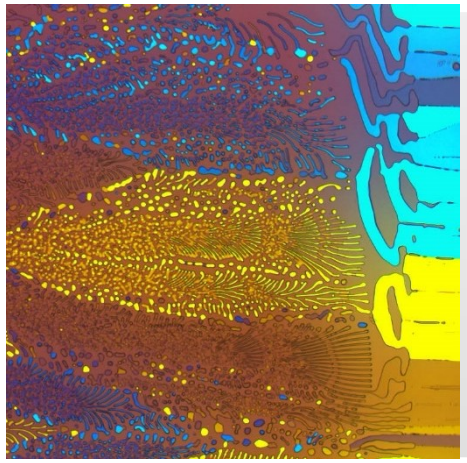
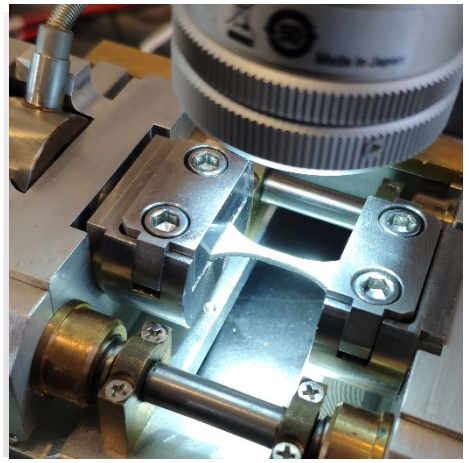
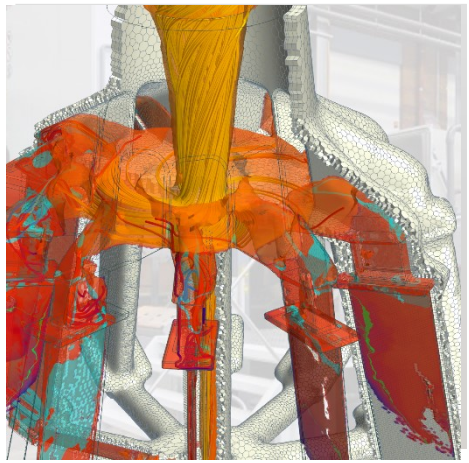


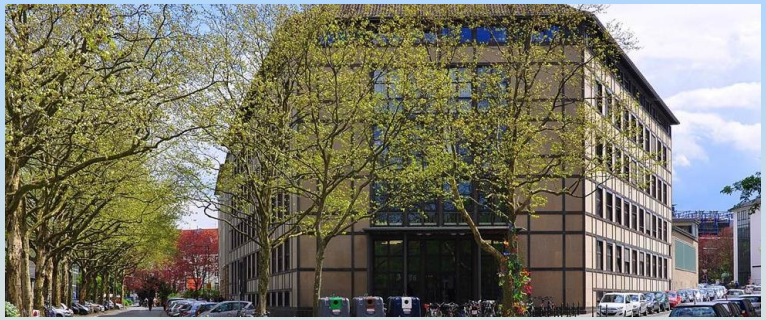
Optimized Production of FeAl-Based Steam Turbine Blades Using MAGMASOFT® Rotacaster & Investment Casting and Technology Transfer towards High-Strength Aluminium Components

Emir Subašić, Martin Hamacher

Magma IUM, Frankfurt, 9.-11. October 2024

access

Access e.V.



Headquarters Access e.V.:
Intzestraße 5
Founding year 1986
RWTH space: 1200 m²

- Administration
- Research laboratories
- Workshops
- Analytics and quality control
- Microstructure and process simulation

Access e.V. TechCenter:
Jülicherstraße 322
Founding year 2000
Ind. real estate: 4200 m²

- Prototype development and small series production
- Pilot plants for various casting processes
- Production of ceramic molds
- Material development
- Heat treatment

Access e.V. Cottbus:
Vetschauer Straße 13
03048 Cottbus
Founding year 2021

- Process simulation
- Process acceleration investment casting
- Additive pattern and mould shell production for investment casting

Access e.V.: Expertise and working groups

Materials science

Computational thermodynamics

Phase transformation kinetics

Fundamentals of solidification

Novel materials

Process technology

Ceramic shell molds

Melting and casting technologies

Prototypes and small series

Focus: investment casting

Microscopy

Microstructure simulation

Software development

Multi-phase-field model

Multicomponent alloys

micress®

HOMAT

AixViPMaP

Process scale simulation

Computational fluid dynamics

Mold filling and solidification

Stresses and strain

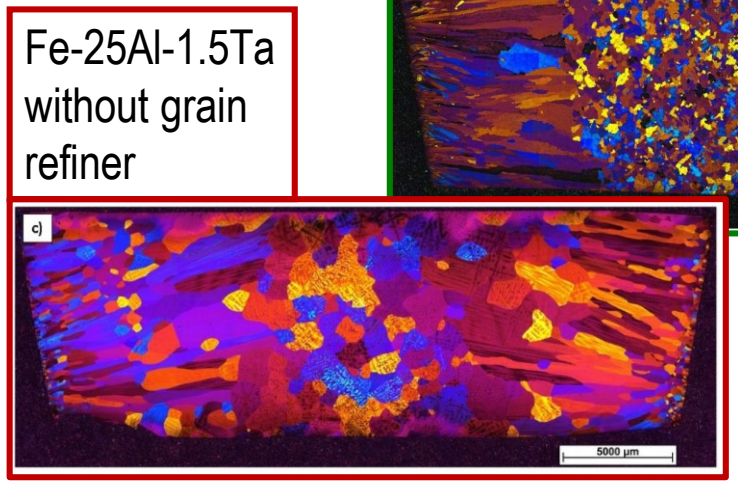
Content

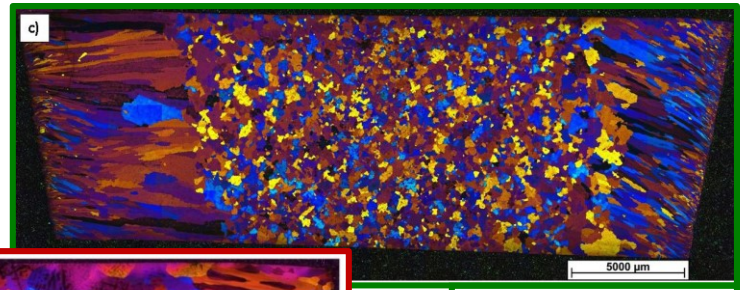
- Introduction & Motivation
- Material and process description
- Modelling approach
- Mould filling analysis
- Solidification analysis
- Technology transfer towards high-strength aluminium components (project GATE)
- Conclusions & Outlook
- Acknowledgments

Introduction & Motivation

- Substitution of expensive nickel-base superalloy materials and high alloyed stainless steels with iron aluminides
- Development of a suitable “near-net-shape” casting process route (smooth filling, melting under inert gas…)
- Establishing of a corresponding “digital twin”
- Technology transfer towards high-strength aluminium components (project GATE)

