Prediction of Distortion of Simple Geometries as a Function of Flow Field and Orientation

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Introduction

- Rolled rings are used extensively in industry
  - Wind Turbines
  - Engines
- Often high hardenable alloys are used
- Quench cracking can result
  - Different crack morphologies occur
  - Top or bottom circumferential cracking
  - Inner or outer diameter cracking
  - Suggest different stress fields
- Investigation conducted to understand geometry and orientation in flow field and heat transfer
  - Intent to understand the different cracking mechanisms

Introduction

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Cracking Mechanism	Likely Stress Field
Radial Cracking	High Hoop Stress Field
Top or Bottom Circumferential Cracking	High Radial Stress Field
Inner or Outer Diameter Circumferential Cracking	High Axial Stress Field

Computational Fluid Dynamics (CFD)

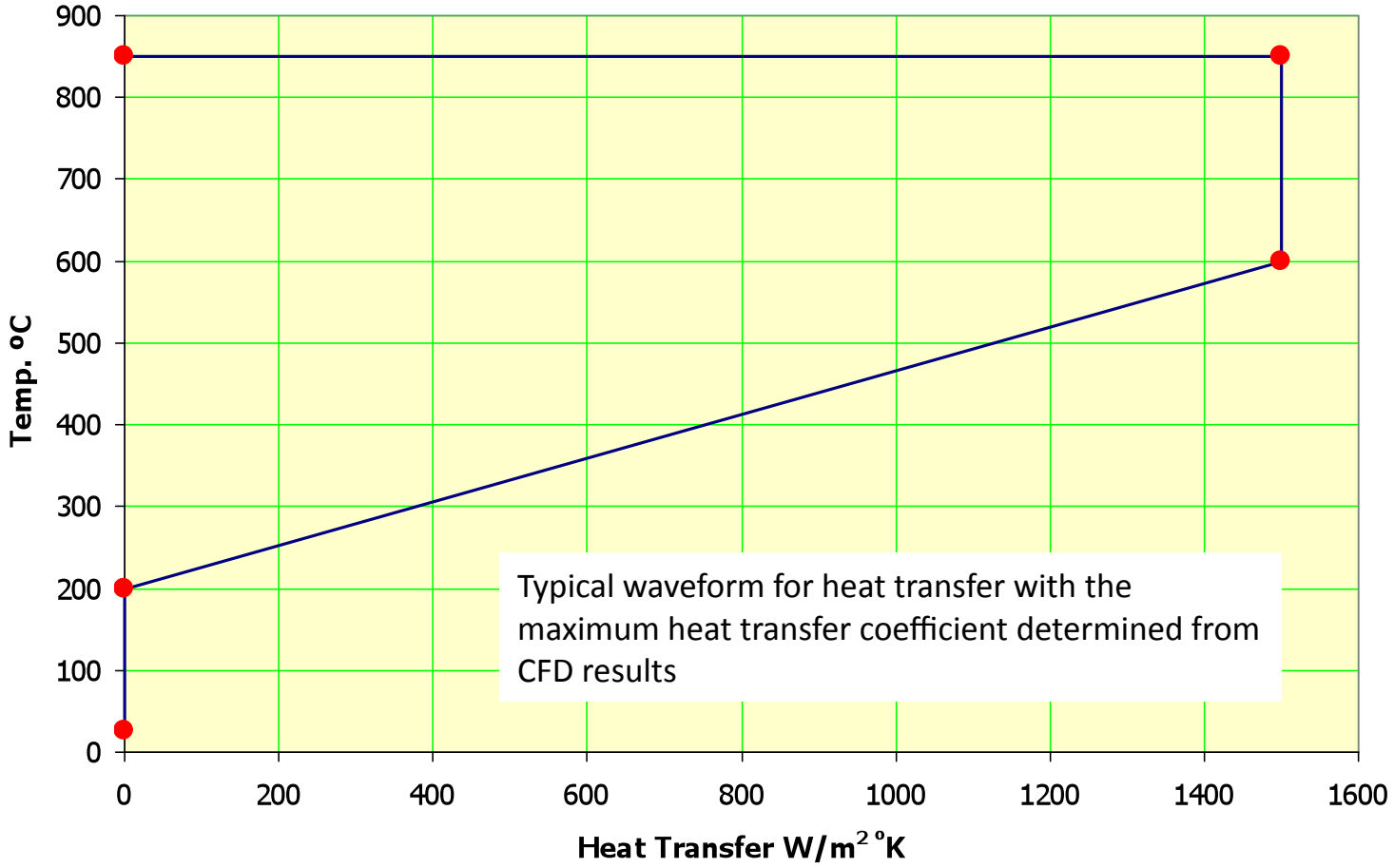
- CFD was used to examine the flow fields and establish heat transfer coefficient
  - Work performed by Airflow Sciences, Inc. (Livonia, MI)
  - Computational Domain is a cube 1524 mm per side
  - Single grid used for each of the three rings
  - Different flow conditions achieved by changing the domain boundary conditions.

Ring	Outer Diameter	Wall (mm)	Inner Diameter (mm)	Height (mm)
Ring 1	610	127	356	127
Ring 2	610	64	482	127
Ring 3	610	25	560	127

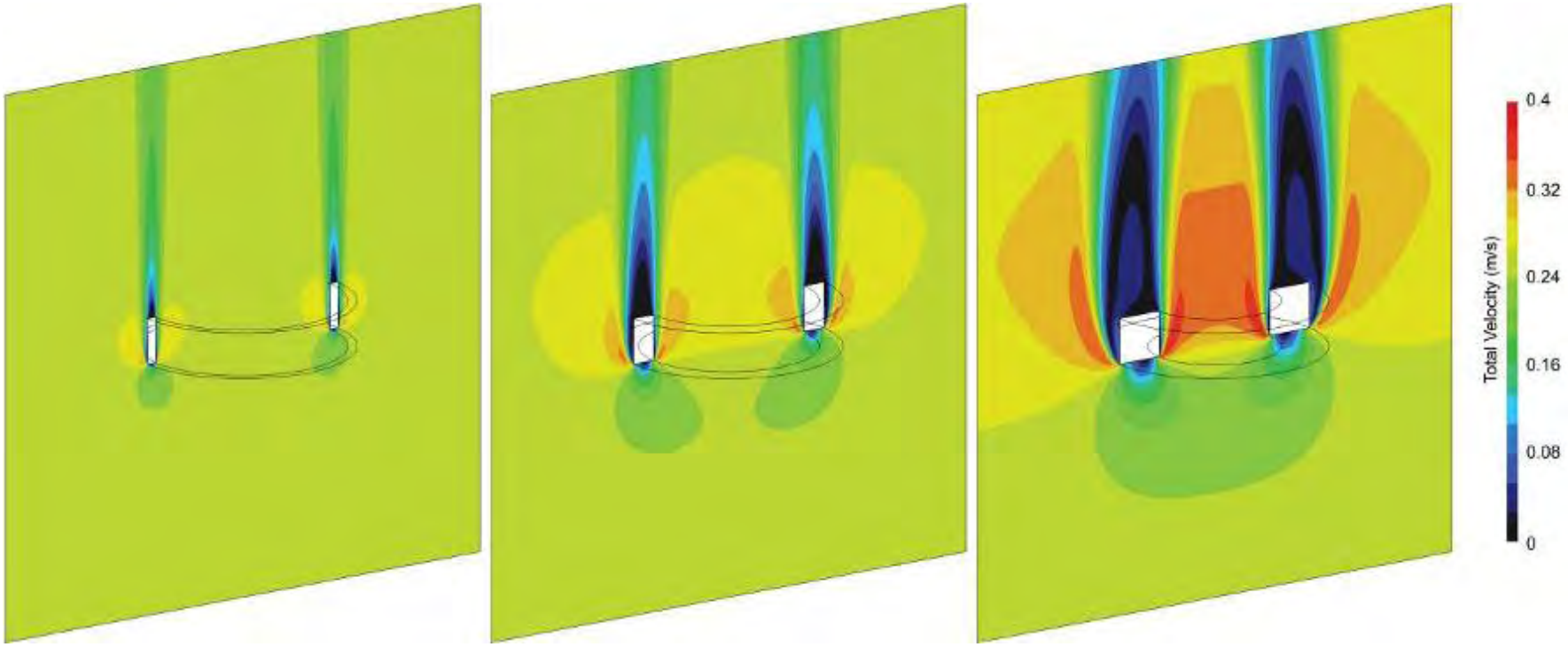
Simulation (CFD/FEA)

- Boundary conditions:
  - Inlet velocity of 0.25 m/s
  - Oil (constant fluid properties)
  - Constant pressure for opposing boundary
  - Four side boundaries assumed to be planes of symmetry
  - Turbulence simulated using standard k-ε model
  - Ring surface maintained at 100°C above inlet temperature
- Heat Transfer Coefficients reported are based on calculated heat fluxes and the temperature differential.
- Heat Transfer Coefficients mapped to surfaces of rings
- Distortion, microstructure and residual stresses determined using DANTE® by Deformation Control Technology

