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Rapid Production Using Additive Manufacturing (AM) / Digital Tooling

Jerry Thiel, Nathaniel Bryant, Sairam Ravi
University of Northern Iowa

Innovative Casting Technologies (ICT)

AMC Technology Review

August 18-20, 2022

UNI University of Northern Iowa

SFSA

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Research Overview

Duration

1	2	3	4	5

- **Needs/Benefits – DPICS / Ceramic Cooling Channel Cores**
  - Increased supply chain ability to respond quickly to DLA casting acquisition requests.
  - Minimize NRE tooling cost, logistics, maintenance, storage, and casting delivery lead-times
  - DoD / Commercial Dual Use technology applications

- **Progress**
  - Material testing phase has been completed for both research areas
  - Preliminary testing has begun with positive results
  - Equipment delays have been addressed and part printing has started
  - In plant foundry trial results have been positive

- **Transition**
  - Three steel foundries have agreed to partner on casting trials
  - The technology will be presented at the SFSA T&O conference when complete

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Objective

- ***Problem***
  - Acquisition of legacy cast components is one of the DLA's leading challenges. The longer a cast component has been out of production, the more difficult it becomes to source replacement components rendering many weapons platforms unusable.
  - Alternate manufacturing processes such as machining or direct printing are costly and require new first article acceptance standards to be developed.
  - Tooling for legacy investment castings are often difficult to locate. New tooling for manufacturing investment casting patterns is often expensive and requires significant lead-times. Differences in supply chain manufacturing equipment often require reworking or replacement of existing tooling if available.
- ***Objective***
  - Minimize costs and lead times required for castings by utilizing AM
  - Benchmark state of the industry for AM technology
  - Review of current and past additive / new technology for investment castings
  - Improve surface roughness of castings produced using printed sand
  - Improve / develop process to produce ink jet powder bed printed casting shells for investment metal casting applications
  - Increase current casting capabilities allowing for improved quality and flexibility of design

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The Technology to Be Developed

- Direct Printing of Investment Casting Molds and Cores (DPIC)
  - Modifications of methods and materials to allow 3D printing of Ceramic Shells for Investment Castings
- In-situ ceramics for cooling channel cores
  - Post processing of printed cores to increase strength and resistance to thermal distortion to allow high length to diameter internal cavities to be cast

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Needs and Benefits

DLA / DoD:

- Decrease of “No Quote” on cast component acquisition
- Identification of possible supply chain partners using AM4MC
- Elimination of non-recurring engineering costs (NRE) associated with hard tooling
- Faster response for sustainment of weapon systems yielding longer service life for existing platforms

Foundry / Casting Supplier / Industry:

- Increased ability to meet DLA needs in a timely and cost effective manner
- AM4MC compresses time required for cost estimates and production
- Development of casting supply chain through training and demonstrations

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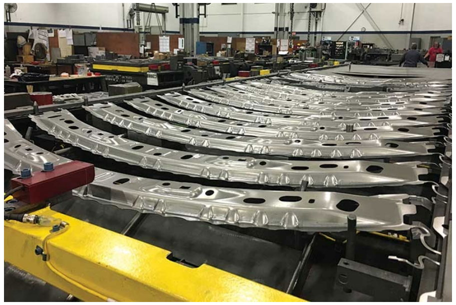
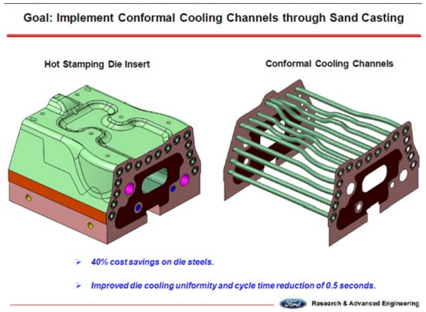
Needs and Benefits

Foundry / Casting Supplier / Industry:

- Improved Cooling channel cores will:
- Decrease stamping dies cost by as much as 40%
- Allow for improved mechanical properties, faster cycle times and lighter weights for structural components
- Allow additive manufacturing to be used on pipe cores for aerospace castings such as gearboxes for the CH-53 Sea Stallion
- Allow for Cast steel dies to be used in plastic injection molding and die casting





Ford

SIKORSKY
A LOCKHEED MARTIN COMPANY

BOEING

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Two Areas of Research

- Direct Printing of Investment Casting Molds and Cores (DPIC)
- In-situ ceramics for cooling channel cores

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Progress to Date

- Several refractory materials have been tested and have been modified to work in binderjet printers.
- Several resins have been tested and modified to work in binderjet printers.
- Ready to print DPIC samples, sinter and cast.
- Favorable preliminary results in cooling channel cores. Preliminary success in DoD weapon system casting.
- In plant foundry trial results have been positive.

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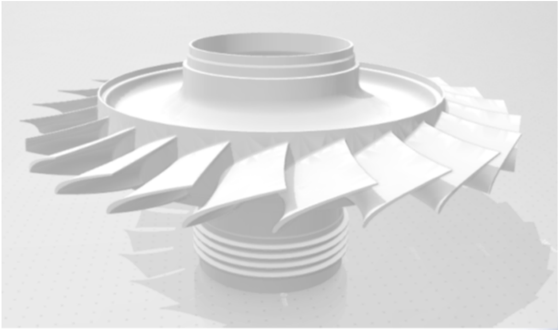
Advantages to Printing of IC Shells (DPIC)

	Time required	Conventional IC	3d Printed patterns	3D printed Shells
Drawing Evaluation	1 week		1 to 2 days	1 to 2 days
Tooling design	1 – 4 weeks		1 to 2 weeks	1 to 2 days
Tooling Manufacture	16 to 32 weeks		Not required	Not required
Wax Injection	1 day		Not required	Not required
Cluster Assembly	1 day to 1 week			Not required
Slurry Coating	3 to 5 days			Not required
Stuccoing	2 to 4 days			Not required
Dewaxing	1 day			Not required
Firing	1 day			
Casting	Same day			
Total Lead Time		20 to 40 weeks	3 to 5-1/2 weeks	1 week



