ATS-85: Advanced Manufacturing Technology for Single Crystal IGT Components

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Turbine Airfoil Manufacturing Technology

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ATS Phase III Program Introduction

State of the Art

- Directional solidification of components is generated by withdrawing the mold at a controlled rate from a heated susceptor into a cooling cavity
- Heated susceptor and cooling cavity develops a high thermal gradient during withdrawal
- Casting yields on fully developed aircraft gas turbine single crystal casting process exceed 95 percent
- Significantly increased size of IGT components compared to aero-sized components

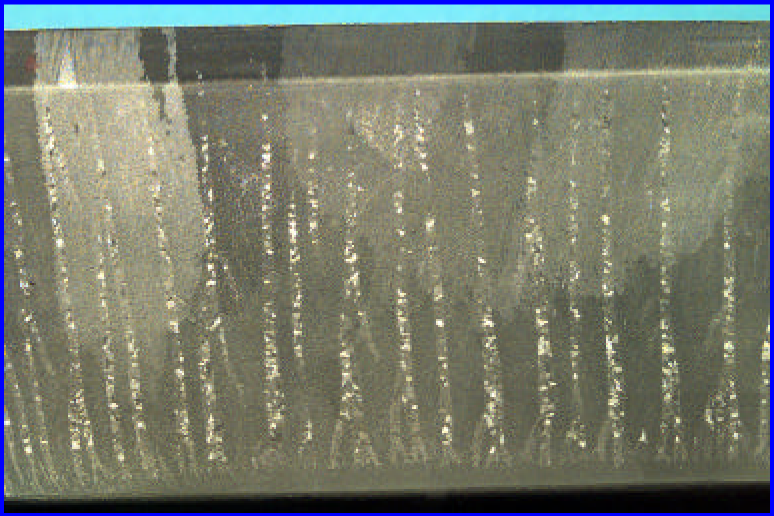
Introduction

Aero-engine/Land Based Turbine Comparison

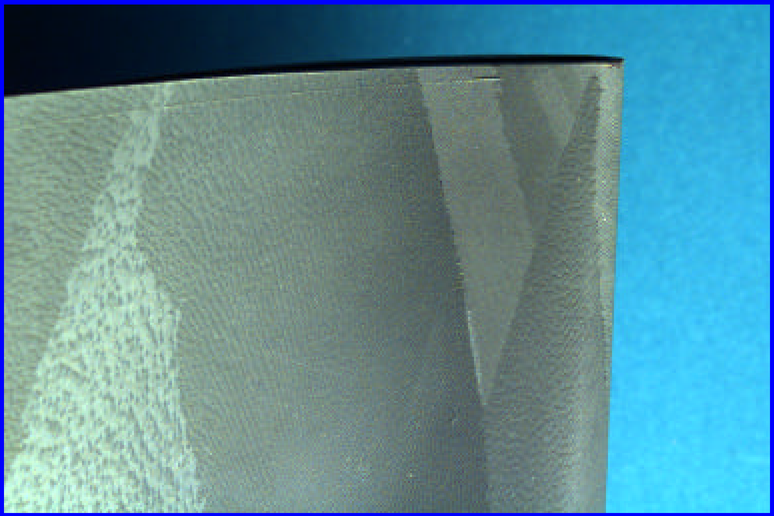
Comparison	Aero	Land Based
– Size differential	1X	2 to 3X
– Weight differential	1X	5 to 10X
– Surface area differential	1X	20 to 100X

Introduction

Casting Defects in IGT Components



Freckle plumes in root



Multiple grain defects in airfoil

Introduction

IGT Casting Difficulties

- Density differences between the interdendritic liquid and the liquid ahead of the interface drive thermosolutal convection and when severe, develops solute plumes
- Freckle defects and macrosegregation then result from the severe solute plumes
- Large cross sections, low thermal gradients, and later generation alloys enhance the tendency to form freckles and segregation
- Increased casting size increase the propensity to form additional grain defects such as high angle boundaries and spurious grains

Introduction

IGT Casting Difficulties (continued)

- Increased casting size also puts additional requirements on the ceramic mold
  - Shell creep due to longer time at temperature
  - Thicker shells reduce thermal gradients
  - Significantly larger and heavier molds lead to structural and handling problems
  - Mold cracking and metal run-outs

Program Objectives

Three Technology Thrust Areas

VIM Furnace Enhancements

- Define furnace enhancements which will improve control of mold temperature and thermal gradient on IGT components

High Conductivity Shell System

- Determine what factors limit shell thermal conductance
- Develop shell to meet needs of high gradient DS/SC casting process

Novel Cooling Development

- Establish & quantify the magnitude of the principle heat transfer modes in an IGT DS/SC casting

Program Approach

Phase II: Feasibility Development

- Evaluate feasibility of improving casting quality in all three technology thrust areas

Phase III: Manufacturing Process Development

- Begin transition of promising, cost effective approaches from Phase II efforts
  - Advanced VIM Furnace Enhancements
  - High Conductivity Shell Systems
  - Novel Cooling System Development

Advanced VIM Furnace Enhancements

Objectives

- Determine furnace enhancements that provide precise control of mold temperatures
- Define process input factors and employ process modeling to evaluate effects
- Validate predictions with experiment

Advanced VIM Furnace Enhancements

Major Efforts

- Benchmark current GEPS 9H 1st Blade
- Susceptor & Baffle material evaluation
- Furnace Control & Configuration Evaluation
- Novel mold designs
- Furnace enhancement modeling
- Production integration efforts
- OEM characterization

