Weber Metals' Experience on Residual Stress of Al and Ti Forgings

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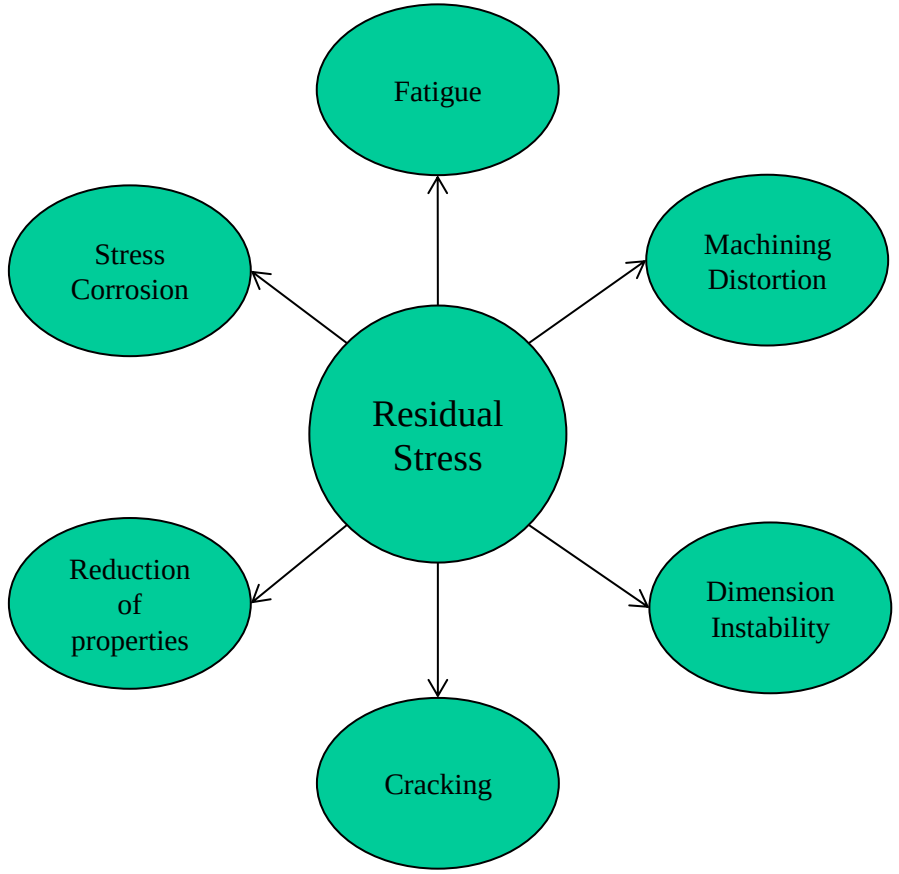
Headline

- Residual Stress Introduction
  - sources
  - effects
  - phenomena
- Residual stress measurement
- Residual stress reduction
- Residual stress simulation
  - Quenching simulation
  - Stress relieve process simulation
  - Machining process simulation
- Summary

Sources and Effects of Residual Stress

- Sources of residual stress
  - Thermal sources
    - Quenching
    - Poor racking
    - Poor agitation
  - Mechanical sources
    - Machining
    - Grinding
    - Straightening (hot or cold)
    - Cold forming operations
    - Forging at low temperature

- Effects of residual stress



Residual Stress Measurement Method

	Measurement Location	Destructive or not	Measurement speed	Cost
Hole-drilling	Surface	Semi-destructive	Medium	Low
X-ray diffraction	Surface	Non-destructive	Fast	Device is expensive
Neutron diffraction	Internal	Non-destructive	Slow	High
Contour method	Cross section	Destructive	Medium	High
Slit method	Volume	Destructive	Slow	Low
Ultrasonic method	Internal	Non-destructive	Fast	Low

How to Reduce Residual Stress

- Reduce residual stress generation source

  (For both Al and Ti forgings)

  - Controlling the cooling rate
    - Hot water quench
    - Glycol quench
    - Fan cool, air cool or nozzle cool
    - Limited by spec and property requirement
  - Adequate agitation
  - Proper racking
  - No hot or cold straightening

