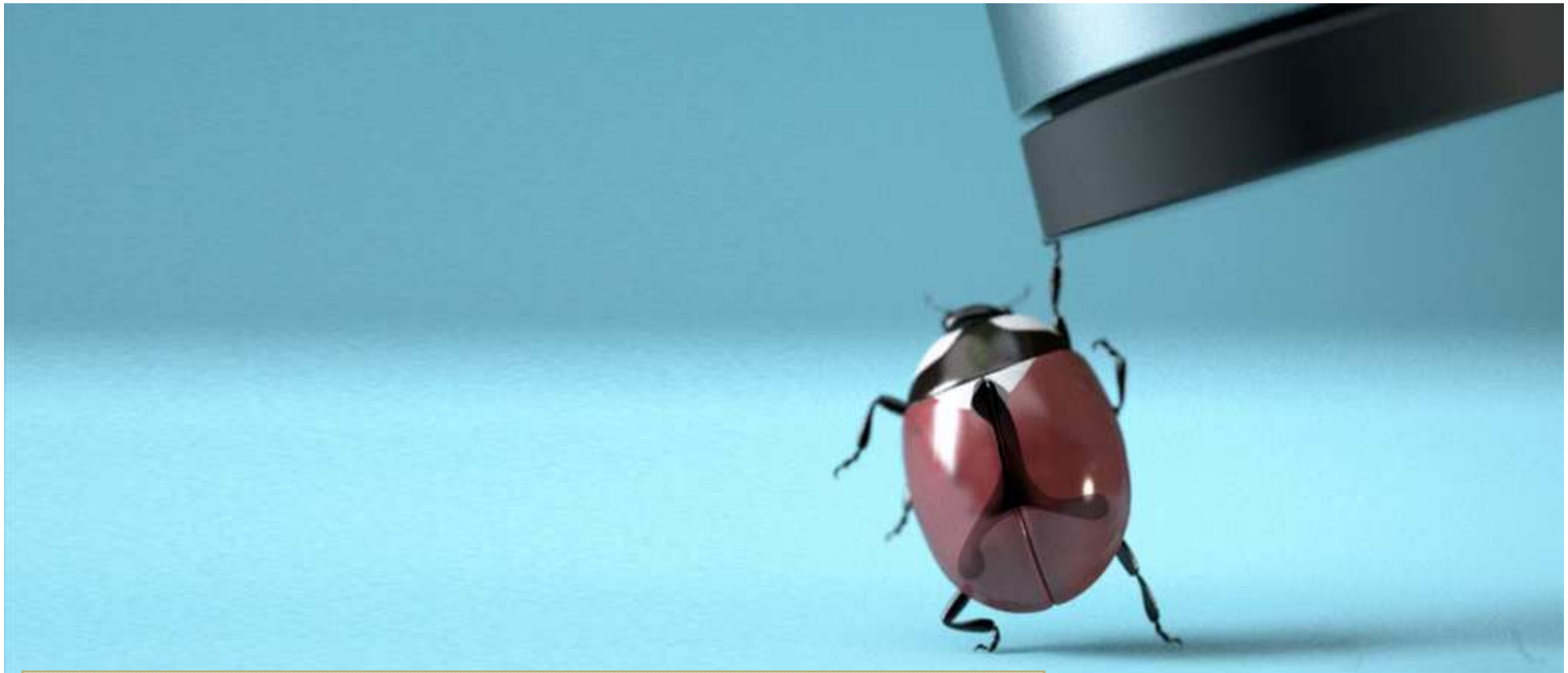


NEAR NET SHAPE CASTING OF INTERMETALLIC TITANIUM ALUMINIDE COMPONETS FOR HIGH TEMPERATURE AEROSPACE AND AUTOMOTIVE APPLICATIONS