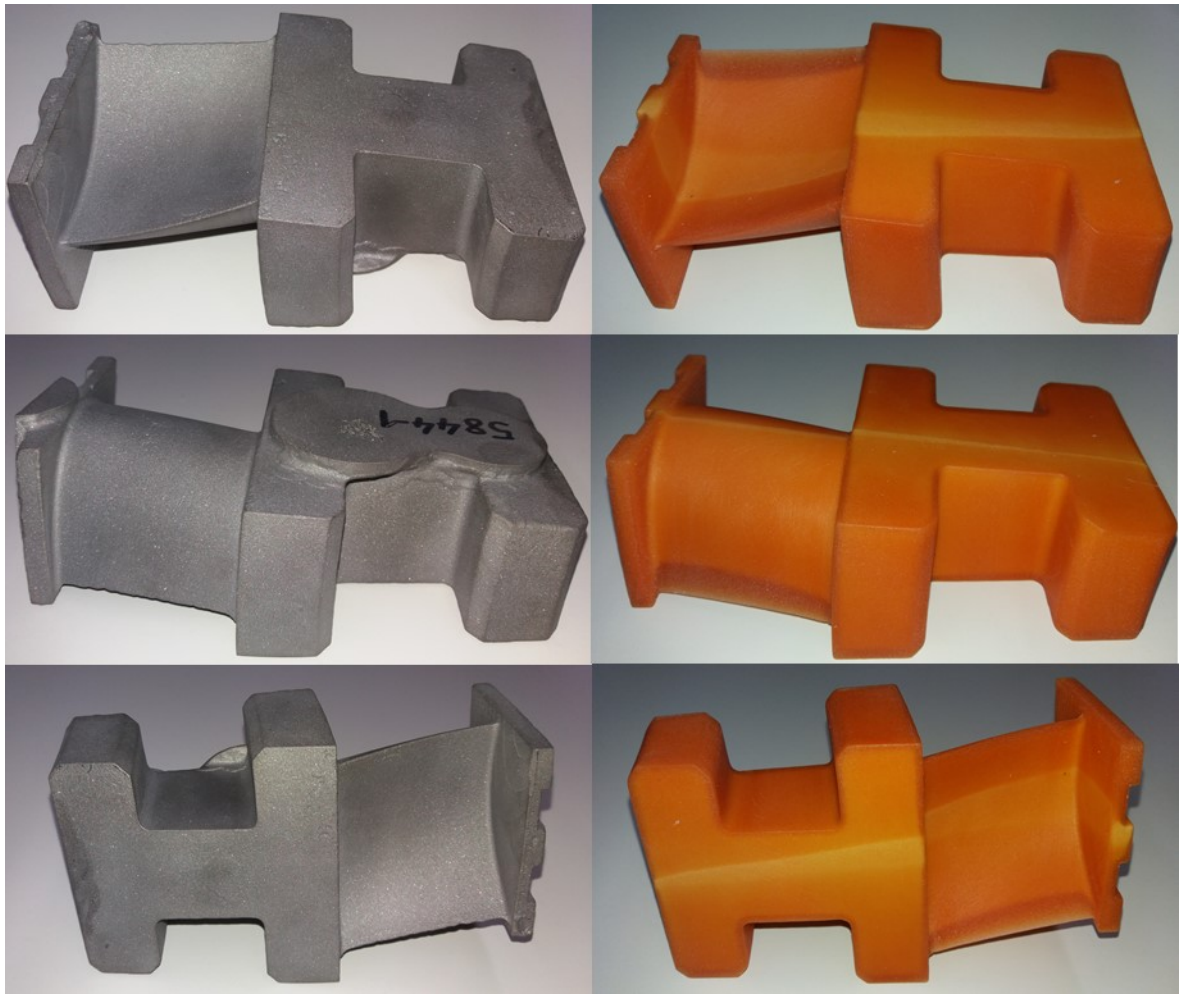
Fe-25Al-1.5Ta without grain refiner





Fe-25Al-1.5Ta with grain refiner (TaC)

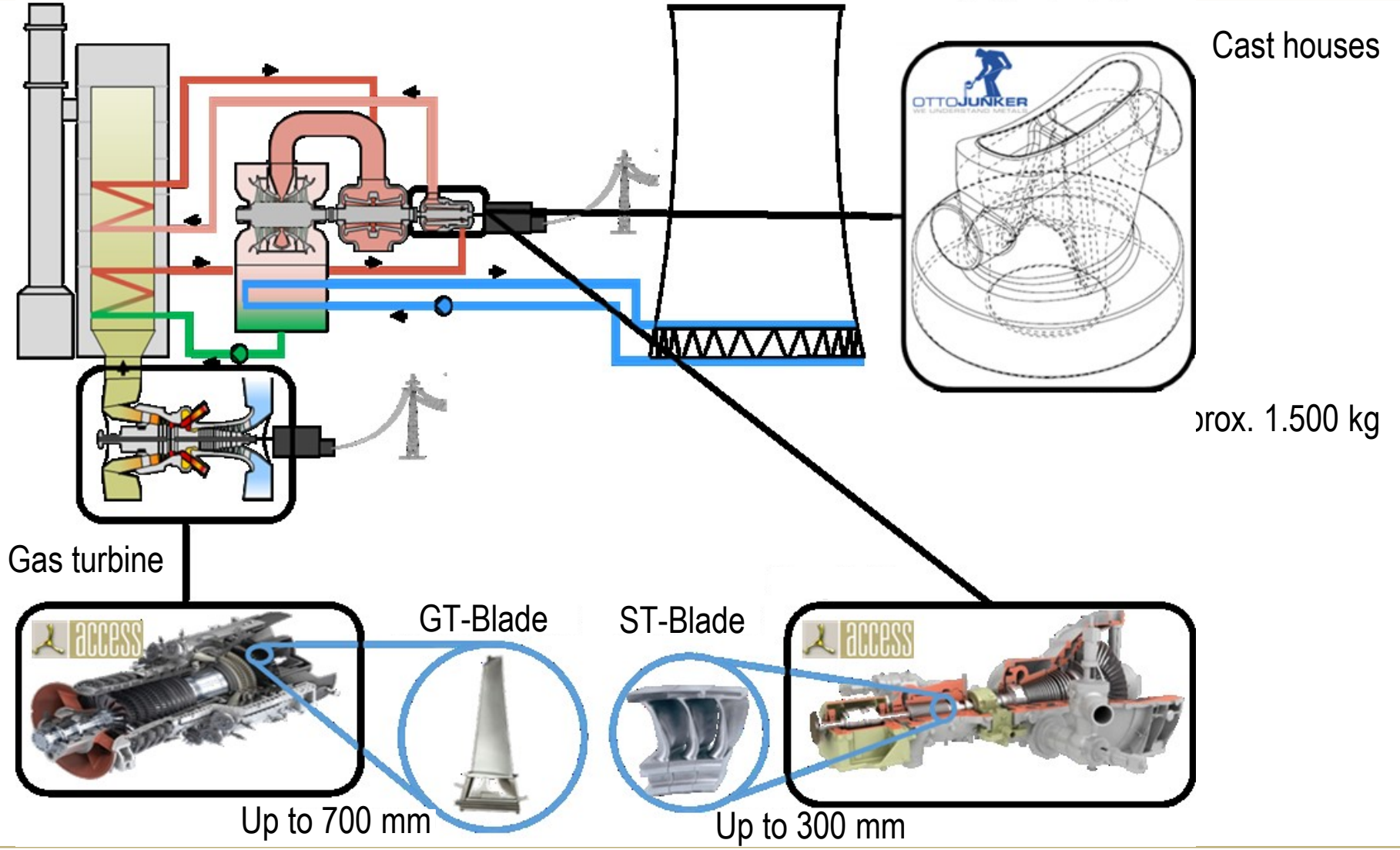
Near-net-shape cast part: steam turbine (ST) blade



FeAl-Casting vs. PMMA-Rapid prototype

„Development of a Two-Stage Etching Procedure for Grain Analysis of Intermetallic Iron Aluminides (Fe-Al-Ta)“, E. Schaberger-Zimmermann, R.D. Pütz, E. Subašić, D. Zander, Practical Metallography, vol. 58, no. 3, 2021, pp. 120-128 (https://doi.org/10.1515/pm-2021-0008)

Introduction & Motivation: Possible application of FeAl-components in gas & steam power stations

