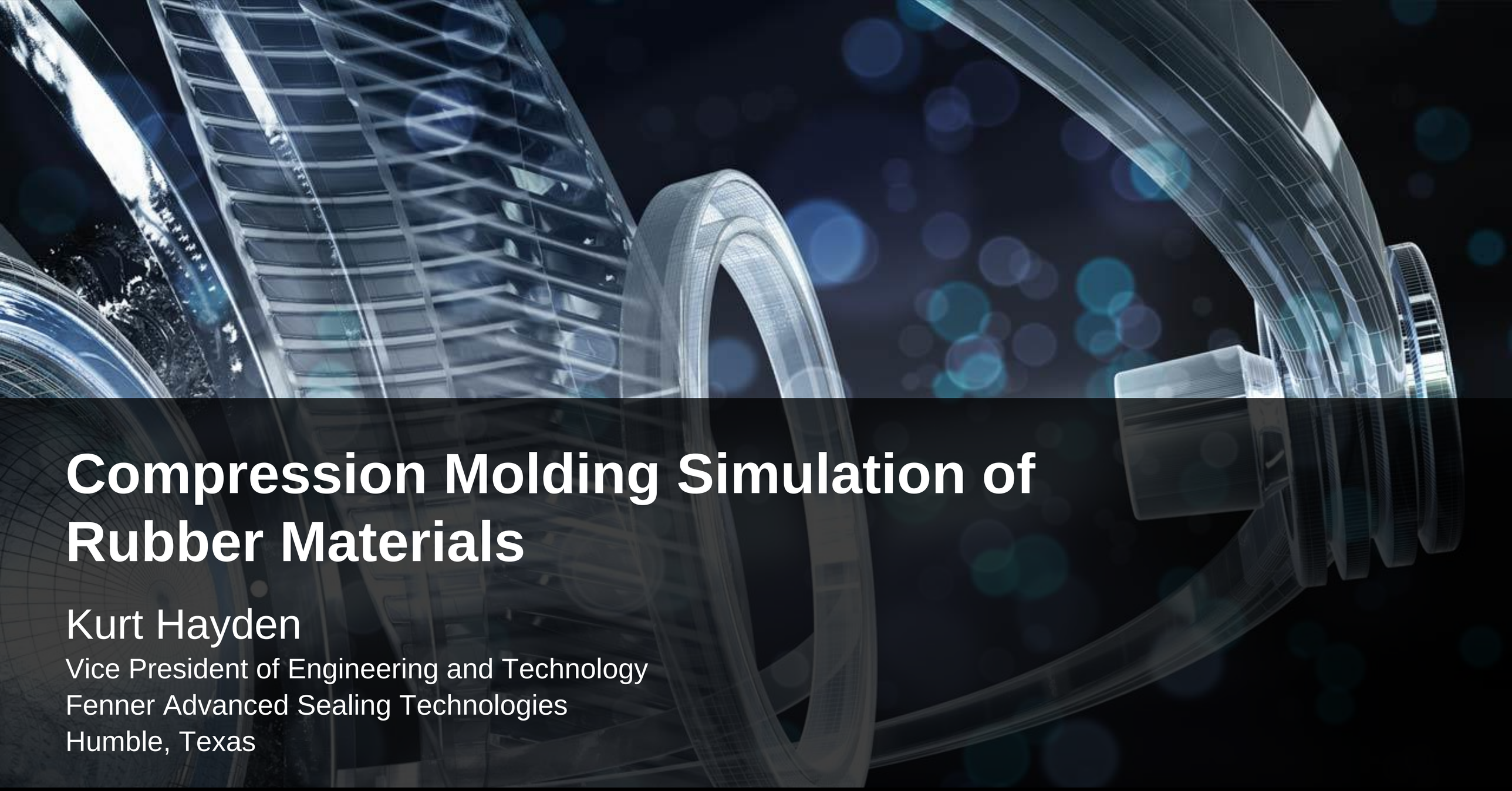

Compression Molding Simulation of Rubber Materials

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Fenner Advanced Sealing Technologies

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Class Summary

This class will give an overview of the compression molding of rubber including material characteristics, the processes involved and tooling considerations. Difficulties encountered during the molding of rubber will be discussed. The opportunities that simulation of rubber molding processes may provide will be considered, including the current state of these types of simulation and thoughts on future enhancements.

Learning Objectives

At the end of this class, you will be able to:

- Understand the composition and characteristics of rubber.
- Conceptualize how rubber is compression molded.
- Be aware of the difficulties of predicting the results of rubber molding.
- Consider how flow analysis can help reduce uncertainties in the development of rubber products.

Class Outline

- Background
- Material Information
- Processing Methods
- Simulation Considerations
- Example Simulations
  - Compression Molding
  - Transfer Molding
  - Bonus Round

“Rubber… But where does it come from?”

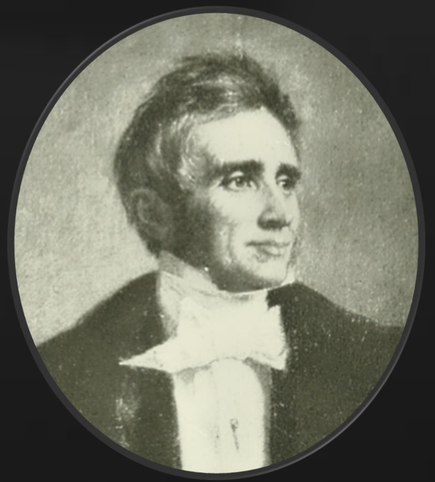
Origins

Charles Marie de La Condamine
- 1736 – Discovery in Ecuador

Joseph Priestley
- 1770 - Termed “rubber”

Charles Goodyear
- 1839 – Sulfur vulcanization

Sir Henry Wickham
- 1876 – ‘Stole’ 70,000 seeds



Natural Rubber

- Nature's best
  - Pará rubber tree (*Hevea brasiliensis)*
  - Gutta-percha (*Palaquium gutta*)
  - Dandelion (*Taraxacum officinale*)
- South American Origins
- Largest Producers
  - Thailand
  - Indonesia
  - Malaysia

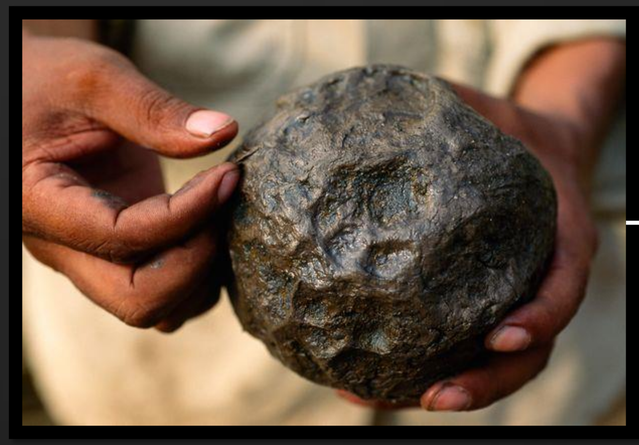
Applications

- 1600 BC – Mayan Game Balls
- Leather replacement
- Clothing
- Tires
- Hoses
- Adhesives
- Drive belts

Material Characteristics

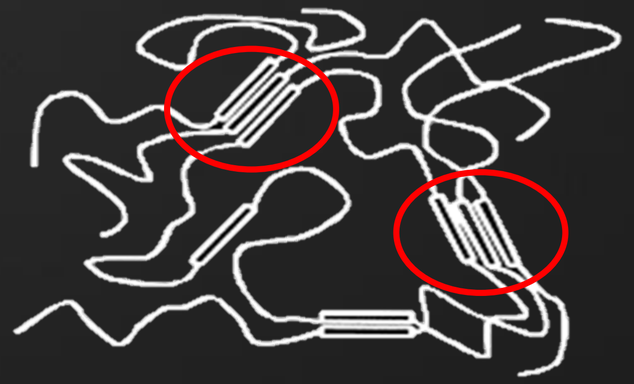
The Basics

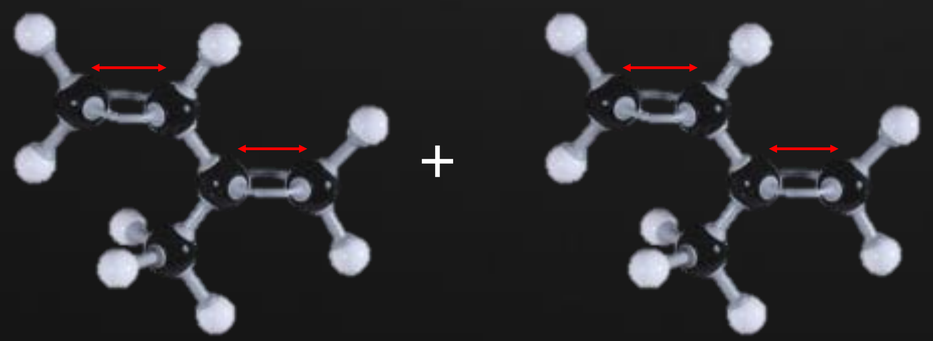
- It’s a Polymer
- Thermoplastic v. Thermoset
- Elastomer
  - How much deformation?
    - 100% reversible
    - 300% reversible
    - 5-700% reversible
    - Up to 1000%



Keep in Mind

- Polymeric nature
- Molecular weight





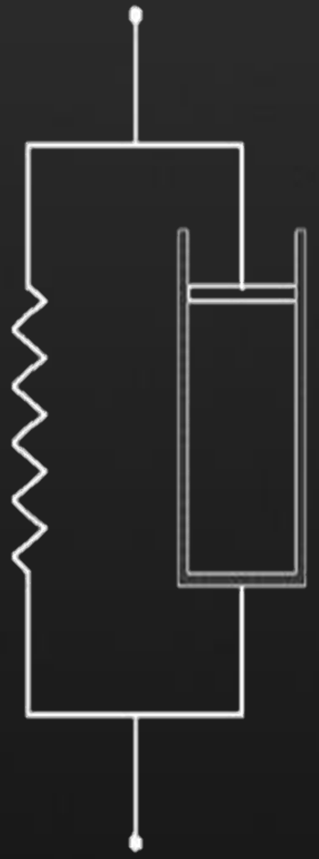
Isoprene + Isoprene

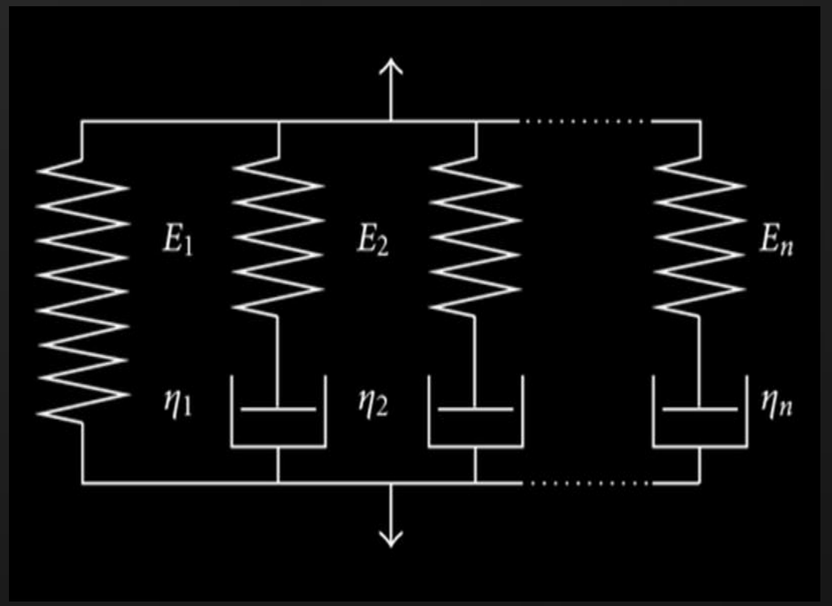
catalysts →

Polyisoprene (natural rubber)

Important

- Polymeric nature
- Molecular weight
- Viscoelastic effects
- Cross-linking





Rubber compounding

Why not pure rubbers?

- Cost
- Properties improvement
  - Mechanical
  - Abrasion resistance
  - Chemical resistance
  - Environmental
- Processability

Typical simple recipe for tire compound

Ingredients	PPH	Function
SBR 1502, synthetic rubber	80	Rubber
SMR 20, natural rubber	20	Rubber
N299 carbon black	60	Reinforcing agent
Naphthenic oil	10	Processing oil
6PPD (phenylene diaming antiozonant)	3	Antidegradant
TMQ (antioxidant)	1	Antidegradant
Wax blend	2	Antidegradant
Stearic acid	1	Activator
Zinc oxide	4	Activator
TBBS	1.2	Accelerator
Sulfur	2.5	Vulcanizing agent

Physical properties

Typical Properties for Selected Rubber Compounds								
Property	**ASTM method**	**VMQ**	**NBR**	**EPDM**	**HNBR**	**FKM**	**FEPM**	**FFKM**
Hardness, A	D-2240	30-90	50-95	50-90	60-95	65-95	75-95	70-95
Tensile, PSI	D-412	1200	2700	2700	4200	2800	3500	2800
Elongation, %	D-412	370	390	170	150	110	150	150
M100, PSI	D-412	340	610	1500	2800	2500	2800	2500
M50, PSI	D-412	240	300	620	1200	1400	1200	1400
General Cost	US$/Lb	5	3	3	10	15	25	2000
General Cost	US$/$in^3$	.22	.13	.12	.43	1.03	1.73	144.00

Processing

Industrial Processing Methods

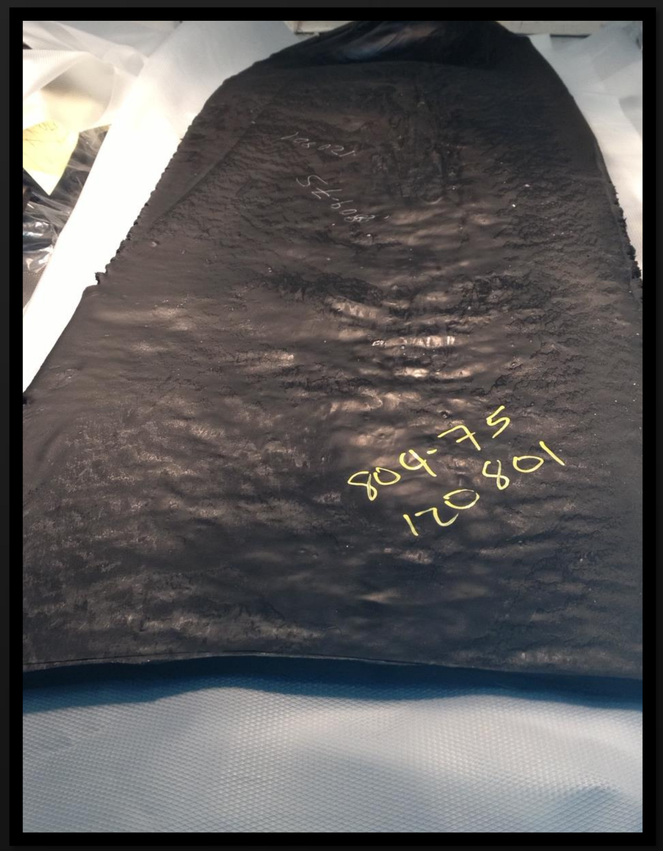
- Compression Molding
  - Minimal “flow”
  - Isostatic
  - Mandrel Wrap
- Transfer Molding
  - True material flow
  - More “work” to the material
- Injection Molding
  - Considerable material flow
  - High Volume

Manufacturing Process Steps

- Mixing
- Milling
- Preforming
- Molding
- Post-Cure

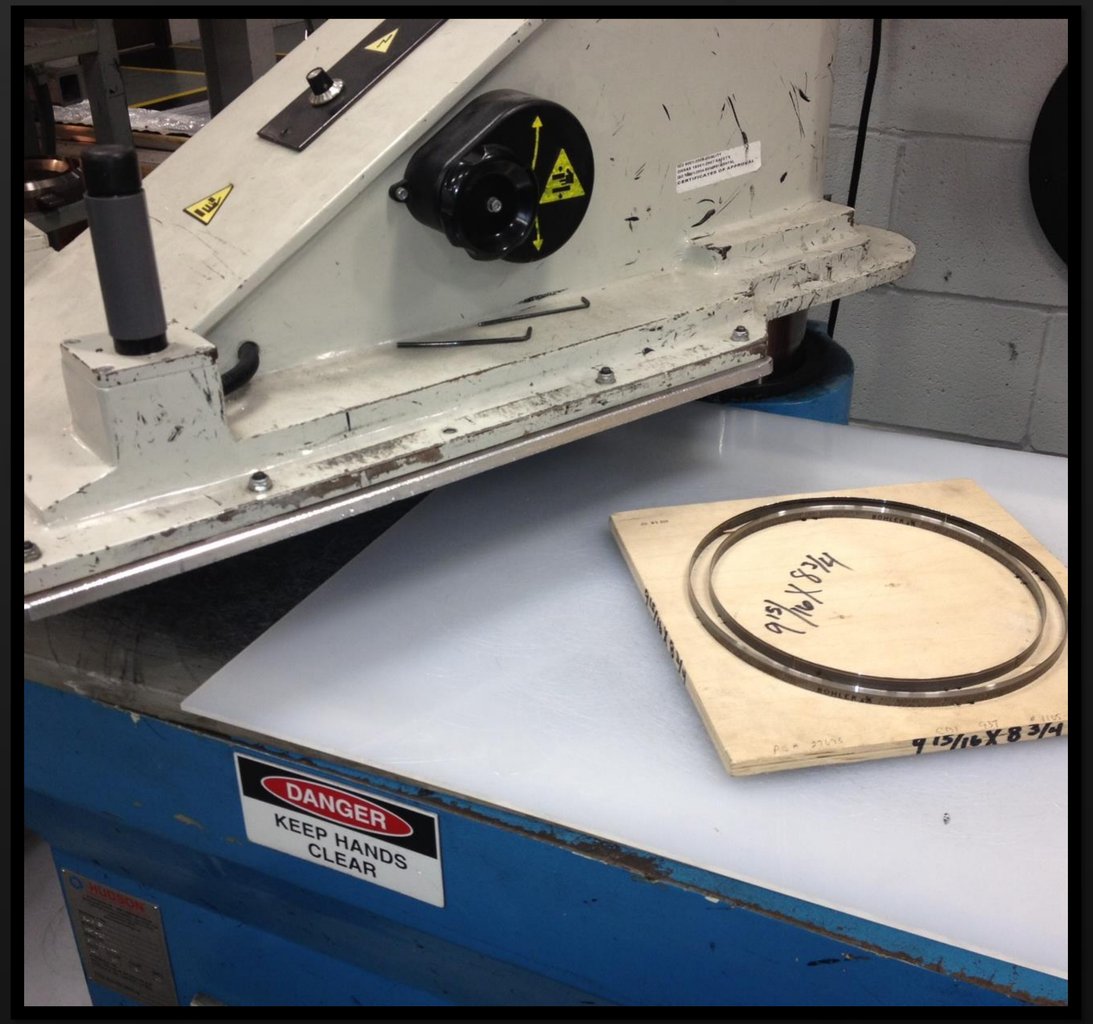
Milling

- Done Right
  - “Energize”
  - Compresses
  - Warms
  - Dispersion
- Can be done wrong
  - “Nerve-y” material
  - Scorched material



