OPTIMIERUNG DES ABSCHRECKENS BEI DER WÄRMEBEHANDLUNG VON AL-GUSSTEILEN MITTELS SIMULATION

FORD
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AVL
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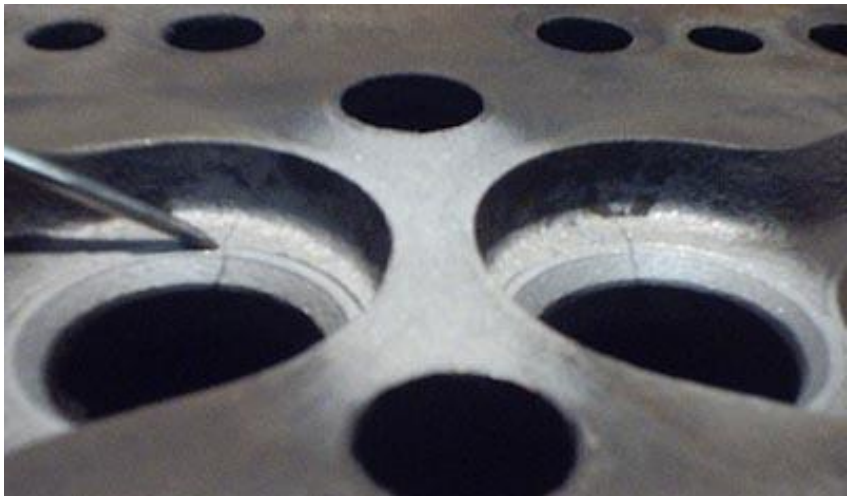
60. Österreichische Gießereitagung mit Fachausstellung
7./8. April 2016, Bad Ischl, Austria

COMPLEX AND CHAOTIC BOILING PROCESS

EINFÜHRUNG
PROBLEMSTELLUNG



Problem:

- Rissbildung im Zylinderkopf
- Deformationen

Mögliche Ursachen:

- Eigenspannungen aus dem Wärmebehandlungsprozeß
- Überlagerung von Betriebslasten
- Überbeanspruchung des Werkstoffs

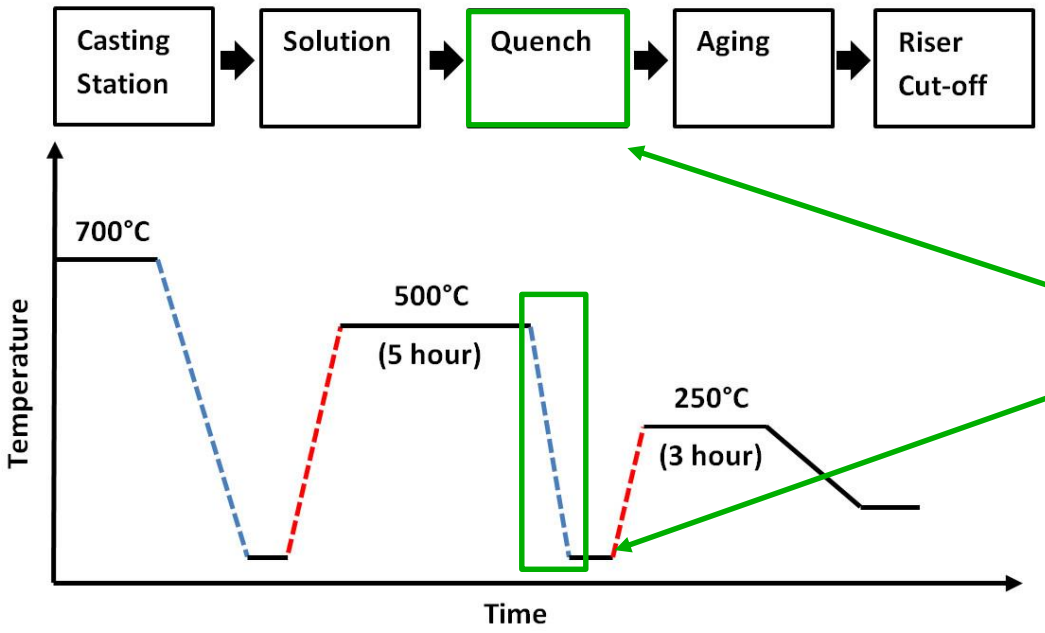
Folgen:

- Leckage, Motorschaden

Lösungsansatz:

- Simulationsverfahren zur Bewertung der Eigenspannungen
- Reduktion der Eigenspannungen
- Optimierung der Wärmebehandlung

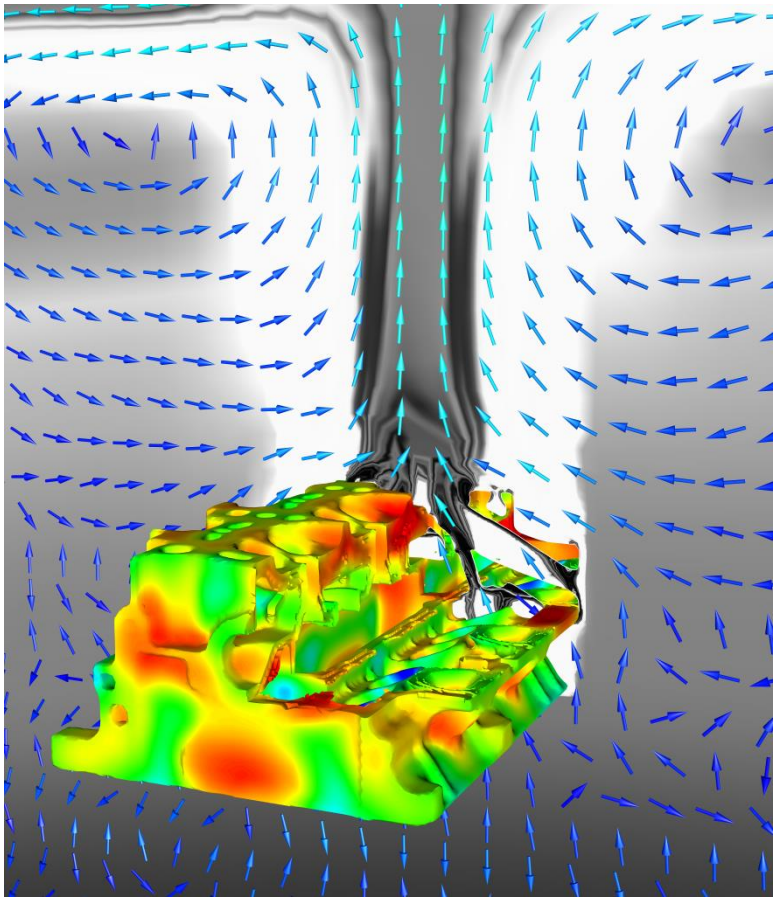
SCHEMATISCHE WÄRMEBEHANDLUNG



Wärmebehandlung für Aluminium-Gußteile

- Gießen
- Abkühlen
- Lösungsglühen bei ~500°C
- Abschrecken
- Auslagern (Altern) bei ~250°C
- Bearbeitung

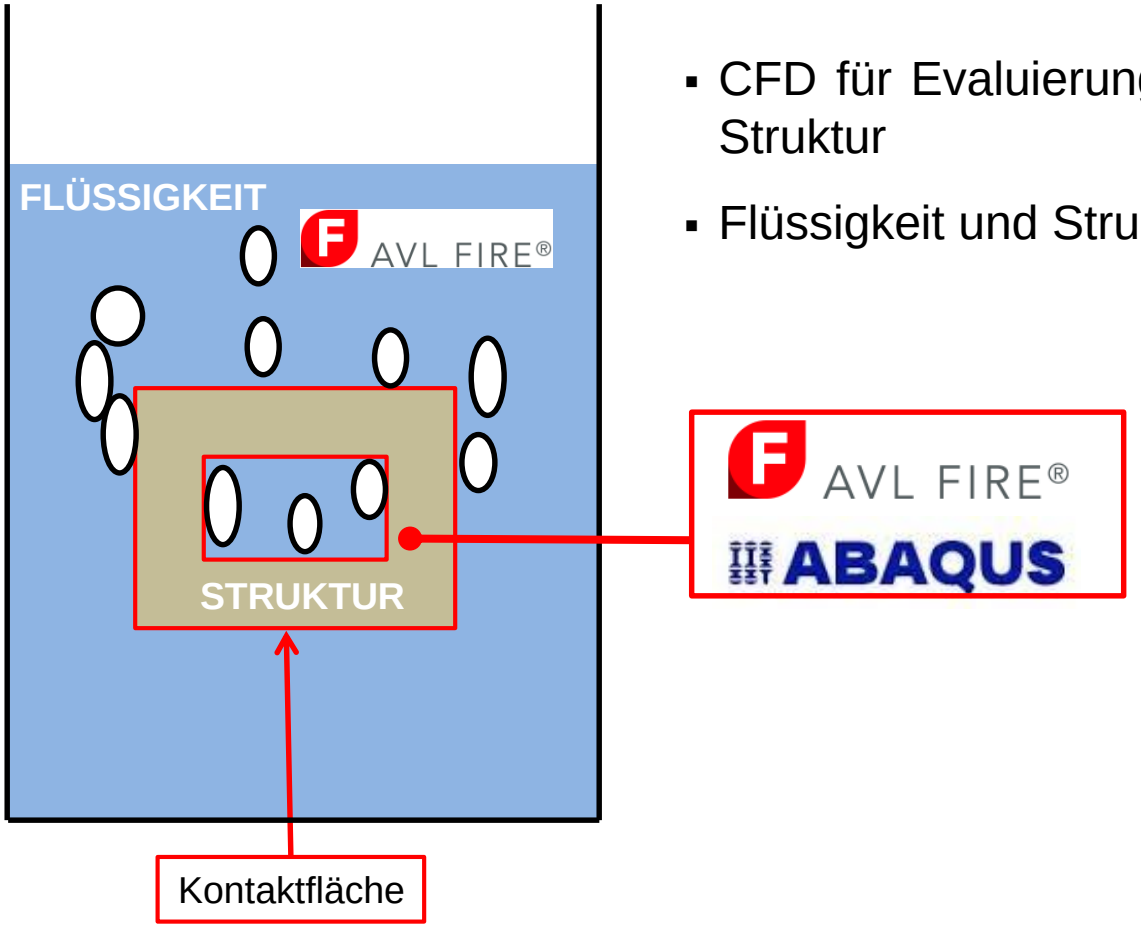
EINFÜHRUNG SIMULATION DES ABSCHRECKVORGANGS



