the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Advanced Filtration to Improve Single Crystal Casting Yield—Mikro Systems

Background

Single crystal (SX) nickel superalloys are a primary material choice for gas turbine hot gas path component castings because of their high resistance to deformation at elevated temperatures. However, the casting yields of these components need to be improved in order to reduce costs and encourage more widespread use within the gas turbine industry. Low yields have been associated with a number of process-related defects common to the conventional casting of SX components. One innovative improvement, advanced casting filter designs, has been identified as a potential path toward increasing the yield rates of SX castings for high-temperature gas turbine applications.

Mikro Systems, Inc. (Mikro) proposes to increase SX casting yields by developing advanced ceramic casting filters that will optimize filtration performance while enabling directional flow of molten alloy during the SX casting process. These performance advantages will be enabled through the geometric design of the filter.

This turbine project was competitively selected under the Small Business Innovative Research (SBIR) Program. It is managed by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL). NETL is researching advanced turbine technology with the goal of producing reliable, affordable, and environmentally friendly electric power in response to the nation's increasing energy challenges. With the Hydrogen Turbine Program, NETL is leading the research, development, and demonstration of these technologies to achieve power production from high-hydrogen-content fuels derived from coal that is clean, efficient, and cost effective, minimizes carbon dioxide (CO_2) emissions, and will help maintain the nation's leadership in the export of gas turbine equipment.

Project Description

Mikro will apply their Tomo-Lithographic Molding (TOMO™) manufacturing platform to improve the SX investment casting process through the development of engineered ceramic filters for SX metal casting. Mikro will design an engineered filtration system comprising a primary central filter (located in the pour cup of the mold tree) and a series of secondary in-line filters that are placed before or within each shell within the mold tree. The primary and secondary filters will be designed to work together to effectively control the metal flow for specific airfoil geometries. The filter designs will utilize flow properties (rate and directionality) based on empirical data derived from existing casting production and theoretical data from casting simulation and flow testing. Filtration performance will be baselined using industry standards and optimized through Mikro's ability to form highly engineered surfaces and geometries from ceramics.

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PCC Airfoils

PROJECT DURATION

Start Date	**End Date**
06/26/2012	08/13/2015

COST

Total Project Value

$1,149,748

DOE/Non-DOE Share

$1,149,748 / $0

AWARD NUMBER

SC0008266

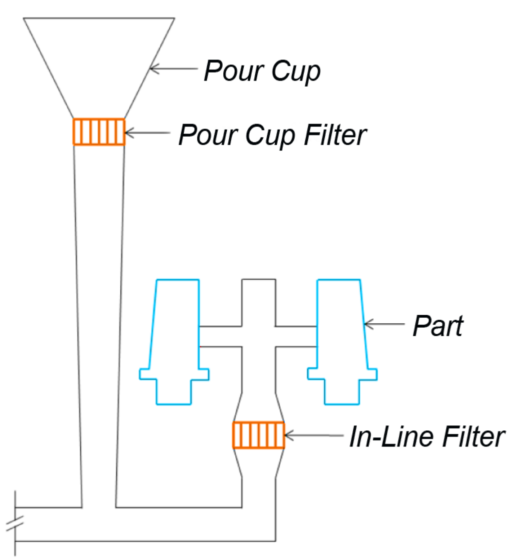
U.S. DEPARTMENT OF ENERGY

Casting filter designs remain very conventional, with no specific engineering consideration for SX castings. Low yields have been associated with a number of process-related defects, and foundry experts estimate that over $7 million per year in scrap castings are due to inclusions that could be prevented with advanced filtering.

