FORD PTME
Global Powertrain
Manufacturing Engineering

Expanding the Quenching Power : Combining MAGMA Casting Simulation with AVL FIRE-M to Create New Applications

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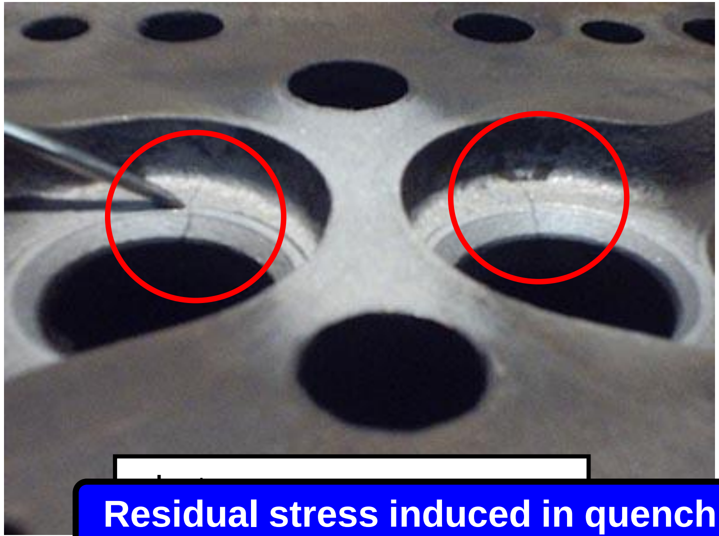
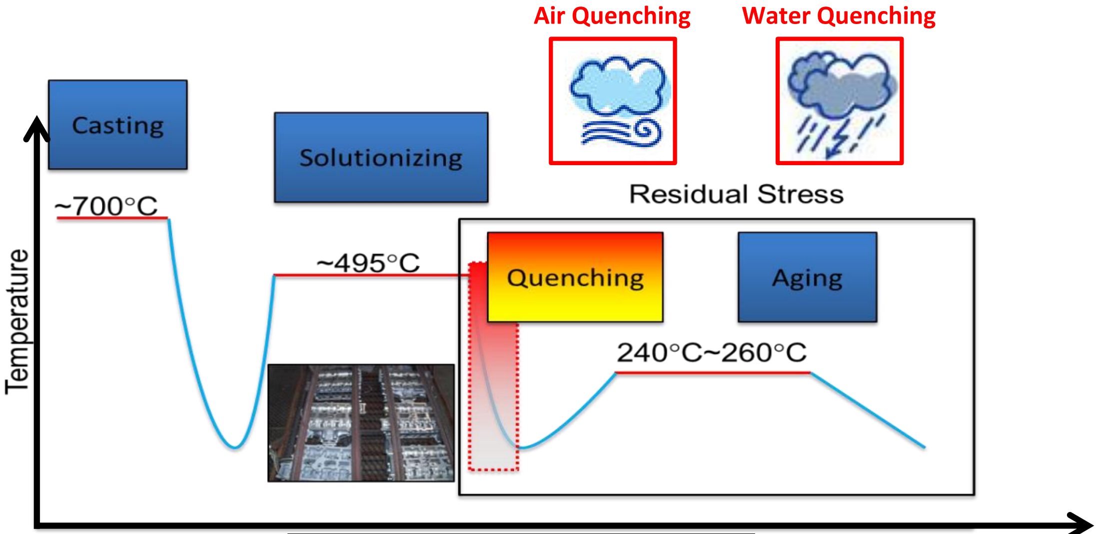
Presentation Outline

- Introduction & Background
- CFD modeling of quenching process for cylinder heads & blocks
- Integration of casting simulation to water quench modeling work flow
- Challenges in mesh generation and poly mesher in AVL FIRE-M
- Conclusion

Project Background

- Cracks due to high cycle fatigue (HCF) is a major quality concern for high performance components.
- The quench phase of a heat treatment process contributes a major portion of residual stress.





Residual stress induced in quenching process very often leads to high cycle fatigue cracks.

Revolution of Product Verification Method – from Physical Testing to Virtual Verification

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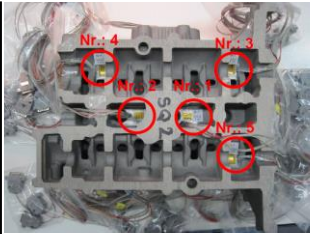
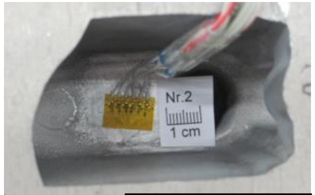
Physical Tests

Virtual Methods

test only





strain gauge

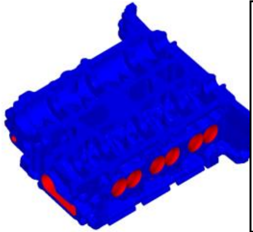
Direct Residual Stress Measurement

n.a.

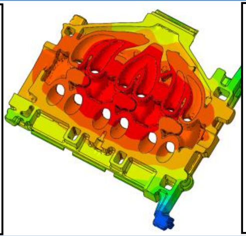
test + virtual

thermocouple

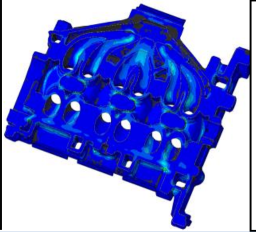
Direct Temperature Measurement



HTC calibration



temperature



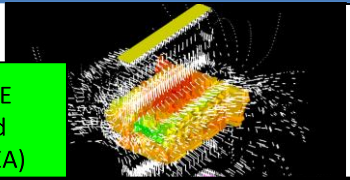
residual stress

virtual only

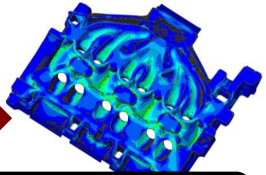
Align with PD & MFG Objectives to Increase Adaptation of Virtual Tools

Prototype & Dyno Test Reduction

New CAE Method (CFD + FEA)



ow + temp.

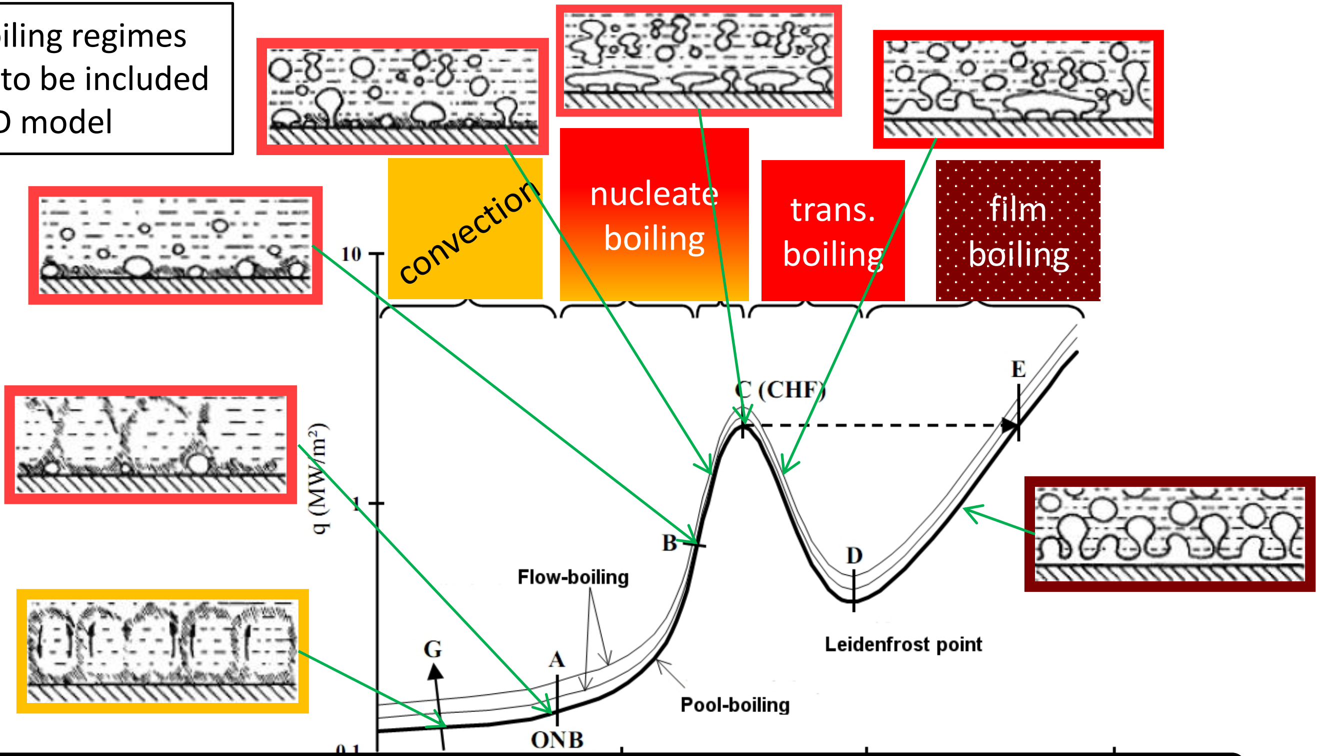


residual stress

Product verification by virtual tools is the key to increase design efficiency.

