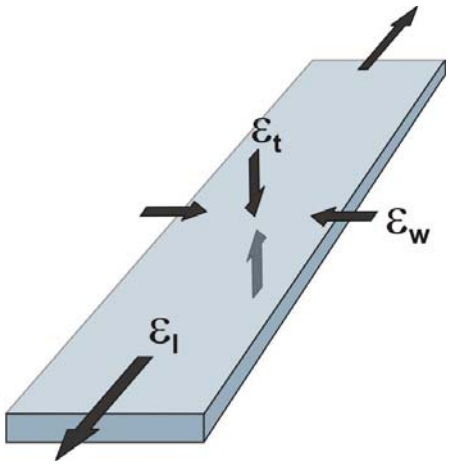


Formability: Yield Stress

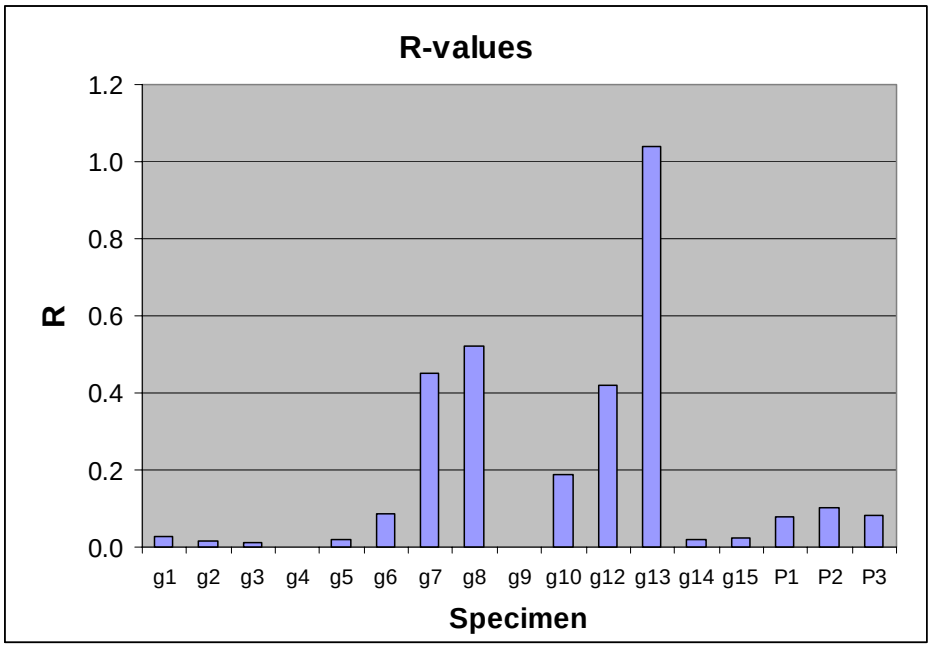


- YS between 25 MPa and 40 MPa
- weak anisotropy
- 25% YS of poly-crystal

Formability: R-Values

