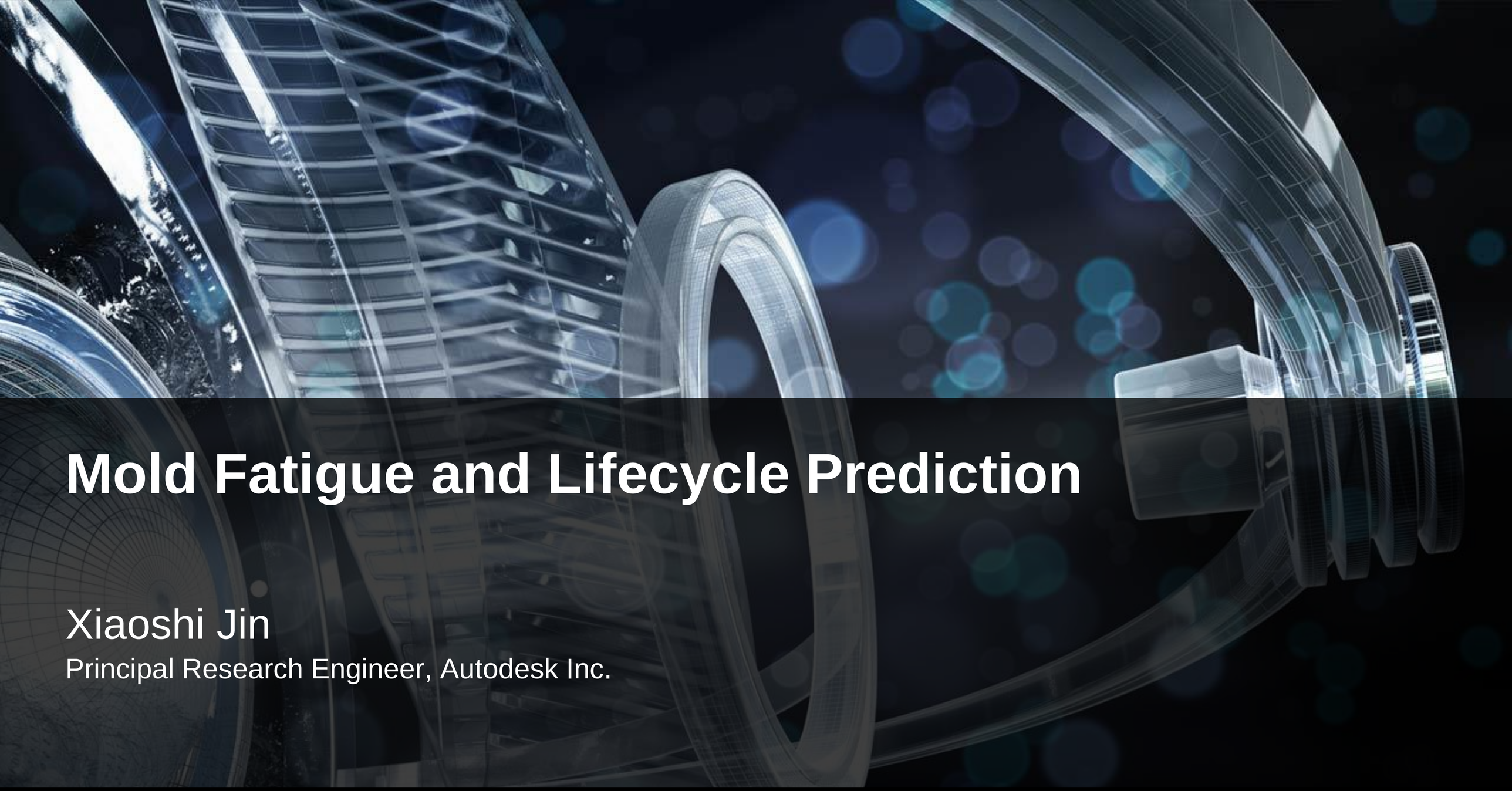


Mold Fatigue and Lifecycle Prediction

Xiaoshi Jin
Principal Research Engineer, Autodesk Inc.

Class Summary

- **Conventional Mold designs in injection molding**
  - Mostly based on expert experience without a careful stress analysis
  - Mold set lifecycle relies largely on a rough estimate
- **Newly developed rapid heating cycle molding (RHCM)**
  - Make mold designs more challenge
  - How to achieve both higher productivity with low cost and better quality?
- **Review of Three Major Causes of Mold Damage**
  - Thermal Stress due to rapid heating and cooling
  - Mold deflection due to injection pressure imbalance
  - Clamping force induced stress inside mold blocks
- **Integrated Tool Developed:**
  - Injection molding simulation: Heat Transfer, Flow with Core-shift, Clamp Force
  - Mold STRESS and FATIGUE analyses

Learning Objectives

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

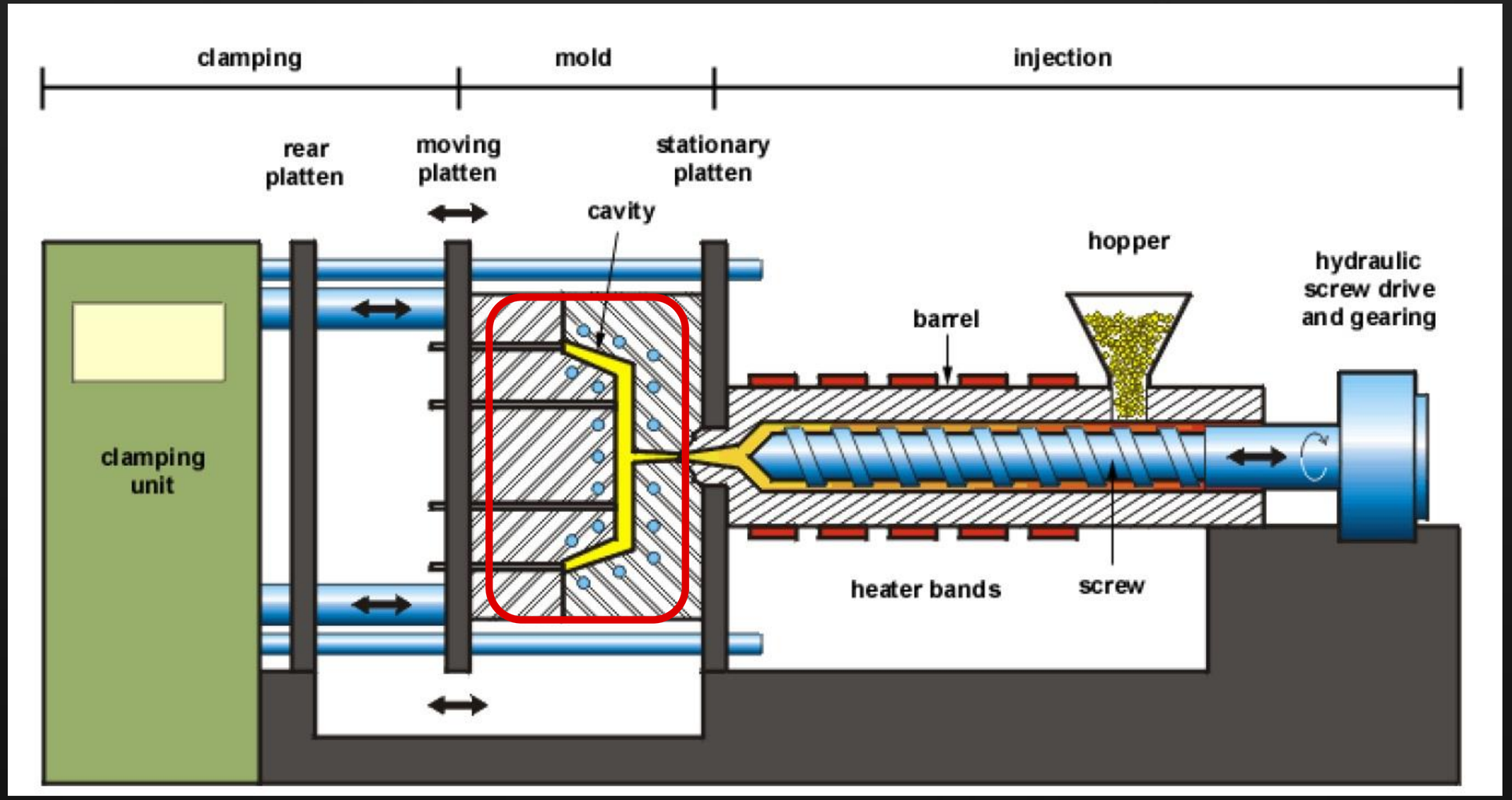
- Understand the nature of mold lifecycle: costs, quality and productivity
- Understand the components of integrated analysis tool
- Know how to set up the right mesh and boundary conditions
- Interpret the results from Mold Fatigue Analysis

Why Predict Mold Lifecycle?

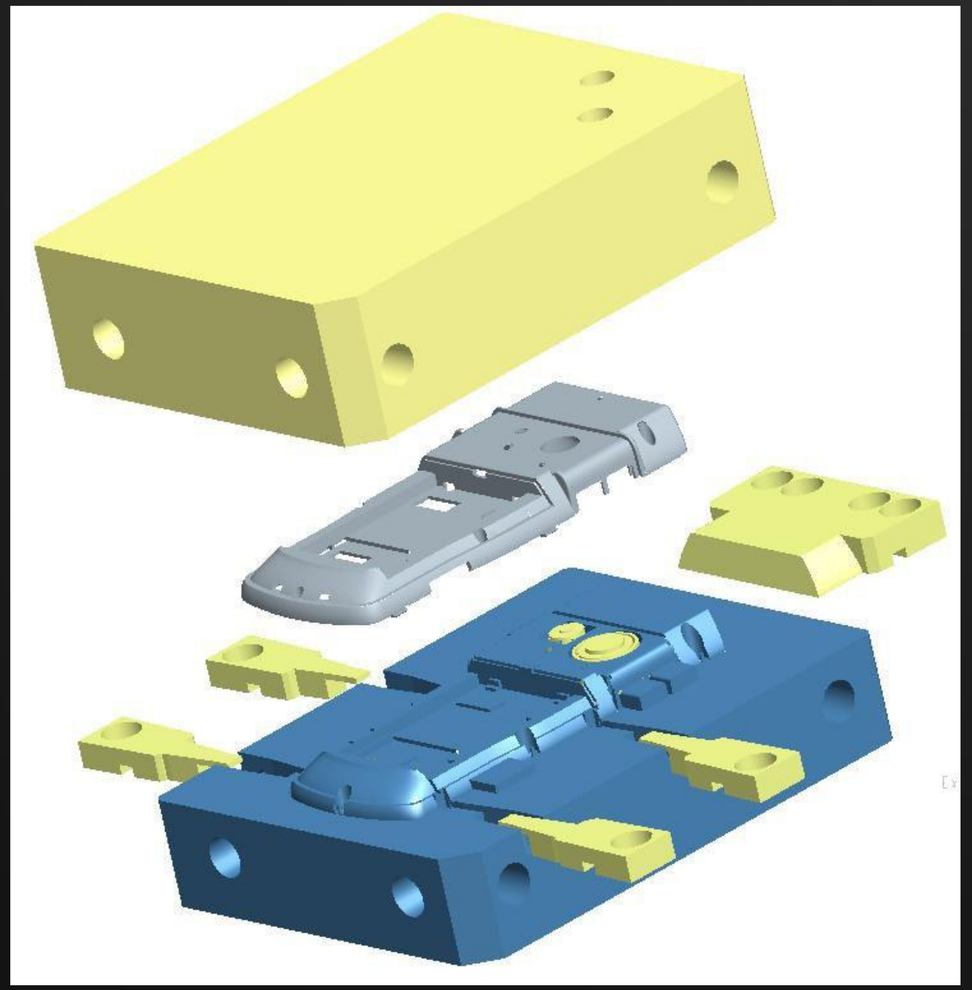
Market requests

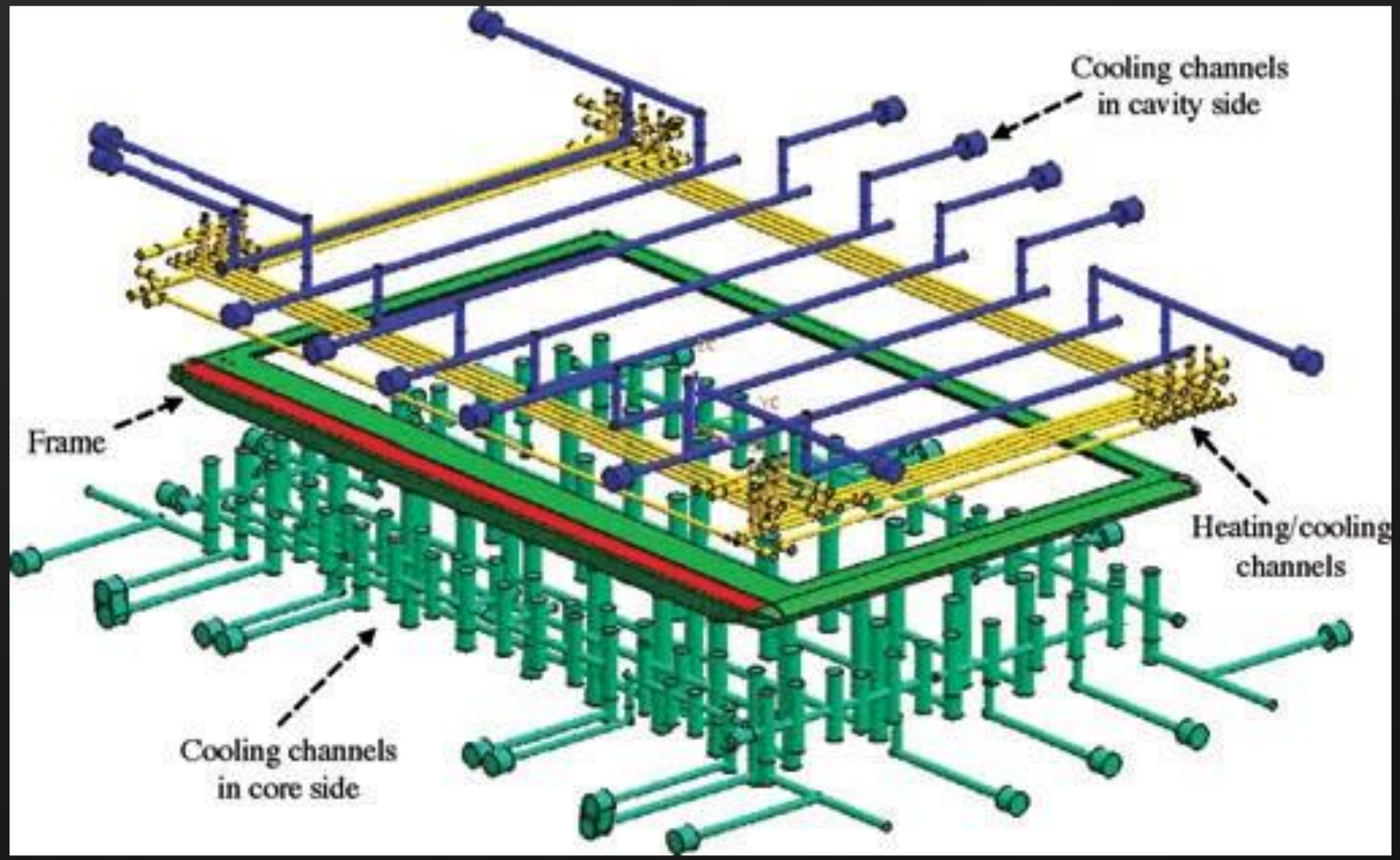
- Requests from far-east
  - Autodesk Moldflow Users' Conferences back in 2010
  - NPE / ANTEC this year
- RHCM in research and reality
  - Papers from Taiwan and China
- Mold failures in Ford
  - Ford did its own "Mold Failure Prediction" with Moldflow and ABAQUS
- Requests from other companies

What we are in: CAE for Injection Molding



What we face: Complexity of Mold Designs

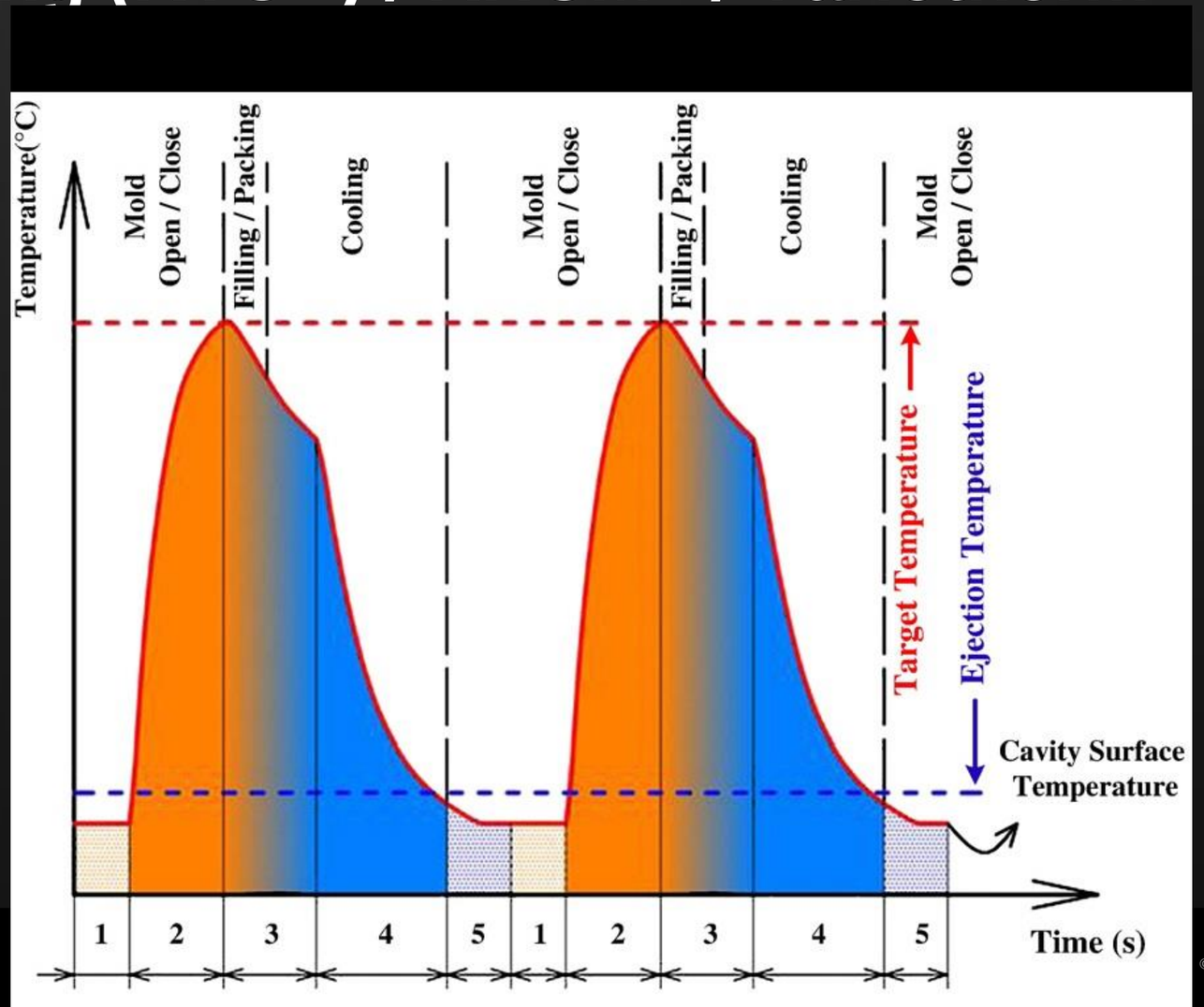




New Technologies drive the need

Rapid Temperature Cycling (RTC ®) / RHCM® / Variotherm ®

- Heat Mold for Filling
  - Eliminate visible weld-lines
  - Increase flow length
  - High (uniform) gloss finish
  - Eliminate Gate Marks (Cold slugs)
  - Typically only the cavity side is heated
- Heat by: Steam,Water, Electrical or Induction
- Cool Mold during Packing
  - Reduce cycle time
  - Conformal Cooling

