Enhanced Investment Casting Quality Using 3D-Printed Ceramic Filters

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Topics

- POK Overview
- Ceramic Filters – Purpose & Background
- Problems with Conventional Filters
- Filter Performance Metrics
- 3D-Printed Ceramic Filters
- Summary and Q&A

PERFECT-3D
Dan Z. Sokol

POK - Nucor
Jorge Okhuysen
• Complex Castings and Precision Machining
  ▪ Company founded in 1894
  ▪ Became part of the Nucor family of companies in 2018
  ▪ Currently 460 employees
  ▪ Both sand and investment casting
  ▪ Many innovations in ceramic technology
  ▪ Steel, bronze, and nickel alloys
  ▪ Casting sizes from grams to more than 5 tons
• Involvement with 3D-Printed Filters
  ▪ Greater demands in aerospace
  ▪ Want better filtering capabilities
  ▪ Seeking more consistent flow rates
  ▪ Early tester of 3D-printed filters
Purpose of Ceramic Filters

• Improve yield and reduce cost by:
  - Removing metal contaminants
  - Avoiding non-metallic inclusions

• Source of inclusions:
  - Foundry contaminants
  - Sprues, runners, molds
  - Ladle refractories
  - Oxidation
  - Ceramic filters
How Does a Filter Work?

- **Surface Sieving** – suspended particles greater in size than that of the filter passages, deposit at the filter inlet.

- **Surface Caking** – particles captured at the surface attract other like particles of smaller size.

- **Depth Capturing** – particles smaller in size than the filter passages enter the filter pathway and adhere to the walls & ligaments.
Casting Filter Types

Types are Typically Defined by Location in Metal Distribution System

- **Pour Cup**
  - Typically 2.0” to 4.0”

- **In-Line**
  - Typically 3.0” to 6.0”

- **Gate**
  - Typically 0.5” to 1.0”
Evolution of Ceramic Filters

**Extruded Filter**

1\textsuperscript{st} Generation

**Foam Filter**

2\textsuperscript{nd} Generation

**3D-Printed Filter**

3\textsuperscript{rd} Generation
• Filters are typically treated as a commodity by the purchasing department, which picks the low bidder

• Use of filters on specific mold trees is typically a decision for the process engineer

• Typical evaluation approach is not sophisticated

“If we have a problem in making a casting, we’ll throw a filter on the mold tree... or if we already have a filter, we’ll remove it and pour without a filter”
• Filtering is primarily surface sieving which limits effectiveness
• Large changes in flow rates from clogging pores leads to scrap

• Filter breaks down due to small fragile tendrils
• Introduces inclusions leading to scrap and rework
Filter Performance Metrics

1. **Capturing** – Ensuring the capture of any contaminants

2. **Flowing** – Providing consistent metal flow rates

3. **Containing** – Avoiding breakdown of ceramic filter & mold

4. **Smoothing** – Providing a consistent laminar flow of metal
<table>
<thead>
<tr>
<th>Objective</th>
<th>Testing/Evaluation Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Capturing</td>
<td>Controlled testing in casting apparatus</td>
</tr>
<tr>
<td>2. Flowing</td>
<td>Flow rate testing machine</td>
</tr>
<tr>
<td>3. Containing</td>
<td>Material mass &amp; temperature impact testing</td>
</tr>
<tr>
<td>4. Smoothing</td>
<td>High speed videography during flow testing</td>
</tr>
</tbody>
</table>
1. Capturing

Filter testing using castings and FPI evaluation for inclusions
• Foam filters are created by a non-deterministic process that creates random passages for the filtering structure

• A torturous path through the filter body is the fundamental basis for capturing contaminants

• A 3D-printed engineered filter can be crafted to create pre-determined tortuous passages through the filter body
2. Flowing

- Flow rate has commonly been expressed as PPI (pores per inch) for foam filters.
- PPI is useful for broad idea of flow rate but not precise enough for emerging demands.
- Filter flow rate needs to be defined as volume/mass of material per time unit.