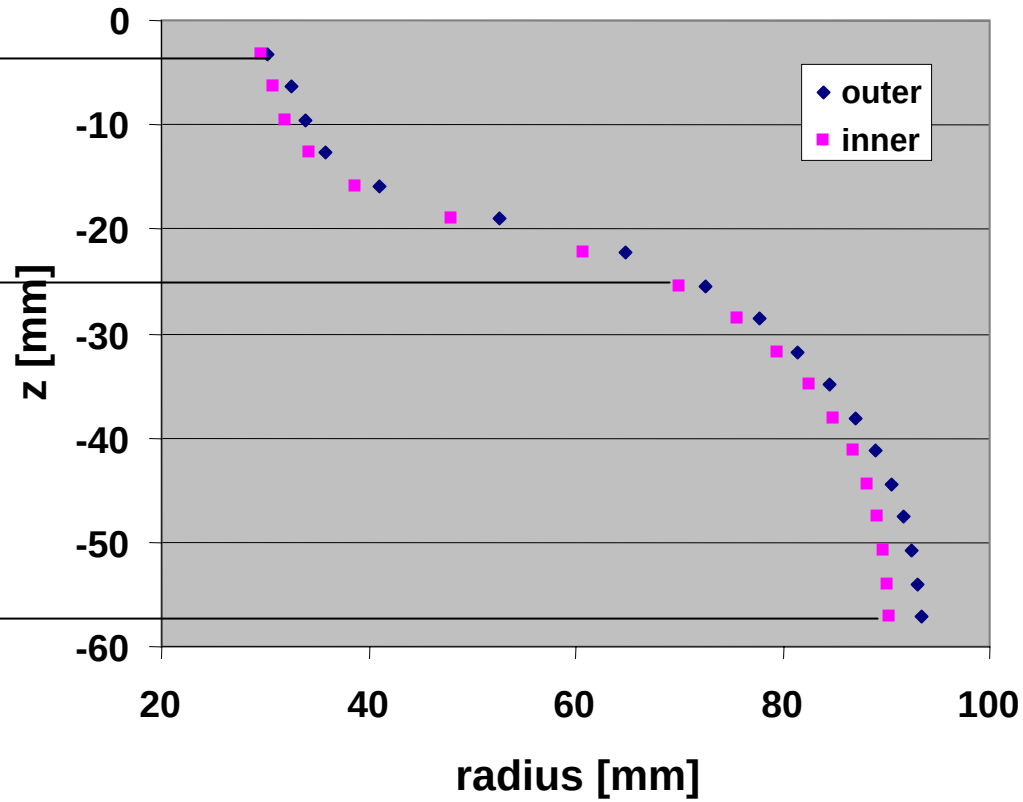


$$R = \frac{\varepsilon_w}{\varepsilon_t}$$



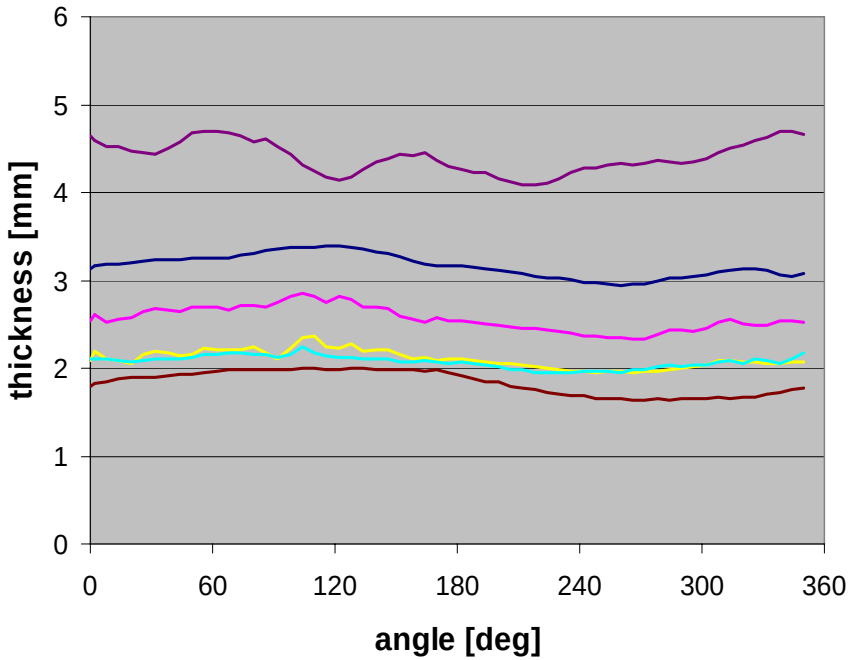
- Extreme anisotropy from r=0 (thinning only) to r>1 (no thinning)
- Polycrystal r=0.1
- Large r-values for {210}<-120>