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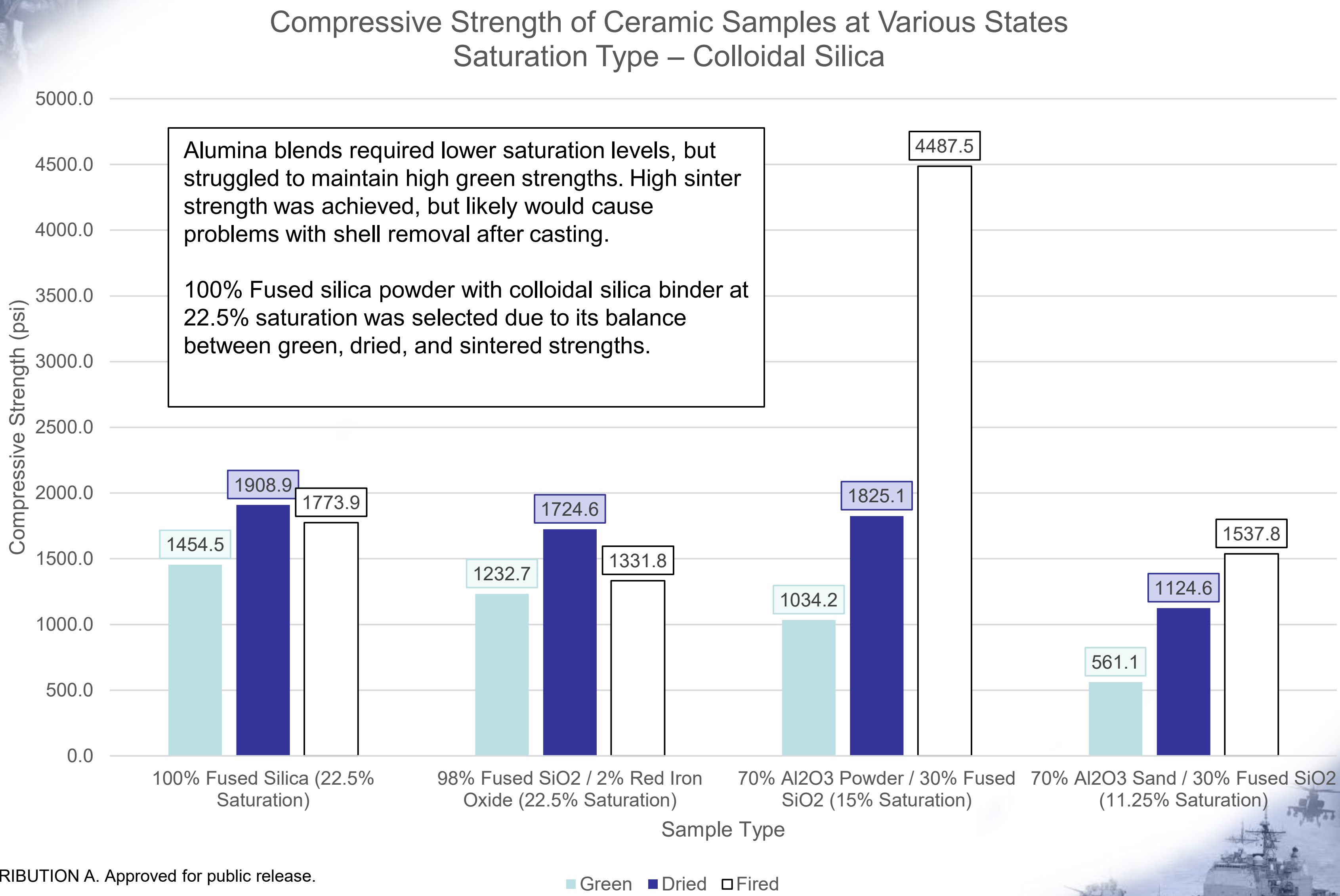
Material Characterization Rammed Samples



