OAK RIDGE National Laboratory

Preliminary Cylinder Hydrogen Vessel Stress Analysis

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U.S. DEPARTMENT OF ENERGY

Cylinder Hydrogen Vessel Stress Analysis Overview

- Hydrogen vessels shall be designed to the intent of the ASME BPVC
- Analysis guided by 2021 ASME BPVC Section VIII D2
  - Elastic Analysis Approach
  - Allowables from code case 2478-1
    - Al 6061-T6 Hand Forging up to 4" thickness – S = 85 MPa, S_{M+B} = 127 MPa
    - Al 6061-T6 Welded – S = 55 MPa, S_{M+B} = 83 MPa
- Only 19 bar Internal Pressure considered
  - Negligible thermal stress due to CTE ~ 0 at 20 K operating temperature
  - Negligible static head and fluid momentum effects due to low density operating fluid
  - Negligible deadweight load – vessel mass is 0.30 kg
  - Non-existent snow and wind loading
  - Earthquake loads will need to be considered in final design

Material Properties

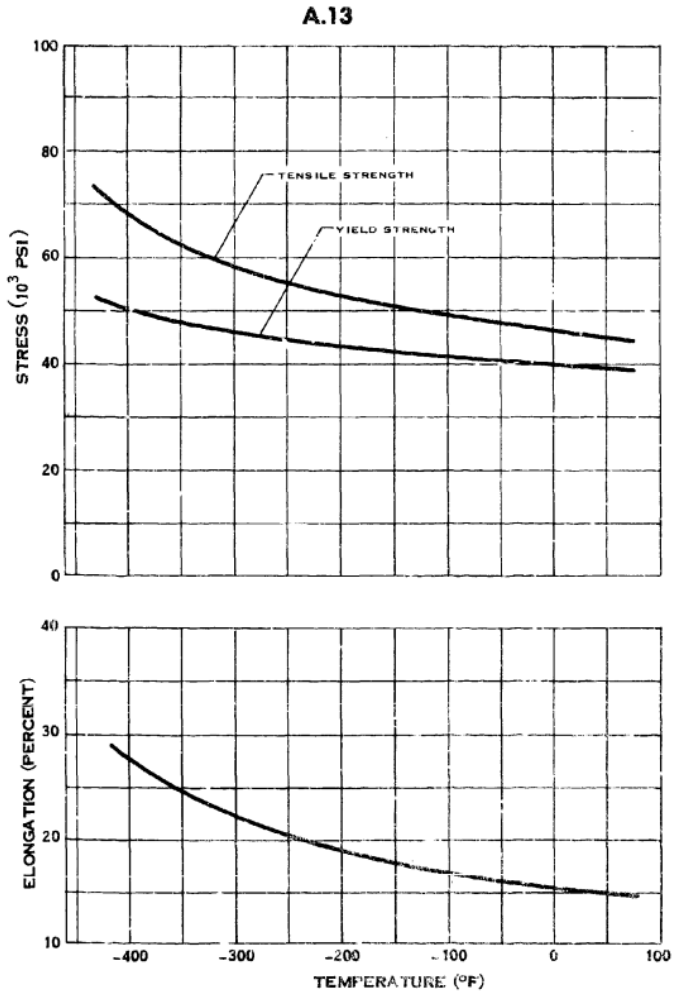
- **Aluminum 6061-T6 properties**

Modulus of Elasticity (GPa)	68.9
Poisson's Ratio	0.33
(100° F) Sm (MPa)	85
Sm Weld (MPa)	55

ASME BPVC Section8 Division 2 Allowable equivalent stress values
Code case 2478-1

	Sm Membrane	**Sm Membrane+ Bending (1.5x)**	**Sm Membrane+ Bending + Secondary (3x)**
Non-Weld Regions (MPa)	85 MPa	127 MPa	254 MPa
Weld regions	55 MPa	83 MPa	165 MPa