Typical Heat Transfer Waveform

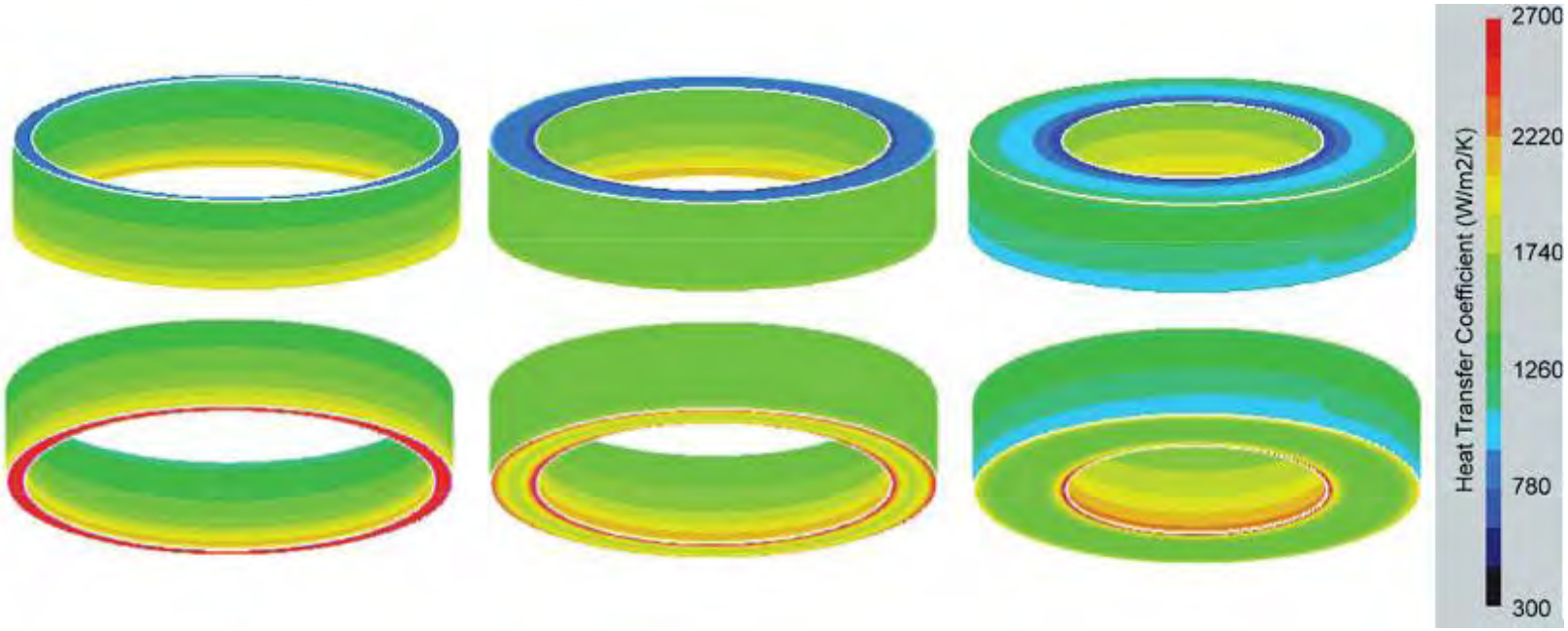


Results – Horizontal Rings



Flow fields surrounding the three different rings with vertical flow (horizontal orientation). Ring 3 is shown at left, while Ring 2 is shown in the middle, and Ring 1 is shown at the right. Flow is from the bottom.

Results – Horizontal Rings



Resultant heat transfer coefficients from the flow field with vertical flow (horizontal orientation). Ring 3 is shown at left, while Ring 2 is shown in the middle, and Ring 1 is shown at the right. Flow is from the bottom.

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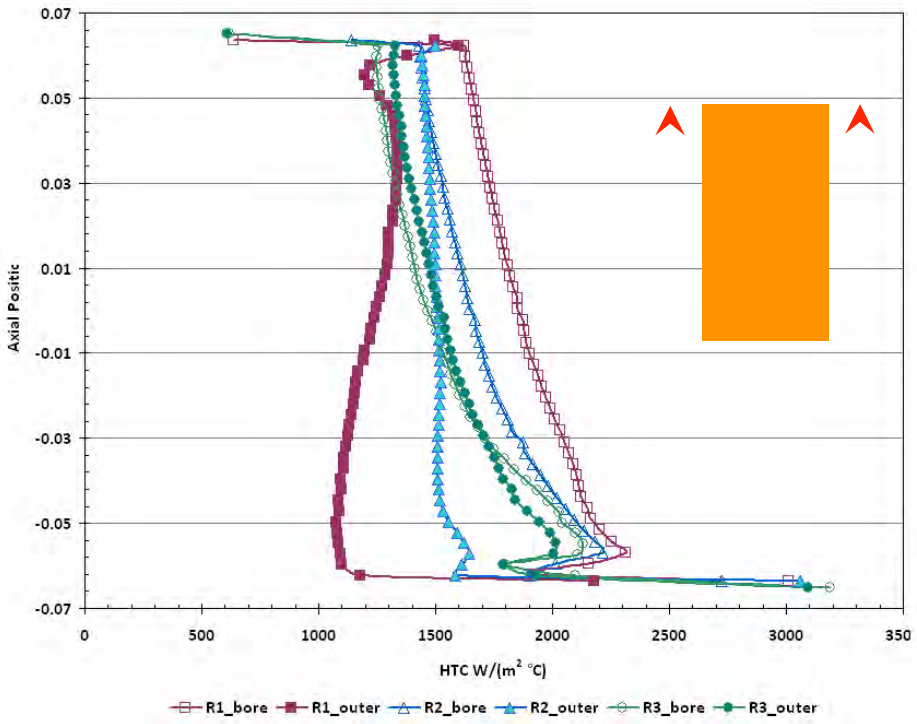

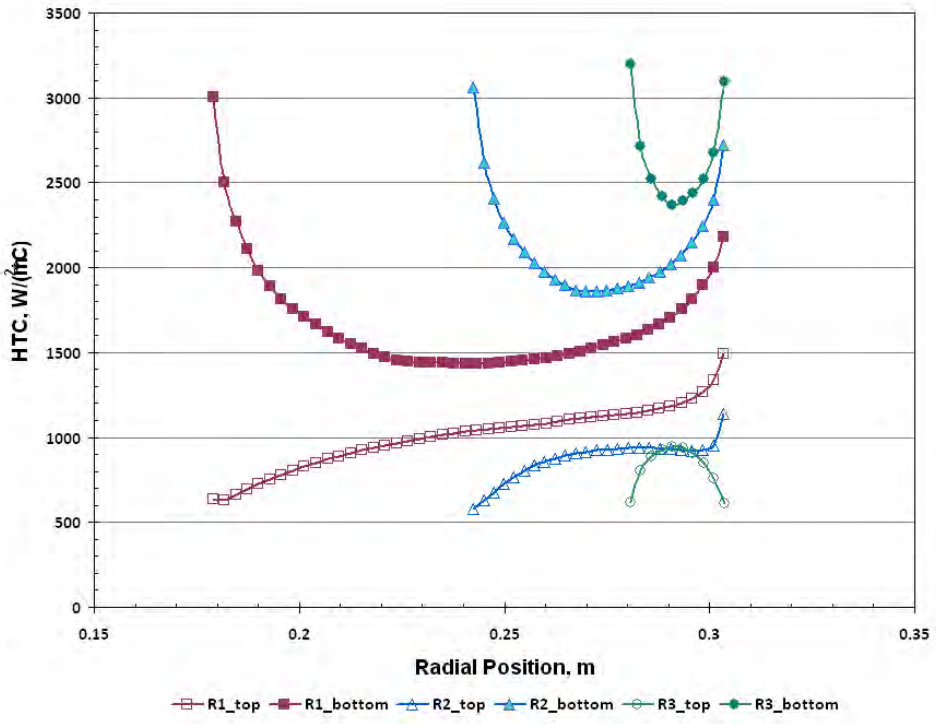

HTC from CFD Model for Oil Quenching of 4140 Steel Rings with three different wall thicknesses.