The Complex Physics in Water Boiling & Quenching Process

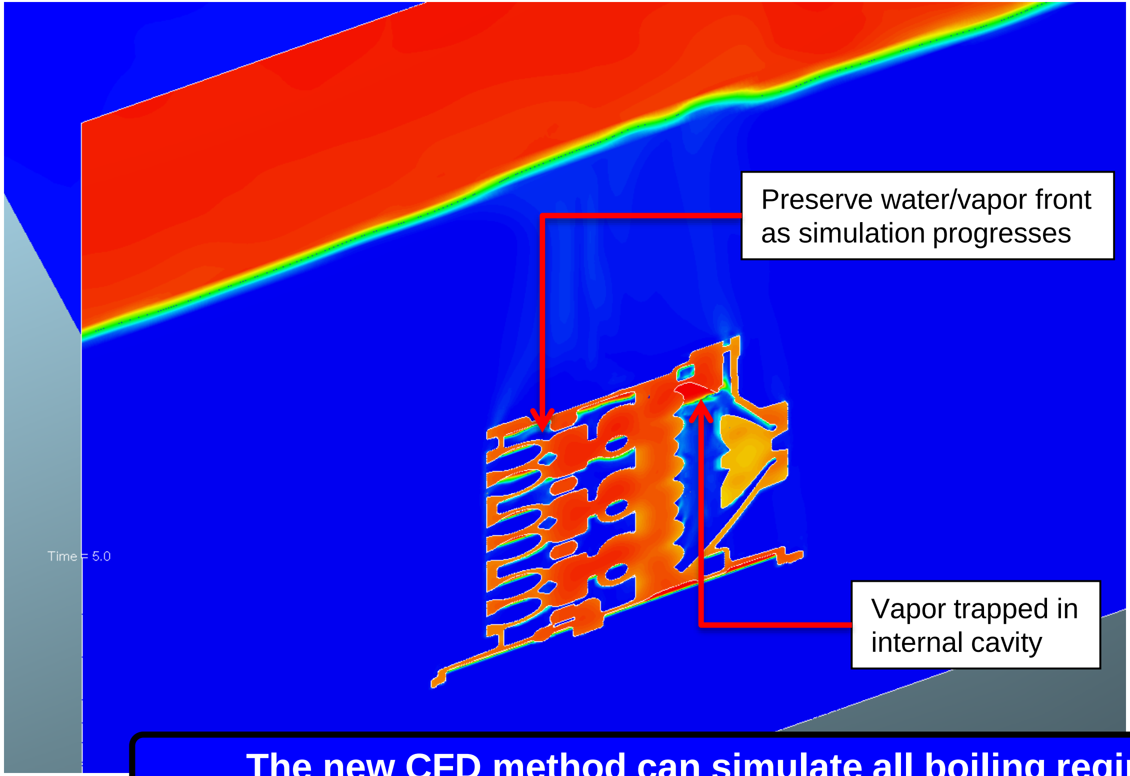
All boiling regimes need to be included in CFD model

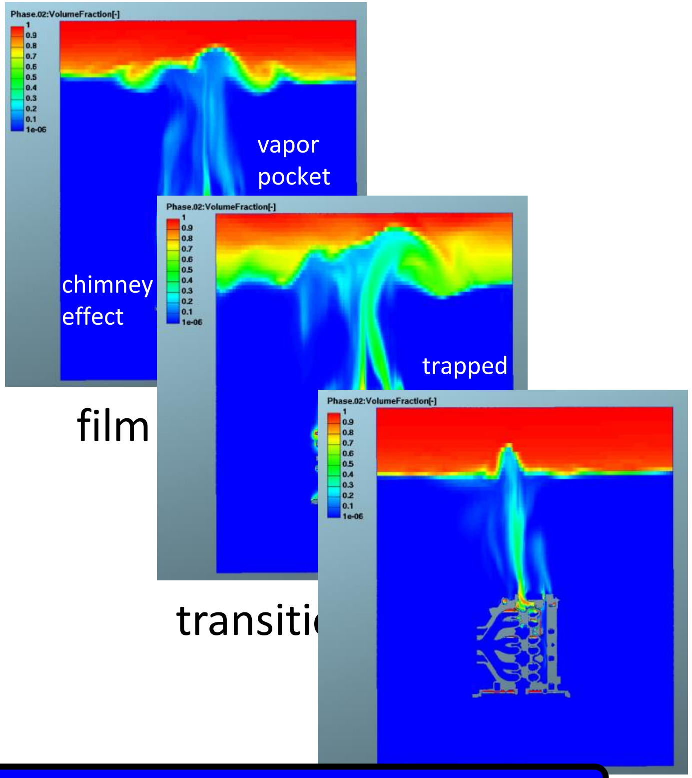


To capture all the physics in water quench process is a big challenge for CAE.

temperature range

Modeling Boiling & Quenching Process in Computer Simulations





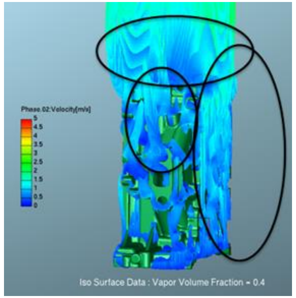
The new CFD method can simulate all boiling regimes in water quench processes.

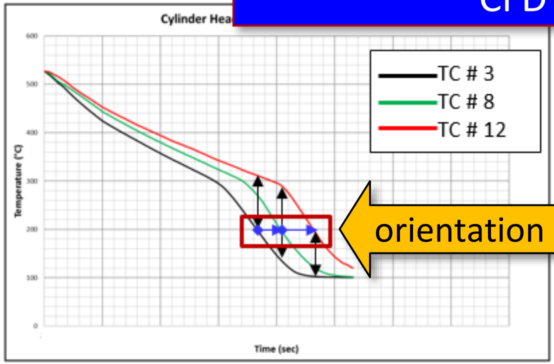
Comparison of Thermocouple Data & Simulation (Cylinder Head)

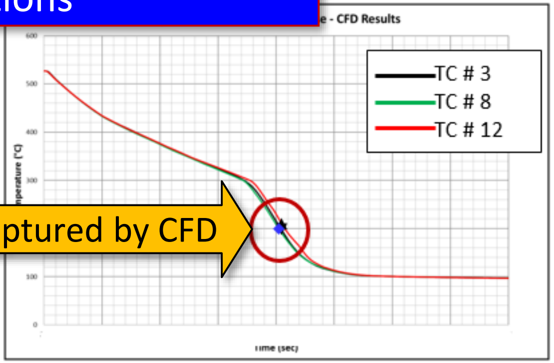
vertical

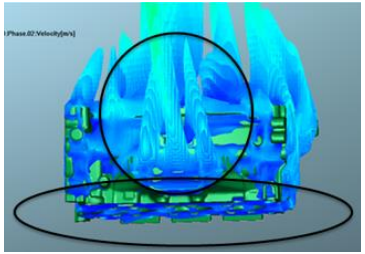
horizontal

CFD simulations

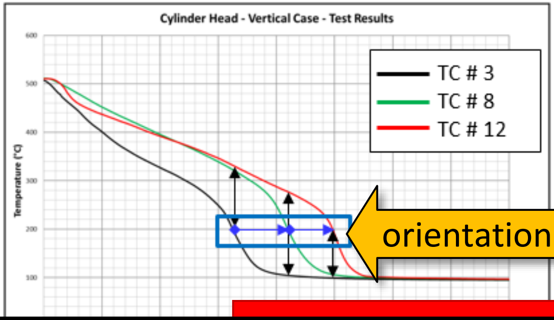


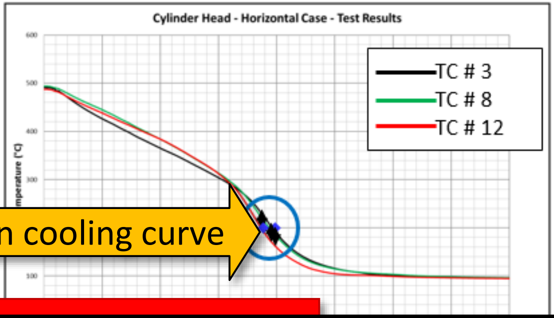






orientation effect captured by CFD

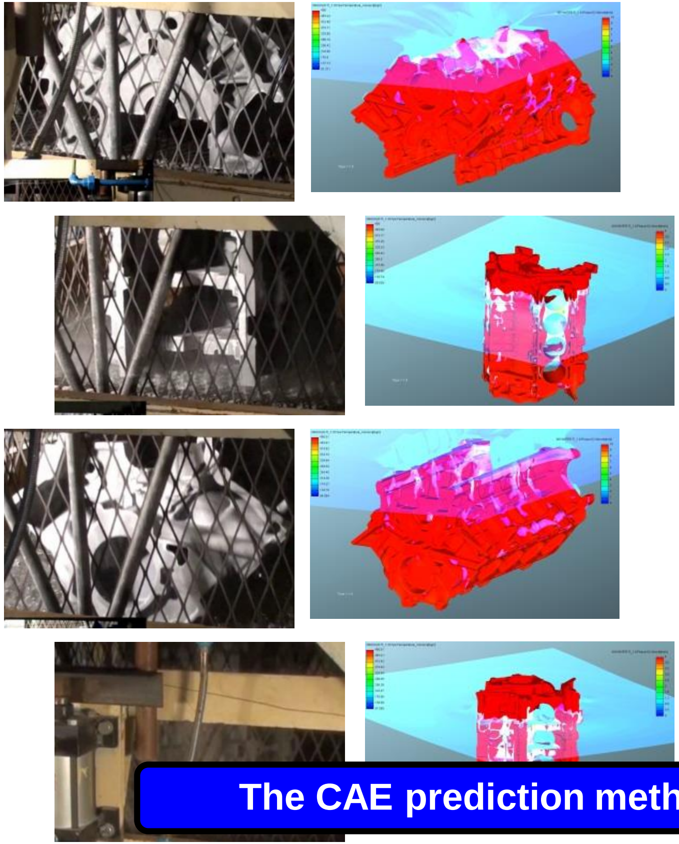


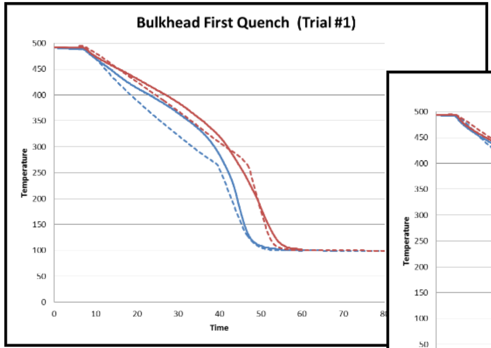


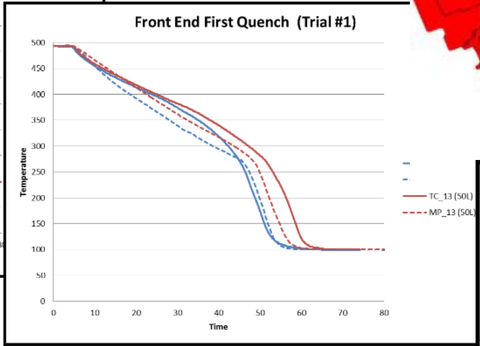
orientation effect on cooling curve

CFD results are in excellent agreement with tests, capturing orientation effects correctly.

