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

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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°C-800°C

Investment casting of near net shape parts

- cost-efficient production process
- well established for titanium alloys
- series production of turbocharger wheels in Japan
- world-wide efforts viz. casting aero-engine parts
TiAl Investment casting: Key technological features

Requirements resulting from peculiar properties of TiAl

- Melting
  - induction melting (ISM, ceramic crucible)
  - prevent loss of Al by evaporation and contamination
  - control superheat for optimum mould filling

- Mould filling
  - tranquil mould filling
  - synchronous filling of all parts in a casting cluster
  - directed solidification for porosity management

- Ceramic shell mould
  - gas permeable, shock resistant shell mould
  - chemically inert shell mould surface
  - Abrasion-resistant mould surface
TiAl Investment casting: Overview of process steps

1. Design of wax core
2. Wax core construction
3. Wax pattern manufacturing
4. Ceramic shell mould manufacturing
5. Ceramic shell mould drying
6. Ceramic shell mould inspection
7. Casting and after-treatment
8. Cast part inspection
9. Inspection of cast product
10. Wax and shell mould production
11. Alloy production
12. Casting
13. Quality control

- Visual inspection
- Roughness measurement
- Dimensional accuracy
- X-ray

- Wax and shell mould production
- Alloy production
- Casting
- Quality control
**TiAl Investment casting: Access shell mould system**

**Y₂O₃ face-coat and backup layers**

- Temperature stability up to 1680 °C
- 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: $\Delta T$, $\omega$, 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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TiAl Investment casting: Cast Turbocharger Wheels
TiAl Investment casting: Surface defect analysis

Typical Casting Defects

- Spalling
- Cold run
- Ceramic inclusions
- Gas porosity

powered by technology
TiAl Investment casting: Internal defect analysis

Computer Thomographie

gas porosity

ceramic inclusion
**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)
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: $\epsilon_w*\epsilon_{sm}*\epsilon_c$ 76%

* Good parts complying industry specifications for TiAl Turbocharger wheels
TiAl Investment casting: Yield Improvement

5 Different Compressor Vane Geometries to Establish Production Technology

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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.