Advanced VIM Furnace Enhancements

Status of Efforts

- Benchmark GEPS 9H Blade
  - Comparison of blades cast in production and previous ATS program (PDAS, SDAS, & Freckles)
  - Furnace surveys using GEPS 9H empty mold (Furnace control, susceptor & baffle configuration
  - Solidification model updated to include new control factors and model solved with both empty & filled mold
  - Highly instrumented mold cast to verify model predictions

Advanced VIM Furnace Enhancements

Status of Efforts - continued

- Susceptor & Baffle material evaluation
  - Computer models developed to analyze potential and current susceptor and baffle materials
  - Models solved using
    - Current baffle thermal conductivity and varying thickness
    - Current baffle thickness and varying thermal conductivity
    - Modified baffle designs
  - Thermocouple data compared to predicted profiles & second modeling iteration underway

High Conductivity Shell Systems

Objectives

- Develop shell system with higher heat conduction during metal solidification
  - Improve heat extraction from solidifying metal and increase the gradient at the solidification front
- Develop a shell system that has equivalent or improved creep resistance at casting temperature
- Develop a shell that resists defect formation during production and pattern removal

High Conductivity Shell Systems

Major Efforts

- Thin shell evaluation
- Shell conductivity enhancement
- Shell system integration

High Conductivity Shell Systems

Status of Efforts

- Thin shell evaluations
  - Investigating material additives to strengthen shell and then compare to current shell system and silica shell system
  - Some conditions have shown a 25 to 90% reduction in creep deflection compared to current shell system
  - Some also have non-uniform shrink & expansion which would lead to dimensional variation

  - Continue to evaluate strengthening mechanisms

High Conductivity Shell Systems

Status of Efforts - continued

- Shell conductivity enhancements
  - Investigating material additives to enhance shell thermal conductivity and then compare to current shell system and silica shell system
  - Some conditions have shown up to a 5X improvement in thermal conductivity compared to current shell system
  - But also have limited pot life due to material braekdown

  - Continue to evaluate shell additives for enhances thermal conductivity

Novel Cooling Methods

Objectives

- Establish and quantify magnitude of three principle heat transfer factors
  - Heat transfer between casting and mold
  - Thermal conduction through mold shell
  - Heat removal from mold external surface

Novel Cooling Methods

Major Efforts

- Sensitivity Evaluation of Novel Cooling Techniques
- Novel Cooling Experimental Evaluations
- Novel Cooling Method Feasibility

Novel Cooling Methods

Status of Efforts

- Sensitivity Evaluation
  - Thermal model developed to characterize several different input factors
  - Taguchi L16 model experiment defined
  - Models analyzed using
    - Fraction of solids plot
    - Thermal gradients (G)
    - Solidification Rate (R)
    - Casting mapping factor at center & edge of casting

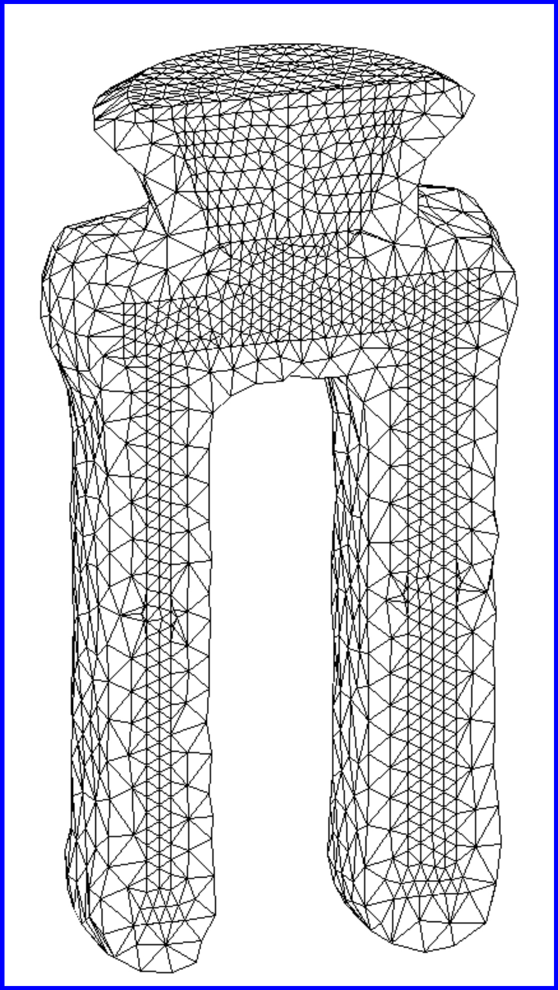
Novel Cooling Methods

Status of Efforts - continued

First Taguchi L16 Factors

Factor	Level 1	Level 2
A: Metal/Mold Interface	Standard	Experimental
B: Shell Emissivity	Standard	Experimental
C: Shell Conductivity	Standard	5X
D: Shell Thickness	Standard	Thin
E: Susceptor Temperature	Standard	Low
F: Baffle Temperature	Standard	Experimental
G: Withdrawal Rate	1X	5X

Model has 1” and 1/2” thick slabs x 12” tall



Novel Cooling Methods

Taguchi Experiment Observations

- Withdrawal rate is a consistently significant factor
- The impact of other factors vary with measured response

Second L16 Taguchi Experiment Begun

Program Summary

- Address freckle defect formation
- Define & evaluate key thermal factors
- Improve current production process & equipment
- Production ready process at end of program