Julio Aguilar, Andre Schievenbusch

TiAl – castings for automotive and aero-engine applications

TiAl-based intermetallic materials

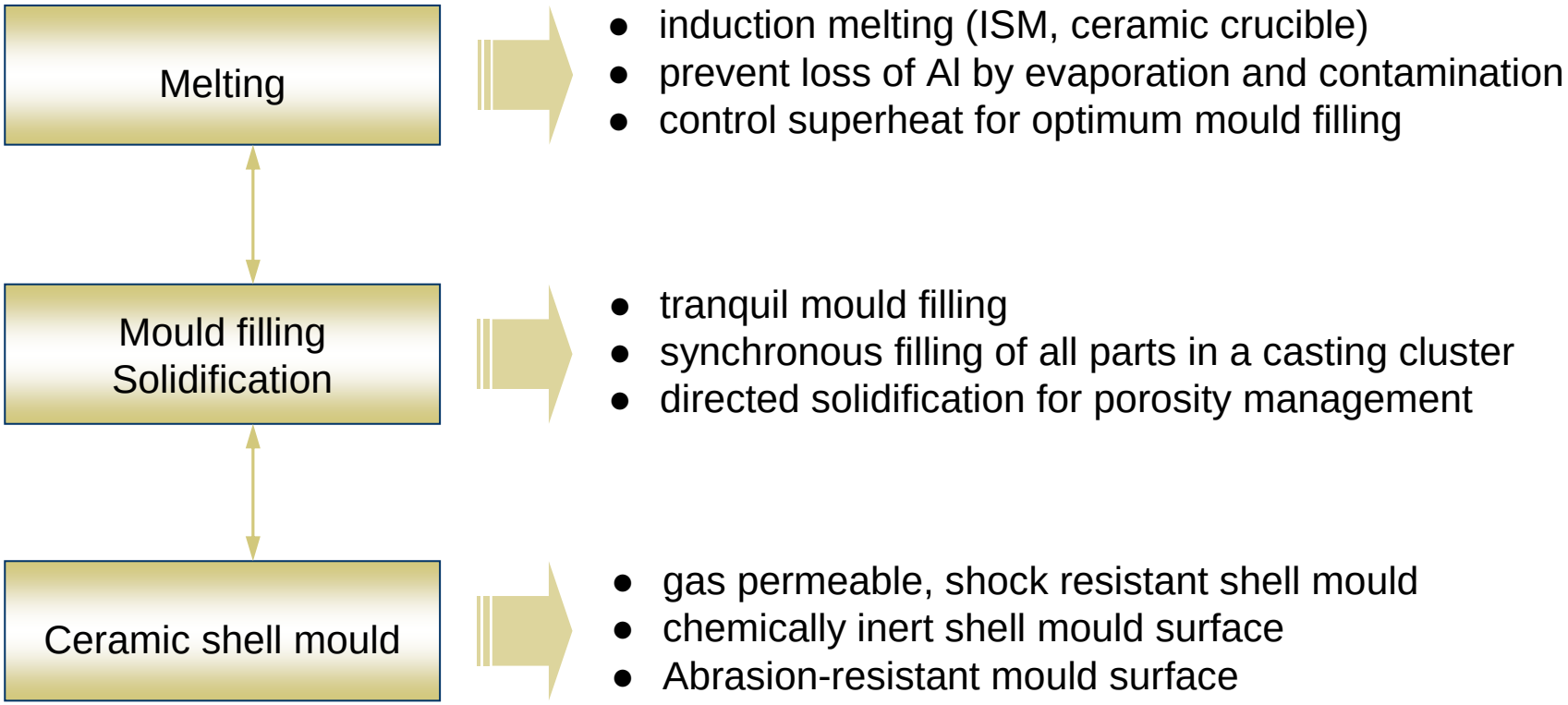
- low density, high stiffness
- good oxidation resistance
- attractive high temperature properties
- limited ductility & fracture toughness below BDT
- service temperatures 600℃-800℃