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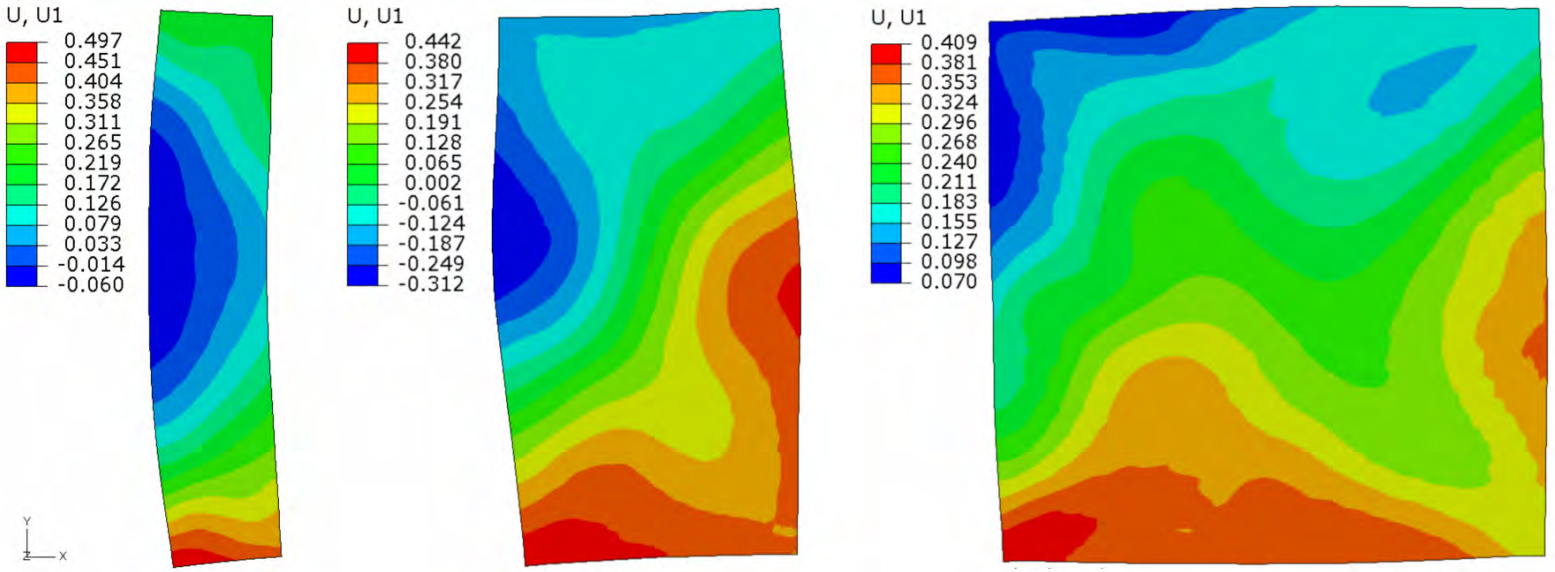
Results – Horizontal Rings



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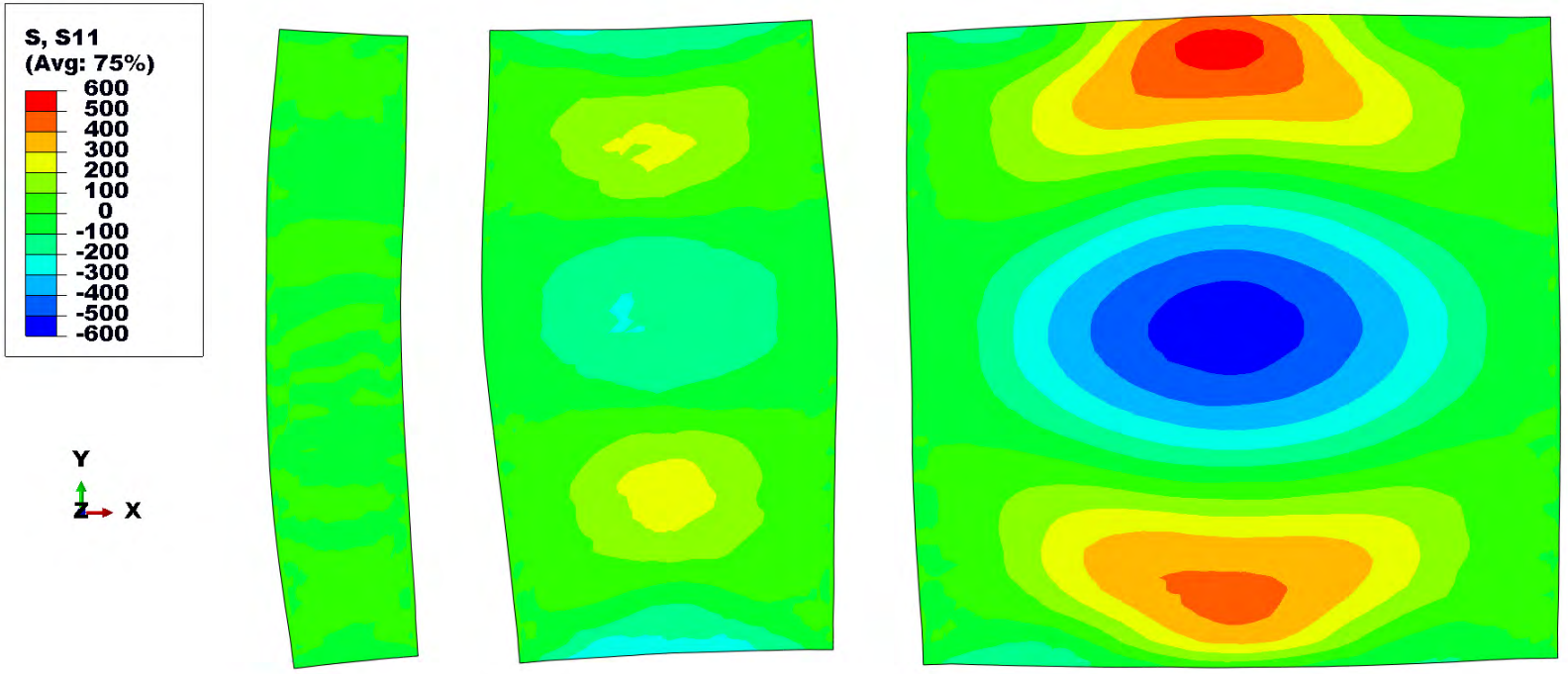

Radial Stress

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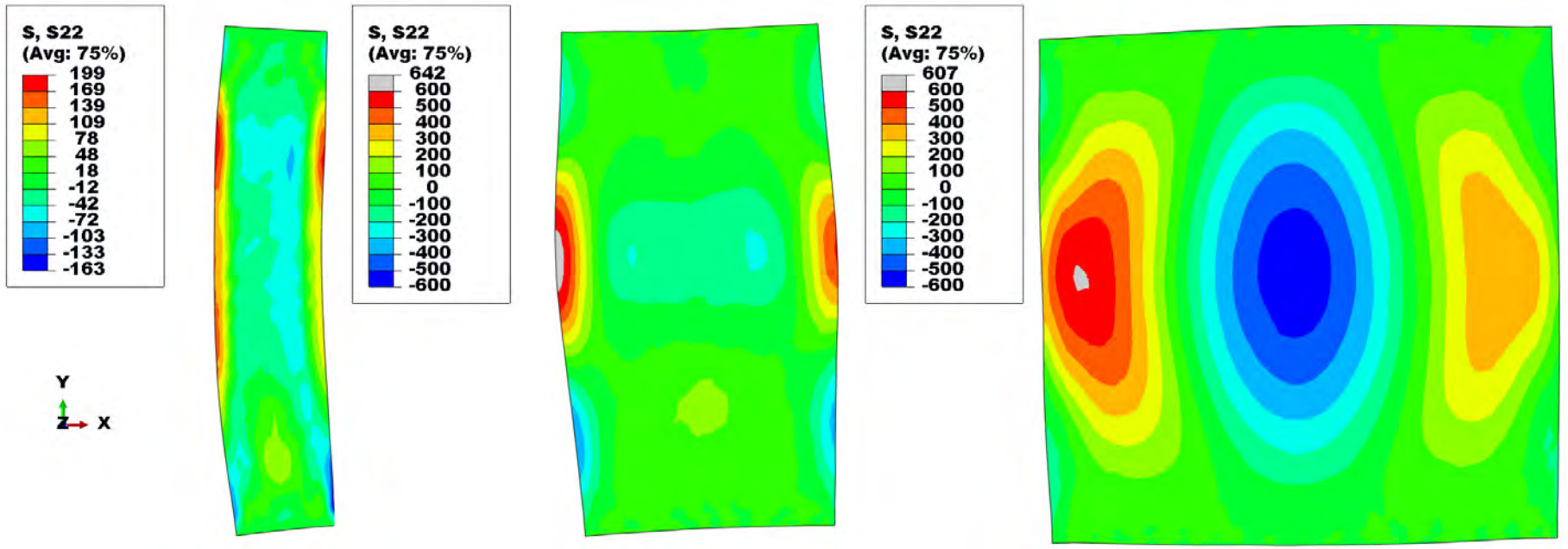
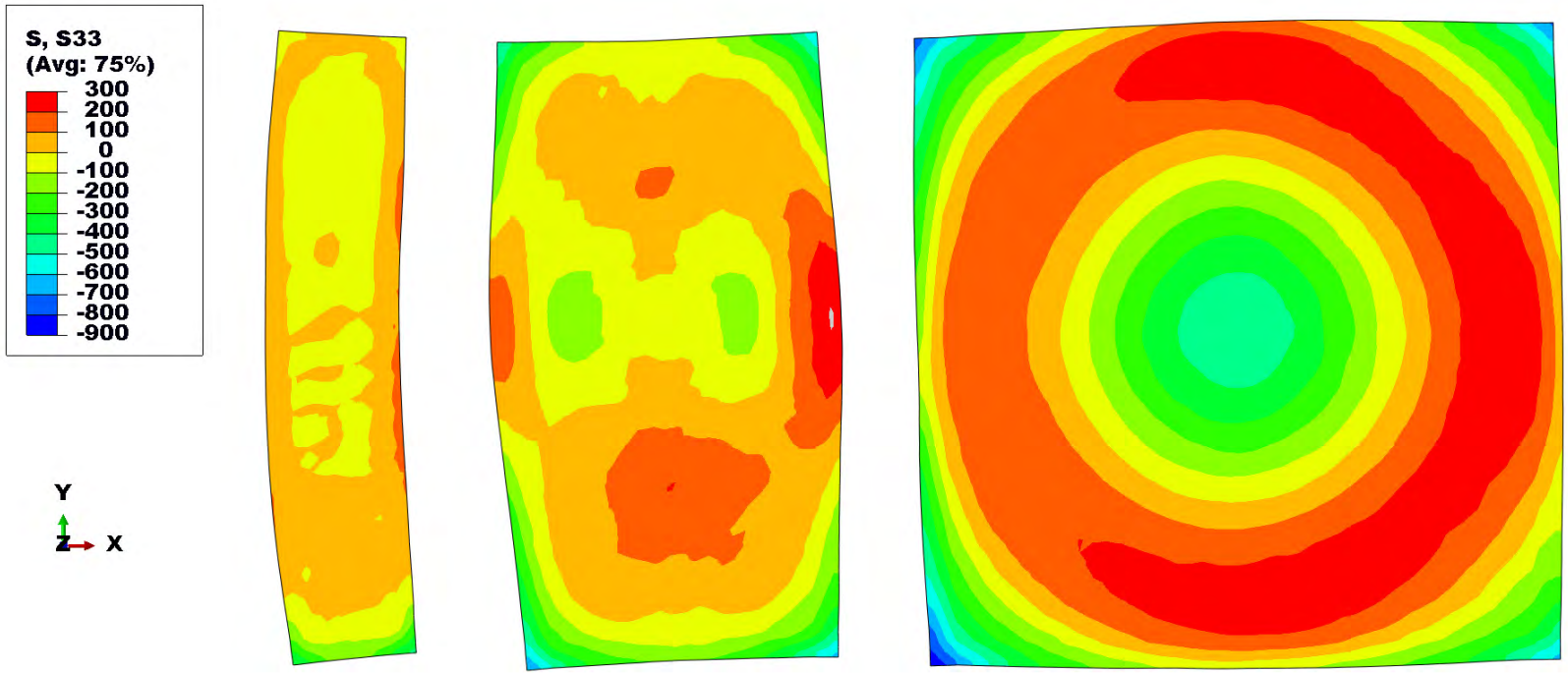
Results – Horizontal Rings



