

# Simulation in support of the development of innovative processes in the casting industry



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Dr.-Ing. Dipl.-Phys. M. Todte, Flow Science Deutschland

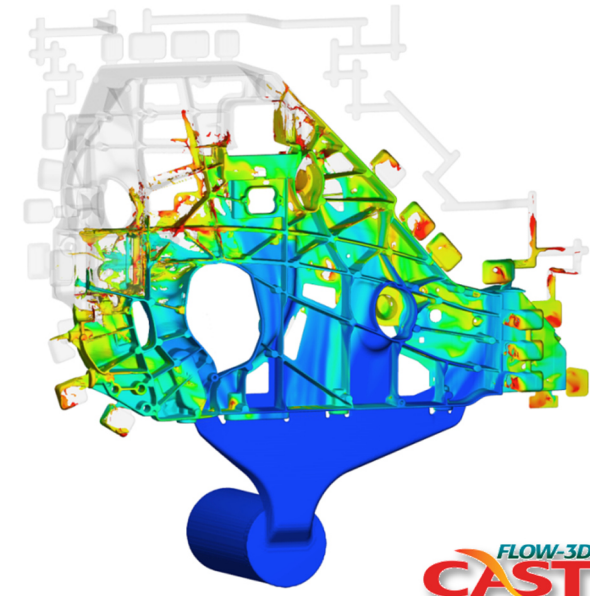
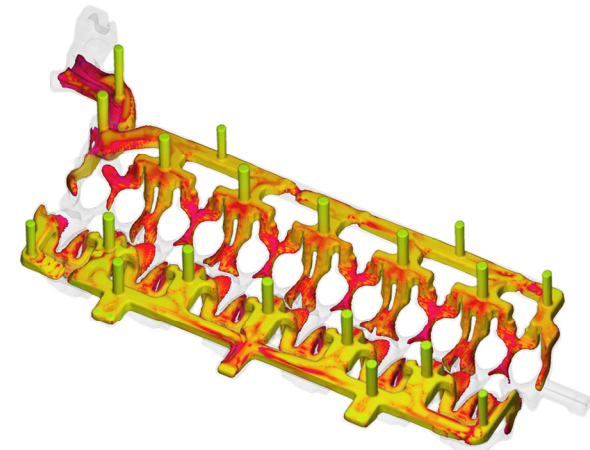
Dr.-Ing. A. Fent, BMW Group, Light Metal Foundry

Dipl.-Ing. H. Lang, BMW Group, Light Metal Foundry

## Outline

*“The presentation illustrates the application of simulation for the development of innovative casting processes at BMW Light Metal Foundry Landshut and other foundries.”*

- Introduction of Flow Science Deutschland GmbH
- High pressure die casting of complex structural parts
- Inserts in high pressure die casting
- Innovative ingate system for gravity casting
- Core blowing and core drying for sand cores with inorganic binder systems
- Application of salt cores in high pressure die casting
- Summary



# Introduction of Flow Science Deutschland



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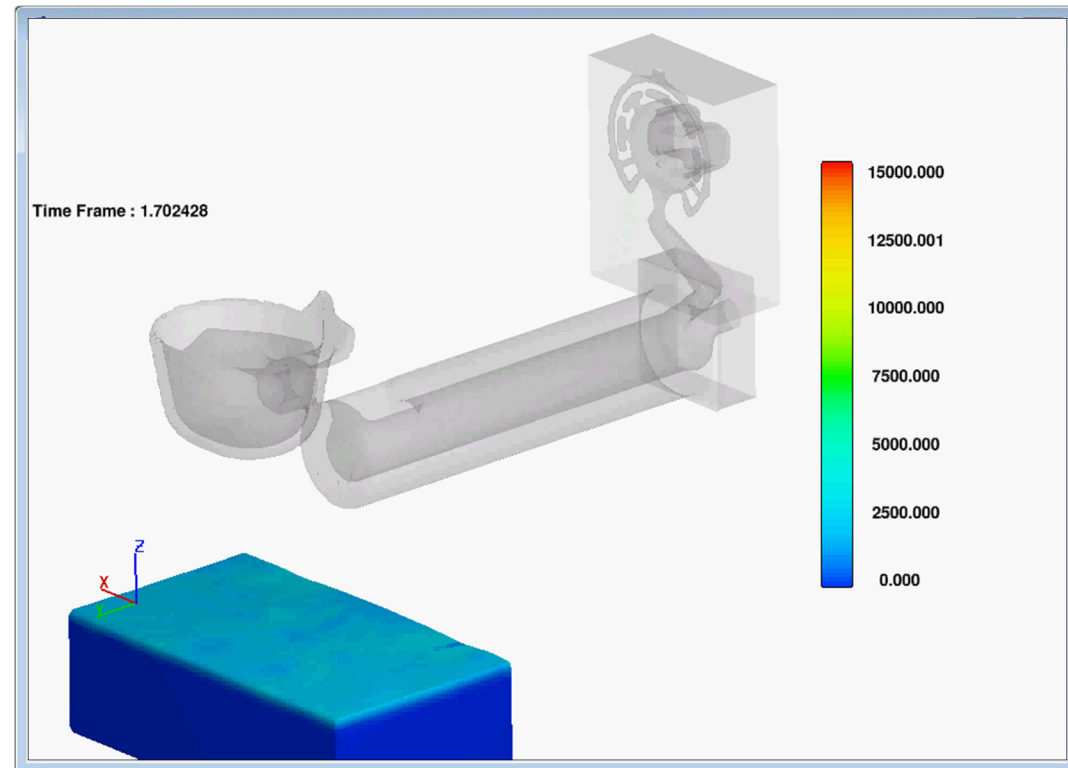
**Dr.-Ing. Dipl.-Phys. M. Todte, Flow Science Deutschland**

**Dr.-Ing. A. Fent, BMW Group, Light Metal Foundry**

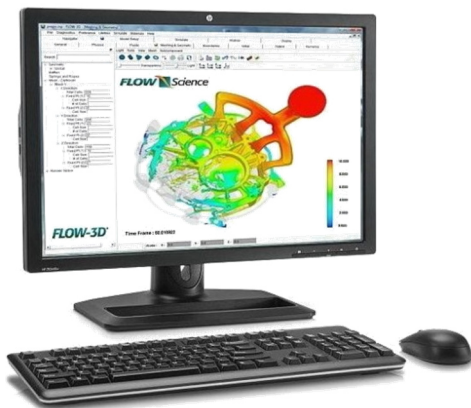
**Dipl.-Ing. H. Lang, BMW Group, Light Metal Foundry**

## Introduction of Flow Science Deutschland GmbH

- Engineering consultants with focus on casting simulations
- Sales and support of **FLOW-3D** in
  - ⇒ Germany
  - ⇒ Austria
  - ⇒ Switzerland
  - ⇒ Norway
  - ⇒ Denmark
  - ⇒ Finland
  - ⇒ Sweden
- Basic and advanced customer specific training
- Customization of **FLOW-3D** (*additional functionality*)
- Consultancy services
- More than 100 customers from industry, research and academia (e.g. all German automotive OEMs, major foundries and casting research institutes)



# High pressure die casting of complex structural parts



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## High pressure die casting of complex structural parts

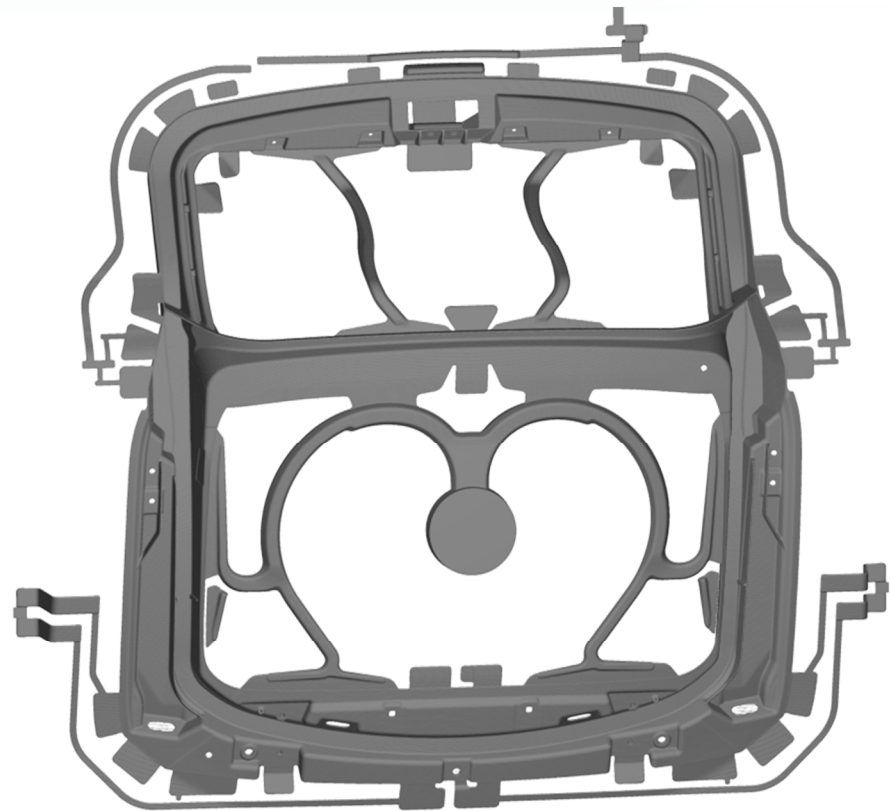
*“High pressure die casting (HPDC) process is a well known near-net-shape manufacturing technology that can provide geometrically complicated shaped products of aluminum alloys and other low melting point alloys at a low cost.”*

### **Advantages of the process:**

- ⇒ Dimensional accuracy
- ⇒ Low machining allowances
- ⇒ Thin walls and complex shapes possible
- ⇒ Good mechanical properties  
*(very high solidification rate)*
- ⇒ High strength
- ⇒ Good surface quality
- ⇒ High productivity due to high level of automation