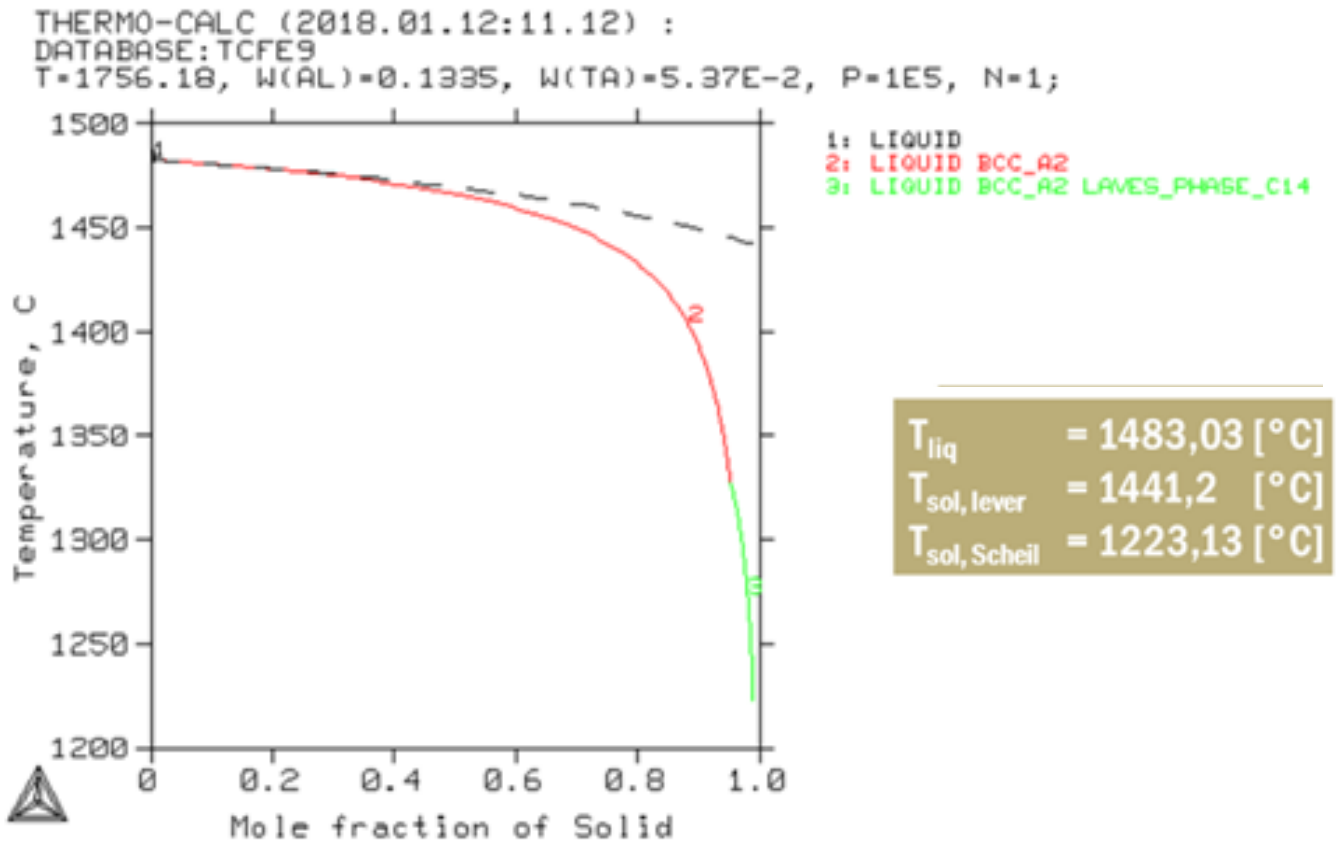


E. Subašić, H. Michels: „Process development for production of FeAl components for gas and steam power stations; Grain refinement – FeAl-GuD", final report, BMWi 03ET7077A, 2022, https://doi.org/10.2314/KXP:1840964502

Material and process description

Thermo-Calc: Solidification interval for Fe-25Al-1.5Ta (at.%)

Fe-25Al-1.5Ta, without grain refiner



T_{liq}	= 1483,03 [°C]
$T_{sol,lever}$	= 1441,2 [°C]
$T_{sol,Scheil}$	= 1223,13 [°C]

Rollover furnace “Inductotherm”

Modelling approach (1/2): MAGMASOFT® Investment casting

Automatic mesh shell generator

Mesh Generation

Specify the parameters for mesh generation.

Mode
- ○ Number of Elements
- ◉ Multiple Parameter Sets

Options
- ☑ Mesh for solver 5
- ☐ Generate core
- ☑ Generate shell

Shell thickness 9.0 mm

Parameter Sets
- Standard
- Advanced
  - Casting ID 1

Cartesian Mesh Parameters (Advanced)

◉ Classic ○ Min. Wall Thickness ○ Equidistant

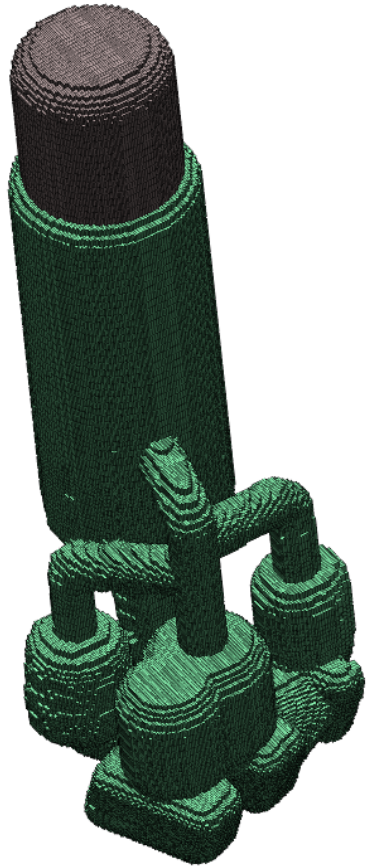
	X	Y	Z	
Geometry filter	4.2	4.2	4.2	mm
Subdivisions	3	3	3	
Minimal element size	1.3	1.3	1.3	mm
Maximum length ratio of neighboring elements			1.6	
Maximum aspect ratio of an element			2.4	

Mesh Size

Number of cartesian cells: 2,010,660 — Number of cartesian cavity cells: 244,330

Mesh Quality

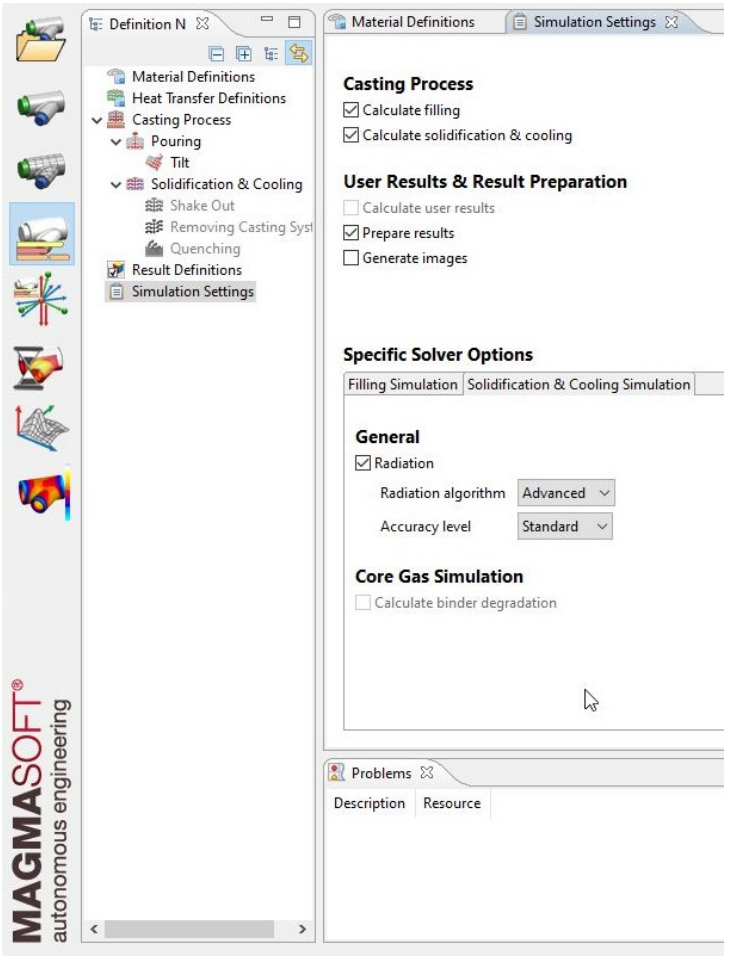
Blocked cells	0	0.0	%
Edge-over-edge connected cells	18	0.0	%
Thin wall elements	147	0.1	%
Air contact cells	3,980	1.6	%



Materials
- Casting
- Feeder
- Feeder
- Feeder
- Runner
- Runner
- Runner
- Runner
- Runner
- Gate
- Shell
- Pouring Basin
- Melt Reservoir