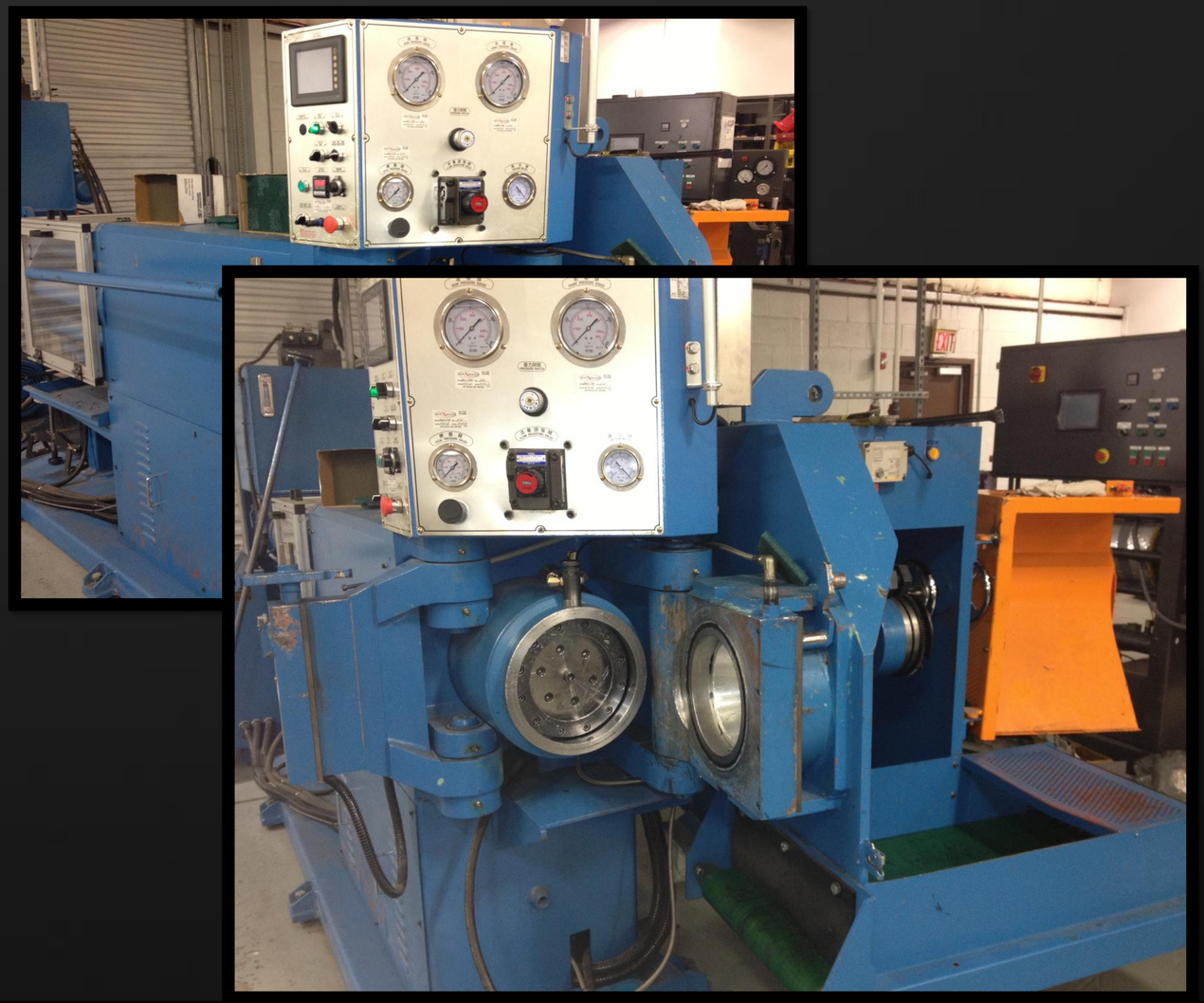
Preforming – Die Cut

- Handcutting
- Clicker dies
- Cut-to-length extrudate



Preforming - Extrusion

- Pigs!
- Barwell v. Screw
- Die design
- Cutoff methods

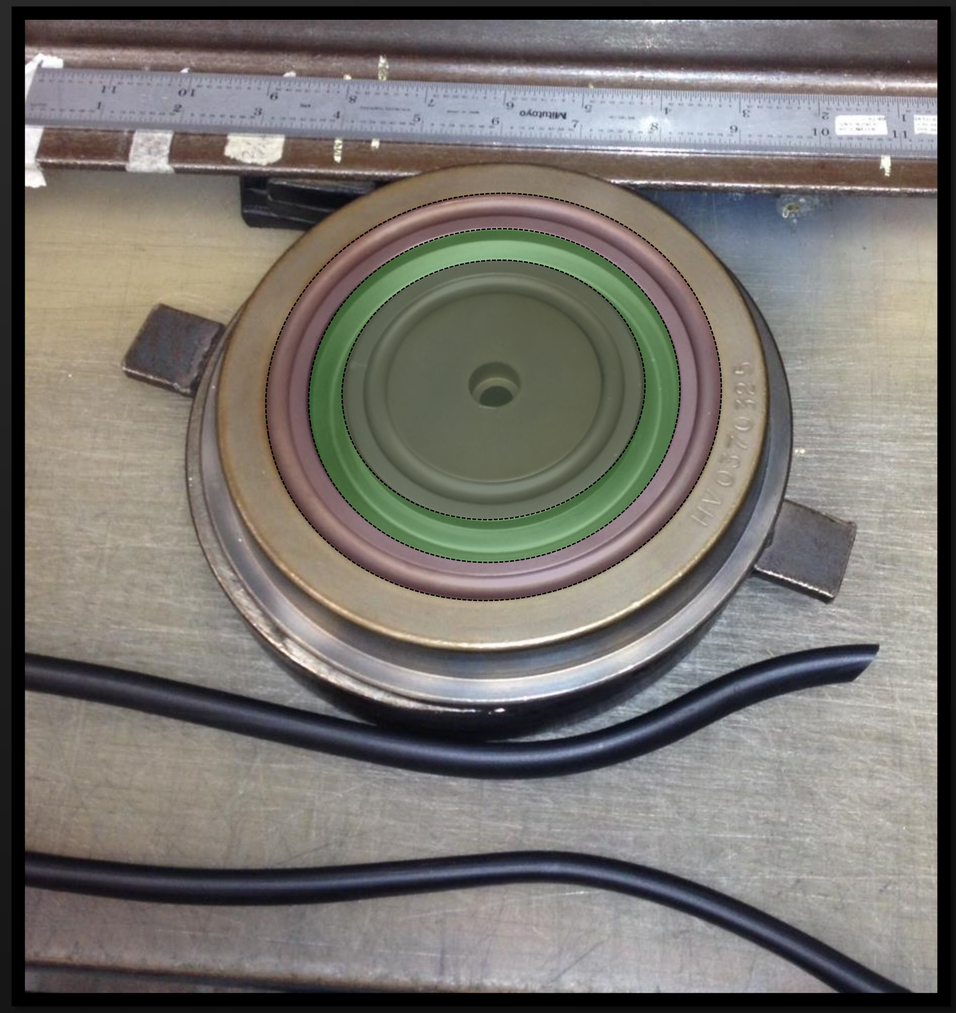


Preforms - Extruded

- Sized to cavity
- Constant cross section
- Weight is best
- Generally cut to length

The Compression Mold

- Plate locating
- Pry tabs
- Cavity
- Overfill
  - Flash grooves
  - Spew grooves
  - Overfill grooves
  - Tear strips



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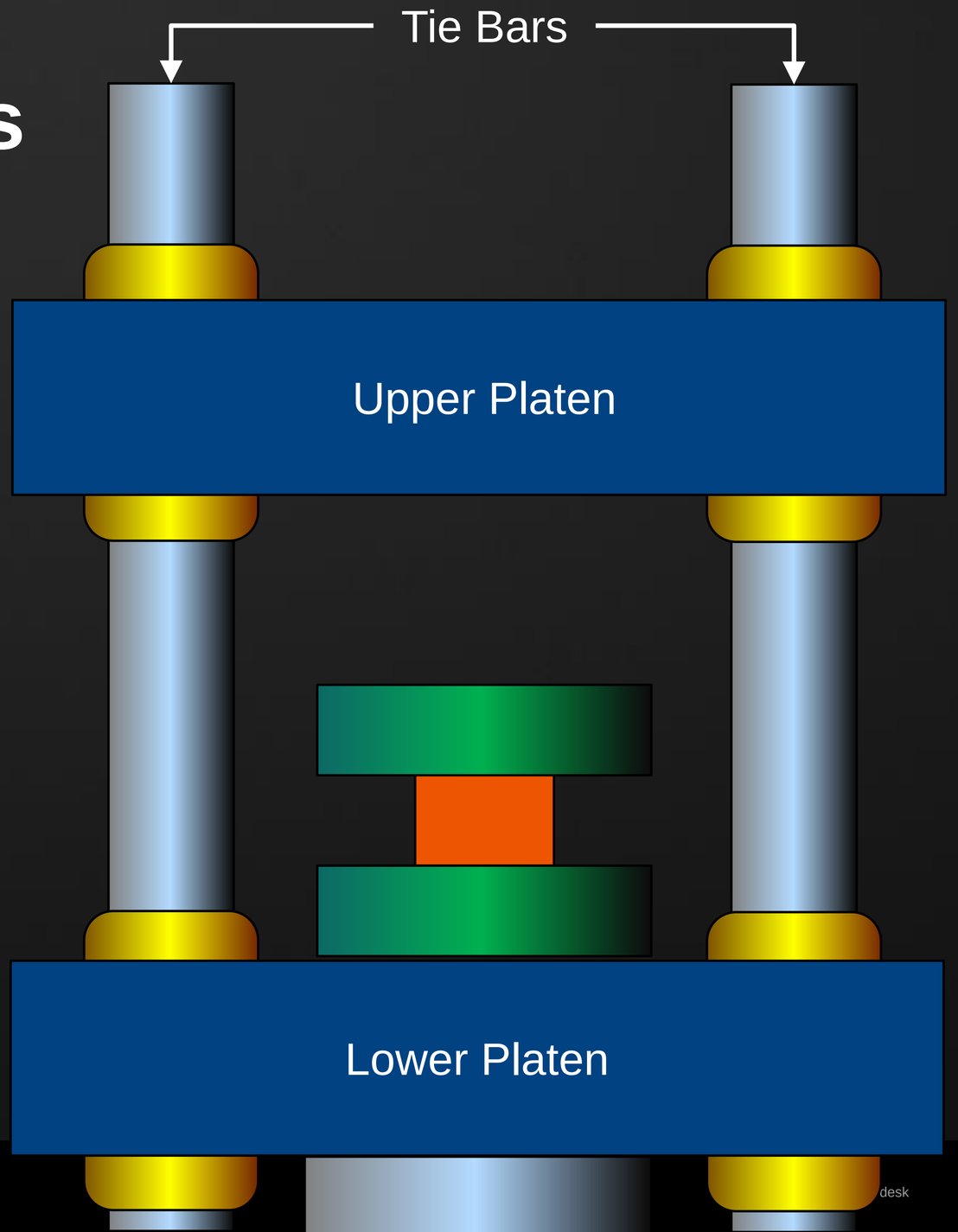
Compression Molding Press

- Components
  - Tie bars
  - Platens
  - Hydraulic cylinder(s)



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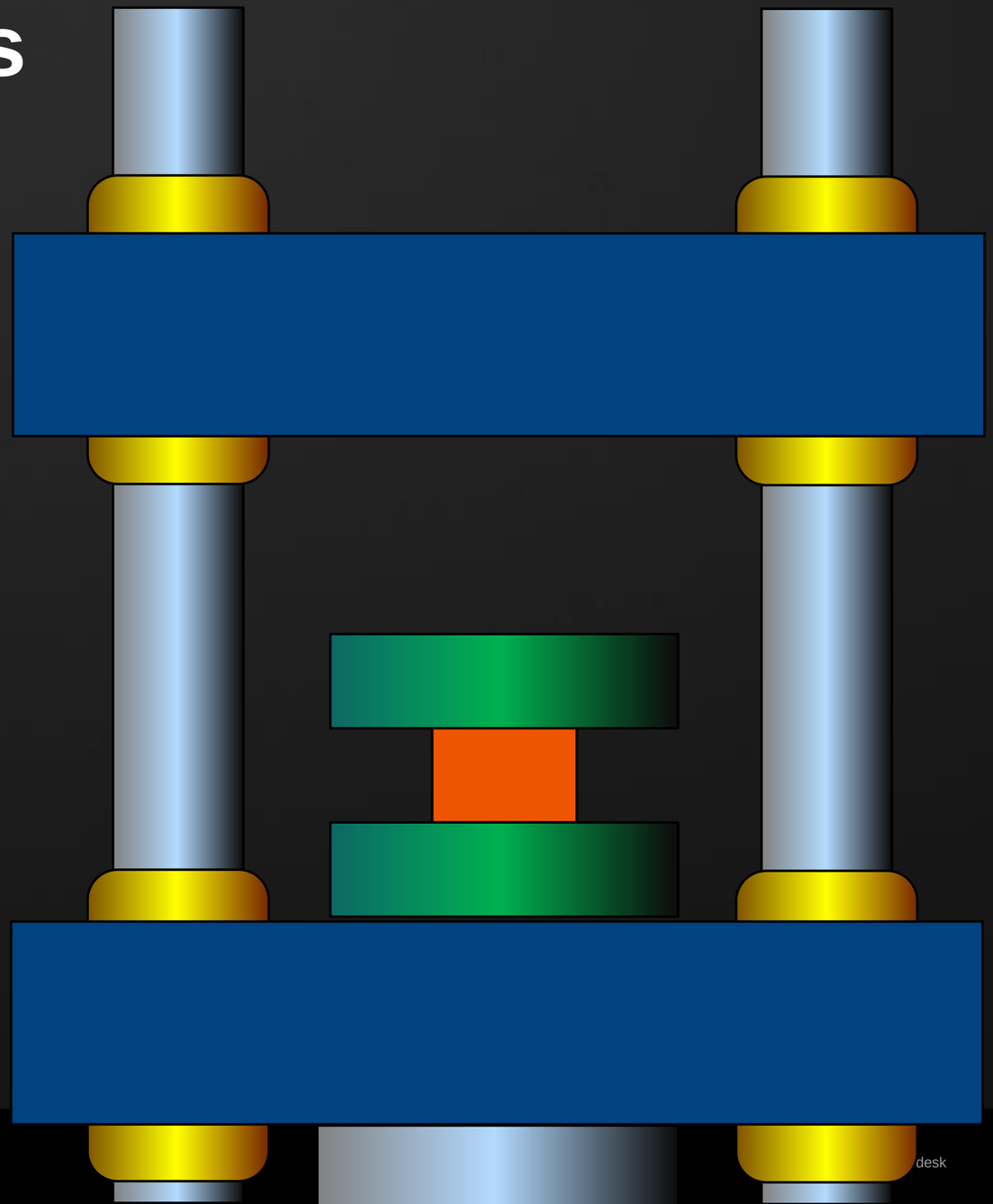

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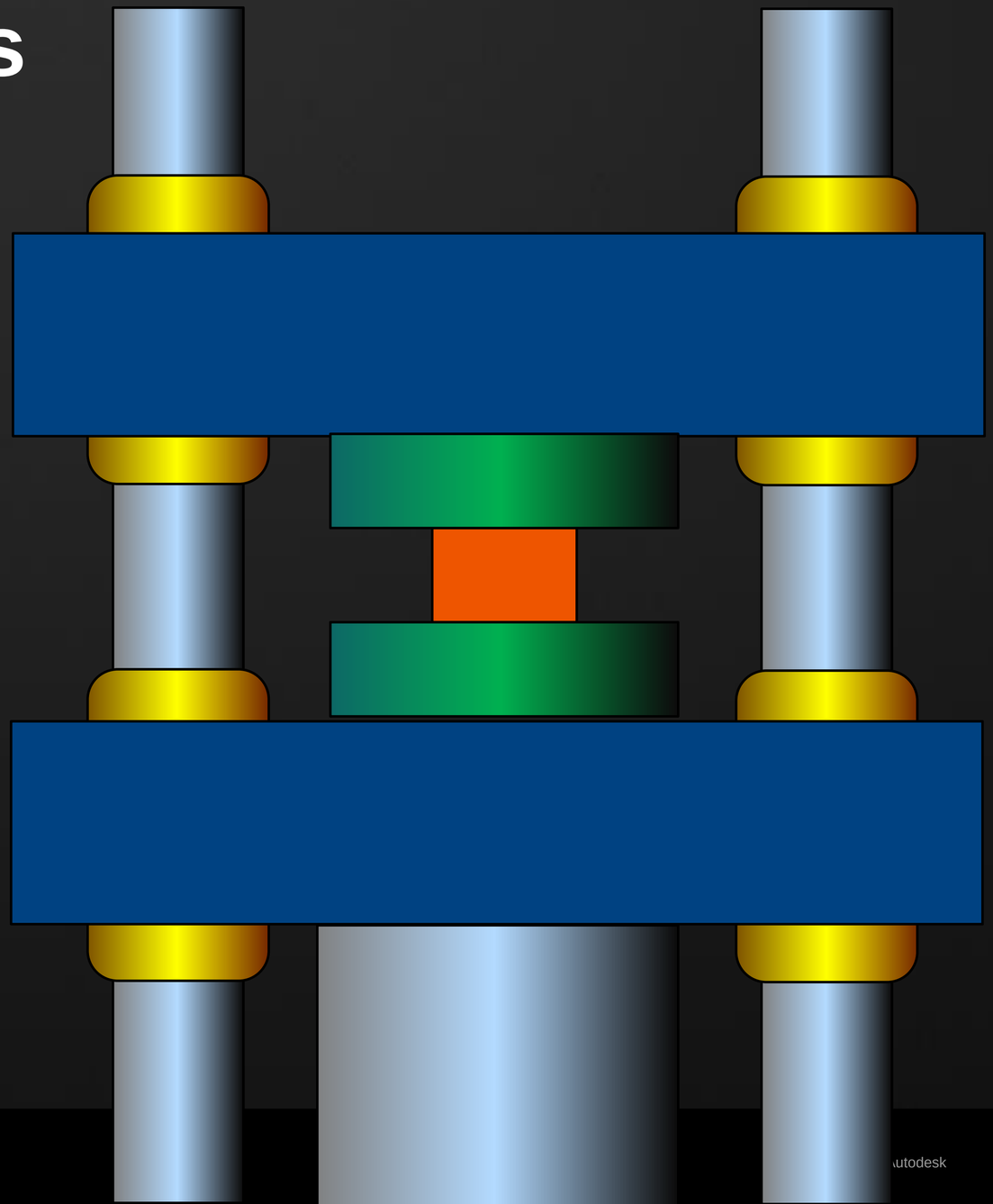
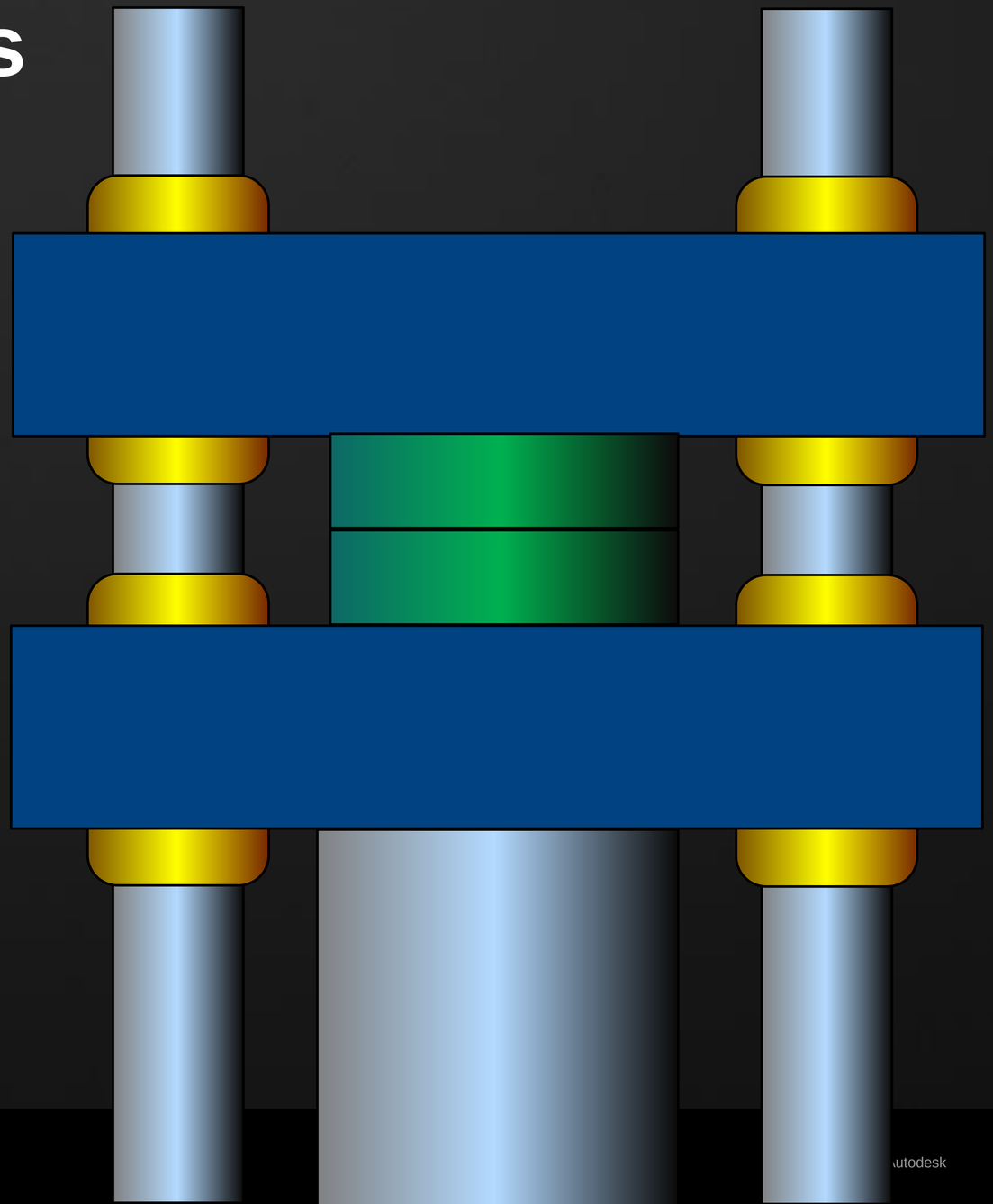