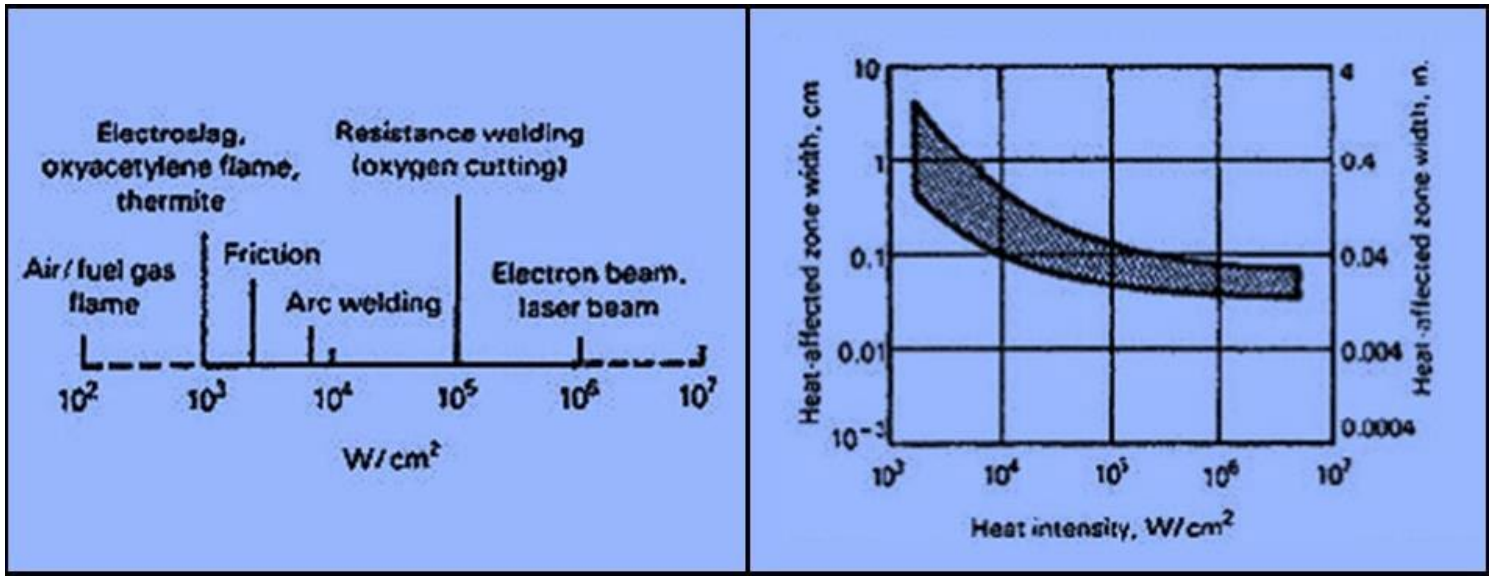
Note: 6061-T6 is stronger and more ductile at 20 K (-423°F) operating temperature, but the BPVC does not allow taking credit for this increase



Cryogenic Materials Data Handbook, AFML-TDR-64-280, Air Force Materials Laboratory, 1970