Investment casting of near net shape parts

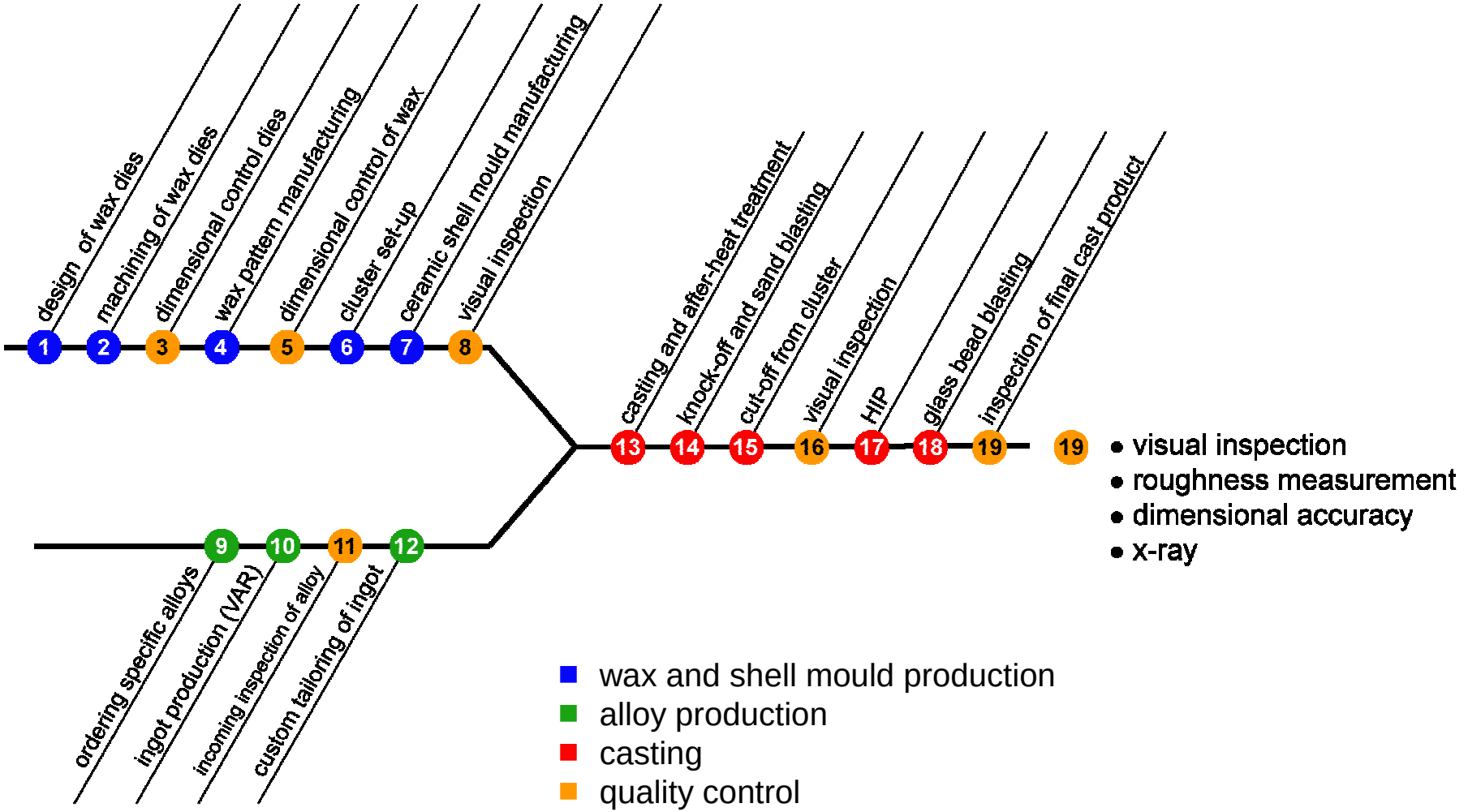
- cost-efficient production process
- well estabished for titanium alloys
- series production of turbocharger wheels in Japan
- wold-wide efforts viz. casting aero-engine parts