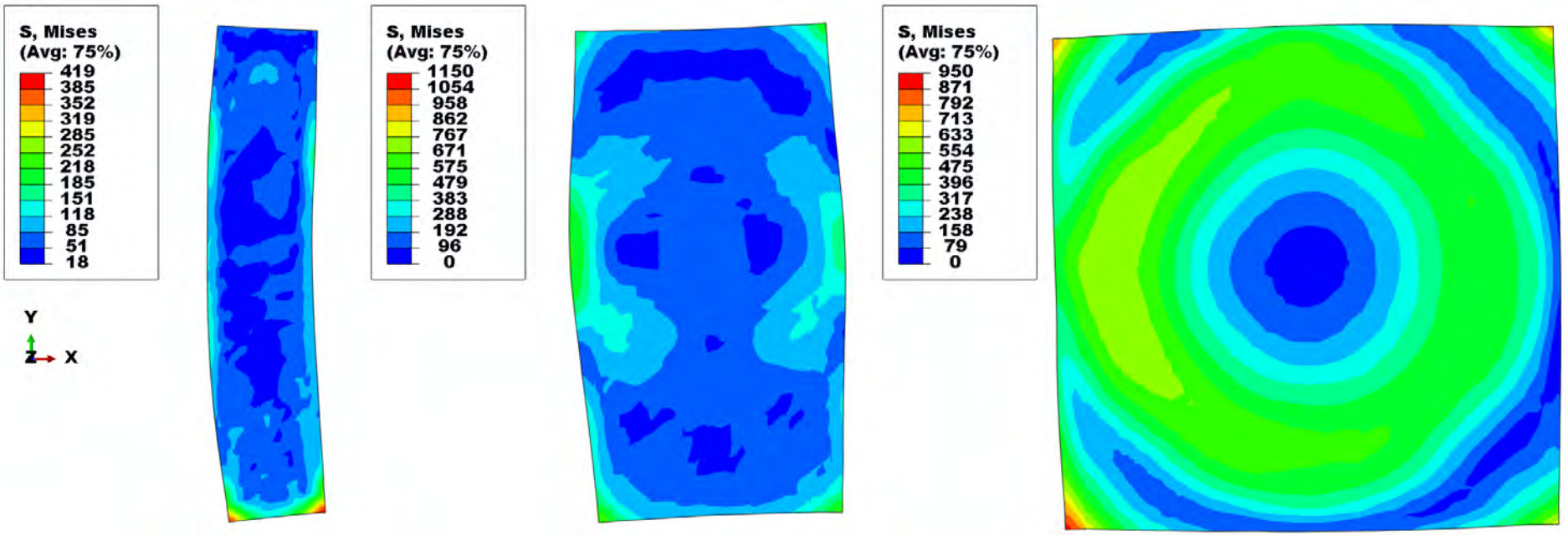
Axial Stress

Results – Horizontal Rings



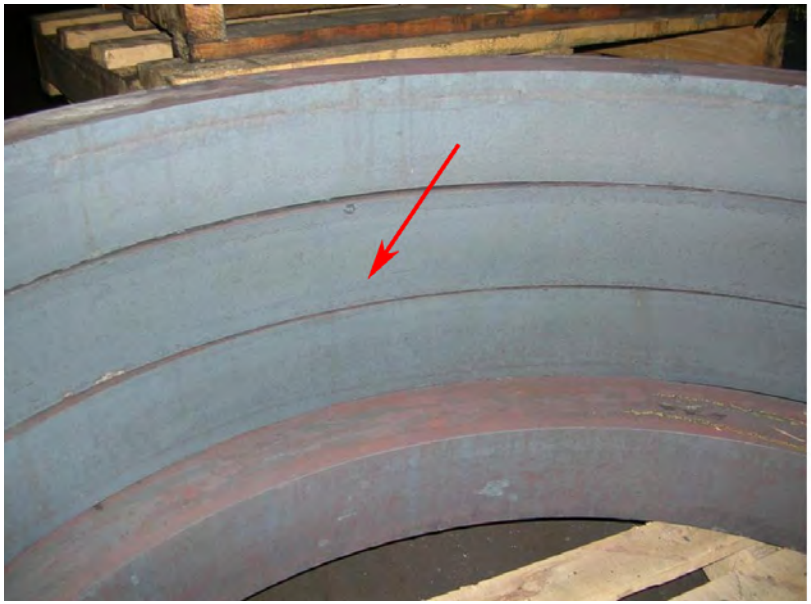
Hoop Stress

Results – Horizontal Rings

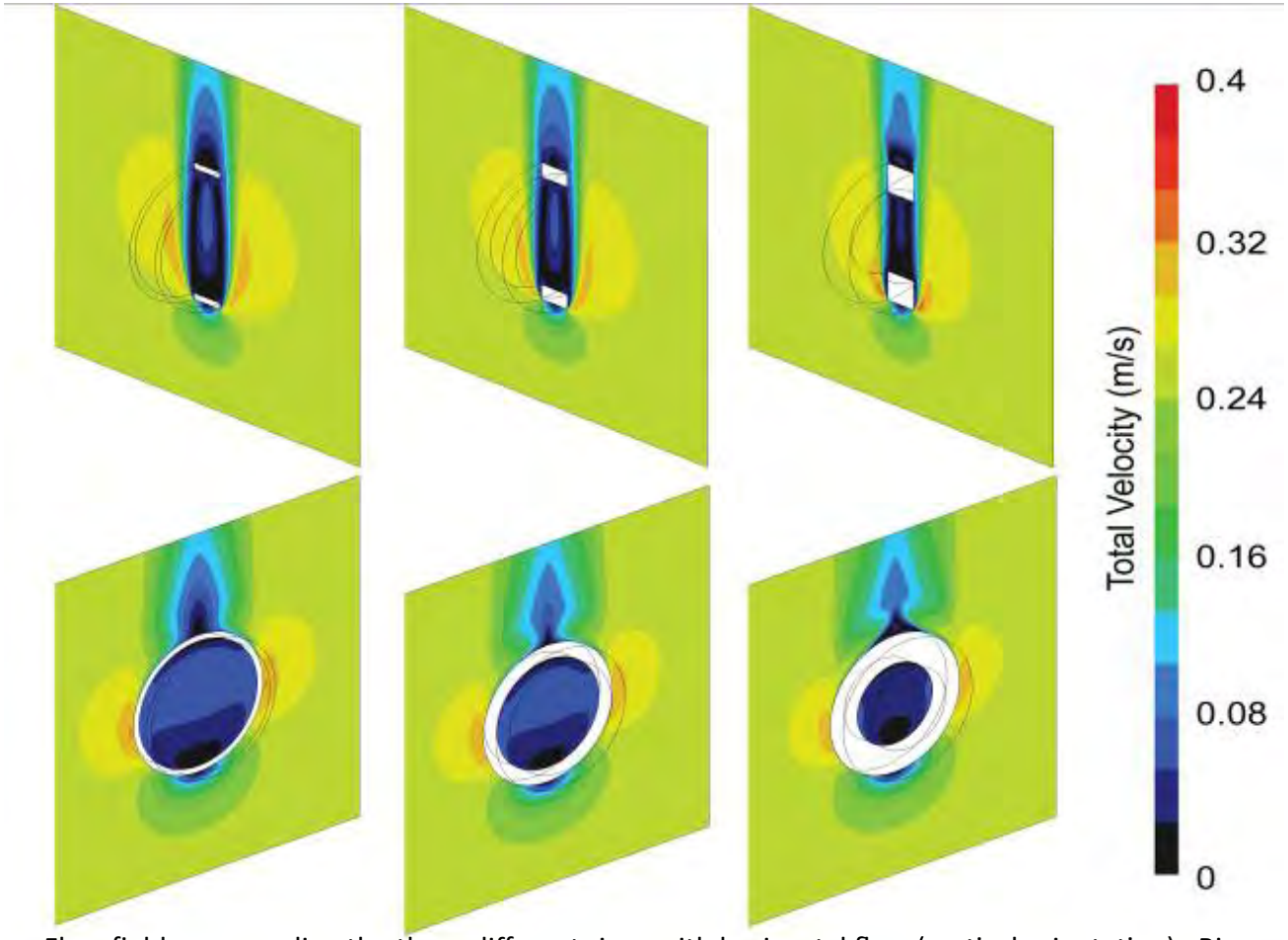


Von Mices Stress

Results – Horizontal Rings



Results – Vertical Rings



Flow fields surrounding the three different rings with horizontal flow (vertical orientation). Ring 3 is shown at left, while Ring 2 is shown in the middle, and Ring 1 is shown at the right. Flow is from the bottom.