- Reduce residual stress after heat treatment

  (For Al forging)

  - Mechanical stress relieve
    - stress relieve by stretching

      (limited to simply shapes)
    - stress relieve by compressing

      (can be applied for both simple and complex shape parts. Special tooling is usually required for die forgings
  - Uphill quenching

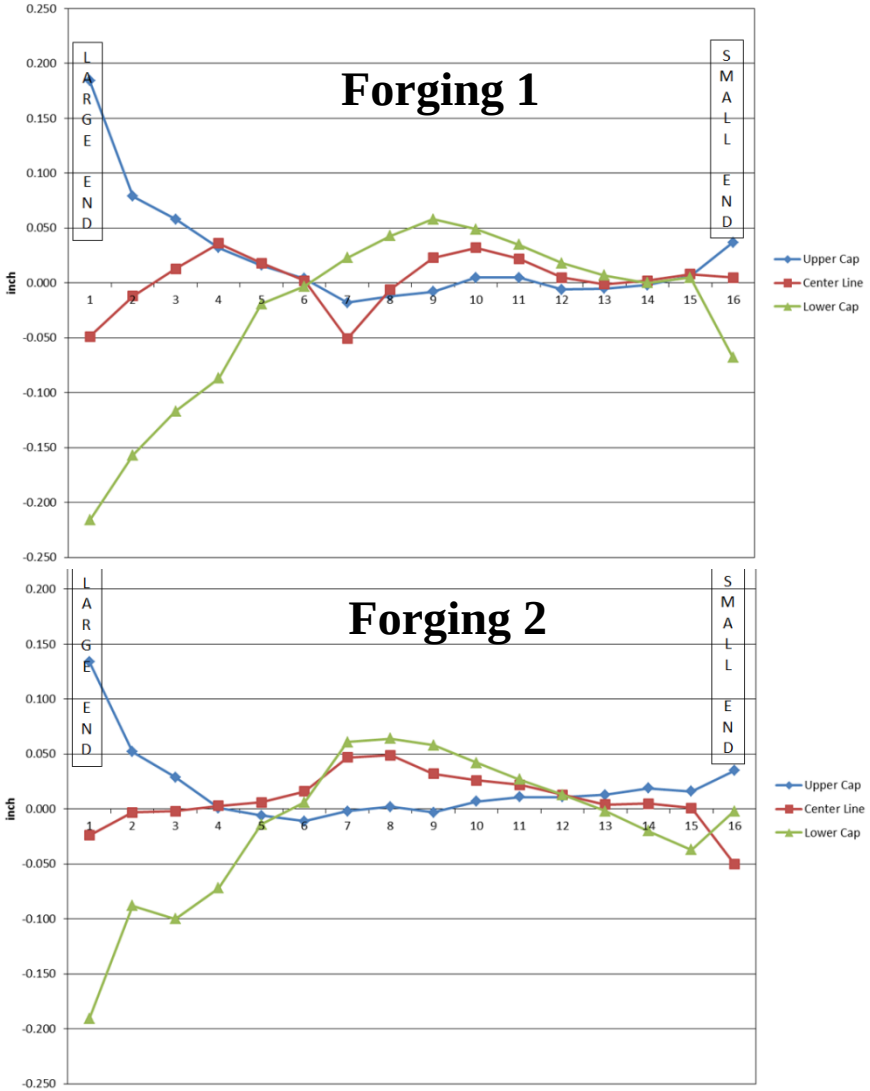
    (limited by cost and part size)

  (For Ti forging)