TiAl Investment casting: Key technological features

Requirements resulting from peculiar properties of TiAl



TiAl Investment casting: Overview of process steps

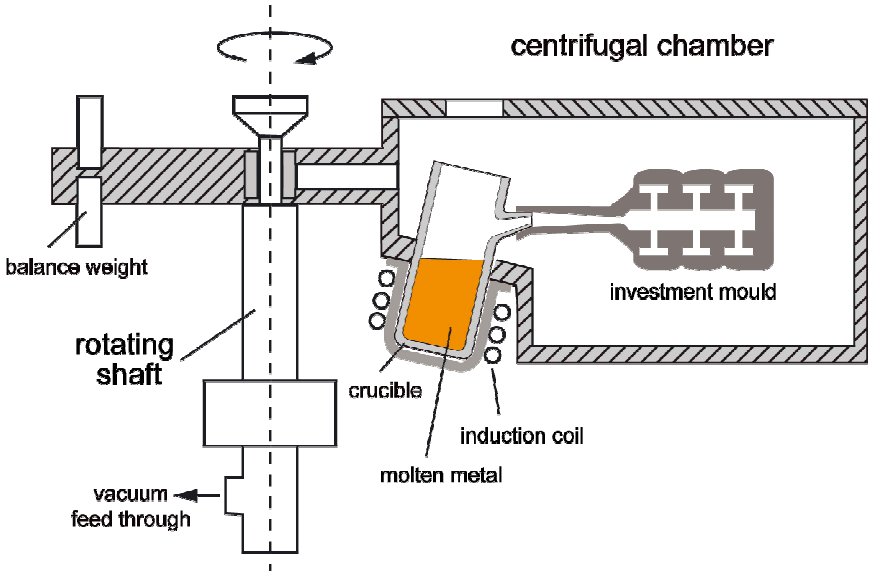


TiAl Investment casting: Access shell mould system

Y_2O_3 face-coat and backup layers

- Temperature stability up to 1680 ℃
- Low chemical interaction with TiAl melt
- High thermal shock resistance
- High strength for dimensional accuracy
- Robust manufacturing process

TiAl Investment casting: Horizontal centrifugal casting



Process characteristics

VIM in ceramic crucibles

Melting capacity: 2.0 kg

Superheat: $\Delta T \approx 20$ to 100 K

Process duration: 6 - 8 min

Rotation speed: up-to 400 RPM

Oxygen pick-up: 300 -500 wt-ppm

Parameters: ΔT, ω, cluster design

Horizontal centrifugal casting: Numerical simulation

Process simulation

Optimization of casting clusters
is supported by numerical simulation
of mould filling and solidification.

- Features
  - Mould filling for geometrically complex industrial parts
  - Extremely flow conditions
  - Compressible gas
  - Permeable ceramic mould
  - Moving grid
  - Computation of centrifugal- and Coriolis force

Horizontal centrifugal casting: Numerical simulation

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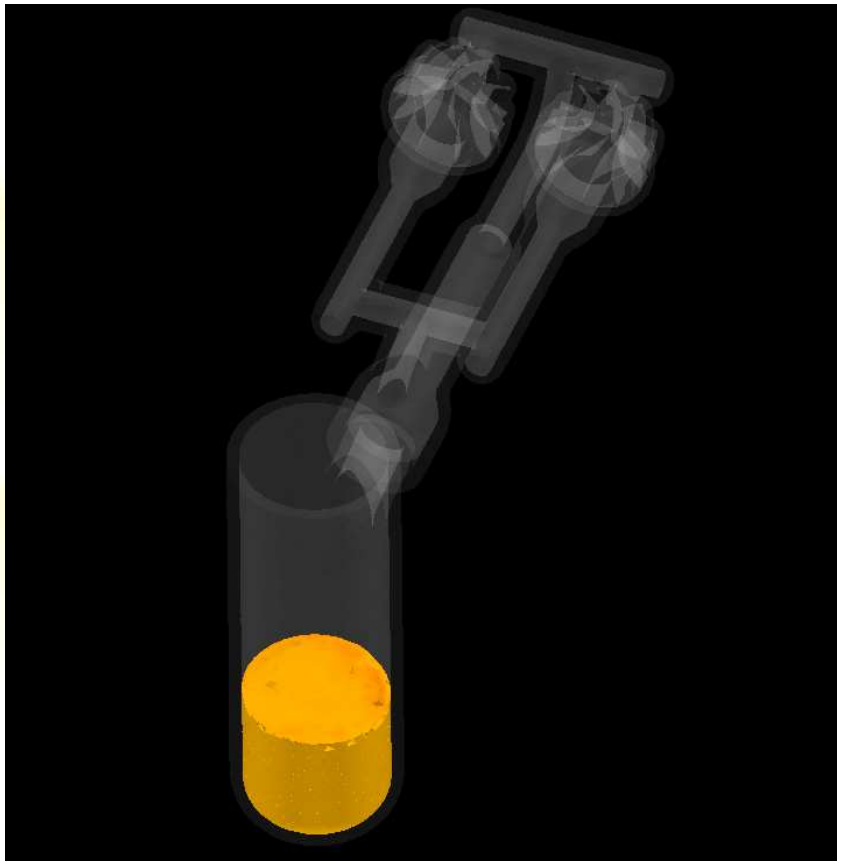