Simulation des Abschreckvorgangs

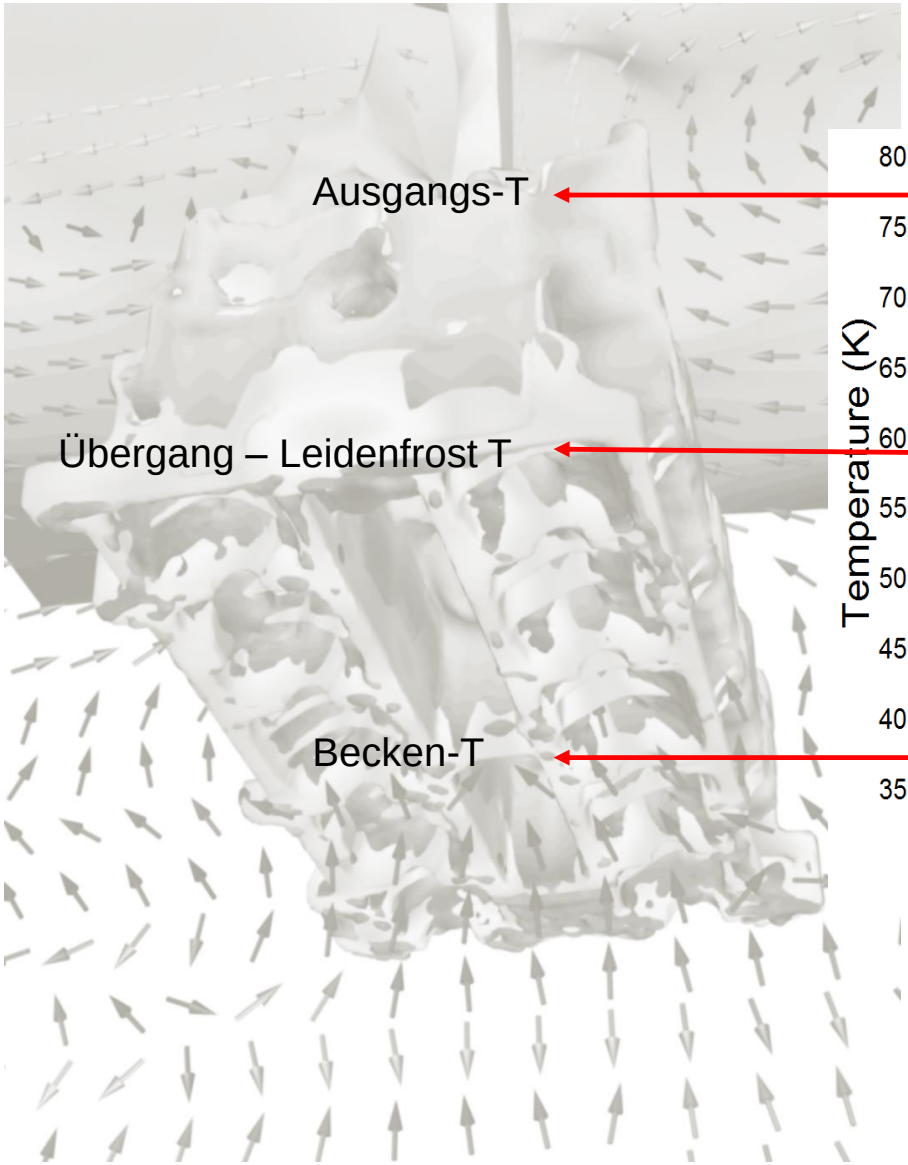
- Mit AVL FIRE™ können Luft- und Eintauchabschrecken sowie Sprayquenching simuliert werden
- Ermittlung des zeitlich aufgelösten Temperaturfelds im Bauteil infolge der Um- und Durchströmung und des Siedens an der Oberfläche
- Erzeugen von Eingabedaten für die Finite-Elemente-Analyse
- Ermittlung des Spannungs-Dehnungsfelds mit geeigneten Materialgesetzen in Abaqus
- Vorhersage der Bauteileigenspannungen
- Grundlage für die Bewertung von Prozeßparametern

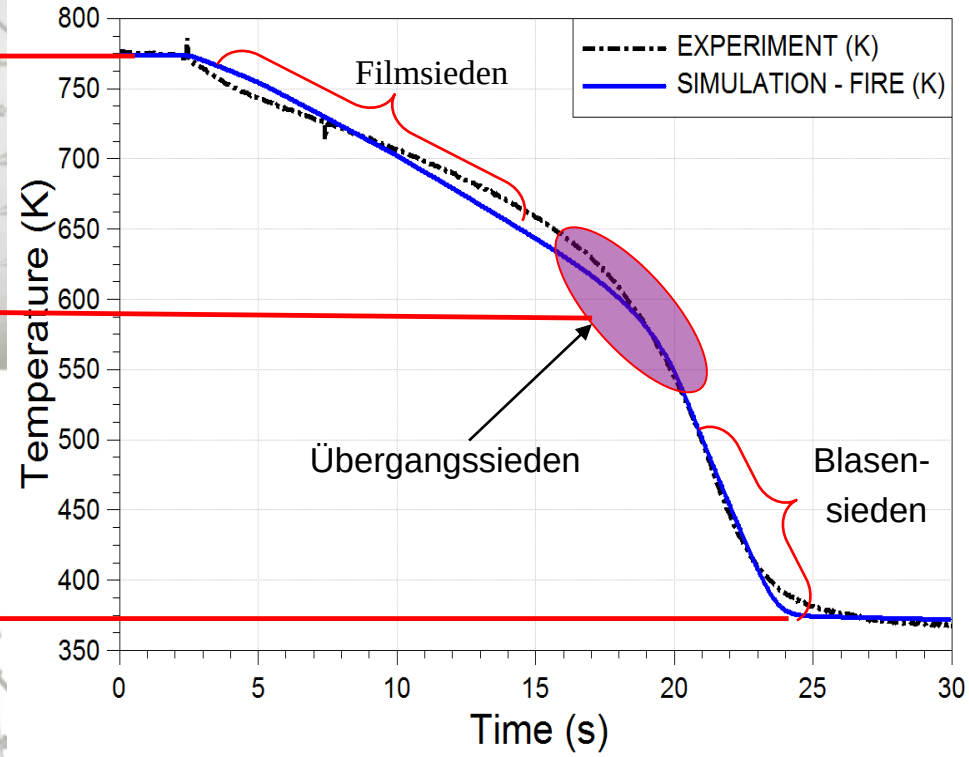
SIMULATION DES ABSCHRECKVORGANGS



- CFD für Evaluierung der Temperatur in der Struktur
- Flüssigkeit und Struktur sind gekoppelt

MODELLIERUNG DES EINTAUCHABSCHRECKENS SIEDEPHÄNOMENE

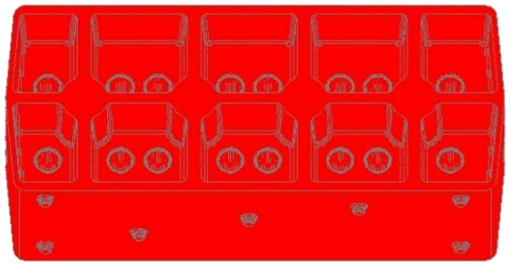




VALIDIERUNG TEST GEOMETRIEN

Kooperation mit NEMAK

- Die Ergebnisse wurden im **FVV Projekt "Quench IT"** ermittelt und zur Validierung herangezogen
- Die Messungen wurden von Nemak als wichtigem Industriepartner durchgeführt
- Geometrie: mittlere Komplexität, realistische Baugröße und Wärmekapazität)



2014-01-0641
Published 04/01/2014
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doi:10.4271/2014-01-0641
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Immersion Quenching Simulation of Realistic Cylinder Head Geometry

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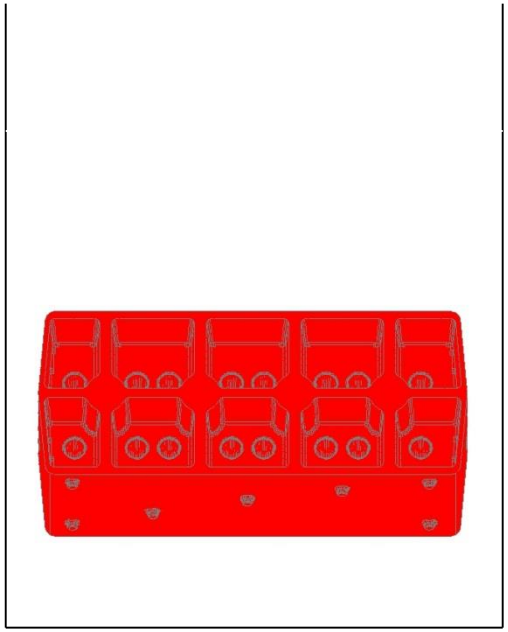
ABSTRACT

In this paper, a recently improved Computational Fluid Dynamics (CFD) methodology for virtual prototyping of the heat treatment of cast aluminum parts, above most of cylinder heads of internal combustion engines (ICE), is presented. The comparison between measurement data and numerical results has been carried out to simulate the real time immersion quenching cooling process of realistic cylinder head structure using the commercial CFD code AVL FIRE®. The Eulerian multi-fluid modeling approach is used to handle the boiling flow and the heat transfer between the heated structure and the sub-cooled liquid. While for the fluid region governing equations are solved for each phase separately, only the energy equation is solved in the solid region. Heat transfer coefficients depend on the boiling regimes which are separated by the Leidenfrost temperature. The objective of the present research work is to present an update of the quenching model where

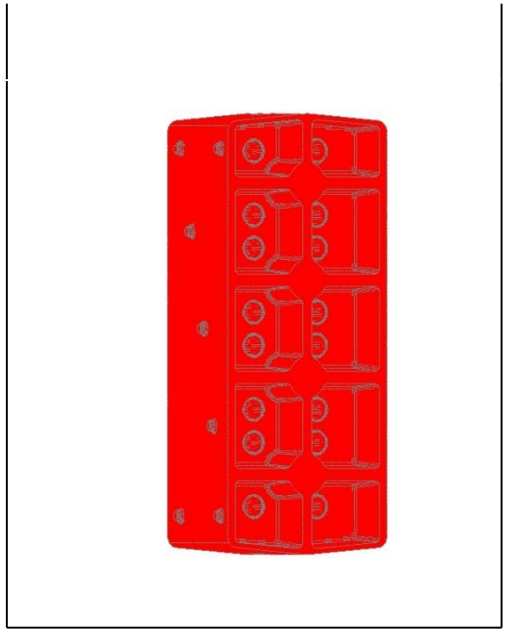
Referenz:
Kopun, R., Zhang, D., Edelbauer, W., Stauder, B. et al., "Immersion Quenching Simulation of Realistic Cylinder Head Geometry," *SAE Int. J. Mater. Manf.* 7(3):520-529, 2014, doi:10.4271/2014-01-0641.