### **Challenge:**

- ⇒ High pressure die casting process for complex structural parts



## High pressure die casting of complex structural parts

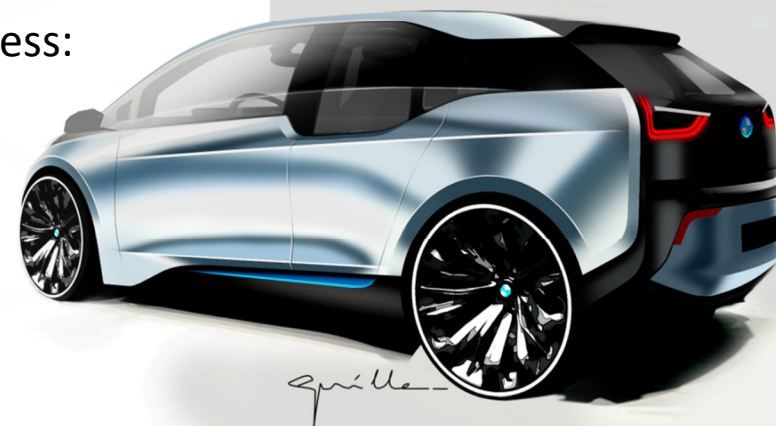
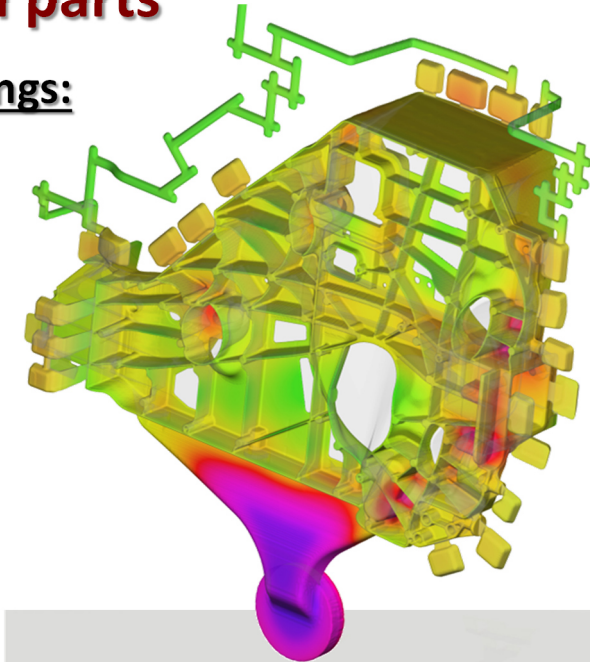
### Requirements for structural high integrity aluminum die castings:

- ⇒ Weight reduction / part integration
- ⇒ High strength / crash performance
- ⇒ Corrosion resistance
- ⇒ Weldable / heat treatable
- ⇒ Surface quality
- ⇒ Distortion free with tight tolerances

“Complex structural parts are very demanding with regard to the HPDC process and the tooling concept.”

- **Detailed simulation analysis** of complete process:

- ⇒ Thermal die cycling process
- ⇒ Filling process  
*(Filling of chamber, modelling of piston movement applying  $PQ^2$  diagrams)*
- ⇒ Solidification and cooling
- ⇒ Calculation of residual stresses

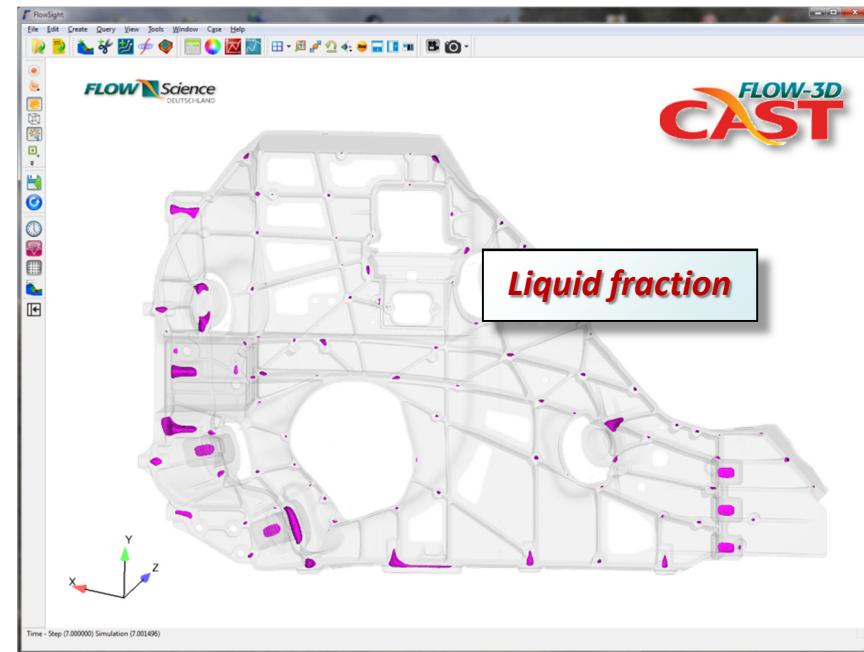


## High pressure die casting of complex structural parts

- Numerical simulation should start in an early stage of product development
  - ⇒ Design requirements due to function, production process and material
  - ⇒ Reduction of development time and costs  
*(due to reduction of number of experimental loops)*
  - ⇒ Prevention of casting defects
  - ⇒ Enhancement of casting quality

### Product development:

- ⇒ Solidification simulation of casting part (incl. stress calculation) without gating and venting system  
(hot spots, stresses, distortion, ...)
- ⇒ Positioning of ingates and vents
- ⇒ Reduction of material accumulation
- ⇒ Avoidance of critical stresses and inadmissible distortions
- ⇒ Design optimization

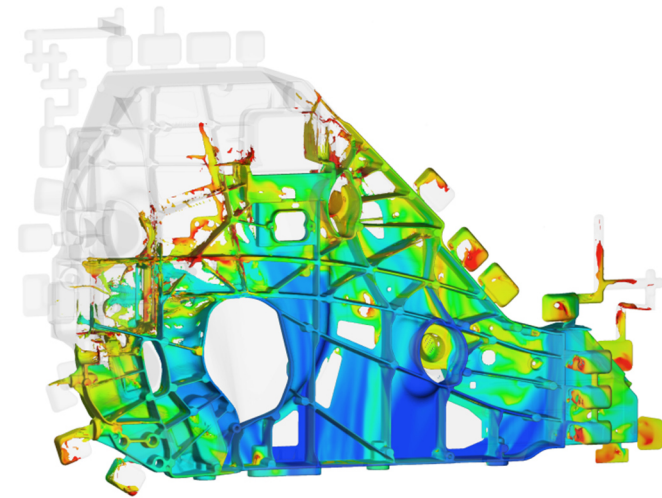




## High pressure die casting of complex structural parts

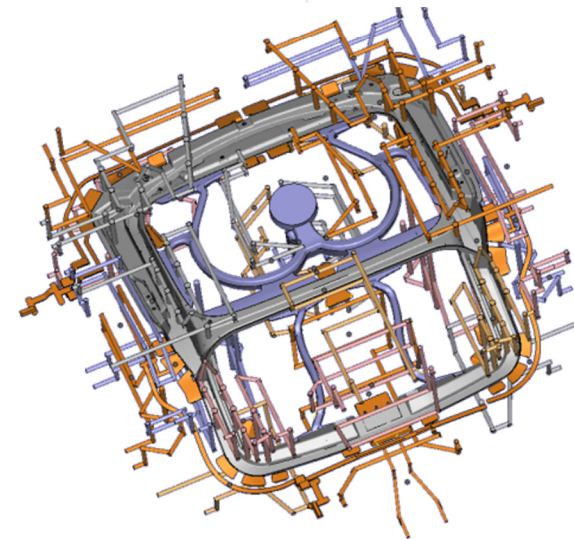
### Casting design:

- ⇒ Filling simulation with “mass sources” as ingates
- ⇒ Definition of ingate and venting positions
- ⇒ Check of castability  
(Cold run, casting defects, ...)
- ⇒ Design optimization
  
- ⇒ Filling simulation with designed gating and venting system
- ⇒ Optimization of casting system



### Tooling design:

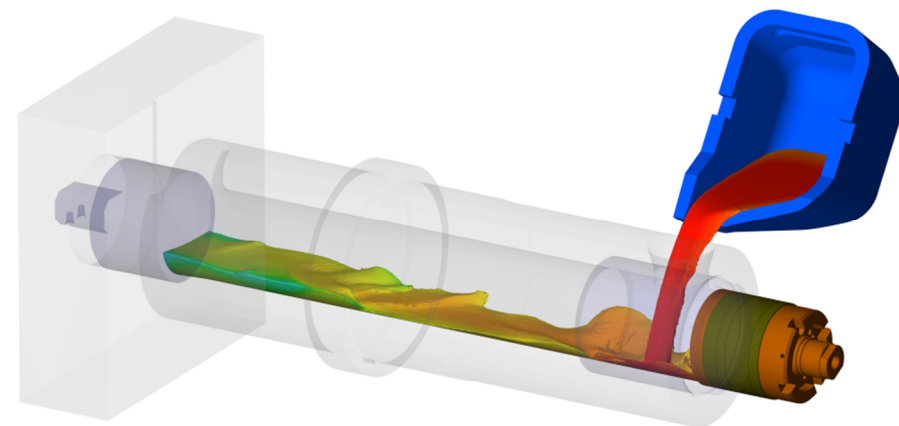
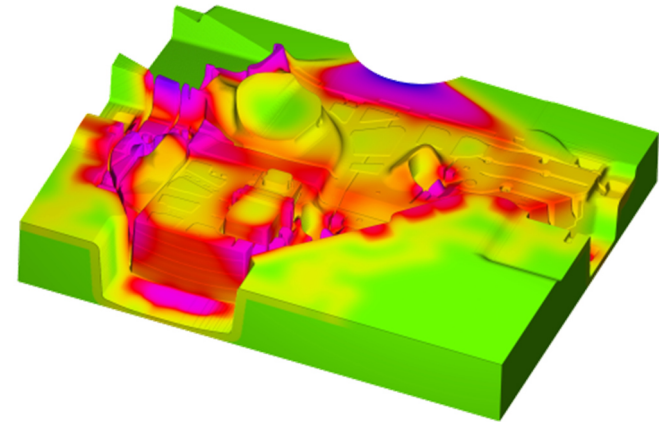
- ⇒ Solidification simulation
- ⇒ Analysis of heat balance
- ⇒ Dimension and position of cooling system  
(special cooling equipment)
- ⇒ Support of tooling design