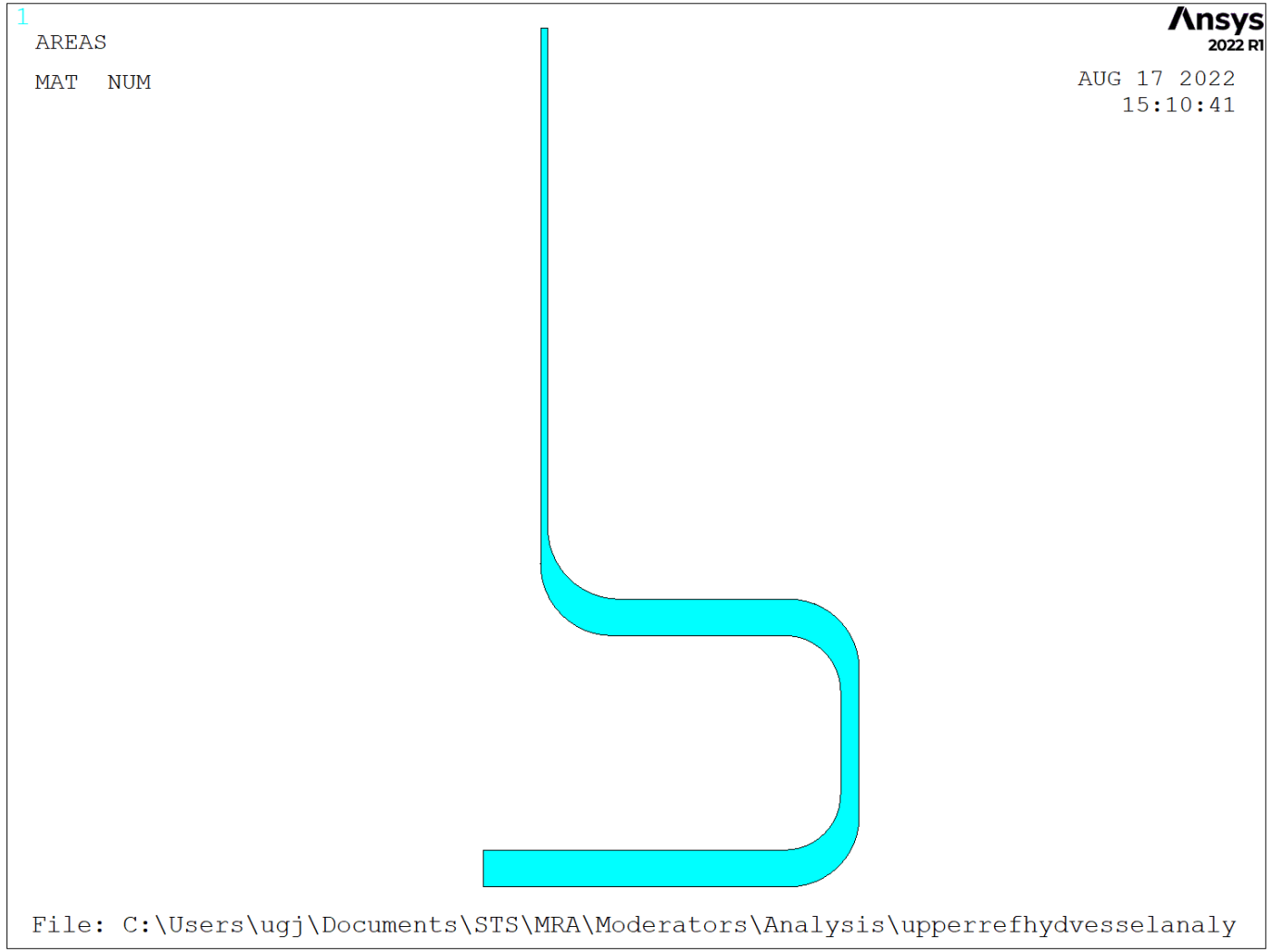
Weld Heat Affected Zone Width

- Weld width of cosmetic pass of up to 5mm from cylinder moderator prototypes
- Heat affected zone width of 1mm from the chart below
- Total weld heat affected zone width of 6 mm, or 3mm from the centerline of the weld



Nominal Cylinder Hydrogen Vessel Geometry

- Cylinder moderator geometry from preliminary optimization
  - 30mm H height
  - 100mm H diameter
  - 5.15mm bottom wall thickness
  - 2.6mm cylindrical wall thickness
  - 5.1mm top wall thickness
- Axisymmetric Model