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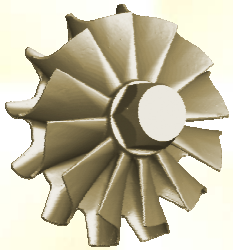
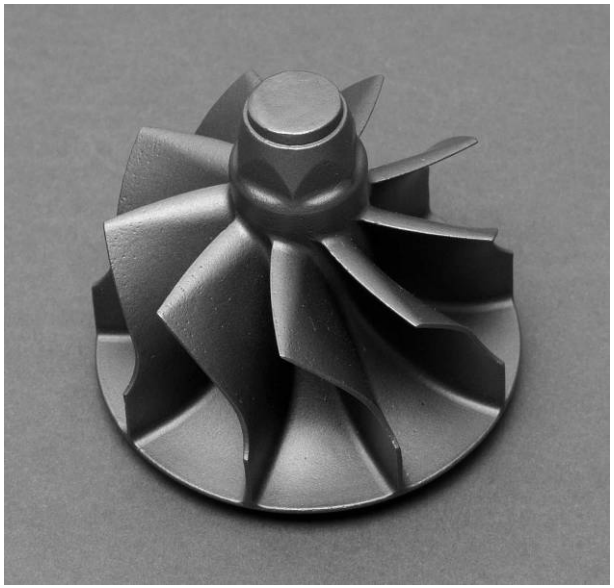