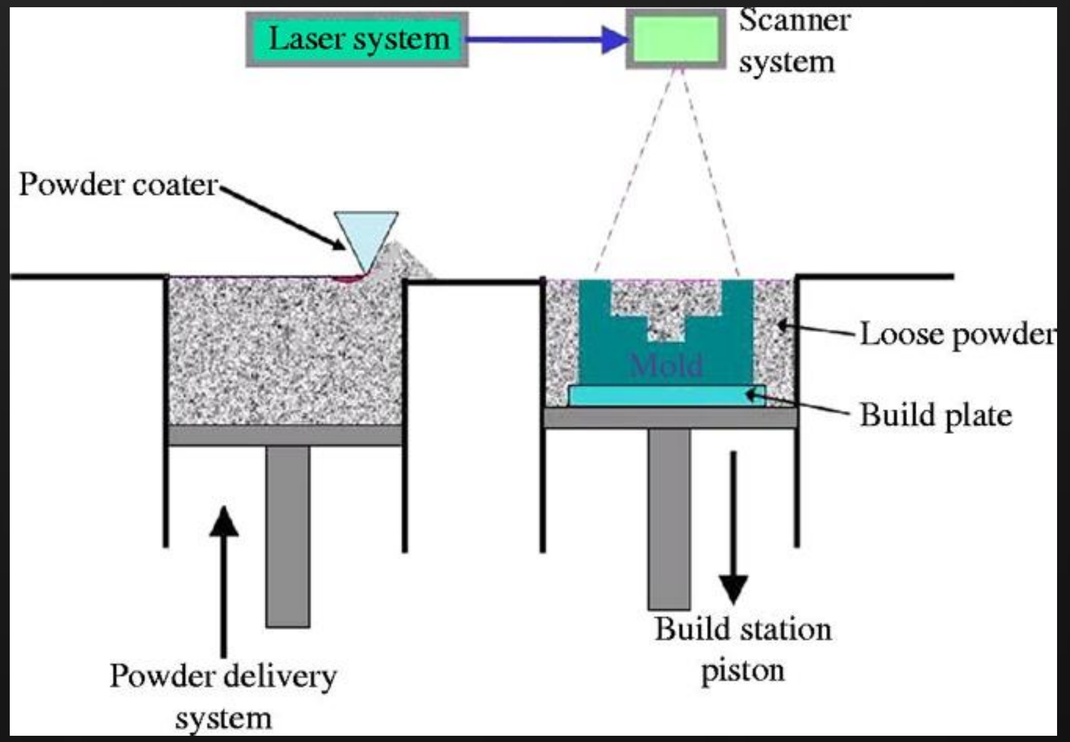


New Technologies drive the need

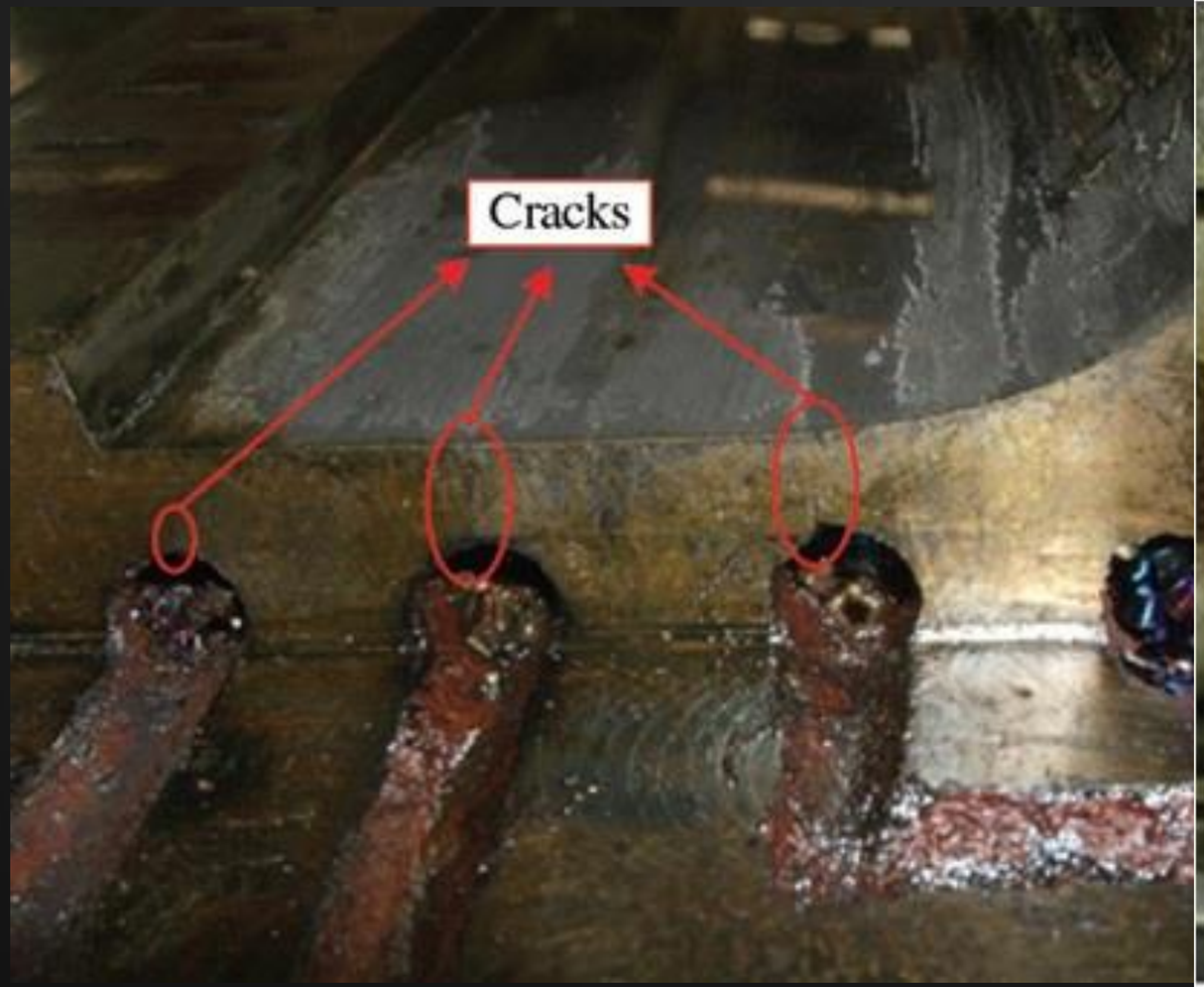
Additive Manufacturing (AM) of Molds

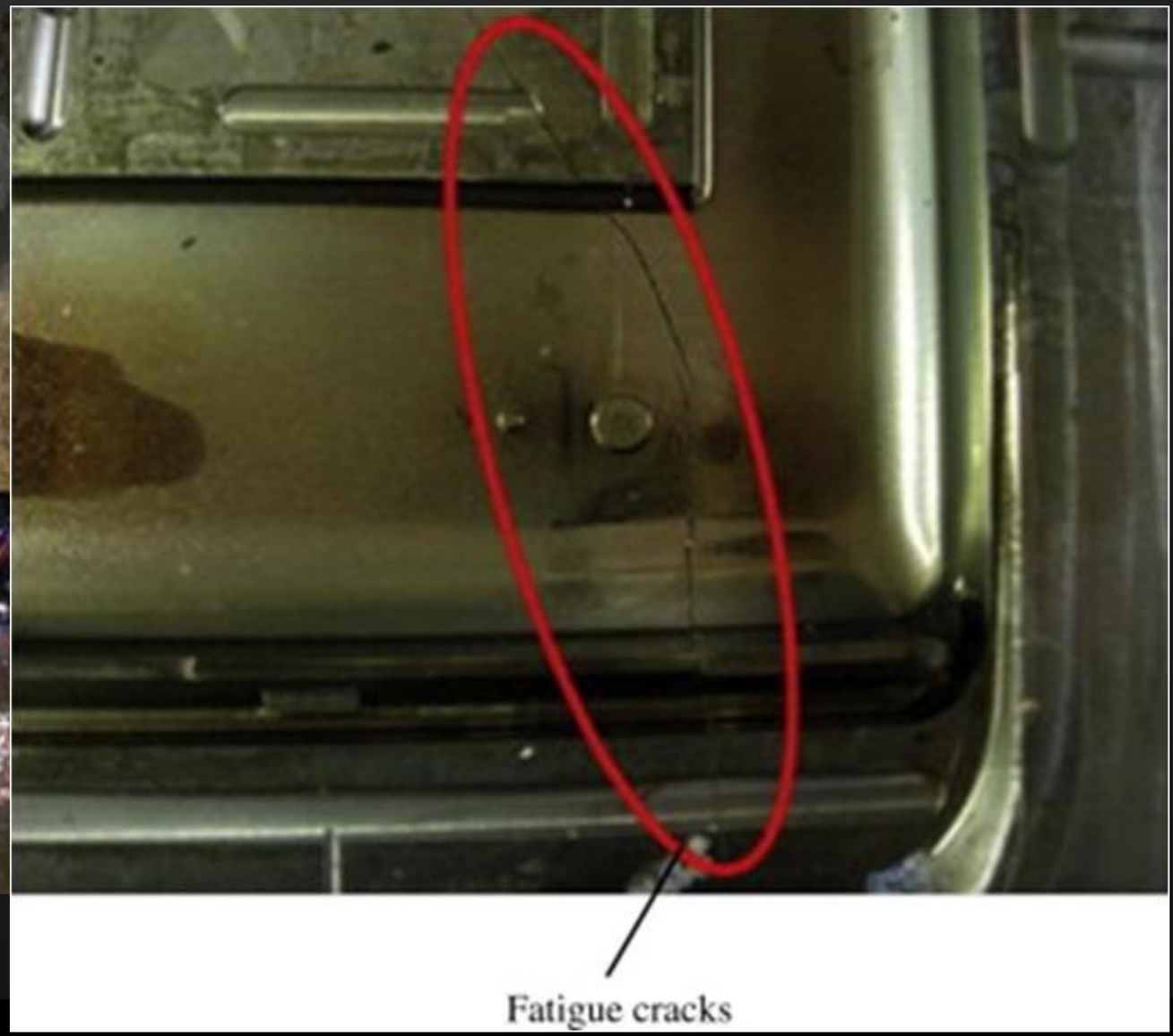
- Powder-based processes
  - Laser Engineered Net Shaping (LENS)
  - Selective Laser Sintering/Melting (SLS/SLM)
  - Direct Metal Laser Sintering (DMLS)
  - Three Dimensional Printing (3DP)
- Rapid Prototyping of Mold
- Low volume

Can we make it?



What we face: Mold Damages, Fewer Shots





Requirements for Mold Fatigue Prediction

- **If a mold is damaged earlier than its expected lifecycle**
  - Repair costs
  - Unexpected downtime
  - A backup mold set could be ordered
- **Mold maintenance service as a preventive care**
  - After certain cycles of molding which is based on failure statistics of different molds in the past
- **New Technology may increase quality, increase productivity**
  - But may not lower costs due to shorter mold lifecycle

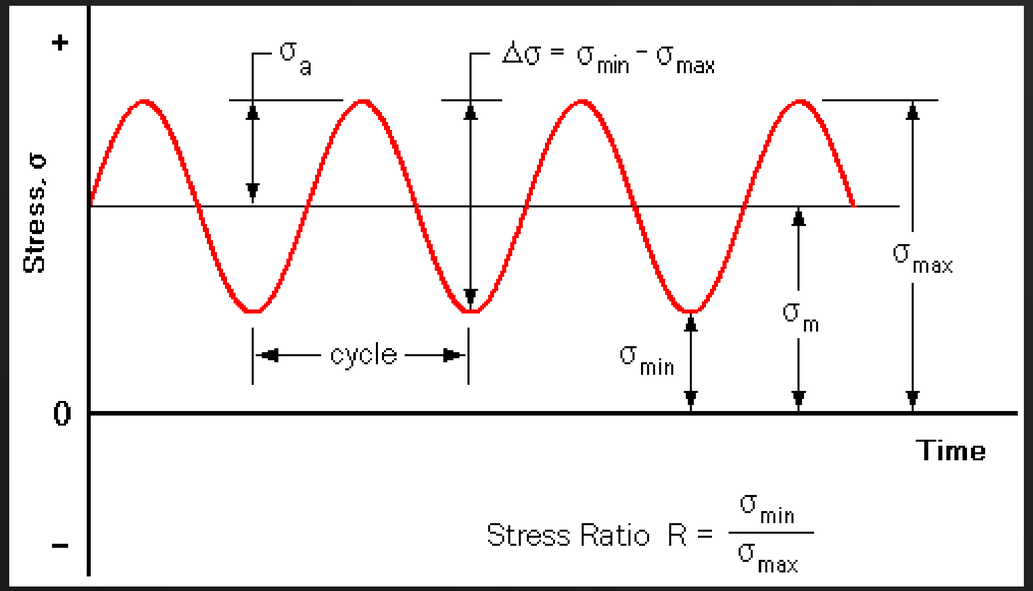
A mold design/making should be based a careful CAE analysis of the intended molding!

What can we do with simulation tools?

What available in Autodesk Simulation

- Autodesk Simulation Moldflow Insight
  - RHCM Heat Transfer Analysis (Cool FEM)
  - Flow with Core-Shift
  - Clamping Force Prediction
- Autodesk Simulation Mechanical
  - Linear Static Stress analysis (LSS)
  - Transient thermal stress analysis
  - Fatigue Wizard
- Autodesk Simulation CFD
  - Application to Conformal Cooling in RHCM

What are the major causes of Mold Damage?



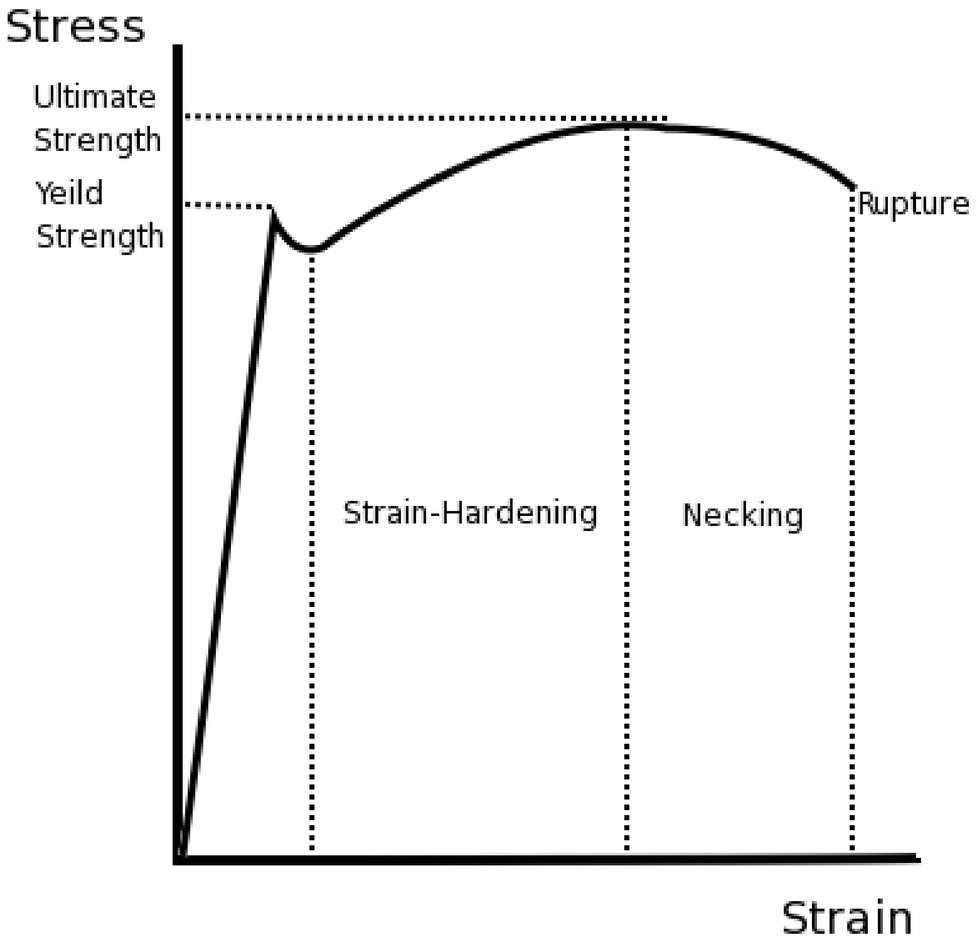
Injection molding has a cyclic nature

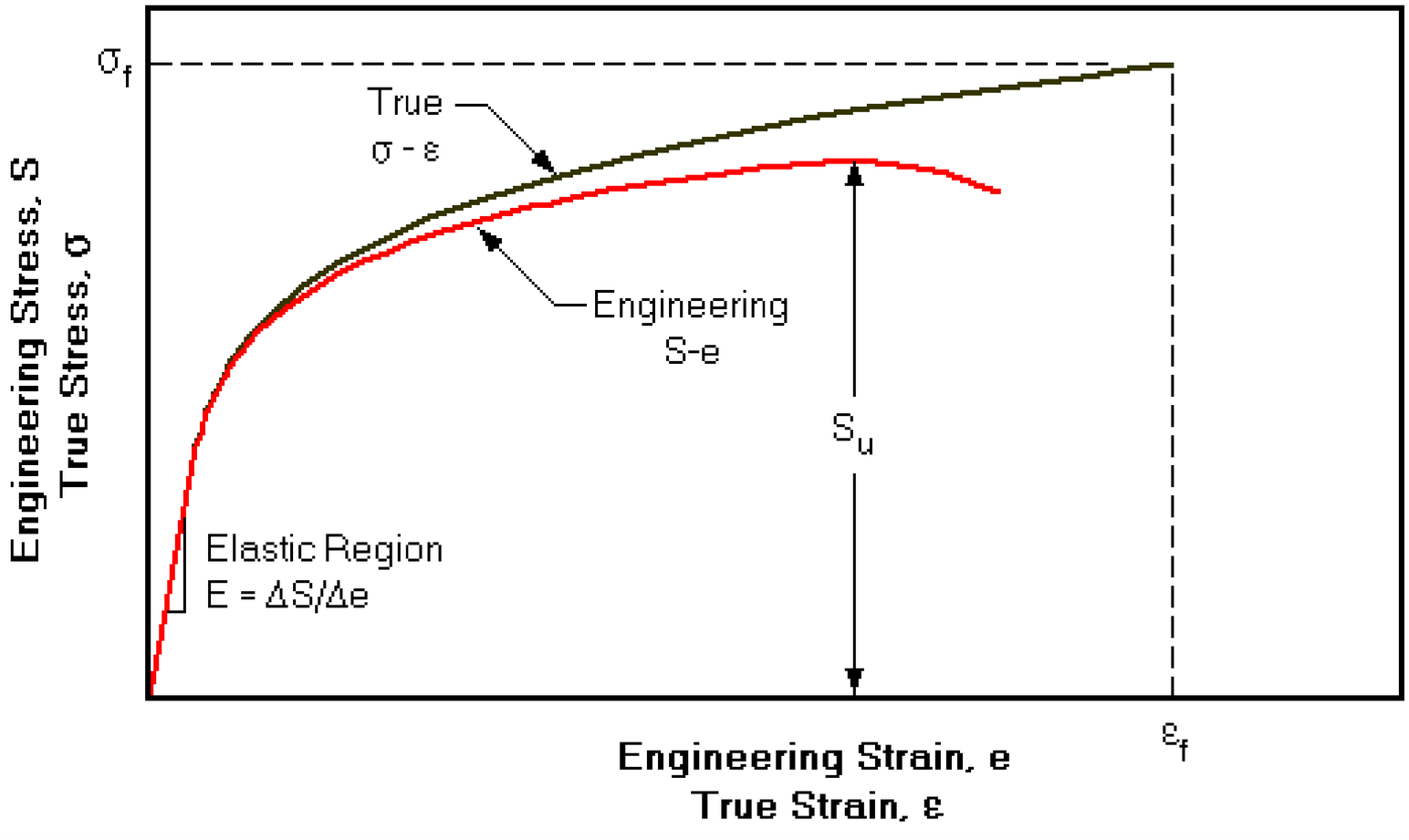
Three cycles overlap together

- **Mold Opening and Closing**
- **Heating up and Cooling down**
- **Injection pressure increases and decays**

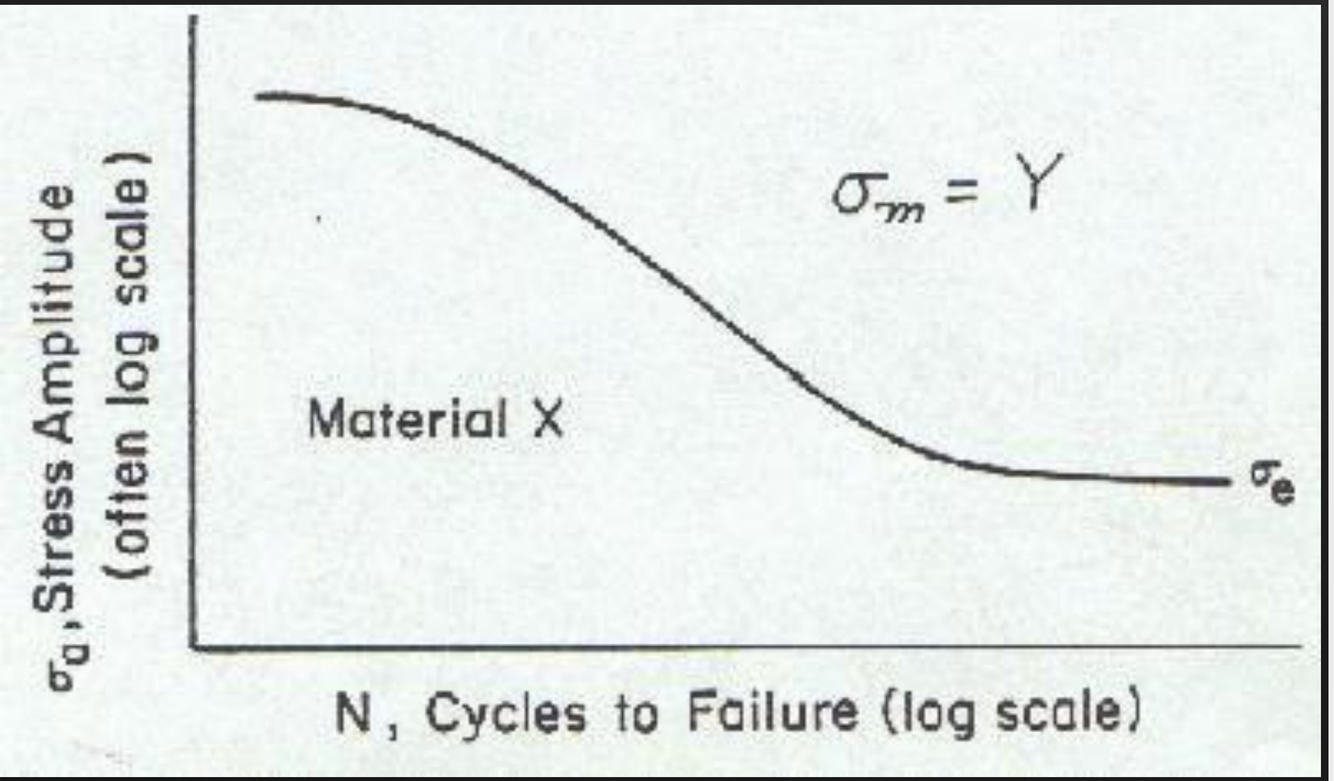
- Heat Transfer induced thermal stress
  - It should be calculated with Heat Transfer Analysis in Cool (FEM)
- Mold Deflection induced stress
  - Core-shift should be extended to Mold Blocks with LSS
- Clamping induced stress
  - Use the prediction of clamping force with optional inputs

