Development of Agile and Cost Effective Routes for Manufacturing Reliable Ceramic Components for SOFC Systems

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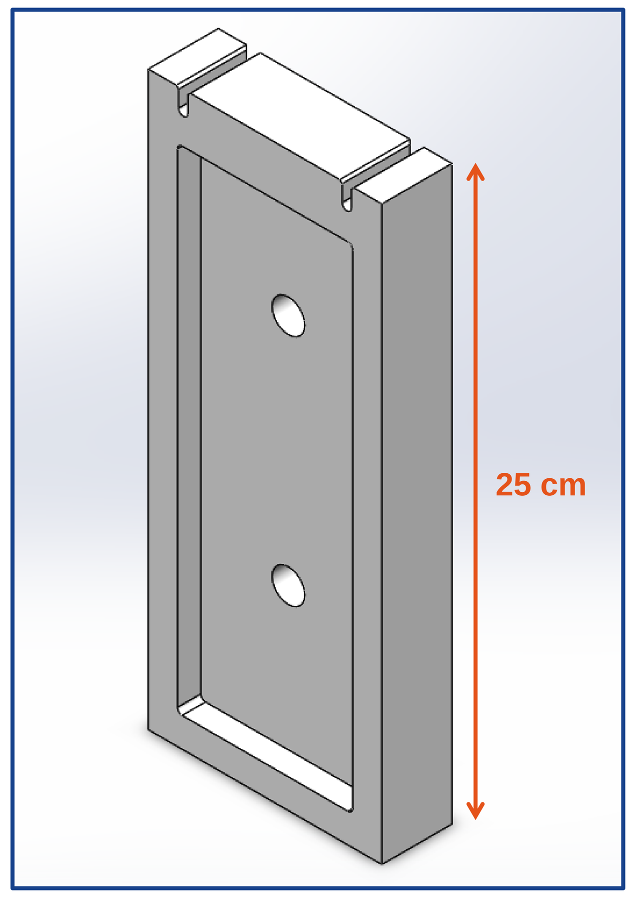
Abstract

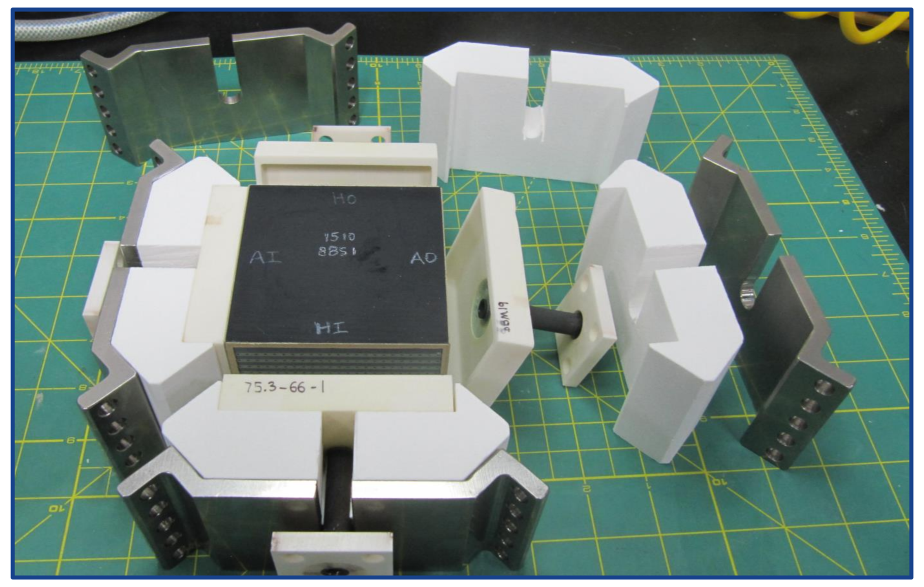
Saint-Gobain, a world leading ceramic manufacturer, draws on a global operations network across 66 countries with annual sales over $43B. Ceramics have broad applicability in solid oxide fuel cell (SOFC) applications such as manifolds, gas connections, heat exchangers, and other high temperature balance of plant (BOP) components. This project aims to develop and evaluate two novel forming methods, 3D printing and gelcasting, for the production of ceramic BOP components for SOFCs, which enable agile and cost effective manufacturing. The methods are applied to MMA (magnesia doped magnesium aluminate), a ceramic of choice for SOFC applications. 3D printing and gelcasting are being developed in parallel with the objective of mapping and analyzing the capabilities and limitations of these methods relevant to SOFC design dimensions and features. This poster will present progress made on the slurry formulations and sintering cycle development of these methods.