TiAl Investment casting: Cast Turbocharger Wheels



TiAl-Casting

TiAl Investment casting: Surface defect analysis

Typical Casting Defects

spalling

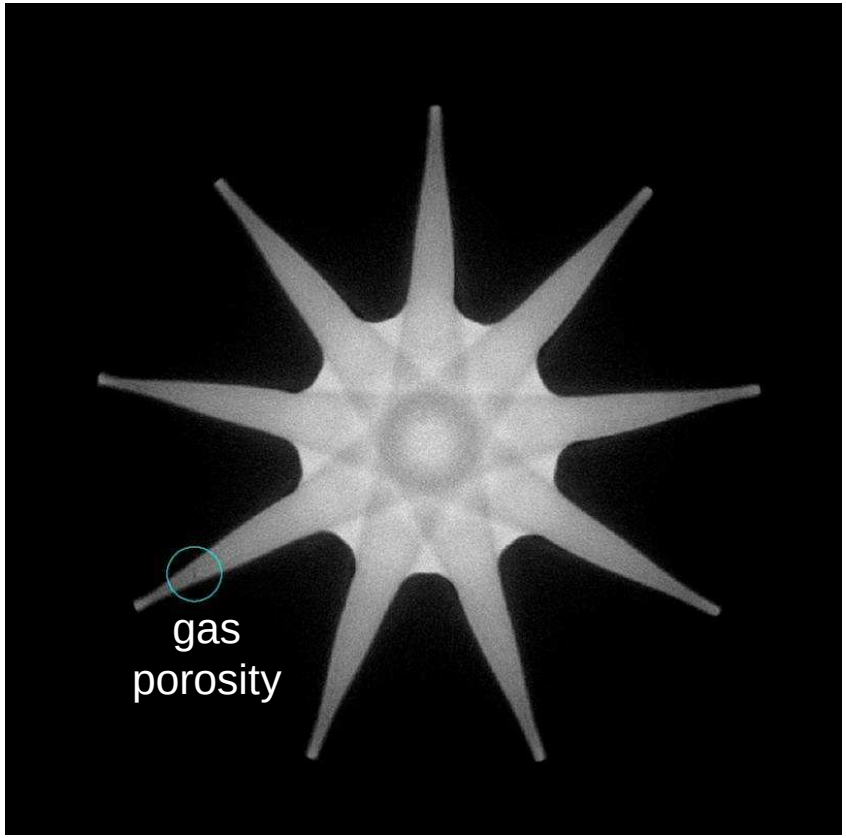
cold run

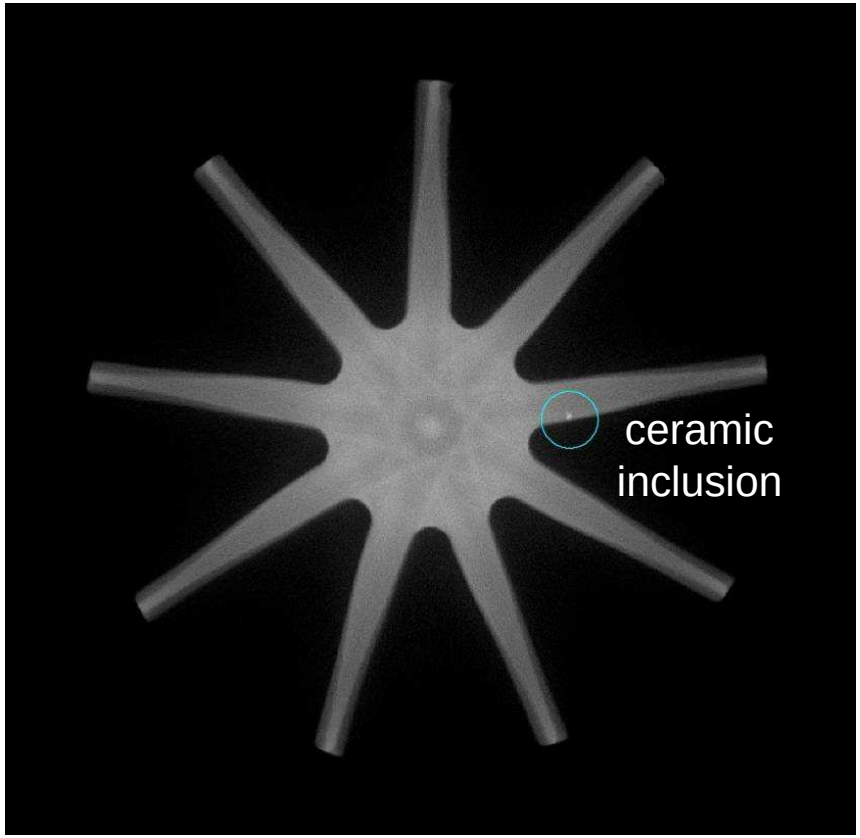
ceramic inclusions

gas porosity

TiAl Investment casting: Internal defect analysis

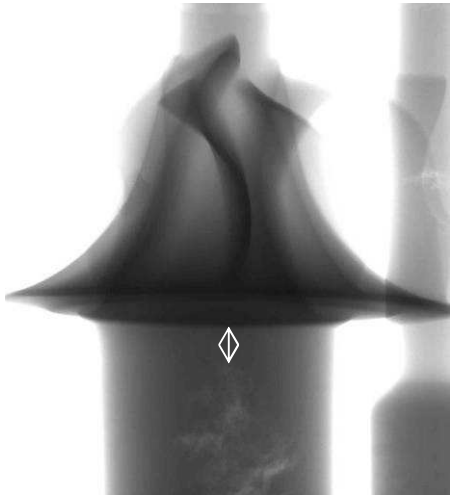
Computer Thomographie