Material properties for fatigue: Yield Strength, UTS

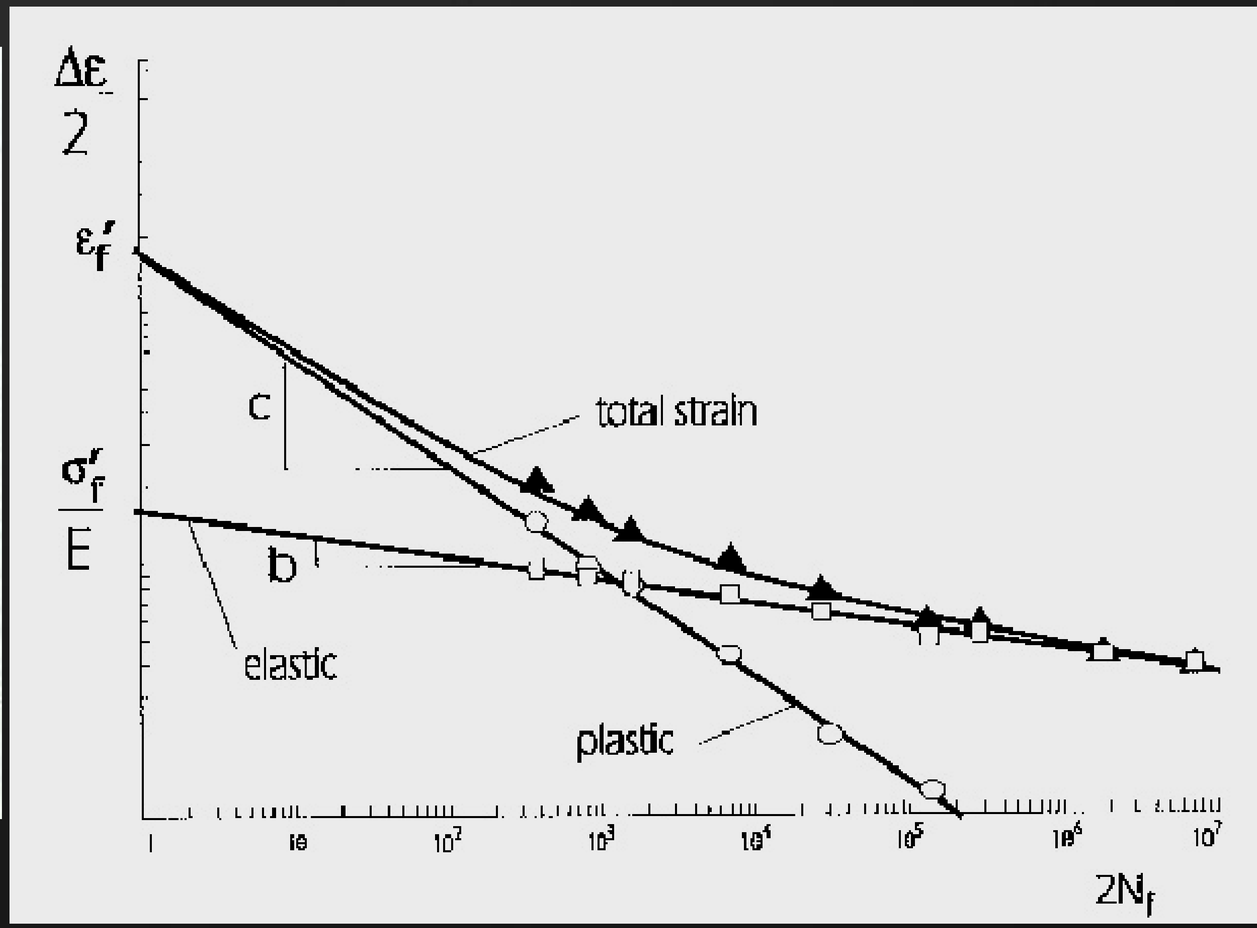




Material properties for fatigue: S-N and E-N data

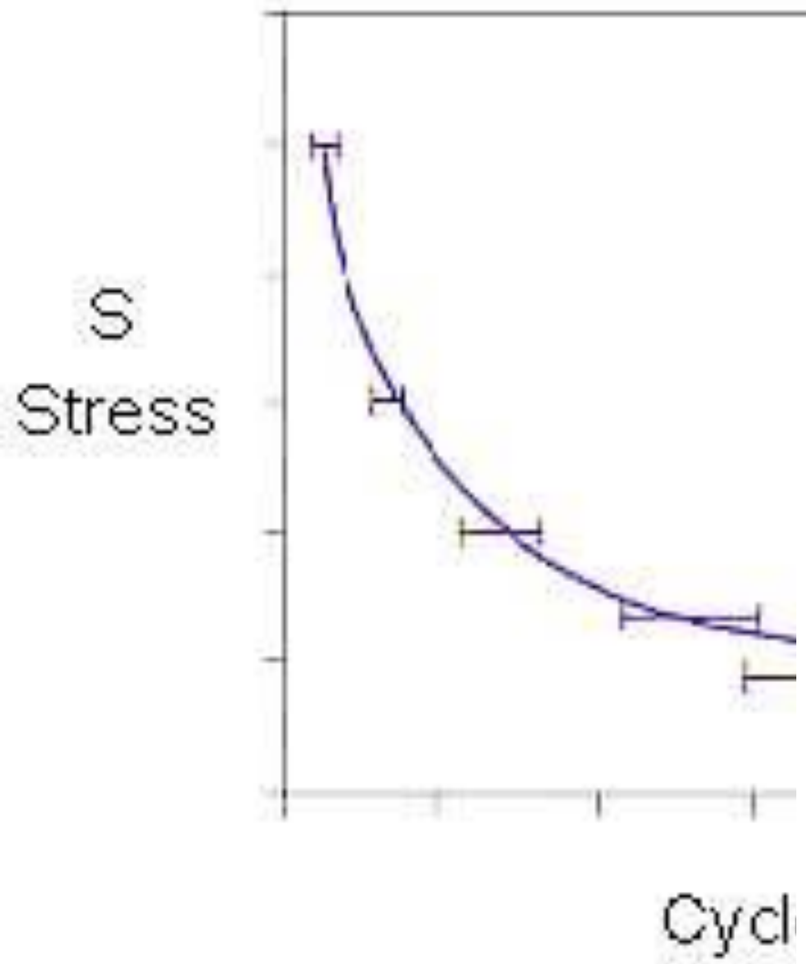


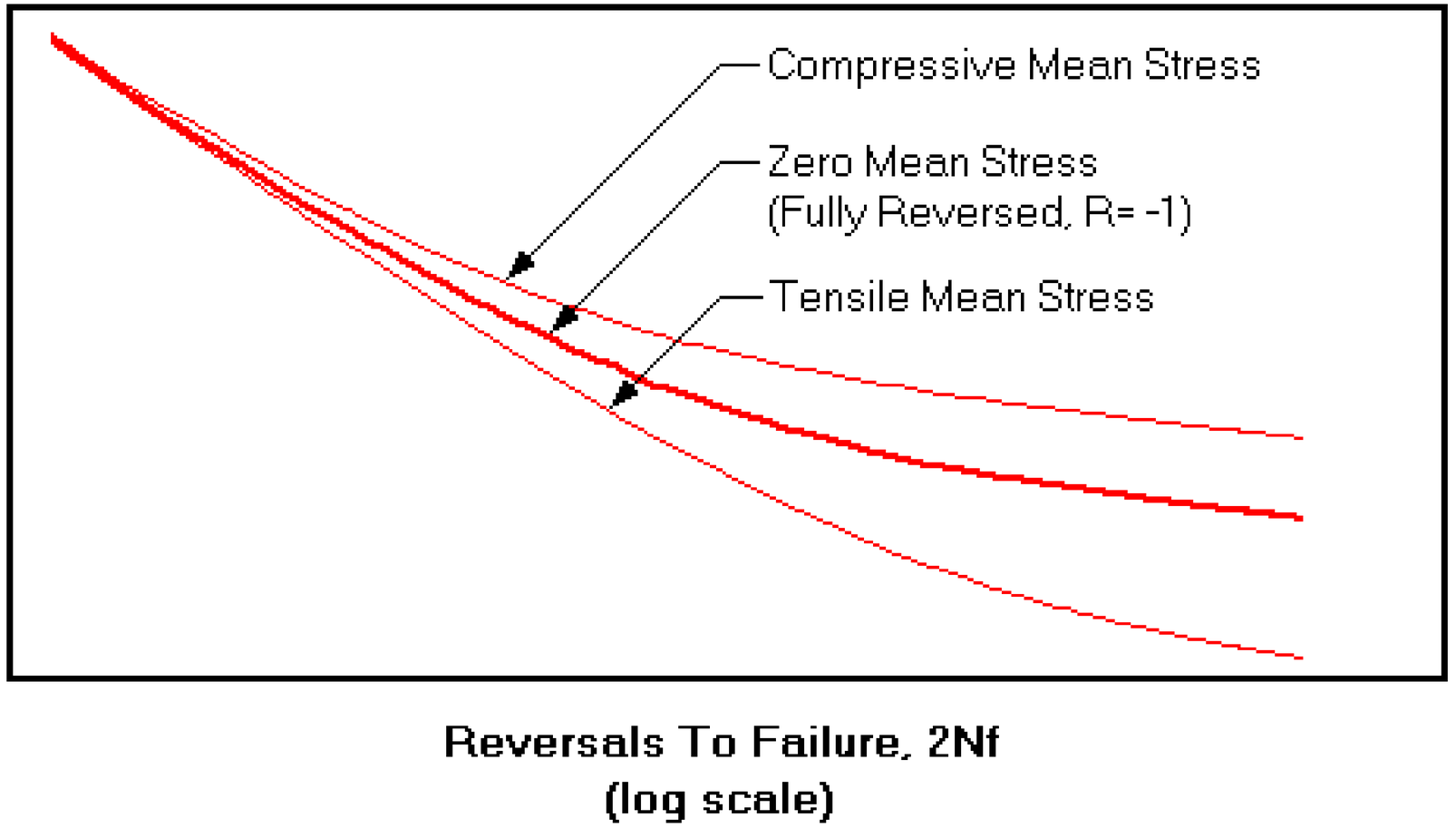
Stress-life log10 curve



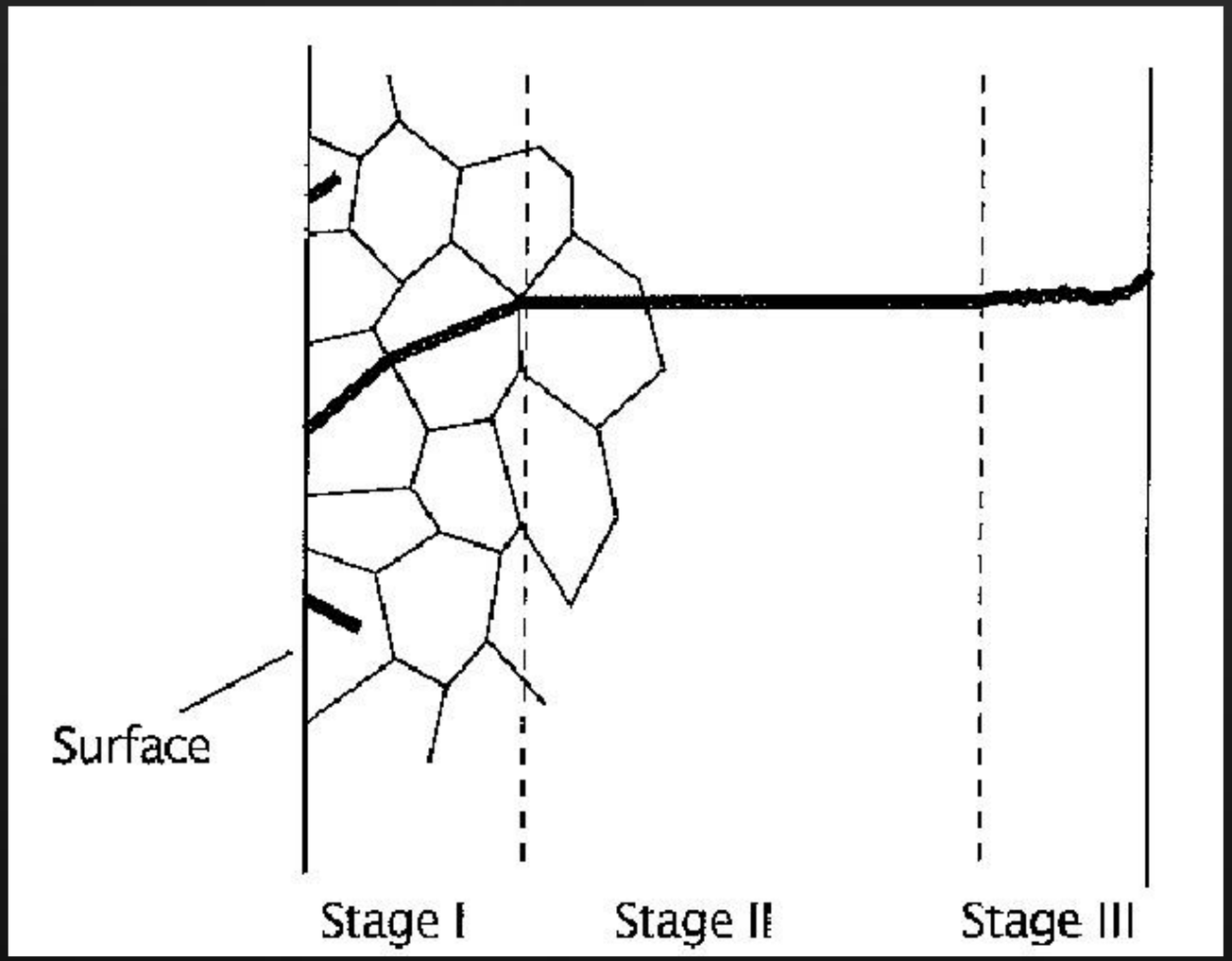
Strain-life log10 curve

Nature of Fatigue Data

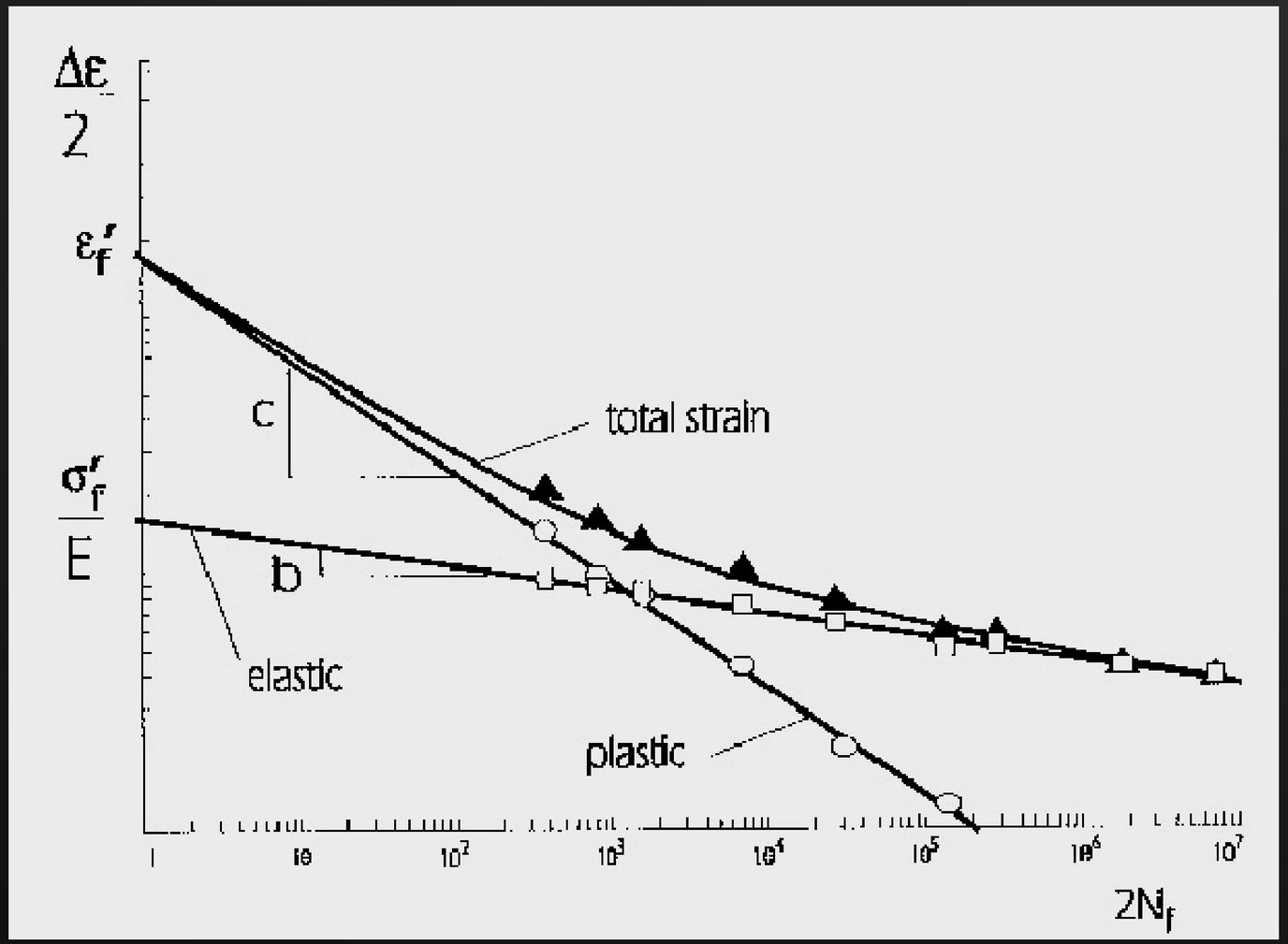


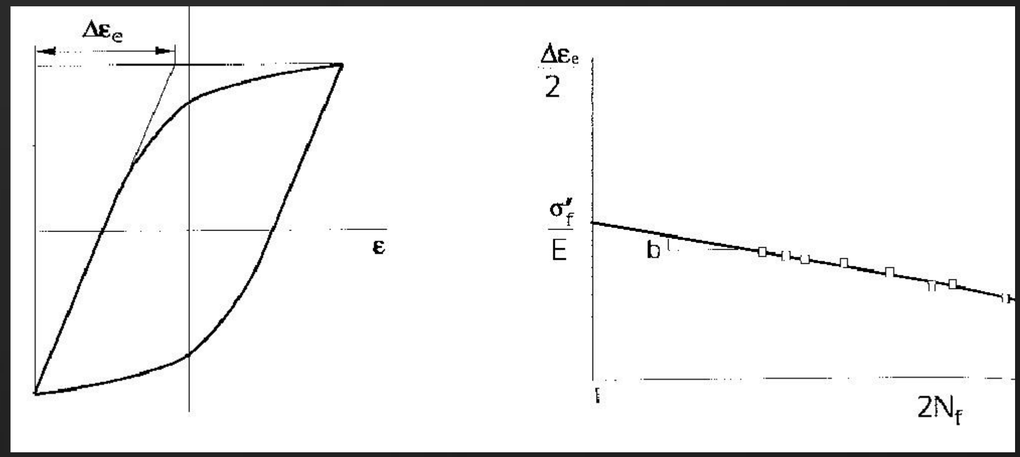


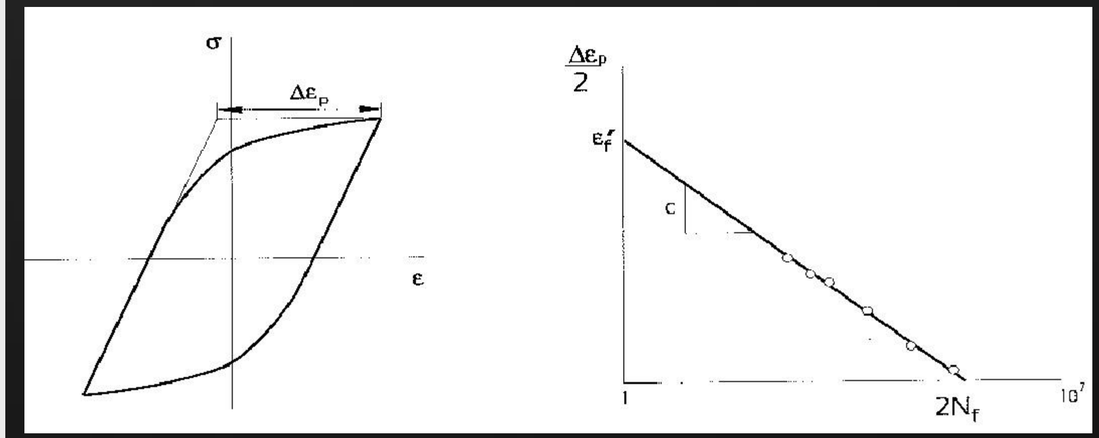
Nature of Fatigue: crack starts from surface



Mold Fatigue Prediction Models





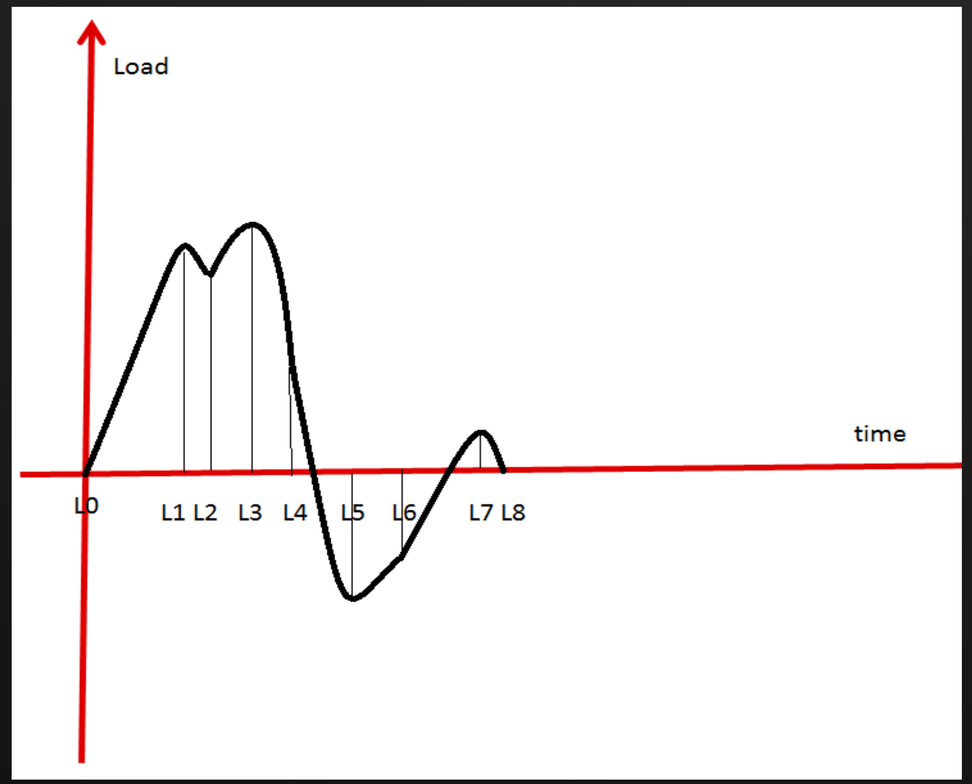


Fatigue Wizard is a Generic Tool…, it can do

- Multi-load Analysis
  - Static loads with user specified time history, all load cases need to be in the same time span

