γ-PAM: Casting of Near Net Shape Titanium Aluminide Alloy Ingots

Presenter:
Christopher Jackson – Retech Systems LLC, Ukiah, CA  USA

Authors:
Rob Haun – Retech Systems LLC, Ukiah, CA  USA
Patrick Voigt – Titanium Solutions, Bremen, Germany
Overview of Presentation

• Brief introduction

• Production & processing of titanium aluminides

• Future steps
Company Introduction

Engineering, Design & Test Facility
Located in Ukiah, CA, 120 miles north of San Francisco
Disclaimer

Certain of the information presented herein relates to matters that are not historical facts but are forward-looking projections or statements that involve risks and uncertainties associated with melting equipment. Actual and future results could differ materially from any projections or assumptions and the viewer relies on this information at their own risk. Retech assumes no responsibility to update any of this information at any time nor any liability for any damage or loss which may be suffered by any person or company as a consequence of any information presented or any error or omission therefrom.
Motivation

- Fuel efficiency
  - Automotive turbochargers
  - Aerospace low pressure turbine blades
- Replace Ni-base superalloys with titanium alloys
- New higher performance titanium alloys
  - Gamma titanium aluminides ($\gamma$-TiAl)
  - Over 25 years of research & development
- Retech / Titanium Solutions Collaboration
  - Bring $\gamma$-TiAl processing technology to market faster
γ-TiAl: General Information

- High aluminum (Al) content: 28-33 wt.%
- Commonly contain refractory elements such as Cr, Mo, Nb
- About 10% lighter than Ti 6Al 4V, but about 50% lighter than Ni-base superalloys
- Excellent high temperature strength & oxidation resistance
- Poor room temperature ductility
γ-TiAl Production & Processing: Historical Challenges

- Compositions tend to be application specific
  - Ti 48Al 2Cr 2Nb, RNT, γ-Tab, TNB, DAT, 47XD, TNM
- Brittle nature requires new designs & fabrication techniques
- Complex melting technology
  - Vacuum or inert gas procedures
  - Multiple melts required for homogeneity
- High price in comparison to Ni-base
  - <40 €/kg for Ni versus >120 €/kg for TNM ingot
Conventional Production Process

- Titanium – Sponge
- Master alloy compacts welded to make electrodes
- Multiple melting of ingots by VAR
- Consumable casting to bars
- Hot-Isothermal-Pressing
- Forging
- Cast part

Master Alloys (V, Nb, Mo, B) + Aluminum

3x melting means high production costs
Conventional Production Results
Schematic of Conventional Production Process

New melting techniques are required to decrease production costs

HANSEATISCHE WAREN HANDELSGESELLSCHAFT MBH & CO.KG

TITANIUM SOLUTIONS GmbH

This document contains Rotech Systems LLC proprietary information and may not be used or disclosed to others without the expressed written permission of Rotech Systems LLC
γ-PAM: Development Goals

1. Develop small diameter ingot production
   • To minimize yield loss for smaller forged parts
   • For potential use as master alloy casting stock
   • For potential conversion into spherical alloyed powder

2. Single step melting operation
   • Raw materials to ingot
   • Will minimize cost
γ-PAM: Development Goals

3. Commonly issues:
   • Eliminate solidification shrinkage
   • Chemical homogeneity from top to bottom
   • Minimize thermal stresses during solidification & cooling
   • Short bar lengths
   • Good surface finish

4. Abbreviated development cycle – 3 years or less
\( \gamma \)-PAM: New Development
Effective, Low Price Melting of \( \gamma \)-TiAl Alloys

- Titanium-Sponge
- Master alloy compacts
- Master Alloys (V, Nb, Mo, B) + Aluminum
- Plasma arc melt, mix, & sequentially cast small diameter ingot
- Cast part
- Hot-Isothermal-Pressing
- Forging

\textbf{Plasma Arc Melt, mix, & cast } \rightarrow \text{ raw material direct to small diameter ingot}
γ-PAM: New development
Effective, Low Price Melting of γ-TiAl Alloys

- Plasma arc based melting system
- Water-cooled copper melting vessels
- Water-cooled, vacuum sealed melting chamber

Picture of the Pilot Scale Unit
**γ-PAM: Ingots**

**Lengths & Weights**

**Pilot scale production unit:**
- length: 400 mm
- diameter: 53 mm
- weight: ~3.8 kg

**Option pilot scale production unit:**
- length: 600-1,200 mm
- diameter: 53 mm (up to 124 mm)
- weight: ~5.5-11 kg

**High volume series:**
- length: 2,000 mm
- diameter: 53-124 mm
- weight: ~18-99 kg
\(\gamma\)-PAM: TNM Ingots

Chemical Homogeneity Over the Length
γ-PAM: TNM Ingots
Chemical Homogeneity Between Batches

- 0.2 wt.% deviation Al content between TOP & BOTTOM
- Max. ~ 500ppm Oxygen content
γ-PAM: TNM Ingots
Microstructure of As-Cast 53 mm Diameter

Center  Edge

9-17-13

This document contains Retech Systems LLC proprietary information and may not be used or disclosed to others without the expressed written permission of Retech Systems LLC.
γ-PAM: TNM Ingots
As-Cast Grain Size of 53 mm Diameter – Edge

Total Edge 50x c-dict hfFilter

Average Diameter = 18.1 µm

Frequency

Cumulative

HANSEATISCHE
WAREN HANDELSGESELLSCHAFT
MBH & CO.KG

This document contains Retech Systems LLC proprietary information and may not be used or disclosed to others without the expressed written permission of Retech Systems LLC
γ-PAM: TNM Ingots
As-Cast Grain Size of 53 mm Diameter – Center

Average Diameter = 20.6 µm
γ-PAM:
High Volume Production of γ-TiAl

Technical Melting Shop Data:

- 1x PAM-system
  - 2 x Plasma arc torches
  - 1 x mold
  - Melting capacity: ≥ 200t/year

- Workshops:
  - Blending & mixing unit
  - Laboratory
  - Mechanical processing
γ-PAM: Conclusions

• γ-PAM produces
  – TNM, Ti 6Al 4V, Ti 6242, etc. alloy ingots without solidification shrinkage defects
  – Fine, as-cast grain size
  – 53 mm diameter ingots up to 1.200 mm long
  – TNM alloy ingots that meet all chemical & microstructural specifications
  – Excellent feedstock for drip-melt style atomizers for spherical powder

• Pilot scale production unit (γ-PAM5) is installed (up to 25t/year)

  • Conceptual design for high volume production is complete (≥ 200t/year)
Thank You!