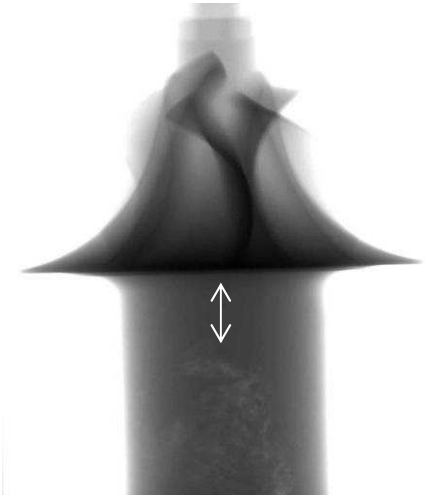


TiAl Investment casting: Internal defect analysis

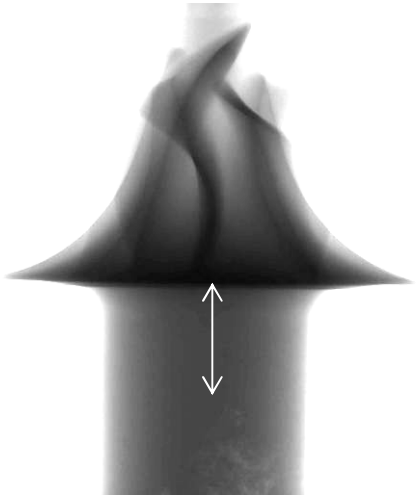
X-Ray Analysis for Process Optimization



Trial A
Shrinkage porosity distance
to wheel back
< 5 mm



Trial B
Shrinkage porosity distance
to wheel back
< 10 mm



Trial C
Shrinkage porosity distance
to wheel back
> 15 mm

Incrementing Rotation Speed (metallostatic pressure)