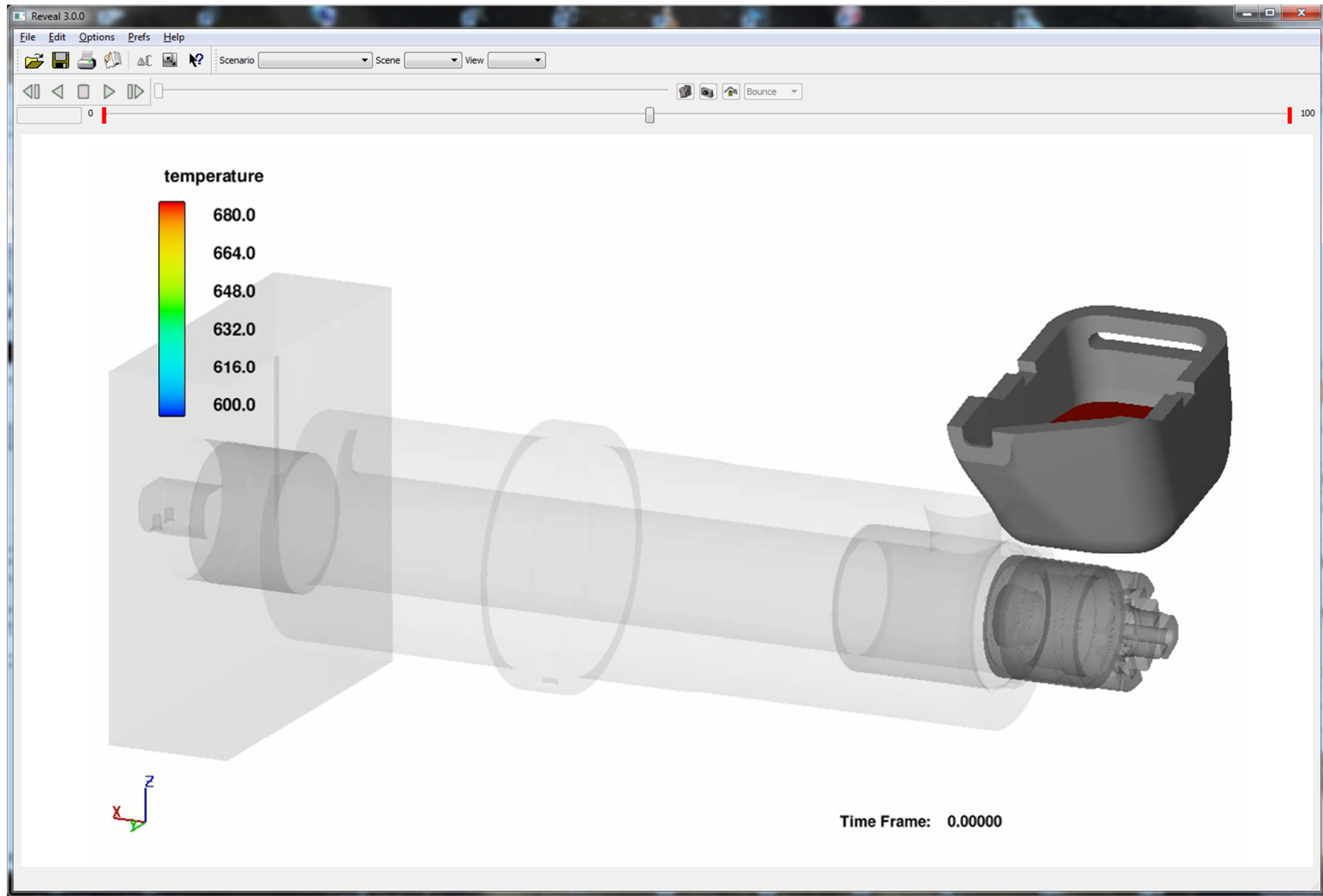


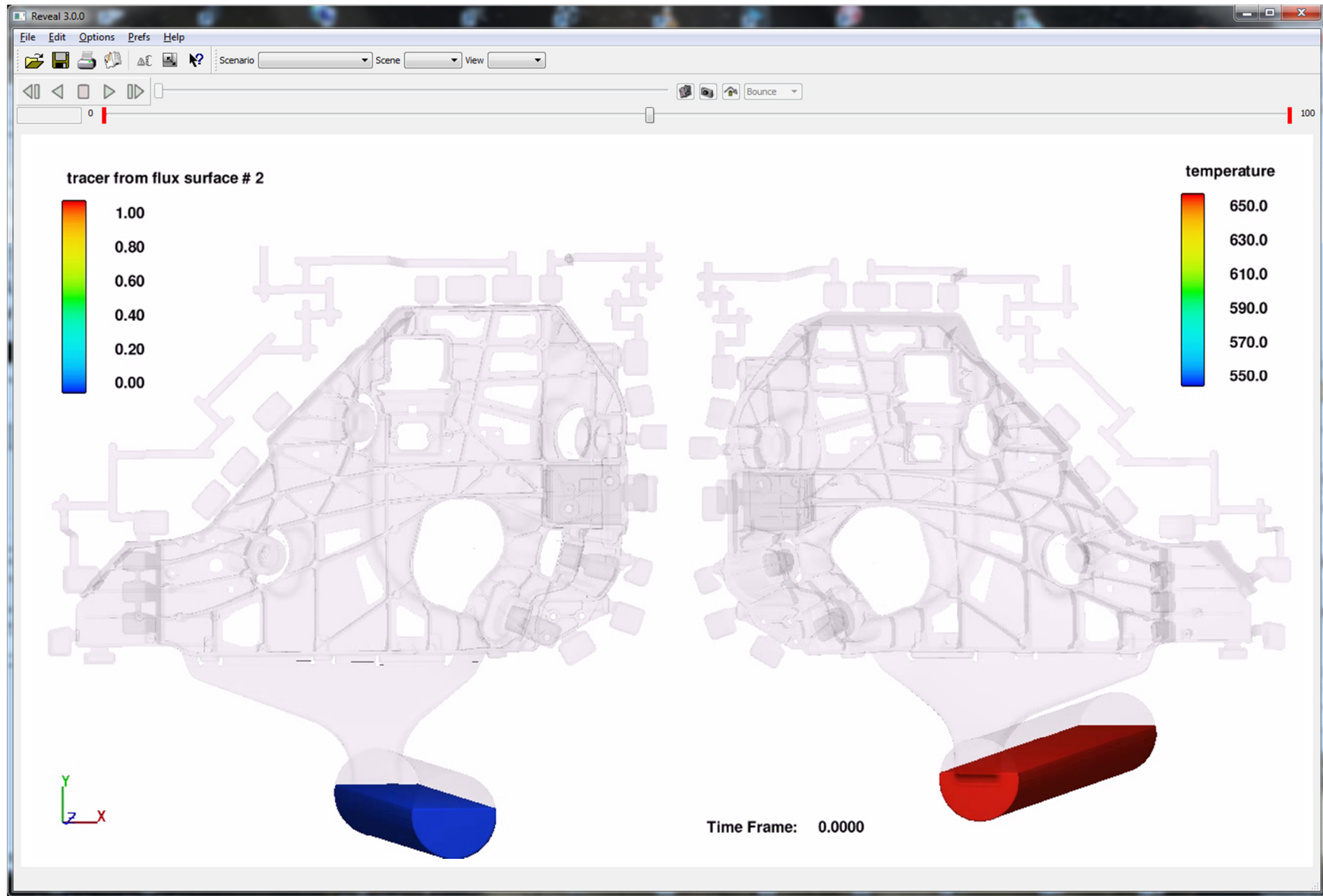
## High pressure die casting of complex structural parts

### Casting Process:

- ⇒ Thermal die cycling simulation  
(with stress simulation)
  - ⇒ Analysis of heat balance
  - ⇒ Definition of process parameters  
(times, temperatures, ...)
  - ⇒ Optimization of cooling system
  - ⇒ Improvement of tooling design
- 
- ⇒ Simulation of complete process with filling of the shot chamber and modelling of piston movement applying  $PQ^2$  diagrams, solidification and cooling
  - ⇒ Definition of process parameters
  - ⇒ Final optimization loop for gating and venting system
  - ⇒ Final changes to tooling design



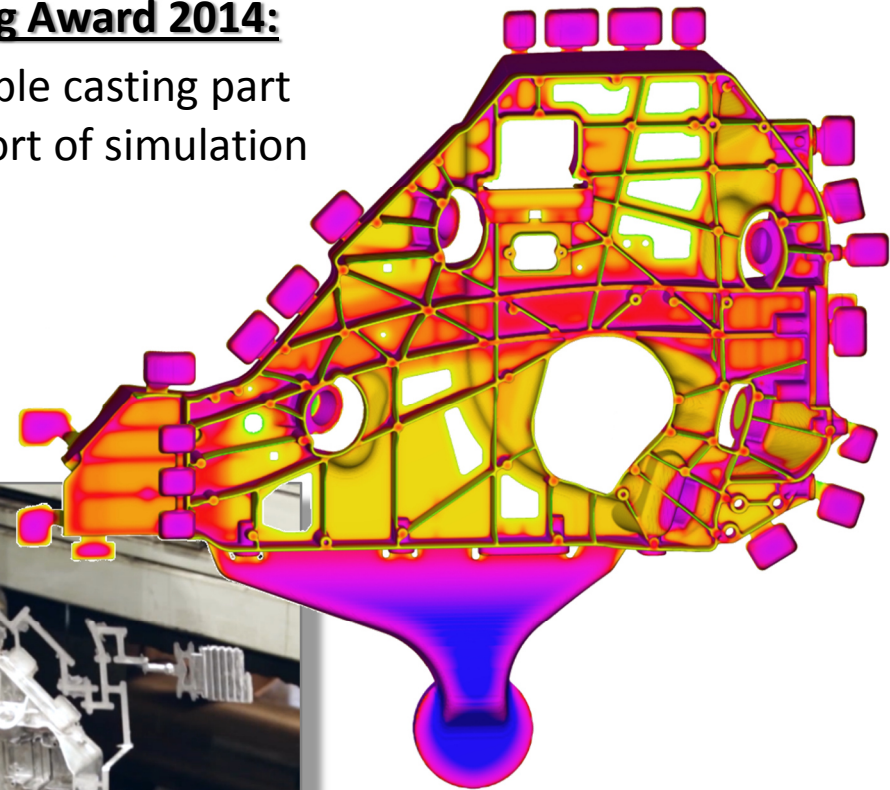
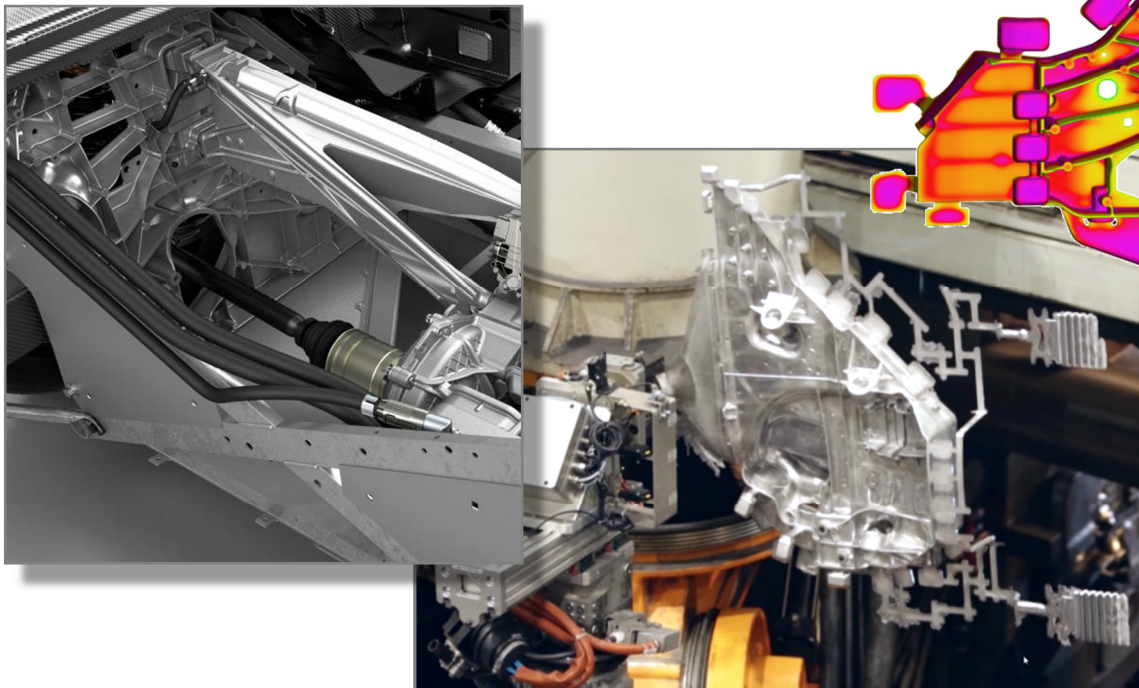




## High pressure die casting of complex structural parts

### Winner of International Aluminium Die-Casting Award 2014:

- ⇒ Trial & Error does not result in a producible casting part
- ⇒ Development is only possible with support of simulation
- ⇒ Castability, ingate- and venting system
- ⇒ Tooling design, process parameters, ...