Dimensional Analysis by CMM

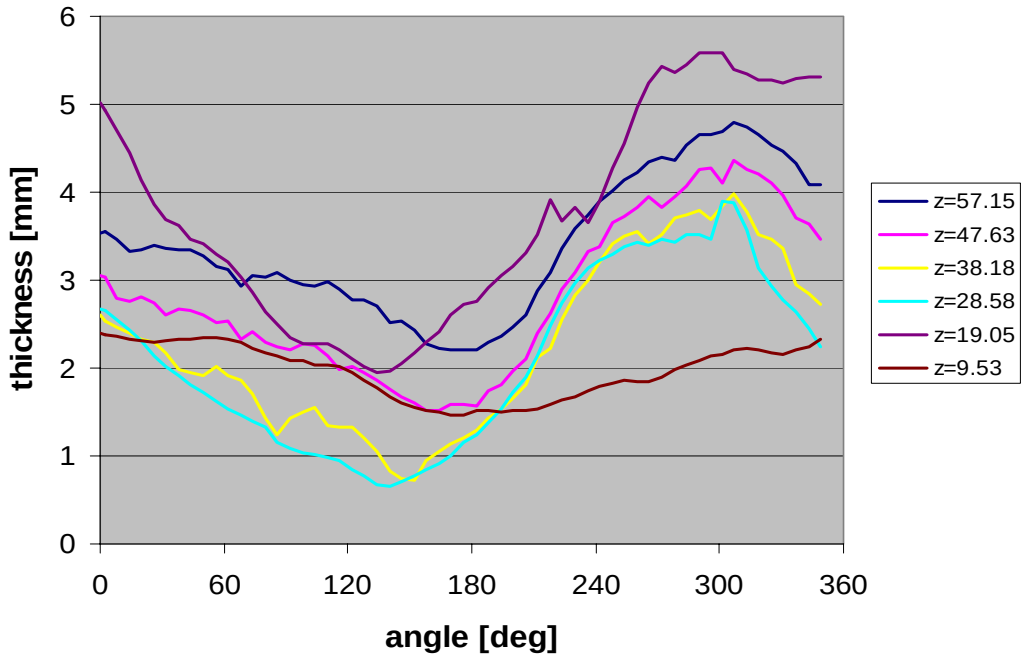


Forming: thickness variations

polycrystal cavity



single crystal cavity

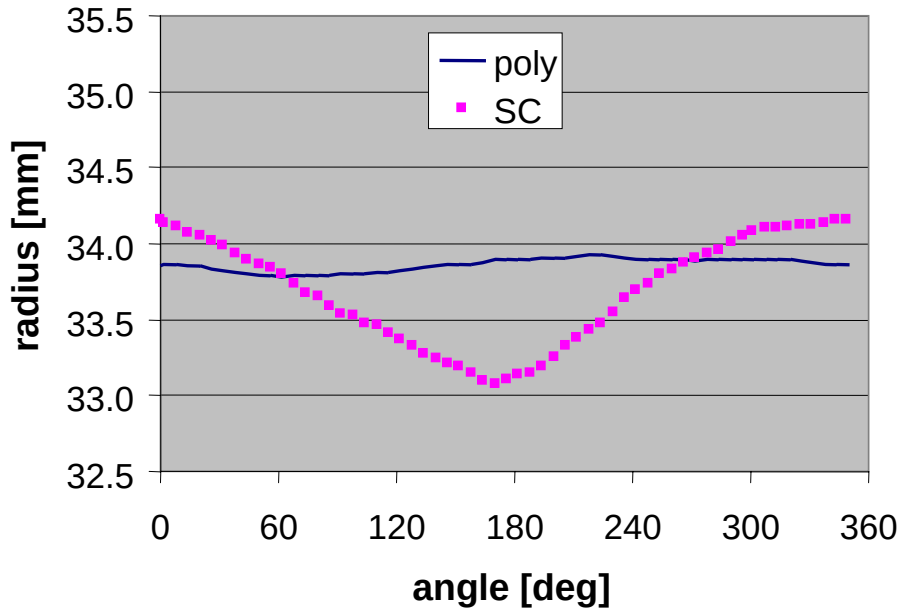


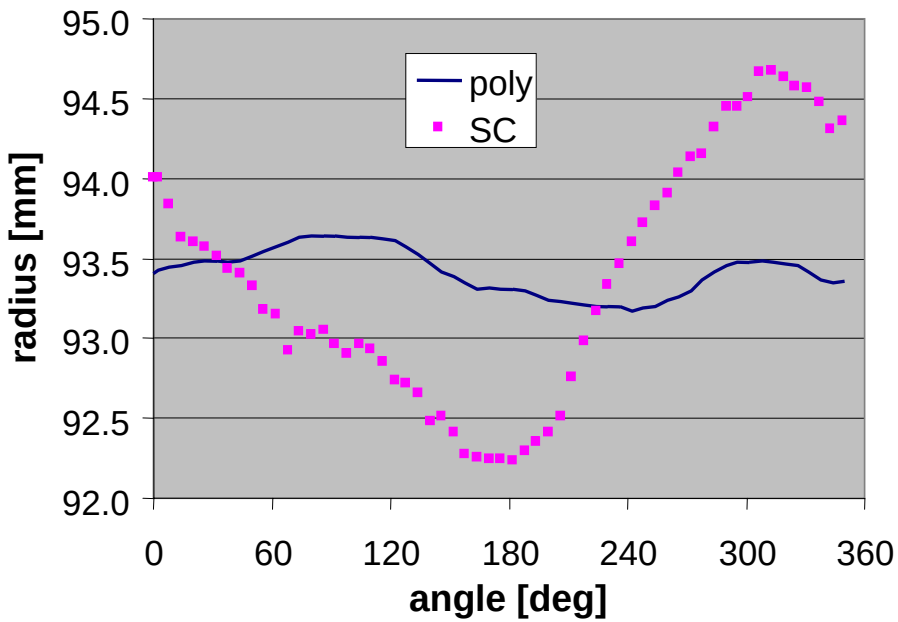
Standard deviation of thickness

0.06 mm ….0.22 mm

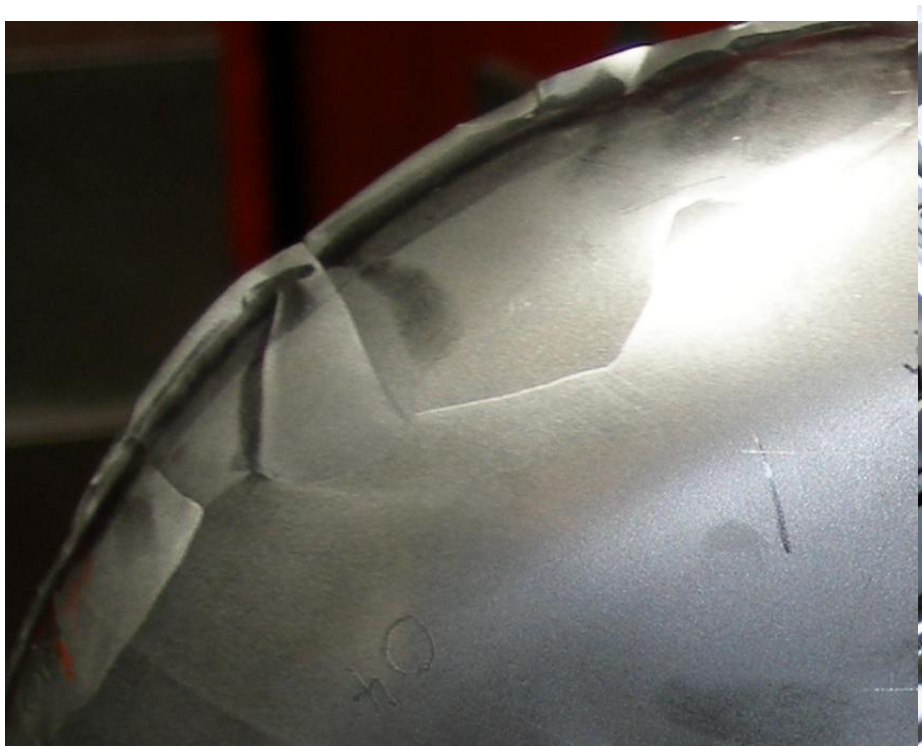
0.3 mm ….. 1.23 mm

