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

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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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Simulation in support of the development of innovative processes in the casting industry
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 PQ² 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 PQ² diagrams, solidification and cooling
- Definition of process parameters
- Final optimization loop for gating and venting system
- Final changes to tooling design
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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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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
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
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Innovative ingate system for gravity casting

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

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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 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
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Application of salt cores in high pressure die casting

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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
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Summary

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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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