Compression Molding Press

- Components
  - Tie bars
  - Platens
  - Hydraulic cylinder(s)
- Controls
  - Pressure
  - Temperature
  - Timers
  - Bumps
  - Speed



Transfer Molding Press

- Two Methods
- By the mold
  - Transfer pot
  - Sprues & gates
- By the press
  - Pot on the machine
  - Note the cylinder on top

Molding Cycle

- Preheating
- Cleaning
- Release
- Loading
- Pressing & Curing
- Unloading

The Shot

- Part (cavity)
- Flash Rings

Post Cure Process

- Forced air oven
- Programmed cycle
  - Times
  - Temperatures
- Optimizes crosslinking
- Removes volatiles
- Dimensional issues

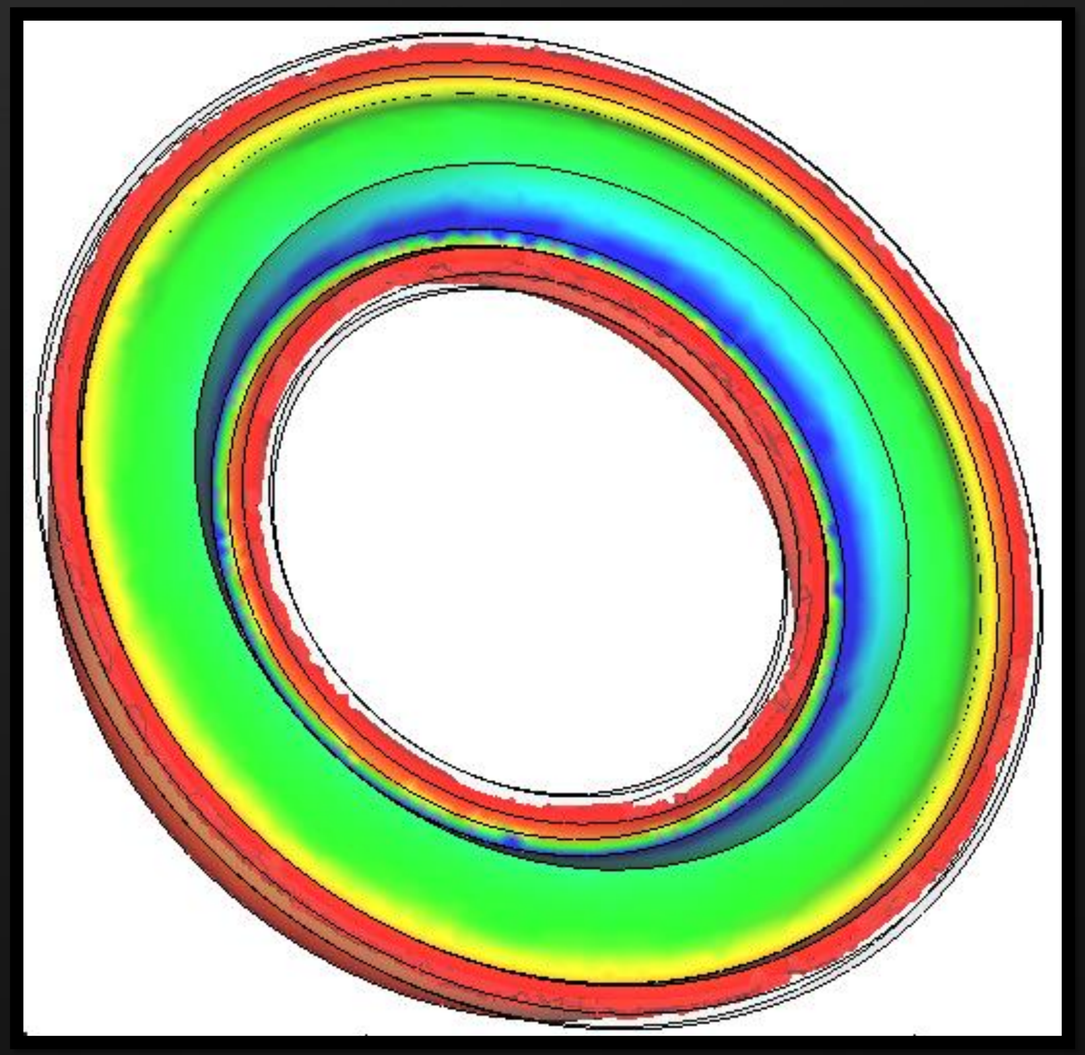
Trimming

- Before or After Post-cure
- Manually
  - Knife
  - Sandpaper
- By machine
  - Die cut
  - Buffing wheel
  - Shot blasting
  - Cryogenics deflashing

Considerations for Simulation

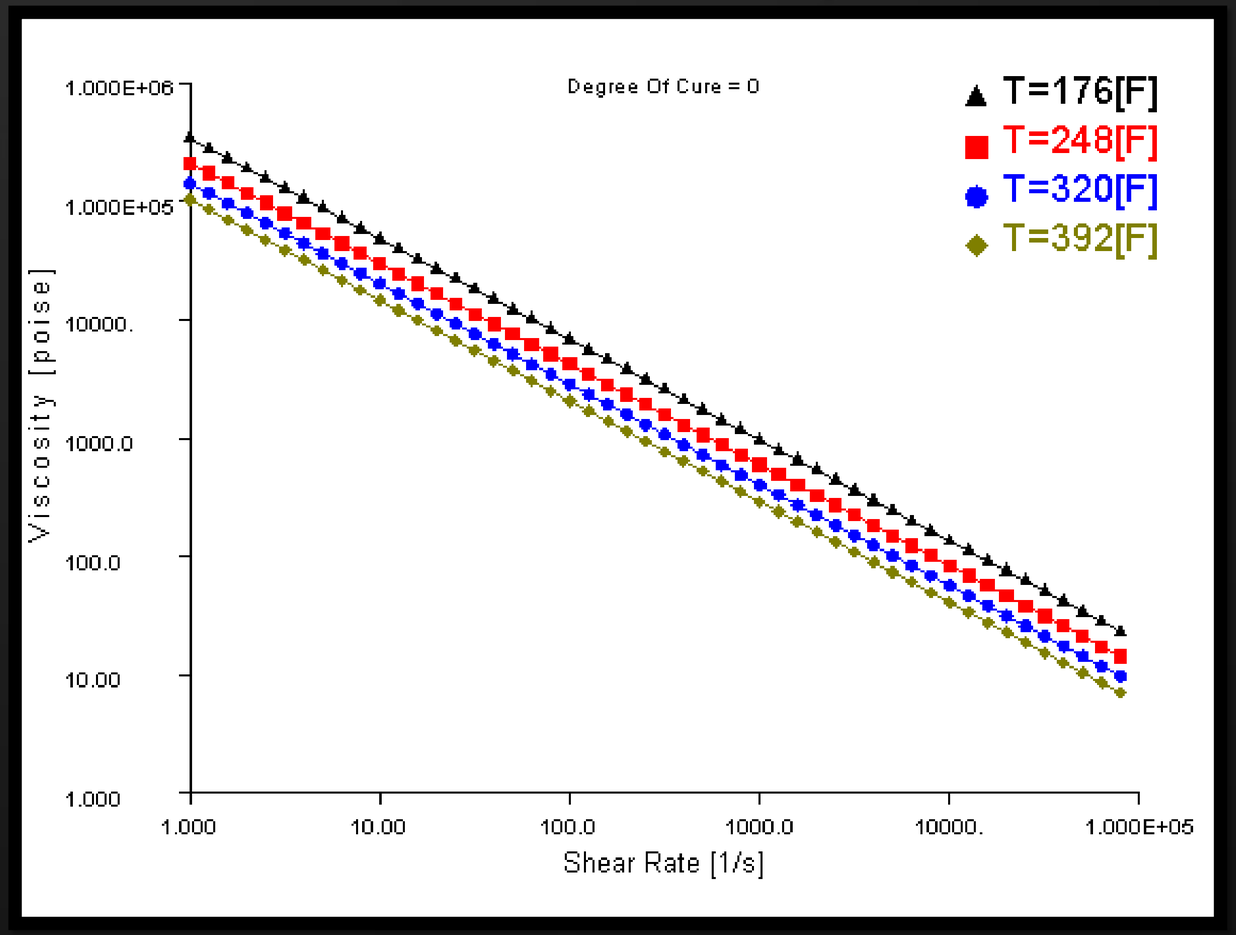
Compression Simulation

- Through a mirror… darkly
- Adapting reality
- Constraints
  - Material data
  - Process model



Material Data

- Rheological properties
  - Multiple temperatures
  - Multiple shear rates
  - Degree of cure
- Physical properties
  - PVT - cure
  - Thermal conductivity
- Curing kinetics
  - DCS curves
  - Kamal's model

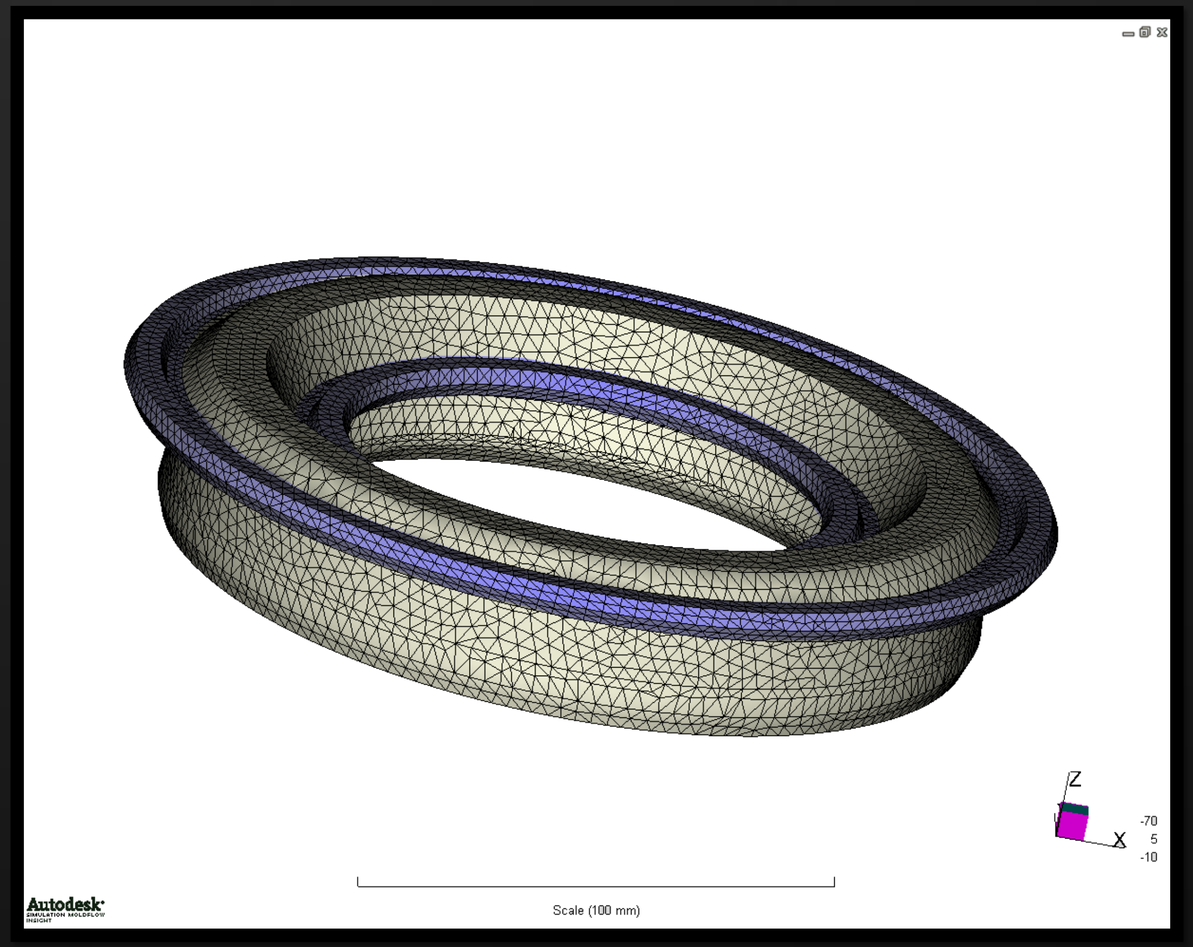


Adapting the Part to Model

- Spring energized seal
- Application:
  - 22,000 psi
  - 482ºF
  - Dynamic (minimally)
- Endless ring preform
- FEPM – AFLAS®

The Model

- Components
  - Cavity
  - Flash ring
  - Overfill groove
- Tetrahedral mesh
- For transfer molding
  - Transfer pot
  - Sprues



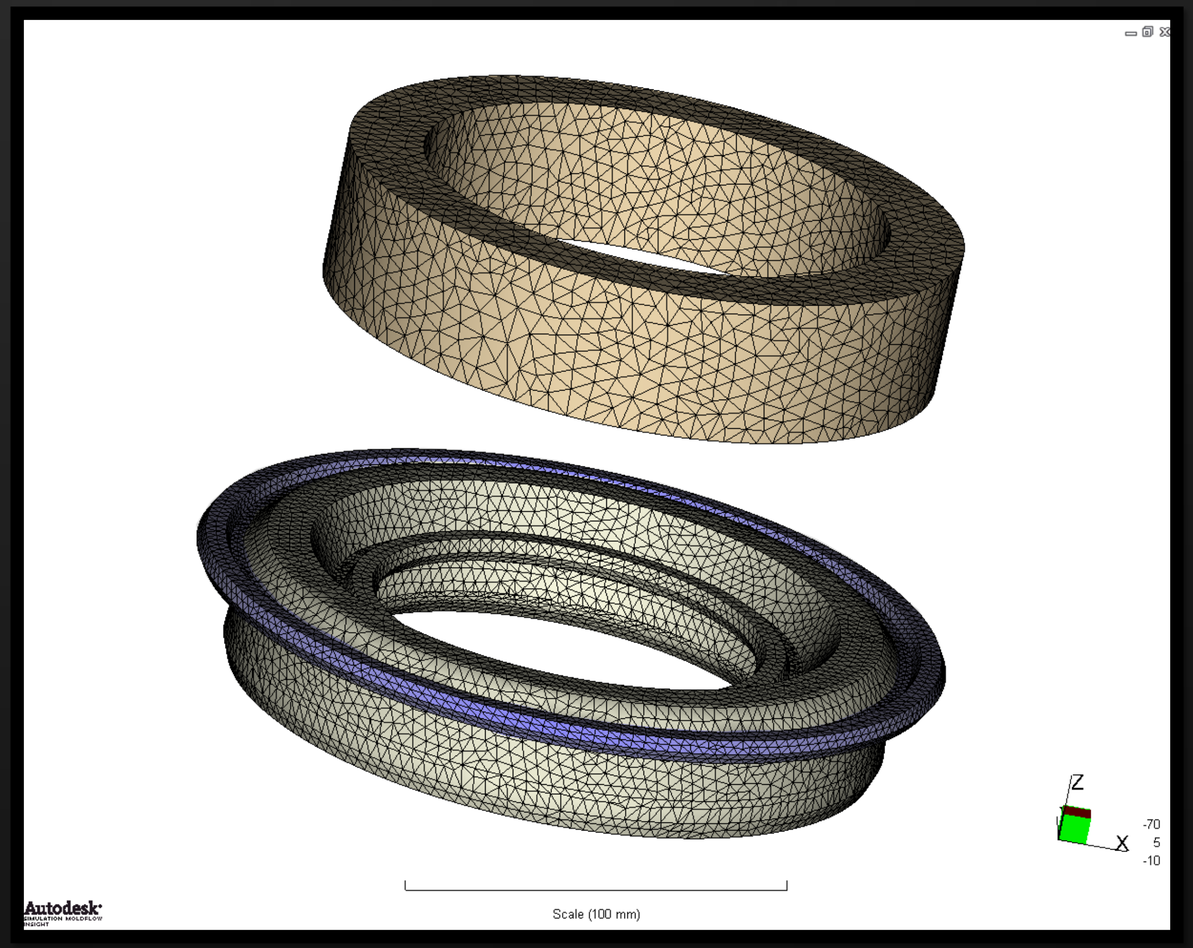
The Preform

Practical:

- Size by weight
- Size by shape

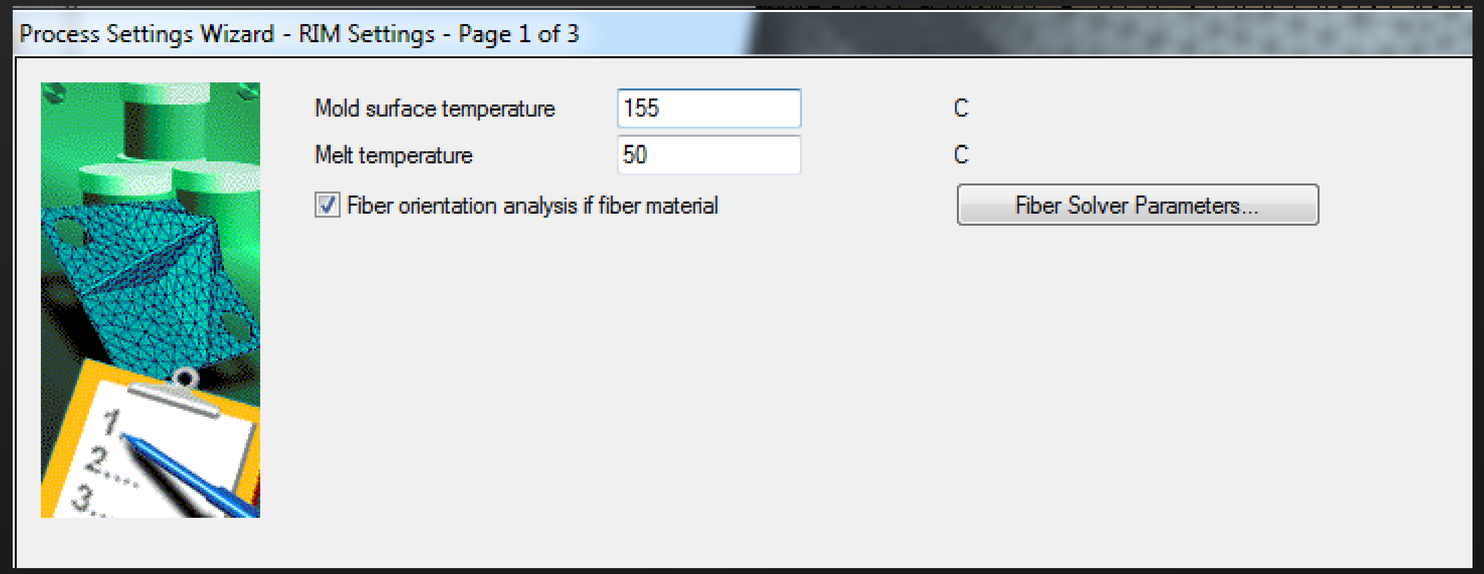
Simulation:

- Size by volume
  - Fill Cavity
  - Partial fill of overfill grooves



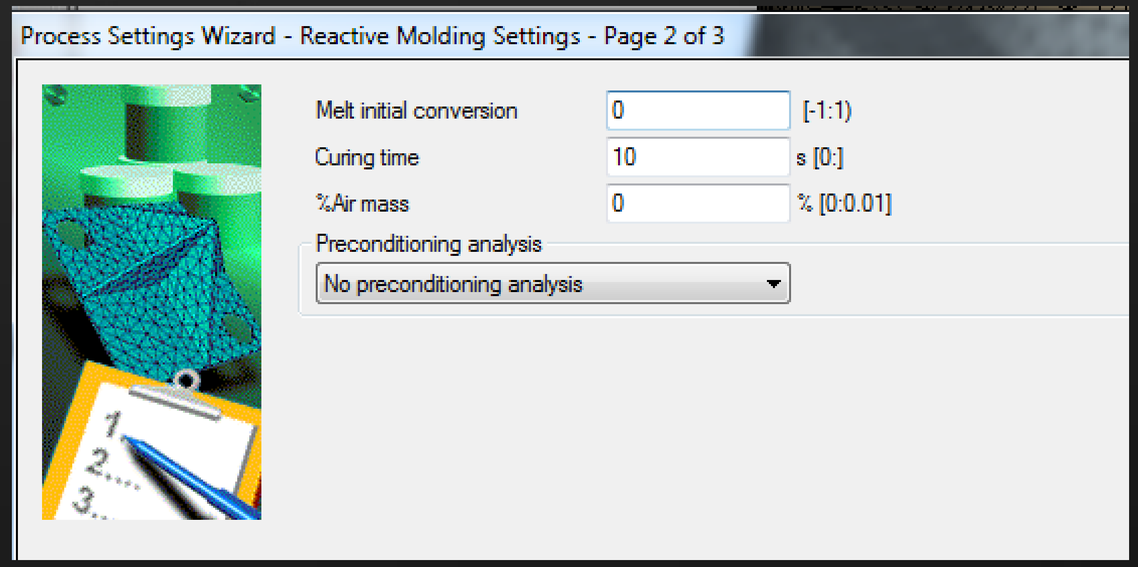
Adapting the Process

- Mold temperature
- Preform temperature



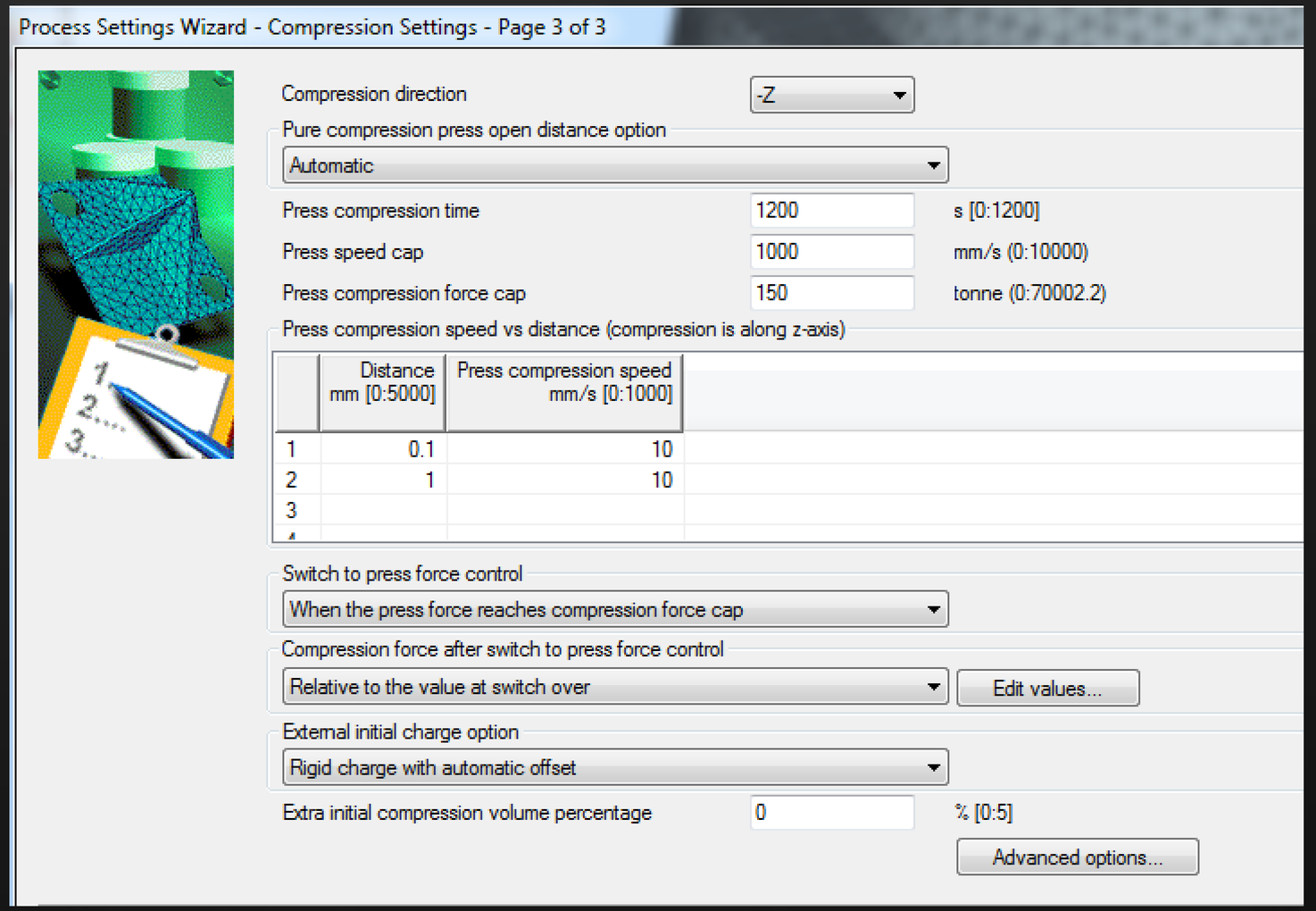
Adapting the Process

- Mold temperature
- Preform temperature
- Initial cure
- Cure time



Adapting the Process

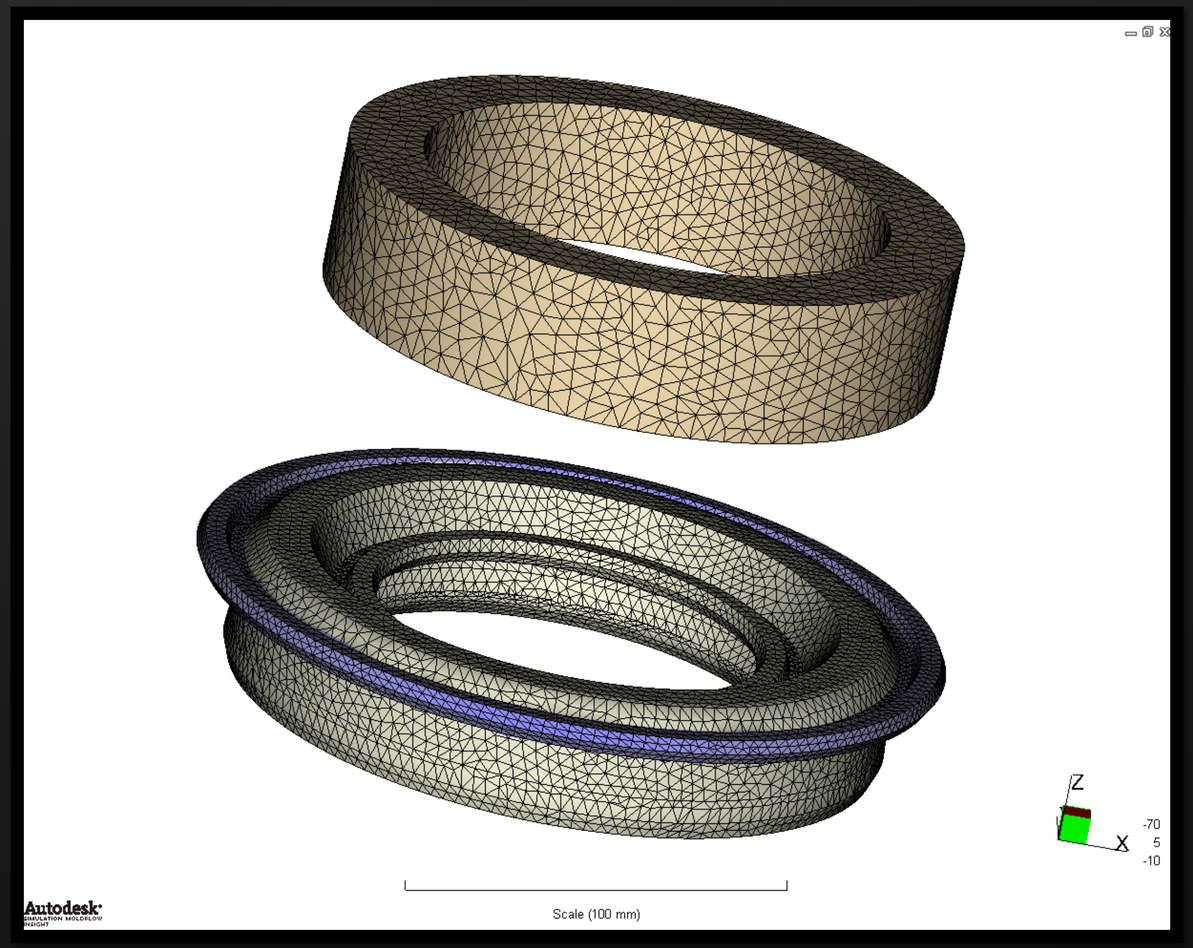
- Mold temperature
- Preform temperature
- Initial cure
- Cure time
- Close time
- Pressing force
- Pressing speed