CFD SIMULATIONSERGEBNISSE VALIDIERUNG

- Horizontale Eintauchrichtung



- Vertikale Eintauchrichtung



Aluminium
L×B×H =400×170×140 mm
Representatives Gewicht

2014-01-0641
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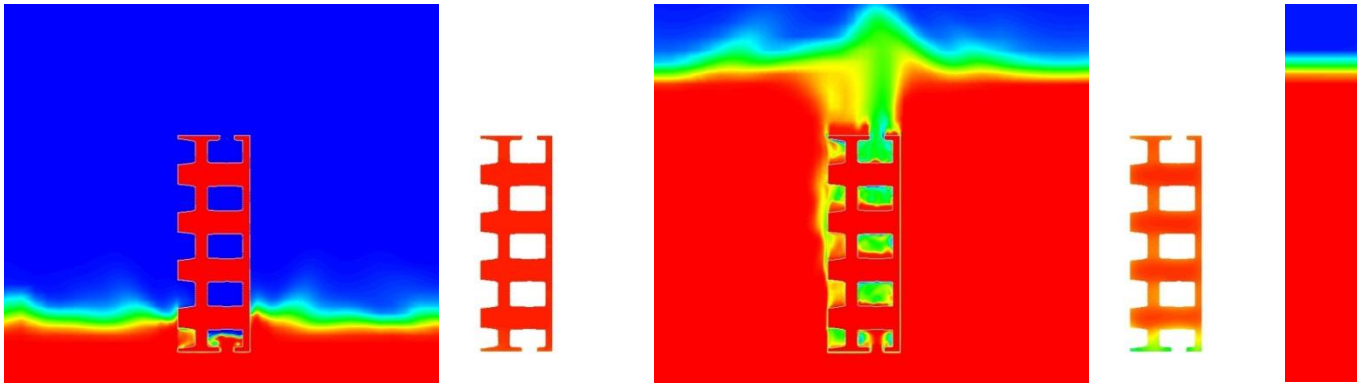
CFD SIMULATIONSERGEBNISSE VALIDIERUNG

Time: 1 sec

Time: 5 sec

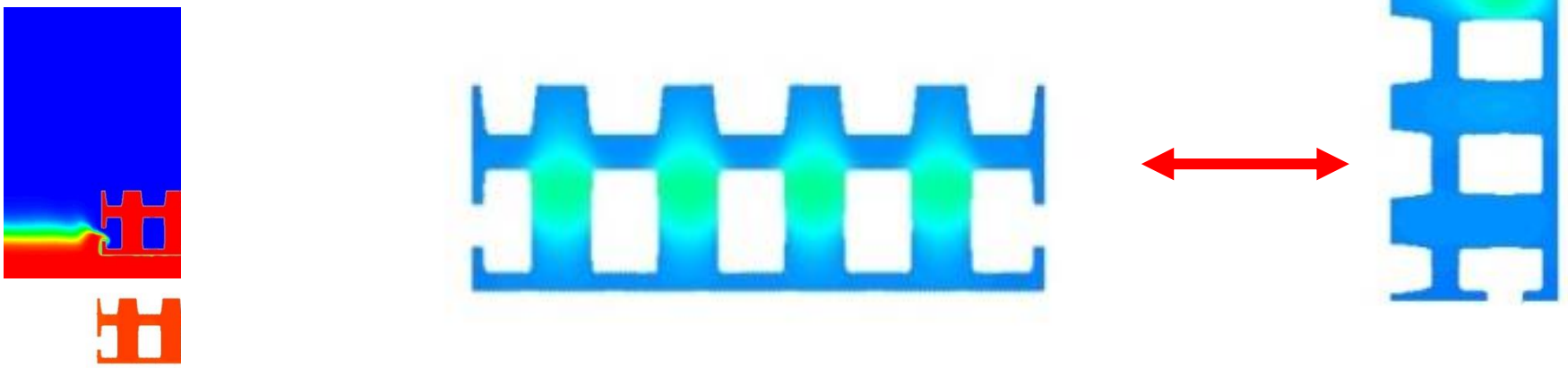


Volume fraction

0

Temperature

Time: 30 sec



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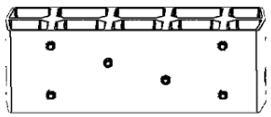
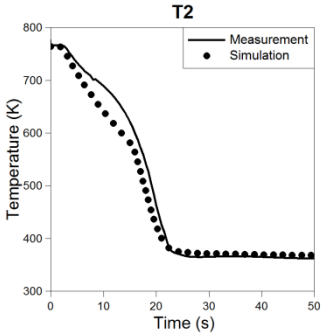
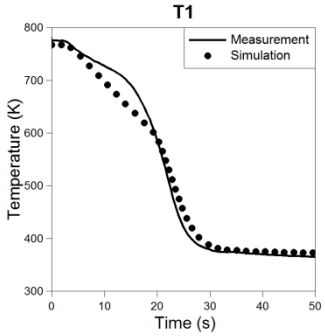
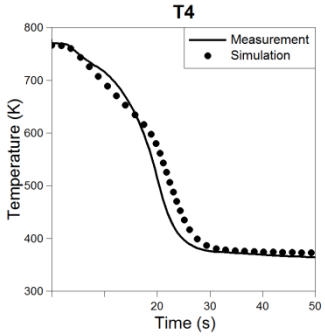
CFD SIMULATION RESULTS VALIDIERUNG

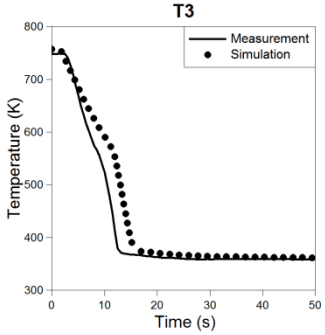


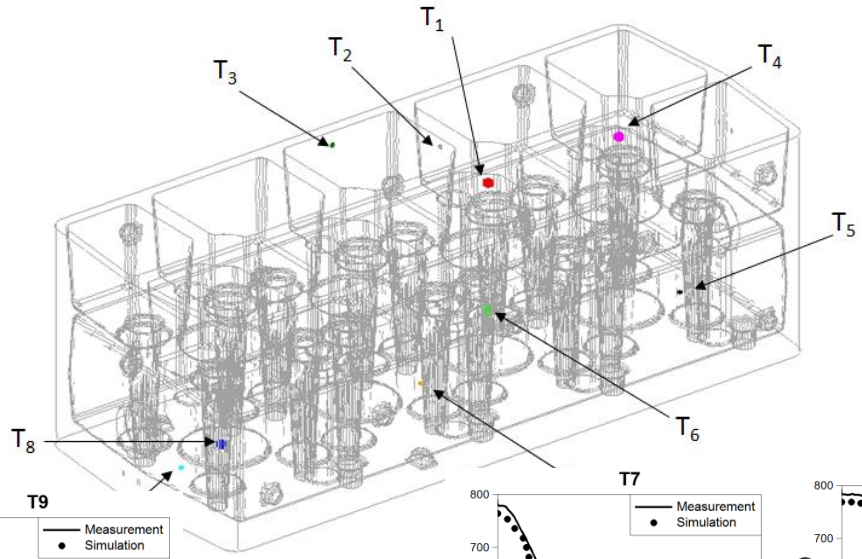
Horizontal

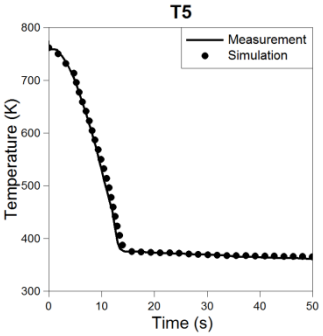


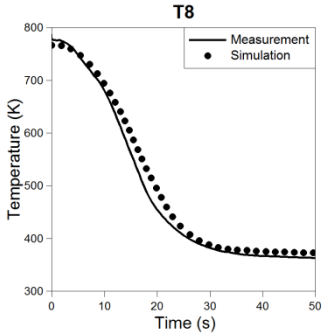


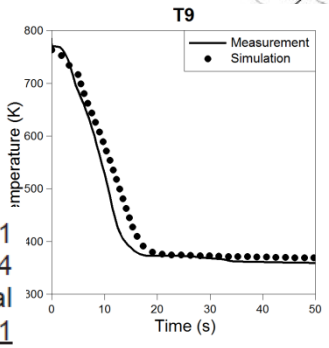


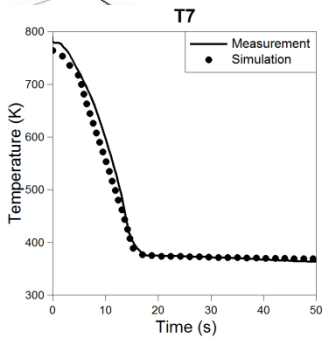


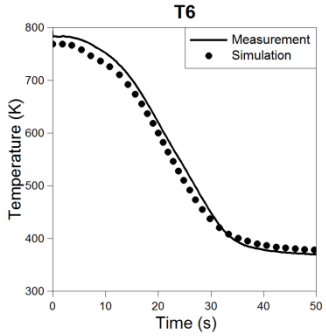












2014-01-0641
Published 04/01/2014

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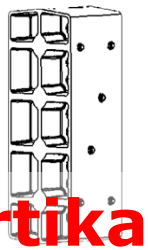
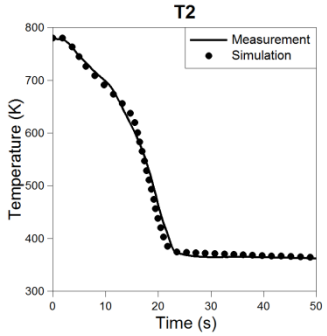
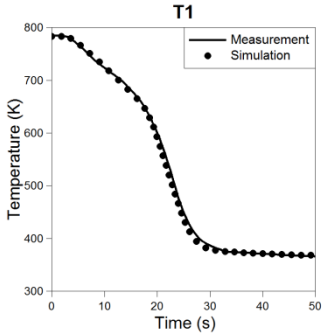
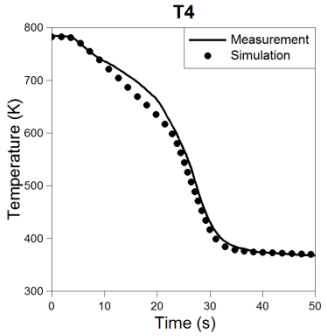
CFD SIMULATION RESULTS VALIDIERUNG