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# Inserts in high pressure die casting



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**Dr.-Ing. Dipl.-Phys. M. Todte, Flow Science Deutschland**

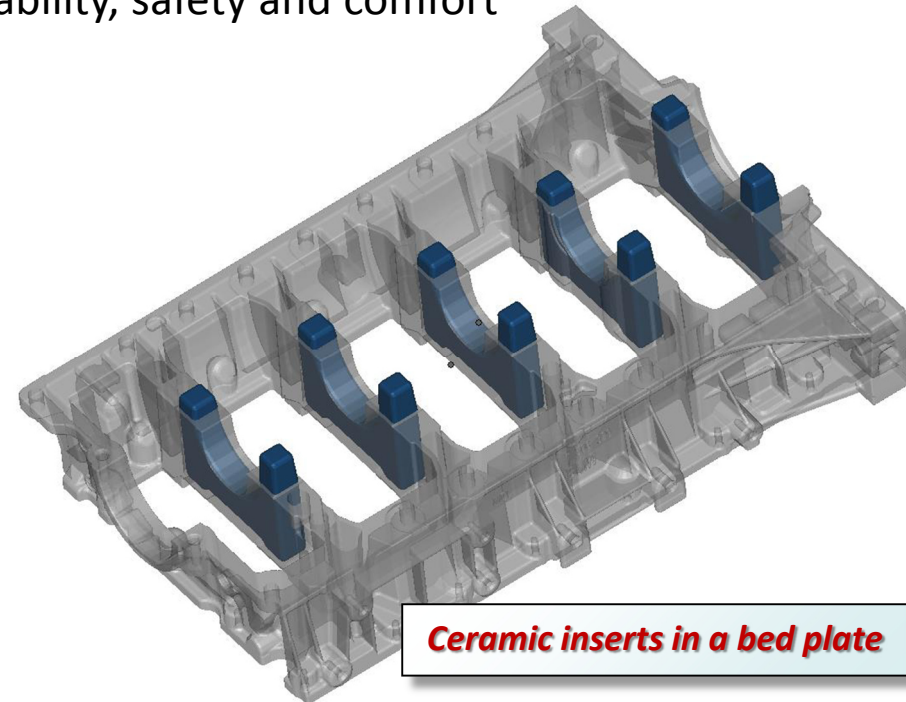
**Dr.-Ing. A. Fent, BMW Group, Light Metal Foundry**

**Dipl.-Ing. H. Lang, BMW Group, Light Metal Foundry**

## Inserts in high pressure die casting

*“HPDC technology has developed rapidly in recent years due to high automation, new die materials, sensor technology and advanced control of foundry systems.”*

- Intelligent lightweight construction
  - ⇒ Problem:
    - Save weight without compromising stability, safety and comfort
  - ⇒ Solution:
    - particularly light high-tech materials
    - modern design of existing parts
  - ⇒ The benefit:
    - more stability, safety and comfort
    - less weight and fuel consumption
- Ceramic inserts in HPDC
  - ⇒ Weight reduction
  - ⇒ Increased strength
  - ⇒ Improved performance characteristics



**Ceramic inserts in a bed plate**

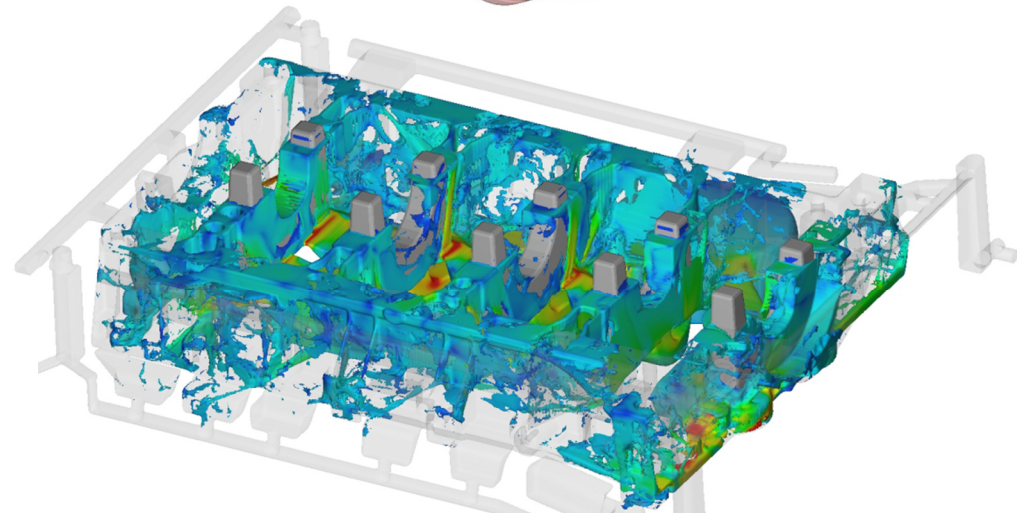
## Inserts in high pressure die casting

### Examples:

- ⇒ Ceramic inserts in a brake disc
- ⇒ Ceramic inserts in a bed plate
- Simulation helps to get answers
  - ⇒ Analysis of the influence on the filling pattern
    - temperatures, casting defects, ...
  - ⇒ Infiltration of the inserts
    - filling direction
  - ⇒ Forces on inserts
    - pressure and shear forces
  - ⇒ Influence on solidification
    - solidification time
    - casting defects (shrink holes, ...)
  - ⇒ Thermally induced stresses
- Simulation helps to optimize
  - ⇒ Process, tooling and design of inserts

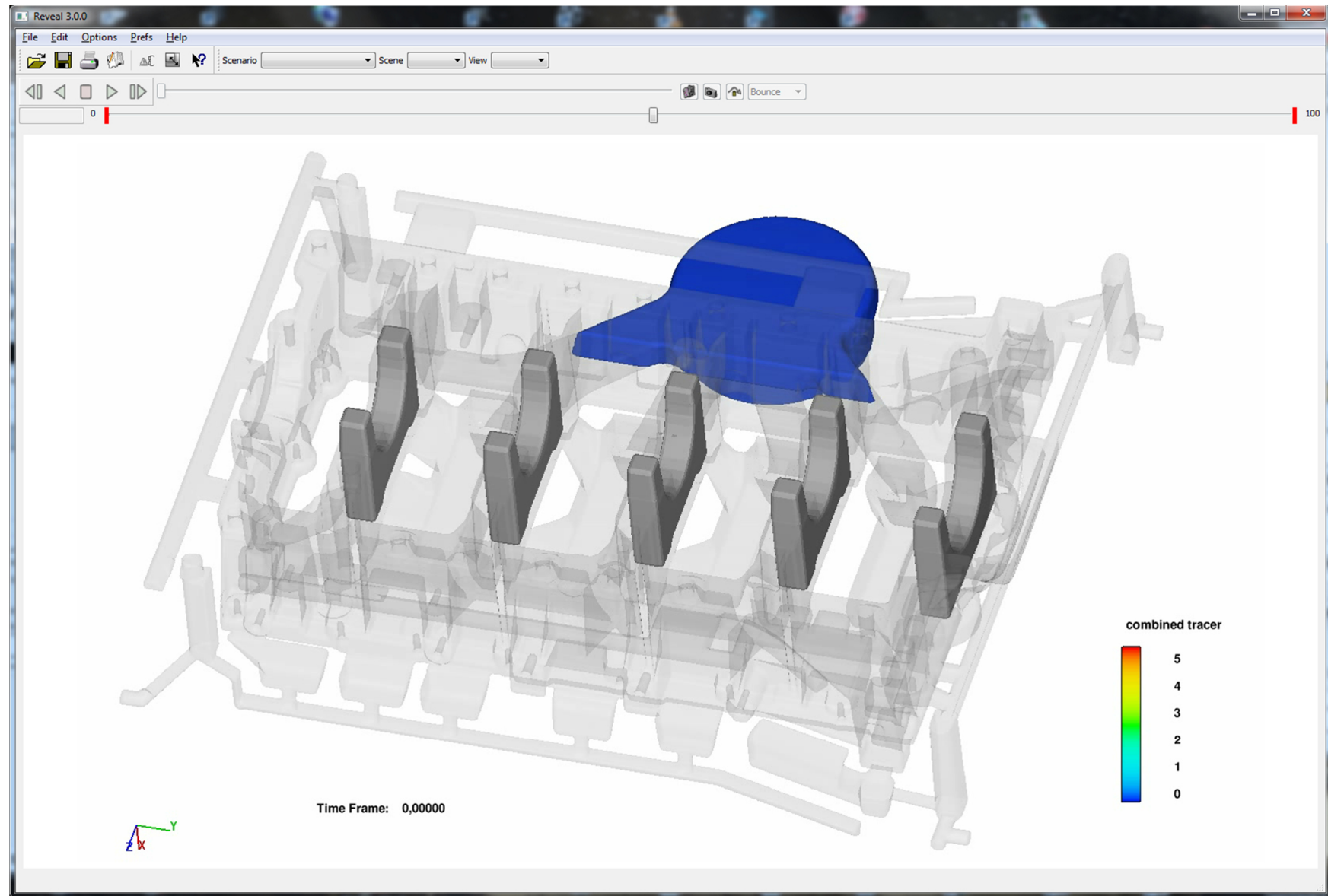


*Ceramic inserts for a brake disc  
(placed in the mould)*



*Ceramic inserts in a bed plate*





# Innovative ingate system for gravity casting



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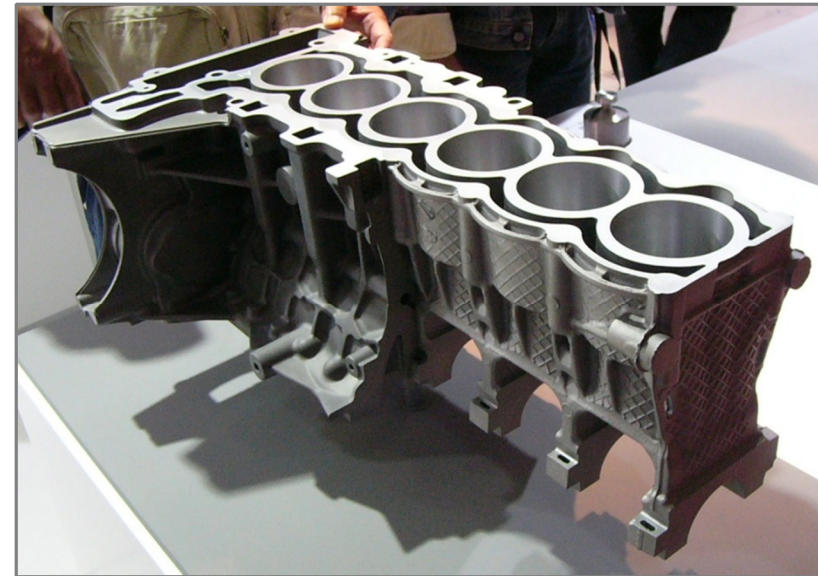
**Dr.-Ing. Dipl.-Phys. M. Todte, Flow Science Deutschland**