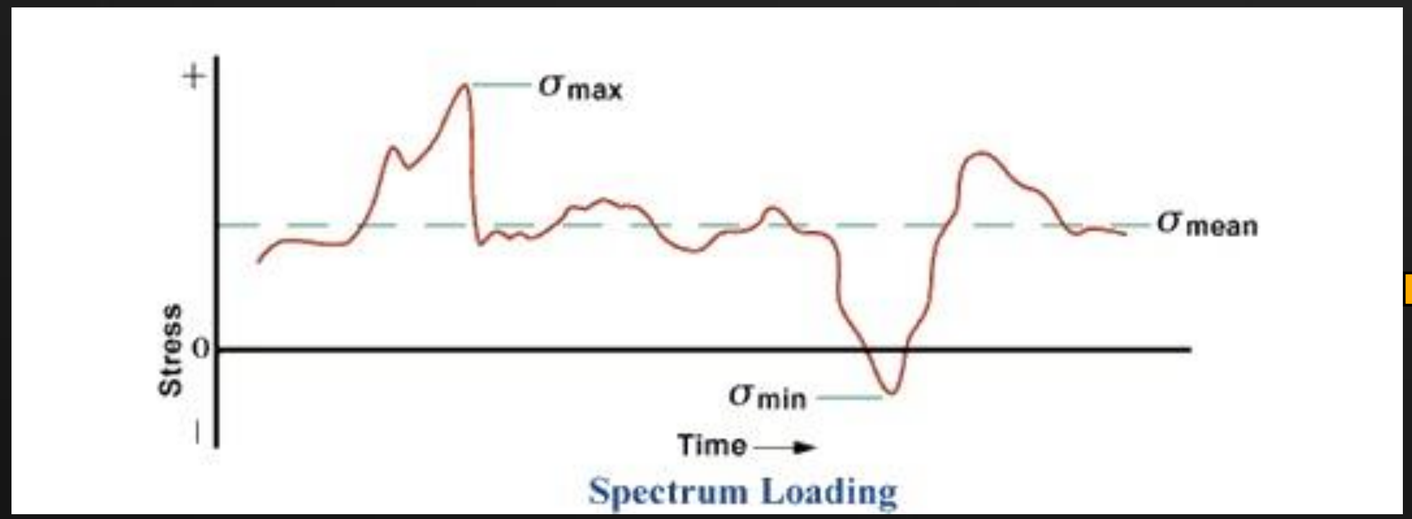
Fatigue Wizard is a Generic Tool…, it can do

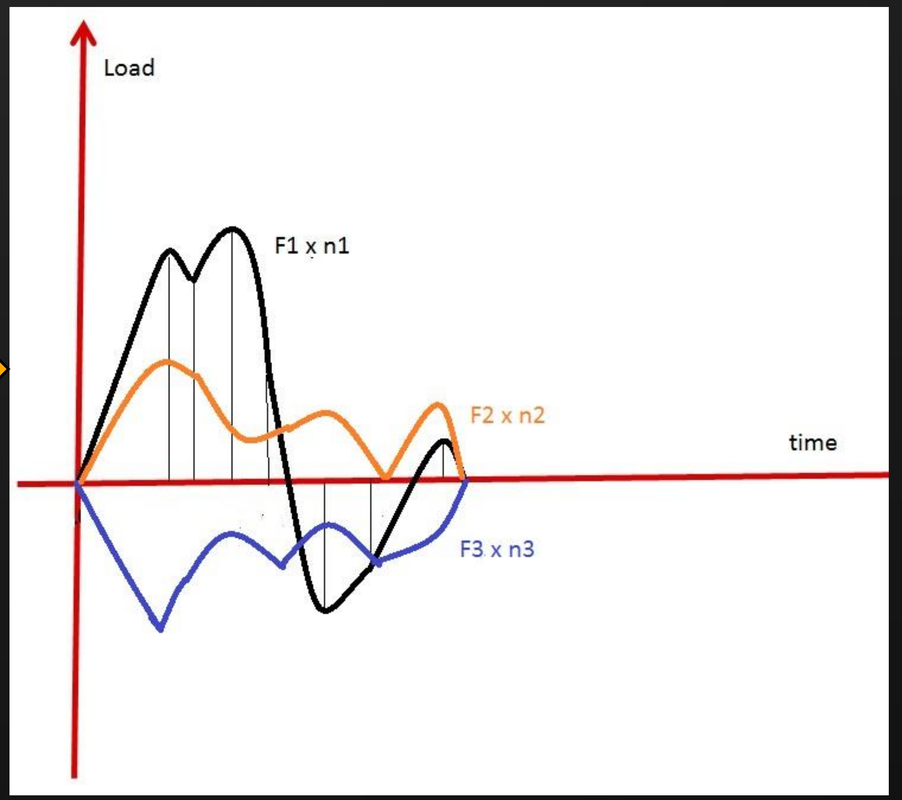
- Transient Analysis
  - Load cases over a time history



Fatigue Wizard is a Generic Tool…, it can do

- Spectrum Analysis
  - Load cases over a time history with specified load factors and repeated cycles

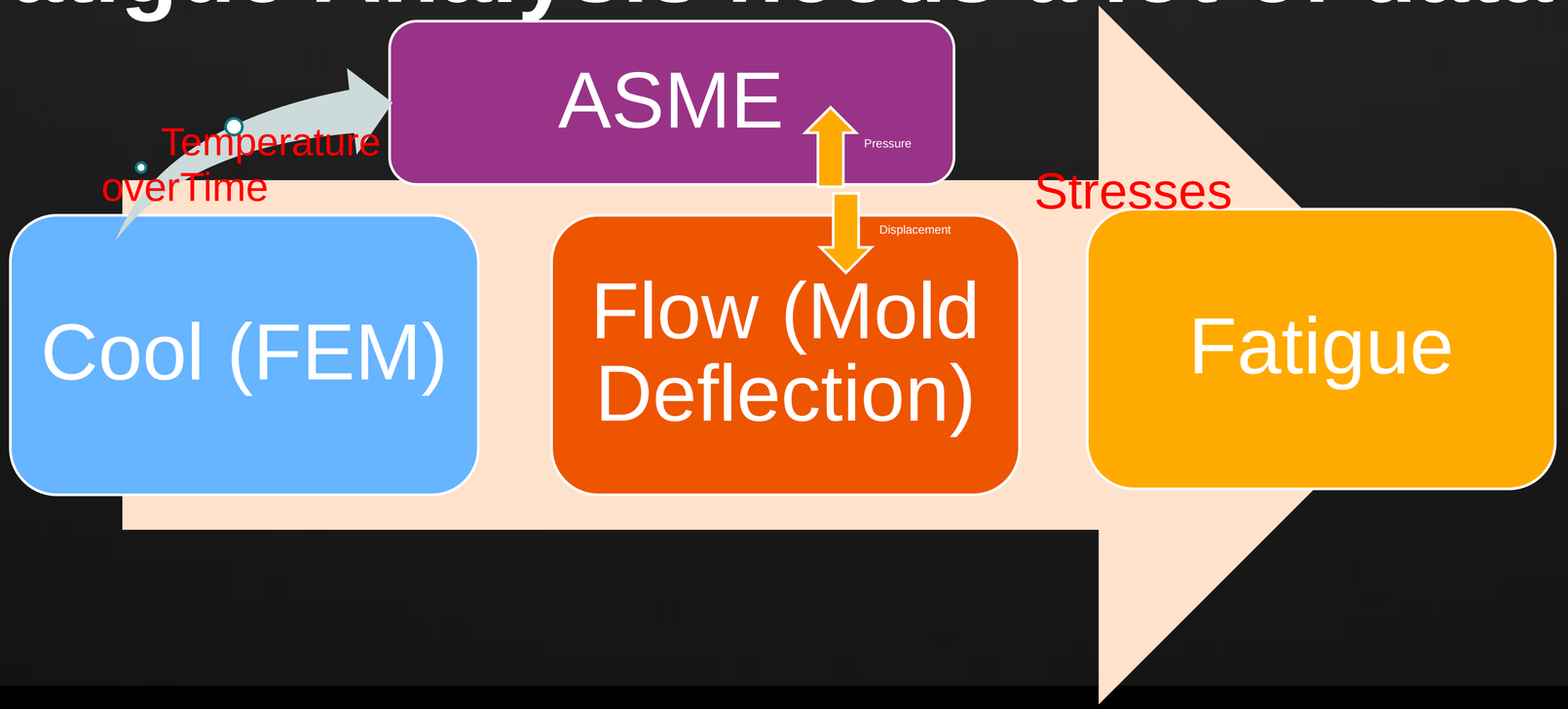




Mold Fatigue Analysis is a Transient Analysis

- Three sets of stress load categories are added up
  - Thermal Stress + Mold Deflection Stress + Clamping Stress at each point
  - Over the same time history
  - The data “input” are built automatically

Mold Fatigue Analysis needs a lot of data transfer

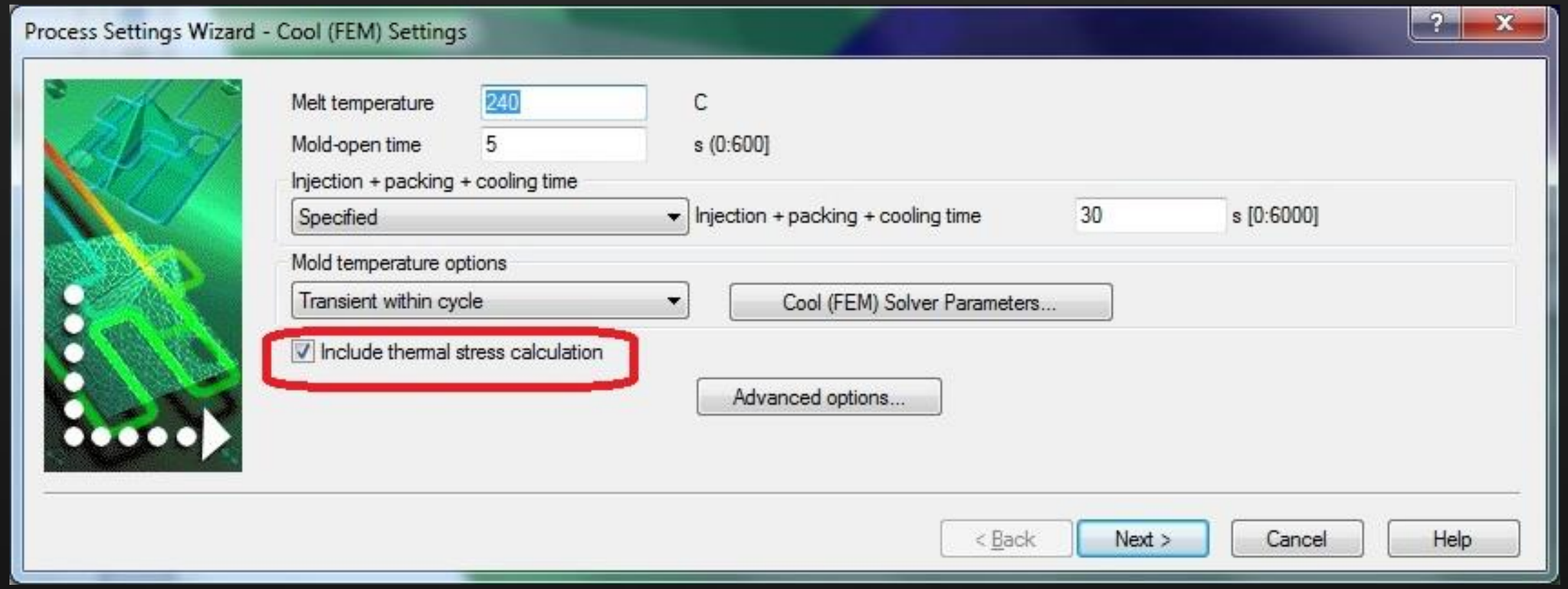


Understand the nature of fatigue prediction

- Accuracy of stress prediction plays a key role
  - A small percent of error in stress prediction can cause a big error in fatigue life
- A pre-existed defect in a mold metal is hard to be modeled in a mesh
- Stress prediction on surface

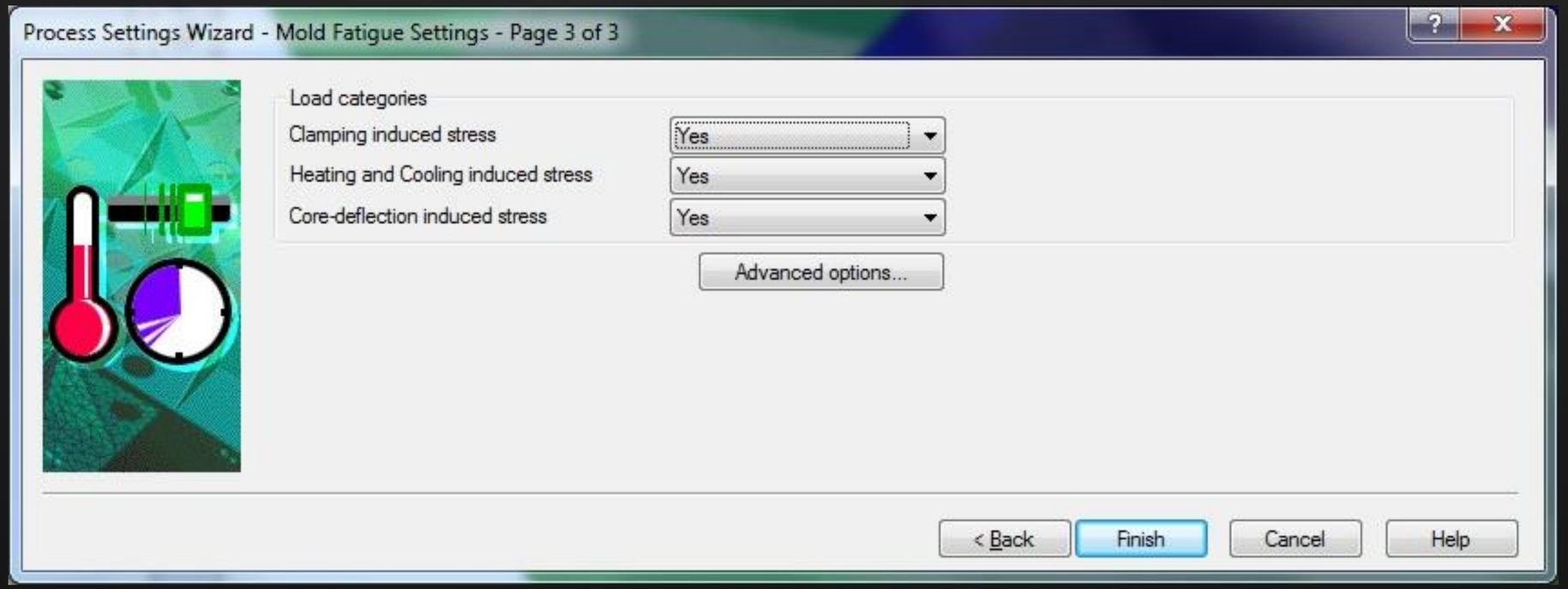
How to setup Mold Fatigue analysis?

Settings in Wizard



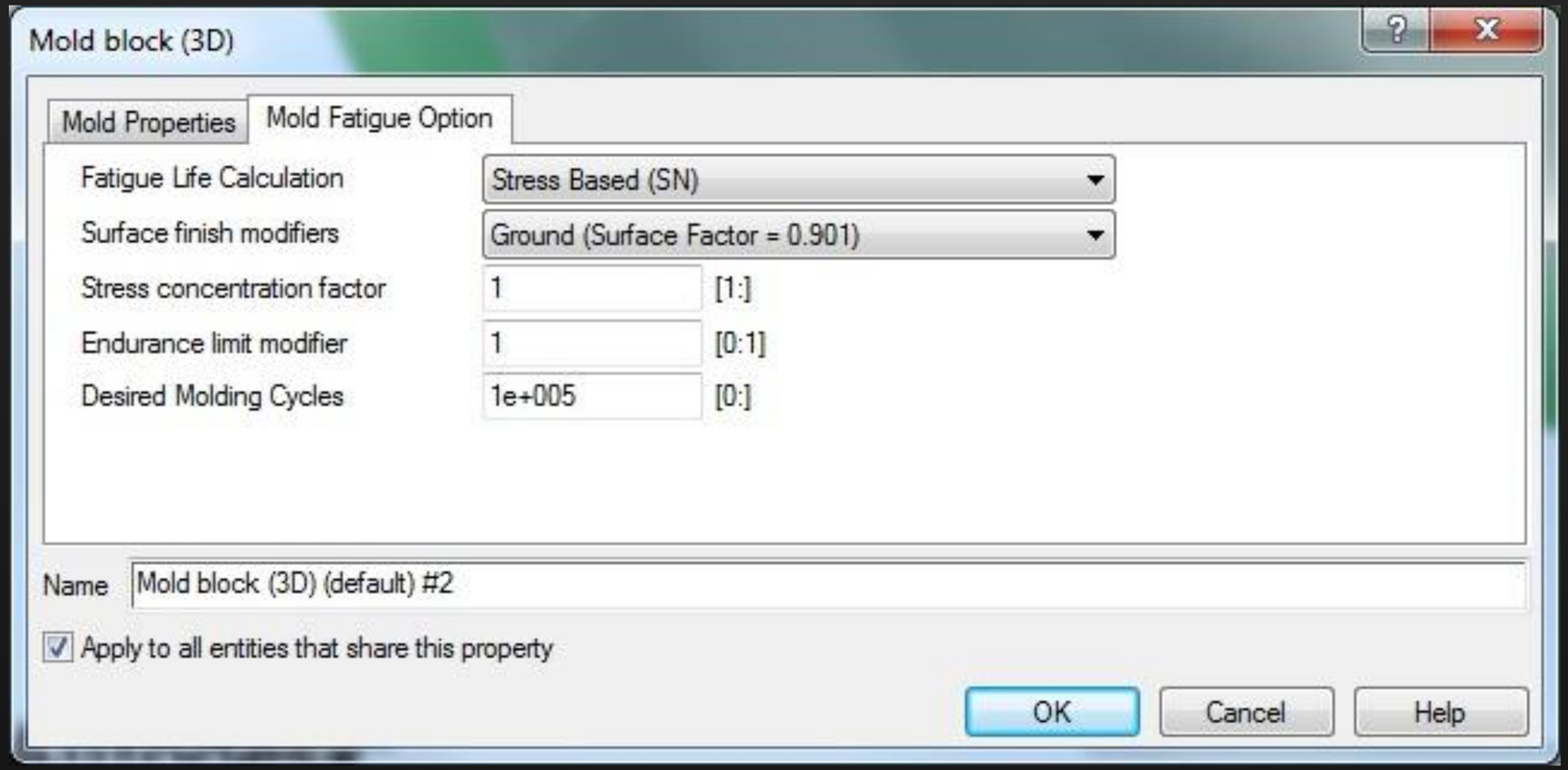
Include thermal stress in Cool (FEM) settings

Settings in Wizard



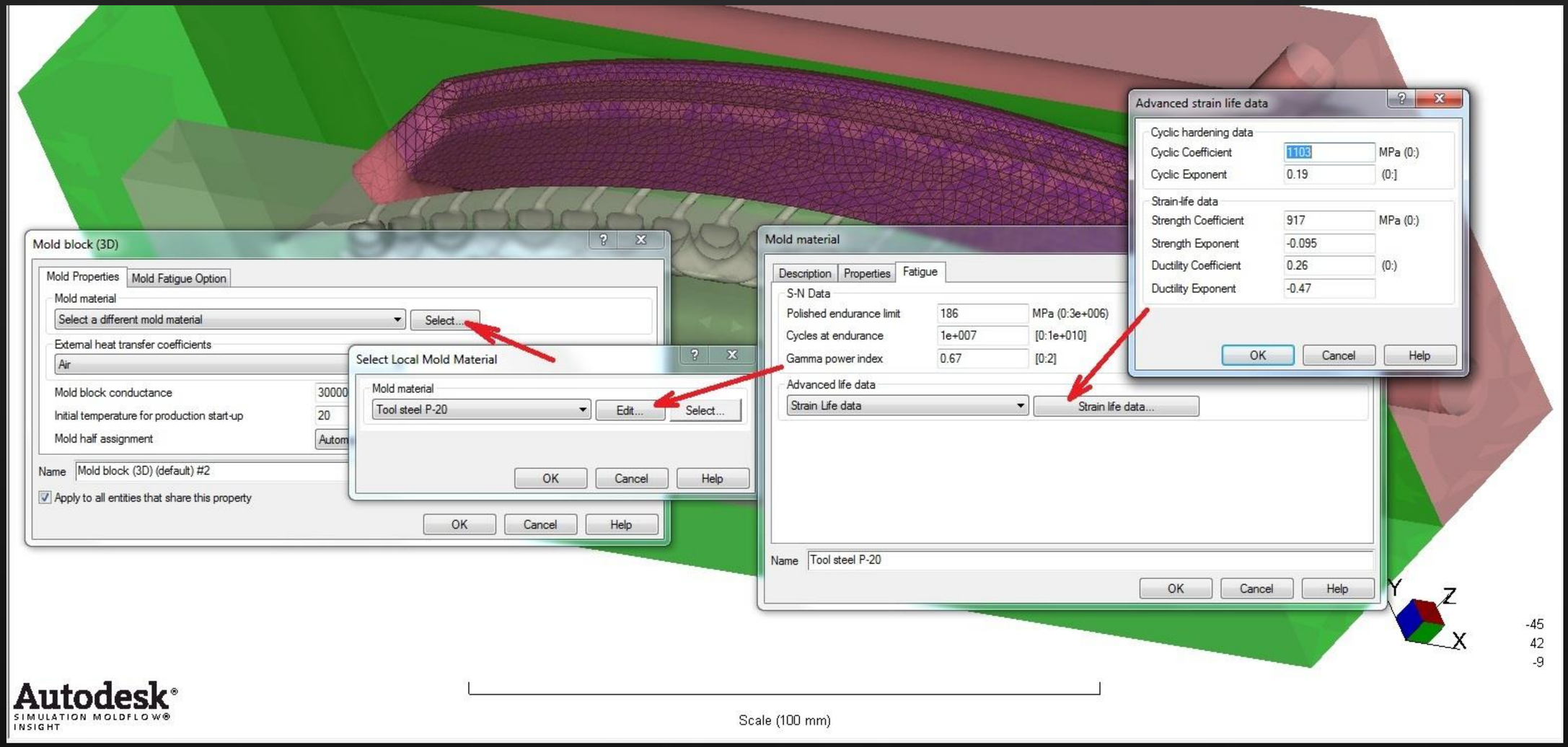
Mold Fatigue Settings for all three load categories