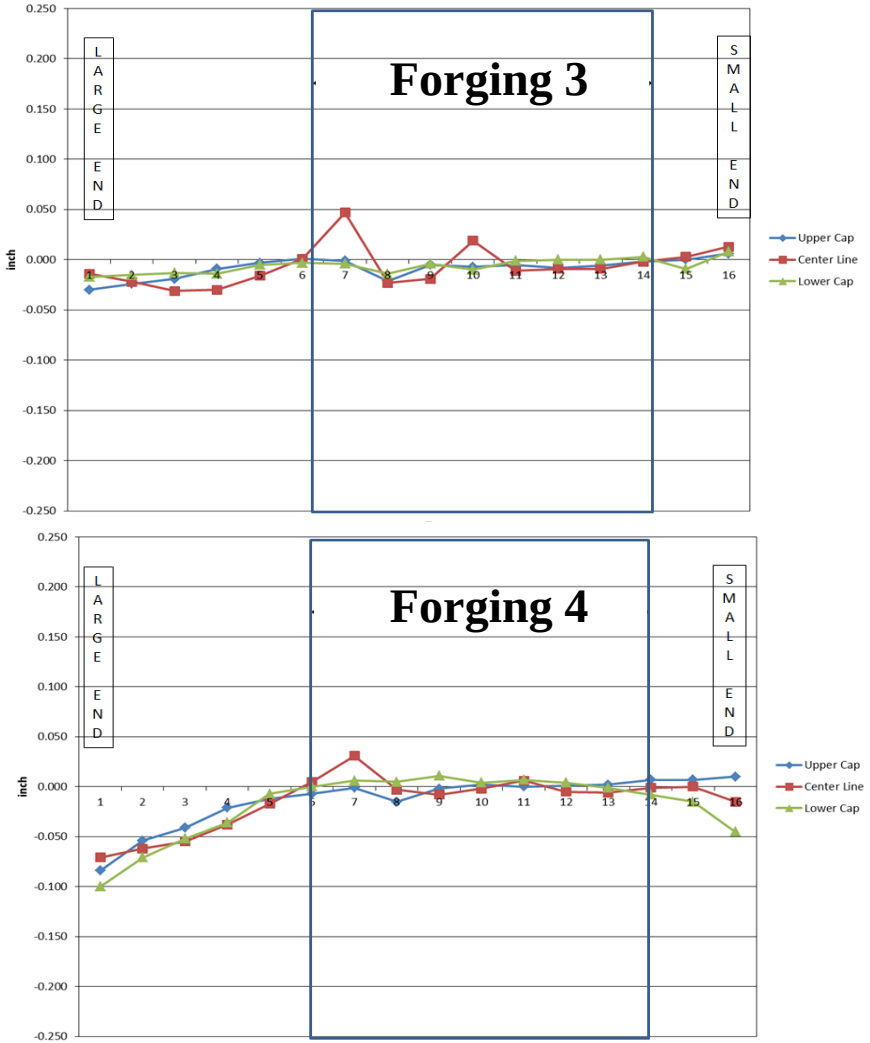
  - Stress relieve anneal

CMM Inspection Results

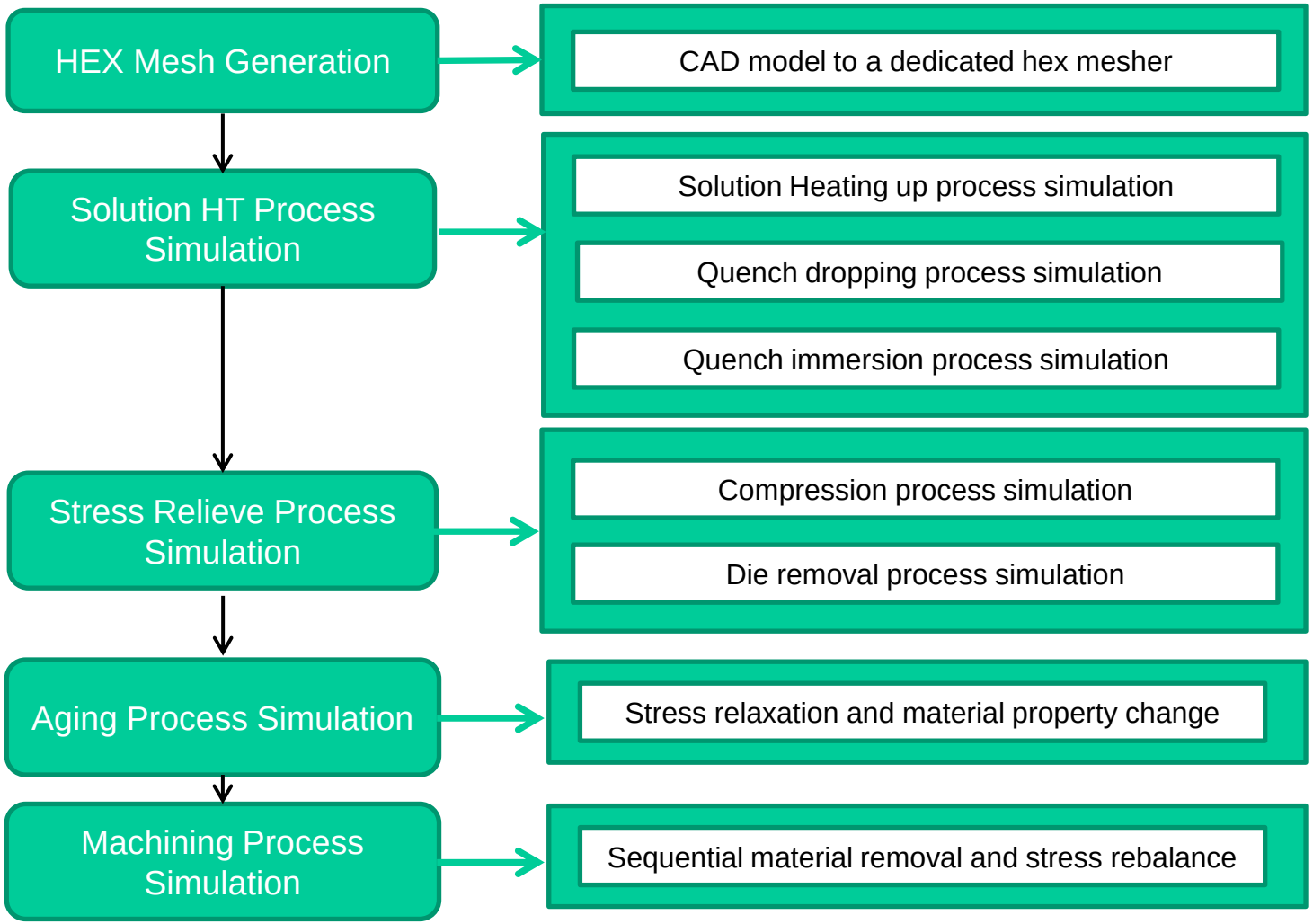
Old stress relieve method



New stress relieve method



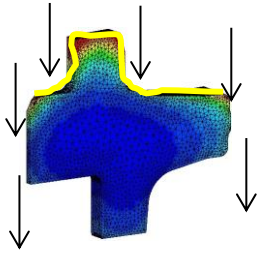
Cold-Loop Simulation for Residual Stress Prediction



Two Approaches For Quenching Simulation

- Two approaches available:
  1. Simplification through HTC (inverse heat transfer/ empirical)
  2. Consideration of fluid flow (CFD)

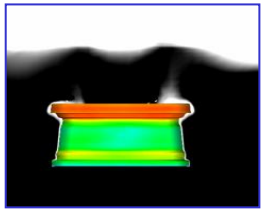
Empirical approach



+ Simple and fast
+ Depending on the fluid, might give satisfactory results
+ HTC regimes can be simplified through a function of HTC and surface temperature

– Differents area needs to have different HTC coeff.,
– Can only be indentified by inverse analysis
– In water quench, cannot predict air pockets or influence of fluid flow