Comparison of Thermocouple Data & Simulation (Cylinder Block)

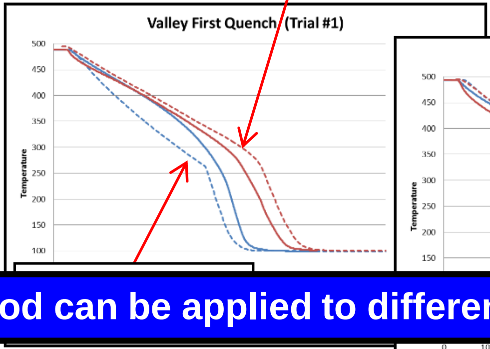


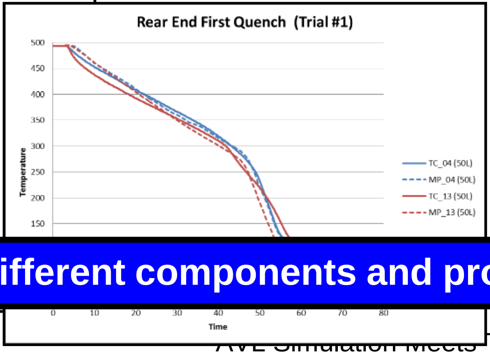




cylinder block – good agreement to thermocouple data for all orientation

Lab: solid line

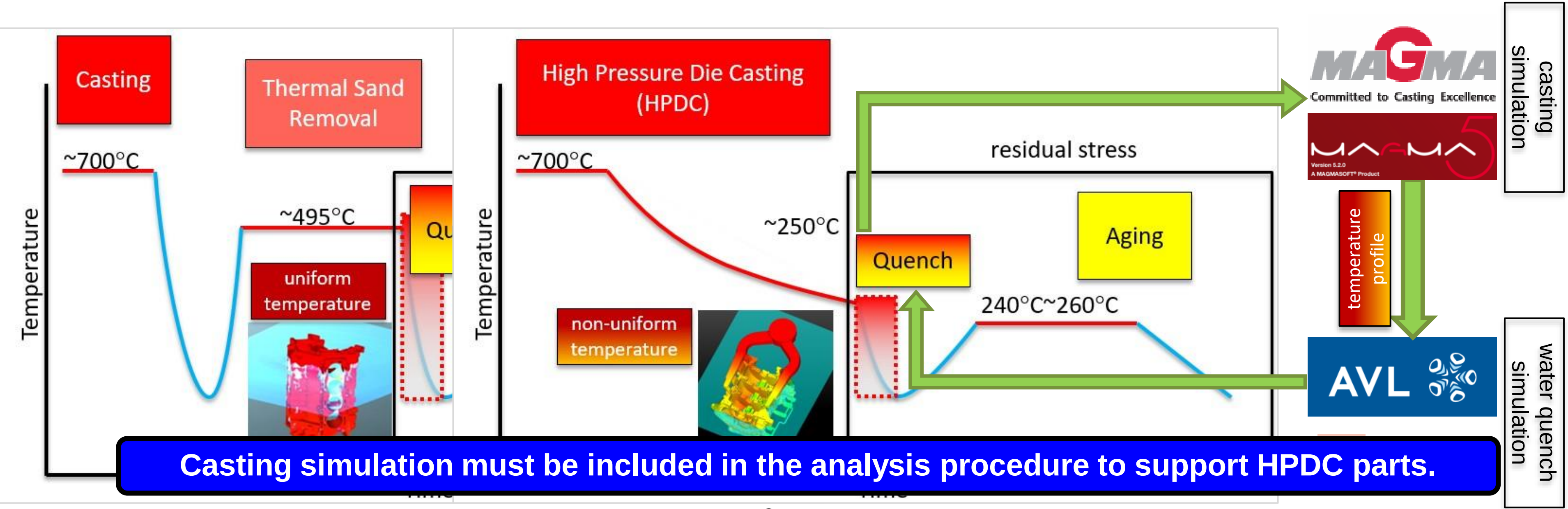




The CAE prediction method can be applied to different components and processes.

So Far So Good. But...

- Current method is only applicable to parts whose initial temperature is uniform (e.g. gravity pour)
- To support parts cast by HPDC, initial temperatures need to imported from casting simulation



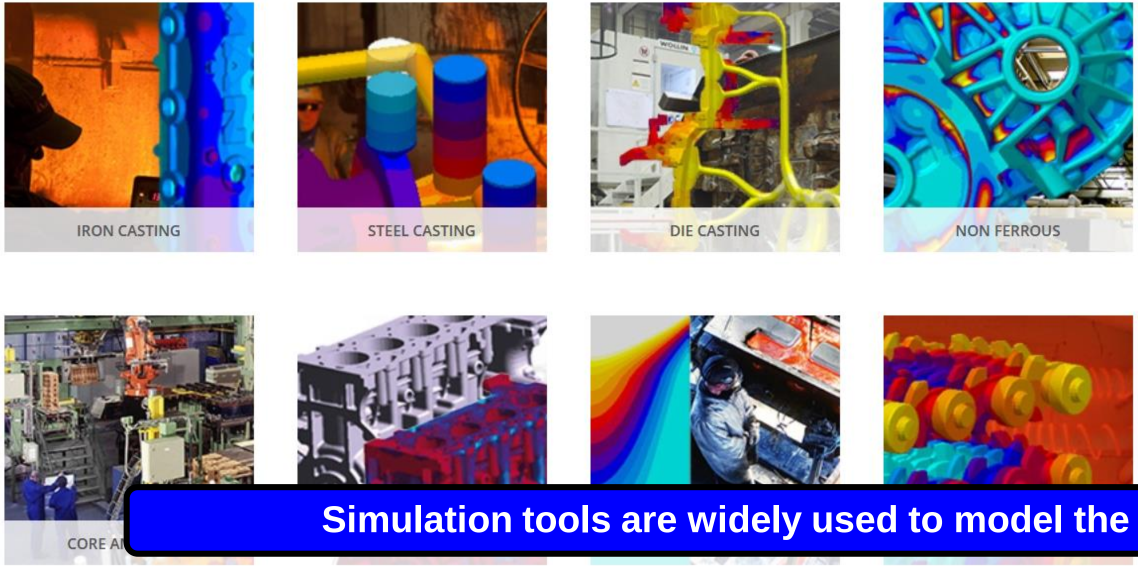
Casting simulation must be included in the analysis procedure to support HPDC parts.

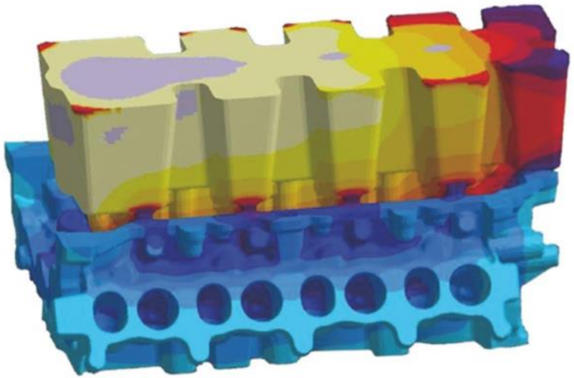
Introduction to Casting Simulation by MAGMA

- Casting simulation at Ford: cylinder head, cylinder blocks, transmission case, convertor housing and other engine/transmission parts.

Committed to Casting Excellence

https://www.magmasoft.com/en/



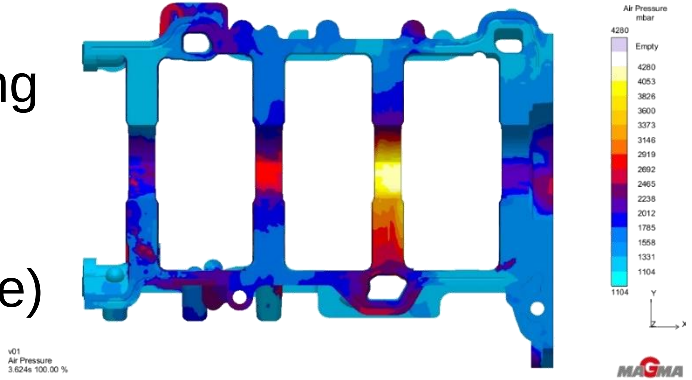


https://www.magmasoft.cn/en/company/references/reference/manufacturing-state-of-the-art-aluminum-cylinder-head-castings/

Simulation tools are widely used to model the casting processes in Ford.