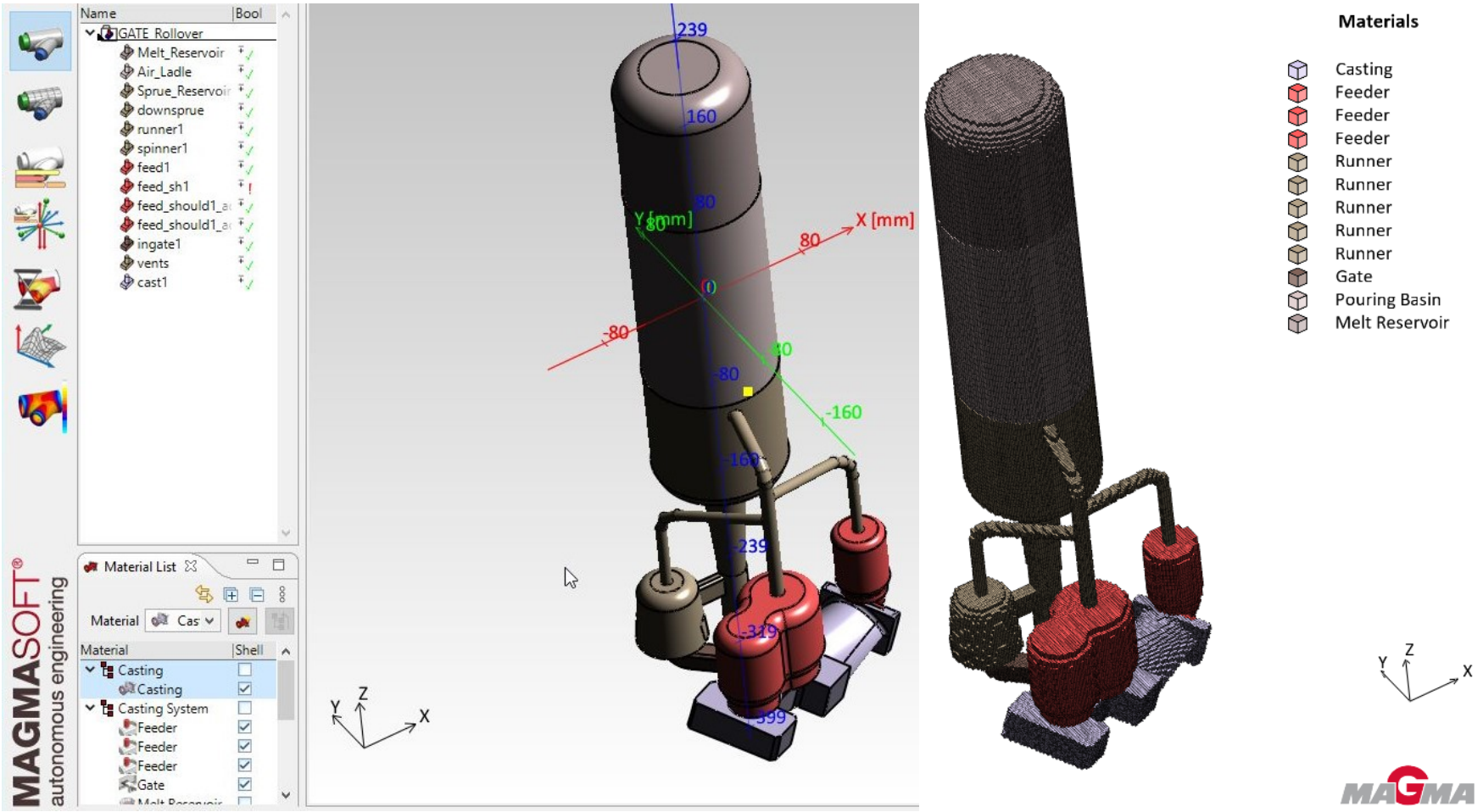
MAGMA

Heat transfer: Radiation

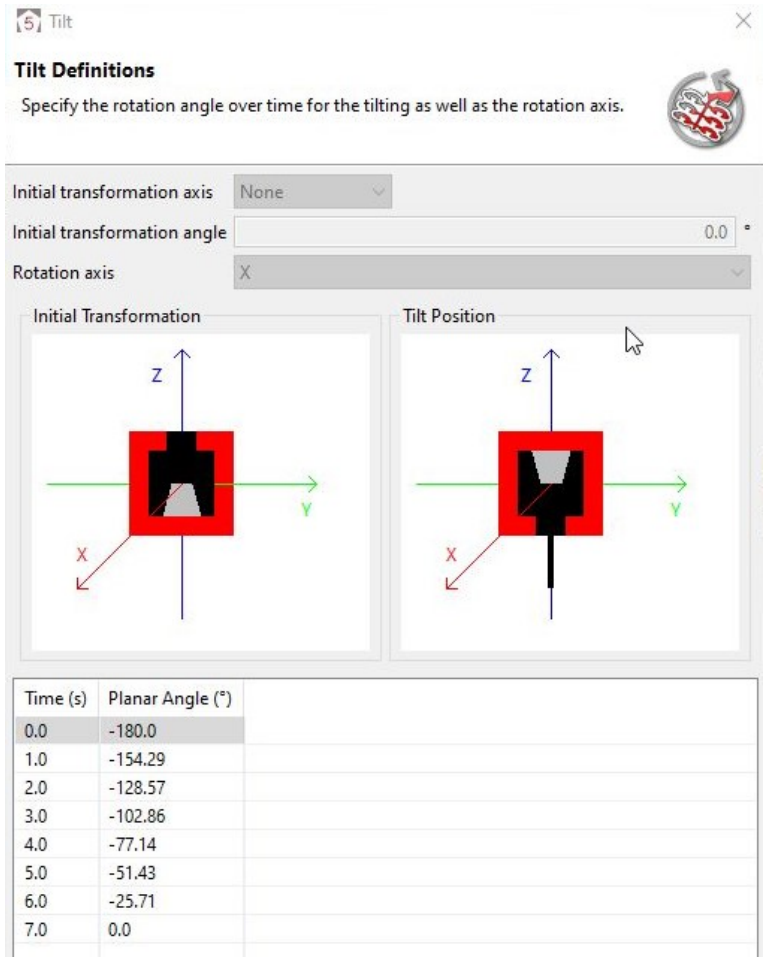


Modelling approach (2/2): MAGMASOFT® Rotacaster

Preprocessor material selection ('Melt Reservoir')