Simulation Examples

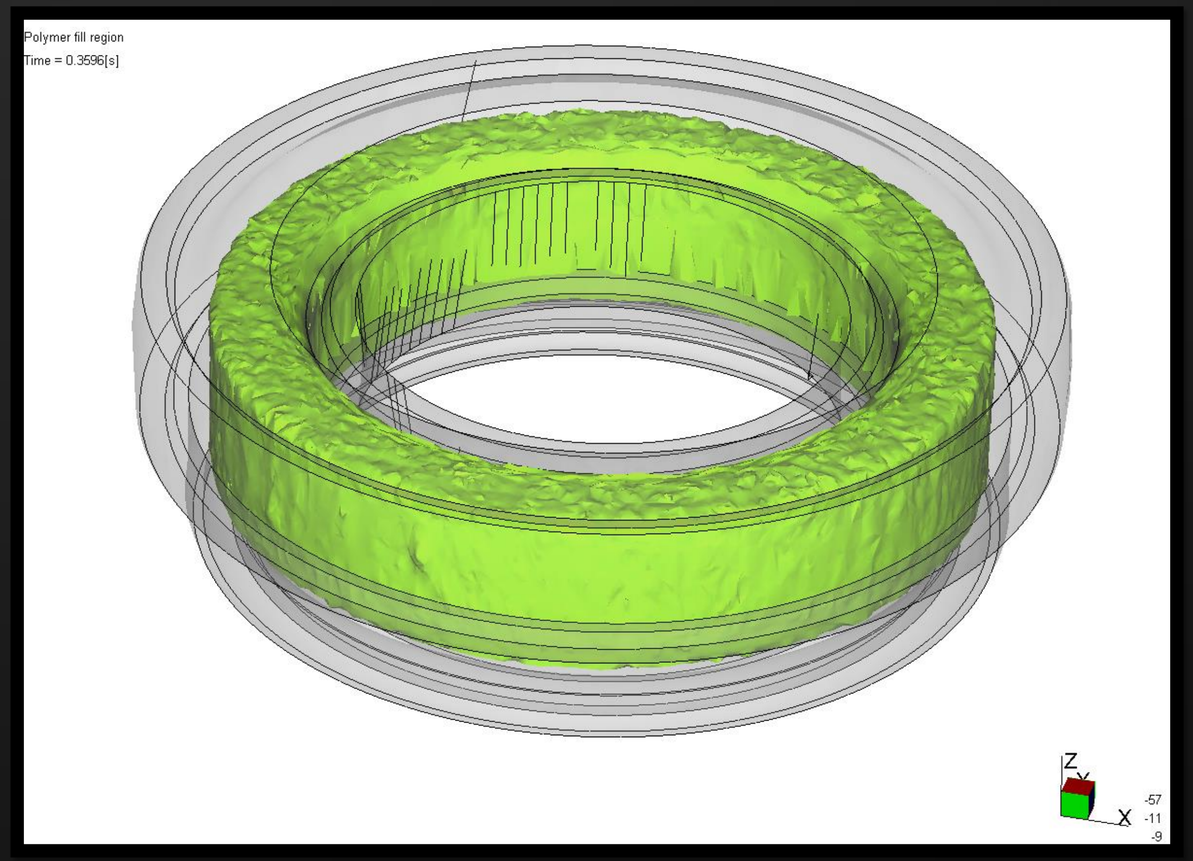
Compression Molding

- Mold Cavity
- Overfill Geometry
- Preform

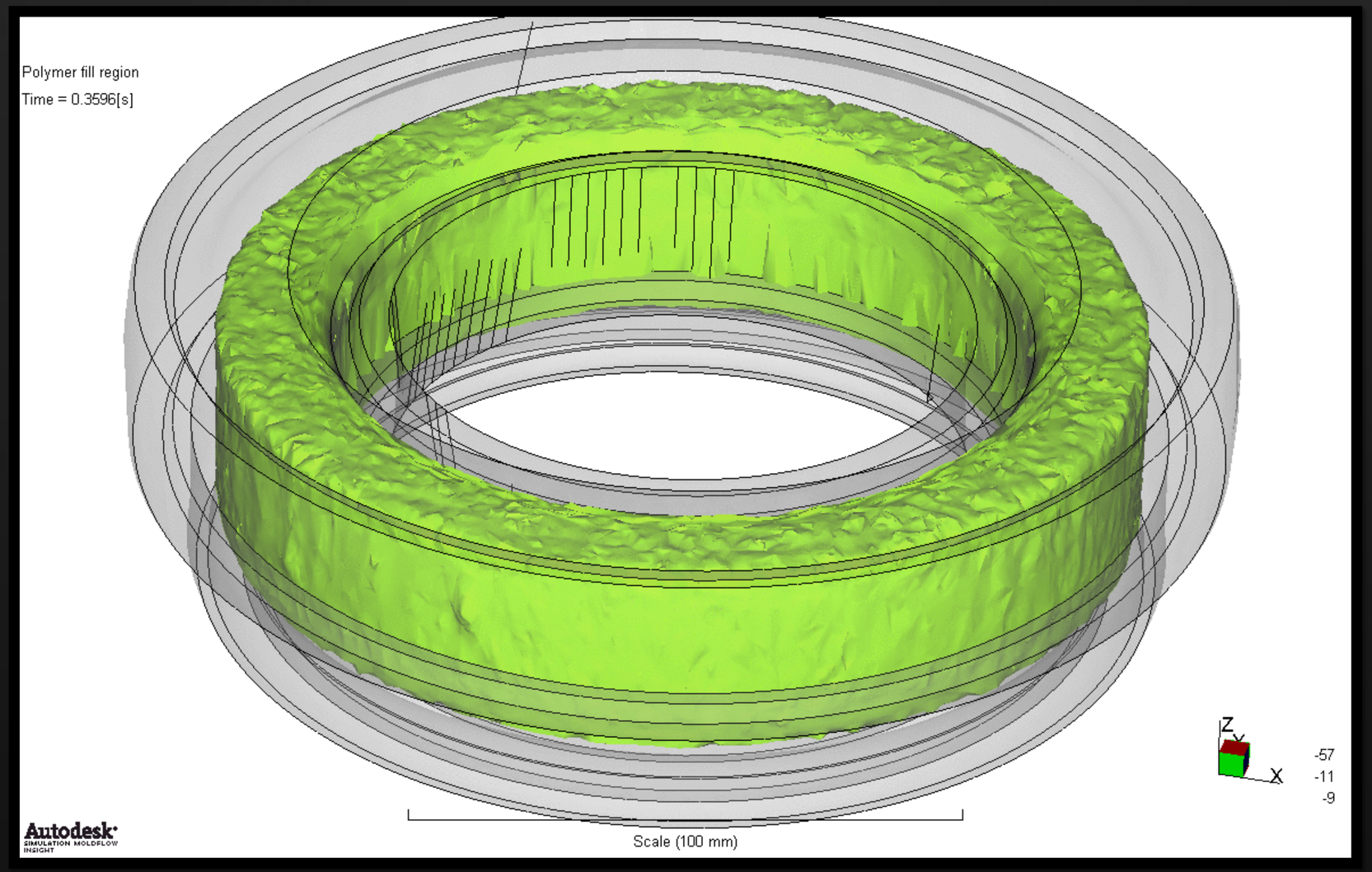


Filling

- Preform in-place
- Mold closing
- Filling of overfill (flash) groves

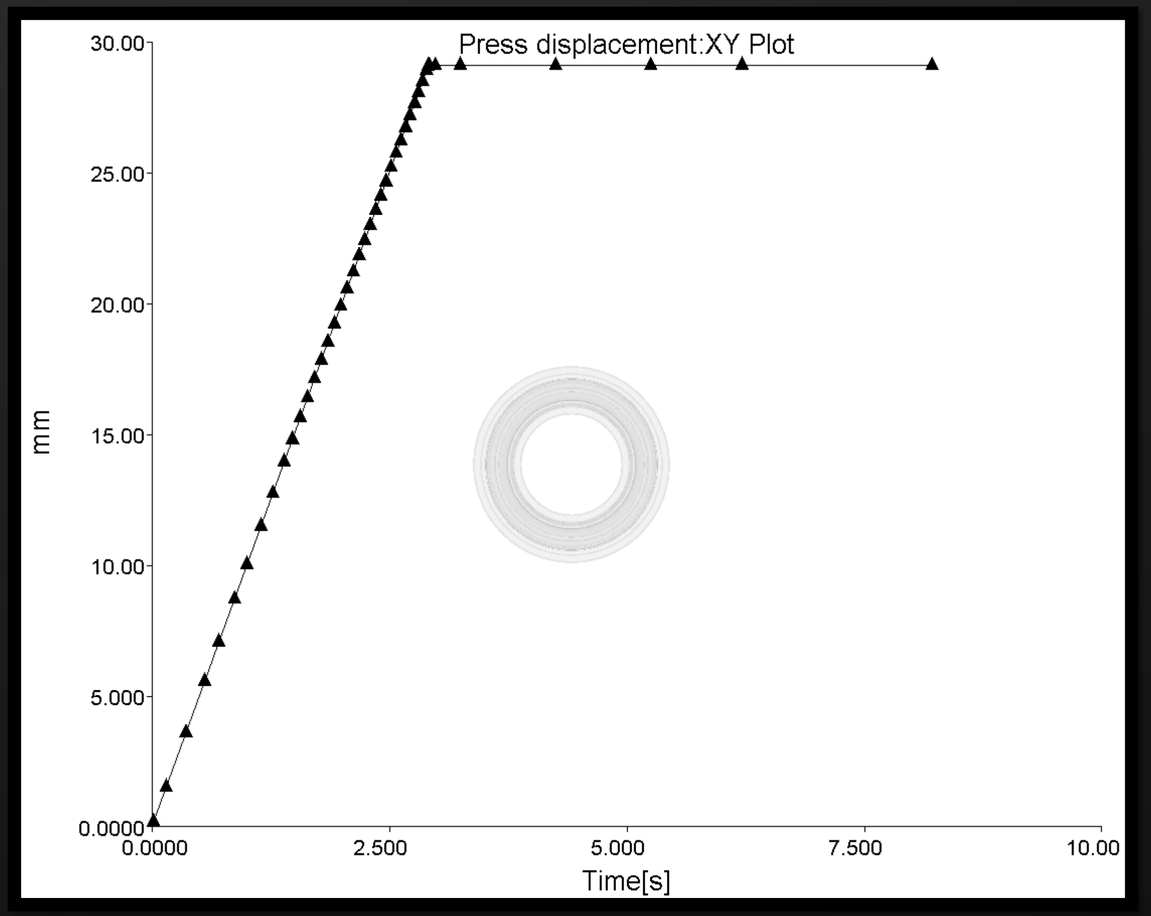


Filling – Animation



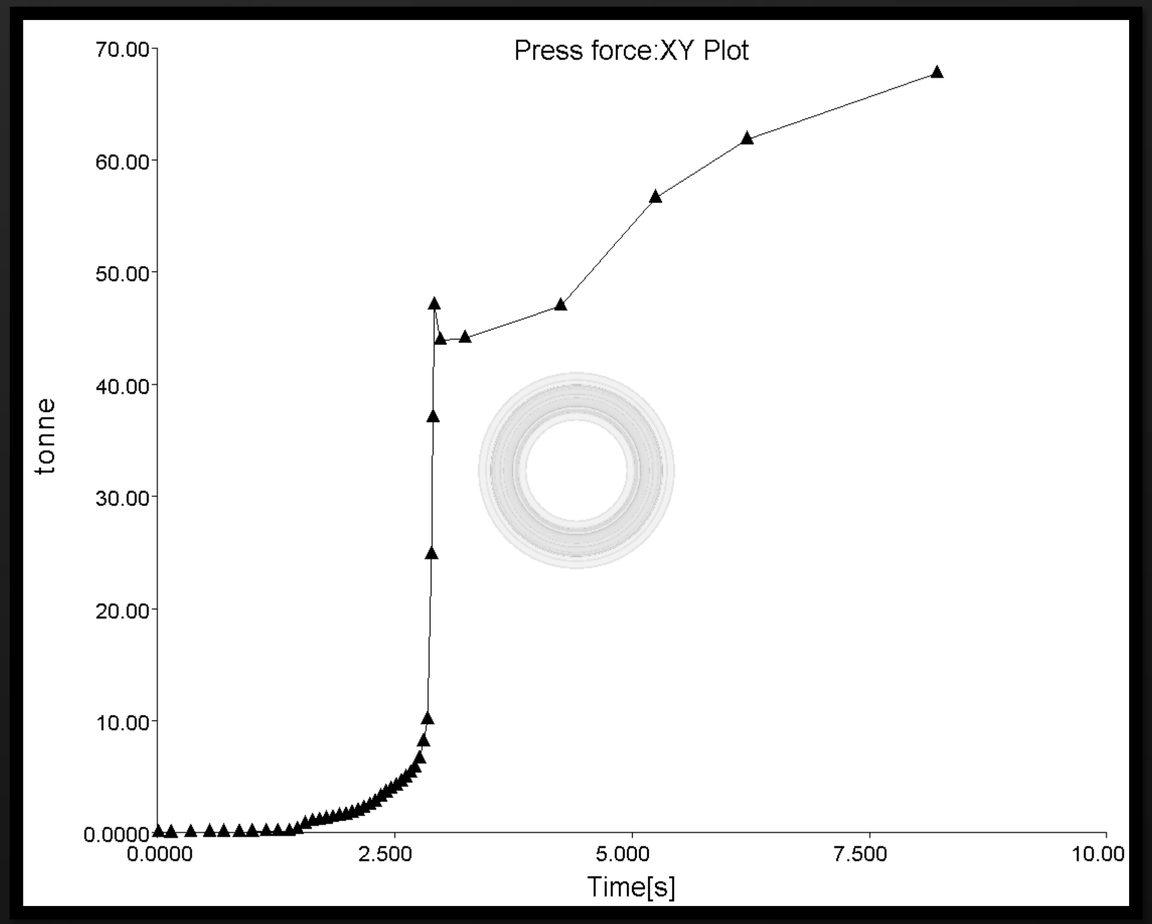
Mold Closing

- Movement of platen
- Linear Rate
- ~3 seconds to close



Clamp Force

- Force to close mold
- Force to keep closed
- Note ramp up after closure



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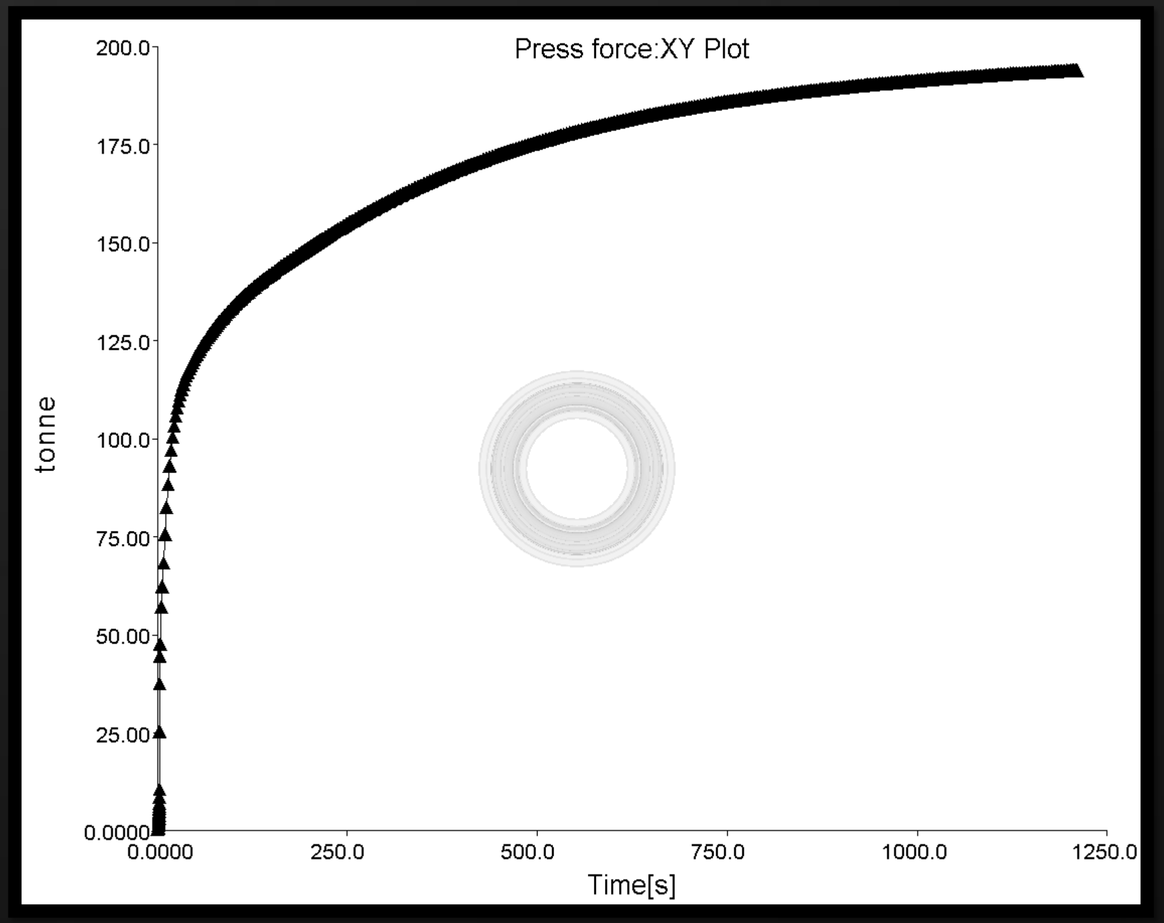
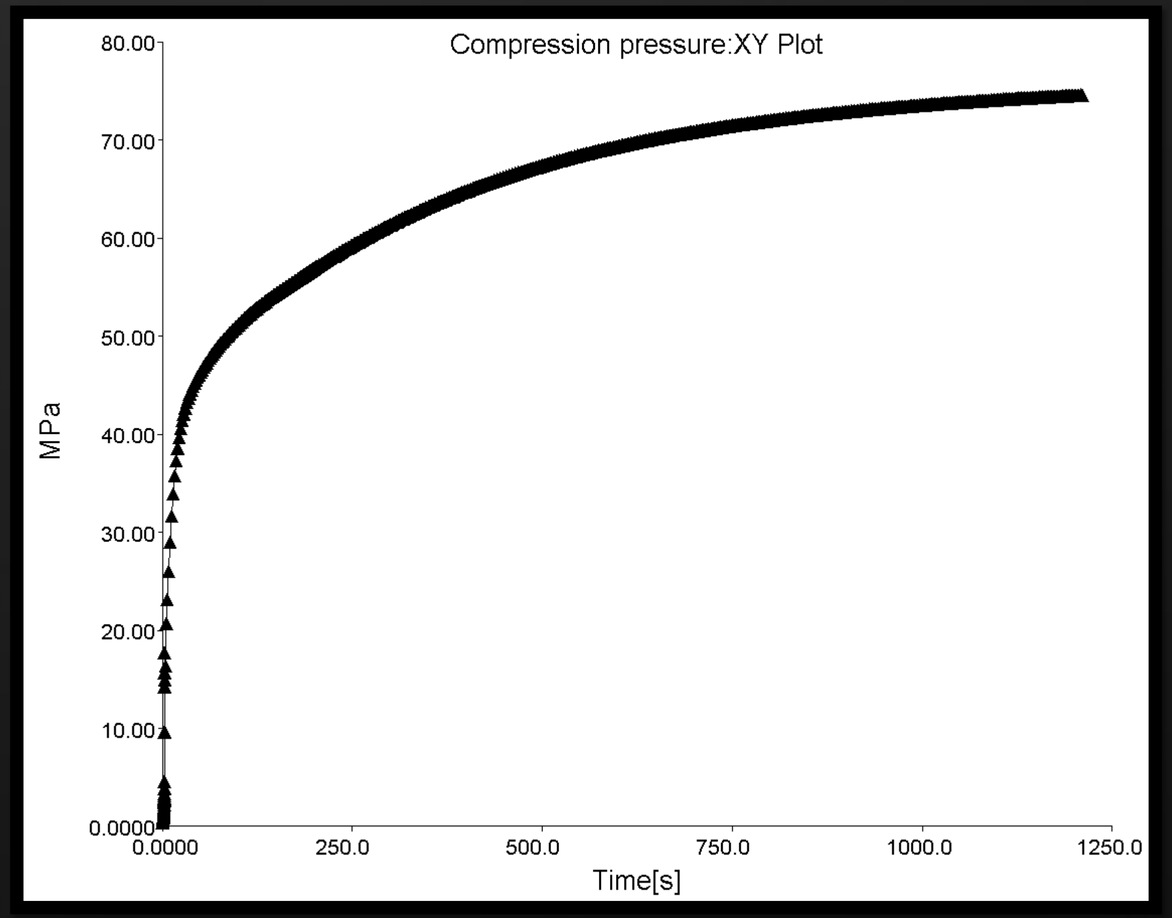
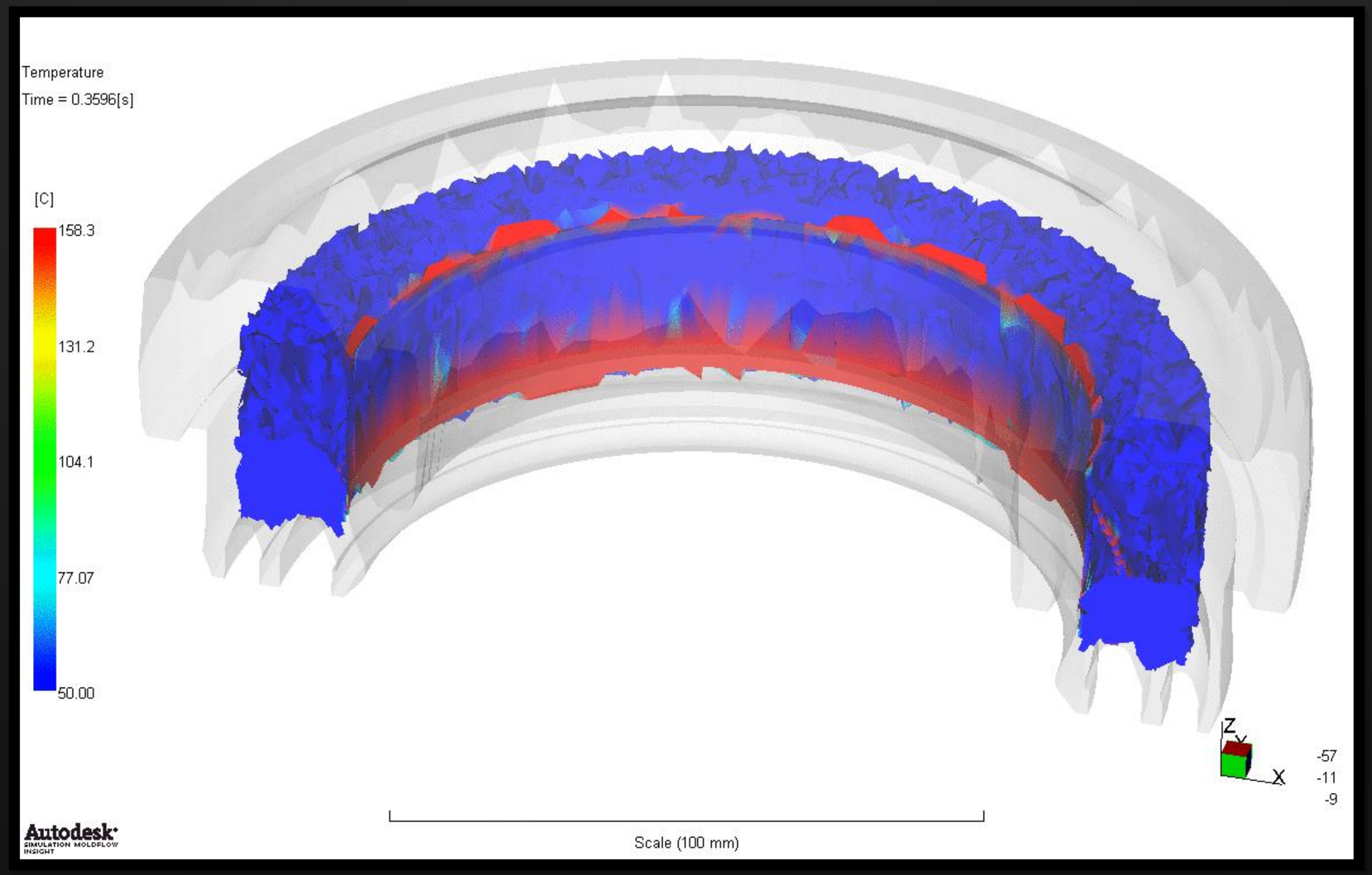


Cavity Pressure

- Pressure within the rubber
- Maximum Node
- Thermal Effect
- Effect of PVT – cure