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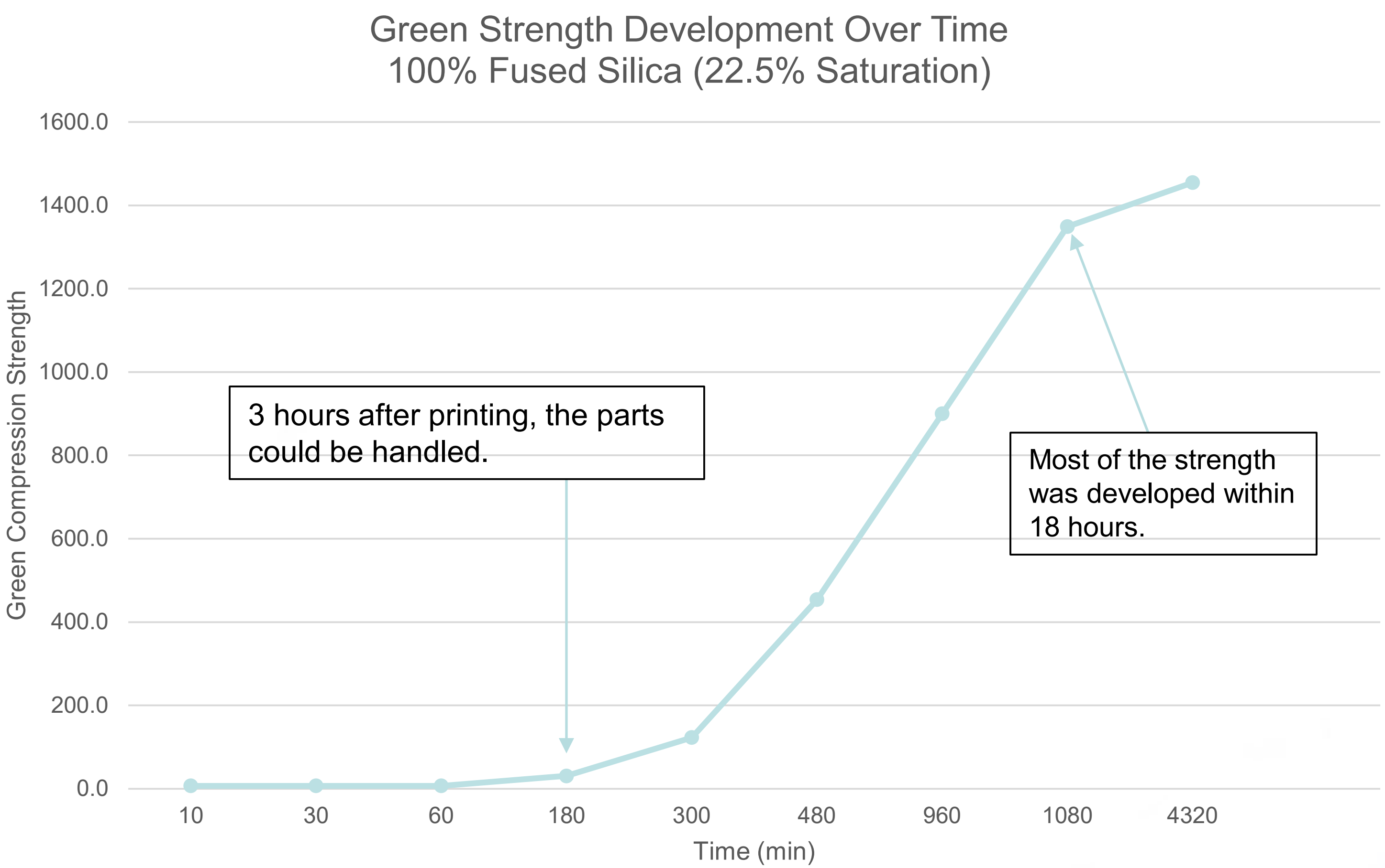
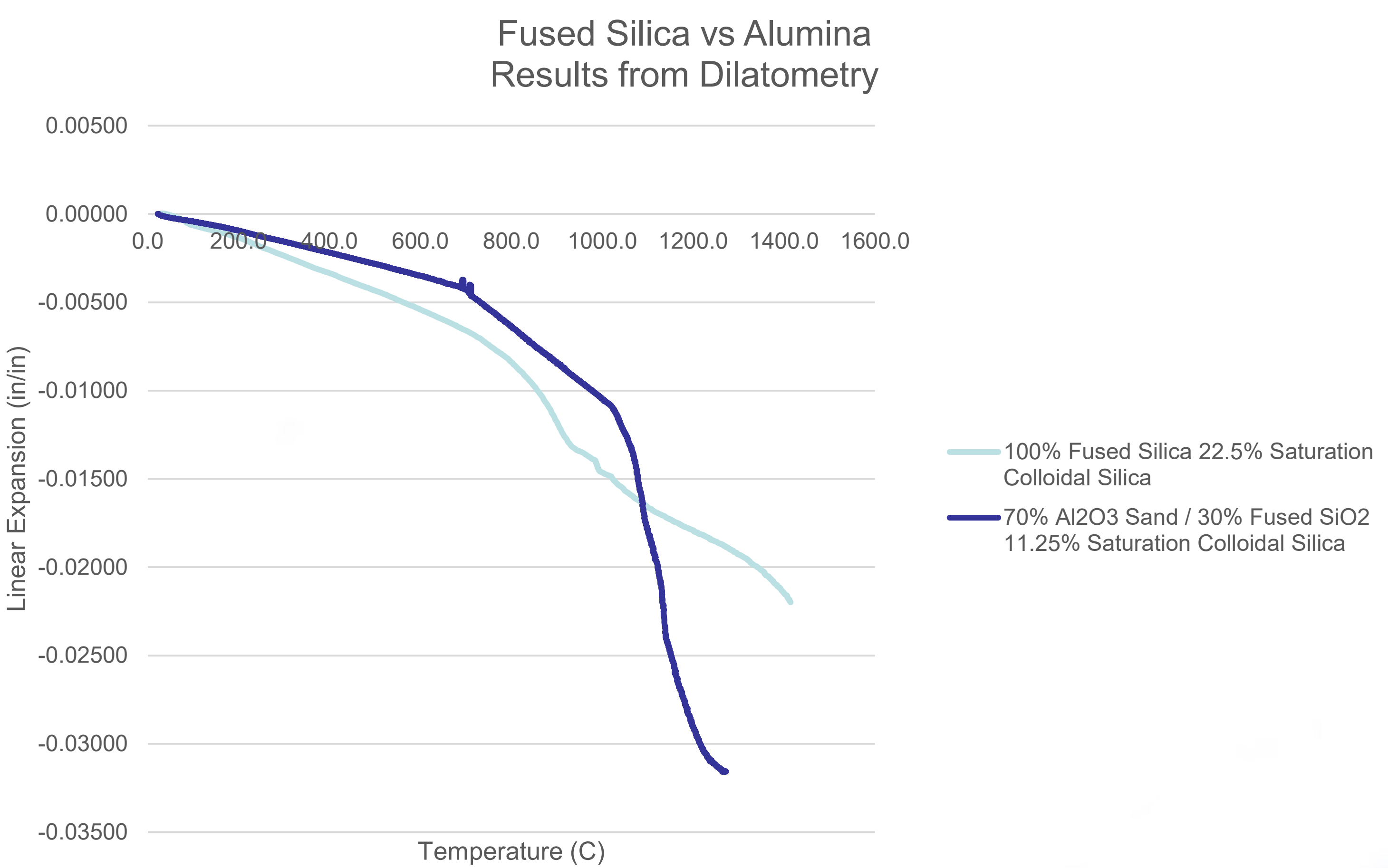
Green Strength Development



Thermal Expansion Results



Initial Printing Trials

- This CJP-660 unit from 3D systems was used initially.
- Typically, this machine prints water-based inks onto gypsum powder.
- Jetting issues with colloidal silica.
- Other binders didn't have adequate strength.

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Further Printing Trials

- X1 Innovent unit from ExOne
- Typically used for binder jet printing of metal powders.
- Uses a glycol based binder system.

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Fused Silica Printing

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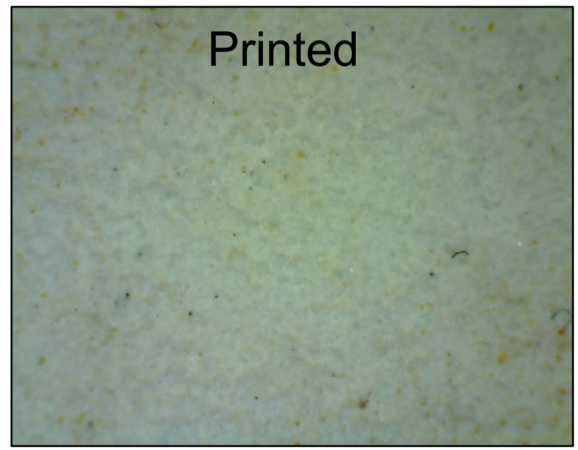
Density Problems

- The resultant sintered strength of the printed fused silica specimen was very low. Only 41.6psi in tensile.
- Possibly due to lowered density from rammed to printed method. (Table)
- Lower density makes it more difficult to effectively sinter the material. (Images)

RP1 Sintered Density Calculations		
Property	Rammed	Printed
Mass (g)	96.961	14.147
Volume (cc)	78.822	15.248
Density (g/cc)	1.230	0.928



Sintered at the same temperature (1300C)