Tilt settings



Mould filling analysis (1/4): Recording rollover process time

Rotation time of rollover furnace and the shell mould: 7 s

t = 6 s

∢ = 154,29 °

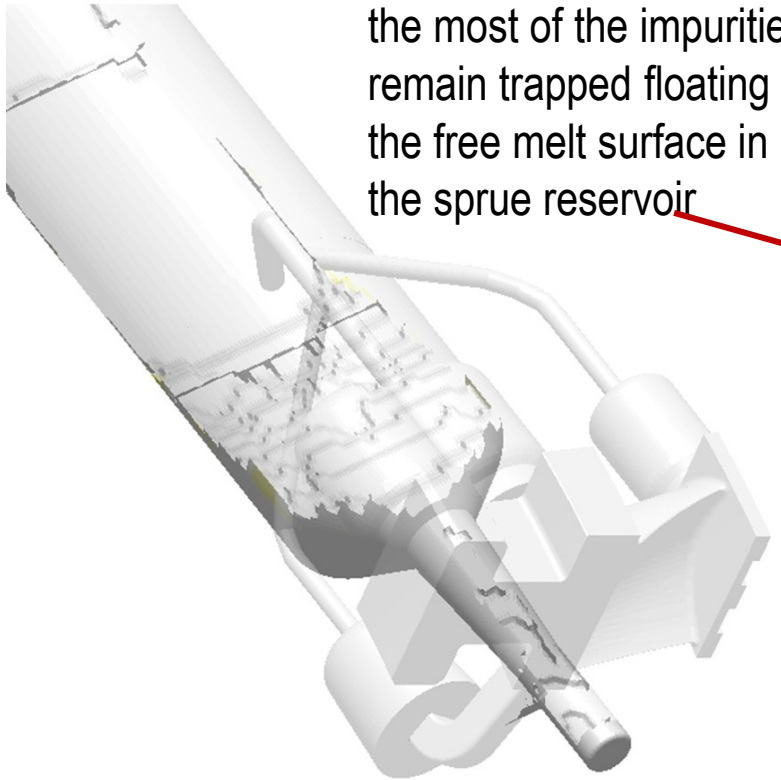
t = 7 s

∢ = 180 °

Mould filling analysis (2/4): Three-stage melt filtration

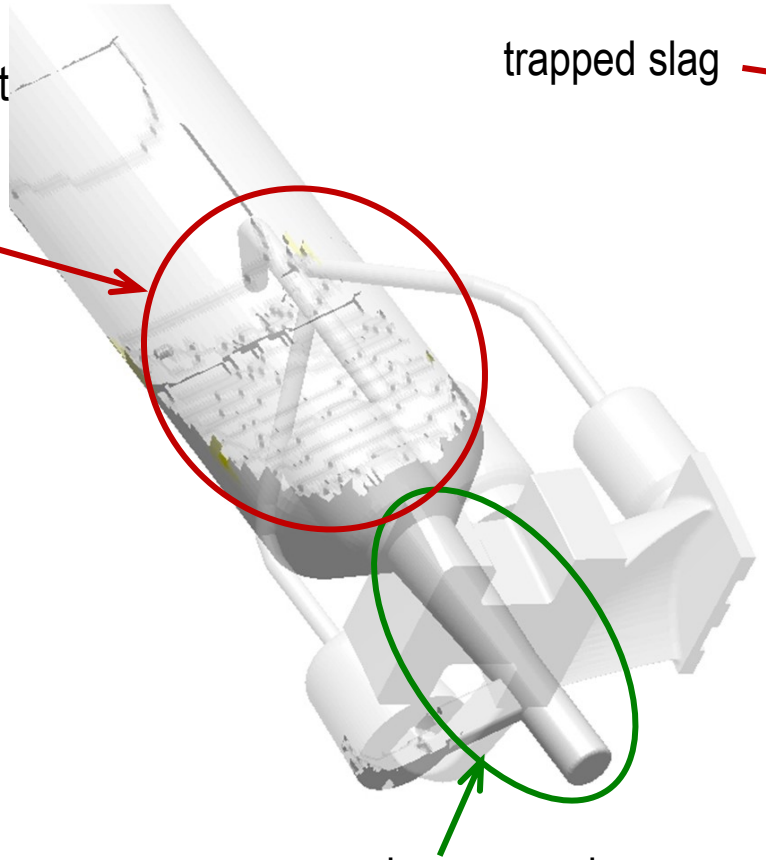
1. Sprue reservoir prevents impurities transport from the melting crucible; down sprue choke reduces melt flow

the most of the impurities remain trapped floating at the free melt surface in the sprue reservoir



v30
Temperature
3.900s, 25.07 % (-79.70°)

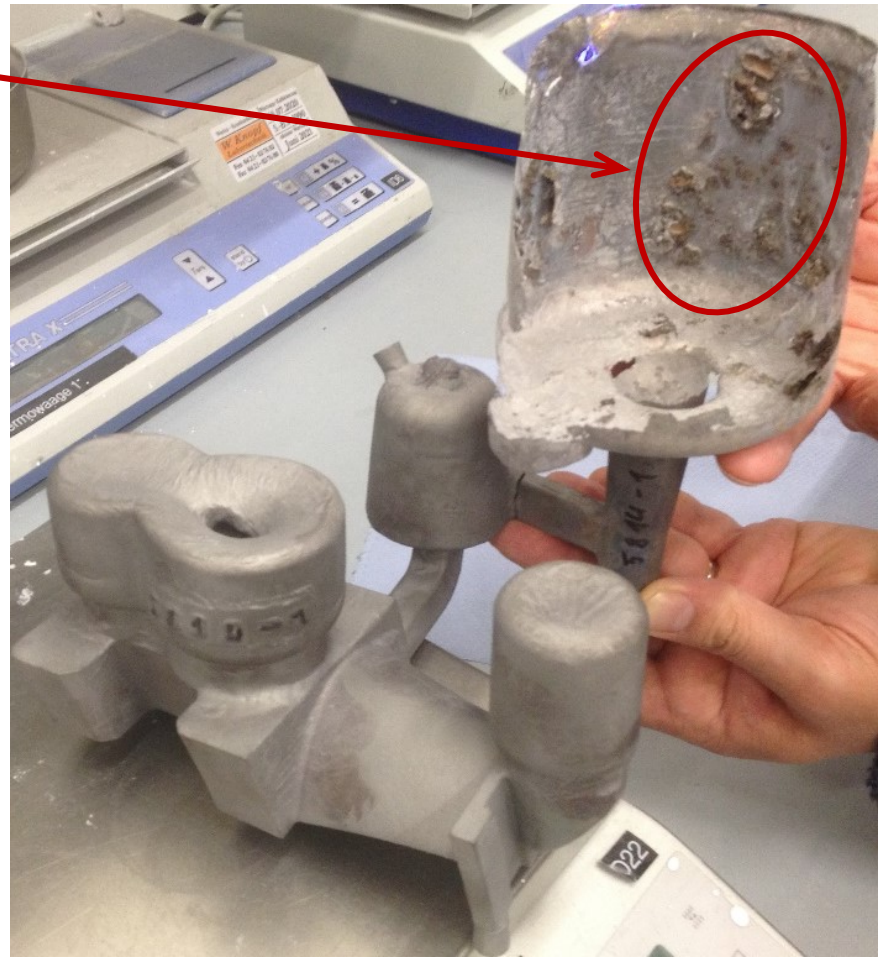
time step immediately before the down sprue is completely filled



v30
Temperature
4.000s, 26.61 % (-77.13°)

down sprue is now completely filled

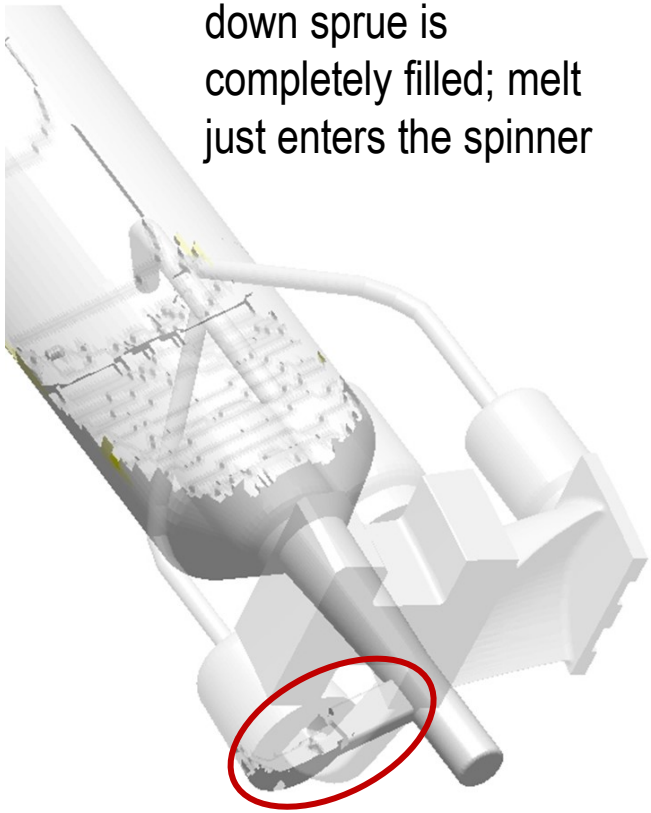
trapped slag



Mould filling analysis (3/4): Three-stage melt filtration

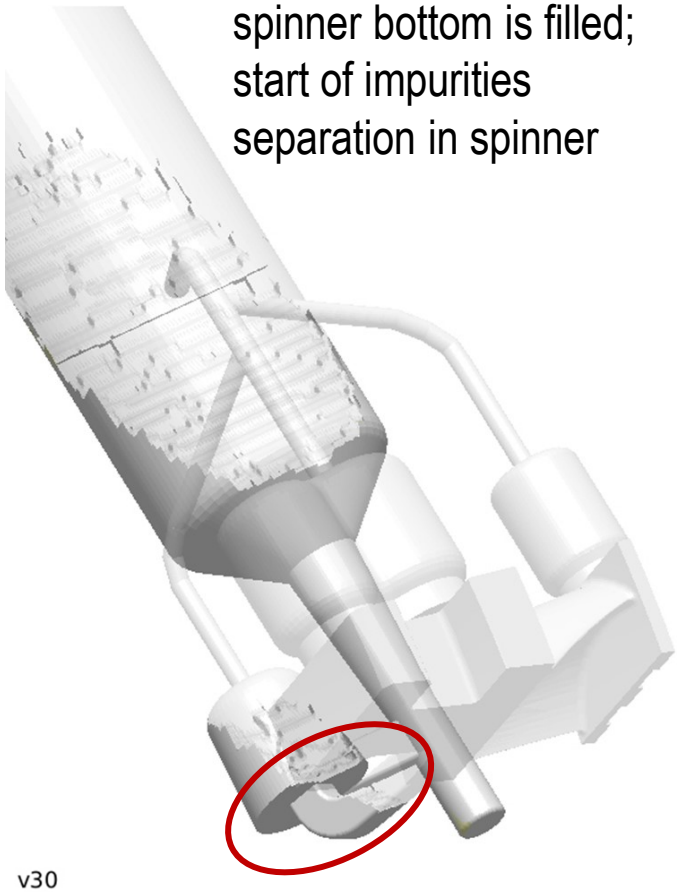
2. Spinner prevents impurities transport into the part cavity; controlled vortex, flotation on top, ingate at the bottom