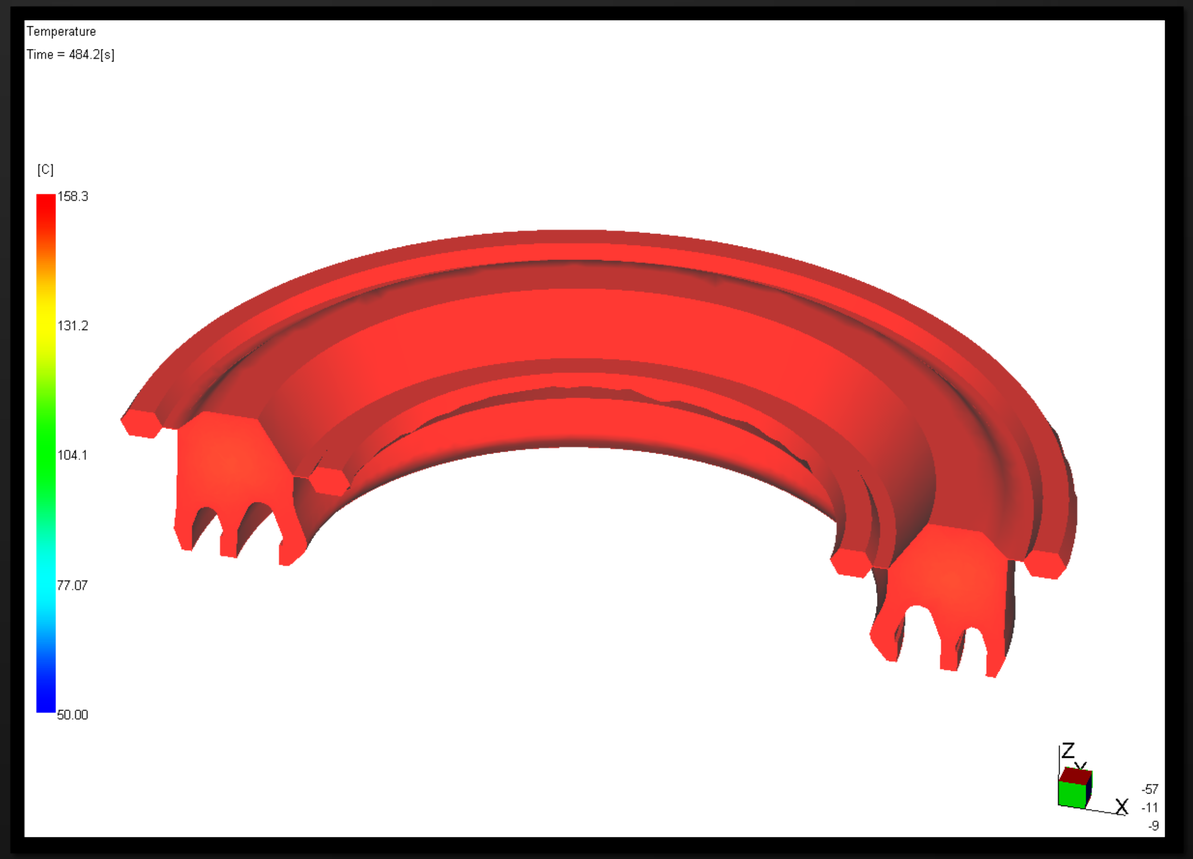


Temperature Penetration

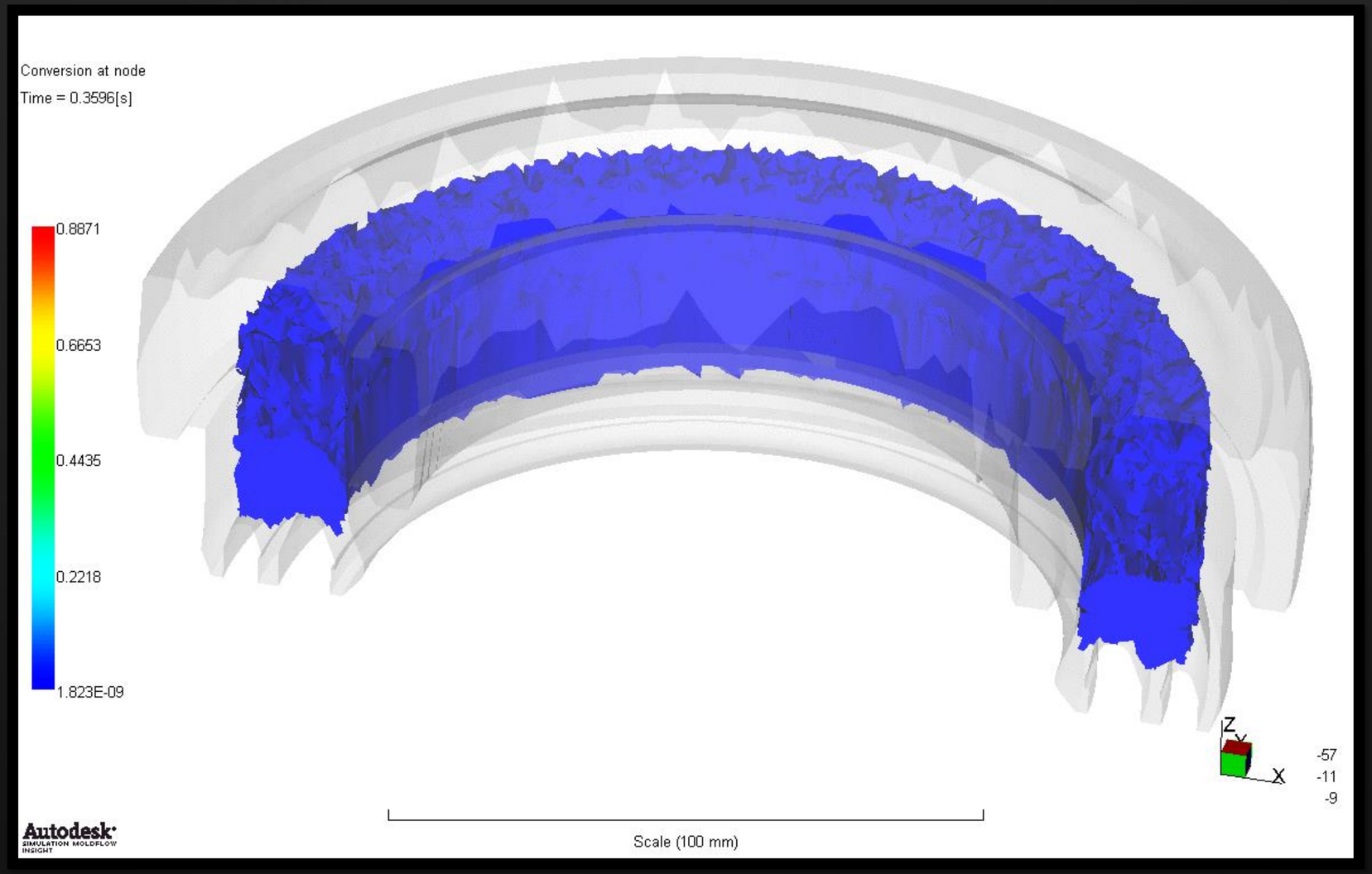


Temperature Penetration

- Thermal Conductivity
- Effects Crosslinking

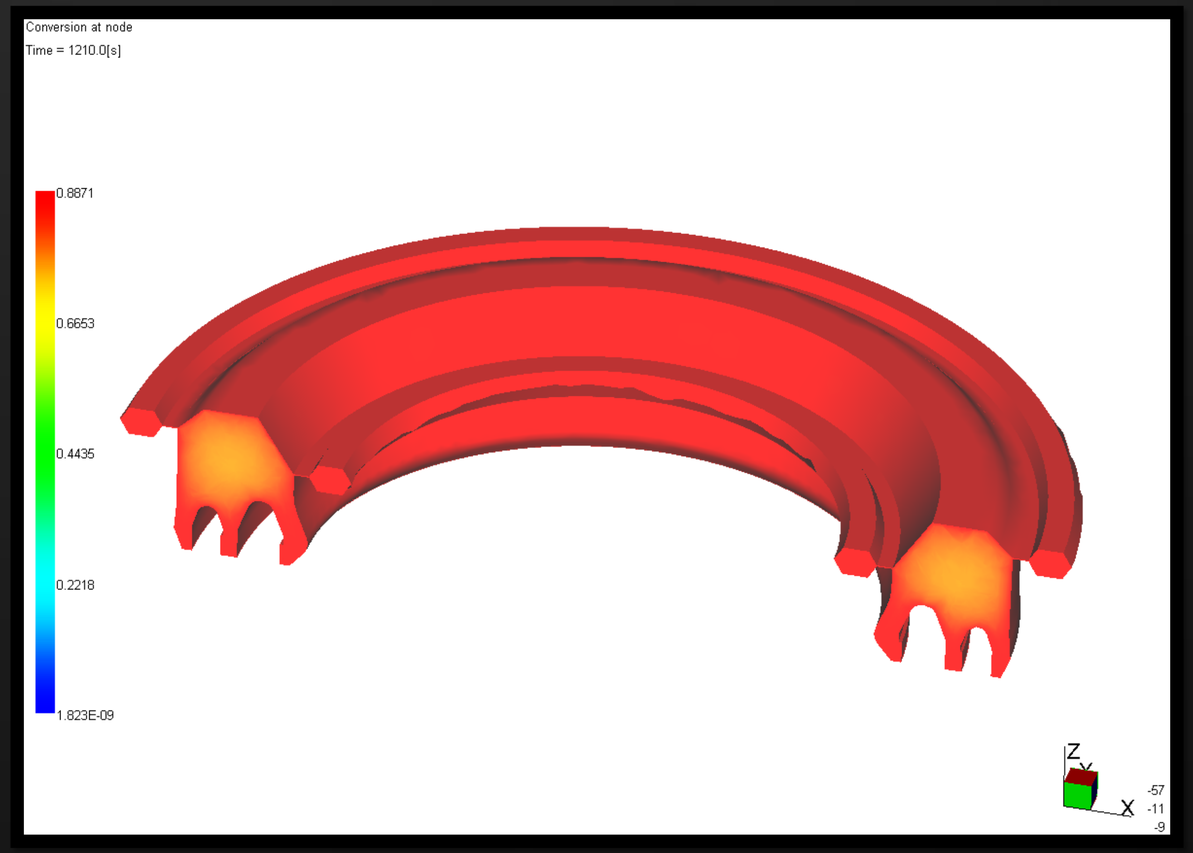


Cure – Degree of Cross-link?



Cure – Degree of Cross-link?

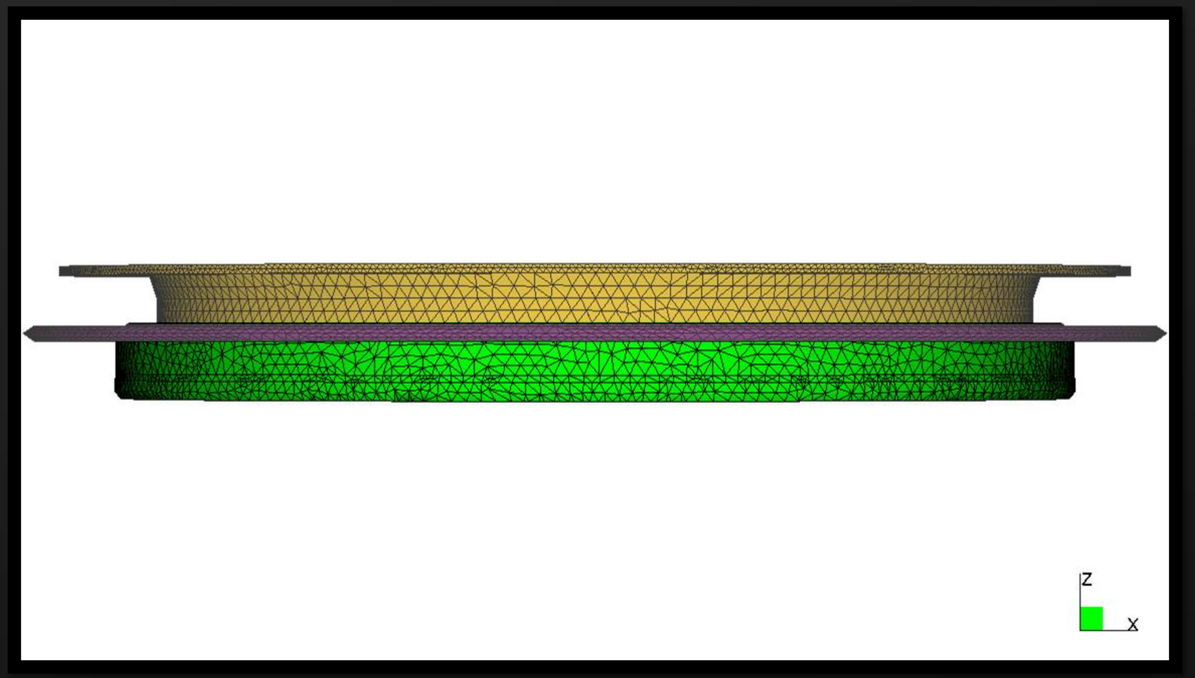
- Not degree of crosslink
- Based upon viscosity
- Approaching infinite



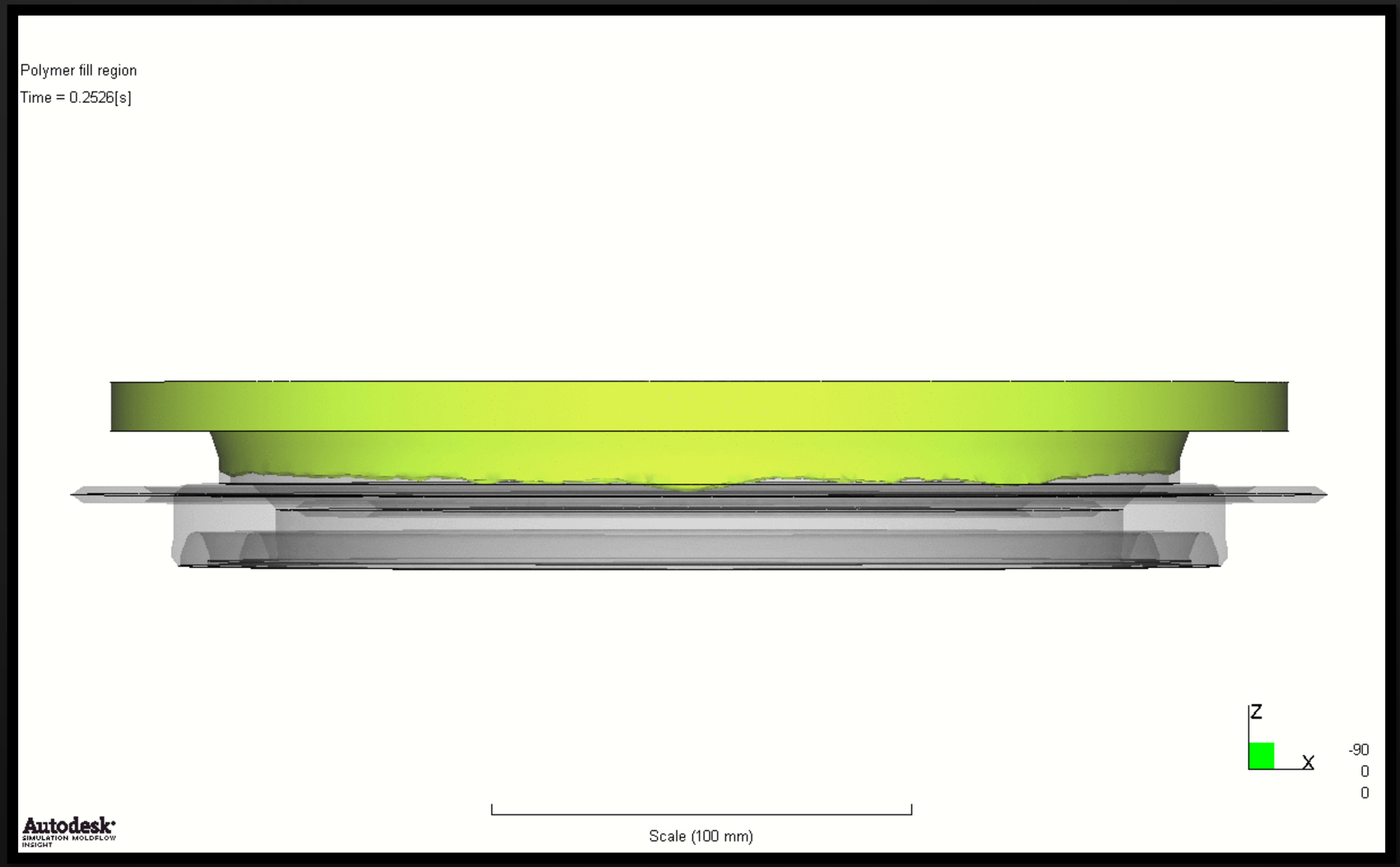
Transfer Molding

Transfer Molding

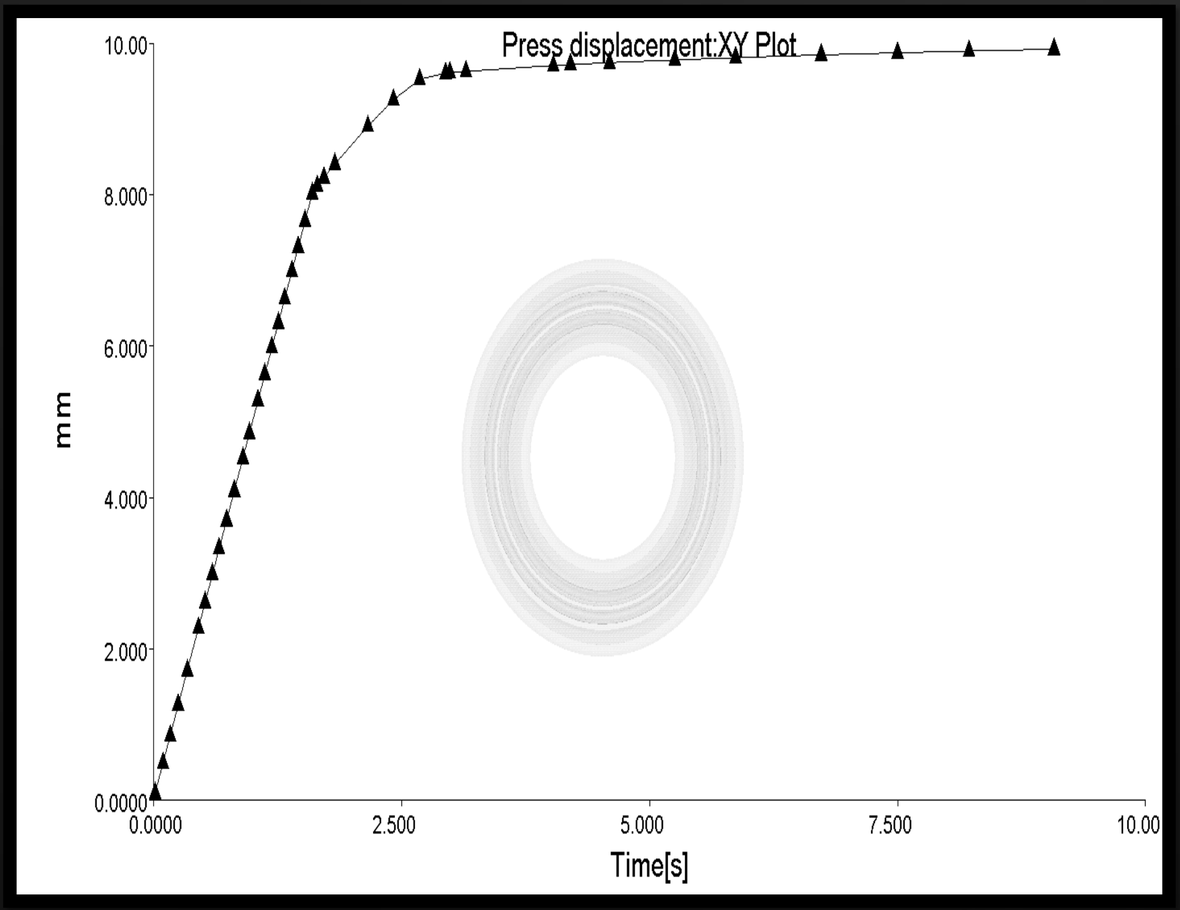
- Transfer Pot
- Preform
- Overfill Grooves
- Cavity