Goals and Objectives

The goal of this project is to increase SX casting yields through the development of engineered advanced geometry ceramic filters for metal castings. During Phase I Mikro demonstrated the technical feasibility of producing advanced designs for pour cup and inline filters using TOMO. Until now, these designs could not be produced due to limitations in current manufacturing methods. Flow tests of Mikro filters demonstrated much lower variability in flow rate and pressure drop from filter-to-filter compared with off-the-shelf filters. The Phase II goal is to build upon Phase I results and further develop/optimize the TOMO process for manufacturing advanced ceramic filters. Phase II objectives include the following:

- Develop a ceramic material system for filters that meets or exceeds foundry requirements for SX casting.
- Further develop and refine the protocols and systems (bench rig and computer simulation) for testing new filter designs for SX foundry casting
- Design, produce and test optimized SX ceramic filters that outperform current state-of-the-art products. SX cast and analyze a small number of complex turbine blades using the Phase II filters
- Develop a business case for producing advanced ceramic filters that are cost competitive with industry standard products.



Mold tree schematic.

Accomplishments

- Two types of production secondary filter parts have been obtained from PCC's foundry and examined at Mikro. Neither of the two production options for filtration available to the market today fully satisfies the needs of the foundry. The foam filter is an effective filter with a torturous path and high surface area, but is non-uniform and prone to damage. The extruded filter is robust and uniform, but is not as effective at removing impurities. The cast TOMO filter has the potential of providing the best of both conditions with a uniform engineered complex internal structure.
- Primary filters consisting of three different designs were CAD modeled, tooling was fabricated, and two of each design were produced at Mikro.
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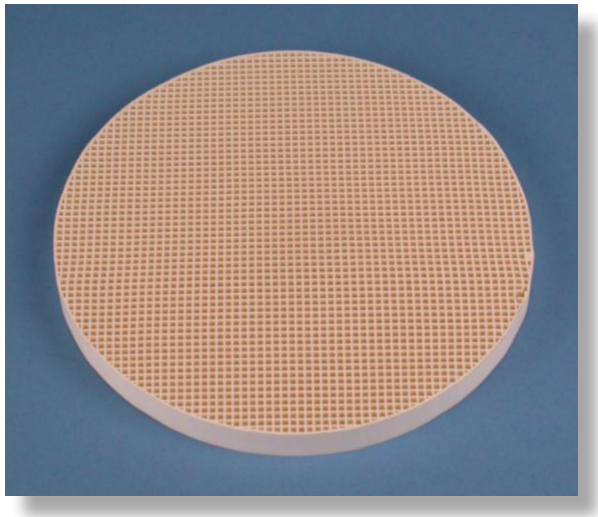
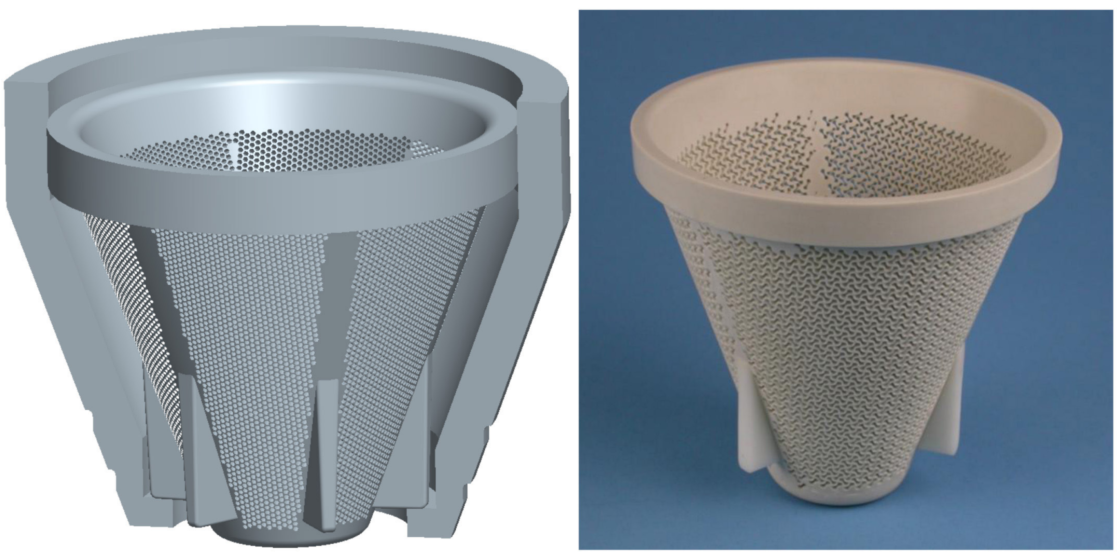
- Specifications for a water test unit were acquired and constructed by an outside test facility. The rig contained pressure sensors to determine flow resistance, and dye injection points to visually evaluate flow turbulence.
- The in-line (secondary) filters produced at Mikro have been flow tested against two different production filter types. The results show a much greater uniformity of the cast TOMO parts as compared to the standards.
- Awarded Phase II SBIR.