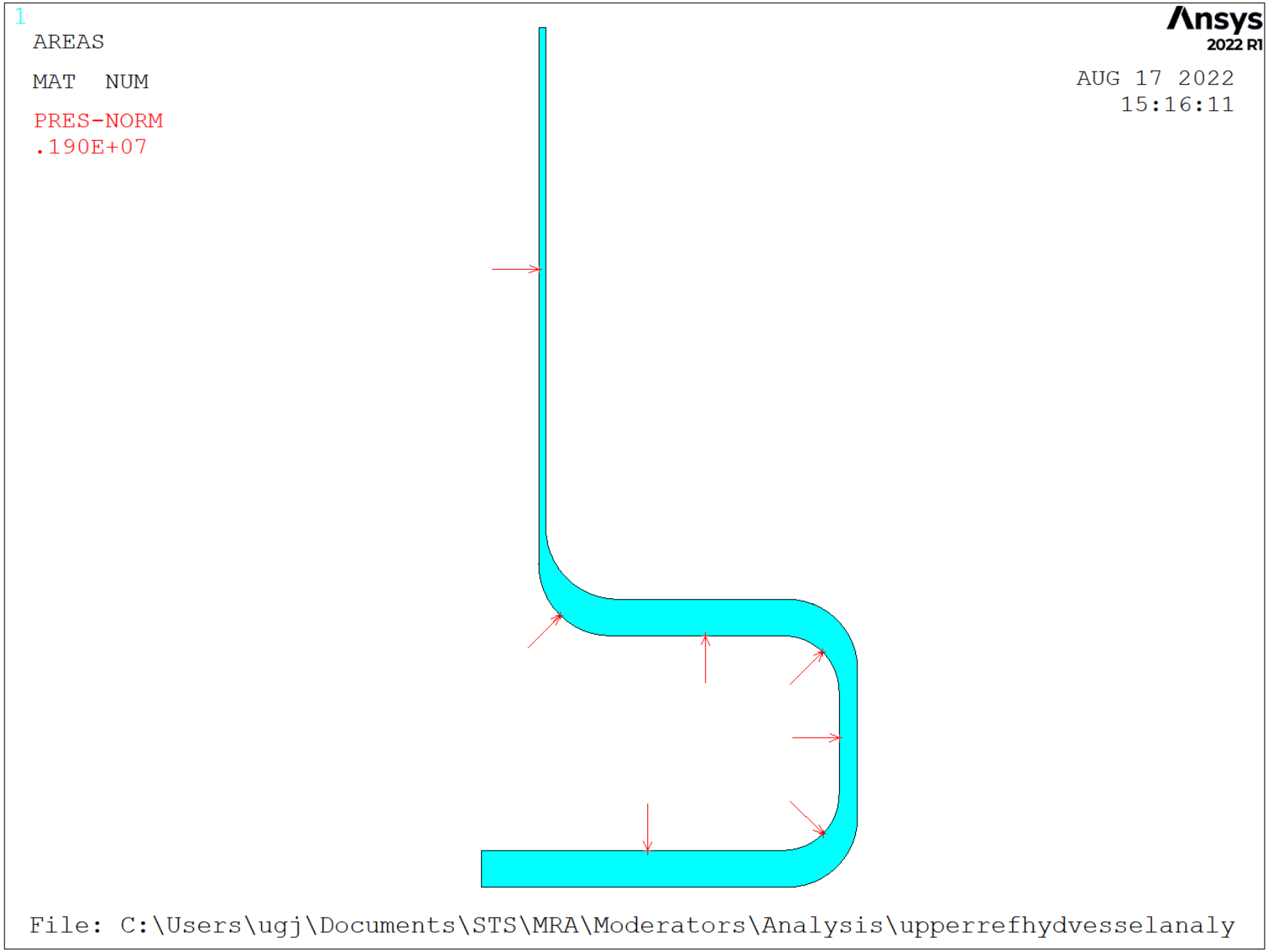
Ansys File Name: upperhydvesselanalysis-r5.db
Parasolid File Name: upperrefhydvesselanalysis-r5c.x_t
Creo File Name: upperrefhydvesselanalysis-r5.prt

Mesh

- 8 node axisymmetric quad elements
- 2678 elements
- 8851 nodes
- 6 to 8 elements thru the wall except in hydrogen pipe