CFD approach

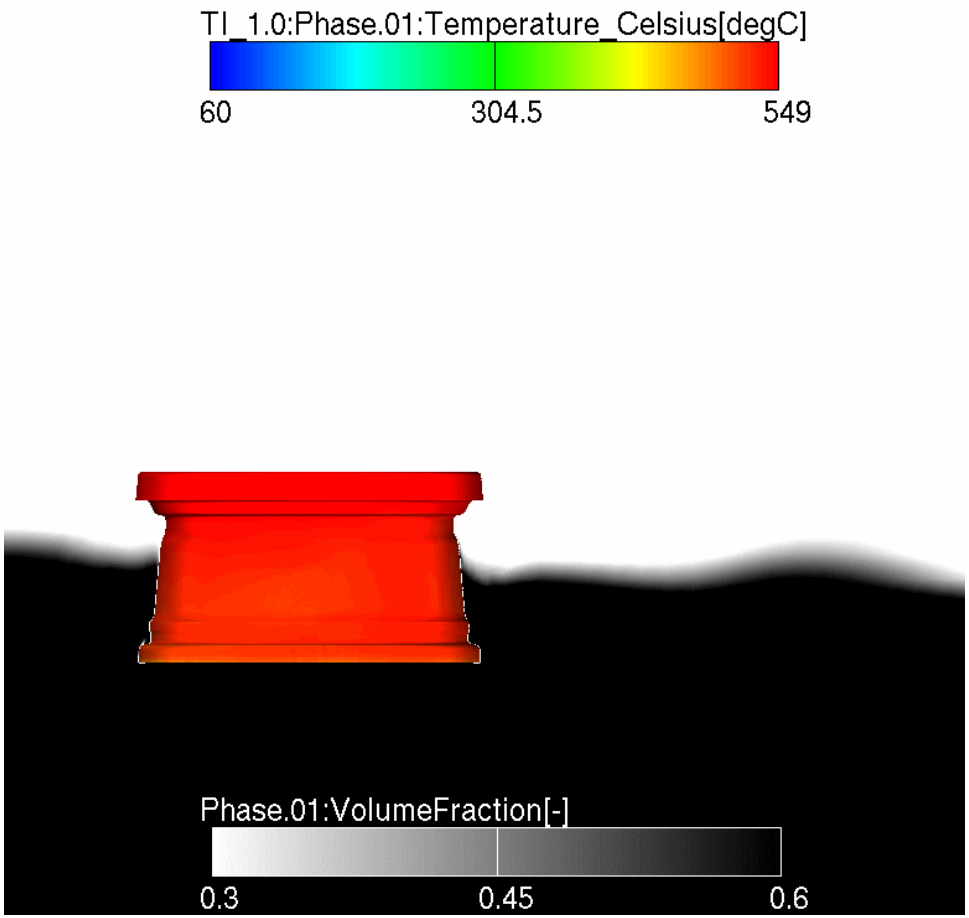


+ Prediction of fluid behaviour and its flow
+ Different HTC regimes are automatically considered
+ Interaction between fluid and part is considered
+ Low or zero previous experiments

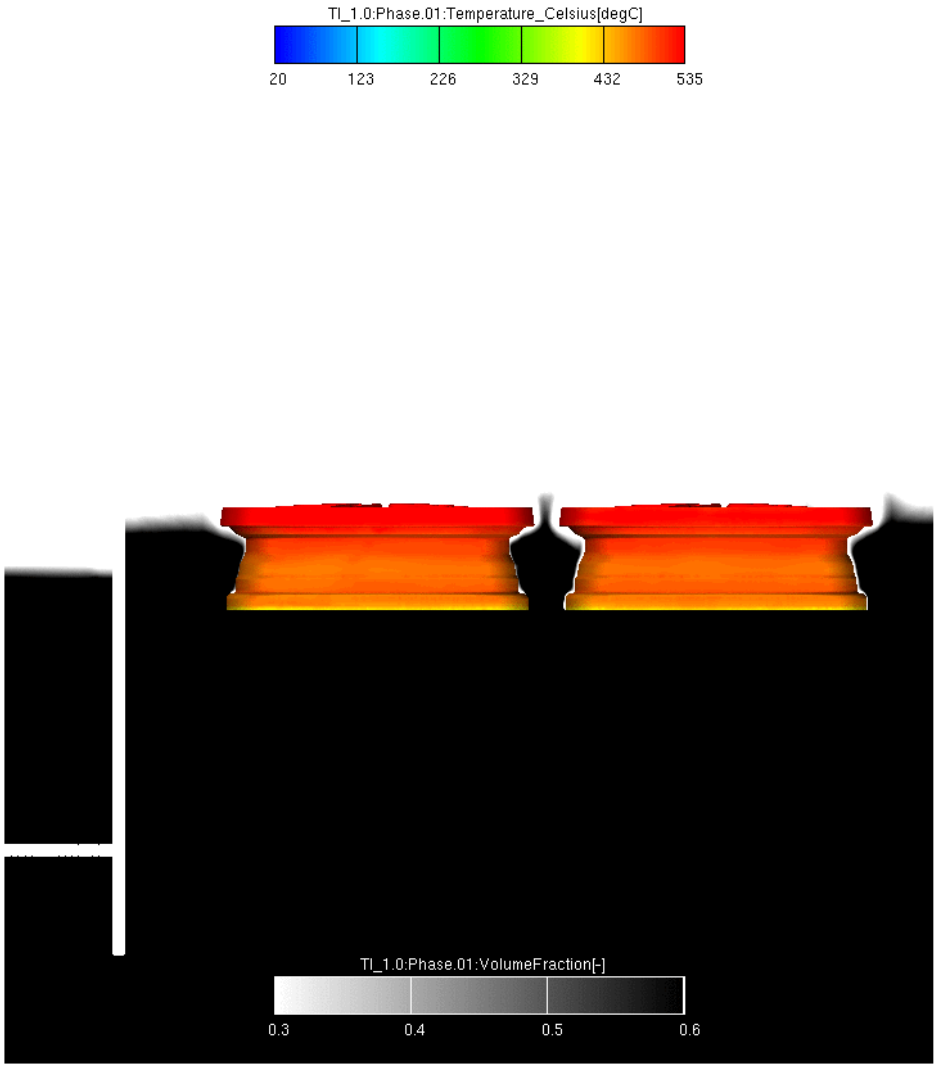
– Time and cost intensive
– Influence of roughness must be analysed experimentally and corrected through factors