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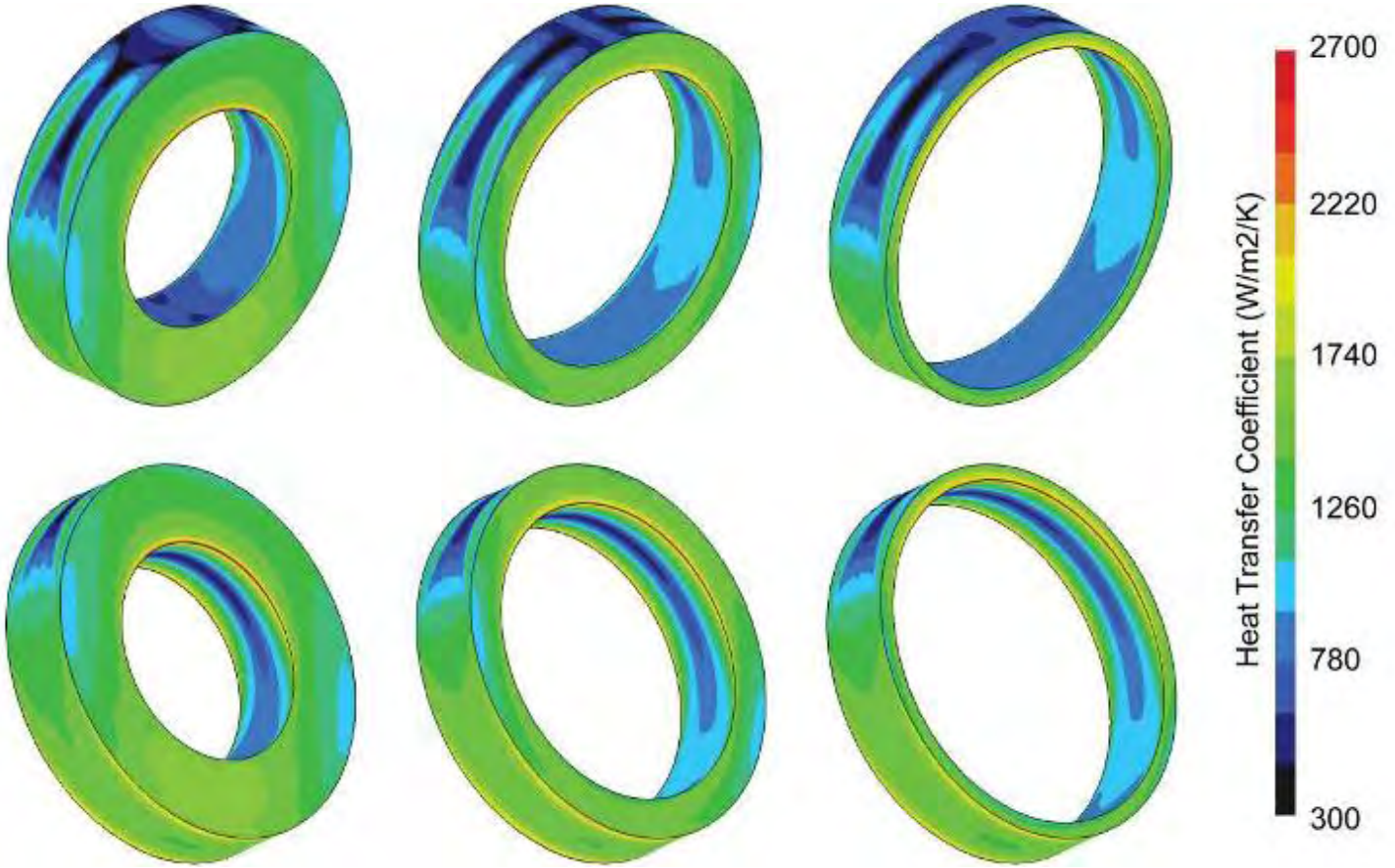

Resultant heat transfer coefficients from the flow field with horizontal flow (vertical orientation). Ring 1 is shown at left, while Ring 2 is shown in the middle, and Ring 3 is shown at the right. Flow is from the bottom.

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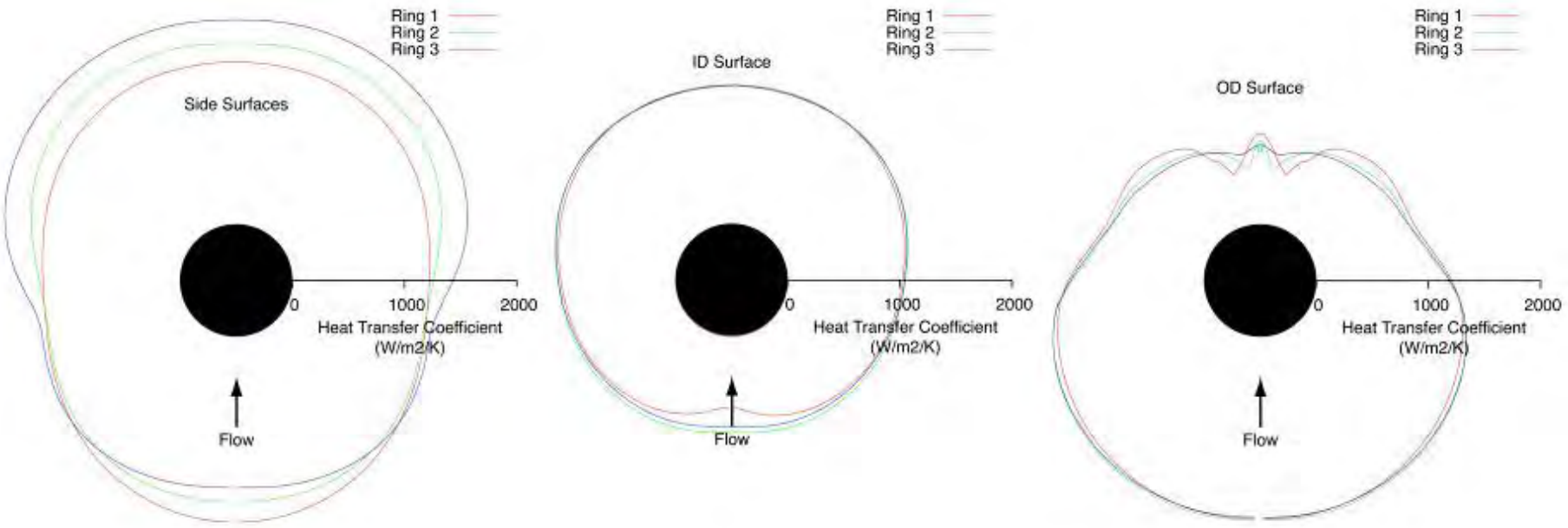
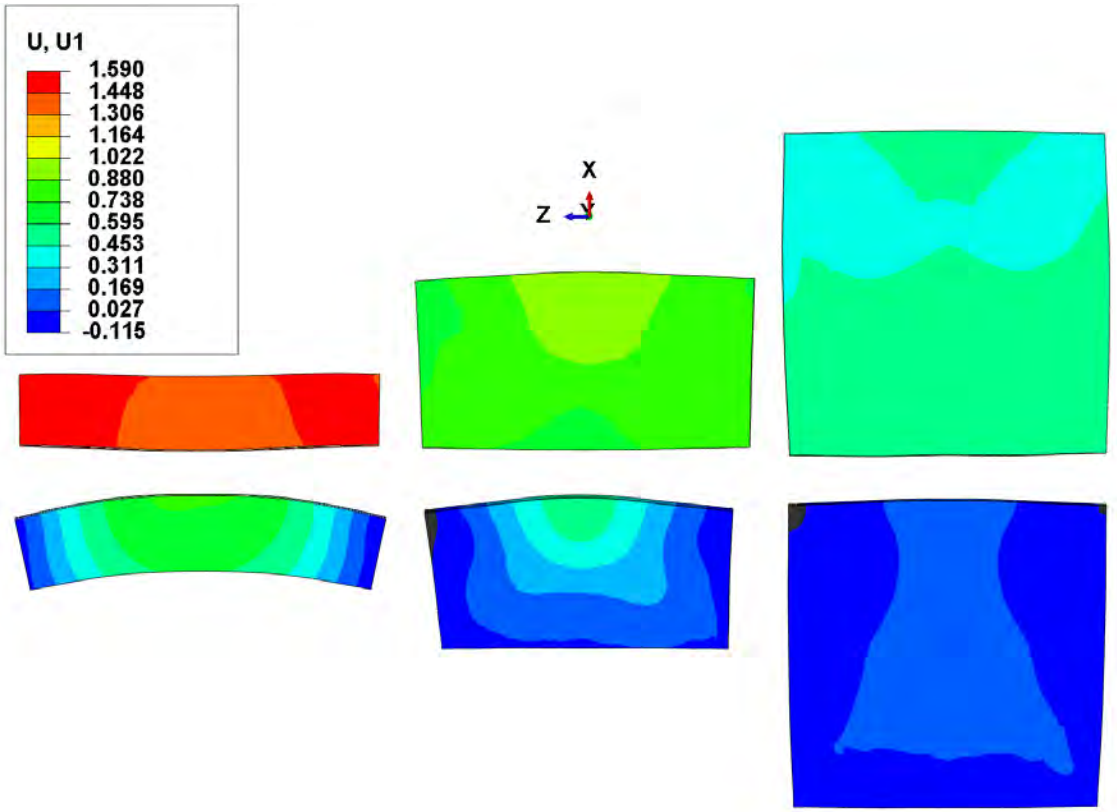
Results – Vertical Rings