down sprue is completely filled; melt just enters the spinner



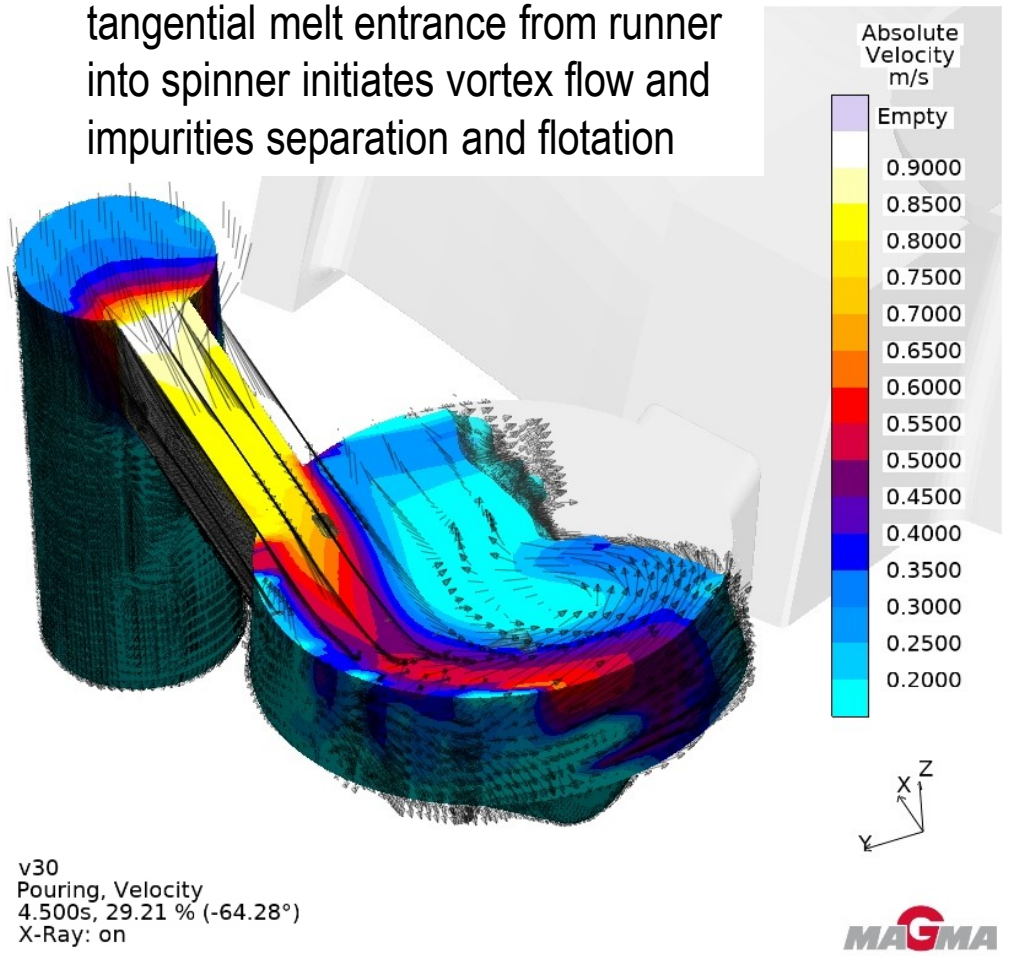
v30
Temperature
4.000s, 26.61 % (-77.13°)

spinner bottom is filled; start of impurities separation in spinner



v30
Temperature
4.500s, 29.21 % (-64.28°)

tangential melt entrance from runner into spinner initiates vortex flow and impurities separation and flotation



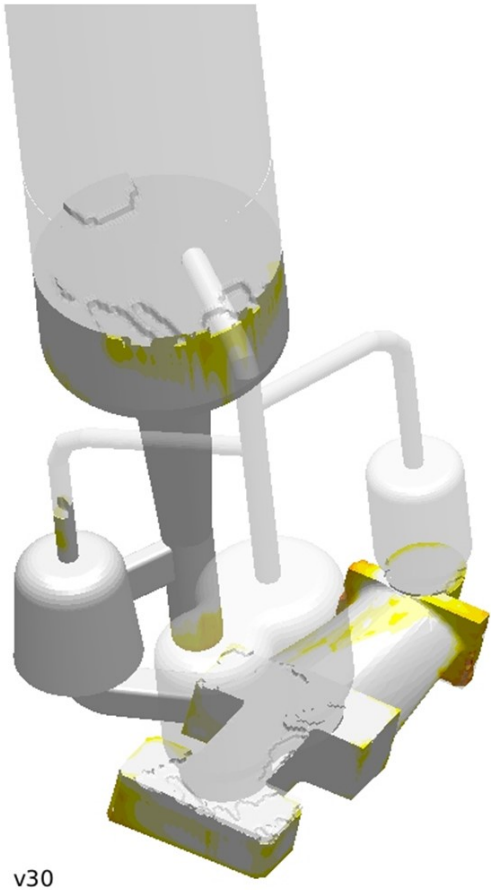
v30
Pouring, Velocity
4.500s, 29.21 % (-64.28°)
X-Ray: on

MAGMA

access

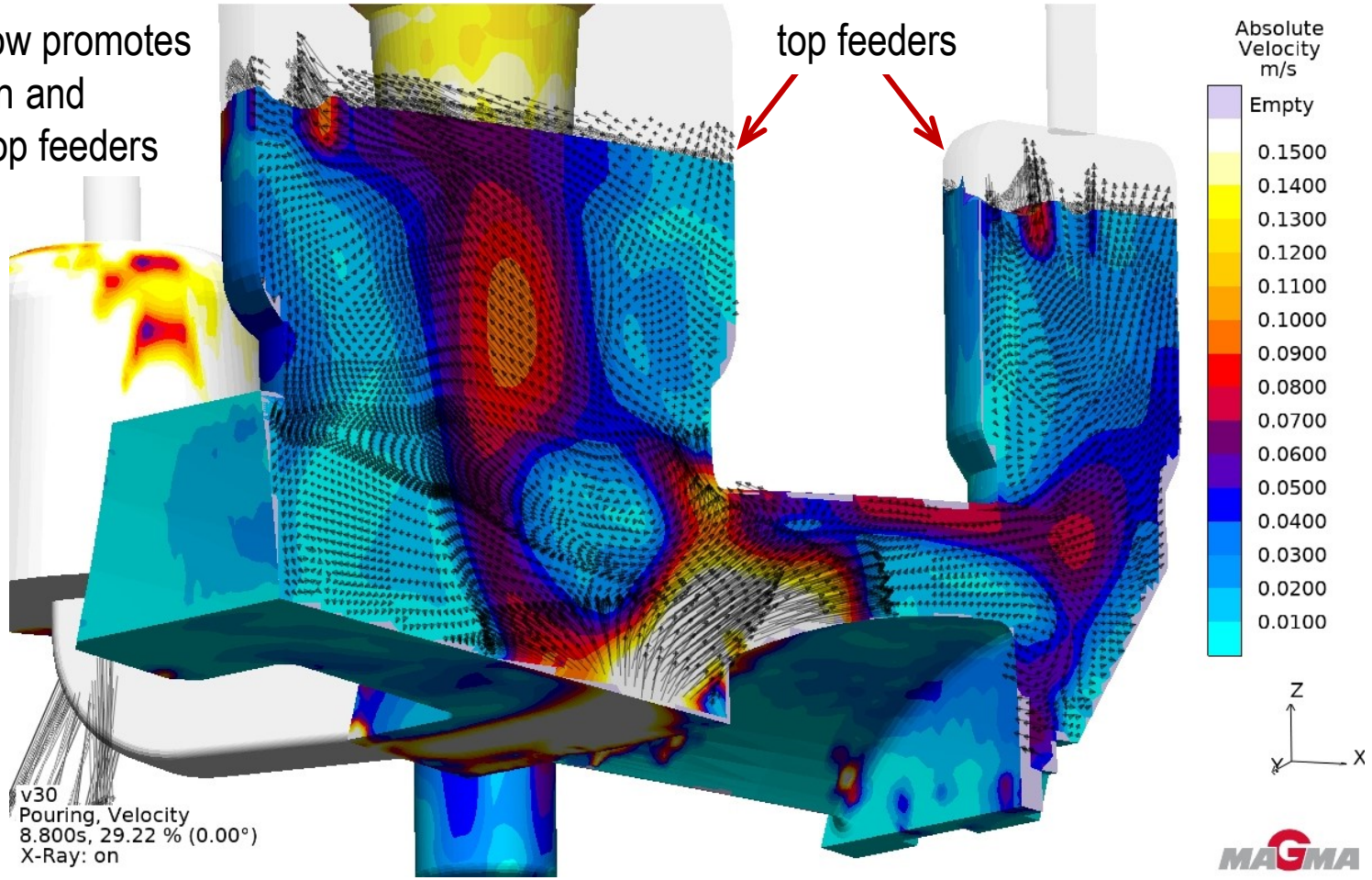
Mould filling analysis (4/4): Three-stage melt filtration