Mold Block Fatigue options



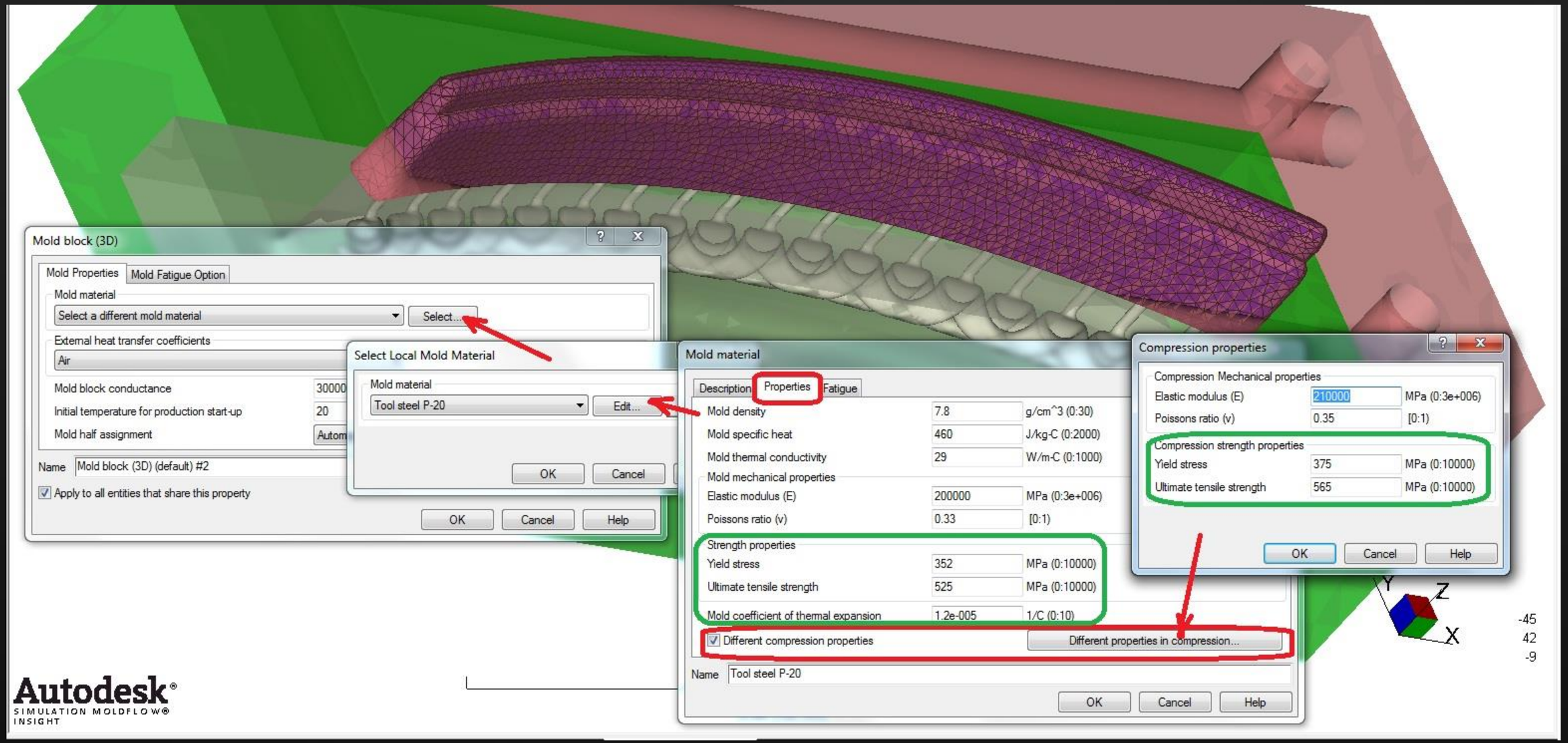
Mold Fatigue Options are based on mold pieces

Fatigue properties



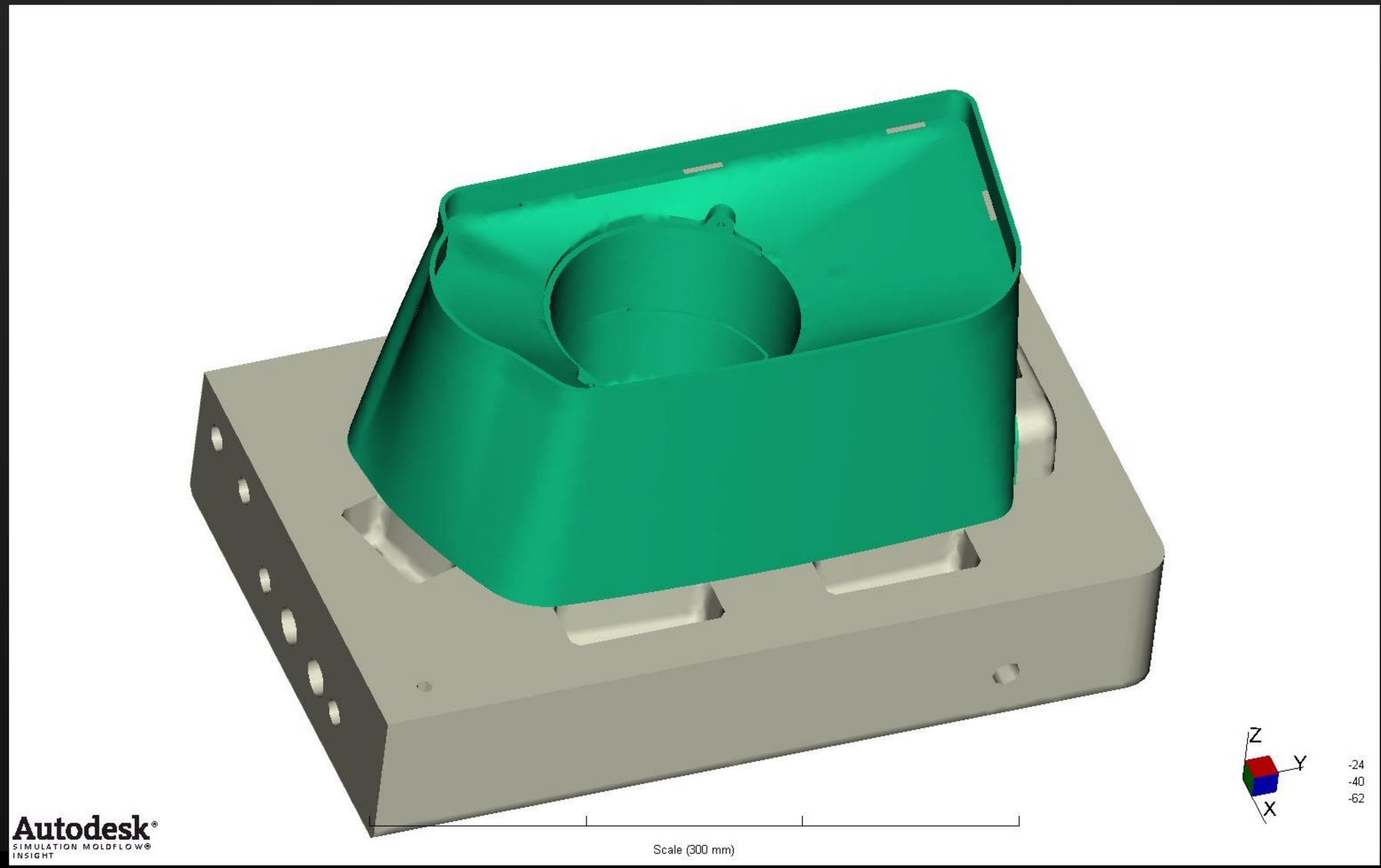
Fatigue properties are associated with mold piece

Additional mechanical / strength properties

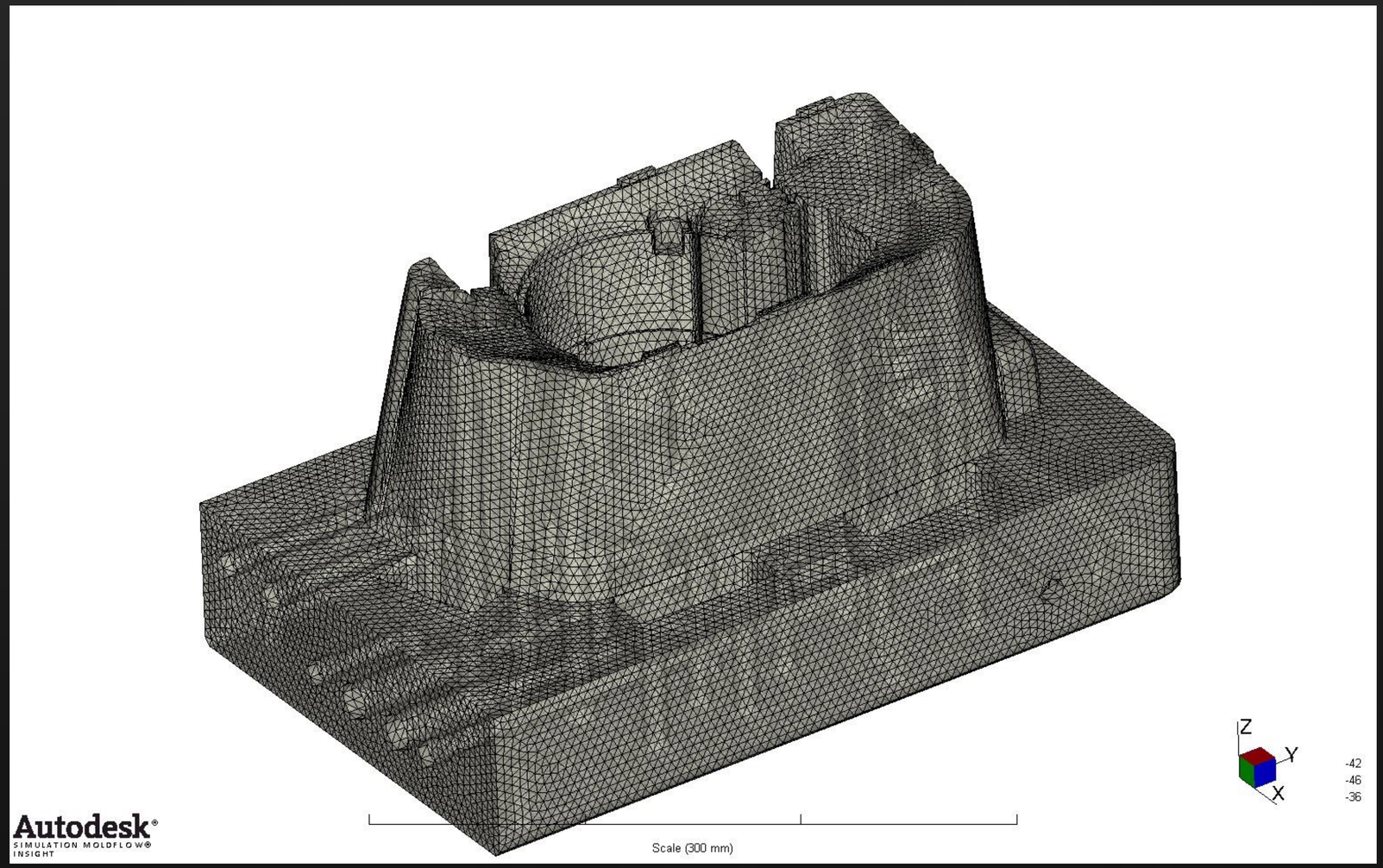


Additional mechanical / strength properties are needed,
Compression may not be the same as tension

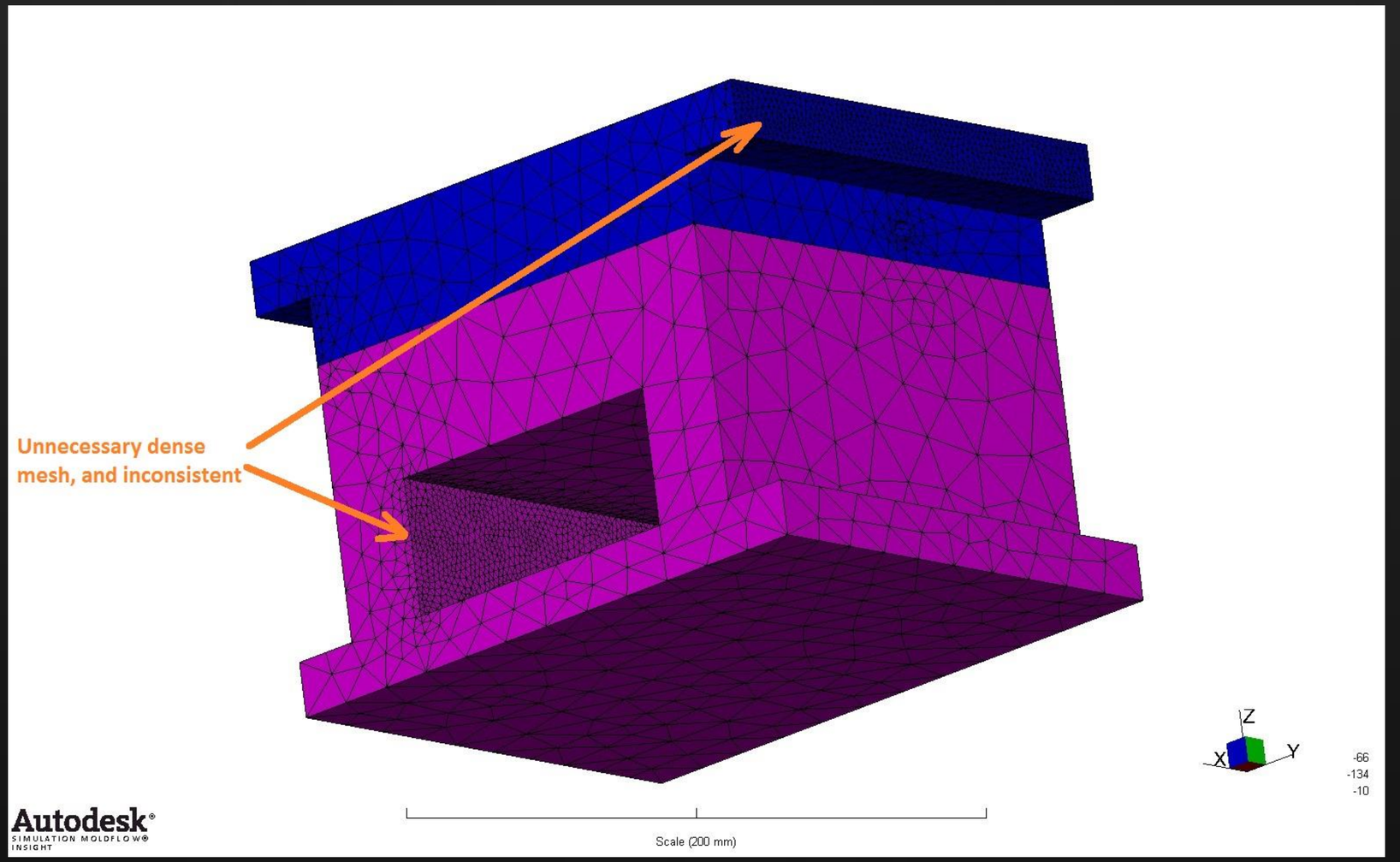
Mesh requirements: Mold Deflection vs. Stress



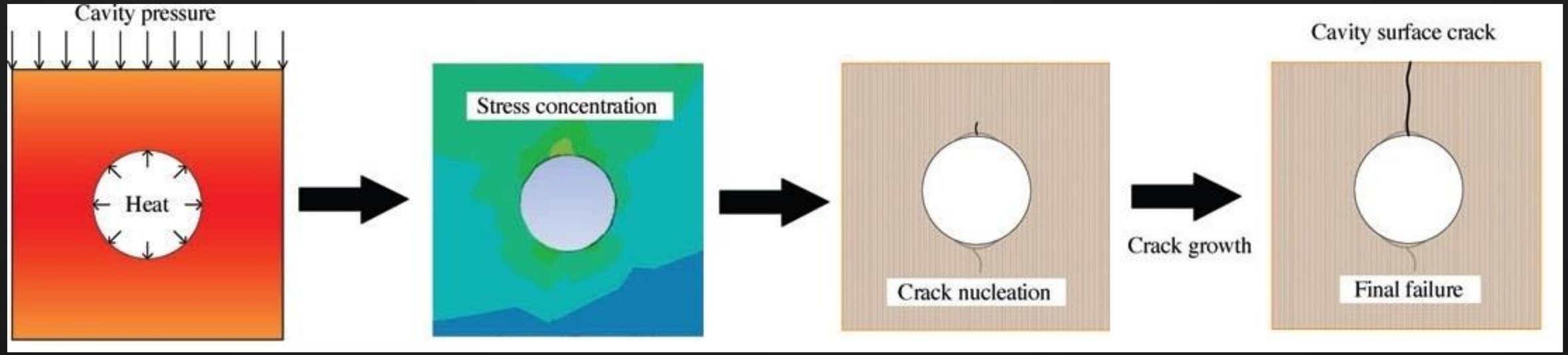
Mesh requirements



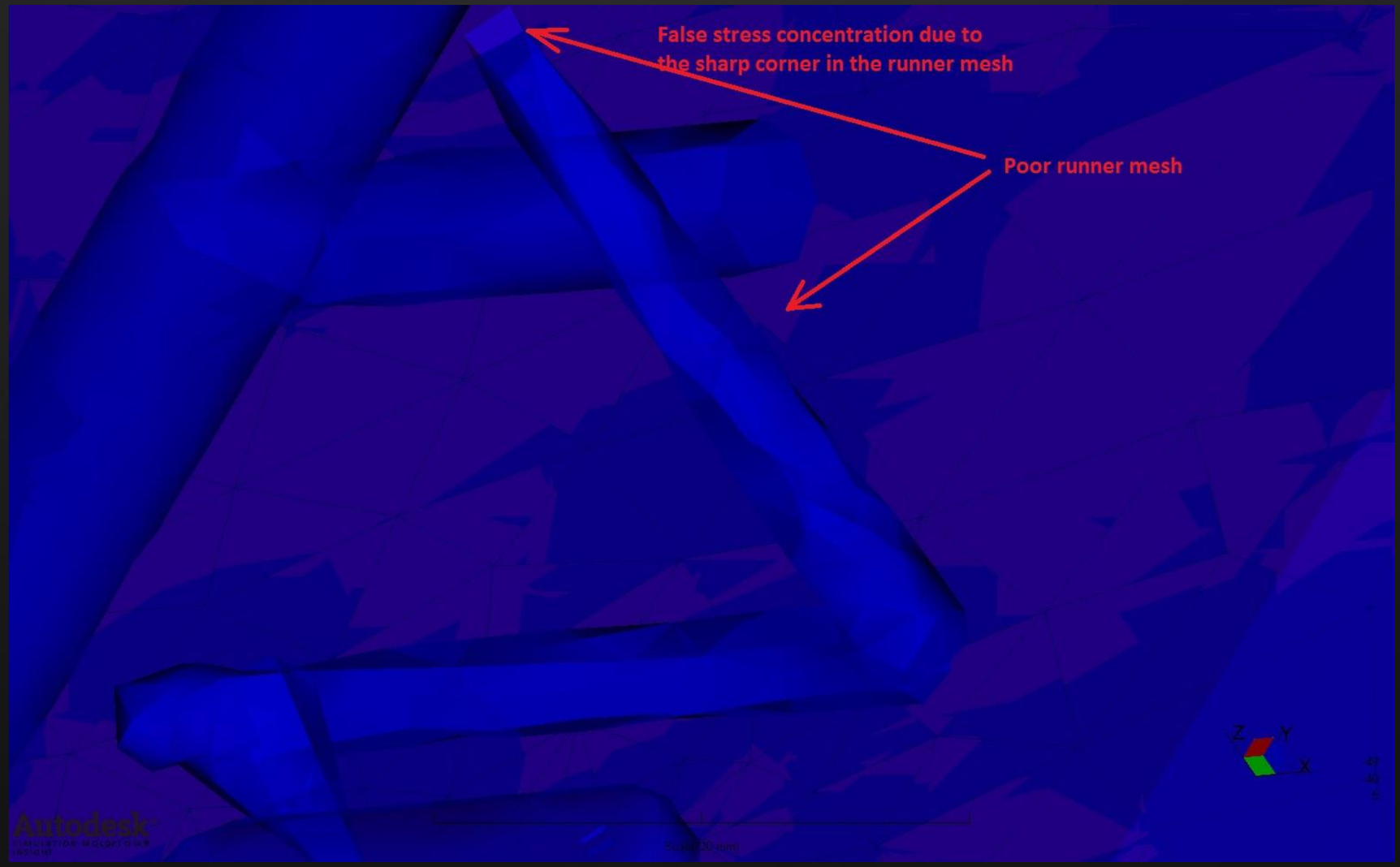
Mesh requirements (continue)