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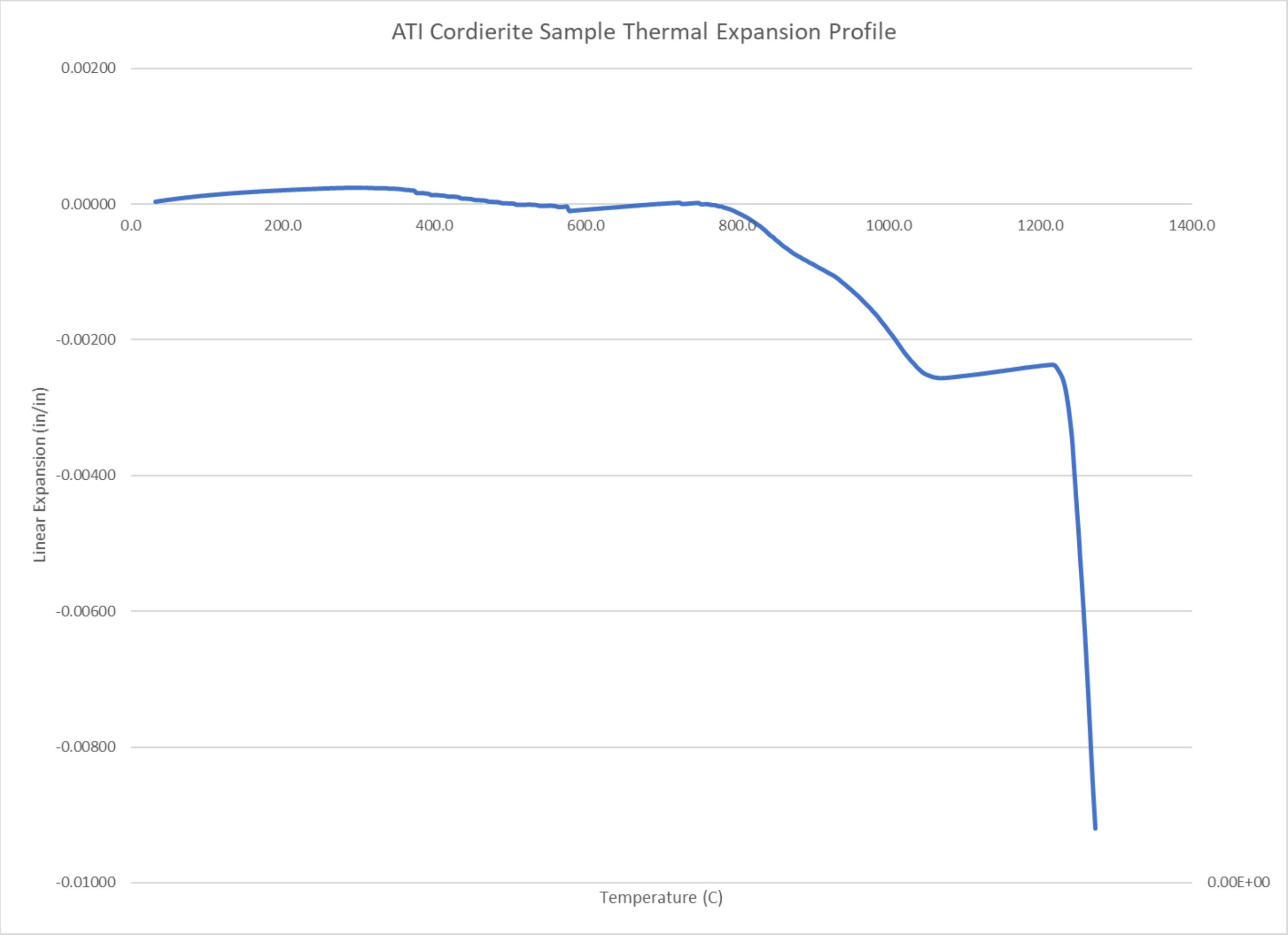
Improving Printed Density with Material Blends

- Target material:
  - Cordierite - $Mg_2Al_3(Si_5AlO_{18})$
- The printed density of cordierite was similar to rammed fused silica.

Material	Fused Silica		Cordierite	
Method	Printed	Rammed	Printed	Rammed
Density (g/cc)	0.928	1.23	1.333	1.72

Thermal Expansion of Cordierite Precursor Material



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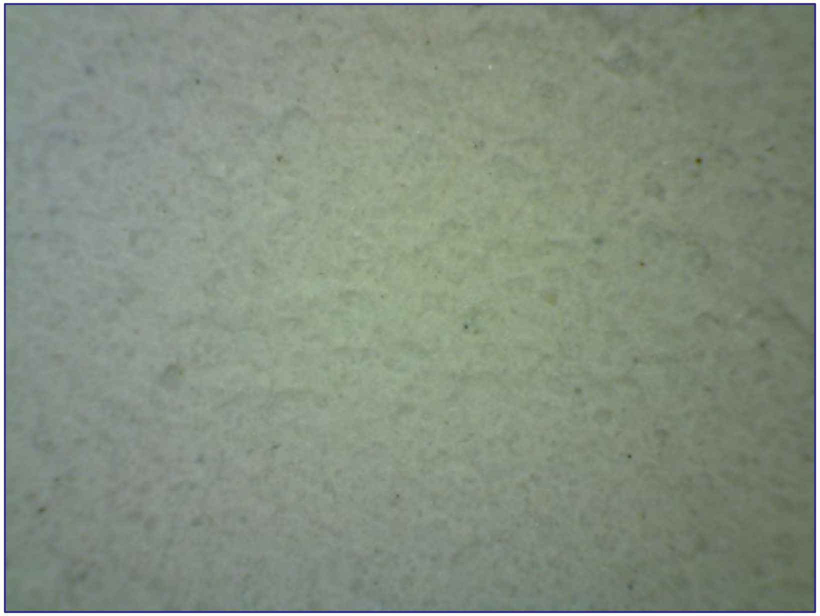
Transformation of Cordierite from Dried to Sintered State

Dried at 140C



Sintered at 1280C

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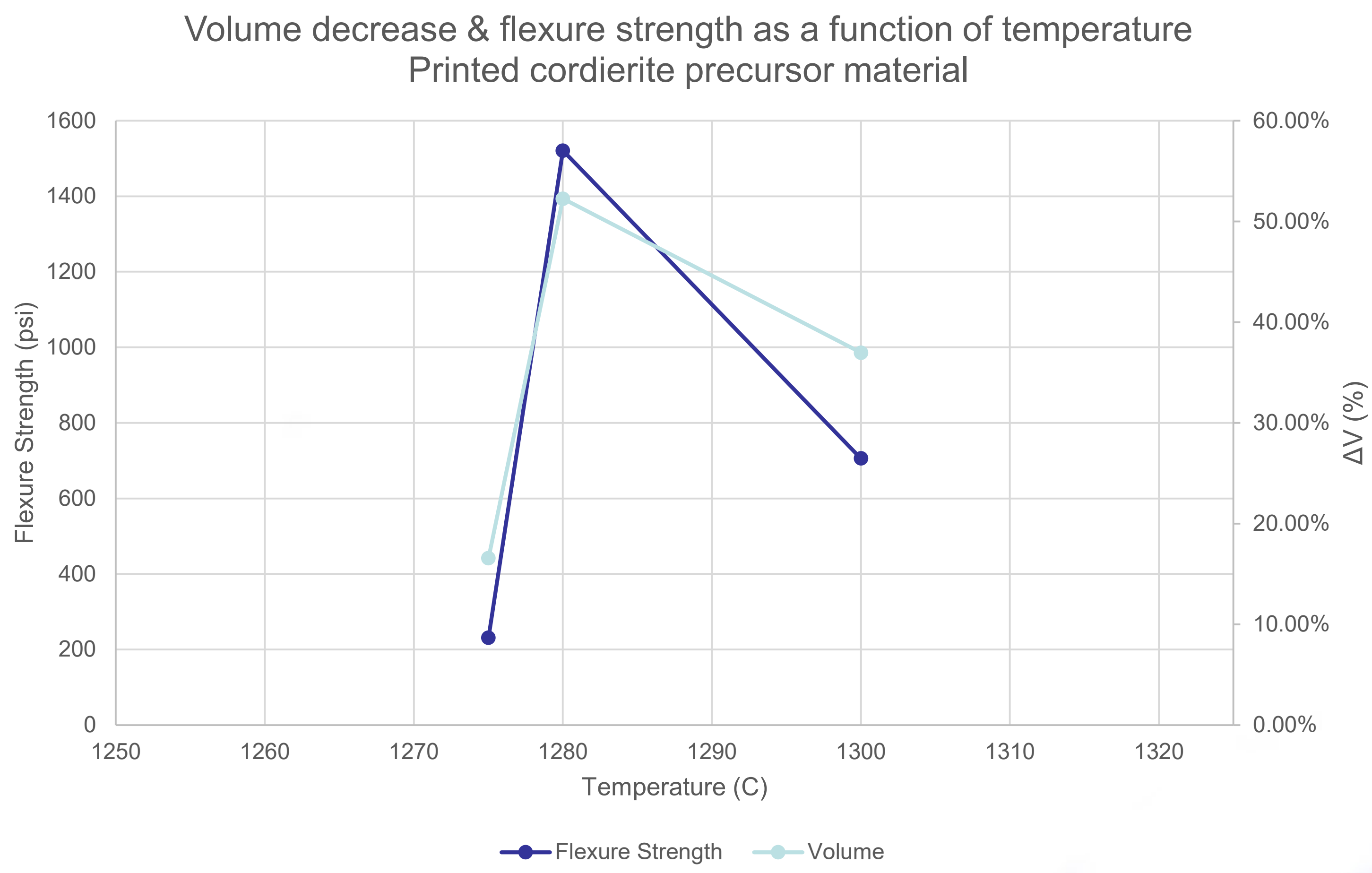
Investigation of Ultimate Sinter Temps