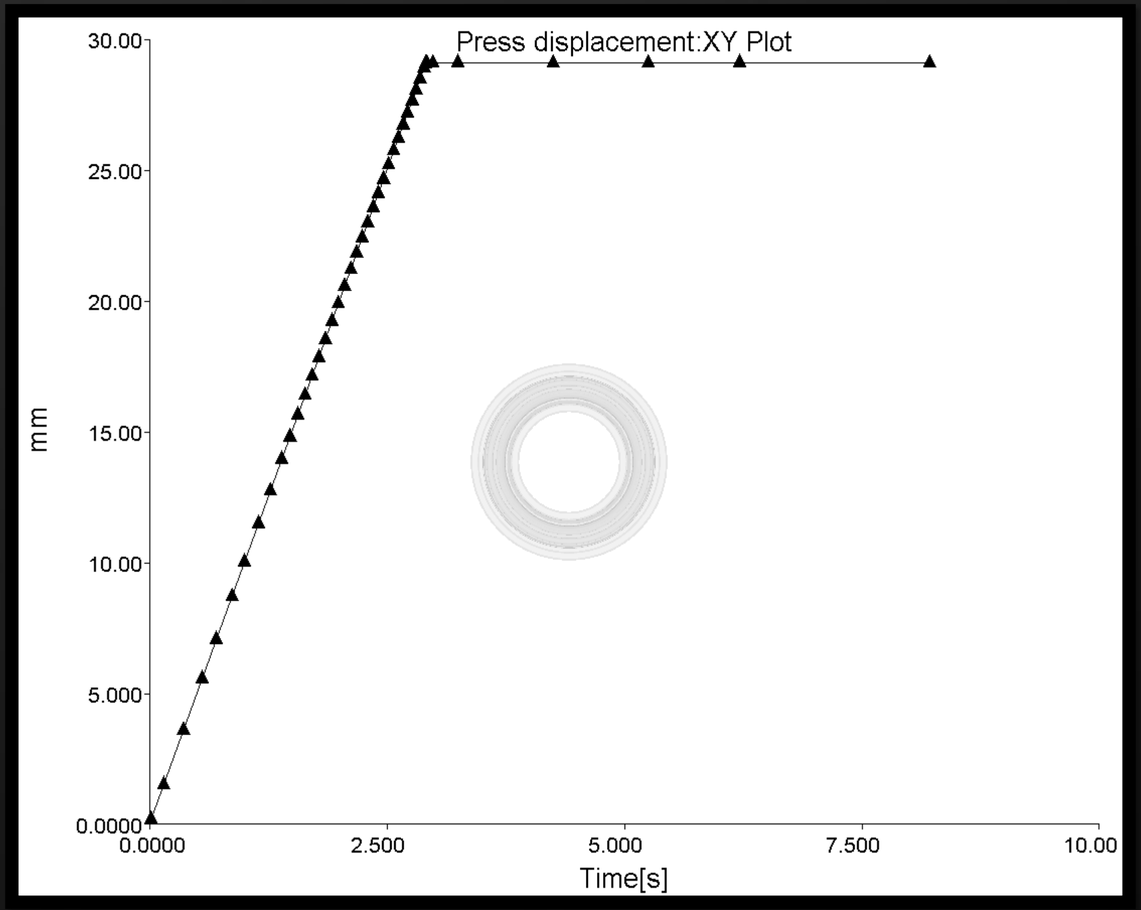


Transfer Molding – Filling – Animation

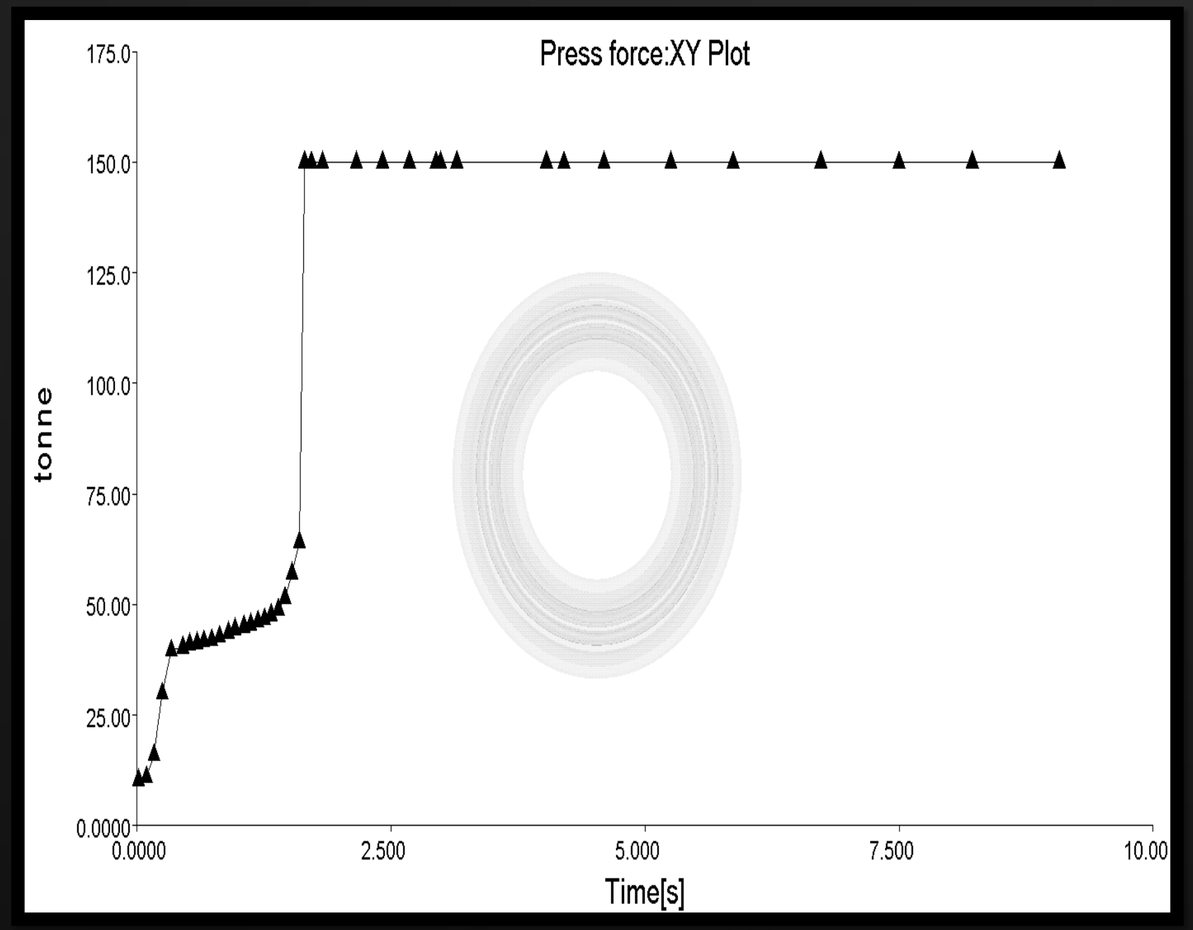


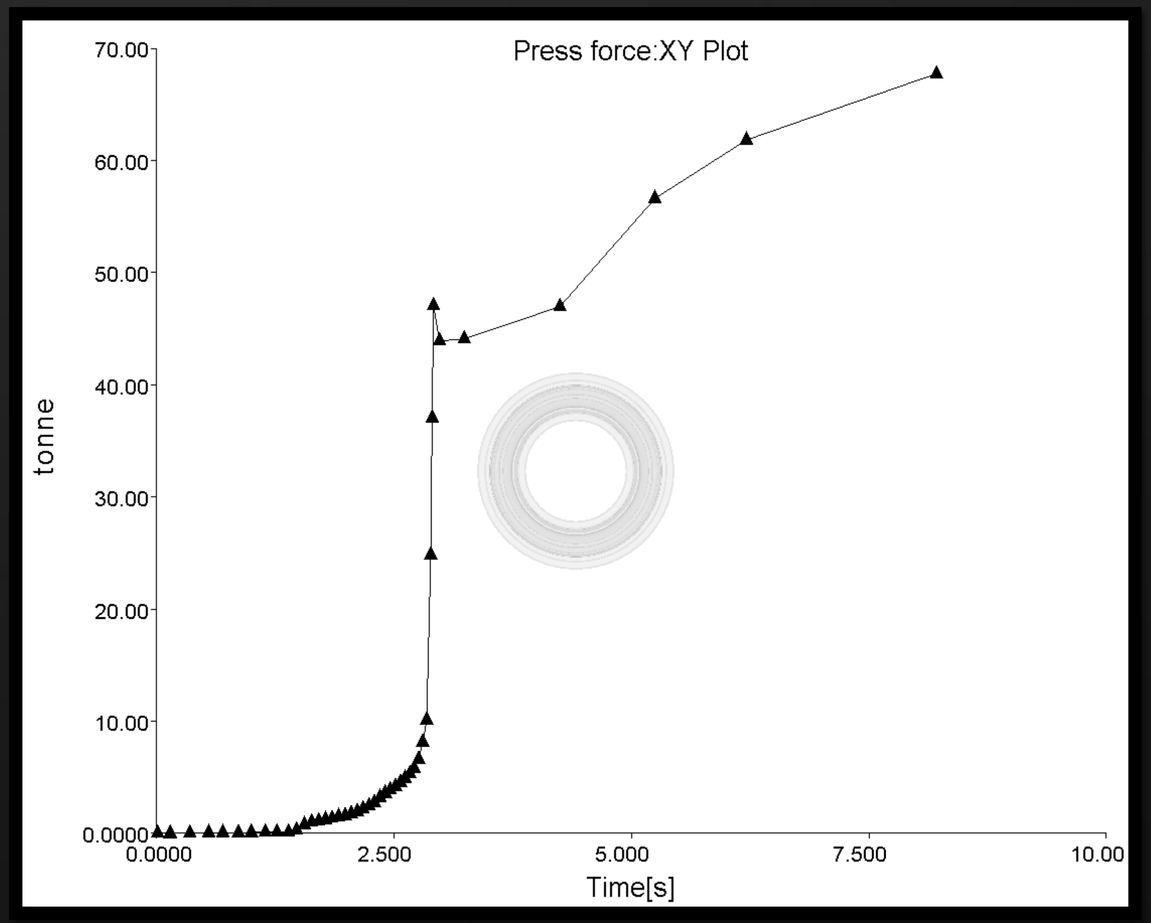
Transfer Molding – Mold Closing



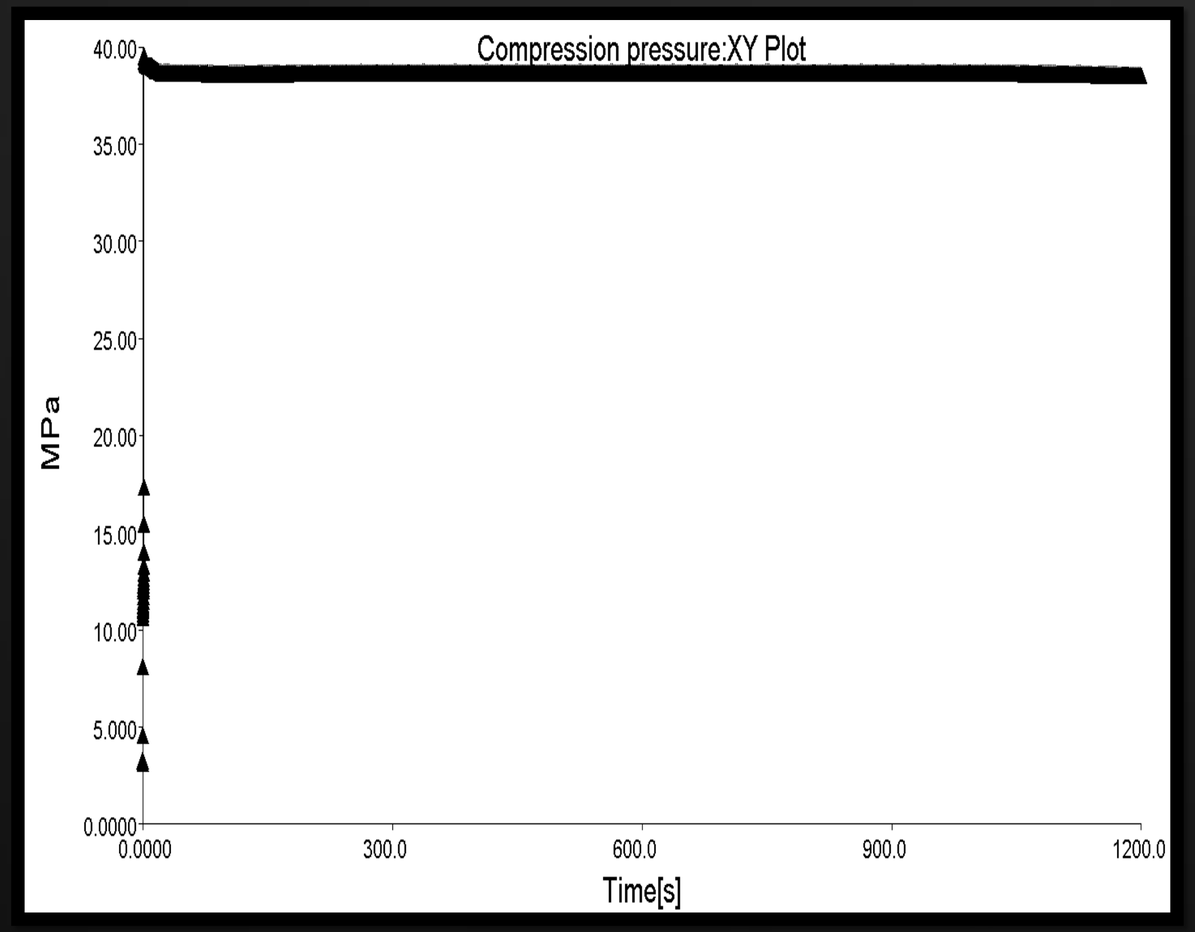


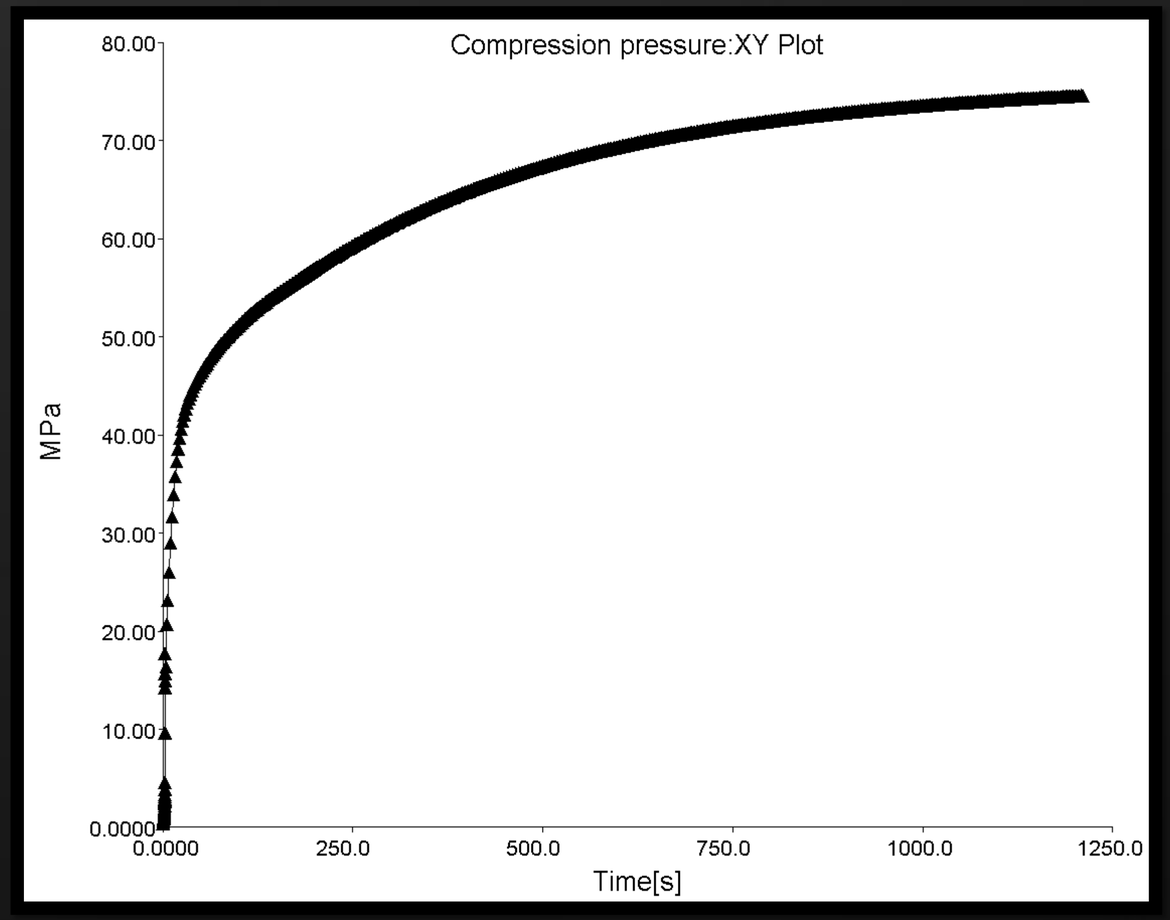
Transfer Molding – Clamp Force



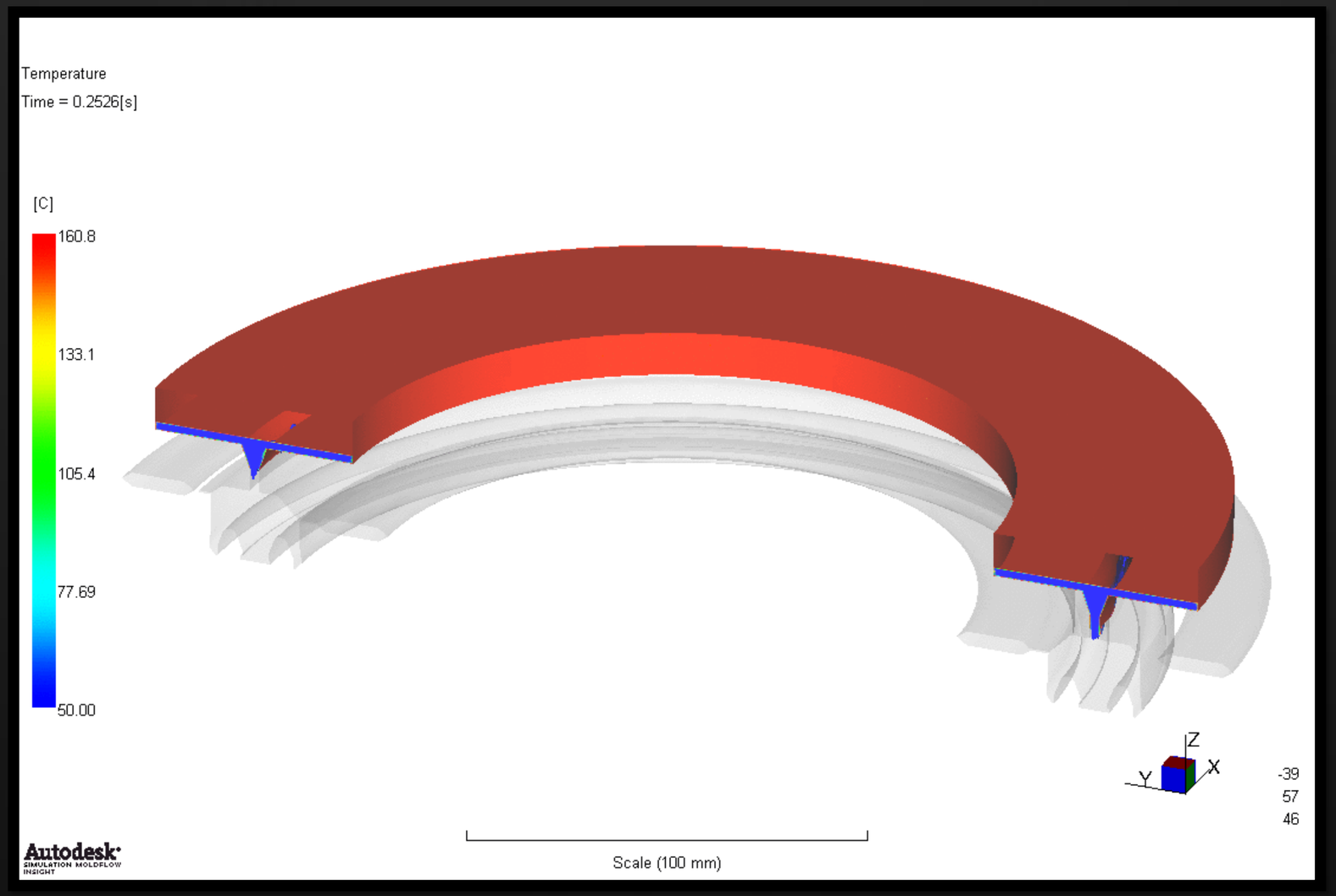


Transfer Molding – Cavity Pressure

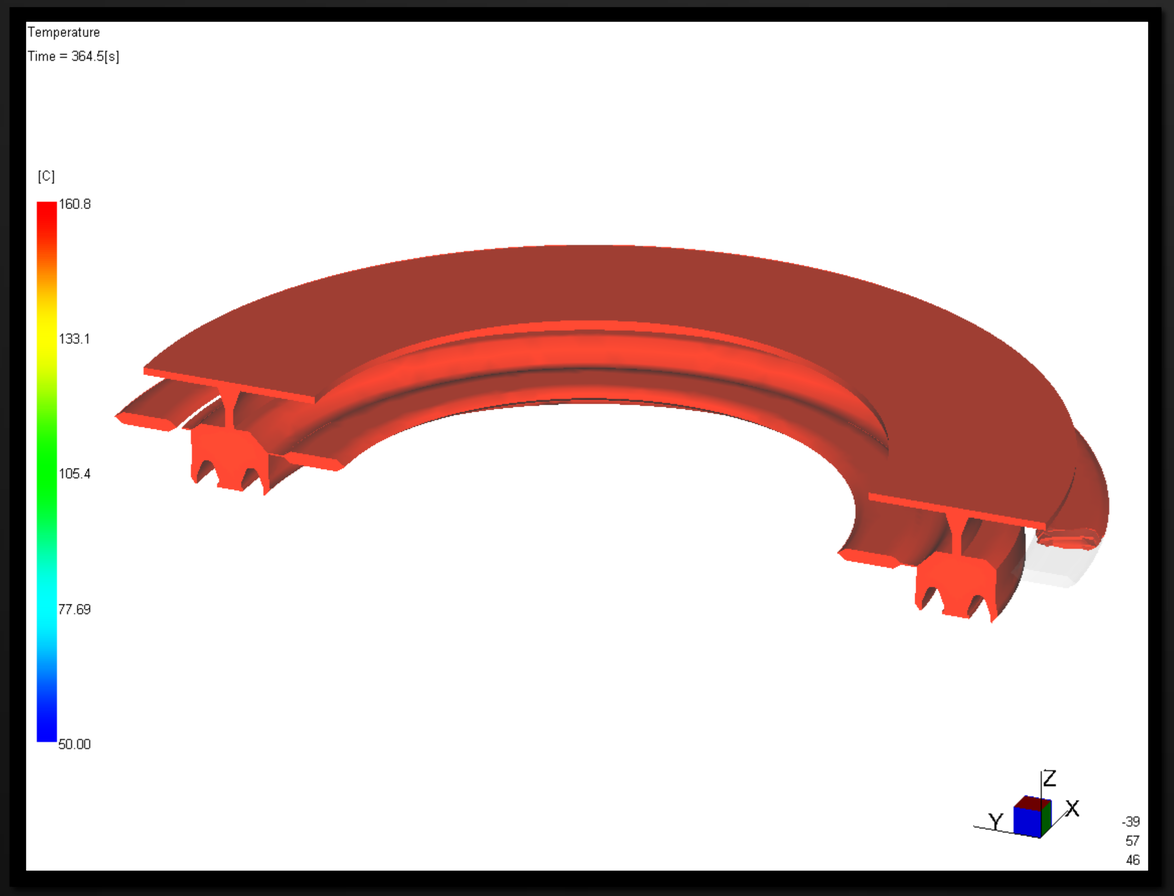


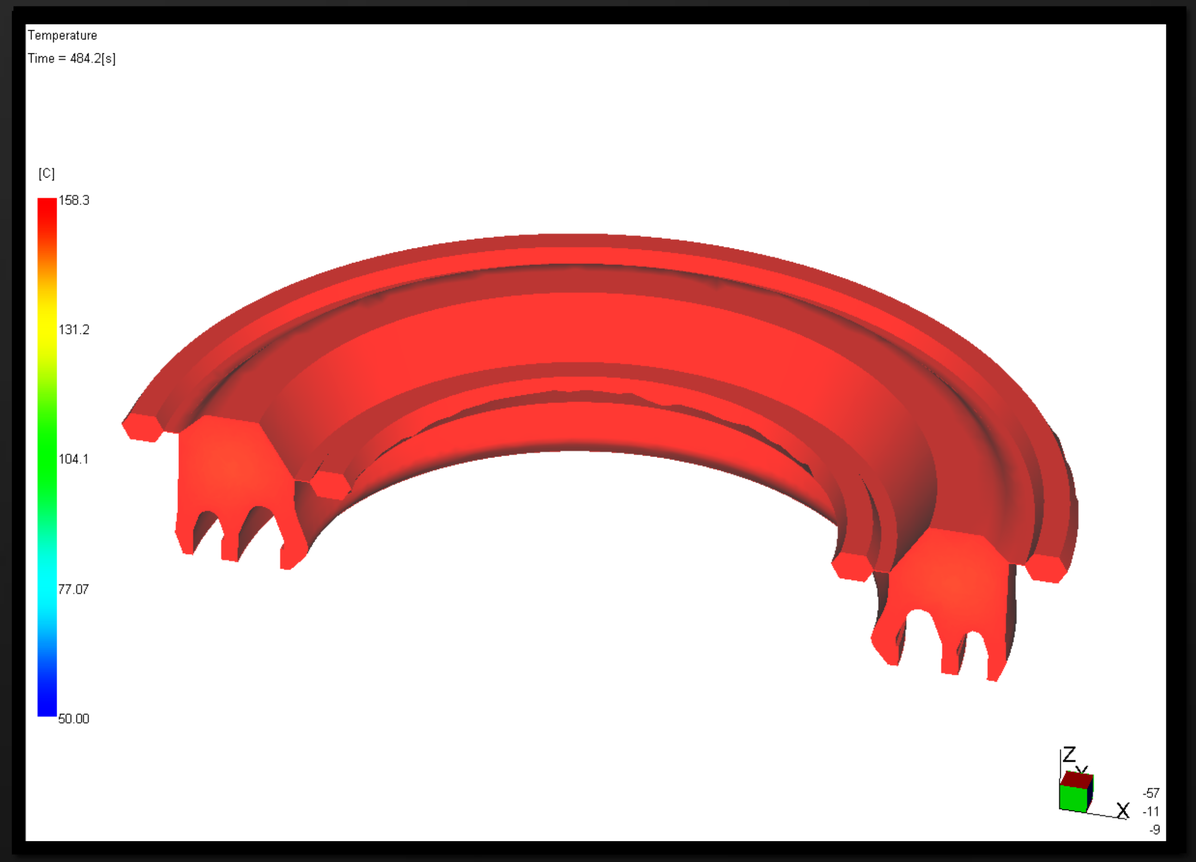