Engine Girdle Casting Simulation – Filling Air Entrapment

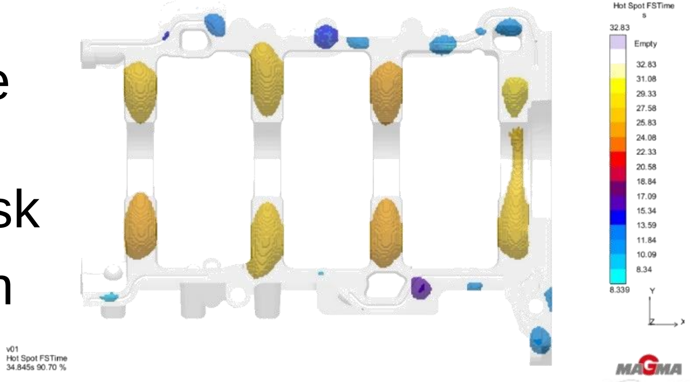
- Evaluate metal casting flow fronts
- Evaluate air pockets that form (air pressure) and air bubbles (air entrapment)
- Mitigate predicted issues by modifying casting parameters (filling profile) or venting strategy

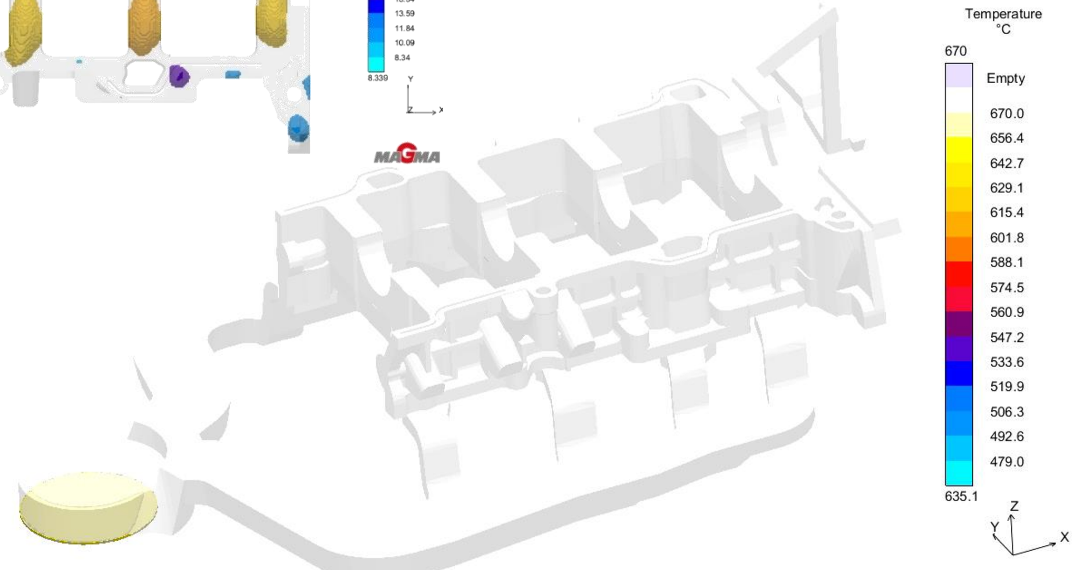


Casting simulations allow Ford Engineers to identify issues upfront.

Engine Girdle Casting Simulation – Temperature And Solidification

- Evaluate temperature during filling to minimize cold-shut risk
- Evaluate solidification to identify hotspots in casting which predict shrinkage voids
- Mitigate predicted issues with changes to cooling lines or changes to part g

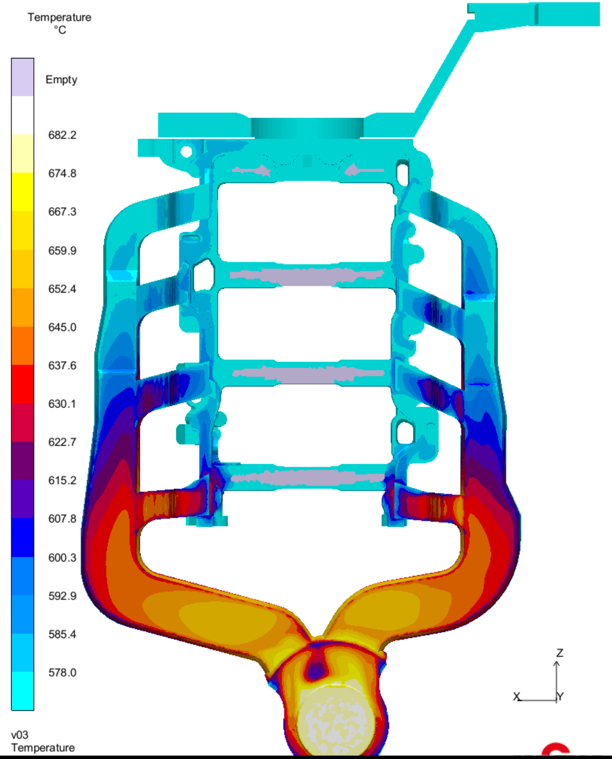


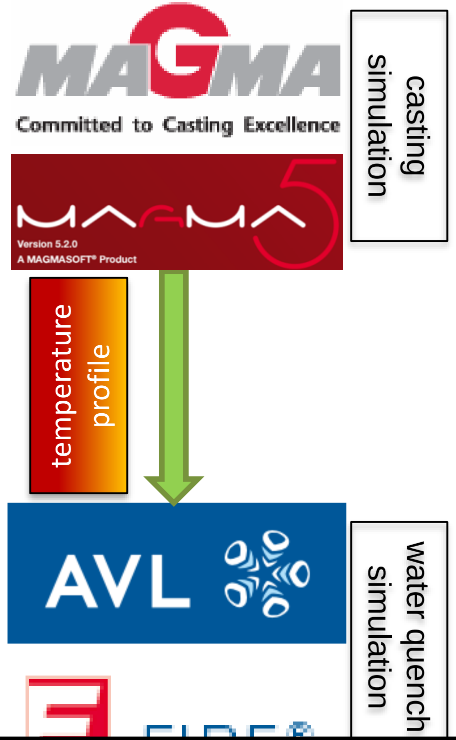


Casting simulations allow Ford Engineers to identify issues upfront.

Linking Casting Simulation to Water Quenching Simulation

- Duration of high pressure die casting: 2.577 seconds
- Temperature from MAGMA model at end of HPDC is input to AVL FIRE as initial condition for water quenching.





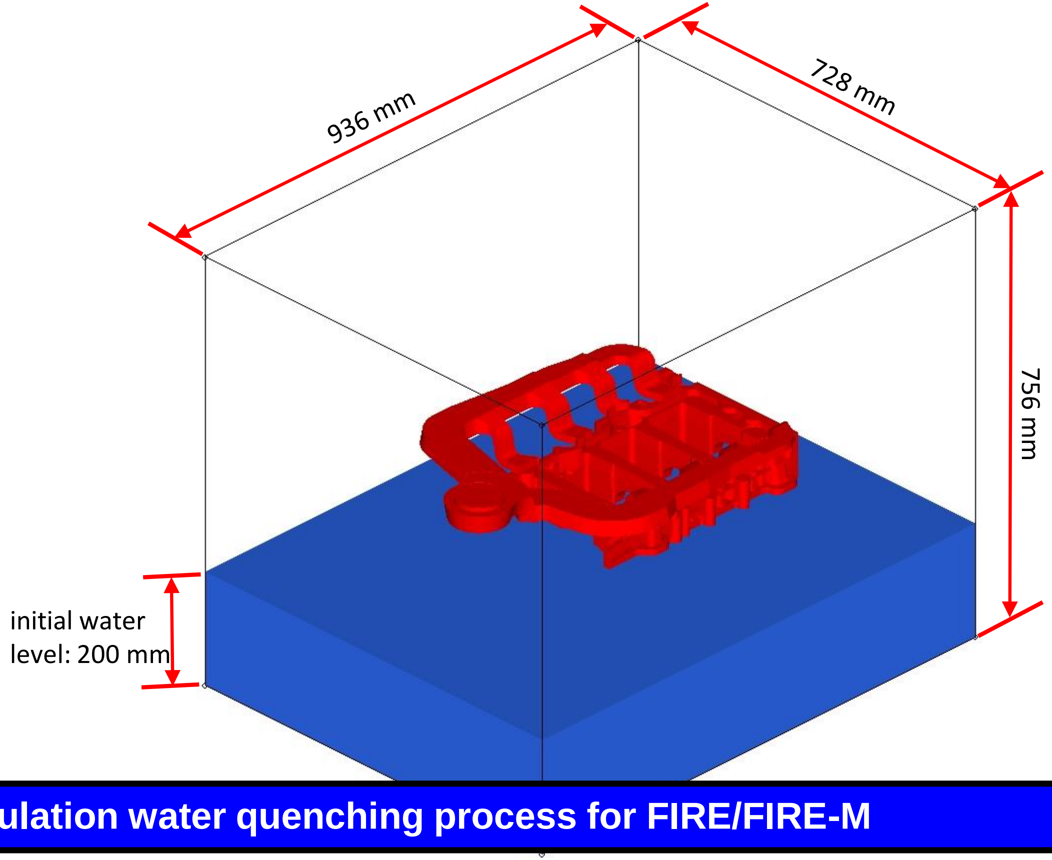
MAGMA simulation is incorporated in CAE method to model quenching of HPDC parts.