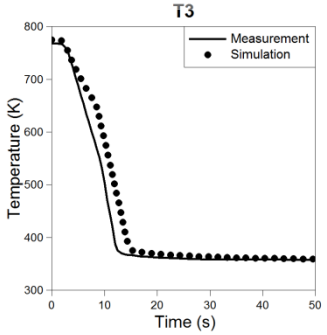


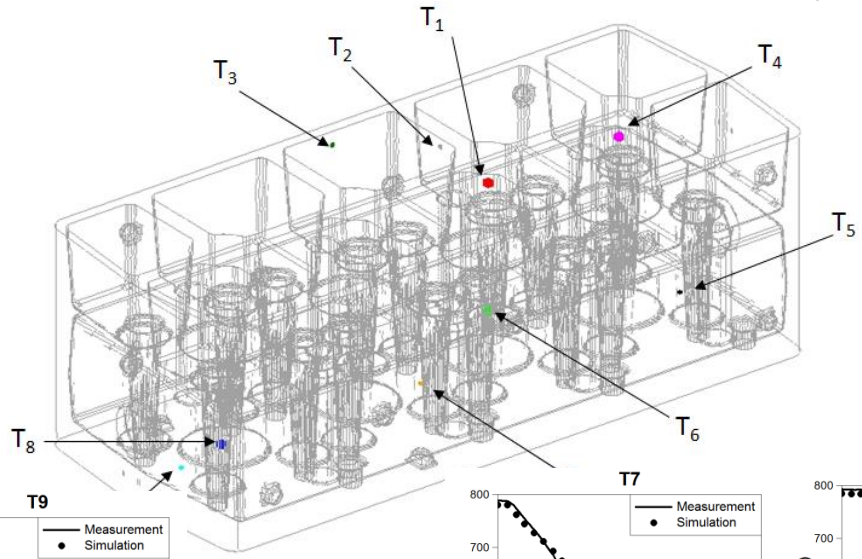
Vertikal

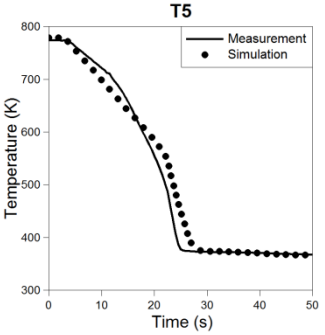


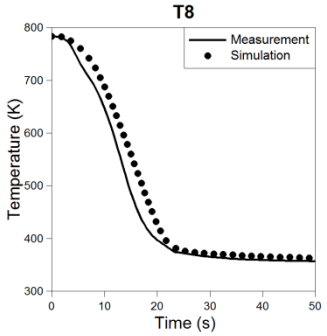


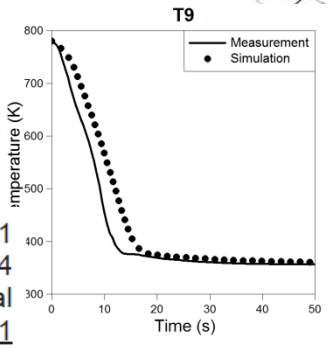


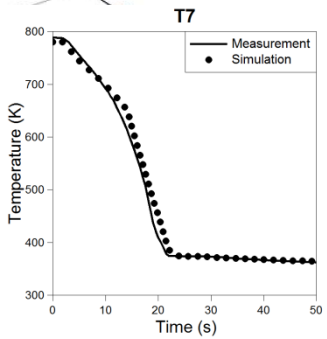


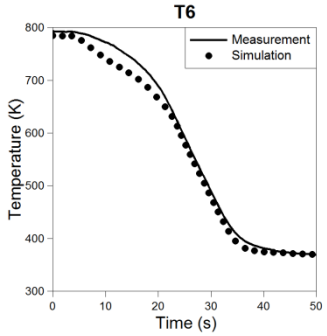








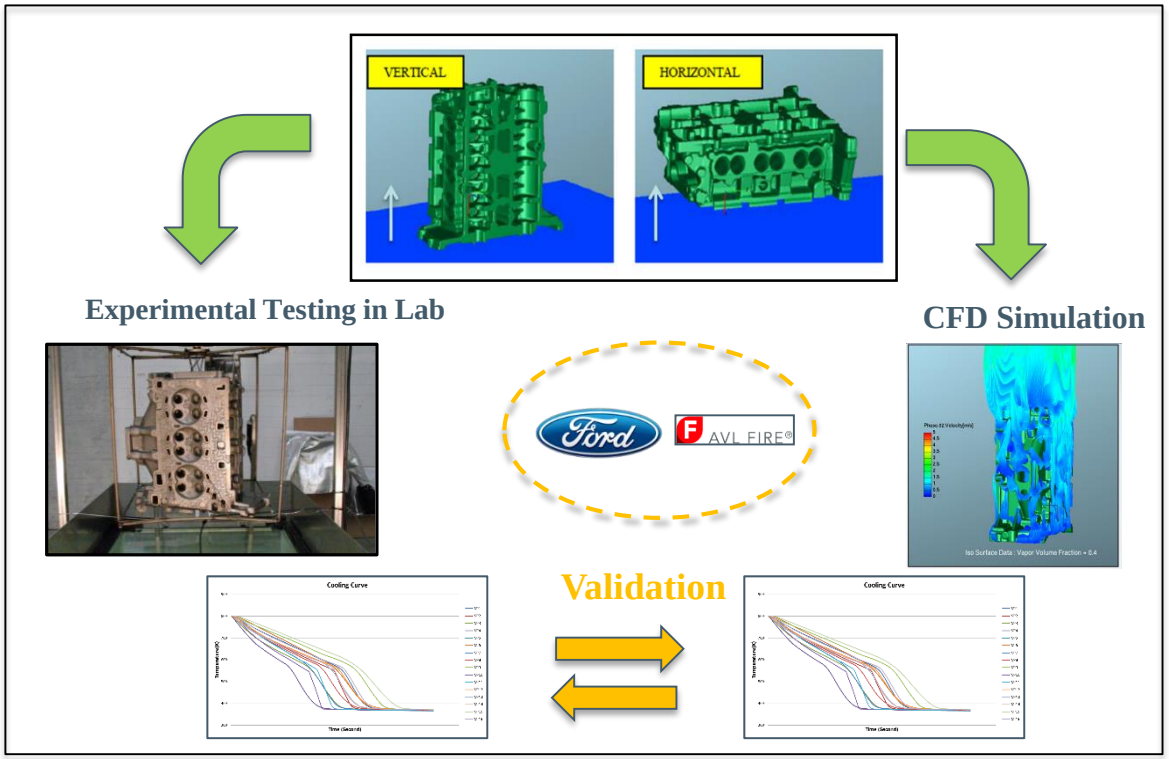




2014-01-0641
Published 04/01/2014

doi:10.4271/2014-01-0641

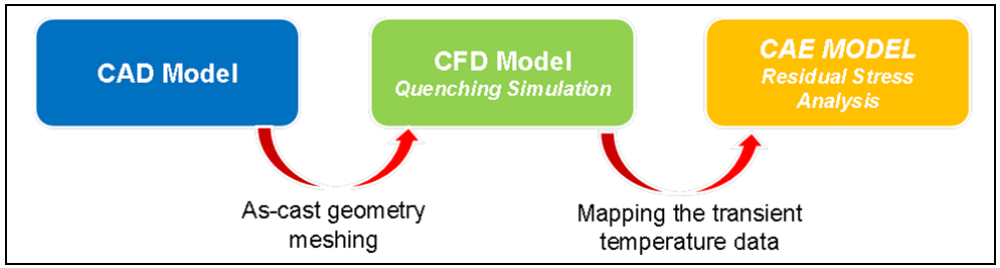
OBJECTIVE



Ford's requirement is a **physical modeling CAE** method to capture transient temperature distribution during quenching.

Software Requirements

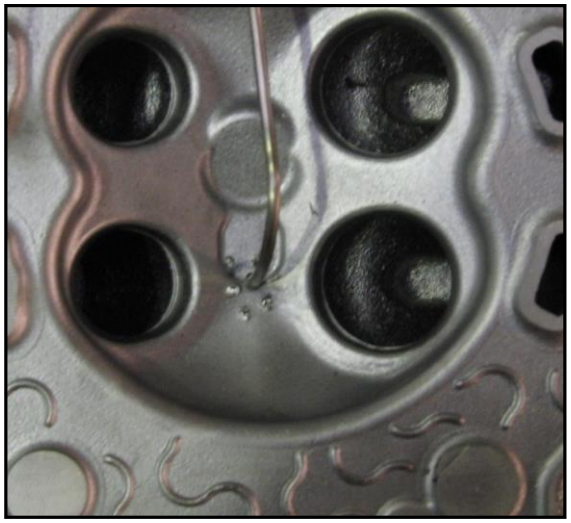
- ✓ **Correlation**
- ✓ **Predictability**
- ✓ **Compatibility**



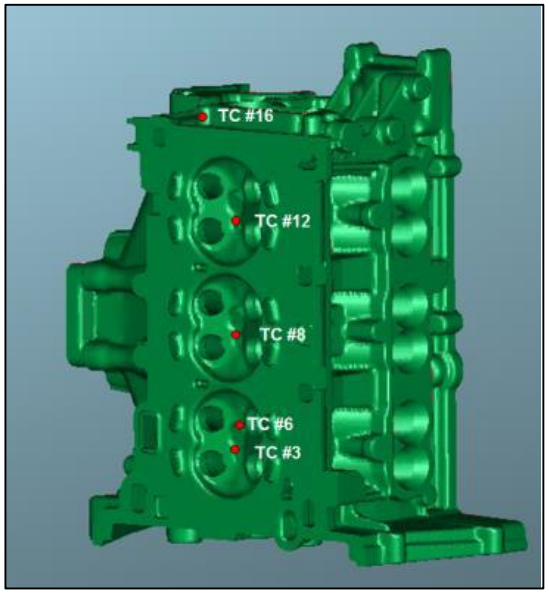
Providing transient temperature data for CAE model

EXPERIMENT - THERMOCOUPLES

- Prototype cylinder heads : **as-cast, not cubed, non-heat treated condition**
- Drilling thermocouple holes (CNC)
- "**Embedded and peened**" method
- Sealing with a **ceramic paste** for the quenching experiments

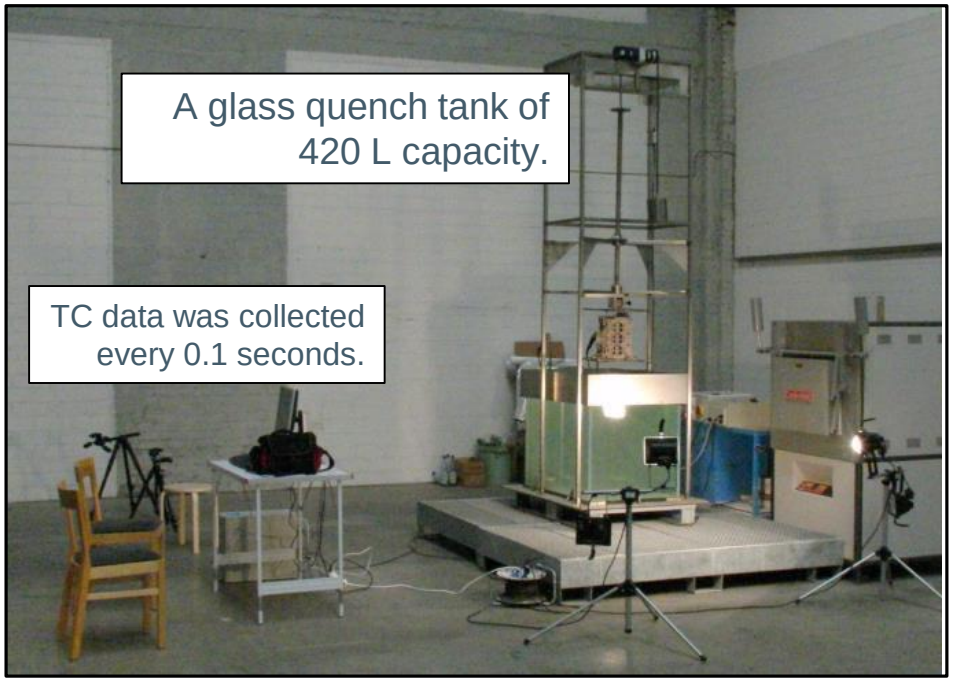


Embedded and Peened Thermocouple (combustion chamber roof location)