Transfer Molding – Temperature Penetration

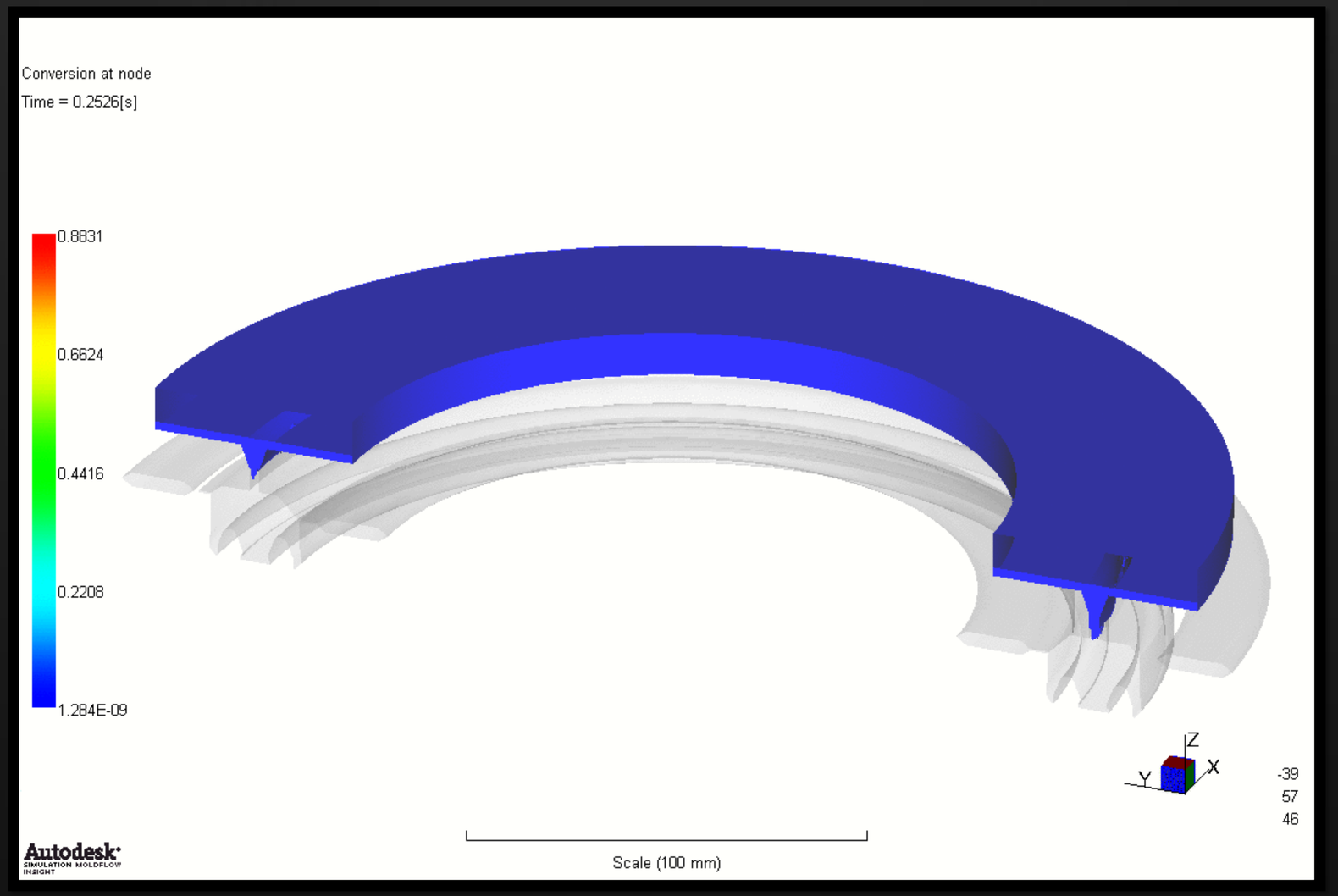


Transfer Molding – Temperature Penetration

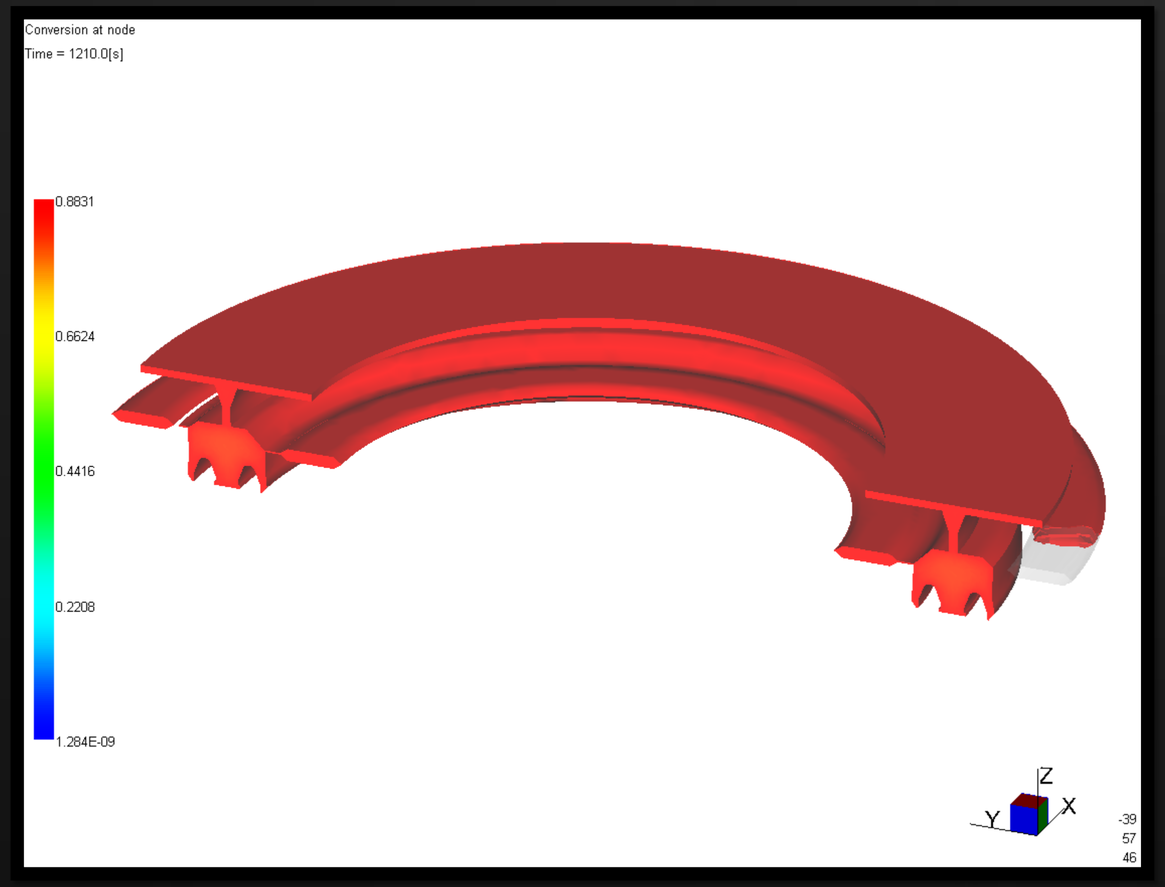


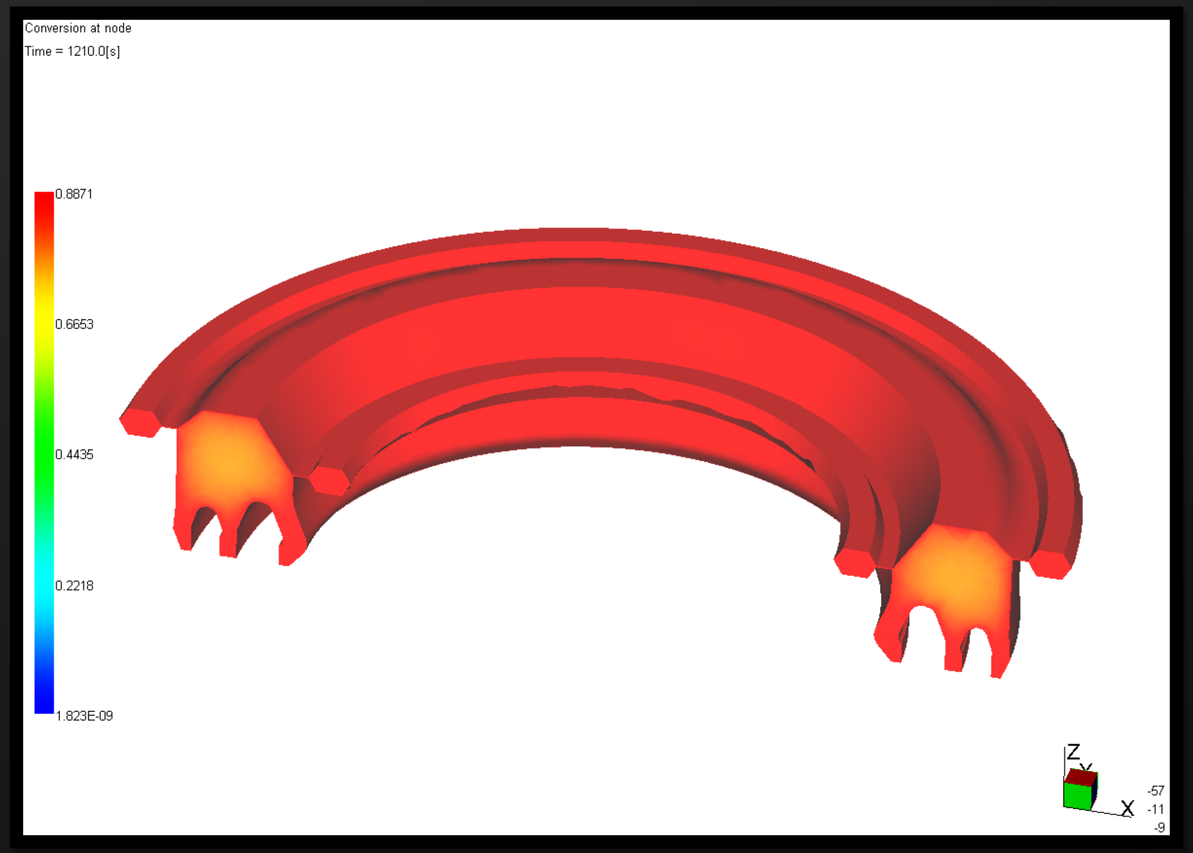


Transfer Molding – Cure – Degree of Cross-link?



Transfer Molding – Cure – Degree of Cross-link?





What do you think?

Opportunities

- Preform Sizing
- Process Development
  - Cure time
  - Cavity pressure confirmation
- Defect detection
  - Short shot
  - Backgrind

Bonus Round

Questions