Engine Girdle Water Quenching Simulation

quenching time
- dipping velocity: 0.5 m/s
- dipping time: 1.08 seconds
- quench duration: 8 seconds

WATER domain (2 phases)
- water
- vapor

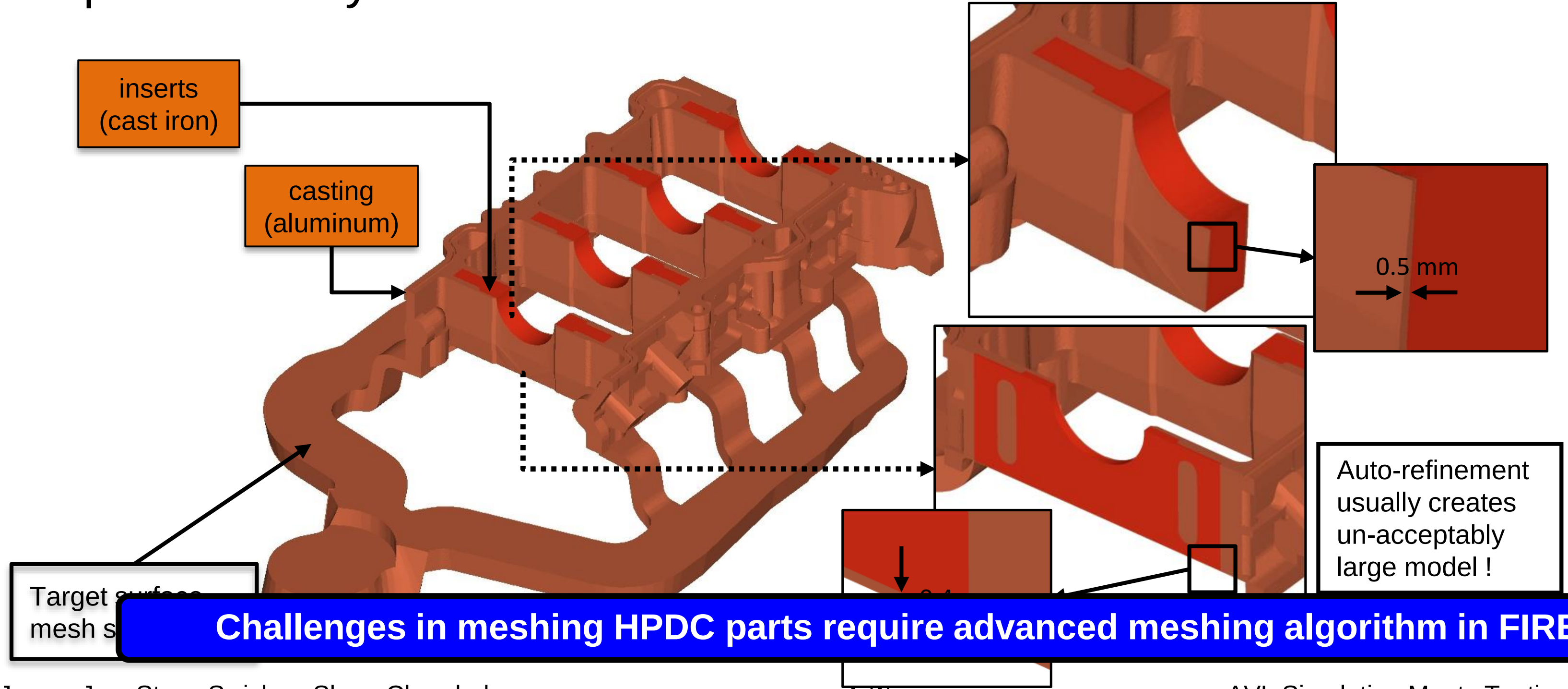
SOLID domain (2 materials)
- aluminum
- cast iron



Model setup to simulation water quenching process for FIRE/FIRE-M

Modeling Challenge – Mesh Generation

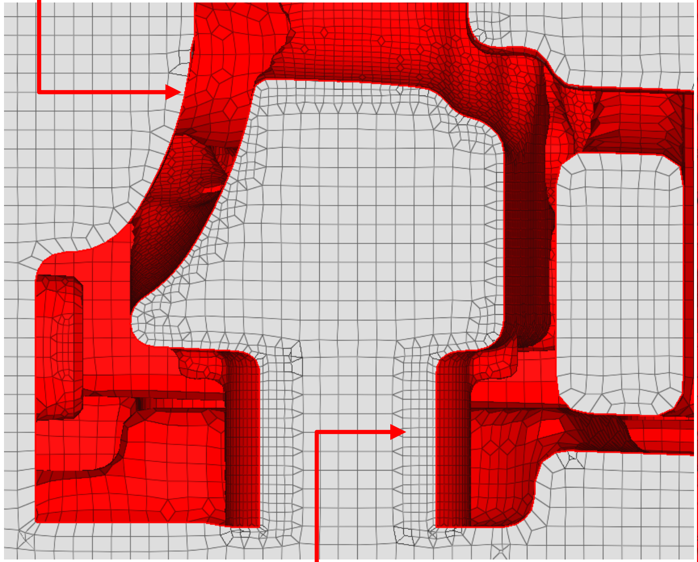
- Runners are still attached for quenching HPDC parts. In addition, HPDC parts usually include inserts of 2nd material.

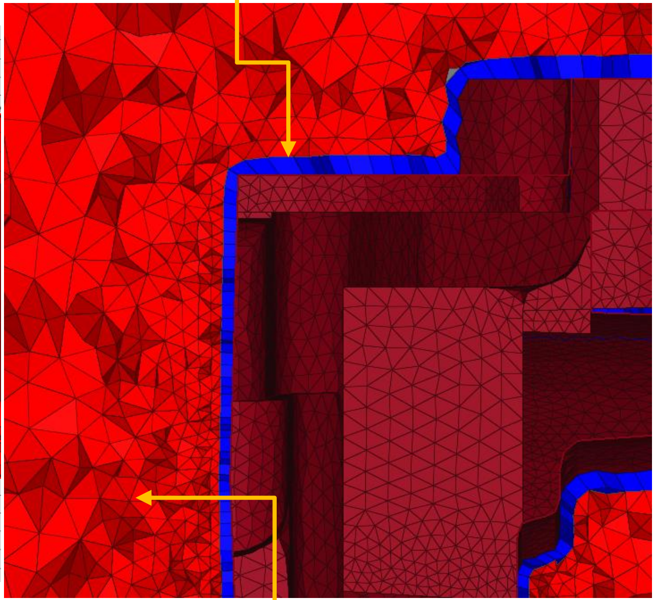


Challenges in meshing HPDC parts require advanced meshing algorithm in FIRE-M.

Mesh Generation Before AVL FIRE-M

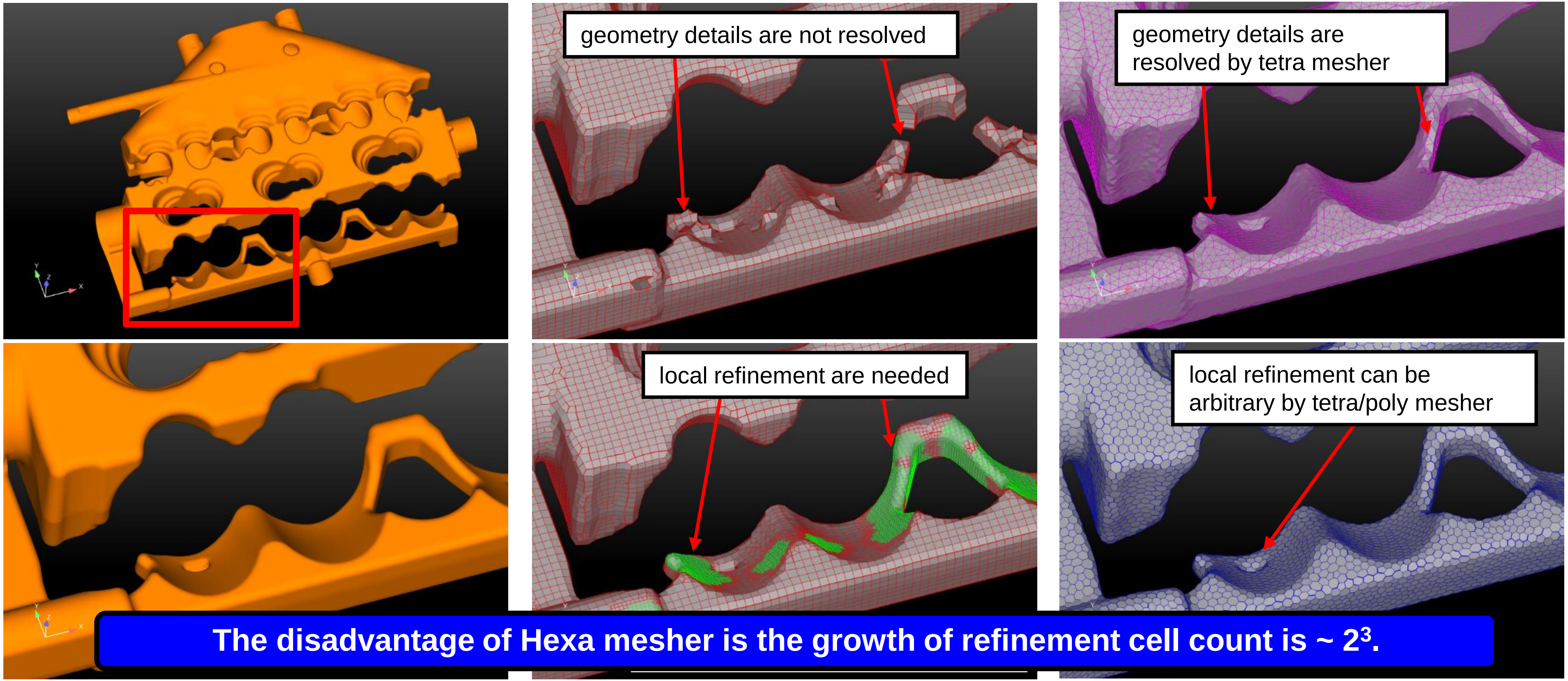
- Auto-meshing
  - Hexa Mesher (*FAME HEXA*)
  - Tetra Mesher (*HyperMesh*)
- Hybrid Meshing
  - Tetra + Block (*HyperMesh*)
  - Hexa + Tetra (*FAME HEXA* + *HyperMesh*)





Hexa and Tetra mesher are the common choice for auto-meshing before FIRE-M.