3. The rest of the possible impurities are collected at the feeders top, floating at the free melt surface



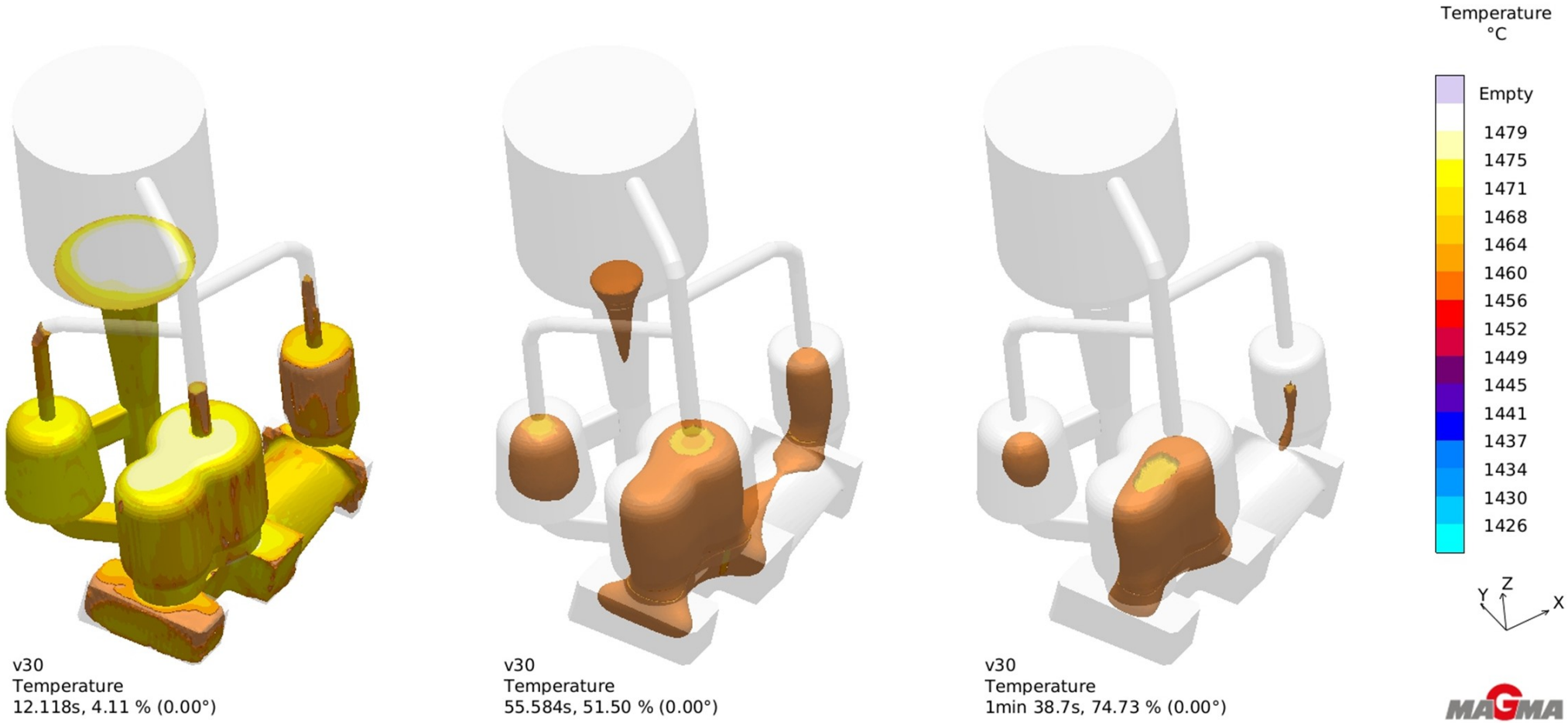
end of rotation

upwards directed flow promotes impurities separation and flotation in both of top feeders



Solidification analysis (1/2): Solidification sequence

Transparent (solidified) areas: $T_{melt} < T_{crit.}$ = 1460 °C (fs = 30%); no isolated melt areas detected



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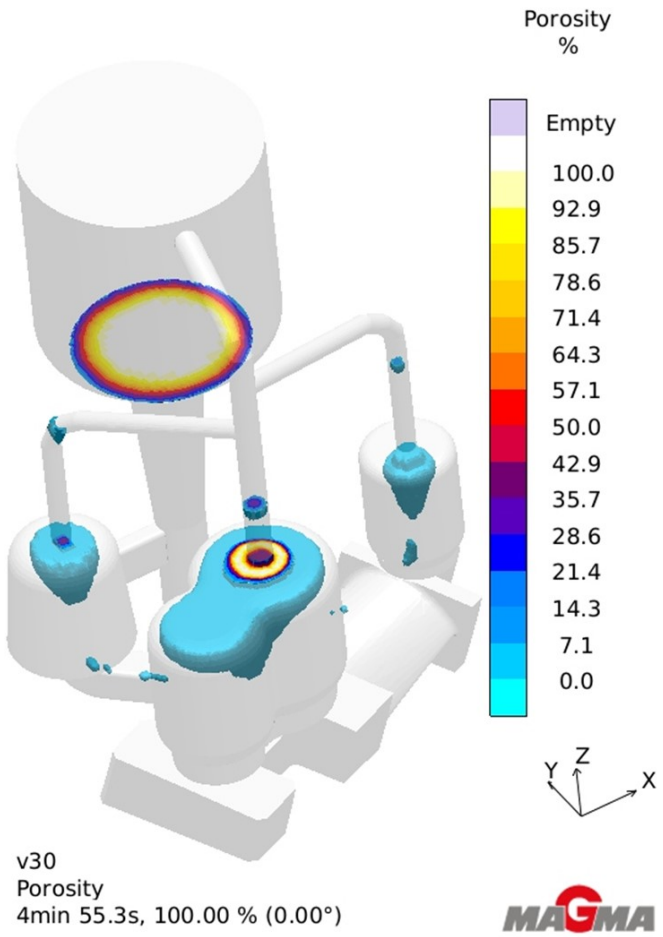
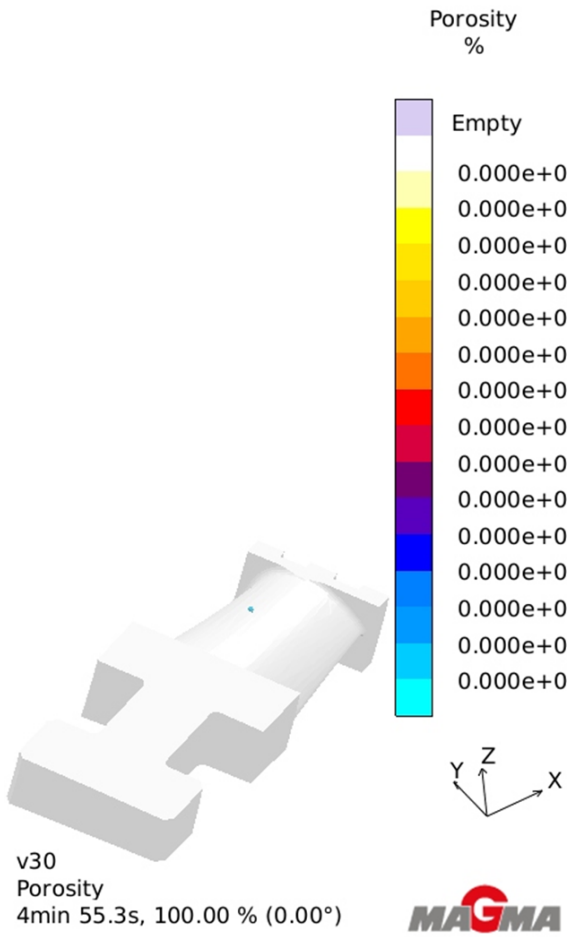
Solidification analysis (2/2): Porosity prediction vs. experiment