**Dr.-Ing. A. Fent, BMW Group, Light Metal Foundry**

**Dipl.-Ing. H. Lang, BMW Group, Light Metal Foundry**

## Innovative ingate system for gravity casting

- BMW light metal foundry Landshut is capable of running five different casting processes for series production:
  - ⇒ Sand casting
  - ⇒ Low pressure die casting
  - ⇒ Gravity die casting
  - ⇒ High pressure die casting
  - ⇒ Lost-foam casting
- Selection of most suitable casting process for each case depends on:
  - ⇒ Engine concept
  - ⇒ Production volume
  - ⇒ Technological requirements
- Casting specialists try to improve standard gravity die casting process:
  - ⇒ Reduction of casting defects
  - ⇒ Higher casting quality
  - ⇒ Better mechanical properties



## Innovative ingate system for gravity casting

### Top pouring system:

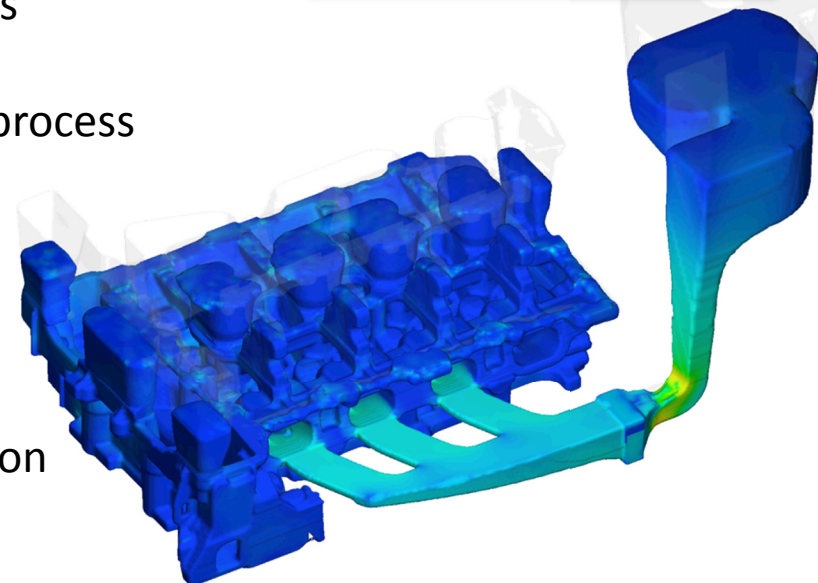
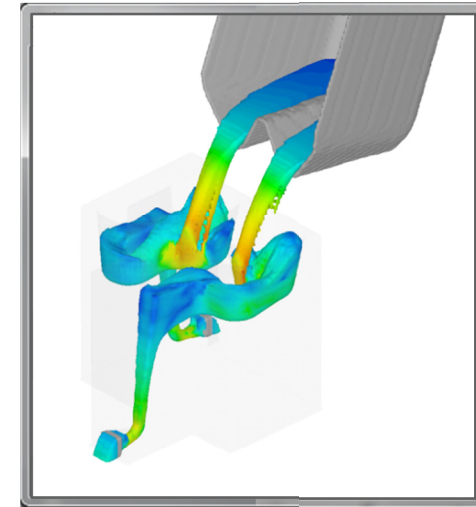
- ⇒ Risers filled with hot material (good feeding)
- ⇒ Bottom plate can be cooled whole filling process
- ⇒ Entrained air due to higher velocity and turbulence
- ⇒ High risk for oxide inclusions

### Bottom pouring system:

- ⇒ Minimal turbulences inside ingate system
- ⇒ No risk for entrained air and included oxides
- ⇒ Risers filled with colder material
- ⇒ Bottom plate can't be cooled during filling process

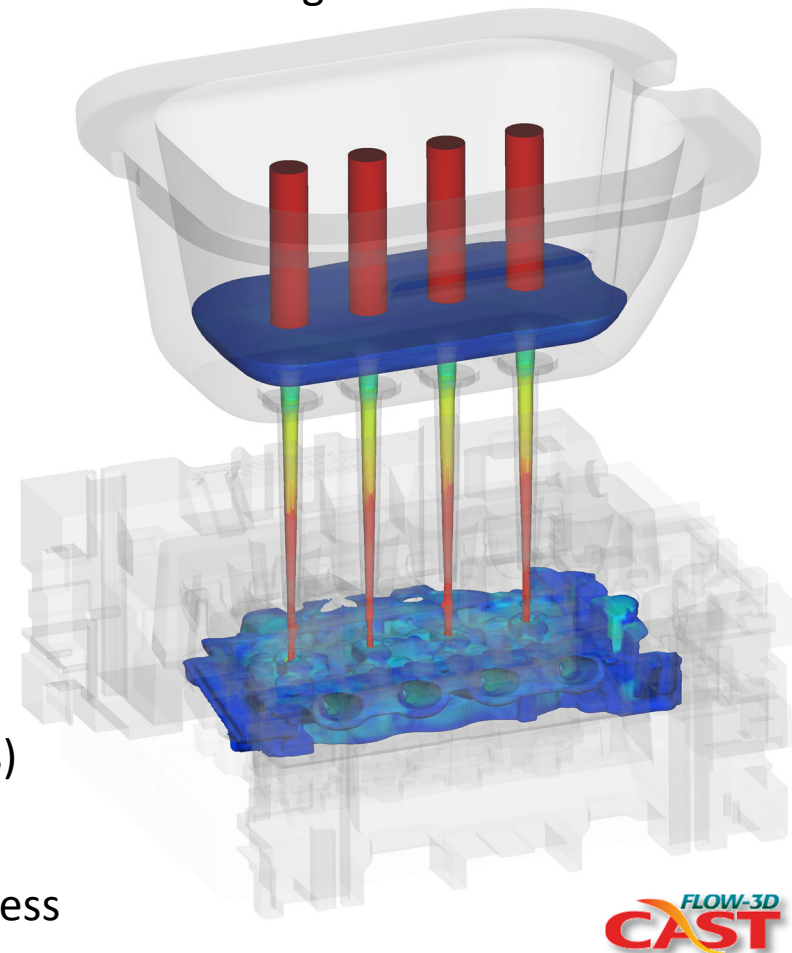
### Tilt casting (Rotacast®):

- ⇒ Low turbulences during filling
- ⇒ Good temperature profile for solidification
- ⇒ Low risk for oxide inclusions
- ⇒ Risk for entrapped air bubbles during rotation
- ⇒ Higher costs for tool and machine



## Innovative ingate system for gravity casting

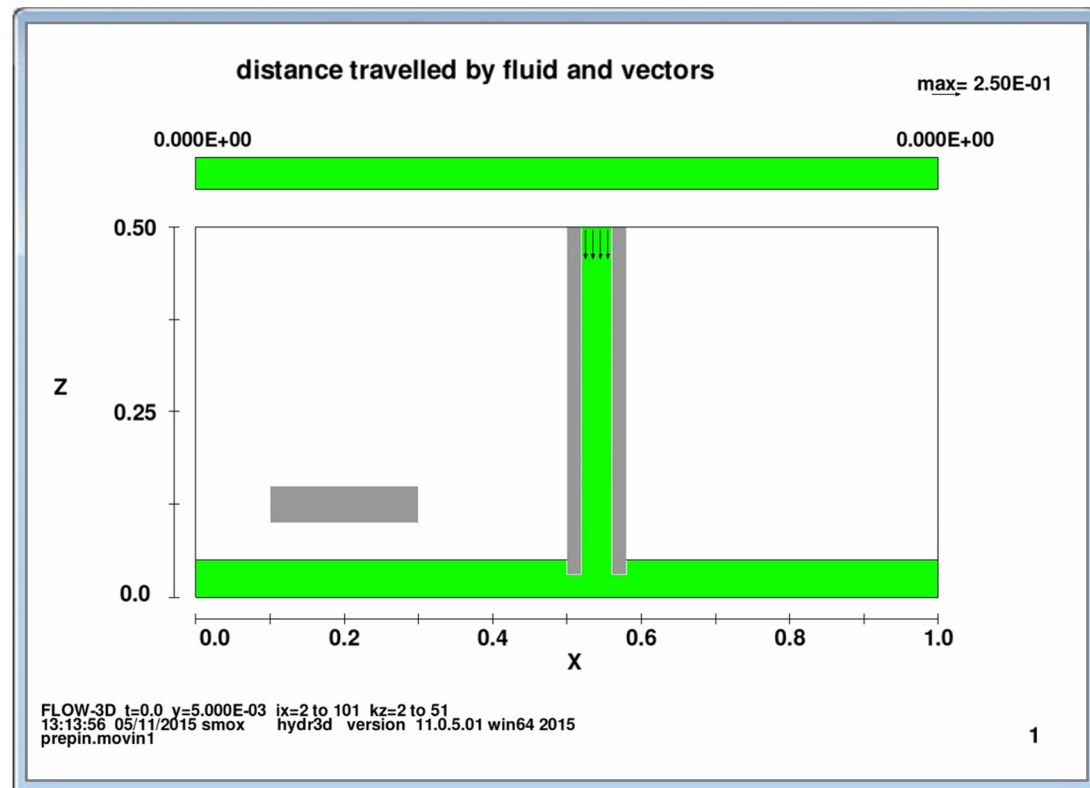
- Newly developed **Injector Casting Process** of BMW combines advantages of traditional processes and avoids their disadvantages by applying a moving ingate system:
  - ⇒ Minimal turbulence during filling
  - ⇒ No pouring basin necessary (reduced turbulence during filling)
  - ⇒ No runner system necessary (reduced development efforts)
  - ⇒ Low risk for entrained air
  - ⇒ Oxides remain inside ladle
  - ⇒ Low risk for any oxide inclusions
  - ⇒ Risers filled with hot material (good feeding)
  - ⇒ Bottom plate can be cooled during entire filling process (better mechanical properties)
  - ⇒ Not applicable for every casting part
  - ⇒ Some turbulence at beginning of filling process