Average heat transfer coefficients as a function of position in the three vertical ring cases.

Results – Vertical Rings



Top and Bottom Cross Section Profiles for Rings Quenched in the Vertical Orientation: Vertical Displacements in mm.

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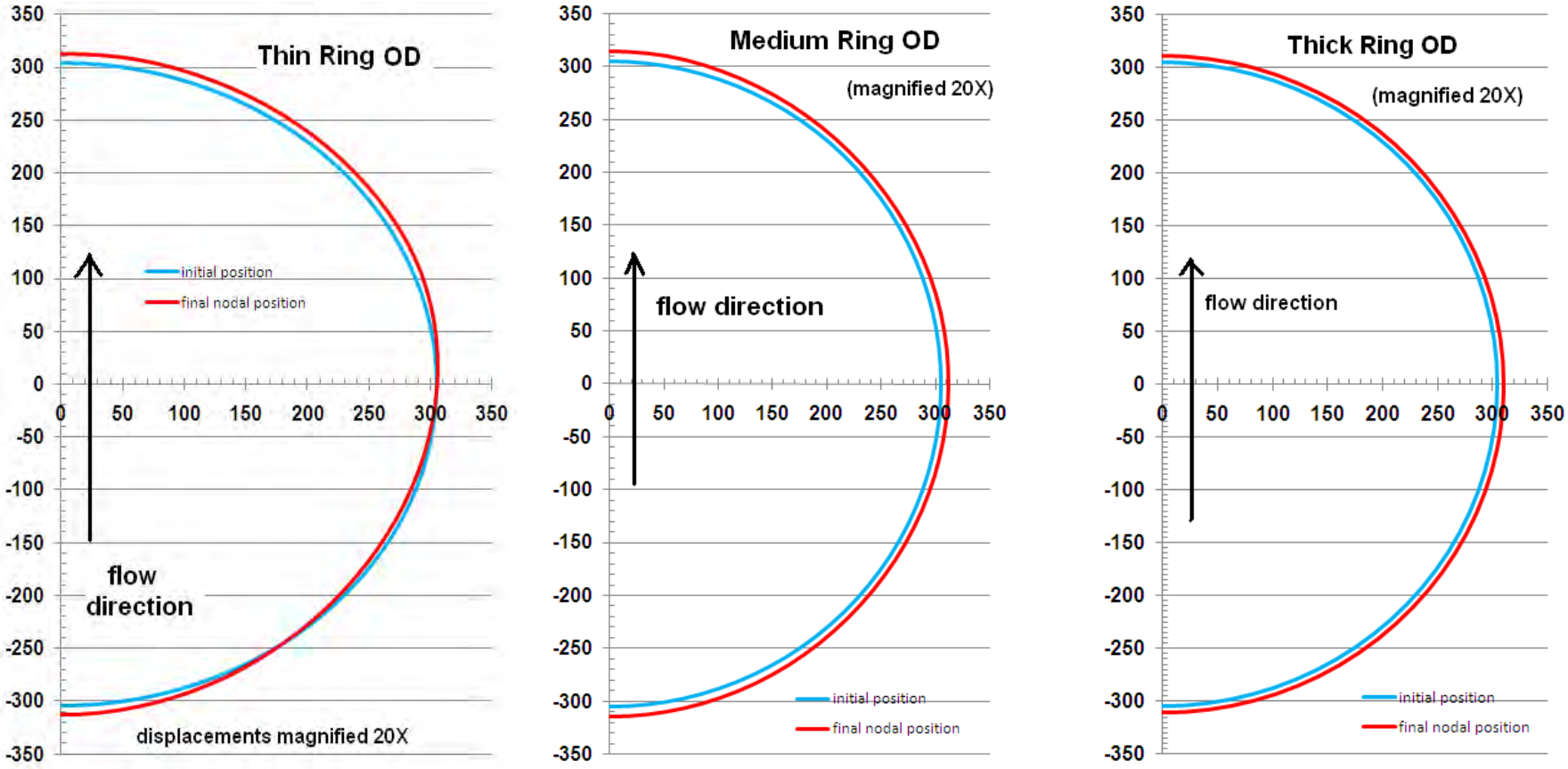
Results – Vertical Rings