Pores Per Inch
2. Flowing

Flow Testing Machine

- Precisely measures the flow rate of water through ceramic filters of various sizes using modern equipment.
- Machine also provides high-speed videography of liquid exiting filter to help determine “smoothing” performance.
2. Flowing

- Foam filters are created by a non-deterministic process that creates random passages for the filtering structure.

- A consistent flow rate of metal through the filters is critical for removing variation from the casting process.

- A 3D-printed engineered filter can be crafted to ensure repeatable and consistent metal flow rates.

### Comparison of Flow Variation for Foam Filter vs 3D-Printed Filter

[Diagram showing comparison of flow variation]
• Conventional foam filters contain many tendrils/tentacles that are fragile and often break-off into the metal flow

• A stable filter structure is critical to ensure that contaminants are not introduced by the filtering construction

• A 3D-printed engineered filter can be crafted to ensure that the filter structure does not breakdown during the metal flow
3. Containing

High-Temperature Superalloy Test Pour at POK

3D-Printed Filter

Extruded Filter
4. Smoothing

- Standard filters split the pour into individual streams that can potentially increase surface area and create erosive flow on sprues/runners.

- A stable laminar metal flow prevents air from getting into the molten metal, which reduces oxidation and porosity.

- A 3D-printed engineered filter can be crafted to ensure that the filter output maintains a smooth laminar flow.
### Key Design Features – 3D-Printed Filters

<table>
<thead>
<tr>
<th>Objective</th>
<th>Design Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Capturing</td>
<td>Stable torturous pathways through the filter</td>
</tr>
<tr>
<td>2. Flowing</td>
<td>Well-defined and consistent filter passages</td>
</tr>
<tr>
<td>3. Containing</td>
<td>Strong multi-stage filter levels and ligaments</td>
</tr>
<tr>
<td>4. Smoothing</td>
<td>Guided ligaments to vector output from filter exits</td>
</tr>
</tbody>
</table>
3D-Printed Filter Design

- Strong multi-stage levels
- Stable & consistent torturous pathways
- Entry & Exit regions to direct flow

US Patent Pending
### 3D-Printed Filters - Evaluation Sites

<table>
<thead>
<tr>
<th>Foundry</th>
<th>Metal</th>
<th>Mold Location</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>POK - Nucor</td>
<td>Nickel</td>
<td>Pour Cup</td>
<td>2.5” dia.</td>
</tr>
<tr>
<td>Foundry 2</td>
<td>Nickel</td>
<td>Pour Cup</td>
<td>3.3” dia.</td>
</tr>
<tr>
<td>Foundry 3</td>
<td>Nickel</td>
<td>Pour Cup</td>
<td>5.0” dia.</td>
</tr>
<tr>
<td>Foundry 4</td>
<td>Nickel</td>
<td>Gate</td>
<td>1.0” dia.</td>
</tr>
<tr>
<td>Foundry 5</td>
<td>Steel</td>
<td>Pour Cup</td>
<td>3.5” dia.</td>
</tr>
<tr>
<td>Foundry 6</td>
<td>Steel</td>
<td>Pour Cup</td>
<td>2.0” dia.</td>
</tr>
<tr>
<td>Foundry 7</td>
<td>Aluminum</td>
<td>In-Line</td>
<td>2.0” x 2.0”</td>
</tr>
<tr>
<td>Foundry 8</td>
<td>Aluminum</td>
<td>In-Line</td>
<td>2.0” x 2.0”</td>
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Evaluate 3D-Printed Filters in Production Environment
The use of ceramic filters for investment casting has steadily increased and is now becoming very common.

One key to the Renaissance/PERFECT-3D effort has been the focus on an objective evaluation of filter performance.

Engineered 3D-printed filters have superior performance versus conventional extruded and foam filters:
- Conducted detailed testing of the performance metrics for 3D-printed ceramic filters versus conventional filters.
- Current production testing and validation with 8 different foundries across North America and Europe.