CFD Simulation of Al Wheels

One Wheel

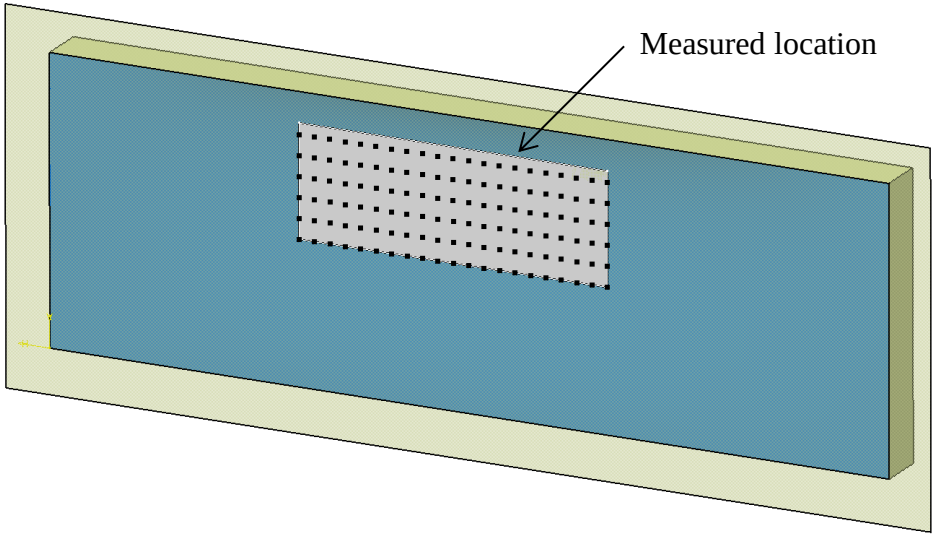


Two Wheels

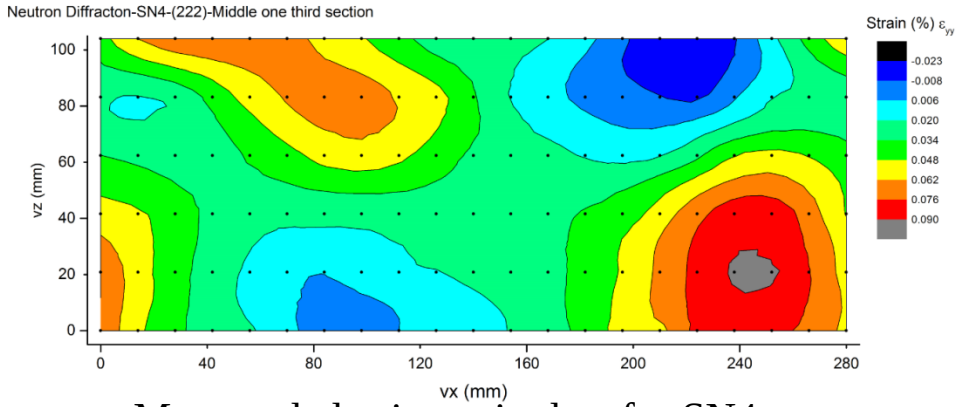


Neutron Diffraction Measurement

- Use ORNL's HFIR HB-2B beam to perform neutron diffraction measurement of 5 pieces
- Spot size 5x5x4 mm^3
- Signals from (222) and (311) crystal plane were received
- Signals from (222) were used for the analysis
- Small sample was prepared in annealed condition for d0 measurement
- Only elastic strain in LG direction is measured
- Stress cannot be calculated due to lack of data in other two directions



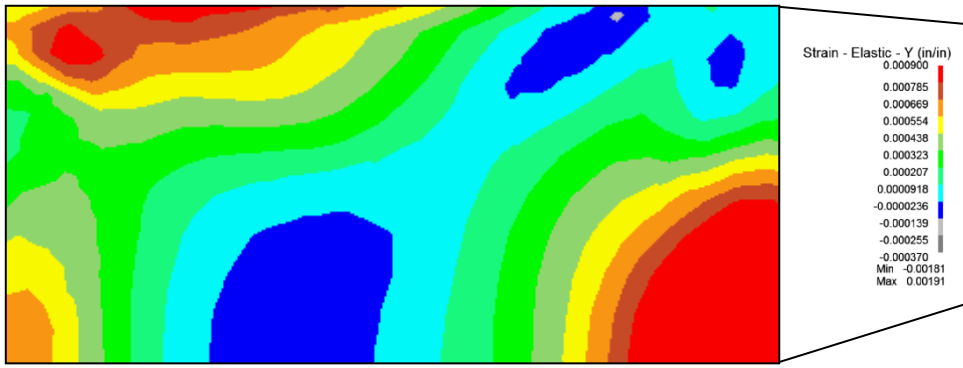
Neutron Diffraction Measurement



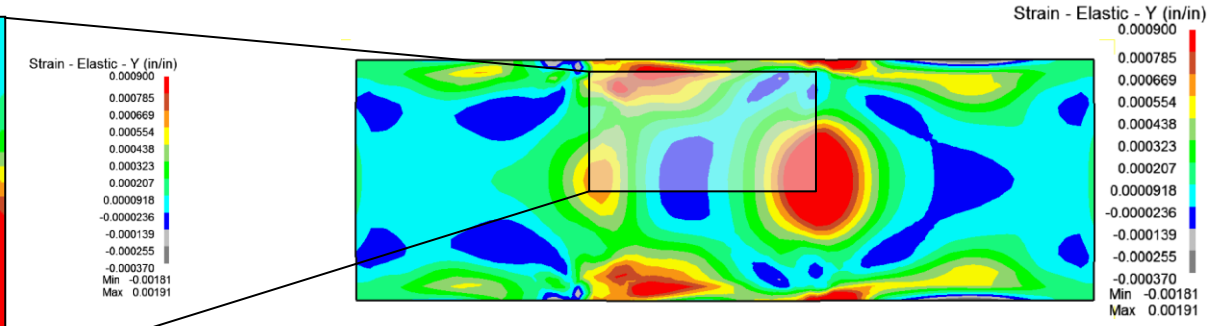
Measured elastic strain data for SN4

- Only about 1/6 of the samples is measured
- Measured area is 280mm x 100mm
- 21 pts/line x 6 lines =126 pts were measured

Simulation is similar to measurement in both the pattern and magnitude.



Predicted elastic strain for SN4



Measured location in SN4

Summary

- Residual stress is a major cause of machining distortion and oil-canning phenomena of Al forgings
- Compressive cold work can reduce residual stress of Al forgings, but the results can vary depending on how it is applied
- CFD is a better way to simulate quenching than traditional HTC method
- Simulation is great tool to predict residual stress and help to reduce residual stress and machining distortion

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