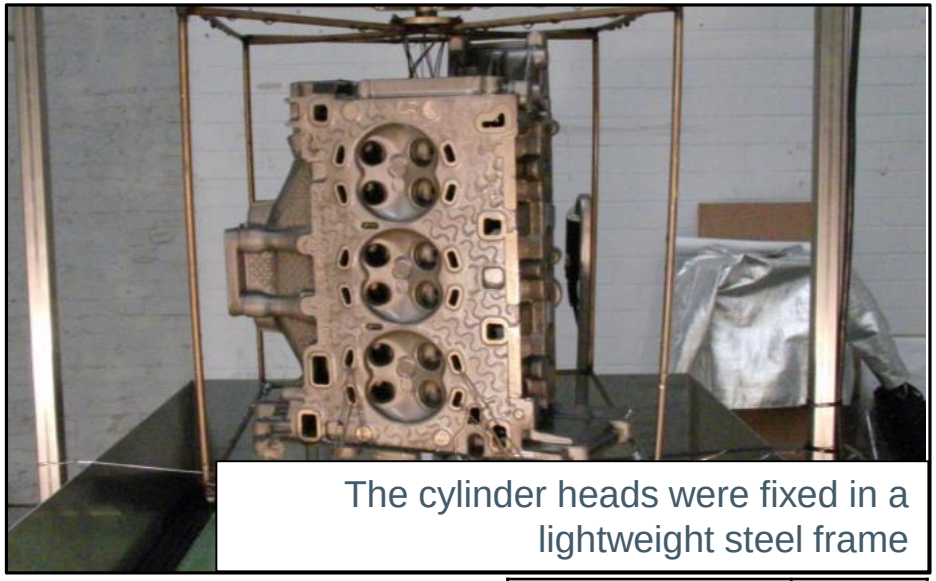
Thermocouple Locations

EXPERIMENTAL STUDY



A glass quench tank of 420 L capacity.

TC data was collected every 0.1 seconds.

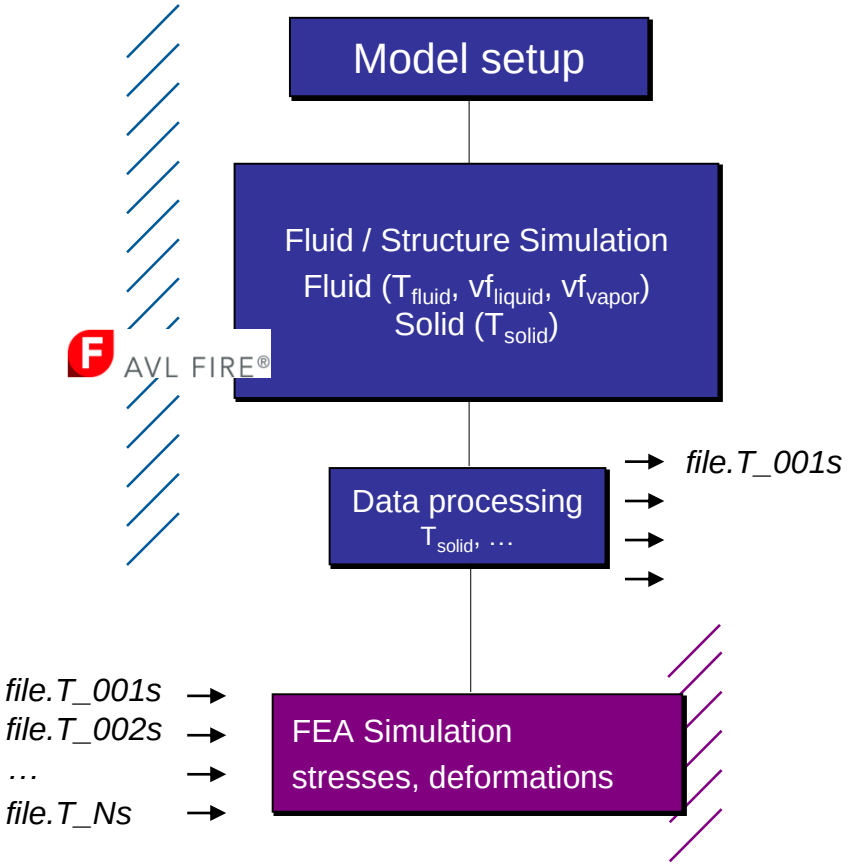


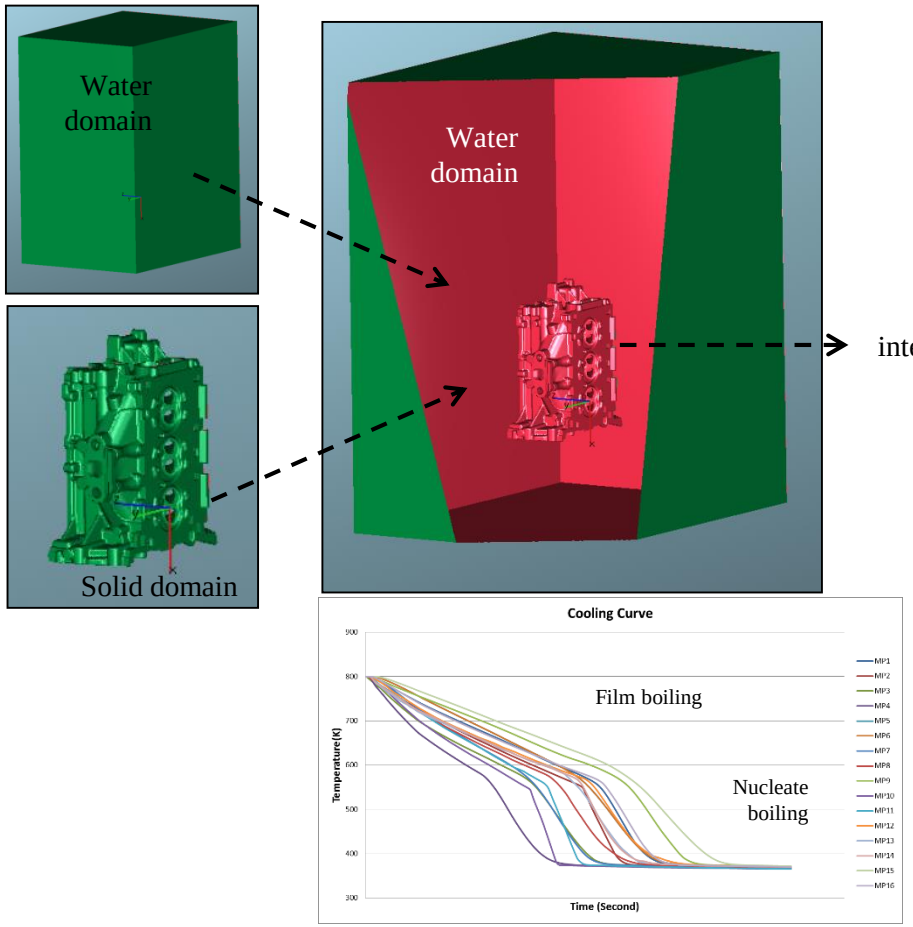
The cylinder heads were fixed in a lightweight steel frame

Temperature	ºC
Solutionization	527
Quenchant	91

Recordings were taken with a rate of 300 frames per second, resulting in a slow motion mode of 1:10 when using standard viewers.

COMPUTATIONAL APPROACH

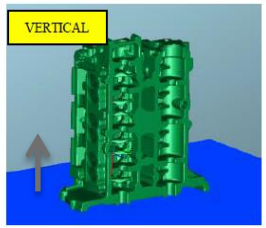


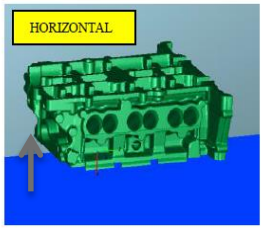


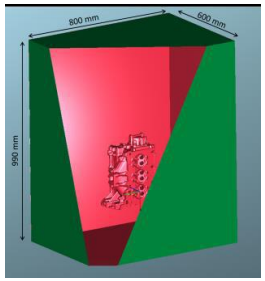
Transient temperature distribution to be used as input for stress analysis

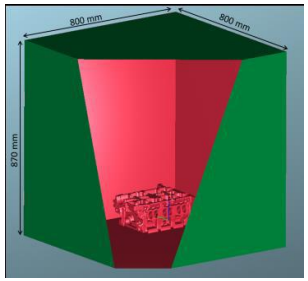
COMPUTATIONAL MODEL

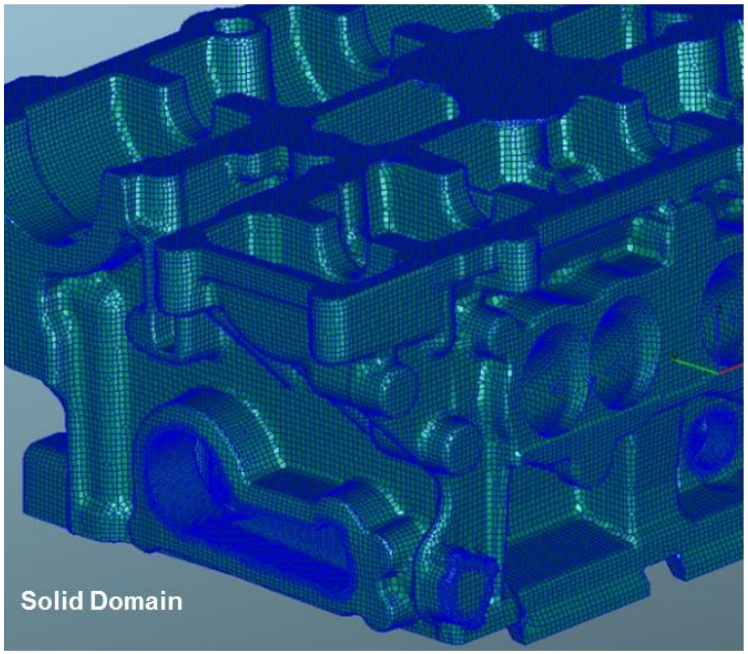
Simulation Parameters	
Solid & Water Temperature	Similar as experiments
Inlet Boundary Condition	Velocity Inlet
Submerging speed	0.7 m/s
Outlet Boudnary Condition	Pressure Outlet
Forced flow	No

