WEBINAR: QUENCHING SIMULATION
A Simulation Approach for the Thermal Treatment of Engine- & Automotive Components

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WHO IS PRESENTING TODAY?

Moderator

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Technical Experts

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MOTIVATION

• Optimization of the thermal treatment of cast parts
• Improvement of quality and durability of components in service

➤ AVL provides a highly developed multi-phase boiling model for Quenching applications
  • Direct, air and spray quenching approaches available
  • Any metal material
  • Oil, water and water-polymer emulsions as quenchants

➤ Goal: Create a quenching simulation methodology that can be used in production
WHY SIMULATE QUENCHING?

Problems to solve:
• Cracks under operational loads
• Deformations during machining / final part

Reasons:
• Material limit exceed due to combination of high operational loads and residual stresses.
• Residual stresses during production.

Consequences:
• Leakages & breakages, engine failure
• Part not within tolerances

AVL’s solution:
• Simulation based residual stresses reduction
• Optimization of heat treatment
HEAT TREATMENT

- Casting or forging
- Cooling of parts
- Reheating to about 500°C
- Quenching
- Reheating to about 250°C
- Aging
- Machining

Temperature

Casting Station → Solution → Quench → Aging → Riser Cut-off

Time

700°C
500°C (5 hour)
250°C (3 hour)
OVERVIEW OVER THE SIMULATION APPROACH

CFD

Preprocessing CFD
(Mesh Generation)

Simulation
Fluid ($T_{\text{fluid}}, v_{\text{fluid}}, v_{\text{vapor}}$) <-> Solid ($T$)

Postprocessing
$T(x,t), \text{grad}(T), \text{min}(T), \text{max}(T)$

FEM (ABAQUS)

Preprocessing FEM
(Mesh Generation)

Mapping of the Results CFD-FEM,
$T_{\text{CFD}}(x,t) \rightarrow T_{\text{FEM}}(x,t)$

Simulation FEM
($u$, PEEQ)

Stress Analysis

500°C
(5 hour)

250°C
(3 hour)

Machining

Time
Simulation of the Quenching Process with AVL FIRE™

- Calculation of the temporal Temperature distribution in the SOLID caused by the flow field around the SOLID and boiling behavior at the SOLID surface
- Input-data for the Finite-Element-Analysis is generated
- Calculation of the Strain / Stress distribution with appropriate constitutive laws in ABAQUS
- Prediction of the residual stresses for the SOLID
- Basis for the evaluation and optimization of process parameters
Simulation of the Quenching Process with AVL FIRE™

- With AVL FIRE™ it is possible to simulate
  - Immersion Quenching
  - Air Quenching
  - Spray cooling
  - Spray quenching

- Alongside Aluminum other alloys as well as Steel are possible!

- Usual Immersion Quenching takes place in Water as cooling medium, but also Oil as well as Water-Polymer-Emulsions are possible!

Under research!
CFD QUENCHING SIMULATION

- The analysis covers heat transfer evaluation over the complete quenching process
- Different boiling regimes require different modeling strategies
BOILING DURING QUENCHING

- Initial solid Temperature
- Transition – Leidenfrost Temperature
- Water Temperature

![Diagram showing temperature changes over time with labels for initial solid temperature, transition-Leidenfrost temperature, water temperature, film boiling, transition boiling, and nucleate boiling.](image)
MODEL APPROACH FOR THE IMMERSION QUENCHING PROCESS

- Experiment

- AVL FIRE™ - Results

- SOLID
- 100 % Gaseous phase (vapor)
- 100 % Liquid phase (water)
TEST GEOMETRY FOR VALIDATION

PURPOSE

- FVV Project “Quench IT” with partner **NEMAK**
- The numerical approach has been validated against measured data
- Sample represents an abstraction of a cylinder head
- Capturing of orientation effects and coolant temperature effects
ORIENTATION EFFECT – CFD RESULTS