Comparison of OD Distortion For Vertical Ring Orientation

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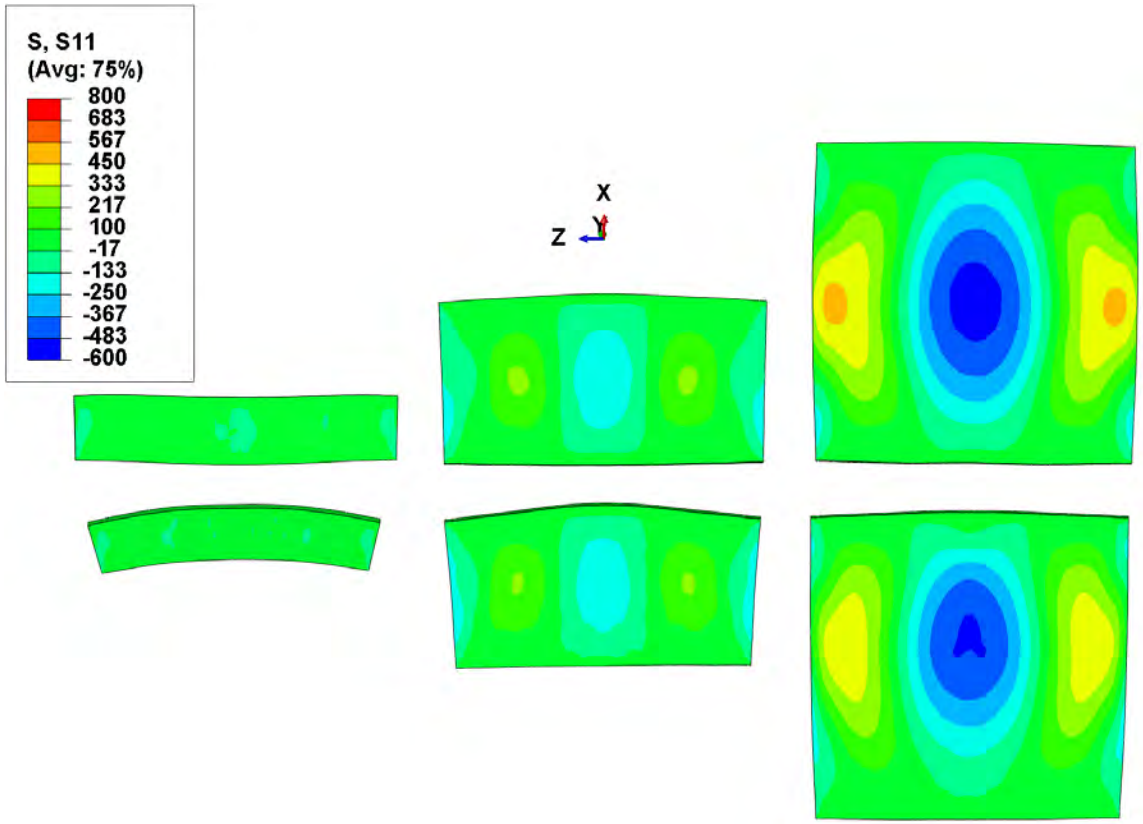
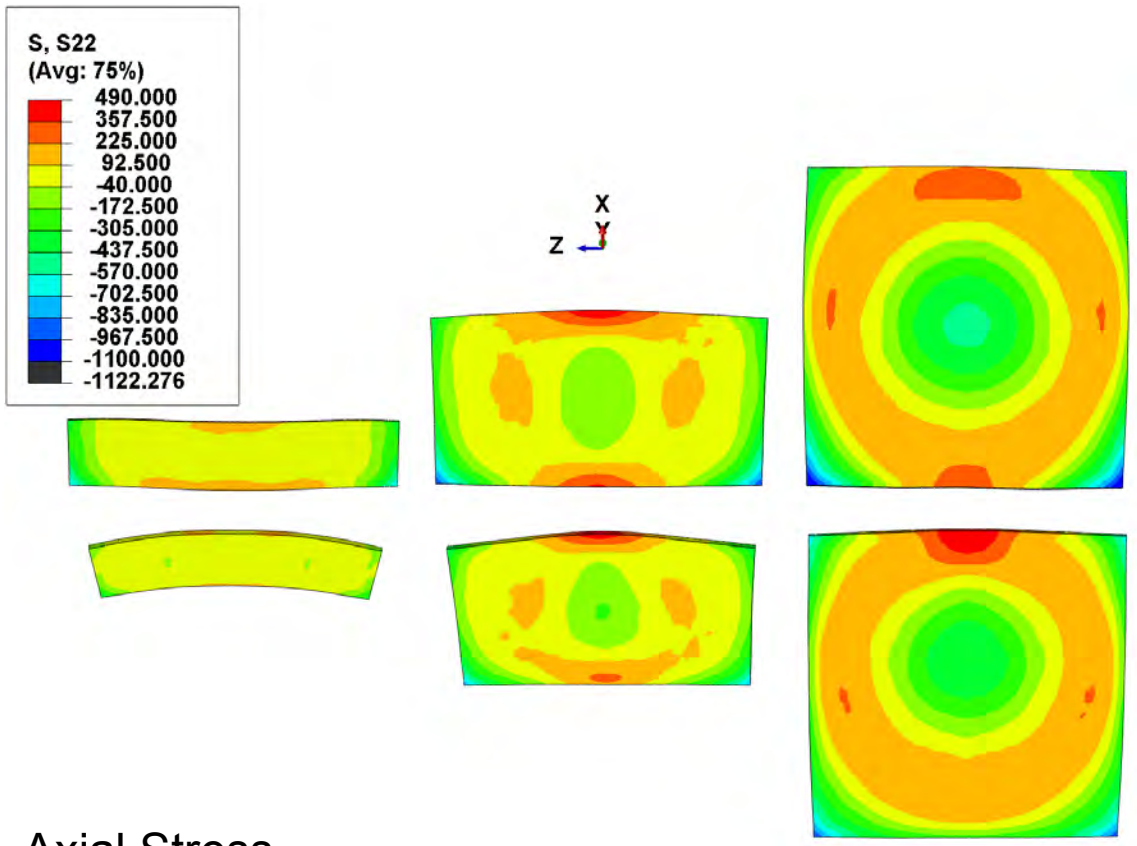
Results – Vertical Rings