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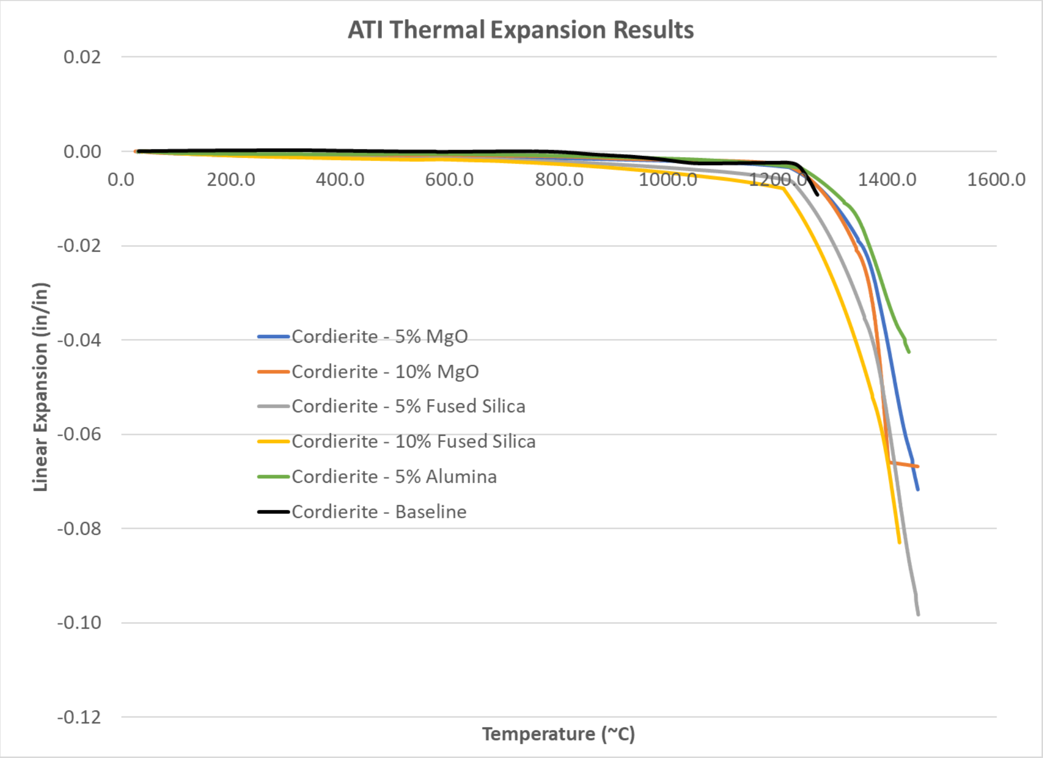
Further Dilatometry Results

- Printing trials utilized a stoichiometric balance in the precursor mineral to make cordierite after sintering.
- Experiments were conducted to understand the effect of each constituent on the sintering characteristics.
- In general,
  - Alumina increases sinter temperature
  - Magnesia and silica reduce sinter temperature



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In-situ Ceramics for Cooling Channel Cores

- Steel dies for hot stamping operations, plastic injection or die casting require extensive machining to provide cooling channels for temperature control
- Gun drilling typically used to create long passages does not allow close conformance to the surface of the die and limits efficiency
- Chemically bonded sands with high length to diameter ratios do not posses the necessary strength to remain ridged during casting operations

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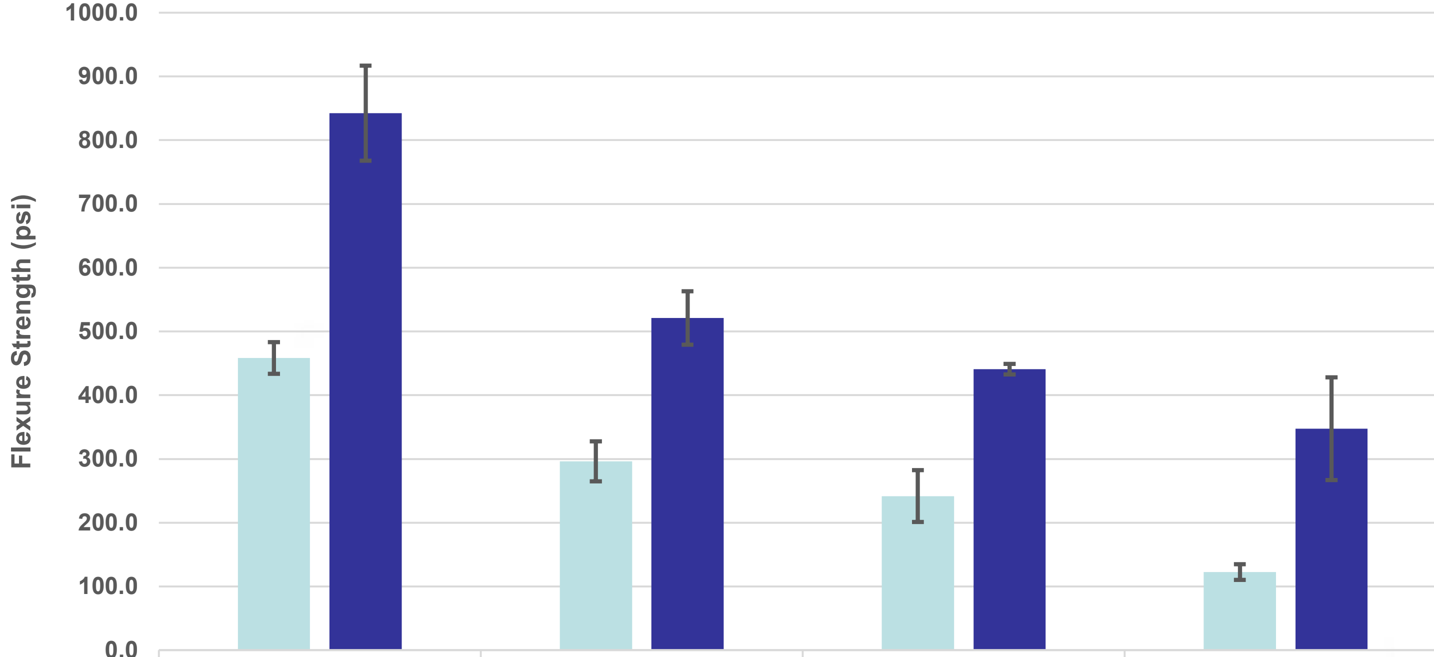
High Temperature Strength Comparison

