Rapid & Affordable Castings from 3D-Printed Ceramic Molds

ICI Annual Conference
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Introduction to PERFECT-3D and HTCI

Casting Industry Challenge

3D-Printed Ceramic Molds

Ceramic 3D-Printing

Throttle Body Case Study

Summary and Q&A
Introduction to PERFECT-3D and HTCI
Partnered with PCC, one of the largest aerospace investment casting companies, to provide rapid ceramic tooling.

Supported BASF, one of the largest chemical companies, in development of materials for 3D printing of ceramics.

Partnered with Pratt & Whitney to provide 3D-printed ceramic molds and cores.

Funded by the US Air Force to develop methods for providing replacement castings for out-of-production planes & engines.

Conducted cooperative research with Lawrence Livermore National Labs to develop ceramic 3D printing processes.
PERFECT-3D Tooling from Ceramic 3D-Printing

Focus is 3D-printed ceramic components to support investment casting
HTCI Overview

HTCI Company

A Registered AS9100 and ISO9001 Supplier of Aluminum Aerospace & Automotive Castings

12170 Milton-Carlisle Rd.
New Carlisle, Ohio 45344
www.htc-inc.com 937-845-1204
HTCI Processes

- Investment Casting
- Plaster Mold
- Precision Sand Mold
- Rapid Prototyping

NDT Inspection
- Radiographic Inspection
- Penetrant Inspection

Mechanical Testing
- Pressure/Leak Testing
- Tensile Testing
Example HTCI Castings
Casting Industry Challenge
Metal Additive Manufacturing
Metal Additive Manufacturing

- “Using 3D printing instead of investment casting allows processing to occur radically differently, with reduced manufacturing steps and minimum processing waste” – Nature, May 11, 2020

- “Metal additive manufacturing gives us rapid design iterations – months versus years” – Forbes, August 20, 2020

- “Many of the components used in the SpaceX rocket engines were direct metal 3D-printed. It’s become a standard method of producing highly optimized, complex components.” – MSC, February 4, 2020
# Metal Additive vs Investment Casting

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<tr>
<th></th>
<th>Metal Additive</th>
<th>Investment Casting</th>
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<tbody>
<tr>
<td>Lead Times</td>
<td></td>
<td>Longer Wait</td>
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<tr>
<td>Tooling Cost</td>
<td></td>
<td>More Expensive</td>
</tr>
<tr>
<td>Material Cost</td>
<td>More Expensive</td>
<td></td>
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<tr>
<td>Mechanical Properties</td>
<td>Less Predictable</td>
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The challenges is providing quicker response times and lower tooling costs.
3D-Printed Ceramic Molds
Why 3D-Printed Ceramic Molds?

1. Improve yield for part designs that challenge the dipping of traditional 3D-printed patterns

2. Reduce cost and lead time by skipping the standard dipping and dewaxing operations

3. Produce castings from ceramic core-mold combos that can’t be made with traditional methods

Provide capabilities not available via traditional investment casting processes
Traditional Investment Casting Flow

- **Machining Pattern Die**
- **Injecting Wax Patterns**
- **Assembling Wax Mold Tree**
- **Coating with Slurry**
- **Coating with Ceramic**

- **Melting Out Wax**
- **Firing Ceramic Mold Tree**
- **Pouring Metal Into Mold Tree**
- **Removing Ceramic Mold**
- **Cleaning the Castings**
Investment Casting with 3D-Printed Molds

3D Print Ceramic Mold

Pouring Metal Into Mold Tree

Removing Ceramic Mold

Cleaning the Castings
PERFECT-3D
Example 3D-Printed Molds
PERFECT-3D Approach for 3D-Printed Molds

1. Cast Part Model Definition
2. Create Basic Mold Design
3. Design All Ceramic Components for Mold
4. 3D Print All Ceramic Components
5. Post-Process Ceramic Components
6. Assemble Components into Mold
7. Ceramic Mold Ready for Pouring
8. Finished Casting
3D-Printed Ceramic Combo Core-Molds for Airfoils

Core-Lock Pins as Cooling Holes
Airfoils with Cast-In Cooling Holes

3D-printing of combo core-molds is the key enabler for this long-desired capability in cooling of airfoils.

Ceramic 3D-printing also enables shells with selective areas of porosity and thermal properties.

3D-printing of ceramics provides many more advancements for complex casting designs.
Applicability Based on Quantity/Complexity

<table>
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<tr>
<th>Complexity</th>
<th>Volume/Quantity</th>
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<tbody>
<tr>
<td>Low</td>
<td>Ceramic 3D-Printing</td>
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<tr>
<td>High</td>
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Ceramic 3D-Printing
Getting Ready to Share Some of the Secrets of Ceramic 3D-Printing
Vat Photopolymerization 3D Printer

DLP Light Source

Mirror

Elevator

UV Light Bean

Recoater Arm

Cured Part

Build Platform

Ceramic Slurry

Vat

Side View
Ceramic 3D Printing - Generic Process Flow

- Designing
- Mixing
- Printing
- Cleaning
- Finishing
- Firing
- Inspecting
Ceramic Additive Manufacturing

Designing Cores, Molds, Filters for 3D Printing Process
Ceramic Additive Manufacturing

Mixing Special Materials for Ceramic Slurry Made for 3D-Printing
Ceramic Additive Manufacturing

3D-Printing the Ceramic Components
Ceramic Additive Manufacturing

Cleaning the 3D-Printed Ceramic Components
Ceramic Additive Manufacturing

Firing the Ceramic Components for Investment Casting
Ceramic Additive Manufacturing

Performing 3D Inspection on the Ceramic Components
Throttle Body Case Study
Case Study Overview

HTCI Customer - Automotive After-Market Throttle Body

Very Small Quantity Production

Aluminum Alloy

Castings Needed in Weeks

Renaissance Services, PERFECT-3D Division - ICI Conference 2020
Machined Model To Casting Model

Finished Part Model

Casting Model

~ 5”
~ 4”
~ 4”

Added Machining Allowances
Filled Most of the Holes
Casting Model with Initial Gating Design
Evolution to 3D-Printed Mold

- HTC1 Decided to Take Advantage of 3D-Printed Molds
- Complete 3D-Printed Ceramic Mold Assembly
  - Pour Cup
  - Filter
  - Sprue/Manifold
  - Mold

Provide Complete Mold Assembly Read-to-Pour
Second Iteration of Mold Assembly Design

Pour Cup

Filter

Sprue/Manifold

Mold
3D-Printed Mold Components
Interior View of 3D-Printed Mold
3D-Printed Pour Cup & Integral Filter
3D-Printed Ceramic Mold Components
Multiple Components Ready for Assembly
Aluminum from Pour Cup-Filter-Manifold

Pour cup

Filter

Sprue/Manifold
Finished Castings
Redesign of 3D-Printed Mold

Flash Indications were drivers for modifications

Original Design

New Design
Summary and Q&A
Summary

- 3D-printed ceramic molds provide the means to improve yield, reduce lead time, and reduce tooling costs.
- 3D-printed ceramic molds enable production of more complex parts than possible with traditional methods.
- The production of molds is becoming more capable and commonplace as a solution for investment casting.
For Further Information about 3D-Printed Ceramics

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