Disadvantage of Hexa Octree Mesher



The disadvantage of Hexa mesher is the growth of refinement cell count is ~ 2^3.

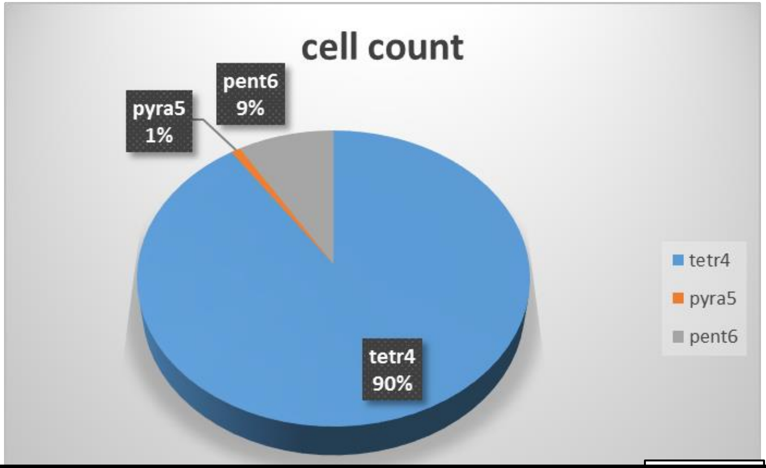
Pros & Cons of Tetra Auto-Mesher

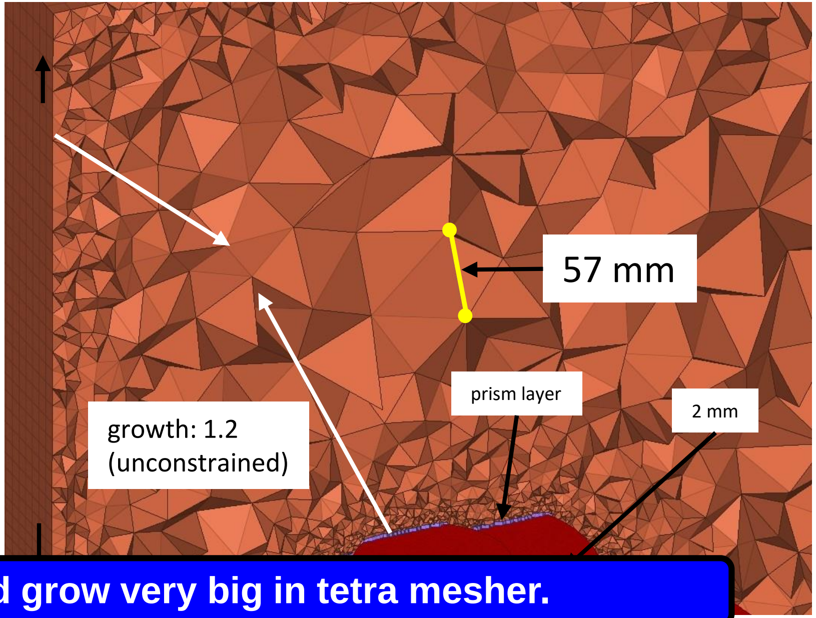
- Pros: arbitrary vs. 2^3 surface refinement
- Cons: on/off only max size constrain

There are two (most common) parameters to control mesh size growth:

- growth rate
- max cell size

	tetr4	pyra5	pent6
cell count	5,777,213	53,668	554,820





If cell size is not constrained, cell size could grow very big in tetra mesher.

Hybrid Meshing – Cell Topology and the Concept of Embedded Mesh

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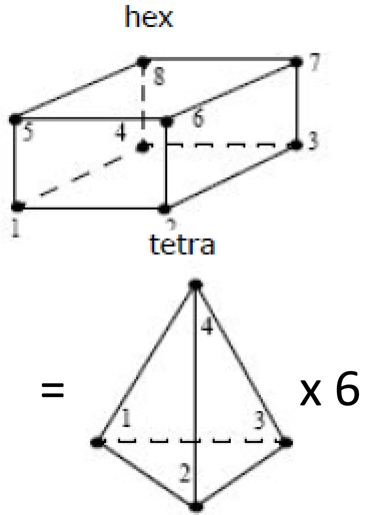
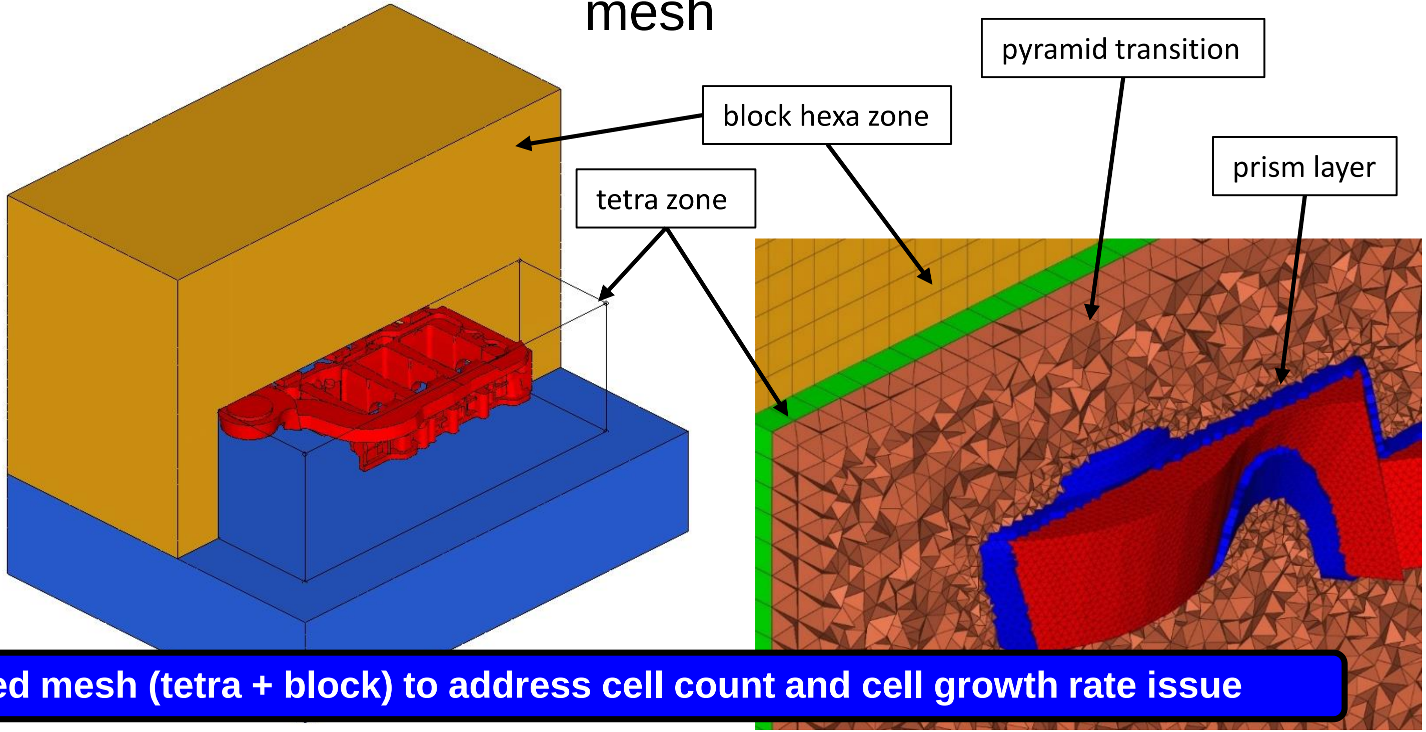
- 1 hexa = 6 tetra with equal edge length