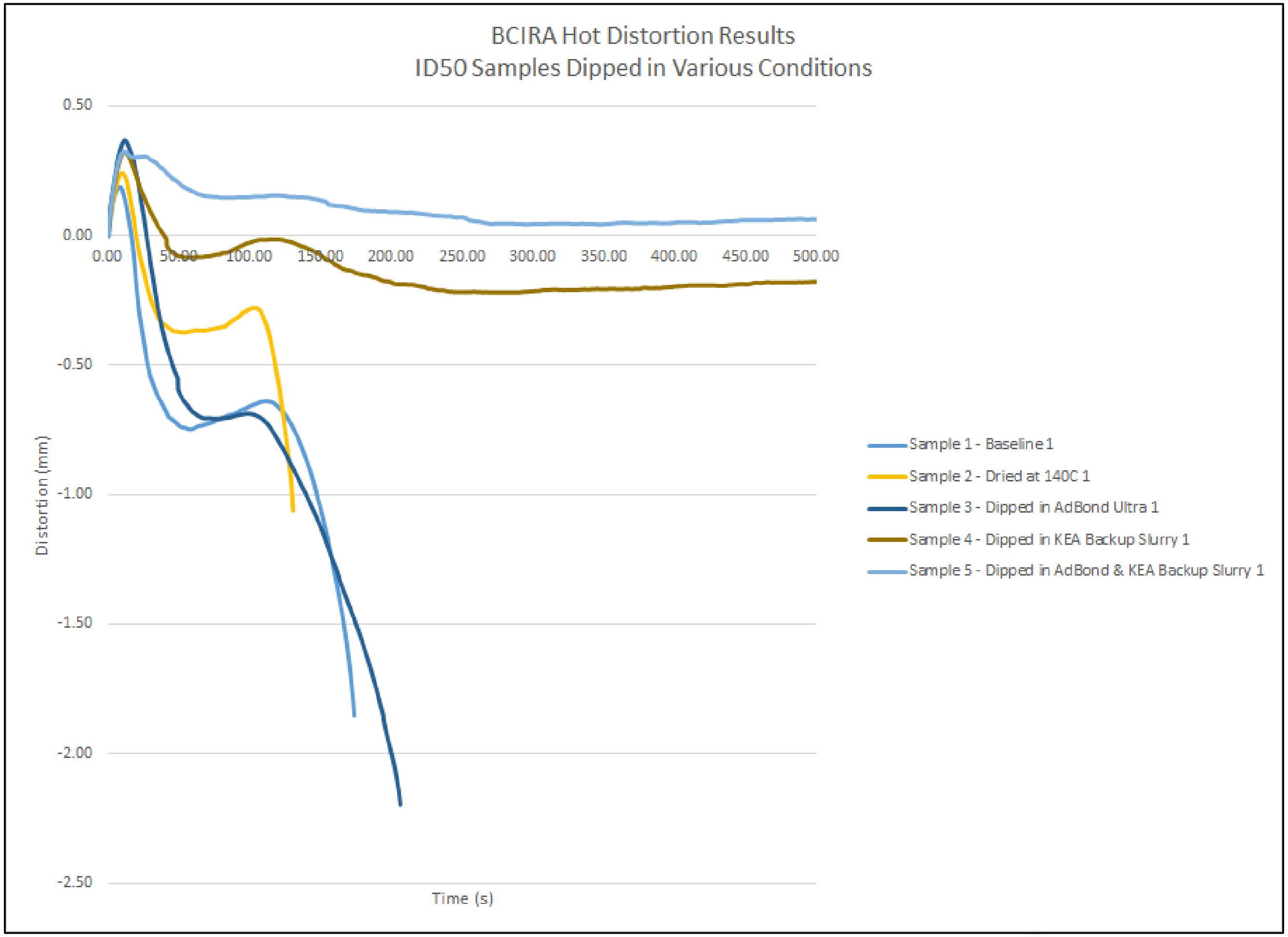
Hot Strength Profile of 3DP ID50 Transverse Bars
Coated vs. Uncoated w/ Ceramic Slurry



	RT	200	400	600
Uncoated	458.4	296.1	241.6	122.7
Coated	842.4	521.1	440.8	347.5

Temperature (C)