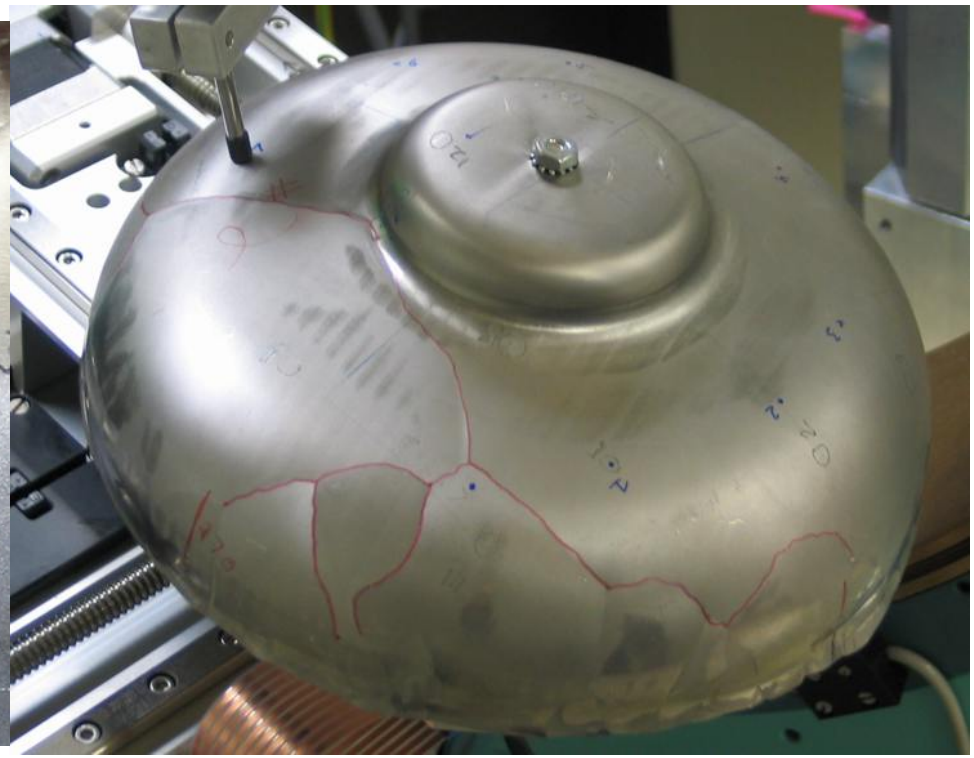
Formability: Roundness





Formability: strain localization on grain boundaries





up to 0.5 mm displacement found between neighboring grains

Formability: Conclusions

- Large strain reserve for SCs
- most orientations will stay in easy glide region (stage I) -> lower hardening than polycrystal
- High potential for local thinning and shape deviations due to highly anisotropic r-values
- strain localizations on grain boundaries
- low yield stress, moderate anisotropy in yield and hardening give low potential for tearing
- Increased scatter in roundness and thickness compared to polycrystal
- Disclaimer: limited scope of uniaxial tensile tests