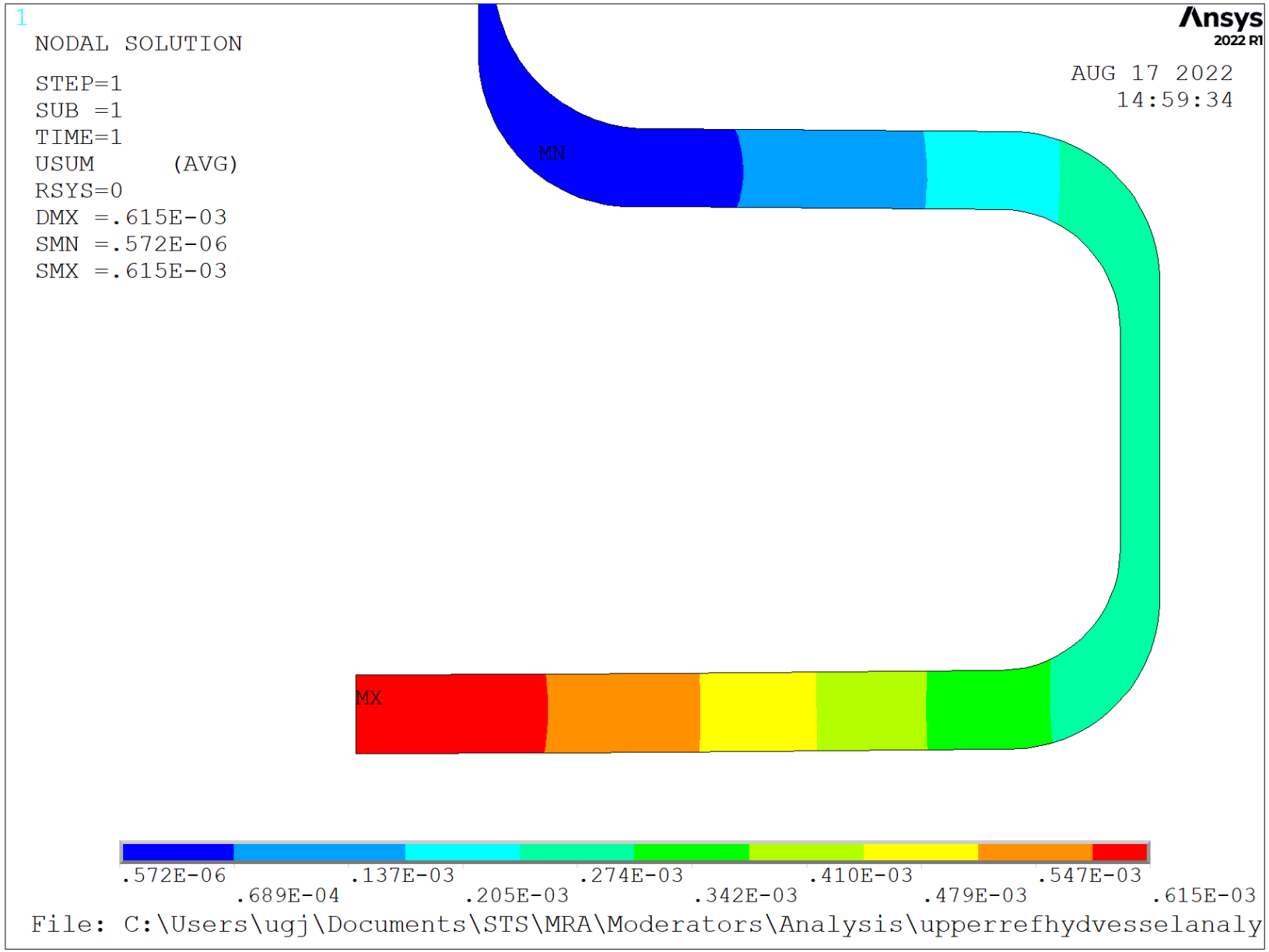
Loads

- 19 bar internal pressure
- Axisymmetric boundary condition
- Fixed vertically at hydrogen pipe end