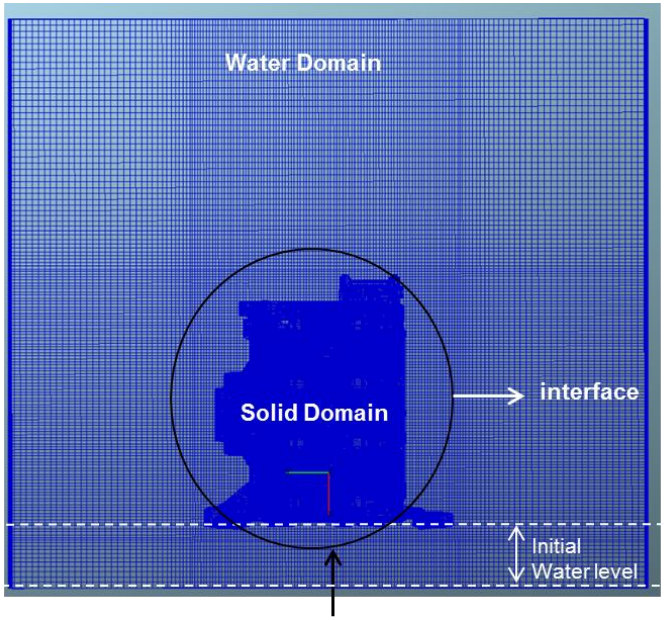












VAPOR FORMATION
VERTICAL ORIENTATION

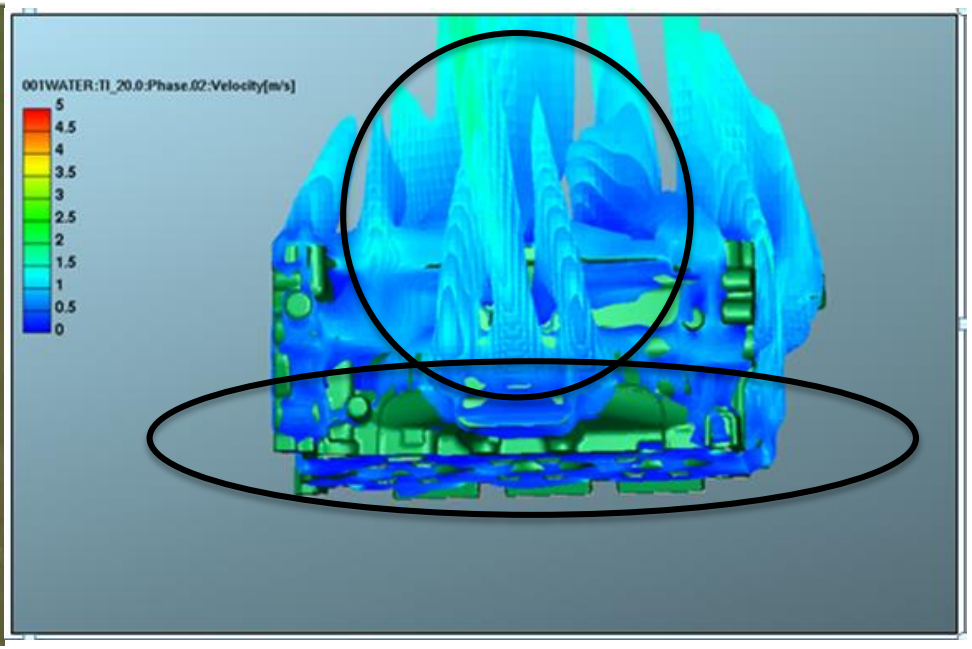
Experiment vs. CFD

VAPOR FORMATION
HORIZONTAL ORIENTATION

Ford Go Further

AVL

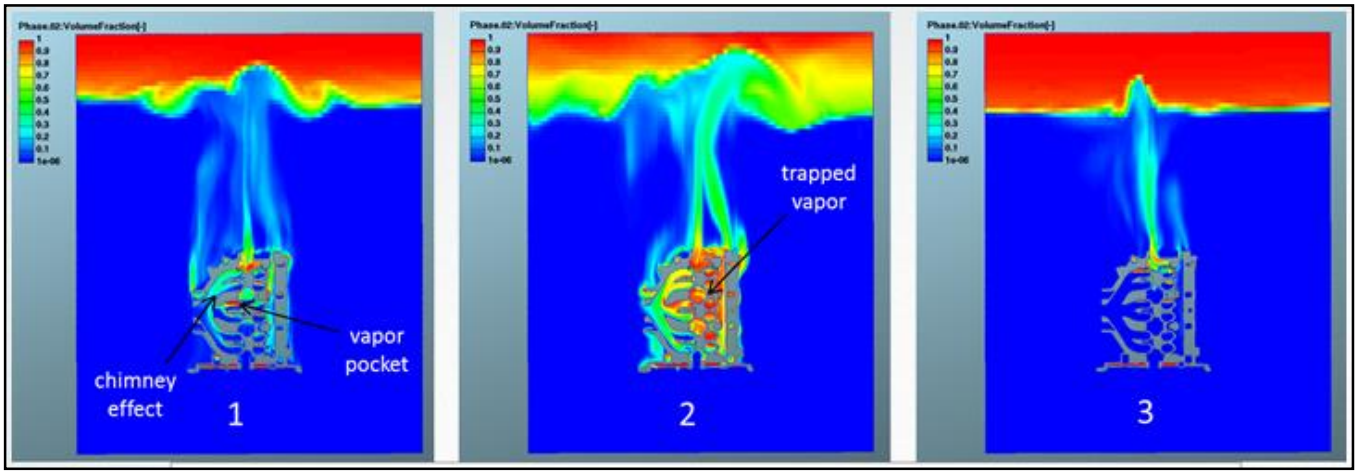
Experiment vs. CFD



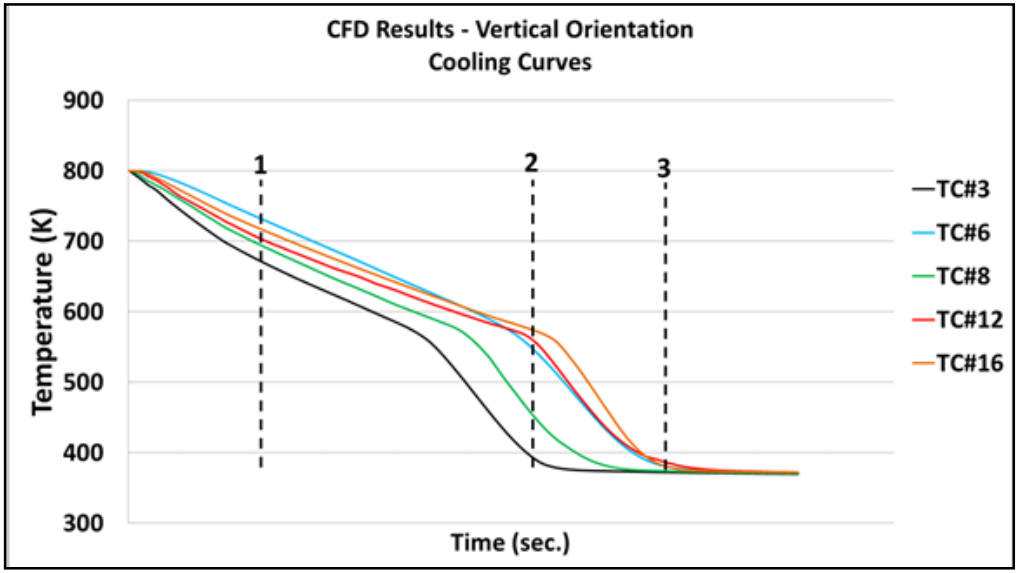
Good correlation in terms of vapor formation!

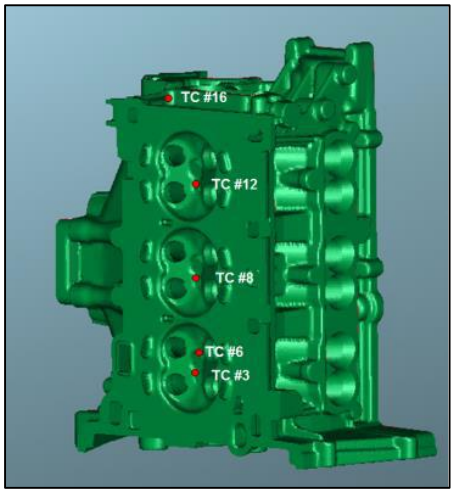
VAPOR FORMATION & TEMPEARTURE VERTICAL ORIENTATION

Vapor Volume Fraction distribution on a plane section for three boiling regimes.(1,2,3)



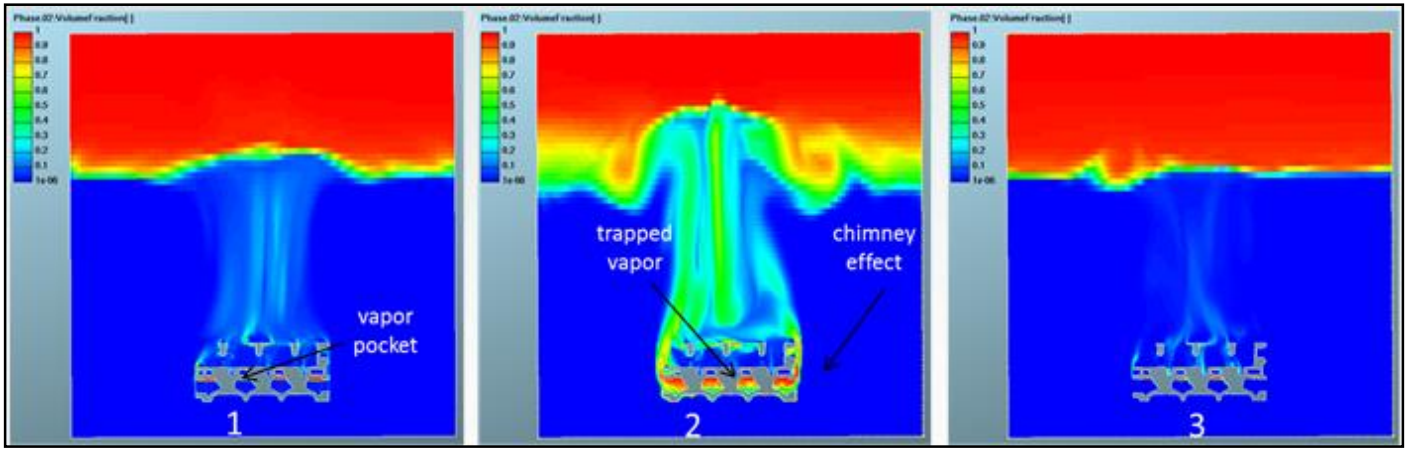
Temperature history data for each monitoring point in vertical orientation.