BCIRA Sand Distortion Test



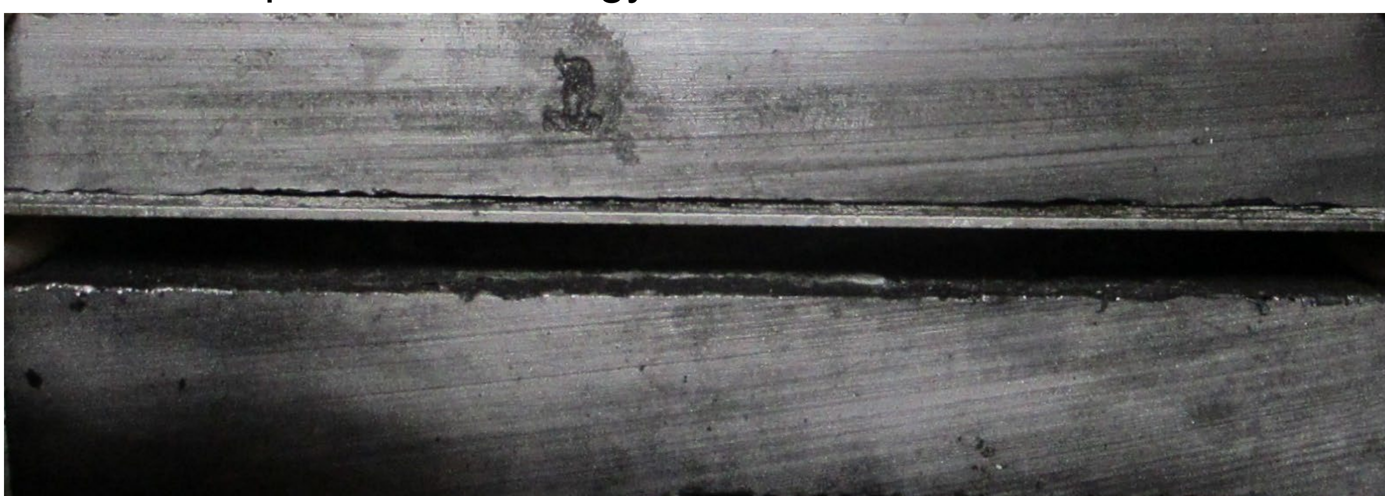
Initial Casting Trials

- Specimen type: rectangular bar measuring 9” x 1” x 0.5”
- One bar used current best practice technology, one with ceramic coating

Improvements in Distortion

Current best practice – Distortion was .079”

Proposed Technology – Distortion was .043”



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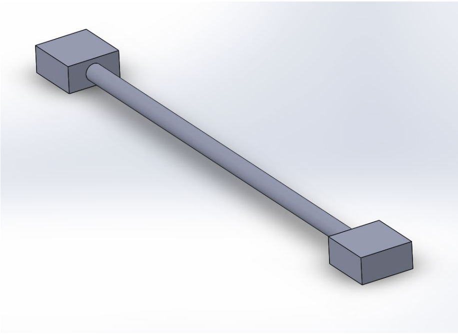
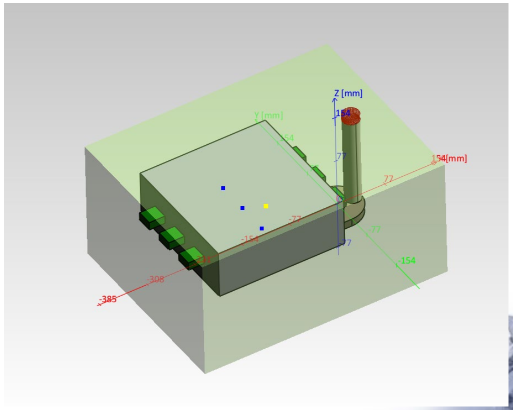
Core and Mold Parameters

- 8mm ø x 228 mm in length
- 28:1 length to diameter ratio
- 3D Printed ceramic limits expansion
- Cast with WCB Steel at 2900F

Core Geometry





Mold & Casting Cavity

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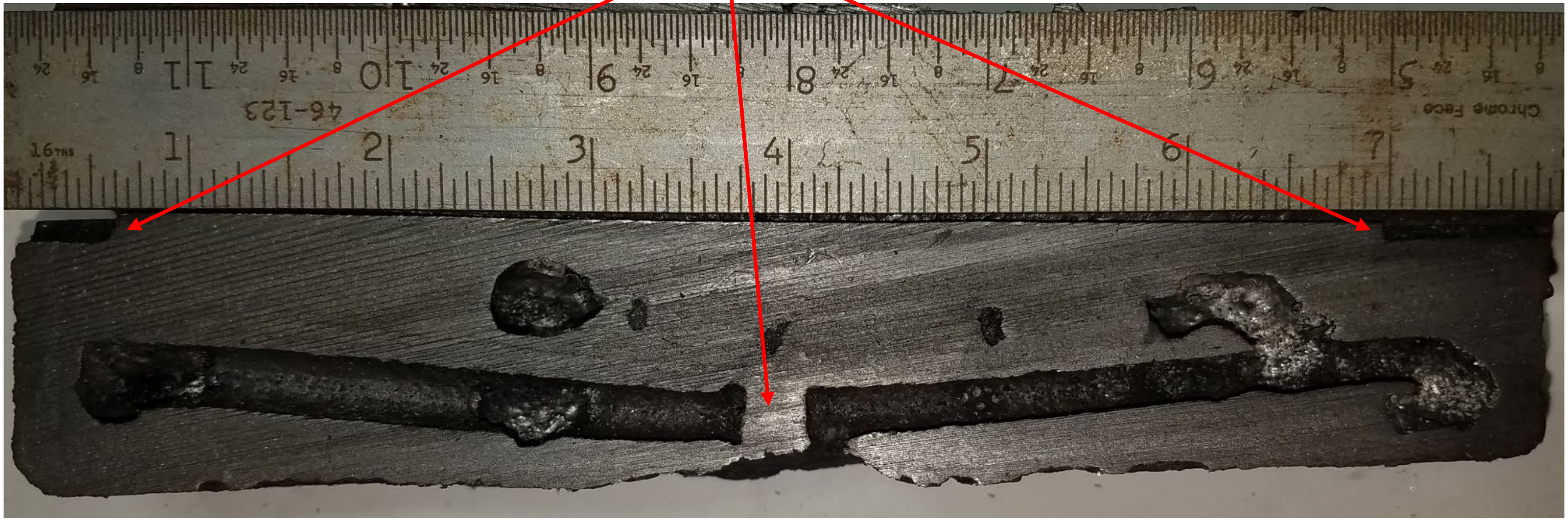
Casting #1 – Baseline (No treatments)

Complete Failure



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Casting #2 – Infiltrated and Ceramic Coated

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In-situ Ceramics for Cooling Channel Cores