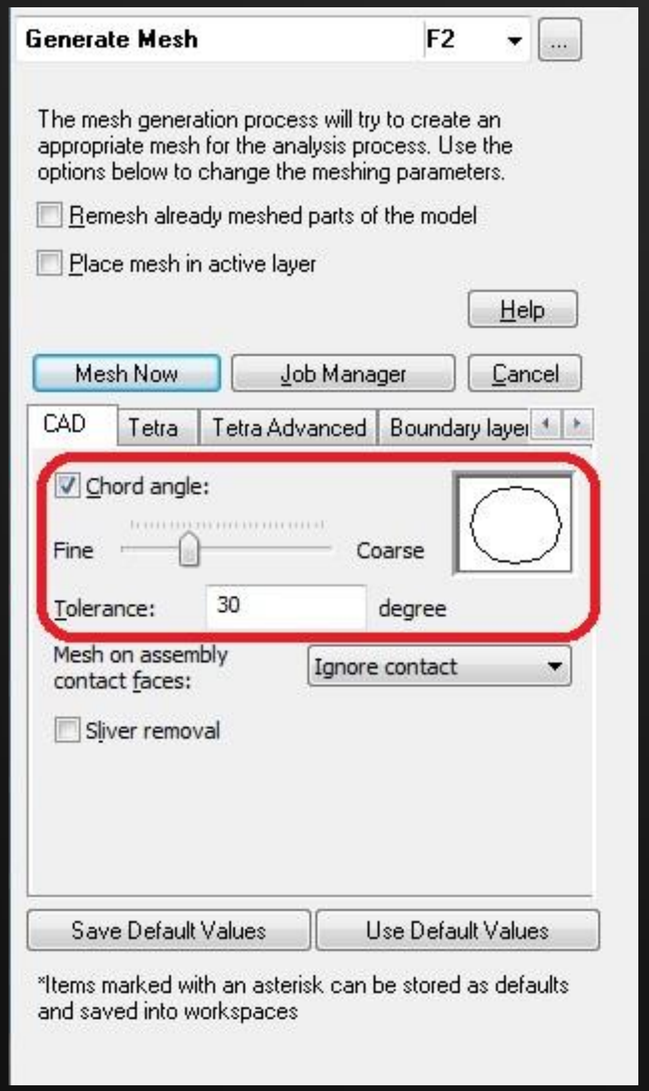
Stress concentration around a hole

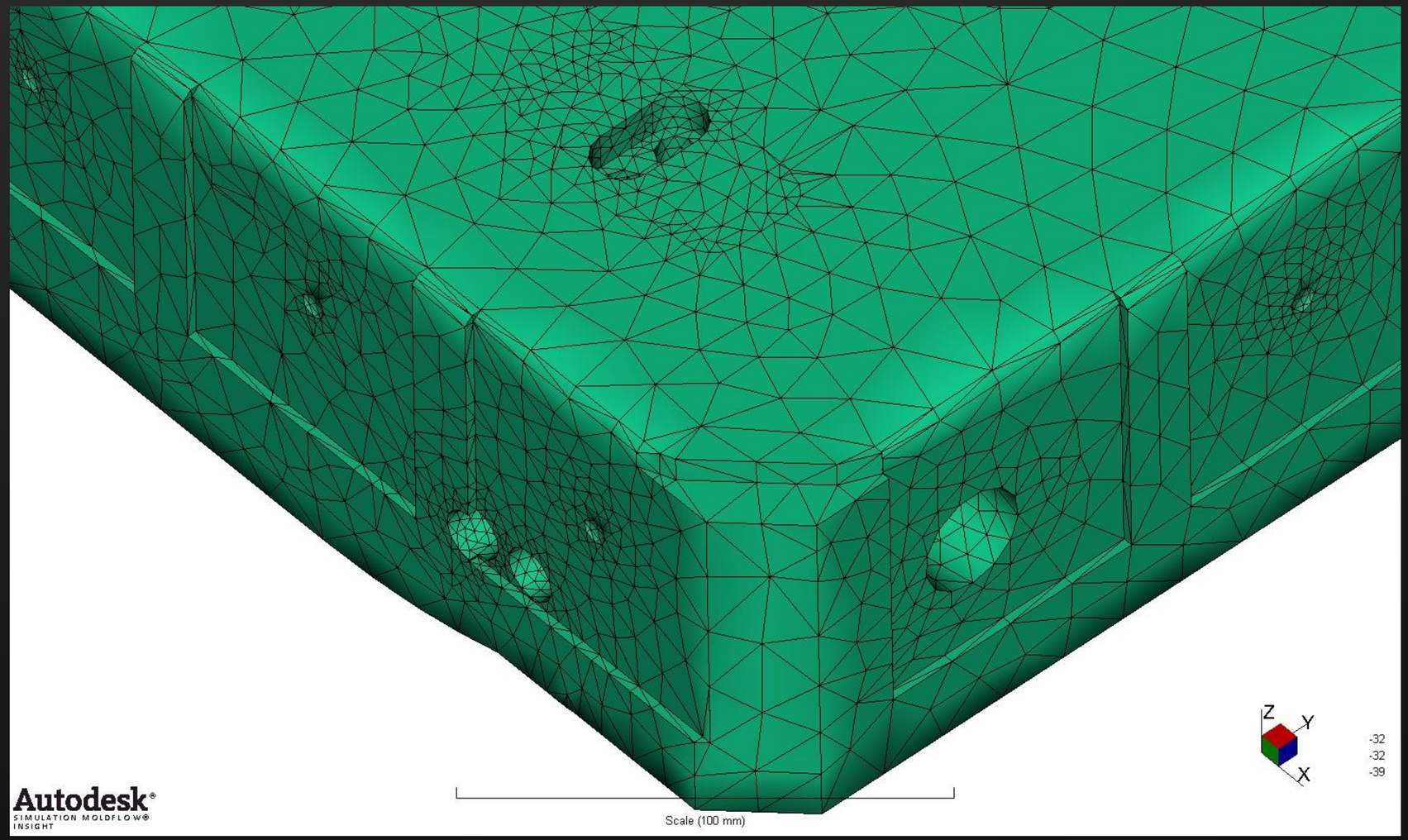


False stress concentration due to poor mesh

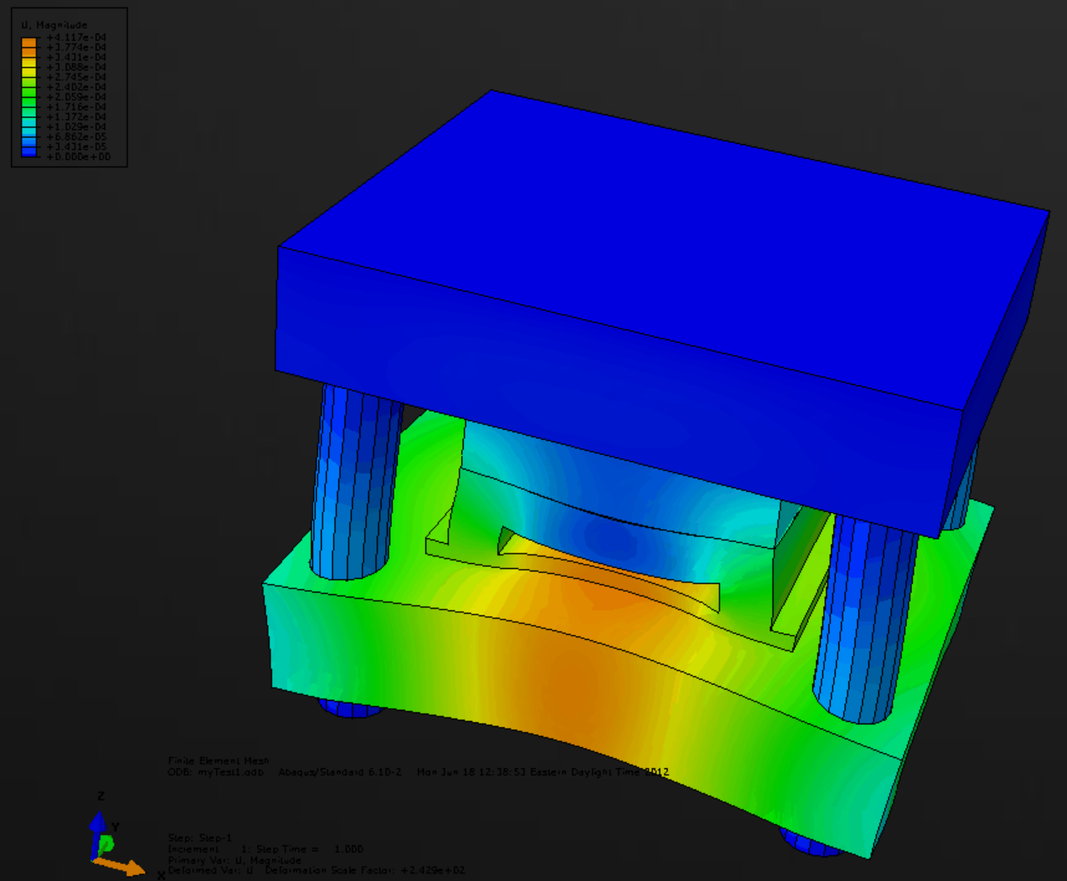


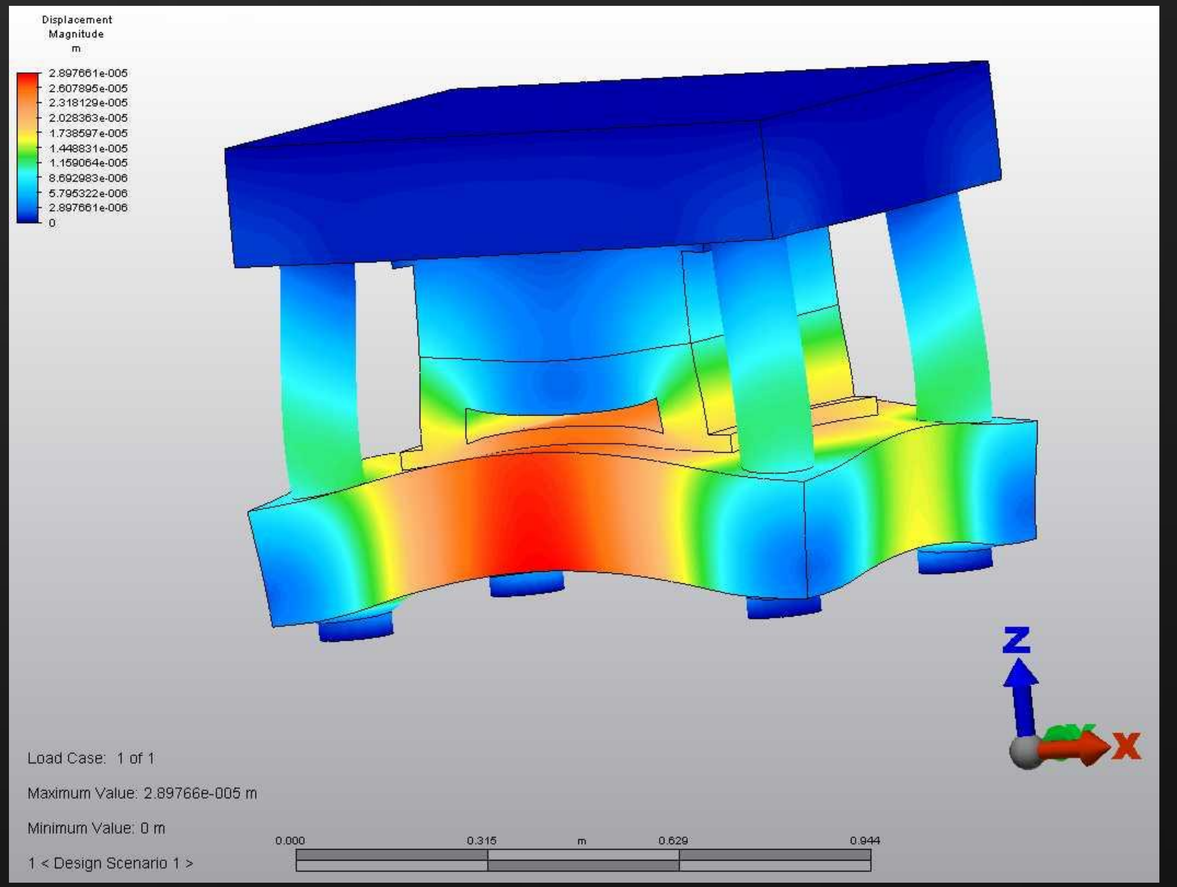
Better mesh around the holes



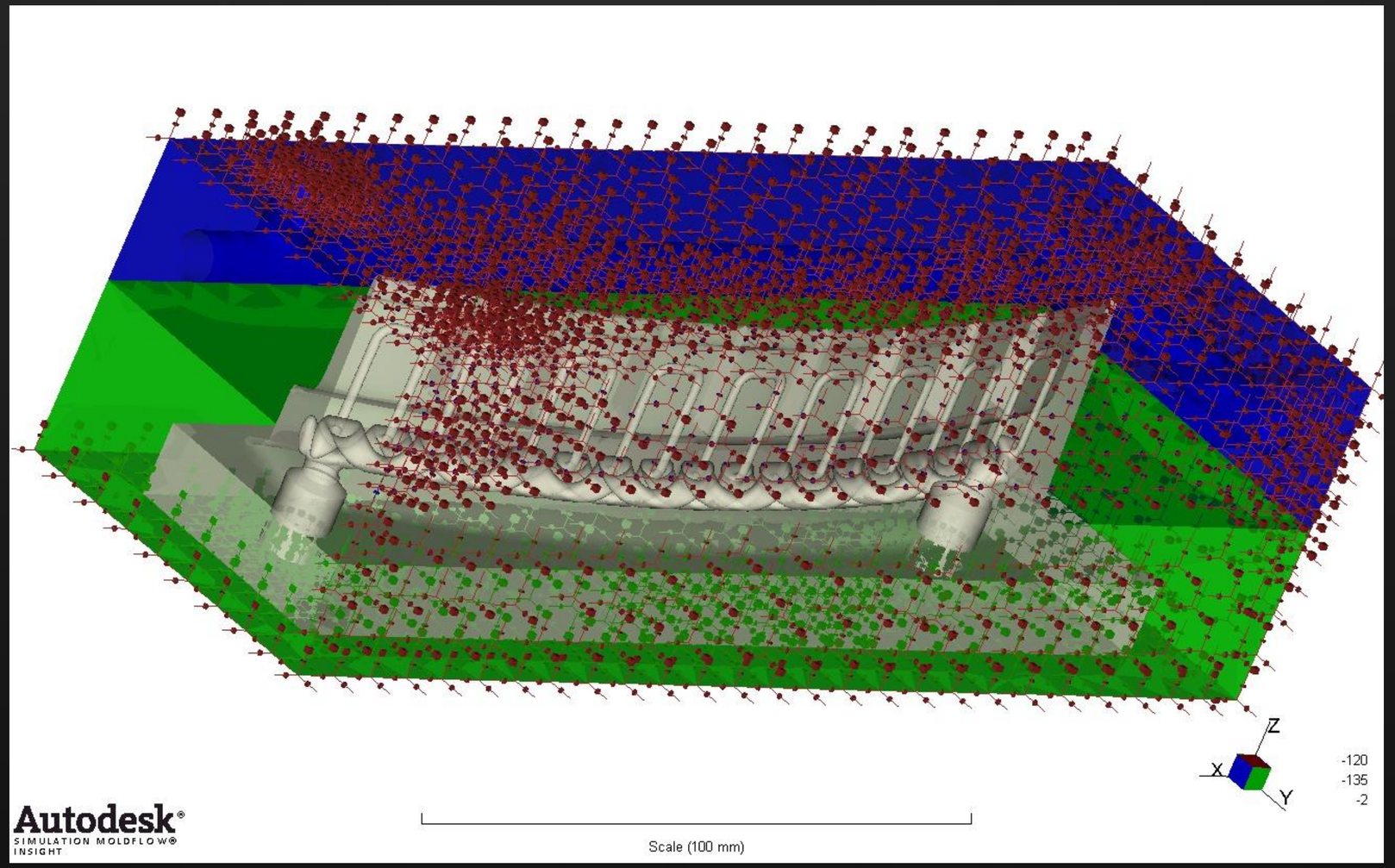


Contact Conditions

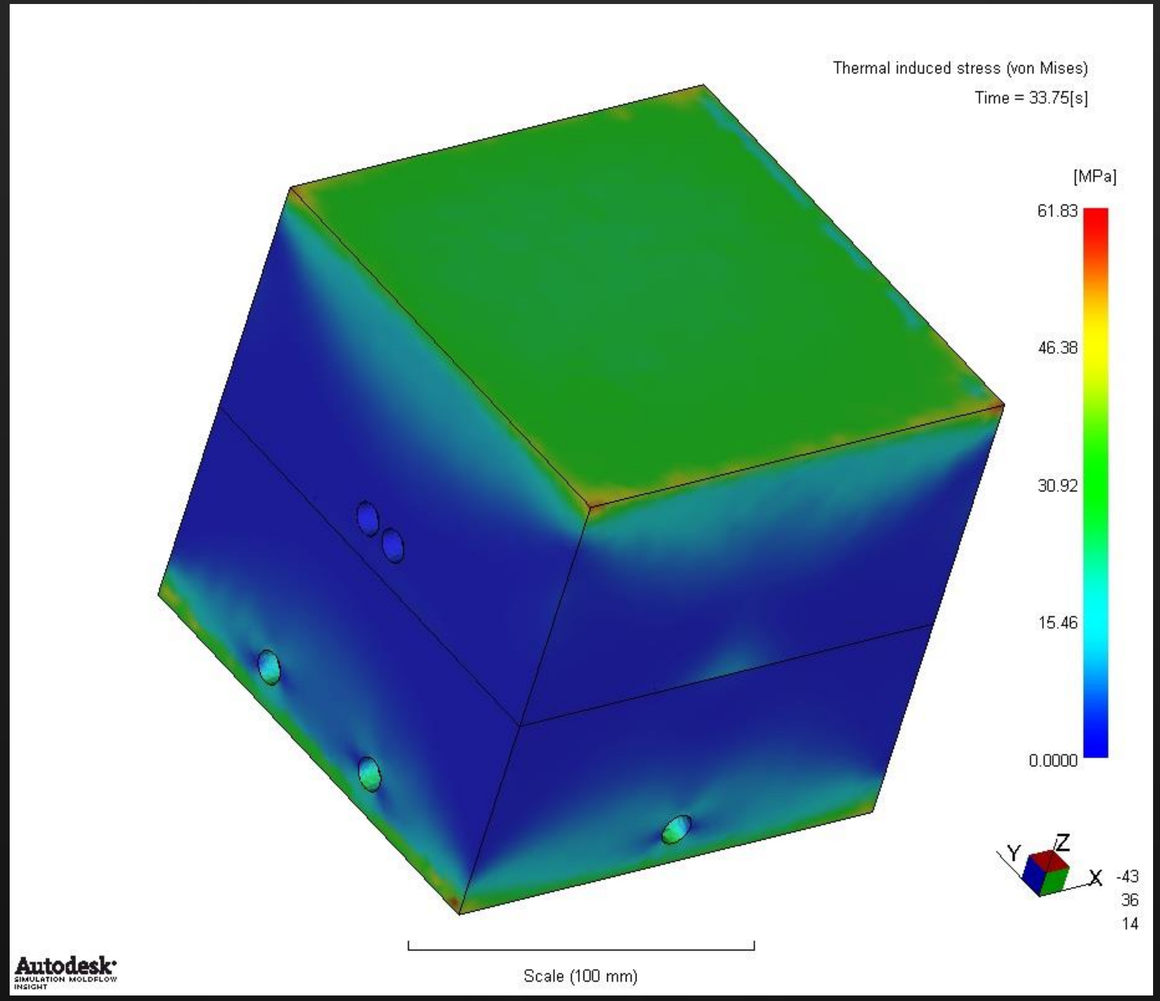




Boundary Conditions

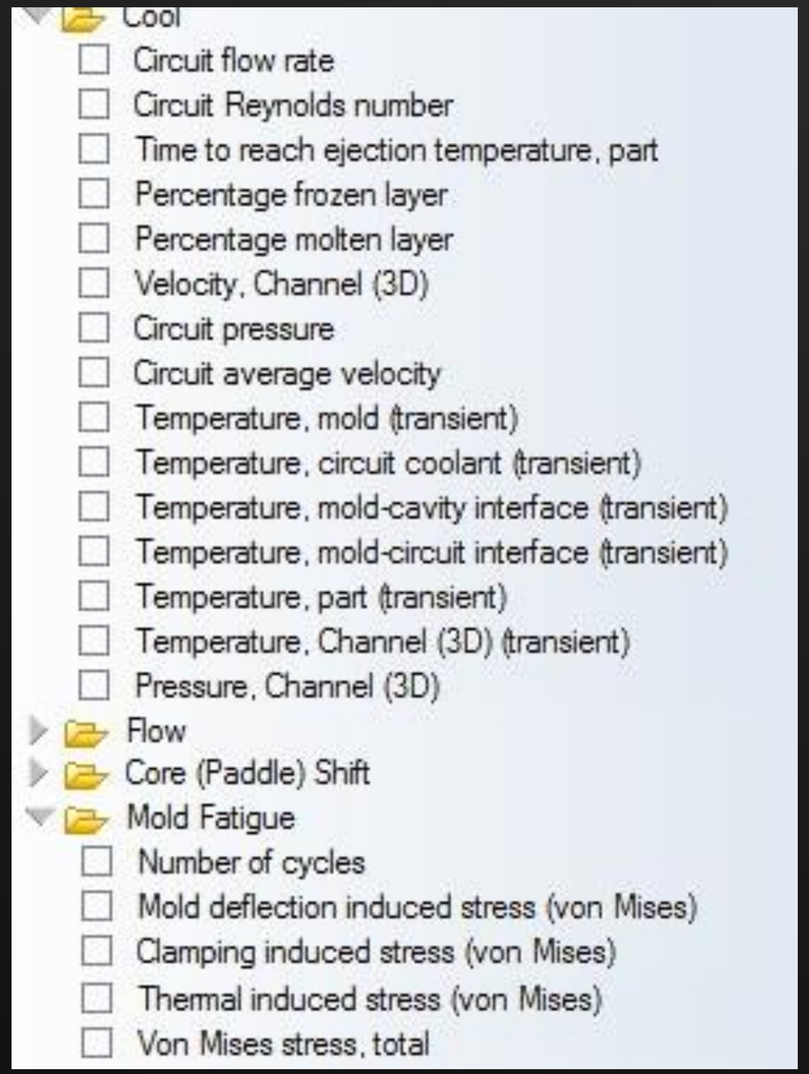


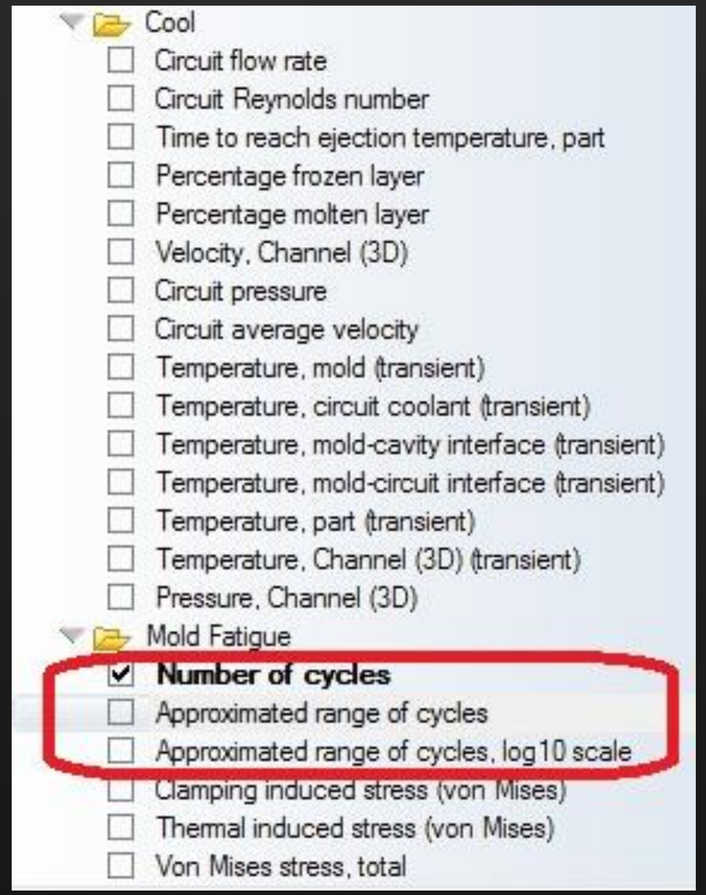
Boundary Conditions:
All fixed could be over-constrained