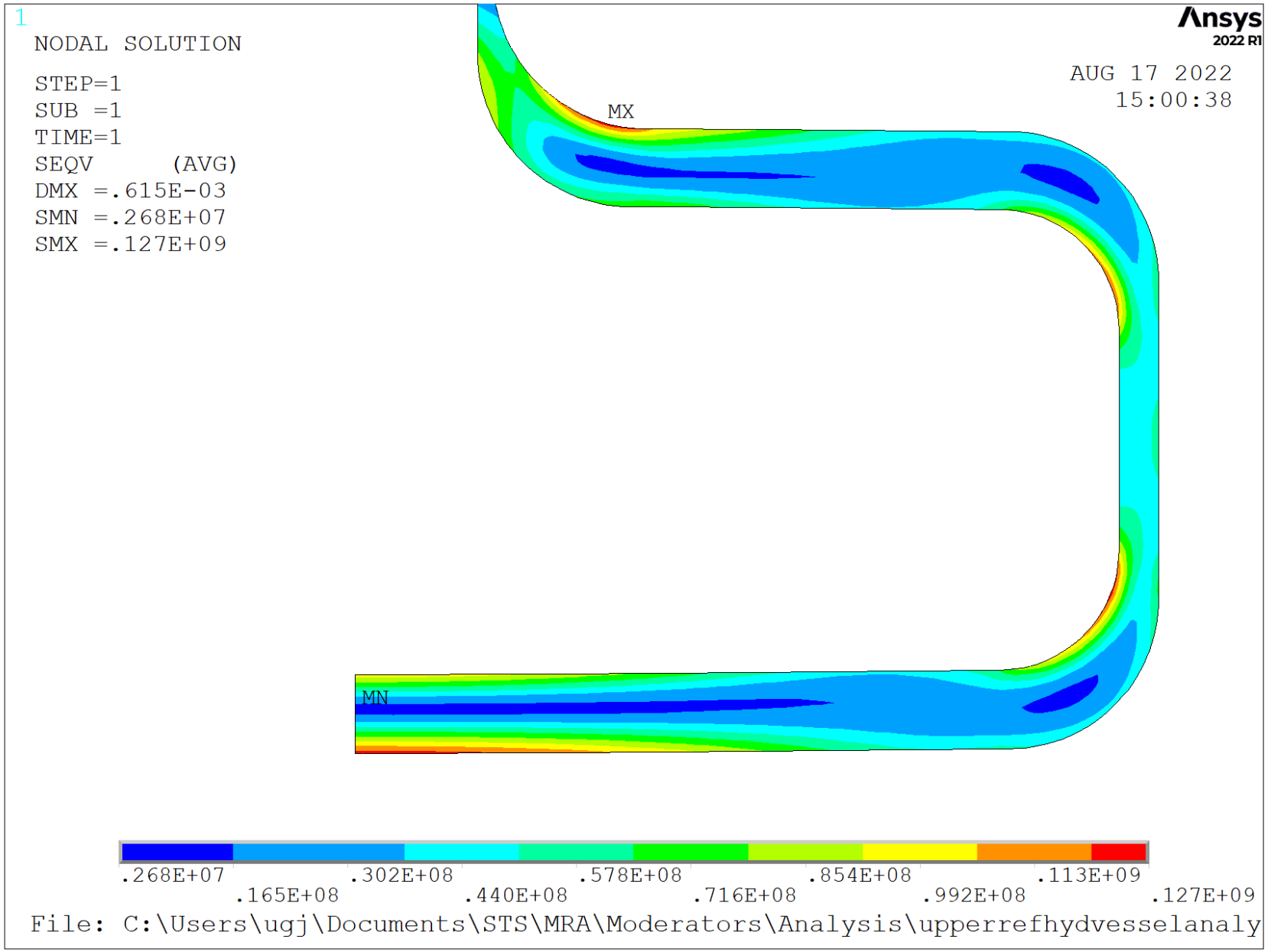
Displacement Contour Plot

- Maximum displacement is 0.615mm
- Cylinder moderator shows significant deflection under internal pressure
  - Need to consider dishing top and bottom surfaces to compensate for deflection at nominal pressure