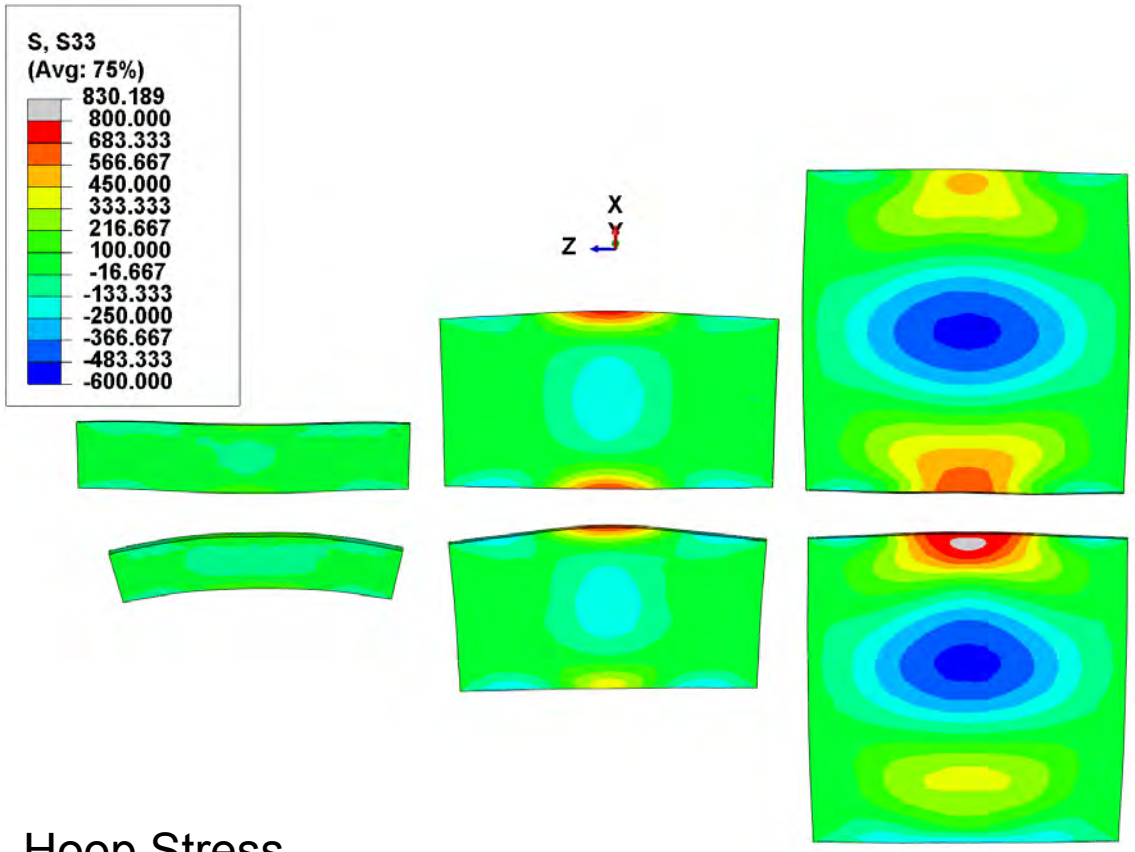
Radial Stress

Results – Vertical Rings



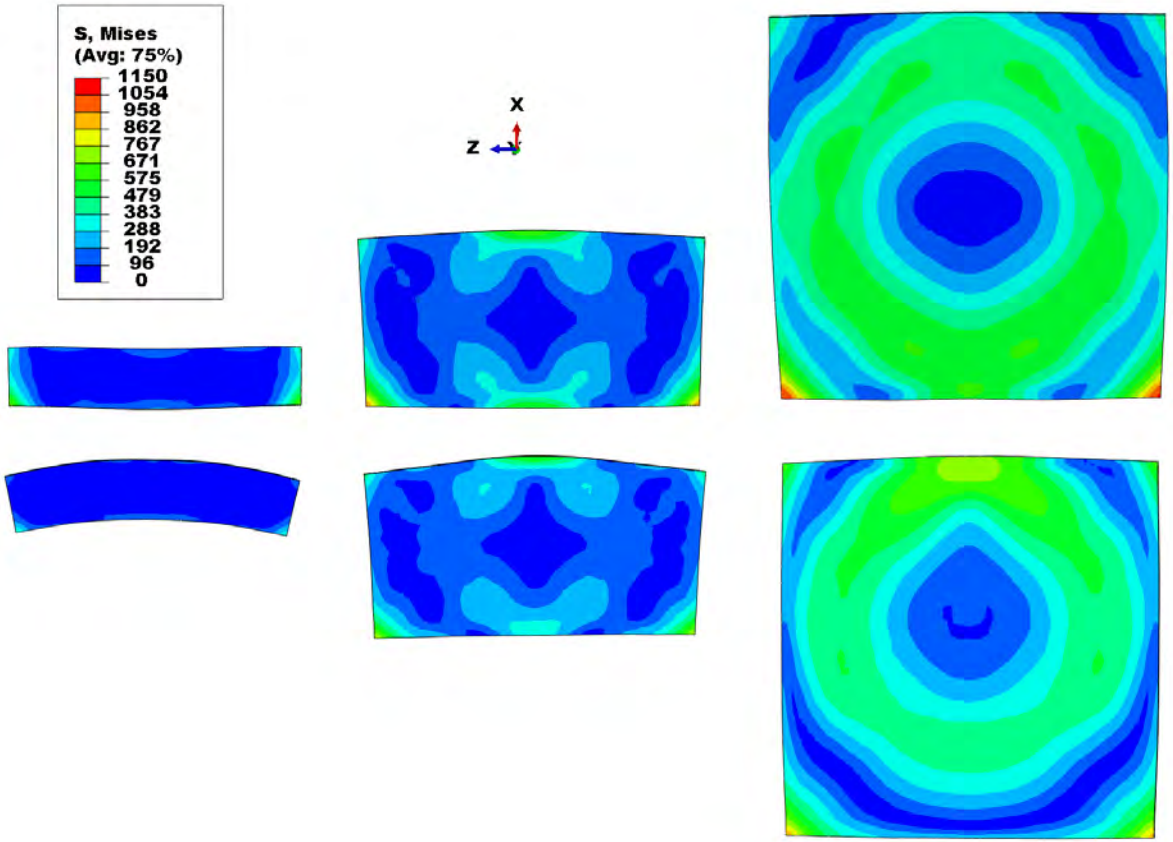
Axial Stress

Results – Vertical Rings



Hoop Stress

Results – Vertical Rings



Von Mices Stress

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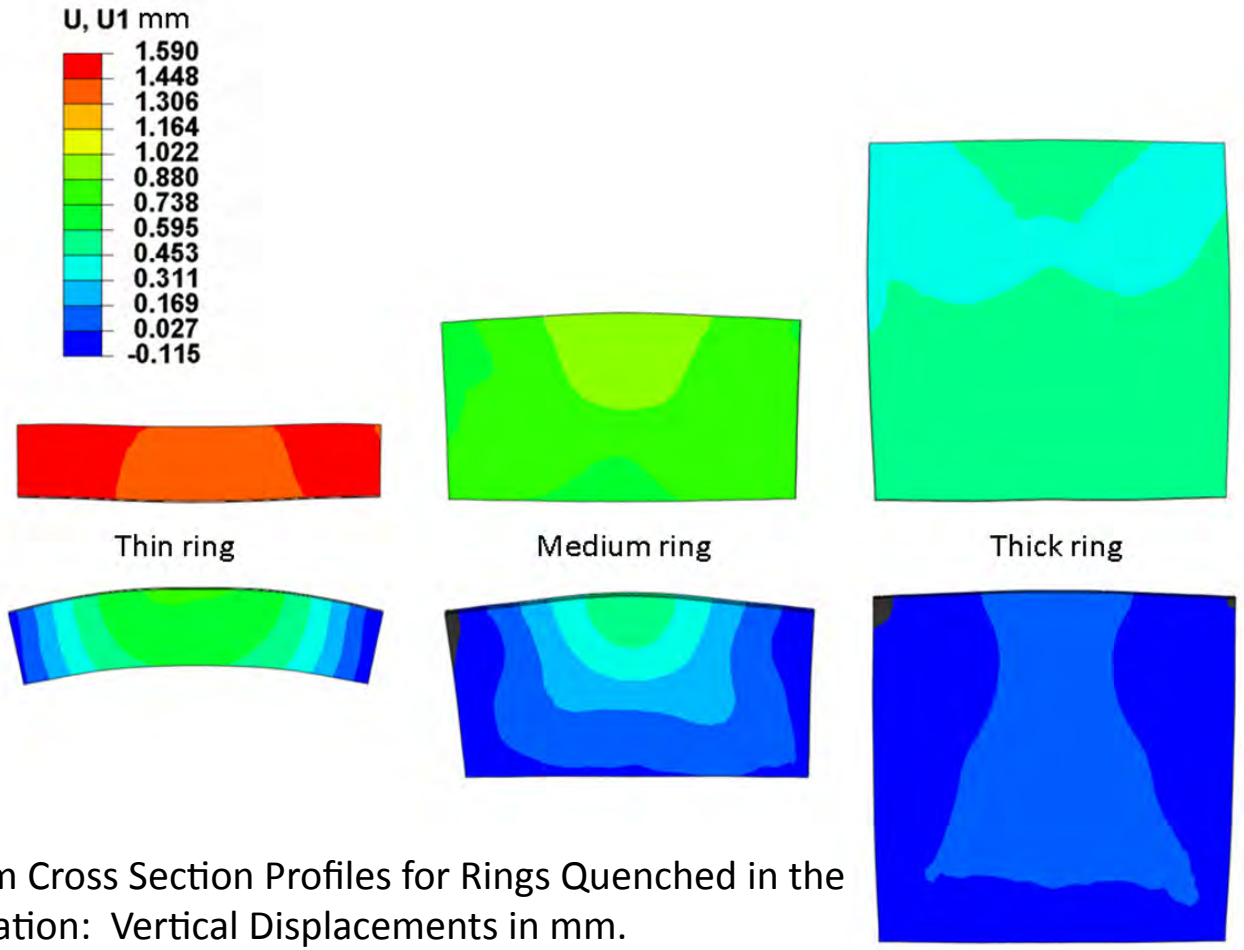
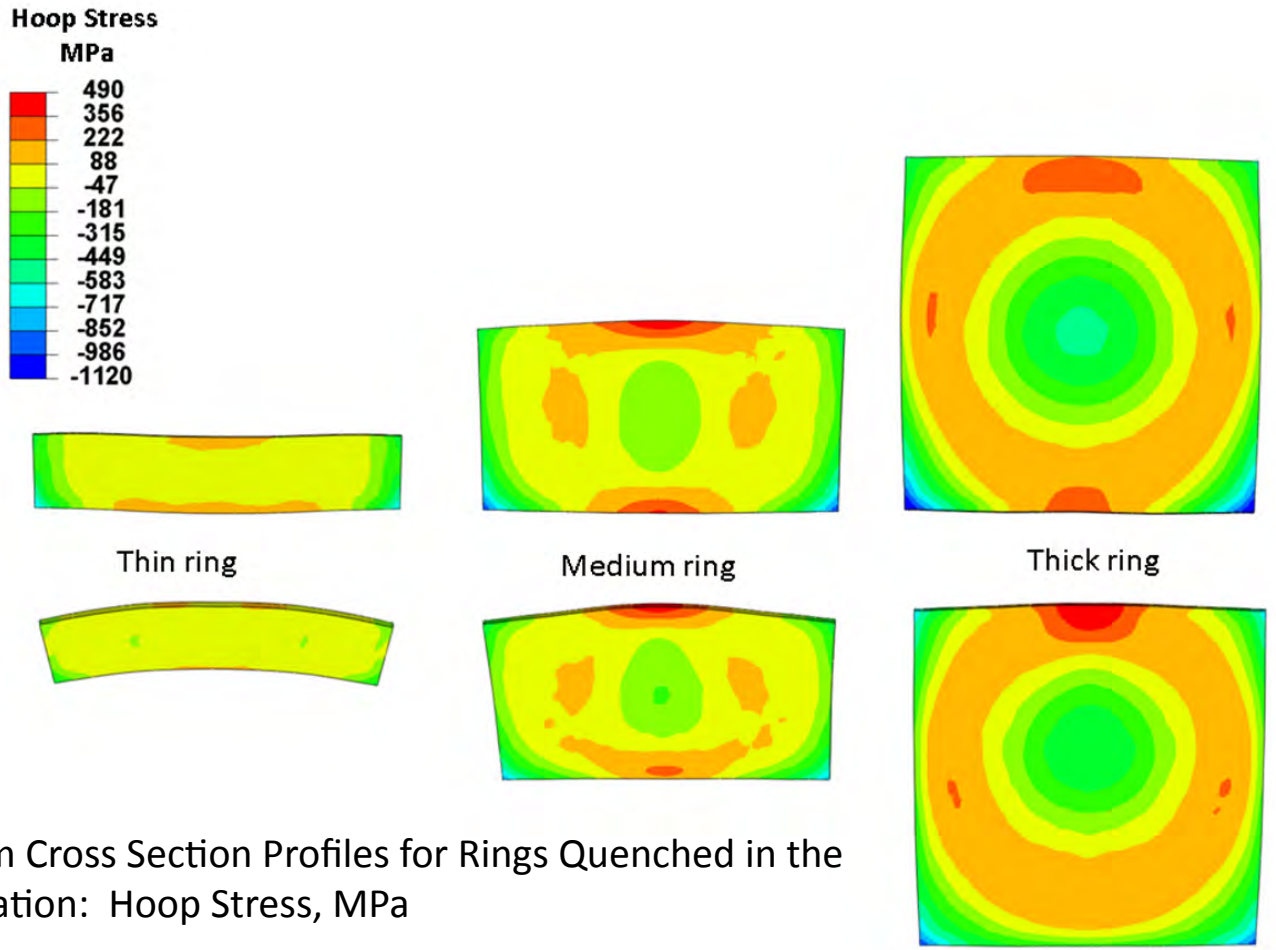
Results – Vertical Rings



Top and Bottom Cross Section Profiles for Rings Quenched in the Vertical Orientation: Vertical Displacements in mm.

Results – Vertical Rings



Top and Bottom Cross Section Profiles for Rings Quenched in the Vertical Orientation: Hoop Stress, MPa

Conclusions

- Horizontal Rings
  - Overall distortion of the horizontal rings is primarily “dishing” and tapering of the inside diameter.
  - Because of overall symmetry of heat transfer, rings remain round.
  - Appears to have a critical thickness where axial stress is a peak
  - Horizontal racking tends to have greater residual stresses along center of inside bore.
- Vertical Rings
  - Distortion is primarily out of roundness and bulging of inner diameter at bottom
    - Bulging is reduced at upper inner diameter because of greater percentage of diffusive phases (bainite and pearlite)
    - Out-of-roundness reduced as wall thickness increases
    - Overall growth of outer diameter
  - Similar to Horizontal rings, in that center of the inner bore exhibits high axial residual stresses at the height center, around the periphery of the inner bore
  - Vertical Rings also exhibit significant hoop stress that increases as wall thickness increases

Acknowledgements

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