Previous Research Review
Steel Surface Finish

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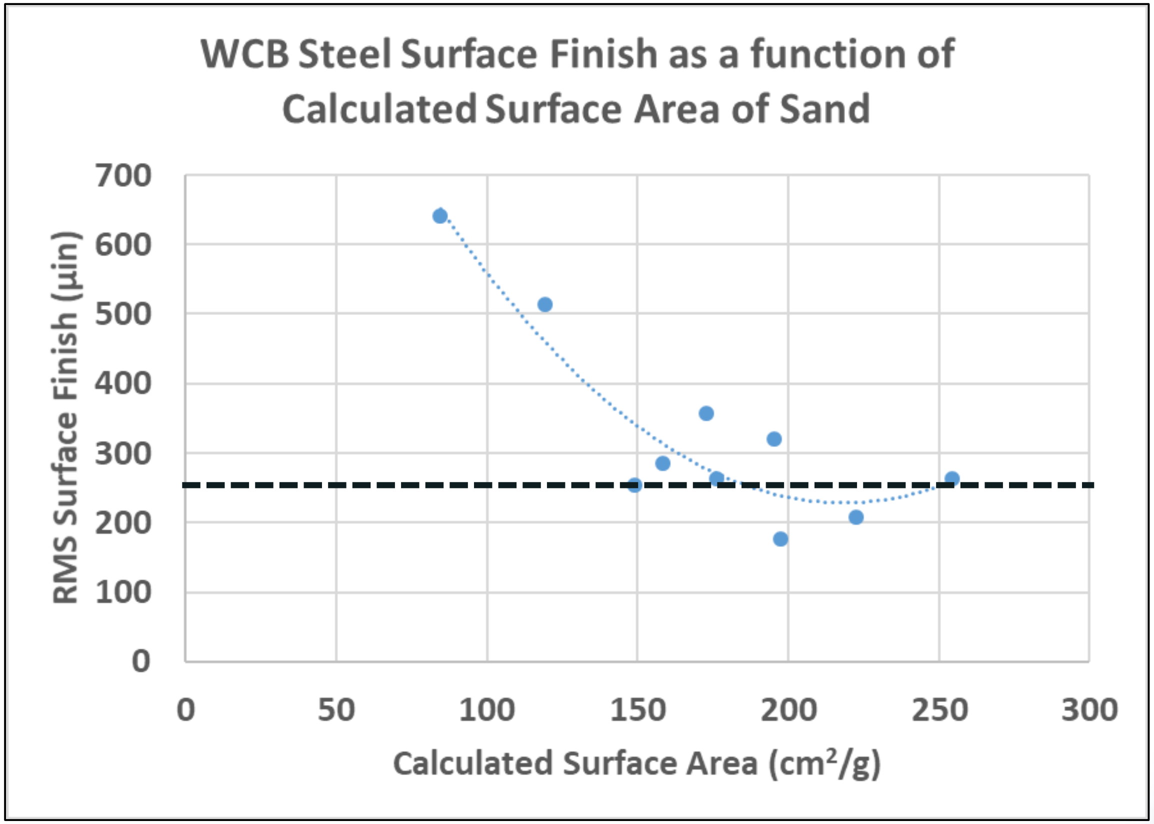
- ~175 cm^2/g is a general requirement to reach <250 RMS surface finish on uncoated material.
- Zircon coating improved coarse aggregate finish to the goal as well.



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6 Month Plans

- Continuation of materials research
  - Higher strengths
  - Low thermal expansion
  - Low liquid metal reactivity
- Equipment modification and printed shells
- Casting trials and industry interaction
  - *Opportunities in DLA M&S cast parts*

Transition Plan

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- Developed technology will be implemented through partner foundries
  - Parallel development for comparison to conventional tooling approach
  - Wisconsin Precision has expressed interest in partnering for DPIC
  - Ford Motor Company has expressed interest in utilizing the Cooling Chanel technology for hot stamping dies
  - Waukesha Foundry and Boeing are currently partnering with UNI
  - Implementation time frame for trials by the end of 2022

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Leveraging

- The project leverages over 20 years of 3D printing and investment casting material research.
  - 2017 – US High Performance Research Reactor Program
  - 2017 – US Navy, Porosity reduction in Nickel Aluminum Bronze Castings
  - 2017 – US Navy Additive Manufacturing Fleet Casting
  - 2017 – Air Force Research Laboratories, Maturation of Advanced Manufacturing for Low Cast Sustainment
  - 2016 - America Makes funding in High Speed Additive Manufacturing for Metal Casting
  - 2015– America Makes funding in Accelerated Adoption of Additive Manufacturing for Metal Casting
  - 2015 – Iowa Department of Economic Development. Additive Manufacturing Center Expansion
  - 2013 – Iowa Department of Economic Development, 3Dimensional Mold Printing
  - 2010 – U.S. Department of Defense, Advanced Titanium Manufacturing Methods
  - 2009 - U.S. Department of Defense, Advanced Titanium Manufacturing Methods
  - 2009 - U.S. Department of Energy, Center for Advanced Bio-based Foundry Binders
  - 2008 - U.S. Department of Defense, High Performance Steel Castings,
  - 2007 – State of Iowa, Battelle Grant, Commercialization of bio-based foundry binders,
  - 2007 – U.S. Department of Defense, High Performance Steel Castings
  - 2005 - U.S. Department of Energy, Center for Advanced Bio-based Foundry Binders (CABB)

- The project leverages over $3 million dollars of state funding for additive manufacturing resources.
  - 2015 – Iowa Department of Economic Development. Additive Manufacturing Center Expansion
  - 2013 – Iowa Department of Economic Development, 3Dimensional Mold Printing

- The project will leverage the future involvement in attributable weapon systems.

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Project Metrics

Description	Baseline	Threshold	Goal	How Measured	Target Date	Progress	How Demonstrated
Additive Manufacturing usage in the foundry supply chain survey	Determine current usage of AM in casting supply chain	Identify barriers and possible solutions to adoption of AM technology	Increase supply chain ability to respond to DLA casting requirements	% task completed	19-Aug	100%	Final report on supply chain adoption
Improving surface finish on 3D sand printed molds	Average RMS finish is excess of 400uin	Improve surface finish to improve performance of steel castings	Surface finish of <250 RMS uin	% task completed, Successful application in demonstration casting	21-Dec	100%	Formal report of technology improvement and application technology
Printed Investment Casting Shells (PICS)	None available	6 casting supply chain members	3 to 4 new casting supply chain members	% task completed	21-Dec	60%	Successful completion of demonstration castings and documentation
Cooling Channel Cores for High length to dia. Cores	None available	3 casting supply chain members	3 to 4 new casting supply chain members	% task completed	21-Dec	60%	Successful completion of demonstration castings and documentation

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Rapid Production Using Additive Manufacturing (AM) / Digital Tooling

DLA - POC: DLAR.DPR@dla.mil

Problem

- Rapid response and more suppliers are needed in the replacement of critical cast components for legacy weapons systems

Objectives

- Enhance the use of AM by:
  - Determining the factors that are preventing or inhibiting the use of additive / new manufacturing technology for metalcasting in foundries
  - Transitioning new additive manufacturing technology into foundries to increase the number of quotes on DLA small quantity orders
  - Minimizing costs and lead times

Benefits to Warfighter

- Enhanced supply chain
- Reduced costs and lead times by utilizing printed tooling

Description of Project:

Enhance the use of additive manufacturing technology in the casting industry to meet the rapid requirements for small quantity orders of DoD legacy weapons systems

Team:

University of Northern Iowa, Steel Founders' Society of America, ATI

University of Northern Iowa SFSA ATI ADVANCED TECHNOLOGY INTERNATIONAL

Milestones / Deliverables

- Benchmark state of the industry for additive manufacturing technology
- Review current and past additive / new technologies for investment castings
- Improve surface roughness of castings produced using printed sand
- Improve / develop process to produce ink jet powder bed printed casting shells for investment metalcasting applications

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For additional information, please contact:

Jerry Thiel
University of Northern Iowa
319-273-7085
Thiel@uni.edu
http://mcc.uni.edu

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