- Embedding tetra in block hexa mesh

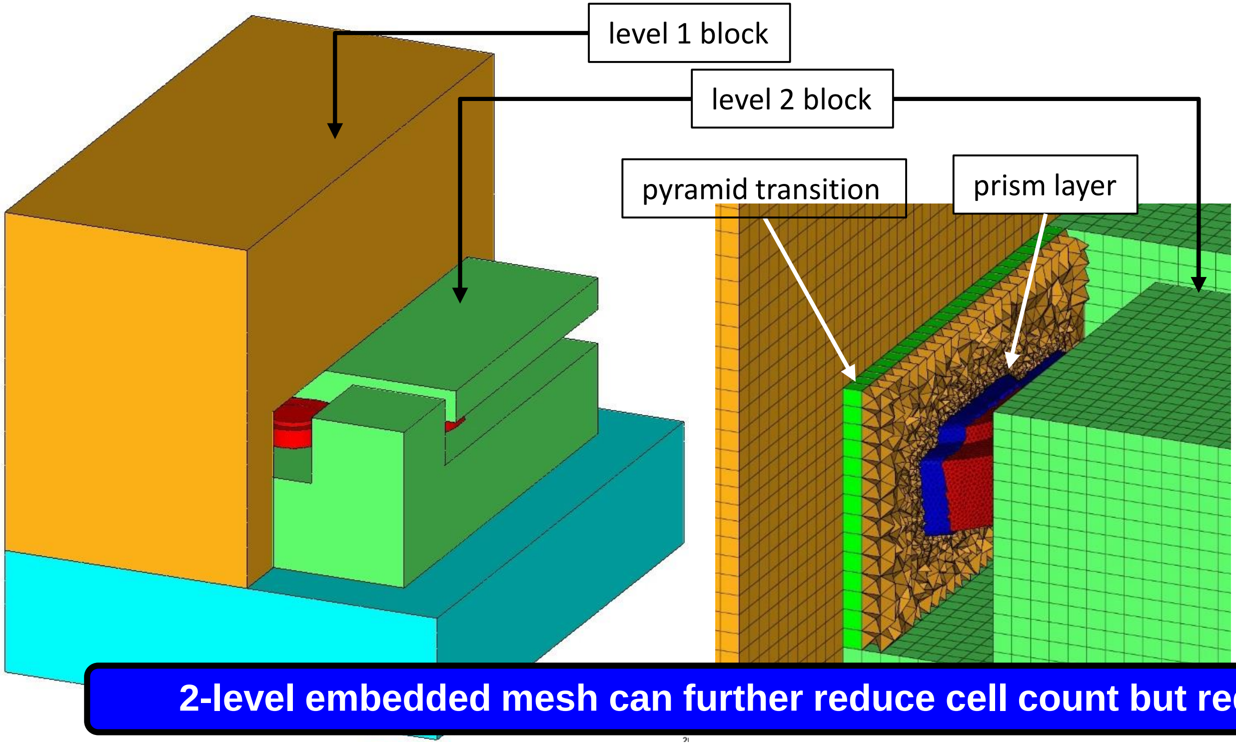


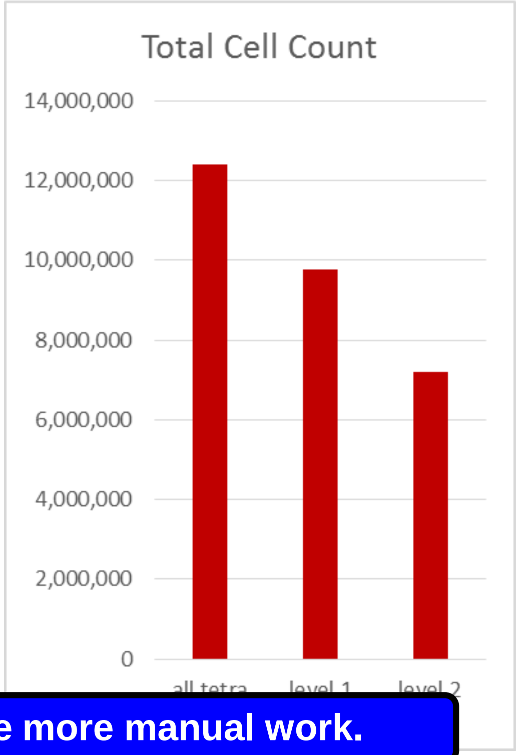
- prism layer: 2mm
- blo

Use embedded mesh (tetra + block) to address cell count and cell growth rate issue

Hybrid Meshing – Tetra + Block : 2-Level Embedded Mesh

- 2-level embedded mesh and cell count comparison

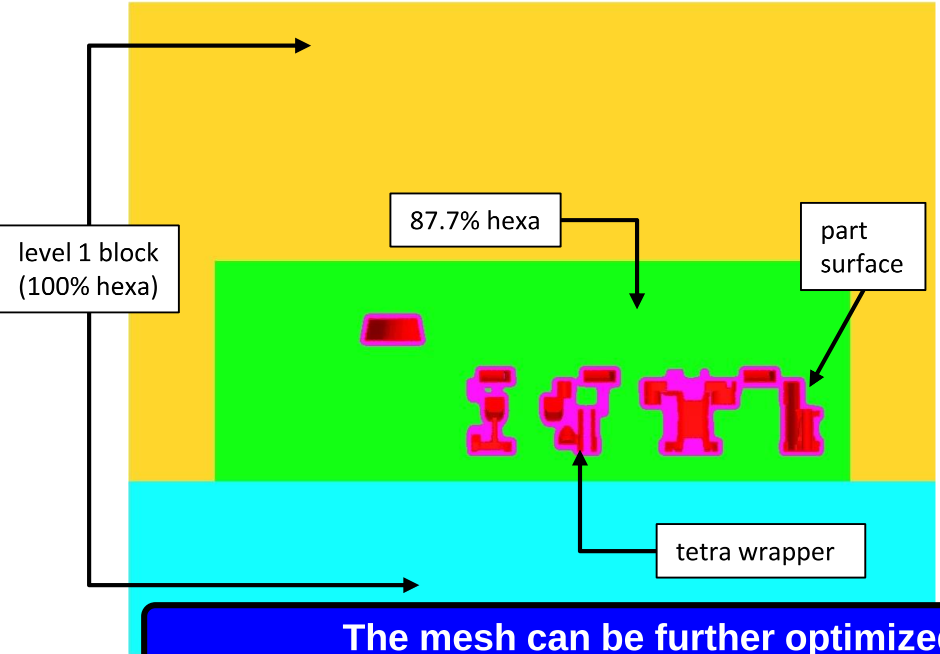




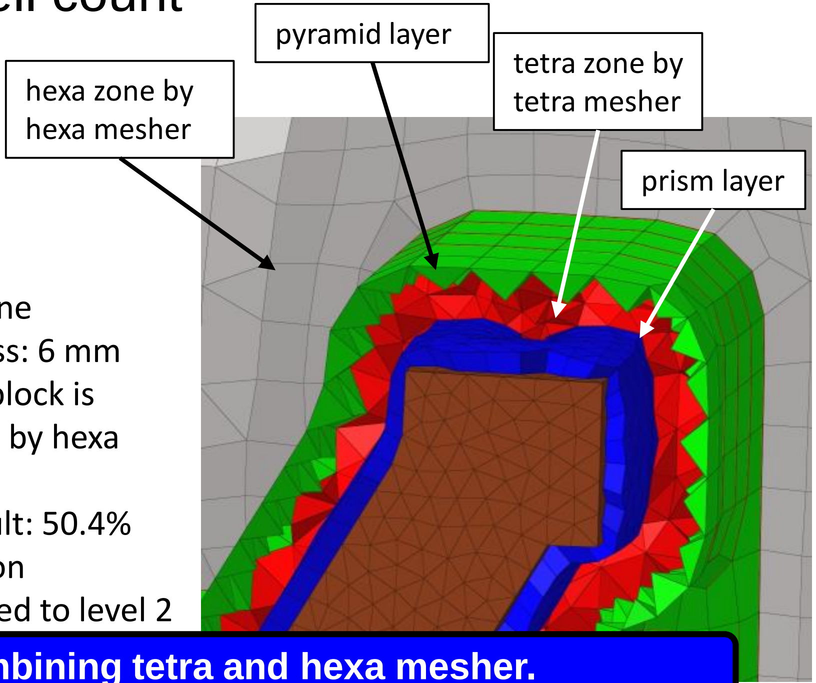
2-level embedded mesh can further reduce cell count but require more manual work.

Hybrid Meshing – Tetra + Hexa + Block : 2-Level Embedded Mesh with Hexa Shrink

- Replace level 2 block by *FAME Hexa* mesher – automate/optimize shape of level 2 block and further reduce tetra cell count



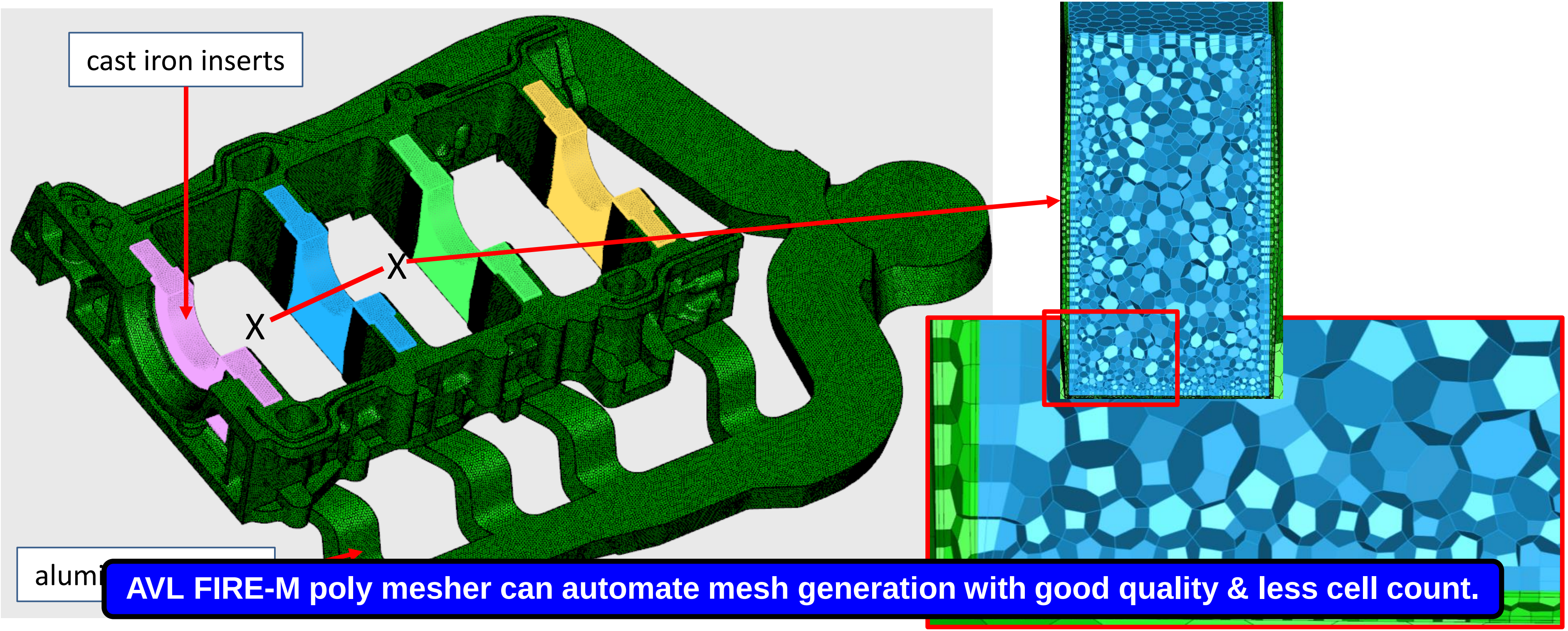
- tetra zone thickness: 6 mm
- level 2 block is meshed by hexa mesher
- the result: 50.4% reduction compared to level 2



The mesh can be further optimized by combining tetra and hexa mesher.