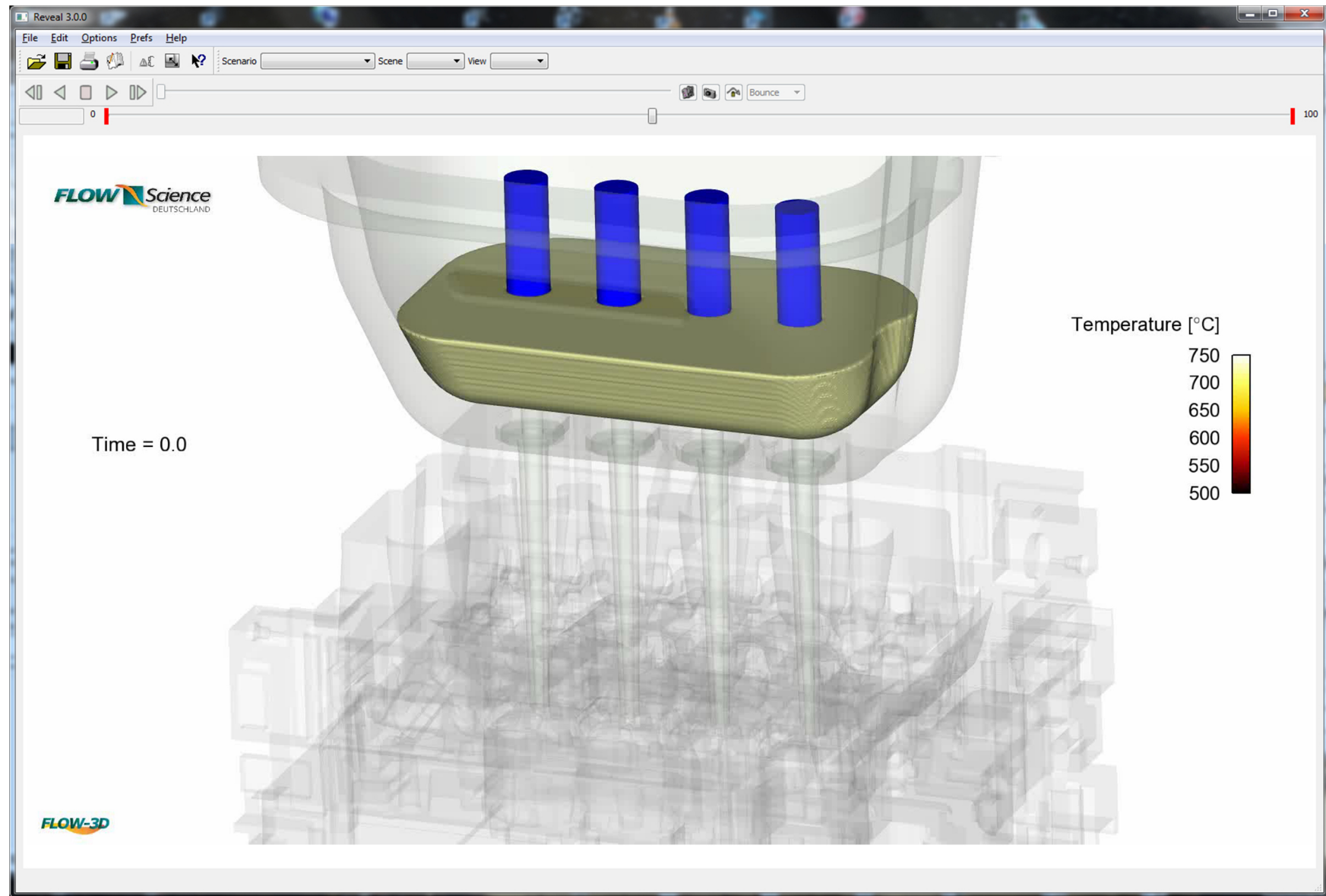


FLOW-3D  
CAST

## Innovative ingate system for gravity casting

- Simulation with **FLOW-3D** was used to develop and study new filling process:
  - ⇒ Filling behavior (turbulence, velocities, ...)
  - ⇒ Fluid flow in injector
  - ⇒ Temperature distribution (ladle, cavity, injector, ...)
  - ⇒ Possible casting defects (oxides, air bubbles, ...)
  - ⇒ Process parameters (temperatures, times, ...)
  - ⇒ Moving regime of stopper
  - ⇒ Moving regime of ladle
  - ⇒ Design of stoppers and ladle
  - ⇒ Design of injectors
  - ⇒ Experimental effort was greatly reduced





# Core blowing and core drying for sand cores with inorganic binder systems



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Dr.-Ing. A. Fent, BMW Group, Light Metal Foundry

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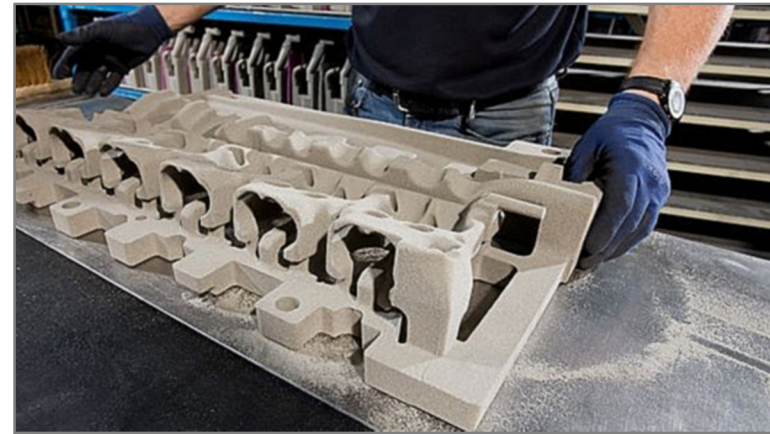


## Core blowing and core drying for sand cores

- The light metal foundry at the BMW plant introduced in 2010 a new sand core production method for gravity die-casting:
  - ⇒ Conventional organic binders were replaced by highly **eco-friendly inorganic binders**

### Environmental aspect:

- ⇒ Virtually no pollutant emissions  
*(Emissions of combustion residues reduced by 98 percent)*
- ⇒ Substantially improved working conditions

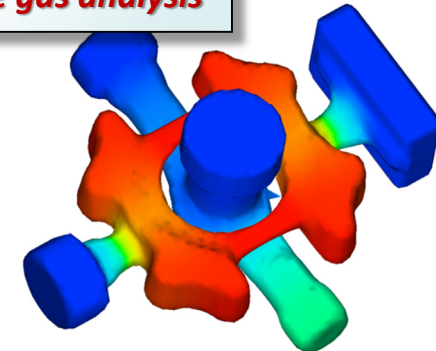


### Economic and ergonomic benefits:

- ⇒ Improved casting quality due to reduced core gas production
- ⇒ Enhanced strength of the resulting light-alloy components (due to faster solidification)

“BMW’s Landshut plant is the world’s first foundry with complete emission-free sand core production.”

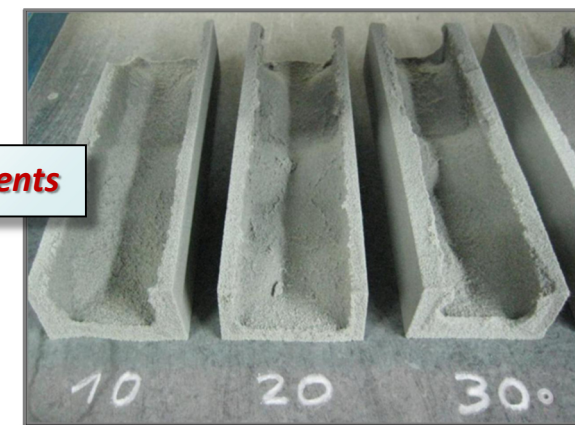
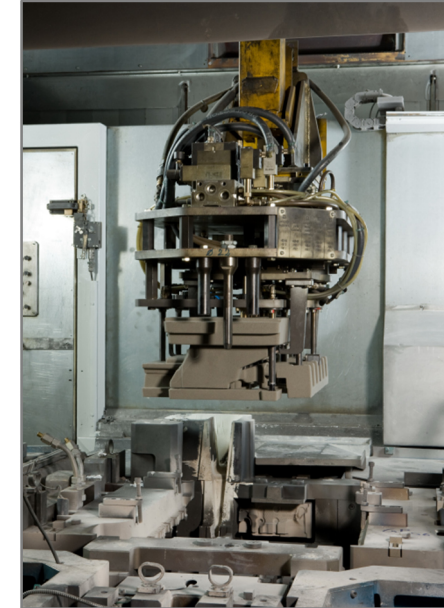
Core gas analysis



## Core blowing and core drying for sand cores

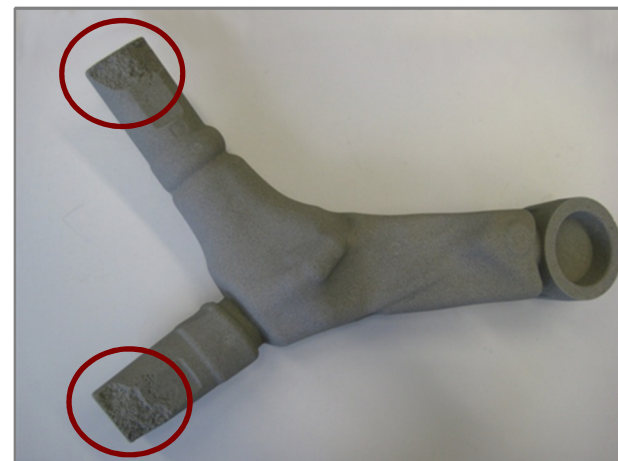
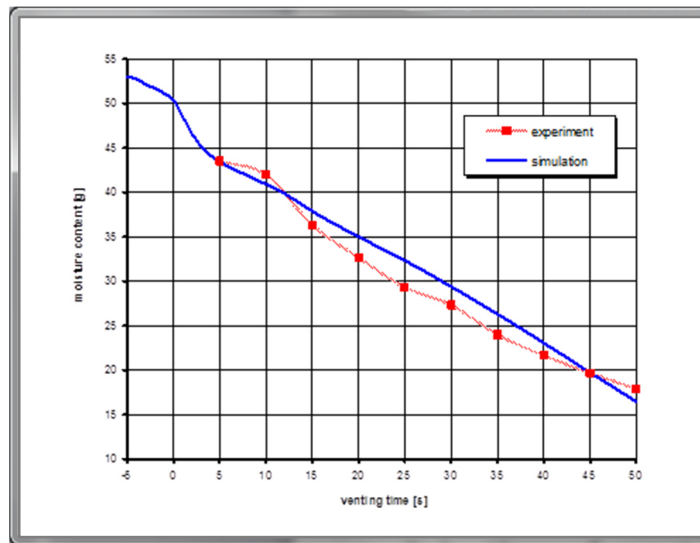
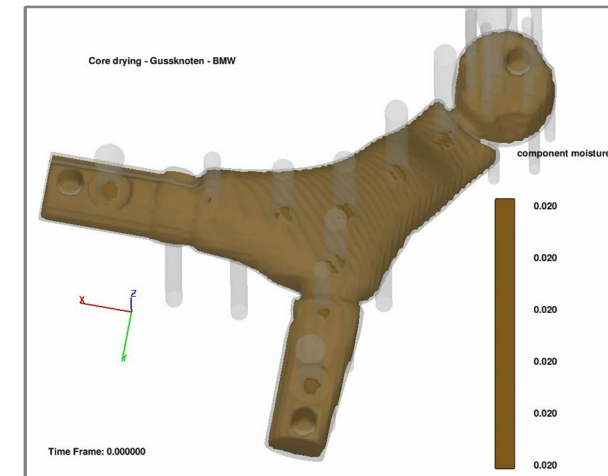
### Process steps:

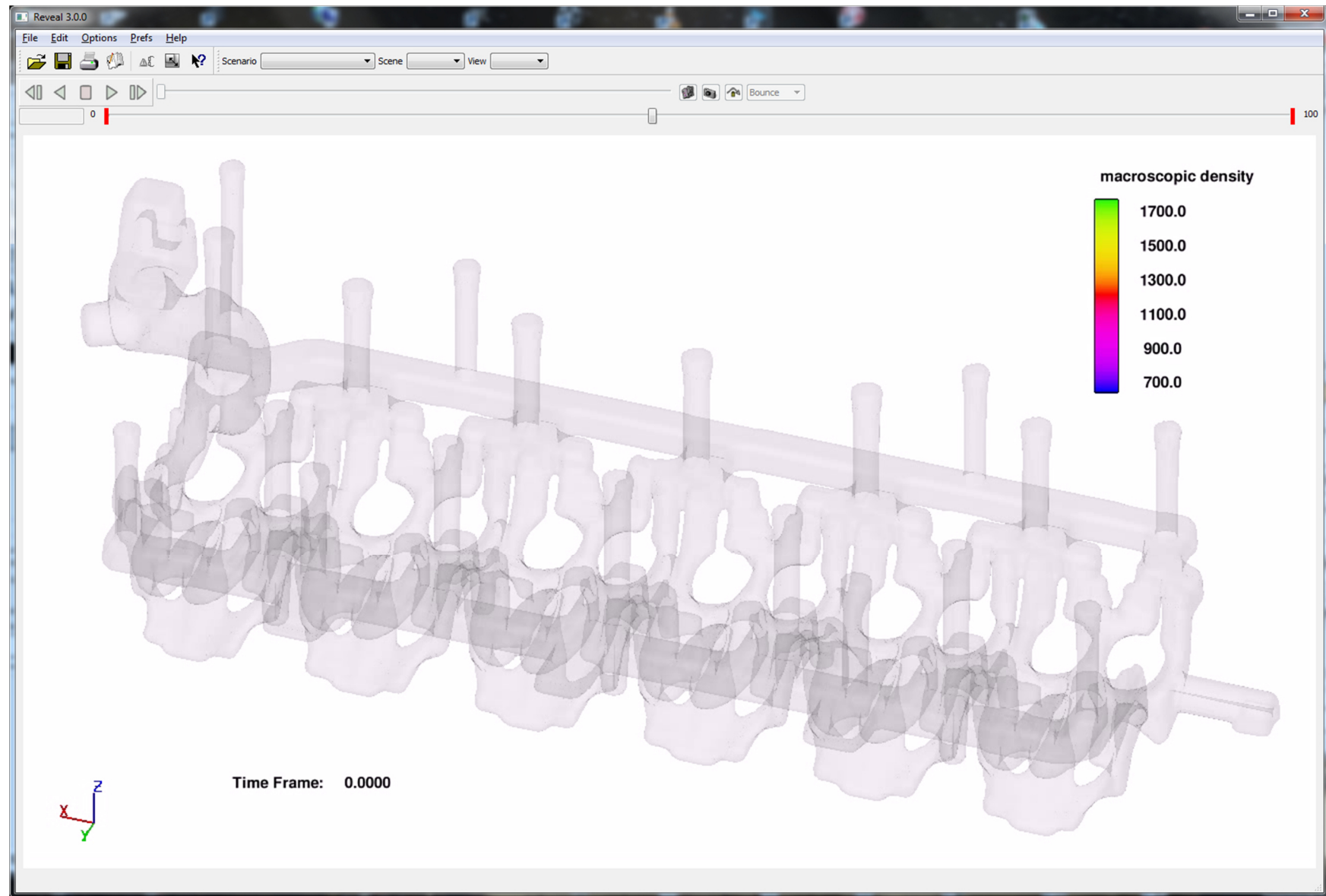
- ⇒ Molding sand (with binder) is shot into a heated mold  
*(using a core shooting machine)*
  - ⇒ The core is dried with hot pressurized air  
*(core dries and hardens first in a thin layer adjacent to wall)*
  - ⇒ Water inside core is vaporized by the hot air  
*(water can condense in colder areas)*
  - ⇒ Air-vapor mixture leaves the core through venting nozzles
  - ⇒ Removal of the water results in the hardening of the core  
*(chemical reaction of the binder)*
- Introduction of new process requires a lot of experiments
    - ⇒ Measurement of sand properties  
(viscosity, porosity, grain size, ...)
    - ⇒ Blowing process  
(filling behavior, process parameters, ...)
    - ⇒ Investigation of drying process  
(method, equipment, process parameters, ...)



## Core blowing and core drying for sand cores

- **FLOW-3D** was used in the process and tool development
  - ⇒ Development of new core drying model (software)
  - ⇒ Simulation helps to understand process
  - ⇒ Comparison of different drying methods
  - ⇒ Study of process parameters
  - ⇒ Design optimization of tool (heating system, nozzles, vents, ...) and equipment
  - ⇒ Substantial reduction of experiments





# Application of salt cores in high pressure die casting



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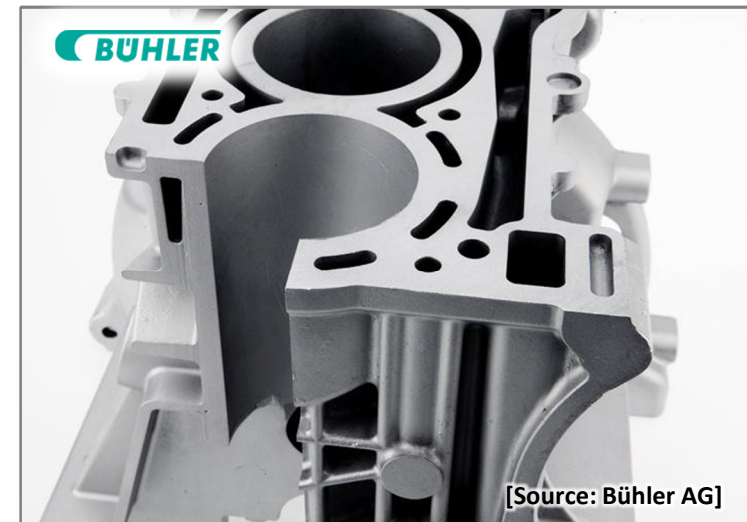
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Dipl.-Ing. H. Lang, BMW Group, Light Metal Foundry

## Application of salt cores in high pressure die casting (HPDC)

- Automotive industry is calling for:
  - ⇒ Cost reduction
  - ⇒ Integral design  
(reduction of the number of components)
  - ⇒ Higher productivity
- Undercuts in HPDC
  - ⇒ Only with complex sliders (*high maintenance*)
  - ⇒ Technology not economically applicable
- Sand cores from gravity casting
  - ⇒ Not suitable for application in HPDC
  - ⇒ Strength insufficient for high pressure and velocities of HPDC process



### Lost Core technology:

- ⇒ Possibility to develop complete new components
- ⇒ Production of hollow parts and complex internal design (*undercuts*)
- ⇒ High degree of function integration
- ⇒ Reduction of machining, sealing and assembling effort

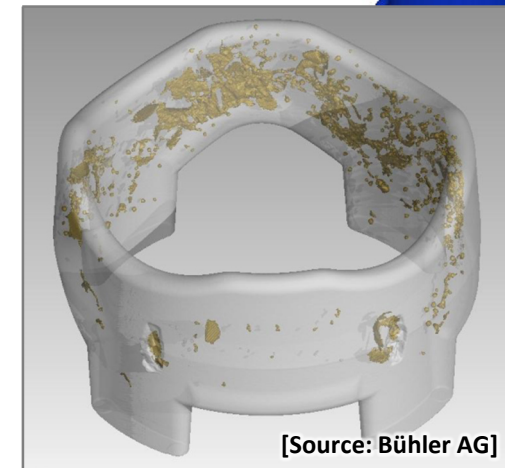
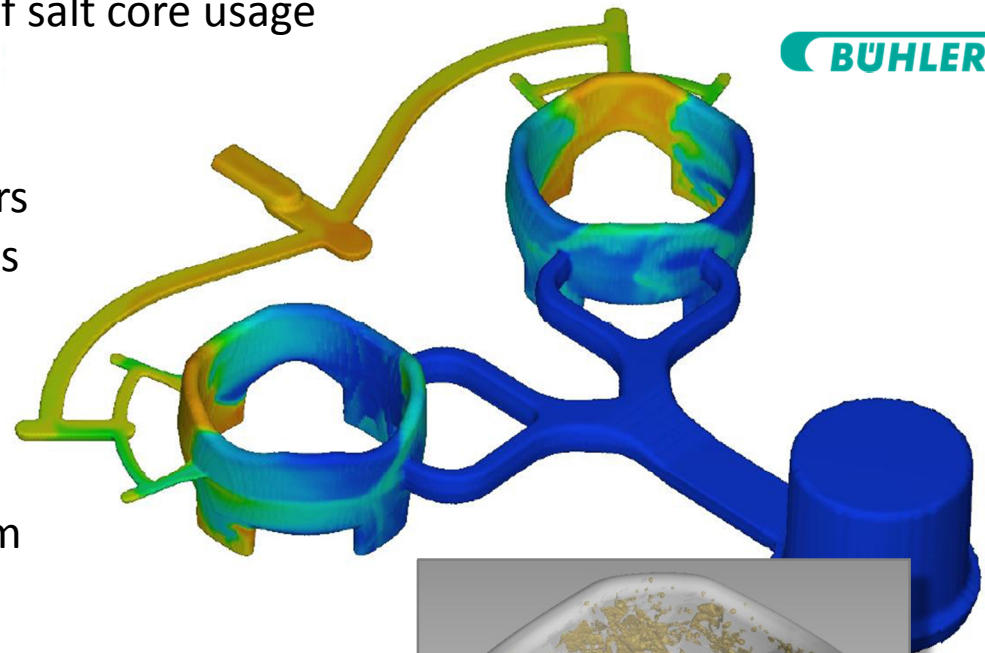
## Application of salt cores in high pressure die casting (HPDC)

- Unknowns of new technology
  - ⇒ Material properties
  - ⇒ Reasonable process parameters (production and usage)
- Production of salt cores
  - ⇒ Process type (gravity casting, HPDC, ...)
  - ⇒ Process parameters
  - ⇒ Quality of salt cores /defects (surface, shrink holes, ...)
  - ⇒ Solidification of salt (very high change in density)
- Usage of salt cores
  - ⇒ High dynamic forces during casting process
  - ⇒ Core failure due to high ingate velocities
  - ⇒ Core cracks due to stresses (due to temperature gradients)