- Side view VF
  - TIME: 50.0 sec
  - Volume fraction
  - 0 0.5 1

- Side view TEM
  - Temperature
  - 300 550 800

Uniform cooling

Non-uniform cooling
ORIENTATION EFFECT – CFD RESULTS

- **Horizontal orientation**
ORIENTATION EFFECT – CFD RESULTS

- Vertical orientation

Transferring the temporal and spatial Temperature results from the CFD simulation onto the FE mesh for further FE Analysis!
TRANSIENT SIMULATION RESULTS FROM FE-ANALYSIS

Visco-plastic stress strain analysis
TRANSIENT SIMULATION RESULTS FROM FE-ANALYSIS

Horizontal Dipping Direction

Temperatures

NT11

Tensile Stresses

S_{\text{max. principal}}
(Avg: 75%)

Comp. Stresses

S_{\text{min. principal}}
(Avg: 75%)
TRANSIENT SIMULATION RESULTS FROM FE-ANALYSIS

Horizontal Dipping Direction

Temperature

Scaling factor for deformation: 50

Time $t = 5$ s

Vertical Dipping Direction

Tensile Stresses

Comp. Stresses
TRANSIENT SIMULATION RESULTS FROM FE-ANALYSIS

Horizontal Dipping Direction

Vertical Dipping Direction

Temperatures

Tensile Stresses

Comp. Stresses

Time $t = 15$ s

Scaling factor for deformation: 50
TRANSIENT SIMULATION RESULTS FROM FE-ANALYSIS

Horizontal Dipping Direction

Vertical Dipping Direction

Temperatures

Tensile Stresses

Comp. Stresses

Time \( t = 50 \) s

Scaling factor for deformation: 50
TRANSIENT SIMULATION RESULTS FROM FE-ANALYSIS

Horizontal Dipping Direction

Vertical Dipping Direction

Time $t = 50$ s

Scaling factor for deformation: 50
TRANSIENT SIMULATION RESULTS FROM FE-ANALYSIS

- Comparison with measurement for horizontal orientation

Qualitative good agreement

![Von Mises Stress](image1)

![Von Mises Stress](image2)
MATERIAL MODEL PARAMETER IDENTIFICATION

Development value

- Database with detailed test results from hardening and creep for quenching available.
- Experience with external partners to measure new materials.
- Experts to implement new materials / material models.
INFLUENCING PARAMETERS FOR MATERIAL MODELING WITH FOCUS ON QUENCHING

Strain rate dependency on yield

- Temperature [°C]
- Yield strength [MPa]
- Strain rate

Creep relaxation during aging

- Creep rate [1/s]
- Time [s]
- Stress level 1
- Stress level 2
- Stress level 3
- Stress level 4
- Stress level 5
TIME HISTORY OF HEAT TREATMENT WITH MACHINING STEP AT END

Temperature time history plot for a aluminum cylinder head

$T$

$\sim500^\circ\text{C}$ initial temp

70$^\circ\text{C}$ water 20$^\circ\text{C}$

30s 100s

< not drawn to scale >

Additional manufacturing steps simulated on FE-side

Creep relaxation during aging

Material switch/Machining

180$^\circ\text{C}$

30min 5 hours 6 hours

20$^\circ\text{C}$ room temp

Timing chain up
INFLUENCE OF DIPPING DIRECTION AND MATERIAL ON THE STRESS AND DEFORMATION

Dipping direction TC up
Time = 30 s

Dipping direction TC down
Time = 30 s

Basic material
materail 1
material 2
INFLUENCE OF MACHINING AND MACHINING ORDER ON THE DEFORMATIONS

1. Machining step

2. Machining step

3. Machining step

4. Machining step

5. Machining step
SUMMARY

• AVL offers a unique single-shot quenching simulation approach
• Simulation of any quenched metal parts is possible
• Direct, air and spray quenching can be considered
• Prediction of residual stresses and deformations for design and optimization of the thermal treatment process

The methodology has matured and has been proven!
ANY QUESTIONS?

Please do not hesitate to contact us:

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