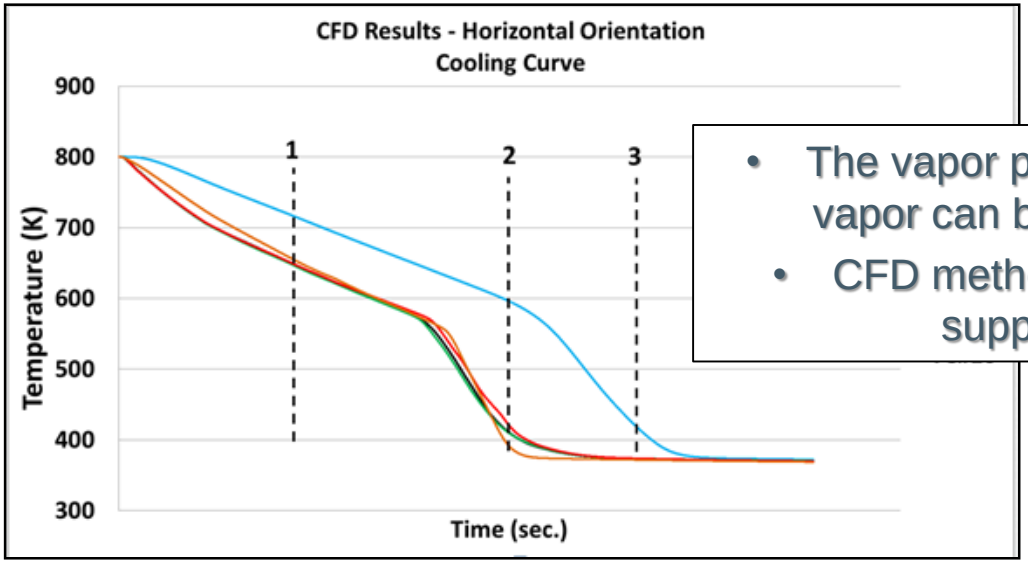


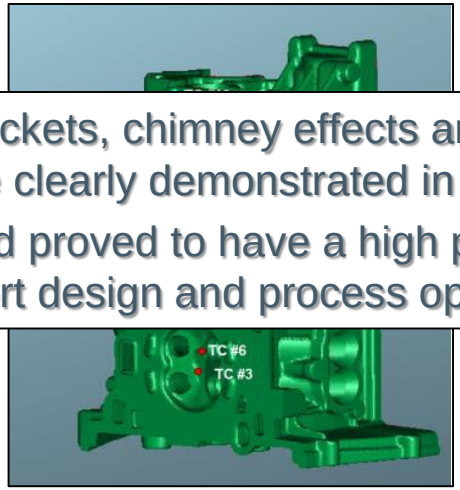
VAPOR FORMATION & TEMPEARTURE HORIZONTAL ORIENTATION

Vapor Volume Fraction distribution on a plane section for three boiling regimes.(1,2,3)



Temperature history data for each monitoring point in horizontal orientation.





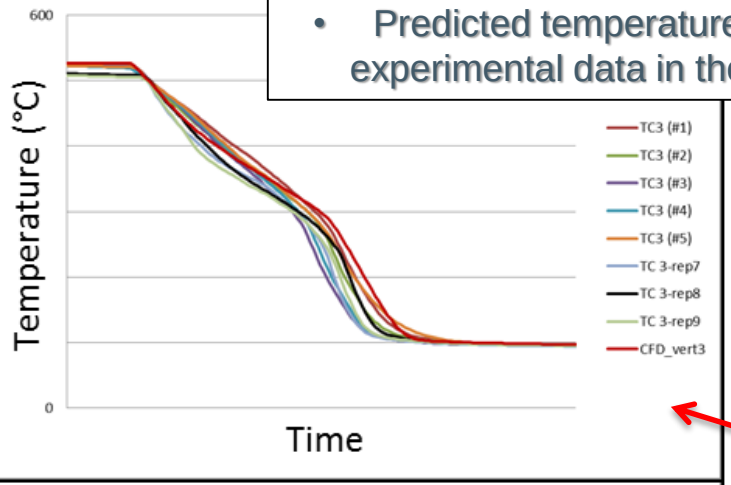
- The vapor pockets, chimney effects and trapped vapor can be clearly demonstrated in simulation
- CFD method proved to have a high potential to support design and process optimization.

RESULTS – EXPERIMENT VS. CFD

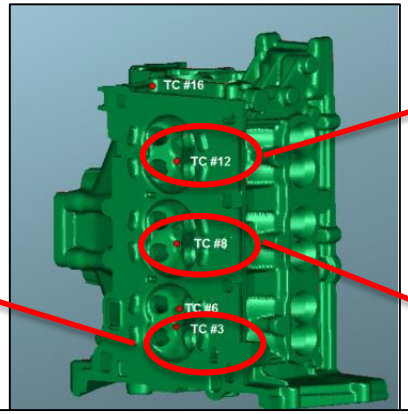
Go Further

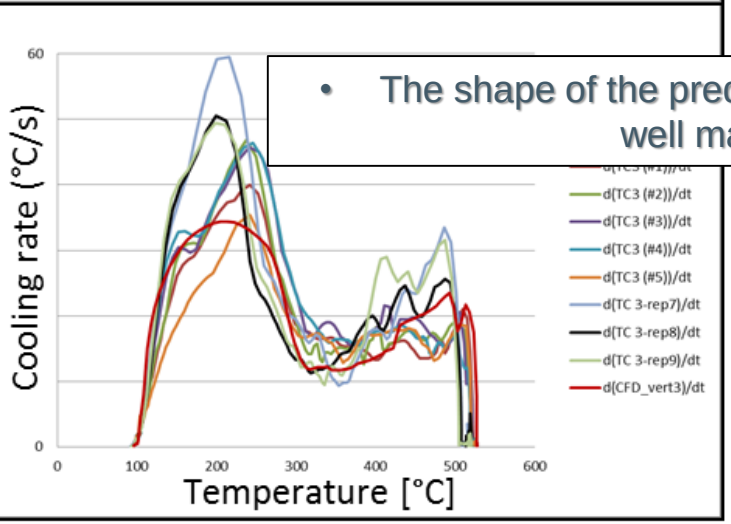
AVL

TC # 3



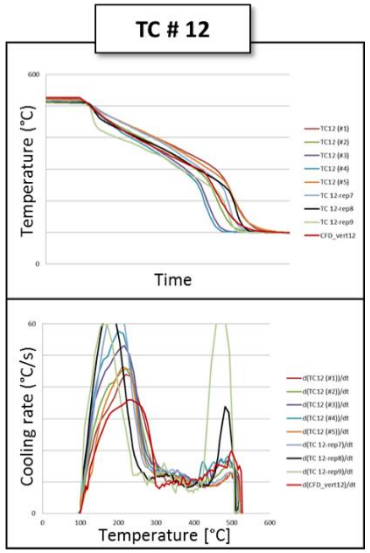
- Predicted temperature history: good agreement with the experimental data in the film and transition boiling regime



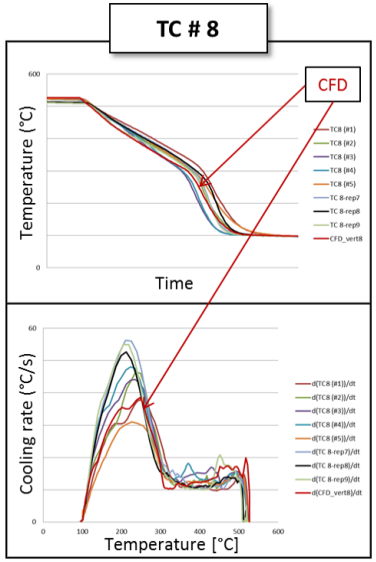


- The shape of the predicted cooling rate graphs are also well matching with the experimental data