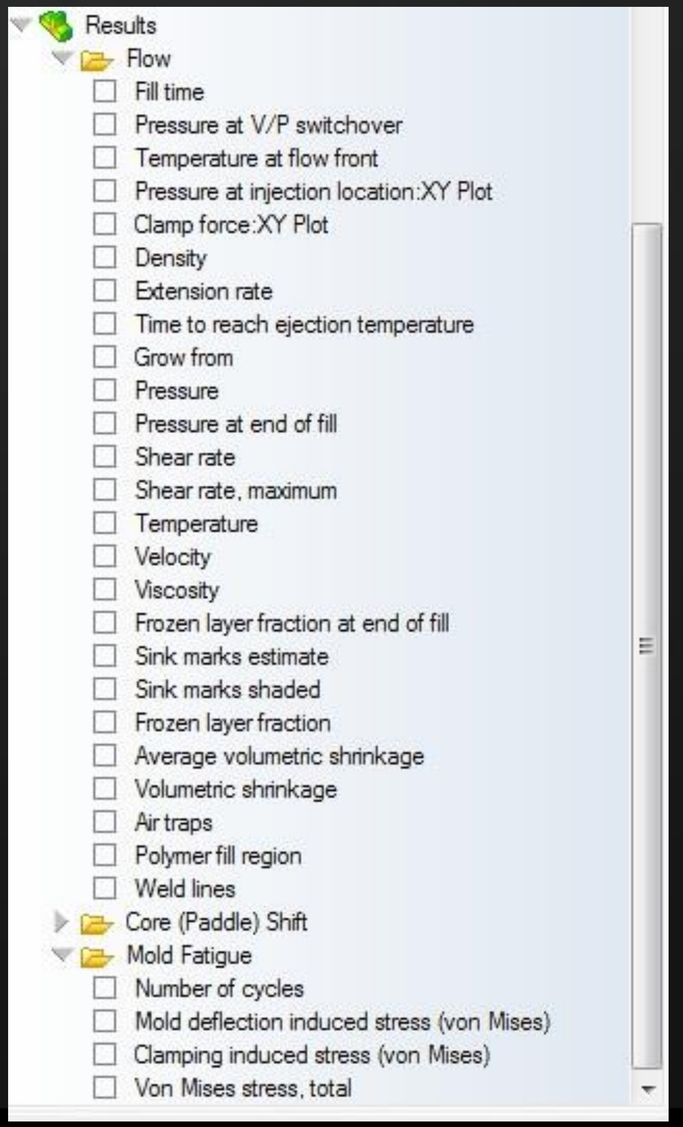


How to interpret Mold Fatigue results?

Mold Fatigue Analysis Results: Stress and Life

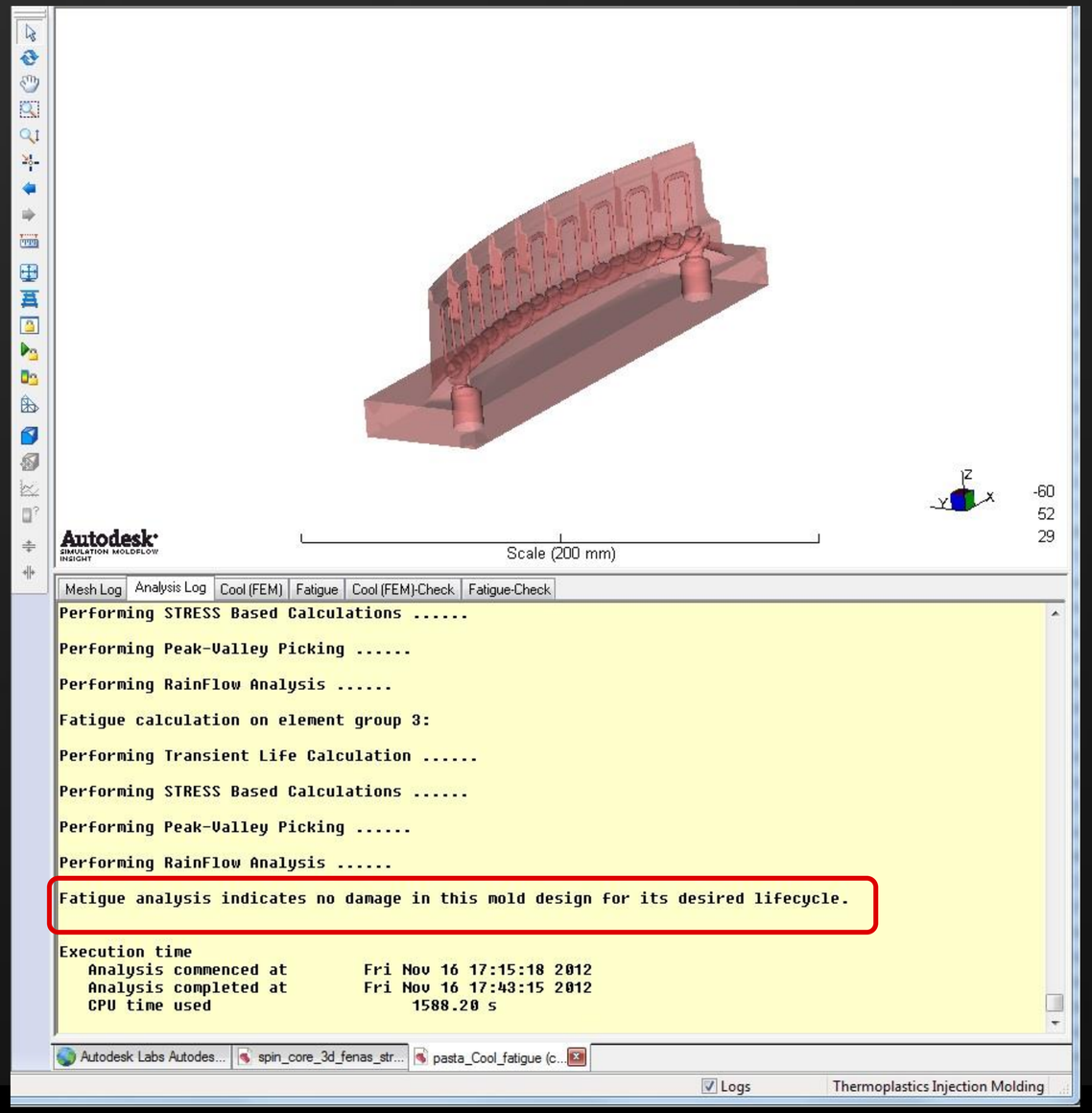




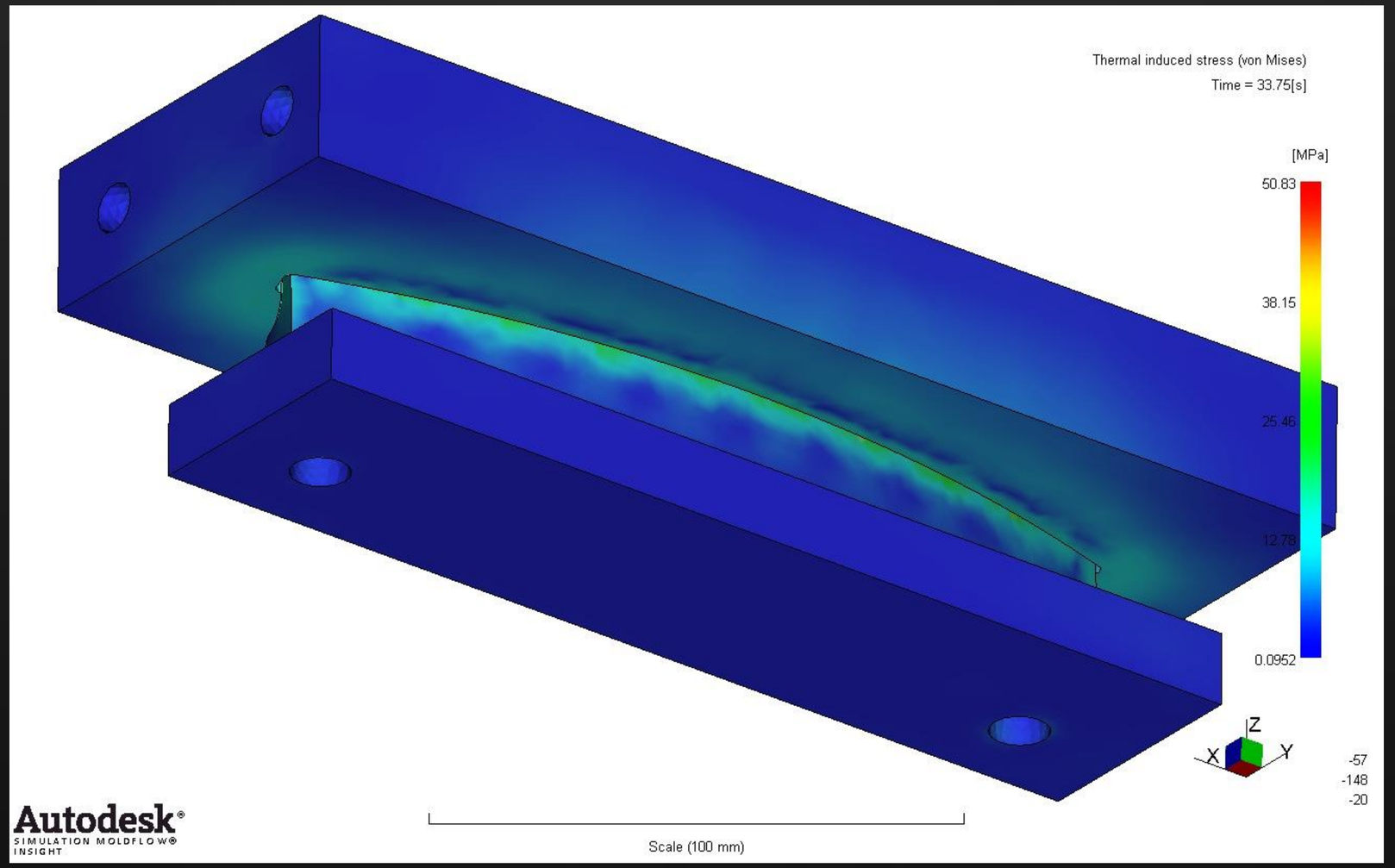


If no damage is found…..

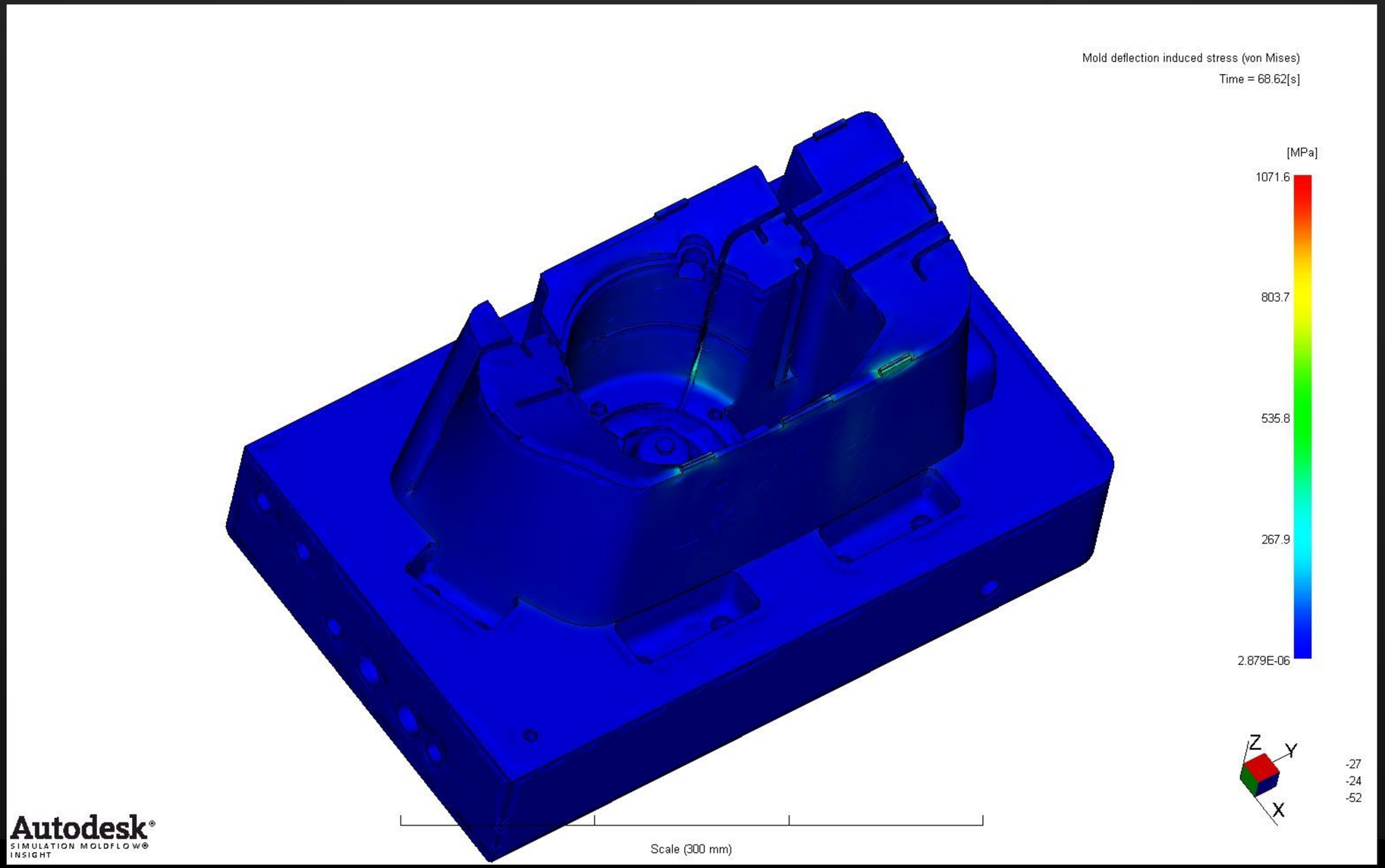
- Cool
  - Circuit flow rate
  - Circuit Reynolds number
  - Time to reach ejection temperature, part
  - Percentage frozen layer
  - Percentage molten layer
  - Velocity, Channel (3D)
  - Circuit pressure
  - Circuit average velocity
  - Temperature, mold (transient)
  - Temperature, circuit coolant (transient)
  - Temperature, mold-cavity interface (transient)
  - Temperature, mold-circuit interface (transient)
  - Temperature, part (transient)
  - Temperature, Channel (3D) (transient)
  - Pressure, Channel (3D)
- Mold Fatigue
  - Clamping induced stress (von Mises)
  - Thermal induced stress (von Mises)
  - Von Mises stress, total



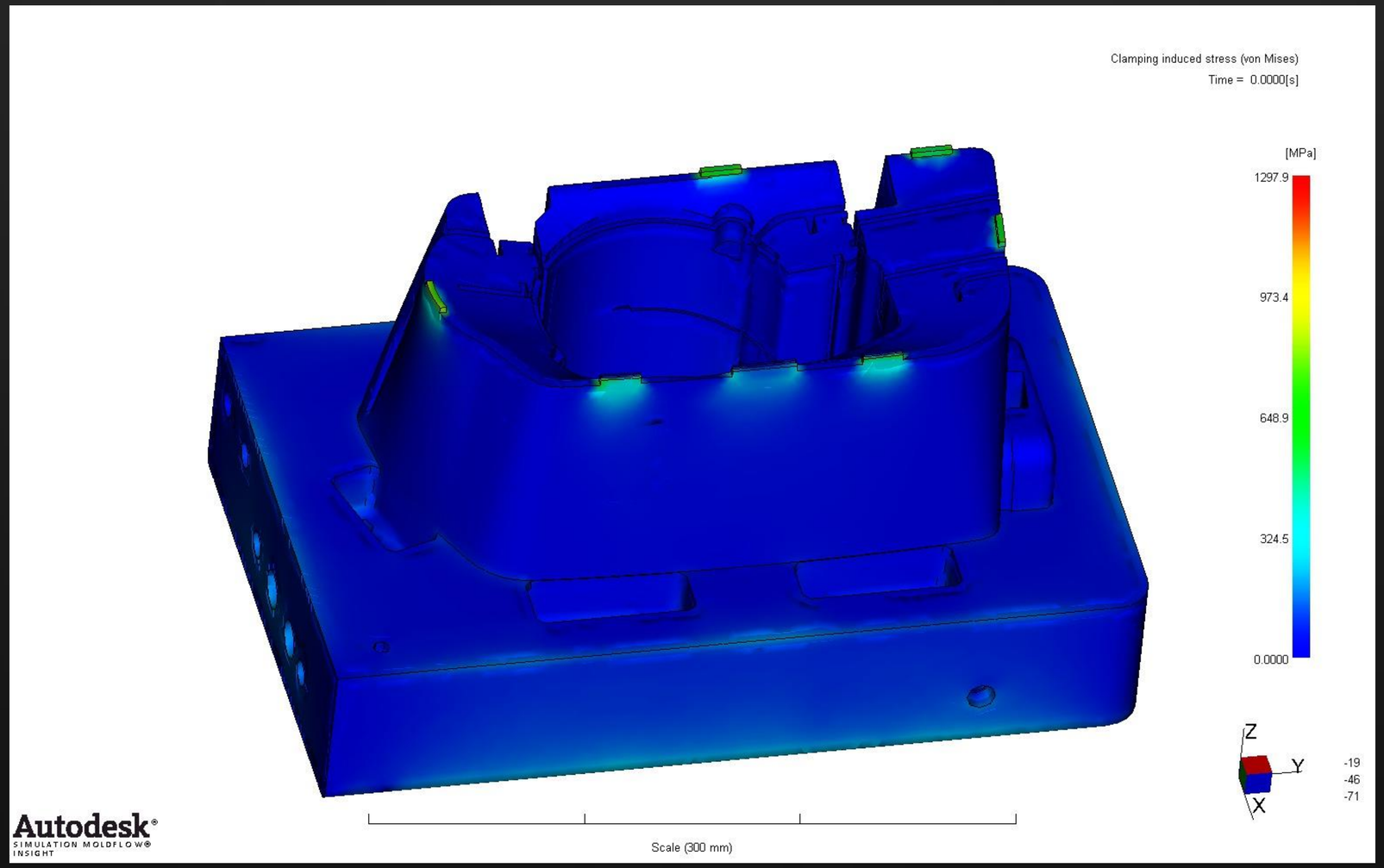
Rapid Heating / Cooling induced thermal stress