## Application of salt cores in high pressure die casting (HPDC)

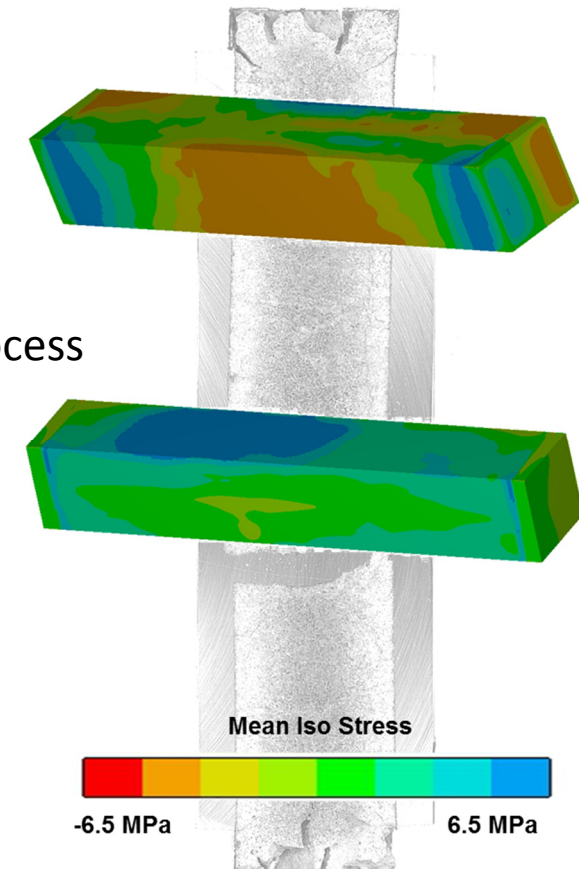
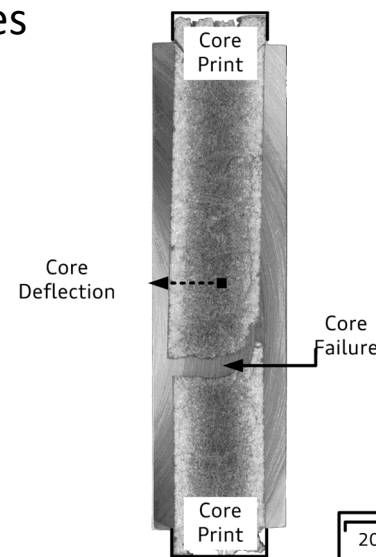
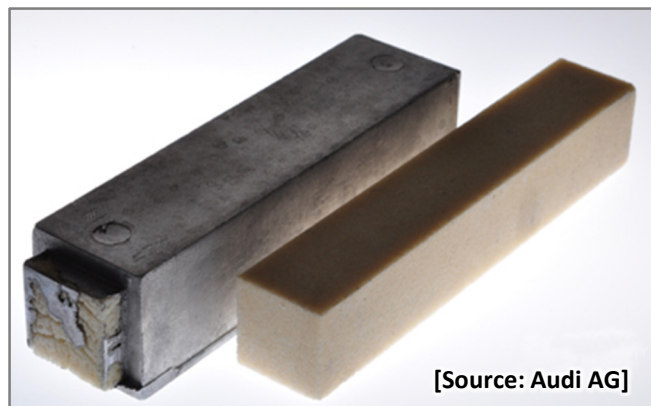
- Simulation in support of development of salt core usage
  - ⇒ Study of process (shrinkage behaviour, ...)
  - ⇒ Determination of process parameters
  - ⇒ Substantial reduction of experiments
- Simulation of salt core production
  - ⇒ Filling behaviour
    - possible defects
    - design of gating and venting system
  - ⇒ Solidification and shrinkage process
    - high change in density
    - shrinkage factor depends on part geometry
    - very rapid solidification of the surface layer
    - surface is an insulator
    - long solidification time of central zone
    - shrink holes
    - stresses (possible cracks)

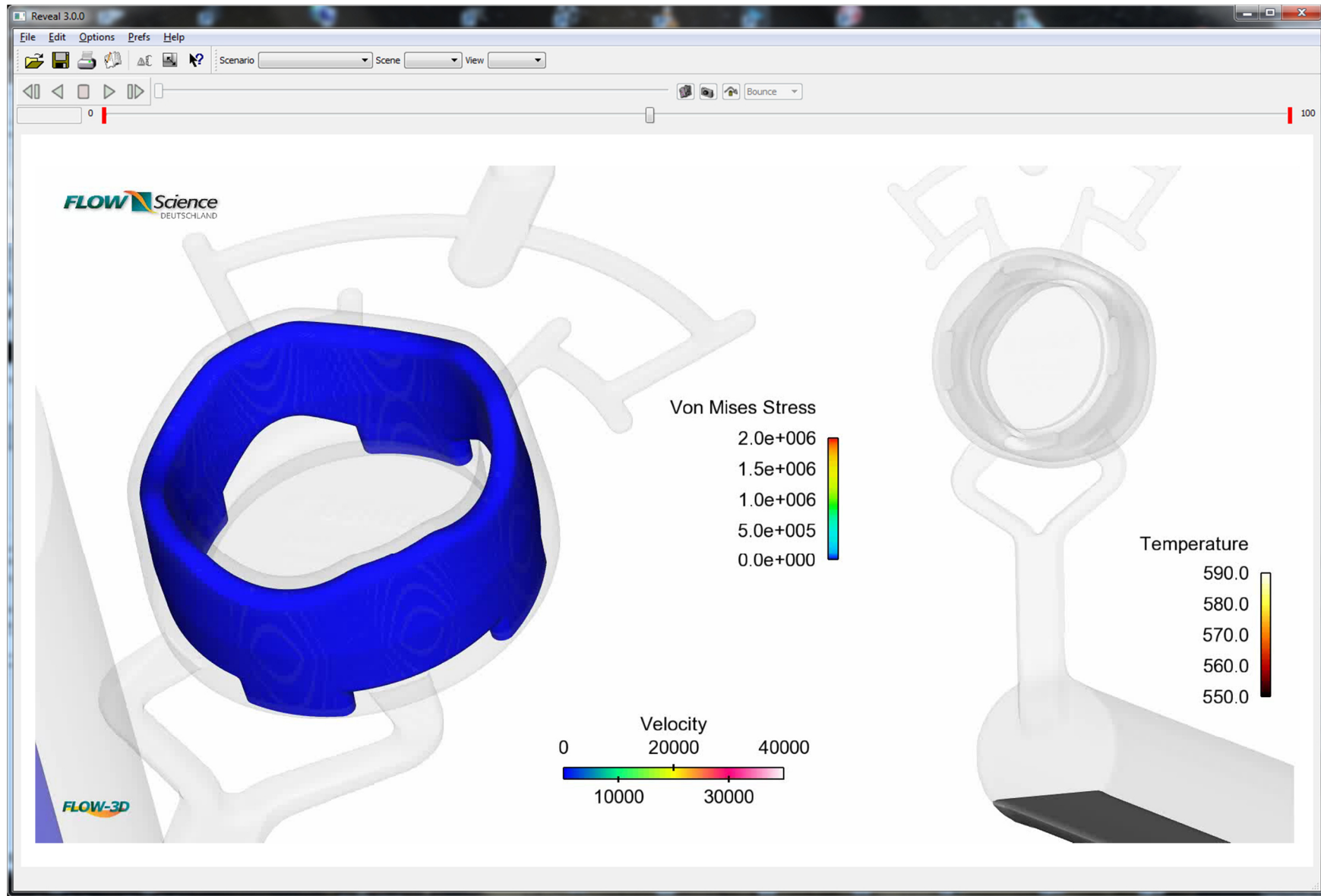




## Application of salt cores in high pressure die casting (HPDC)

- Simulation of salt core usage in casting process
  - ⇒ Filling and Solidification process
  - ⇒ Core failure due to high ingate velocities
- Fluid-Structure-Interaction option in **FLOW-3D**:
  - ⇒ Allows to simulate the interaction of melt and salt core
  - ⇒ Investigation of high forces on the cores during filling process (core cracks due to stresses)
  - ⇒ Thermally induced residual stresses





# Summary



BMW Group



**Dr.-Ing. Dipl.-Phys. M. Todte, Flow Science Deutschland**

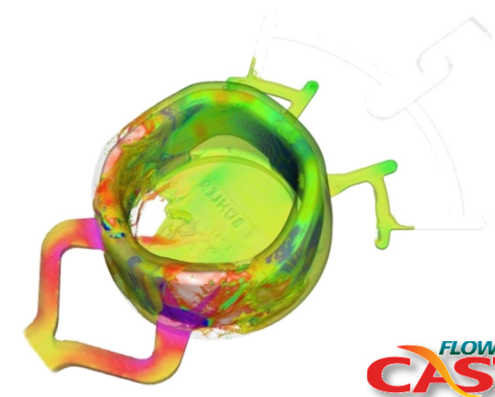
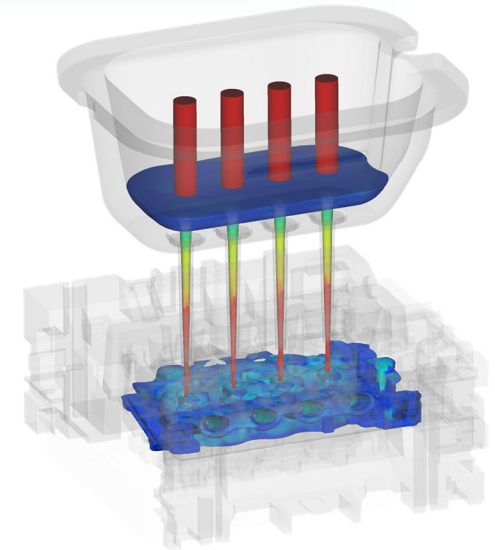
**Dr.-Ing. A. Fent, BMW Group, Light Metal Foundry**

**Dipl.-Ing. H. Lang, BMW Group, Light Metal Foundry**

## Summary

*“The presentation has illustrated the application of simulation for the development of innovative casting processes at BMW Light Metal Foundry and other foundries.”*

- High pressure die casting of complex structural parts  
⇒ *detailed simulation analysis of the complete HPDC process*
- Inserts in high pressure die casting  
⇒ **FLOW-3D** *for analysis of the influence of inserts on the filling pattern and their infiltration*
- Innovative ingate systems for gravity casting  
⇒ *newly developed Injector Casting process of BMW combines advantages of traditional processes and avoids their disadvantages*
- Core blowing and core drying for sand cores  
⇒ *simulation in support of introduction of new sand core production process with eco-friendly inorganic binders*
- Application of salt cores in high pressure die casting  
⇒ *Fluid-structure-interaction option in **FLOW-3D** allows to calculate the stresses on the salt cores*



# Thank you for your attention !



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