TiAl Investment casting: Macrostructure Analysis

Turbo charger wheel

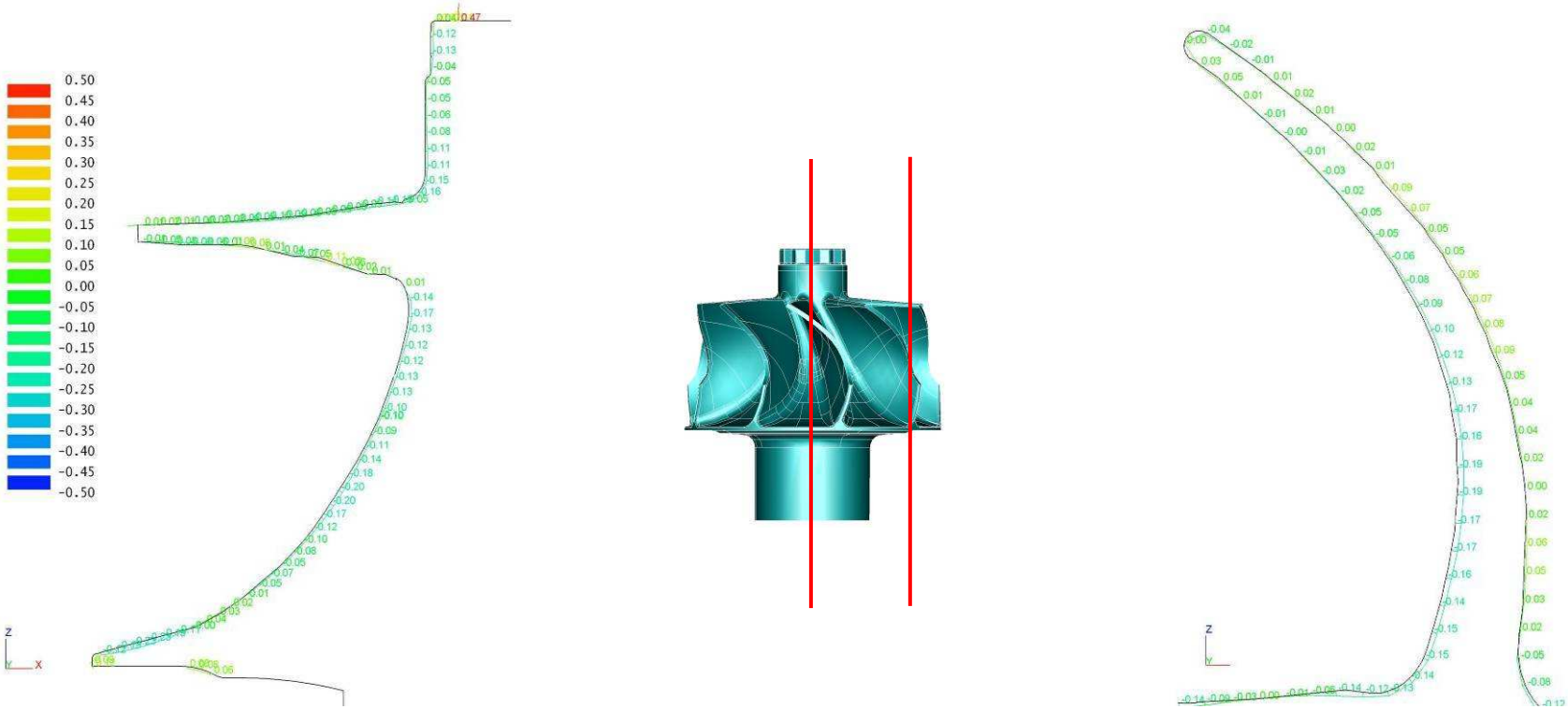
Alloy RNT-650
(Ti-48Al-2Nb-0,75Cr-0,3Si)

- The solidification morphology depends on local cooling conditions (geometry)
- The grain structure (columnar/equiaxed) is sensitively depending on alloy composition
- Grain size and texture have major impact on mechanical properties

TiAl Investment casting: Dimensional Accuracy

Turbocarger Wheel

rotation velocity over 200.000 RPM



xz-Ebene; y=0mm

xz-Ebene; y=15mm

TiAl Investment casting: Yield Improvement

Small Series Production After Process Optimization

- 100 wax patterns — Yield wax: 92/100 or 92,0%
- 15 ceramic shell moulds — Yield Ceramic: 14/15 or 93,3%
- 26 castings — Yield casting: 23*/26 or 88,5%

Overall Yield: $\varepsilon w * \varepsilon sm * \varepsilon c$ 76%

* Good parts complying industry specifications for TiAl Turbocharger wheels

TiAl Investment casting: Yield Improvement

5 Different Compressor Vane Geometries to Establish Production Technology

Stg. 1 variable vane	Stg. 2 single vane	Stg. 3	Stg. 4 segments	Stg. 5

		Stg. 1	Stg. 2	Stg. 3	Stg. 4	Stg. 5
Overall yield	June 2006	10%	24%	25%	16%	20%
	June 2007	---	37%	40%	56%	62%
	March 2008	**40%**	**66%**	**41%**	**52%**	**70%**
Cast parts delivered acc. to spec. for engine tests		47	193	120	106	148

Compressor stator vanes

Process Scale-up For Series Production

Development and commissioning of an automatic casting line in cooperation with LINN HighTherm

- 2 SuperCast centrifugal casting machines
- Advanced automation level
- Continuous heat treatment after casting
- Melting capacity: up to 2 kg
- Productivity: 20 clusters / h

TiAl Investment casting: Conclusions

1. Significant experience with small series production of near net shape aero-engine vanes and turbocharger wheels has been gained.

2. Production scale-up concepts are being qualified for economical production of TiAl components.

3. First European foundrys are willing to take over and establish series production.