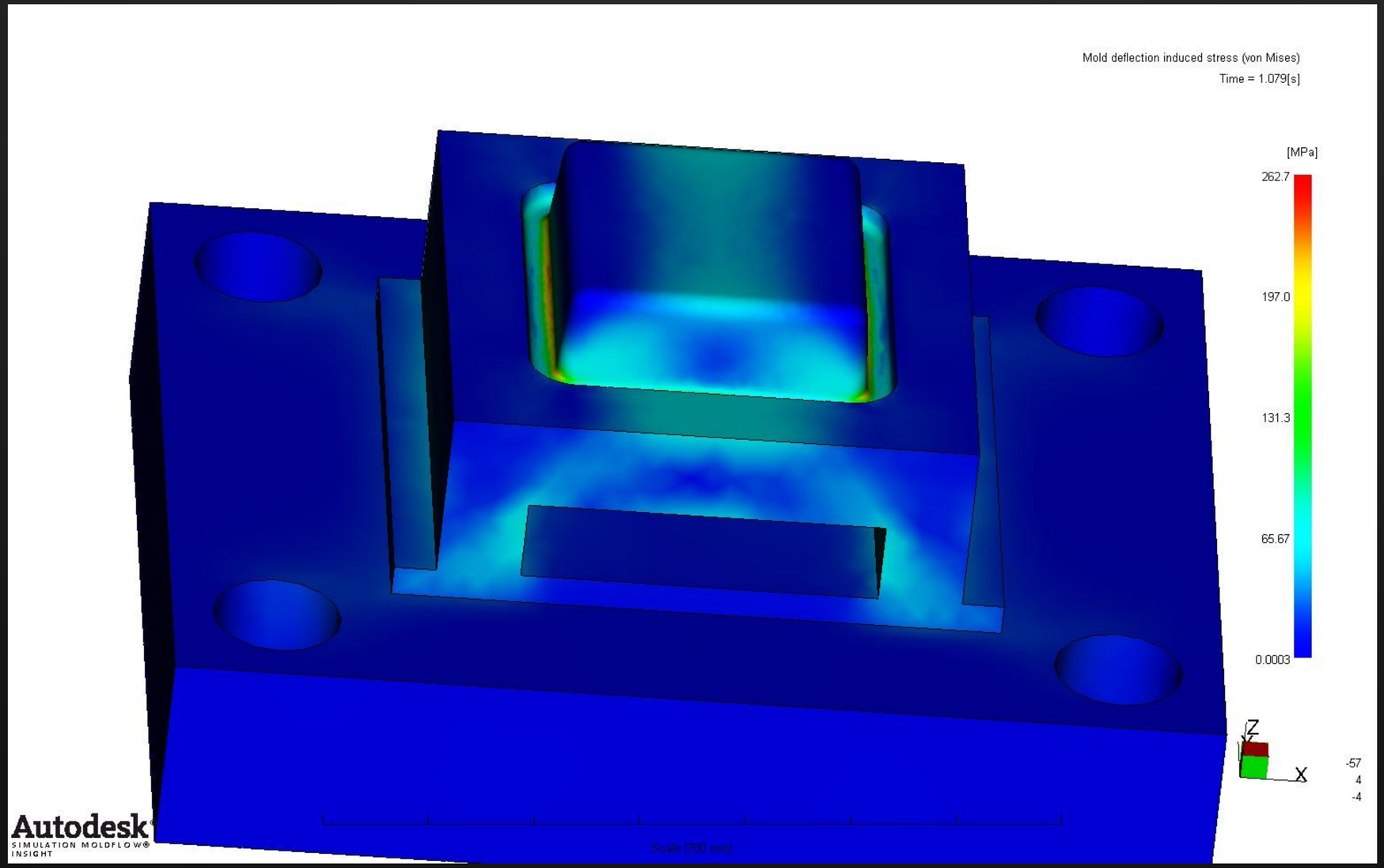
Mold deflection induced stress



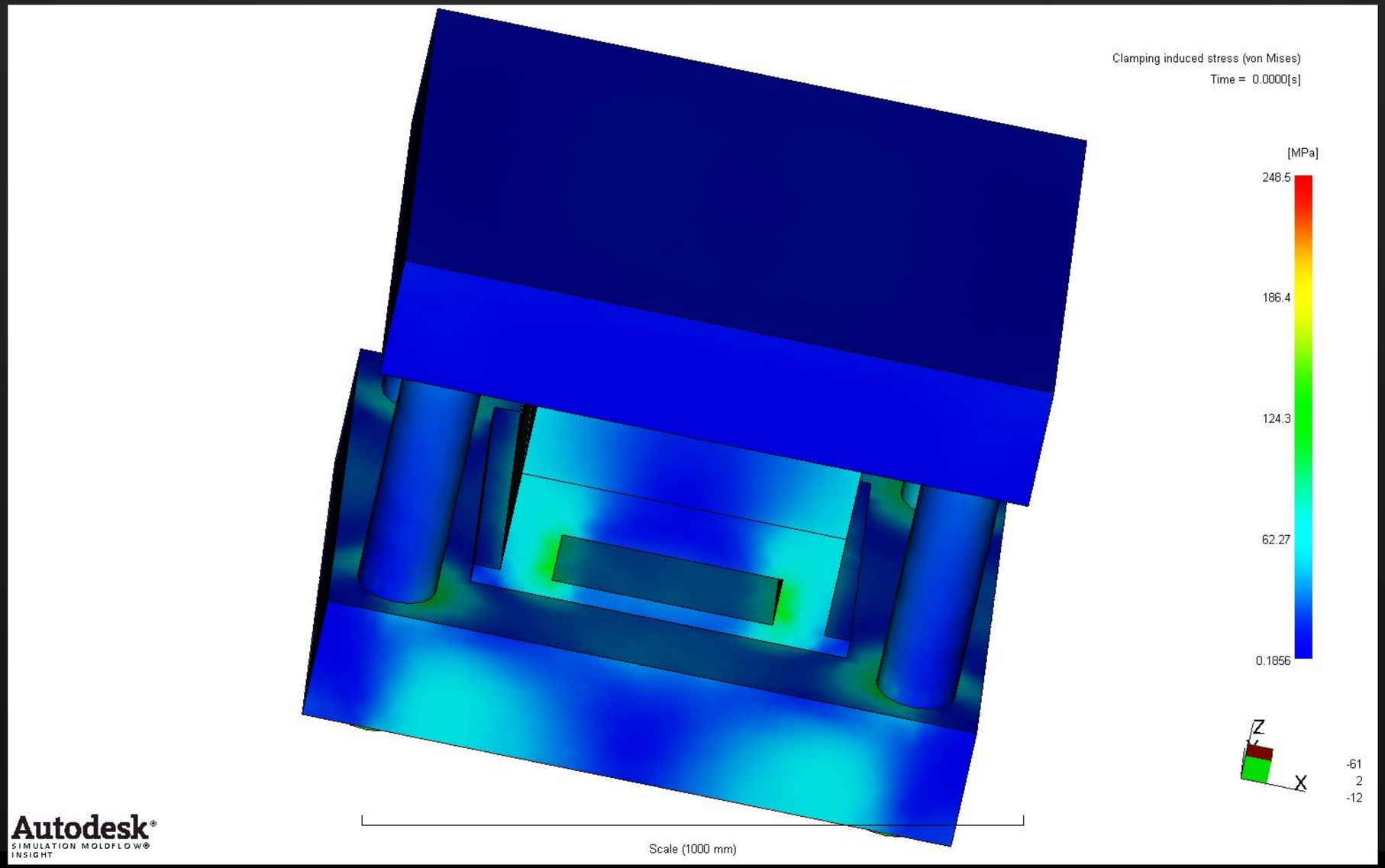
Clamping induced stress



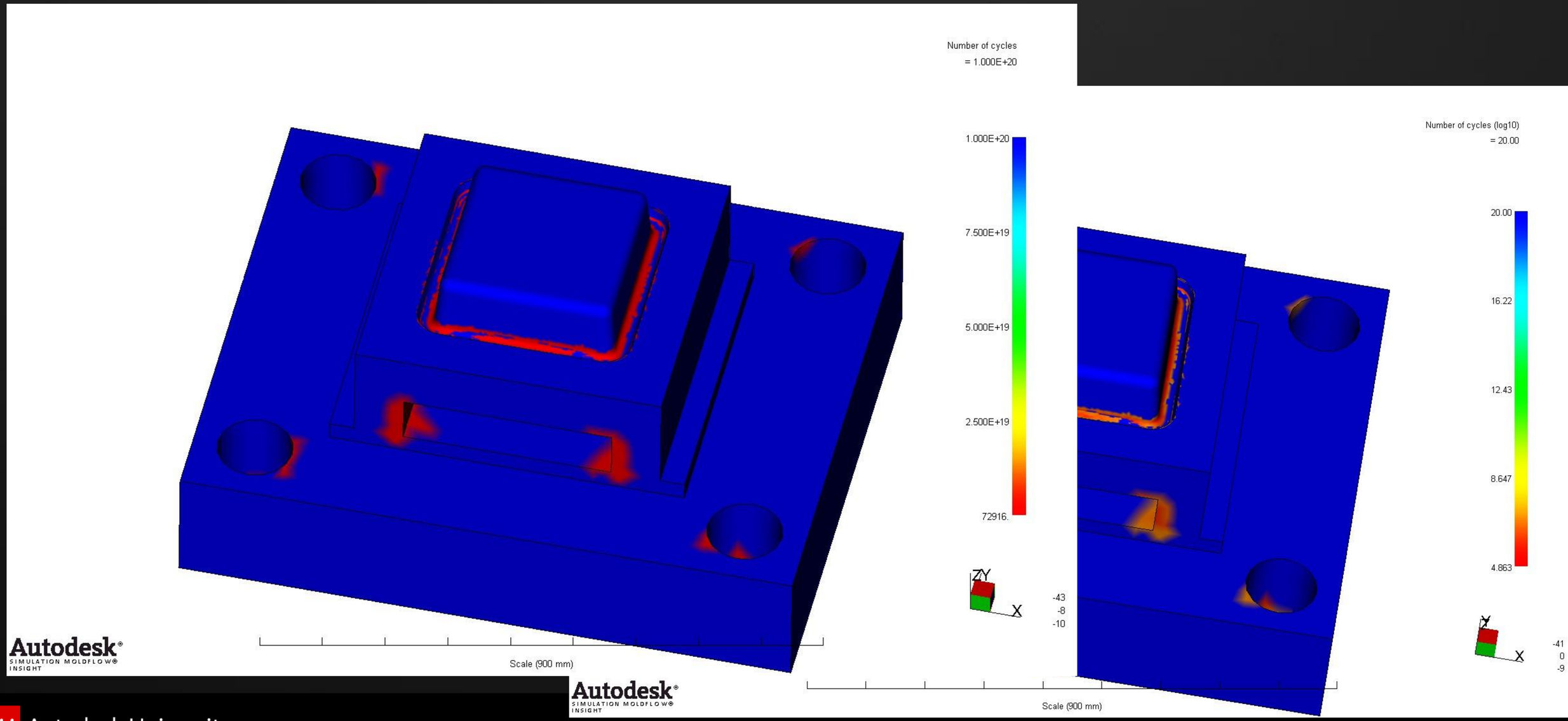
Mold deflection induced stress



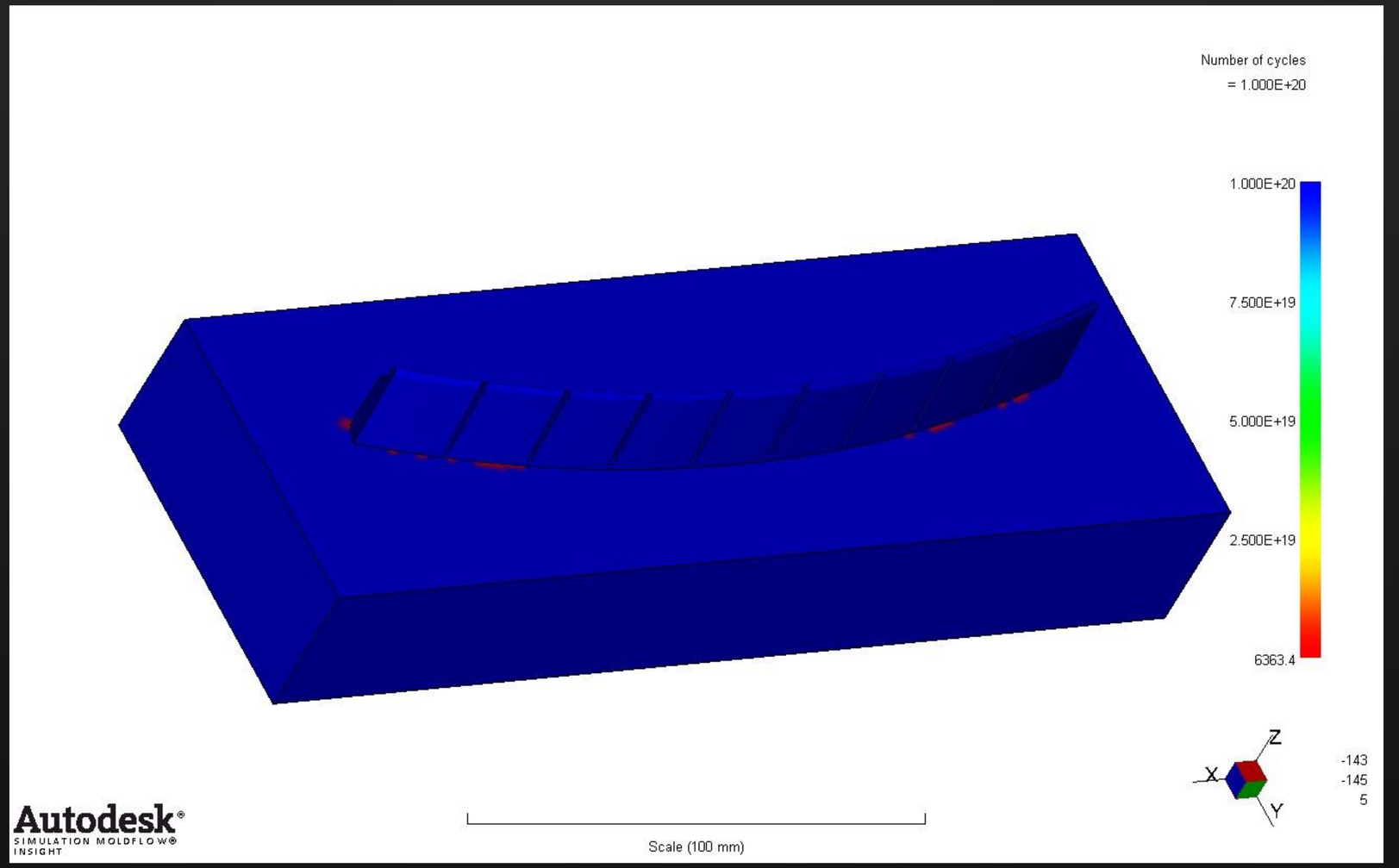
Clamping induced stress



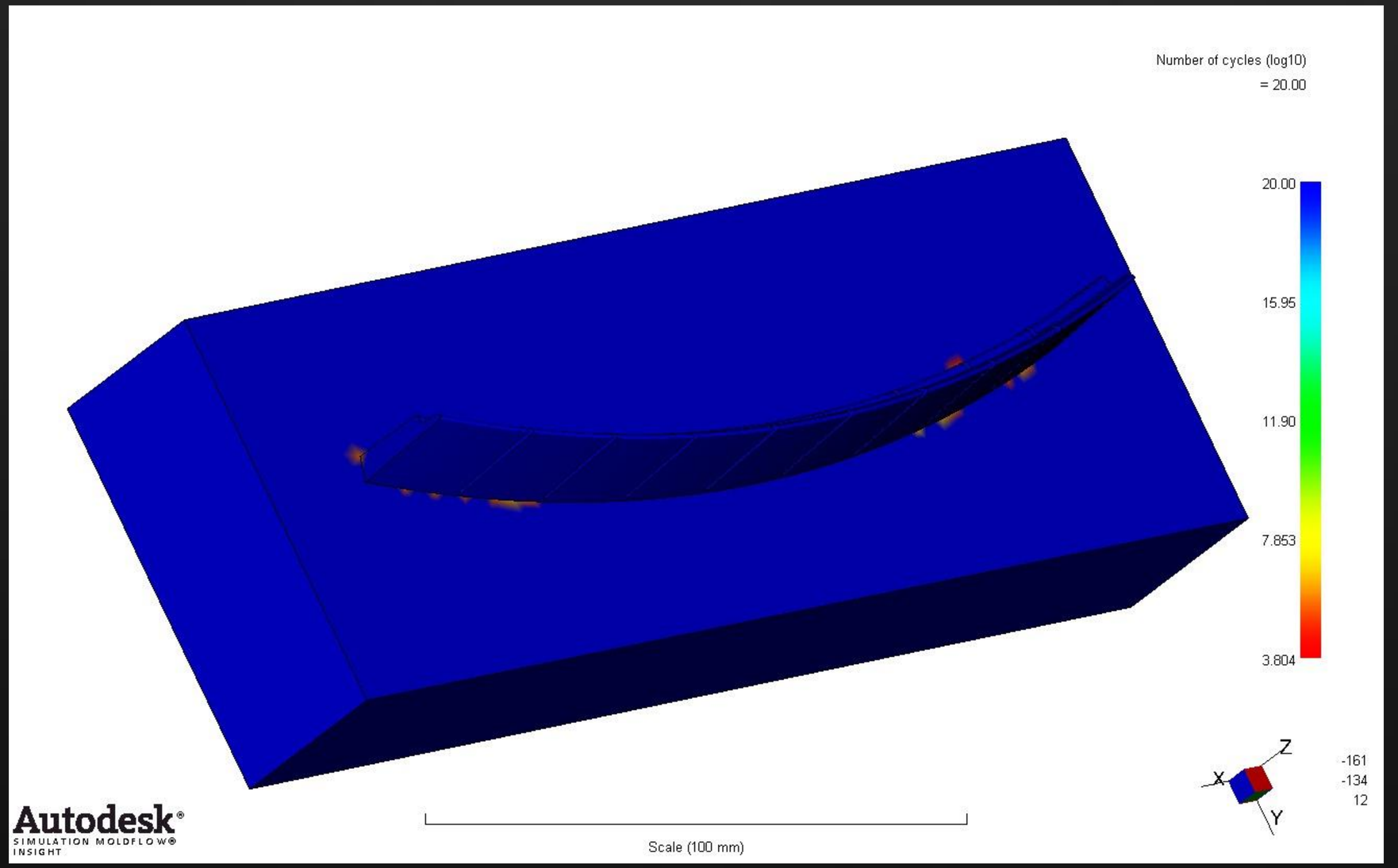
What if the mold metal has a lower S-N curve?



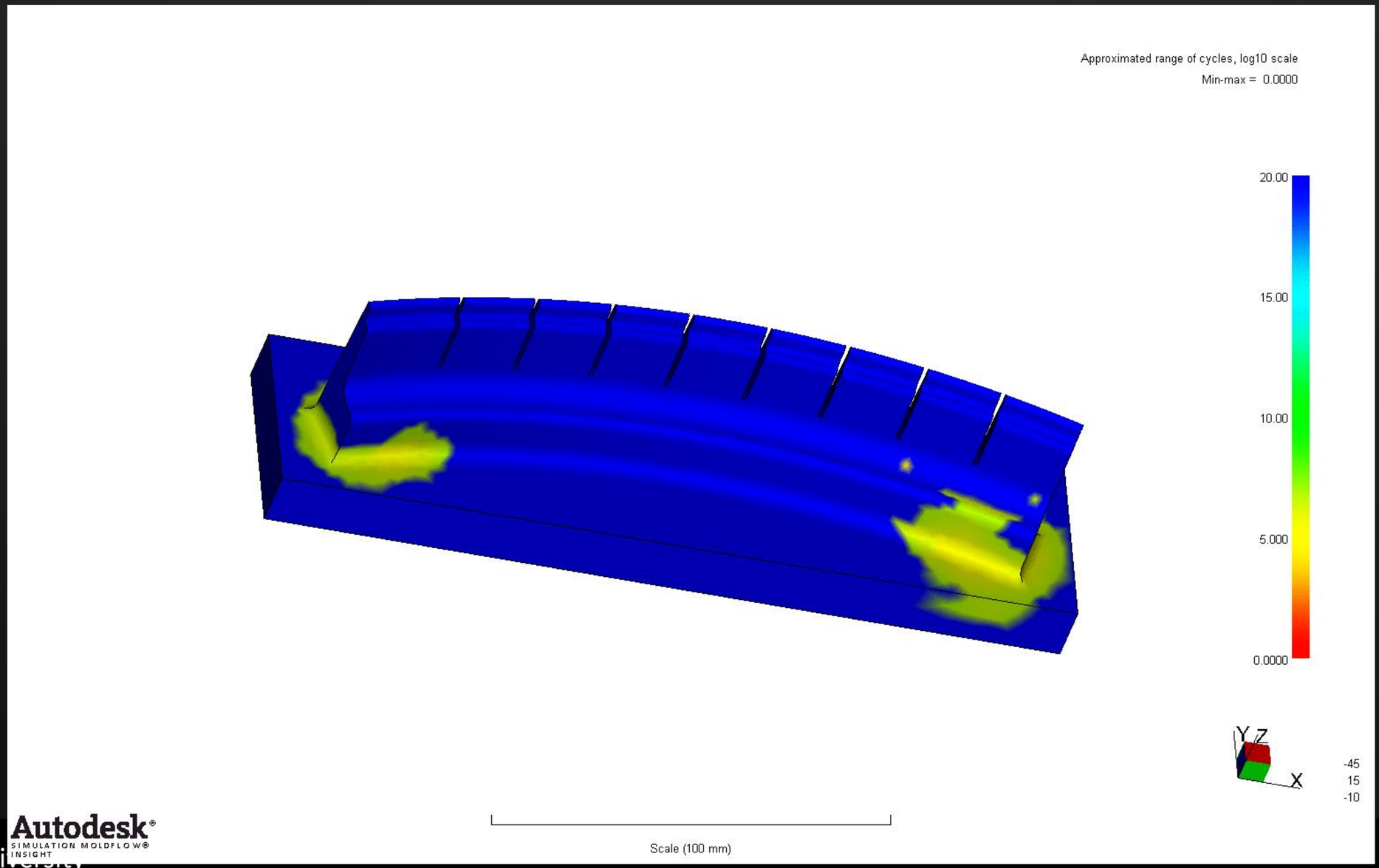
What if a higher clamping force applied?



Number of Cycles (shots) in log10 scale



Approximated Range of Cycles, in log10 scale



Discussions

- Validation cases needed
  - Mold failure cases, where and when the failure happened
  - CAD model of mold and part
  - Process conditions
  - Clamping setup in the injection molding machine
- Any suggestions are welcome