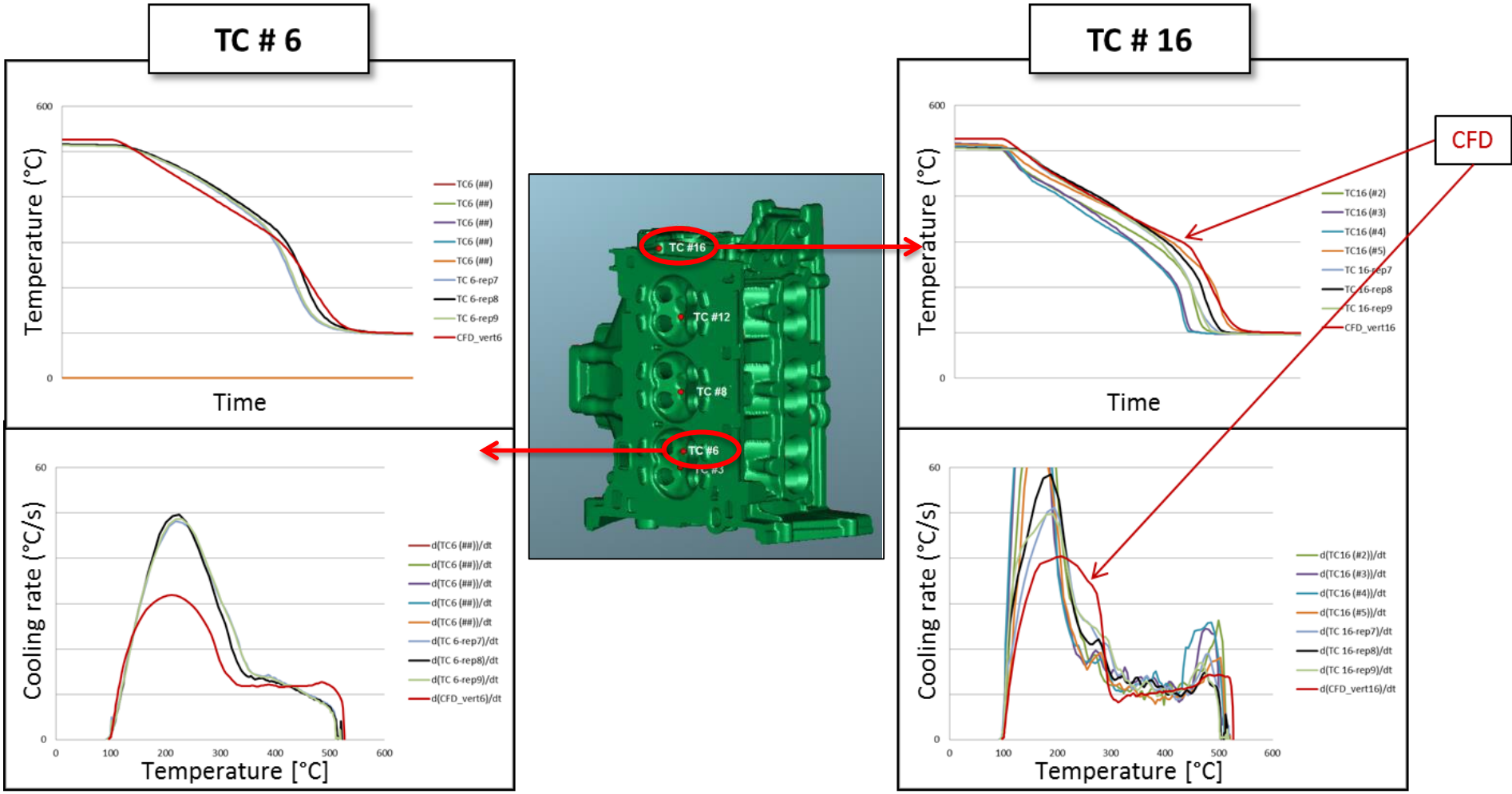
TC # 12



TC # 8



RESULTS – EXPERIMENT VS. CFD

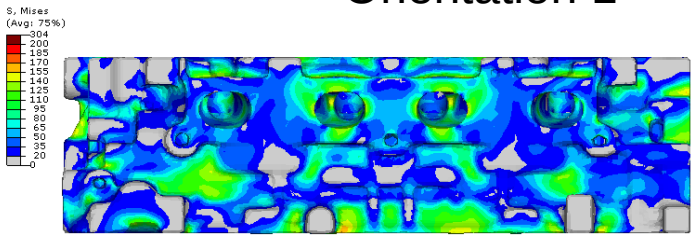


STRESSES AND DEFORMATIONS

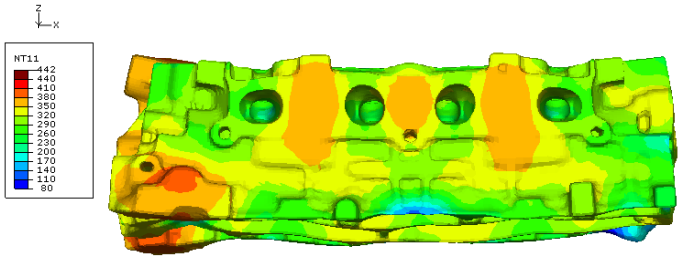
Effect of submerging direction

Orientation 1

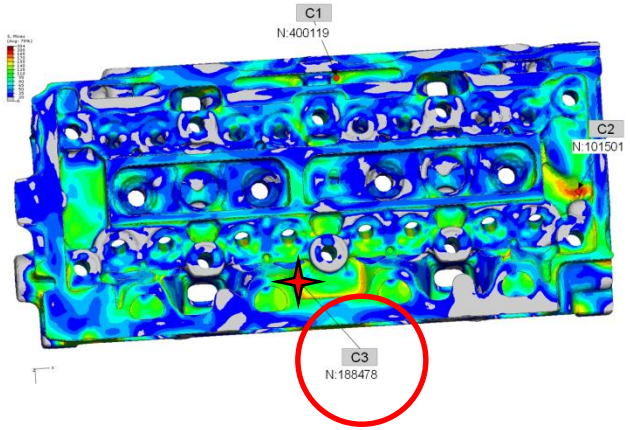
Stress



Temperature and deformation



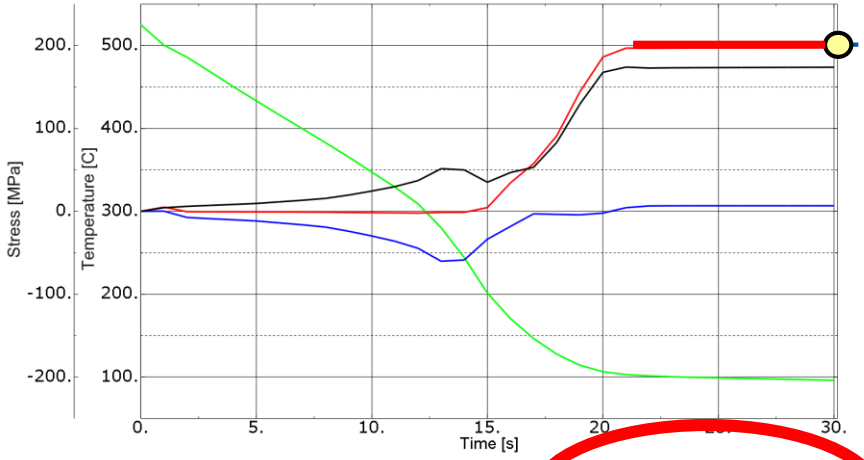
DIRECT QUENCHING
STRESSES AND DEFORMATIONS (FEA)



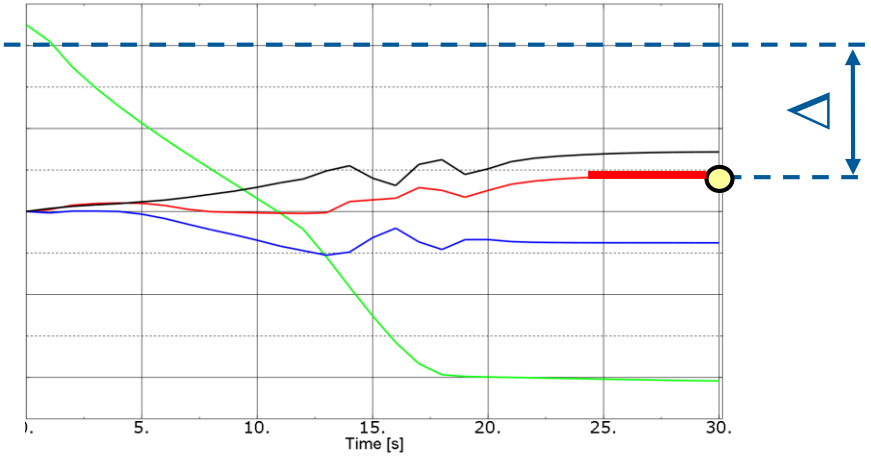
Evaluation point C3

- Tensile stress dominant
- Orientation I > Orientation II

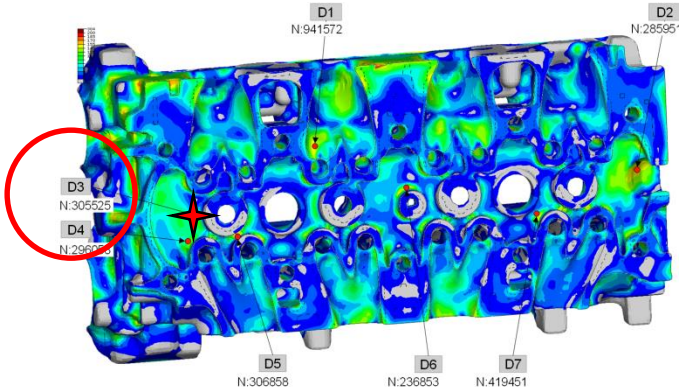
Orientation I



Orientation II



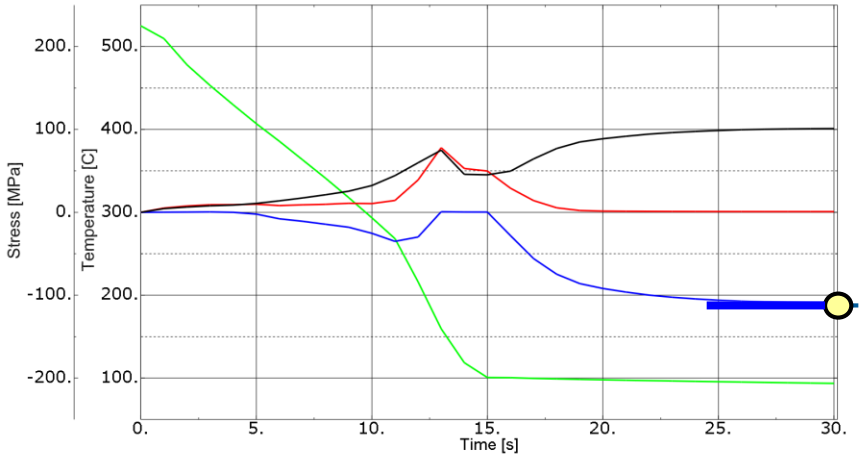
DIRECT QUENCHING
STRESSES AND DEFORMATIONS (FEA)



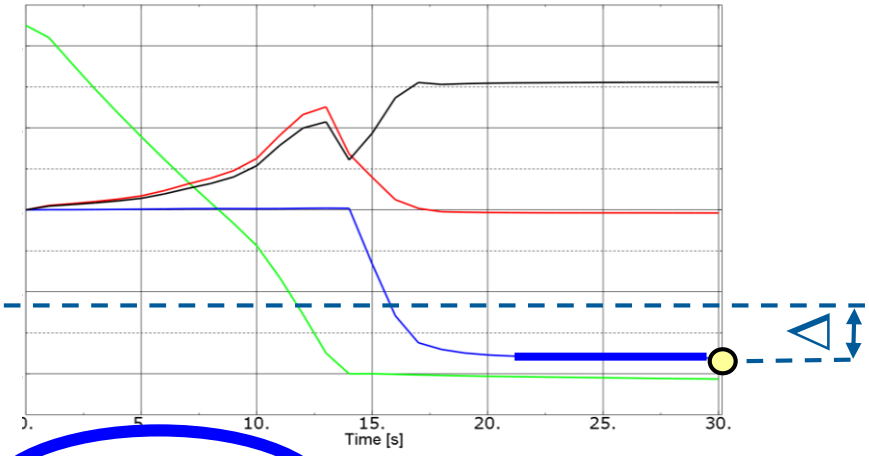
Evaluation point D3

- Compressive stress dominant
- Orientation I < Orientation II

Orientation I



Orientation II



ZUSAMMENFASSUNG

- Die Simulation des Eintauchabschreckens mit AVL FIRE liefert realistische zeitaufgelöste Temperaturfelder, die die nachgeschaltete FE-Simulation der Eigenspannungen ermöglichen.
- Das Modell der Variablen Leidenfrosttemperatur erhöht die Aussagefähigkeit erheblich.
- Das Verfahren wird bereits erfolgreich bei der Beurteilung des Abschreckprozesses von Zylinderköpfen eingesetzt.
- Das vorgestellte Simulationsverfahren bietet ein wertvolles Werkzeug, um simulatorisch ohne Versuche und Messungen Bauteileigenschaften vorhersagen zu können, die durch das Abschrecken verursacht werden.

VIELEN DANK

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