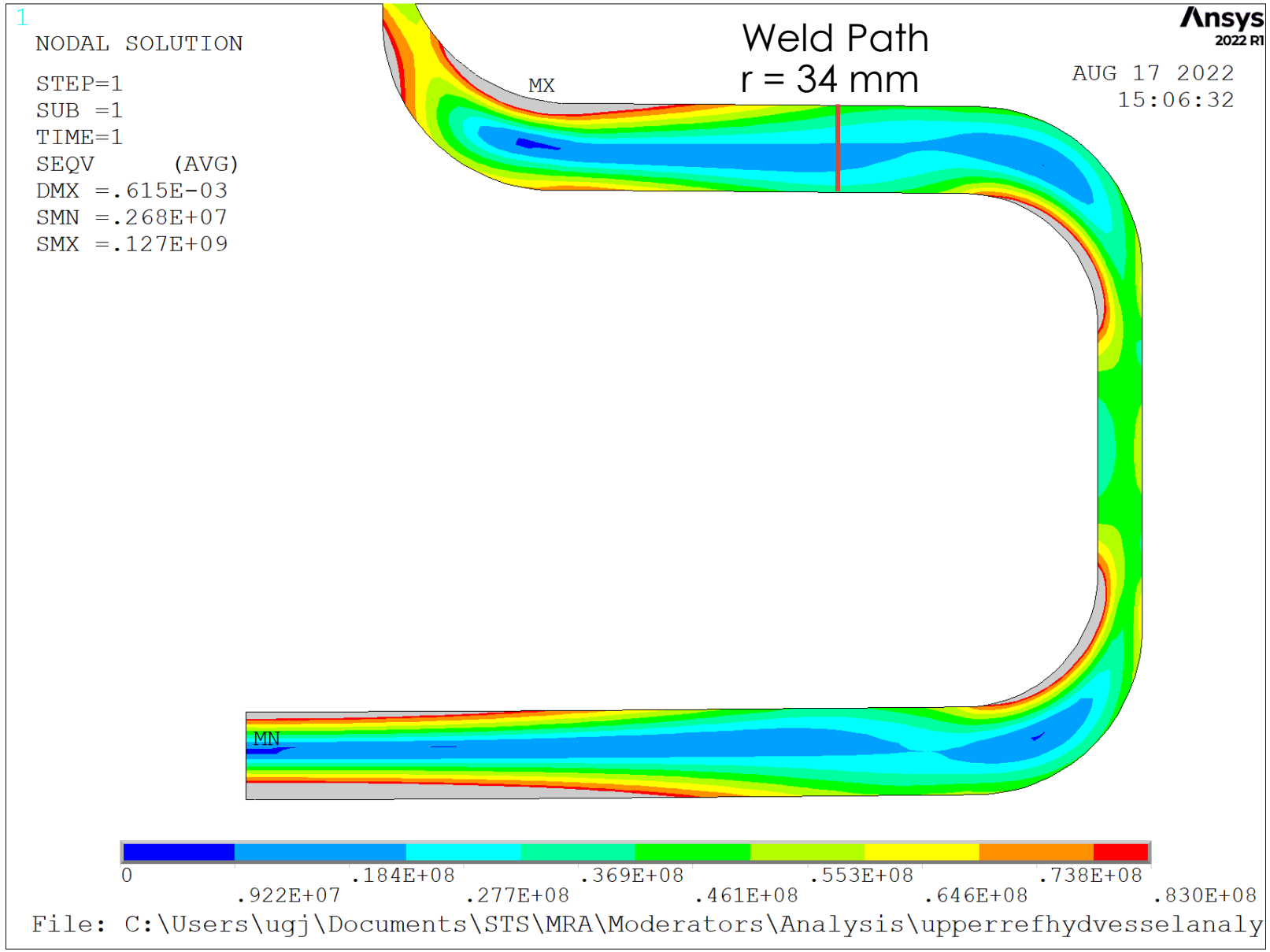
Von Mises Stress Contour Plot

- Maximum Von Mises Stress of 127 MPa on radius of neck
- All locations 127 MPa or lower, which meets the M+B allowable



Von Mises Stress Contour Plot - Welds

- Stresses much below the 83 MPa weld M+B allowable in region of the weld
- Weld is ~8 mm from the high stress zones in either direction



Results Summary

	Maximum Von Mises Stress (MPa)	Minimum Distance Overstress to Weld (mm)
Allowable	127	3
Actual	127	8

Conclusions

- The preliminary cylinder hydrogen vessel design meets the intent of the ASME BPVC
- Stresses in bulk and weld affected zones meet allowable stress requirements
- Deflection of 0.6 mm seen on the bottom of the vessel
  - During final design, consider dishing of the top and the bottom of the vessel to give flat surfaces at operating pressures
- Additional loads to consider during final design – but not expected to affect vessel design
  - Internal vacuum condition
  - Seismic loads

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