No significant porosity defects in part predicted



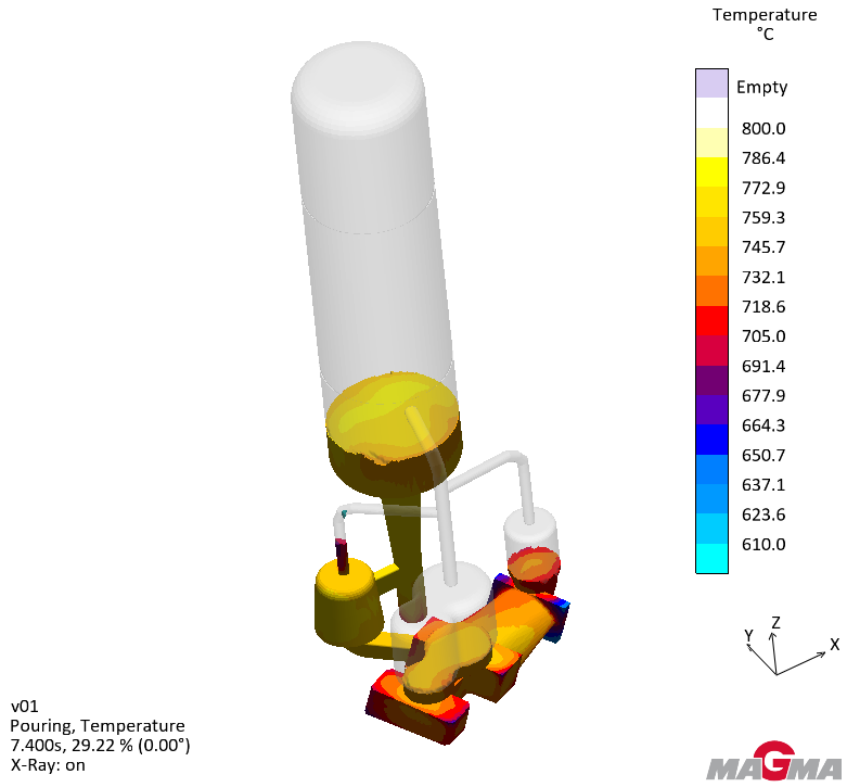


Cast part

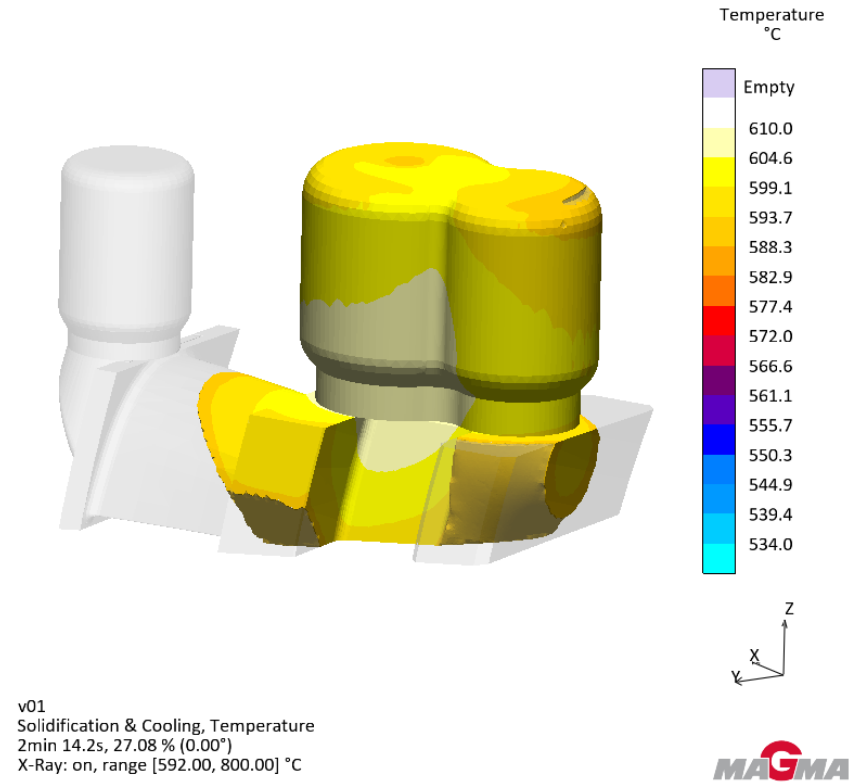
X-ray inspection

Technology transfer towards high-strength aluminium components (project GATE)

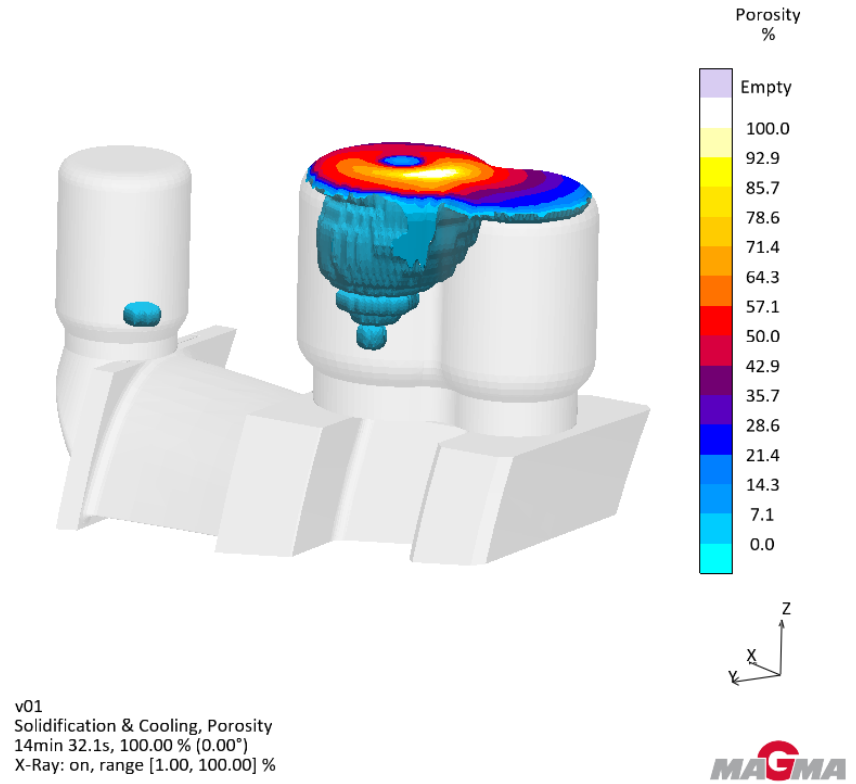
Mould filling



Solidification



Porosity



Alloy: A357
Initial temperature: 800 °C

Liquidus / Solidus = 610 °C / 534 °C
Critical temperature (fs=30%): 592 °C

Conclusions & Outlook

- Investment casting process on “Inductotherm” rollover furnace in Access e.V. has been successfully integrated into the production chain for steam turbine blades made of iron aluminides
- MAGMASOFT® Rotacaster & Investment Casting have been established as a suitable “digital twin”
- Mould filling analysis has proven optimal application of a casting system layout (featuring three-stage melt filtration)
- Solidification analysis has proven optimal application of a defect-free feeding system layout
- Ongoing activities: Technology transfer towards high-strength aluminium components (project GATE)

Acknowledgment

Research work presented in this paper is a part of the research projects “Process development for production of FeAl components for gas and steam power stations - **FeAl-GuD**” and “Development of innovative, ecologically and economically efficient manufacturing processes for climate neutral aviation components based on consistently digital approaches - **GATE**”.

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Emir Subasic
Access e.V.
Intzestr. 5
52072 Aachen
Tel.: +49 241 943249 12
Fax +49 241 38578
Mail to: e.subasic@access-technology.de
www.access-technology.de

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