Benefits

This SBIR project supports DOE's Hydrogen Turbine Program, which is striving to show that gas turbines can operate on coal-based hydrogen fuels, increase combined cycle efficiency by three to five percentage points over baseline, and reduce emissions. The SBIR program is positioned to leverage the agility and innovative competencies of small businesses. An advanced ceramic filtration system enabled by Mikro's TOMO manufacturing technology will embody internal filtration and flow features that are beyond current state-of-the-art systems. This will improve casting yield, lower the cost, and remove a primary obstacle to more widespread use of SX casting for industrial gas turbines and other critical investment-cast products.



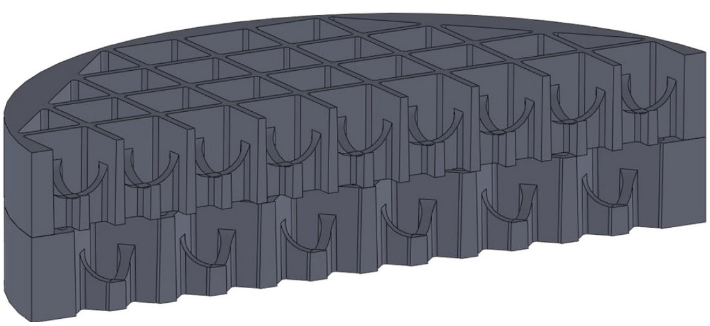
Industry standard flat primary filter.

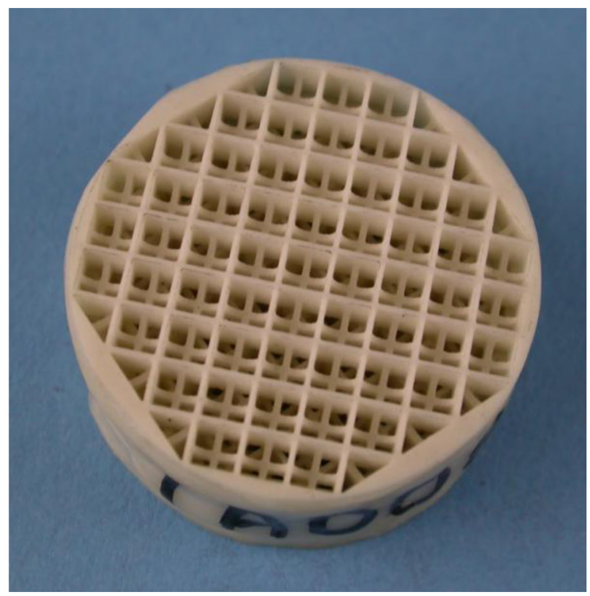


Conical pour cup (primary) filters produced by TOMO during Phase I.

- *3 filter variants*
- *Can be nested to contain multiple geometries to create tortuous path for effective filtration*
- *Conical shape increases available surface area by 7X over current disc filter*
- *Can contain sidewall features*
- *Point blockage causes less disturbance to output flow pattern*

Industry standard in-line filters – fine structures break and cause incusions in castings





In-line (secondary) filters produced by TOMO during Phase I.

- *Support features are designed into castings*
- *Filter design stronger and less susceptible to thermal shock*
- *Geometric pattern makes flow uniform across filter*