AVL FIRE-M Comes to the Rescue!

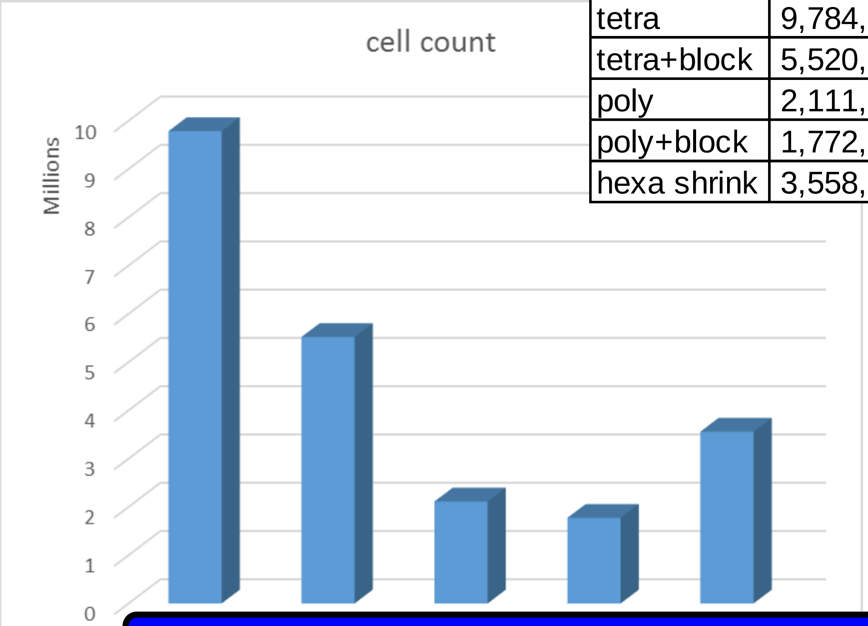
- FIRE-M poly mesher can handle multi-material and thin walls with ease.



AVL FIRE-M poly mesher can automate mesh generation with good quality & less cell count.

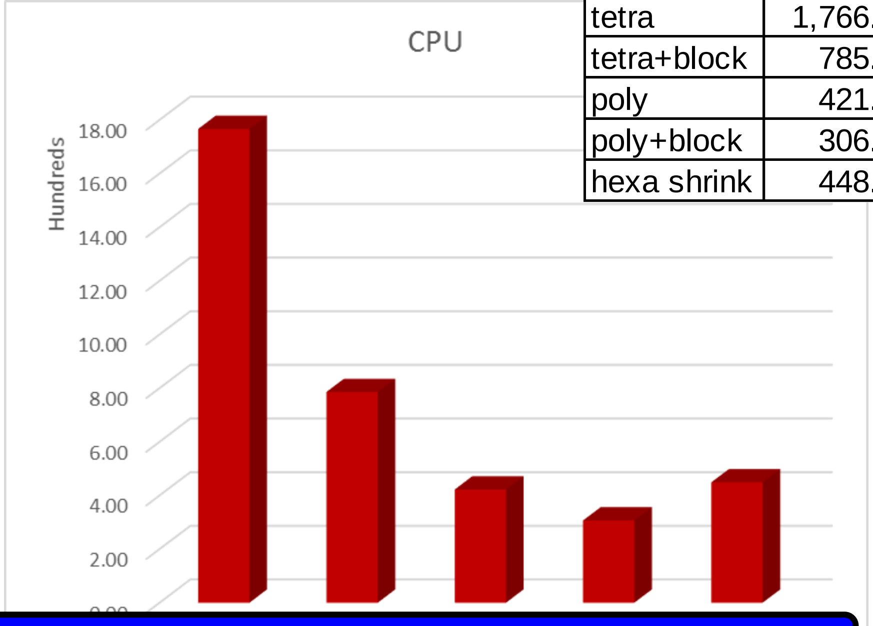
Performance Comparison

- Cell Count



	cell count
tetra	9,784,486
tetra+block	5,520,474
poly	2,111,873
poly+block	1,772,800
hexa shrink	3,558,216

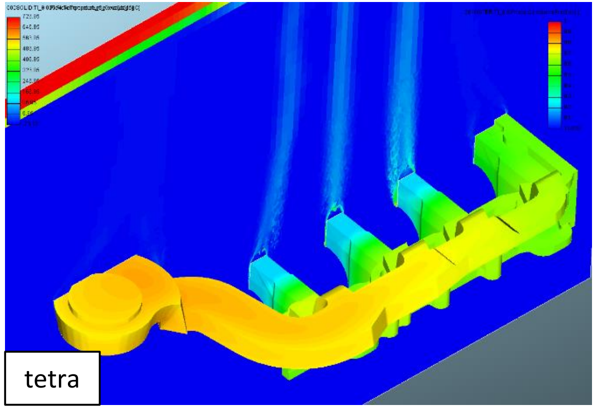
- CPU Time

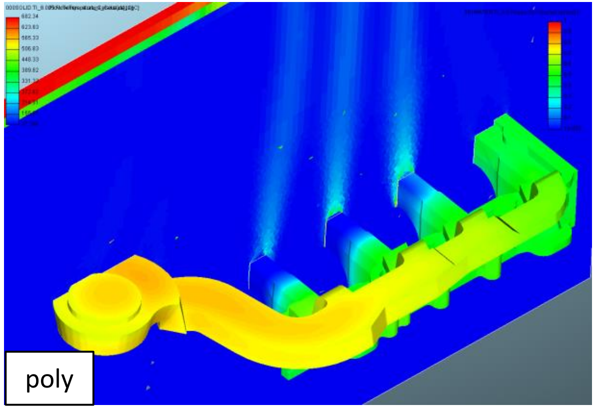


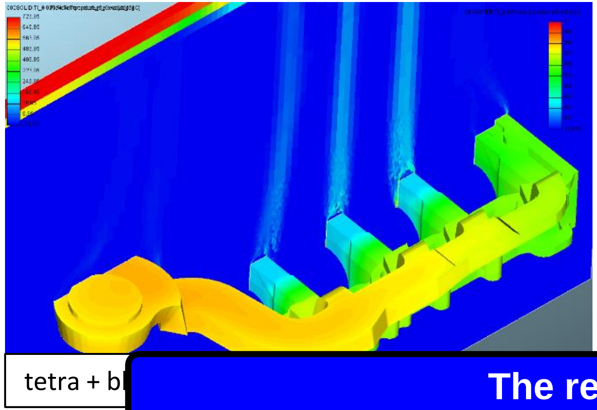
	CPU
tetra	1,766.23
tetra+block	785.44
poly	421.99
poly+block	306.77
hexa shrink	448.81

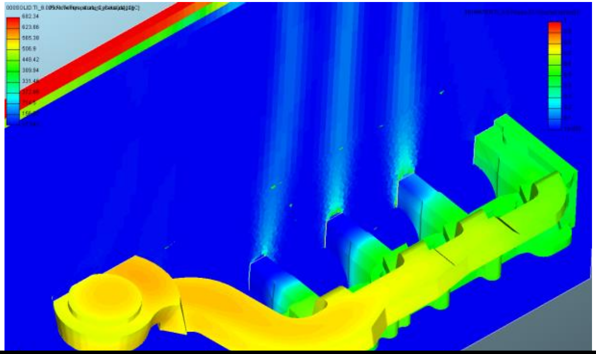
There are clear advantages in cell count and CPU time in using poly mesh by FIRE-M.

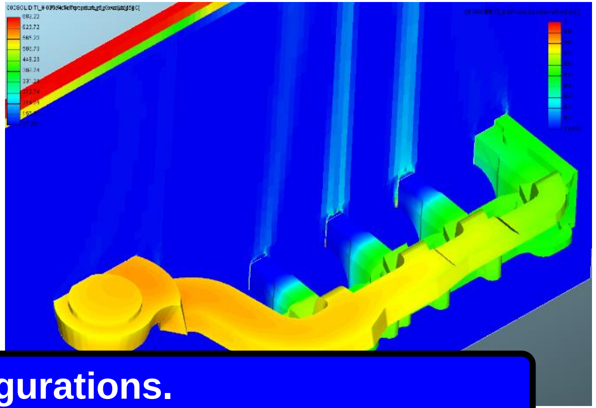
Temperature Profile & Vapor Pattern at End of Quenching











The results are similar for all the mesh configurations.

Conclusion

- Ford had great success in modeling quenching process by CFD.
- Since the initial condition of temperature in current water quench modeling procedure is uniform, it cannot model parts cast by HPDC.
- Ford has successfully integrating MAGMA casting simulation to the water quench modeling workflow, extending applications to HPDC parts.
- Additional challenge in modeling the HPDC parts is geometry complexity.
- Meshing complex geometry parts can be managed by hybrid meshing using embedded mesh but it require additional manual work.
- New poly mesher (*FAME Poly*) in AVL FIRE-M can generate mesh of great quality with less cell count for complex geometry parts.