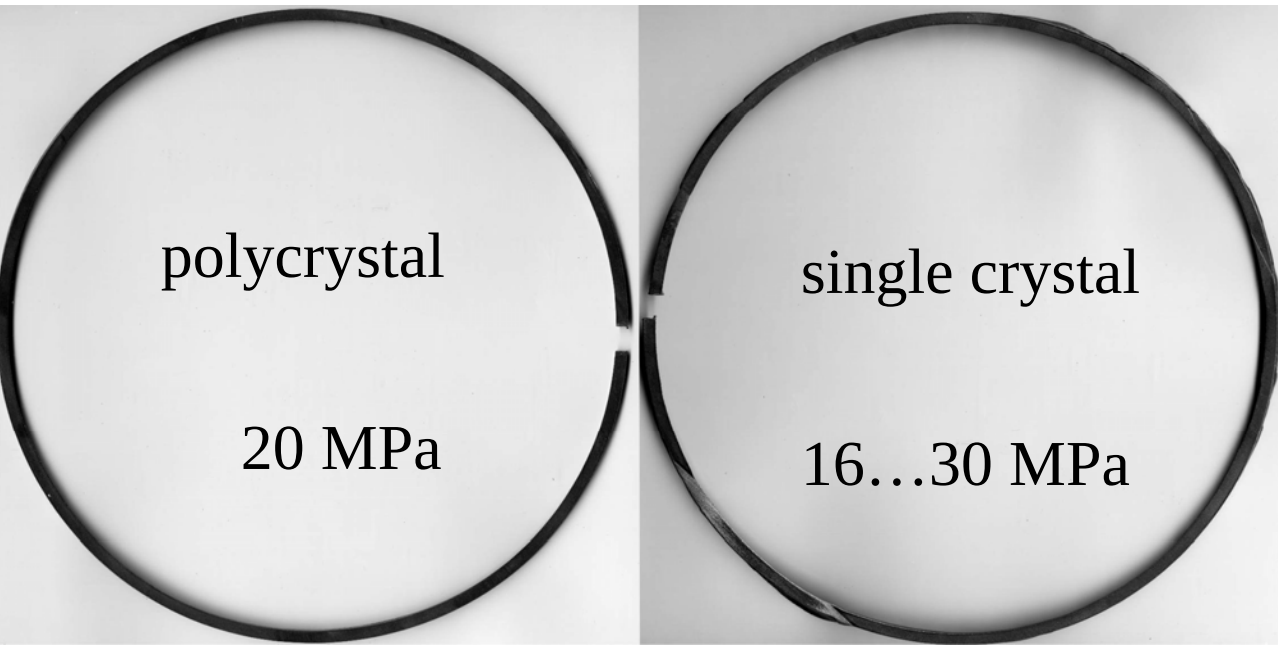
Residual Stress : Properties of Nb

T [K]	E_{poly}	E_{100}	E_{110}	E_{111}
300	105	152	92	82
4.2	112	161	99	88

- large modulus effect
  - E_{Nb} ½ E_{steel}, stress produces large deflections
- small temperature effect
  - stresses at 4 K nearly unchanged to RT
- moderate elastic anisotropy

Springback: Split Ring Test for Hoop Stresses

stress change calculated from elastic ring opening:



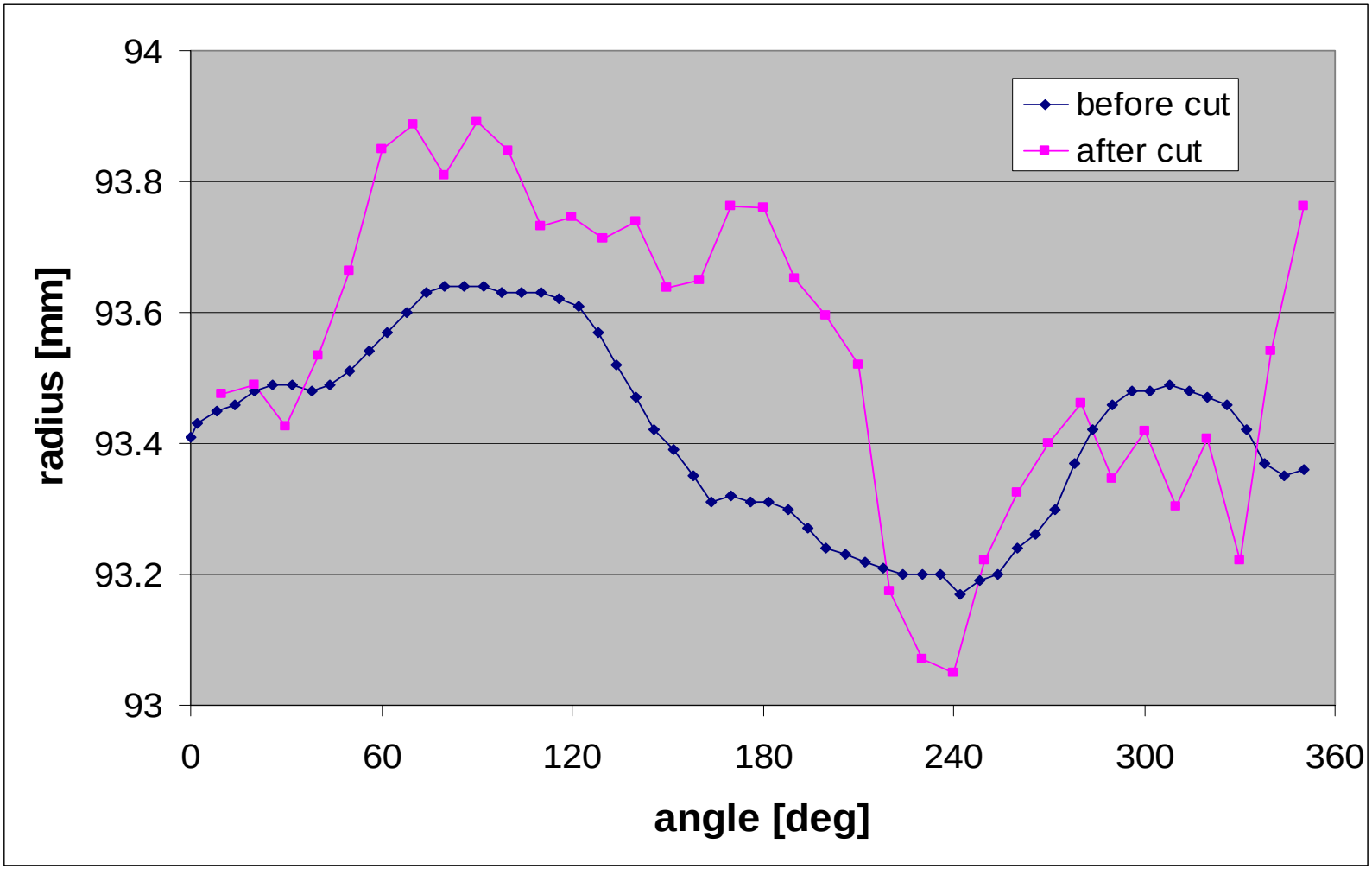
estimated stress change 1/10 UTS

similarly low stress levels are to be expected in this region of the cavity

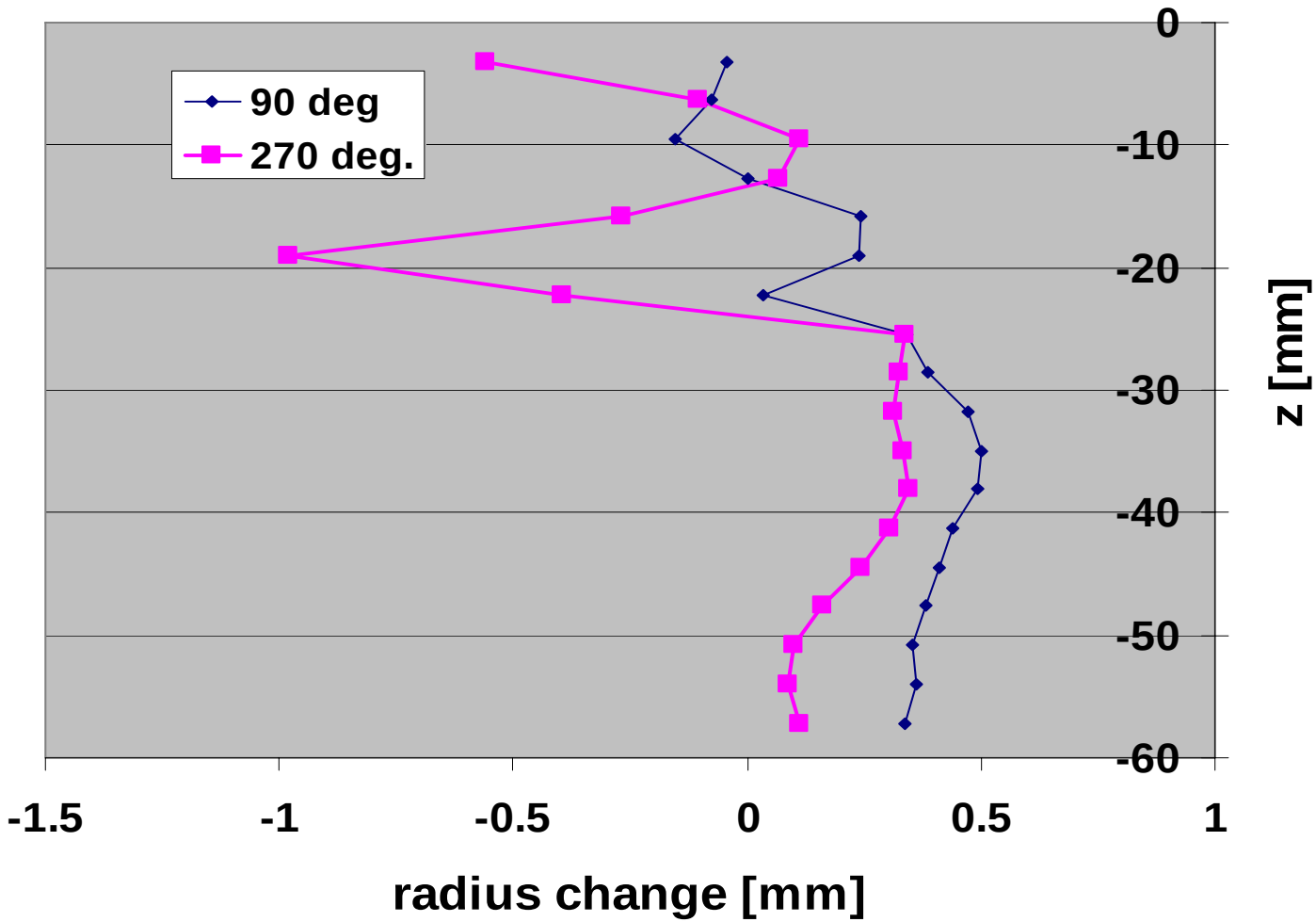
Springback: “Flower” cuts

- release hoop stress, allow unconstrained equilibration of bending moments ***m*** in axial/radial direction
- if ***m<>0*** then petals will open or close in flower-like fashion

Springback: Axial Stress Release



Residual Stress: Movement of the Petals on Stress Release



Residual Stress: Conclusions

- deflections after “flower” cuts similar to roundness deviations
- overall stress levels estimated to be very small (0.1 UTS) and nearly unchanged at 4 K
- stress will be locally higher where
  - small bending radii occur and
  - local thinning causes significantly higher strains
  - <100> orientations coincide with the above
- stresses will **not** cause significant cavity distortions because stresses are simply too low

Conclusions and Recommendations

Problems:

- anisotropy of r-factor causes shape deviations and local thinning
- grain boundaries
- 50% reduced strength compared to polycrystal

Recommendation:

- stringent quality control for every cavity, possibly search for best possible SC orientation to minimize these problems (seed crystals?)
- extend size of the SC
- thickness increase to compensate for strenght reduction