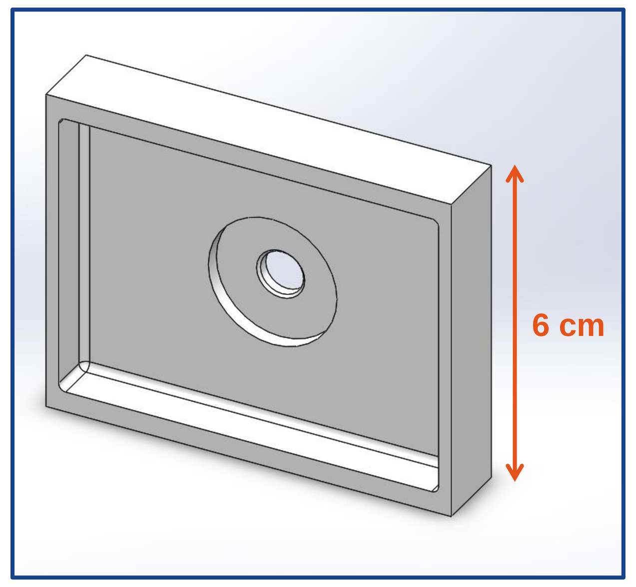
For the 3D printing process, several ink formulations have been developed and rods measuring 0.5 mm in diameter and 50 mm in length were successfully printed using 38 vol.% loaded slurries. For the gelcasting process, slurries have been developed leading to crack-free, green plates measuring 10 x 10 x 1 cm. Green parts have been sintered to 96% theoretical density. Additionally, some fundamental and practical limitations of the current platforms have been identified.

Objectives

- Developing 3DP and gelcasting methods for the short lead-time production of ceramic stack and BOP components with the MMA material.
- Mapping and analysis of the capabilities and limitations of these methods to relevant SOFC design dimensions and features, to establish their breadth of utility and specific cost advantage for SOFC manufacturers.
- Establishing the benefits of these manufacturing methods for producing SOFC manifolds and heat exchangers in commercial SOFC platforms through a validated techno-economic analysis.





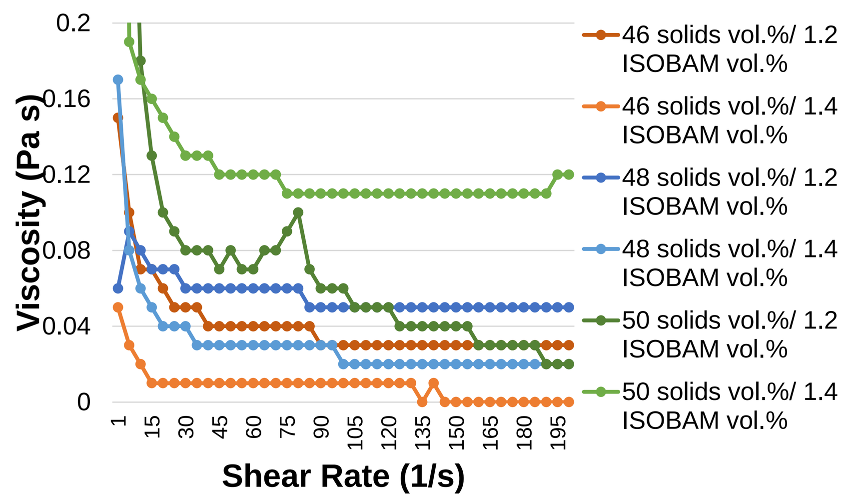


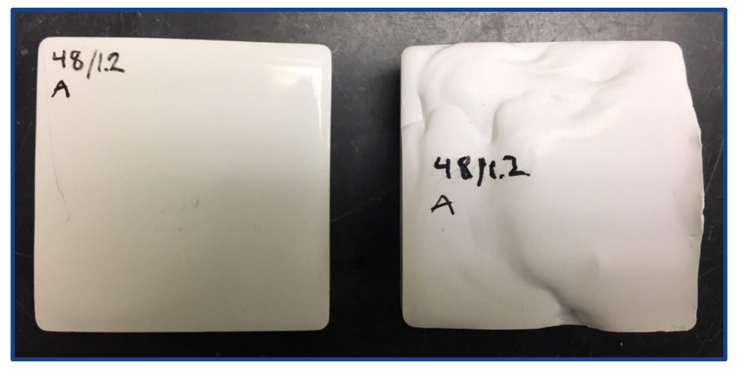
Gelcasting

Overview

- Gelcasting slurries were formulated using MMA powder, a sintering aid, Isobam-104, and deionized water. Isobam-104, a commercial gelling agent, also acted as the dispersant.
- Slurries with an Isobam-104 content of 1.4% and solids loadings of 46% and 48% were successfully cast into 2.5 cm, 5 cm, and 10 cm square plates at 1 cm thickness.
- Further study is needed to increase the working time of the slurry and better understand the effect of temperature on slurry viscosity.

Slurry Formulation and Rheology





30 cc Batch — 90 cc Batch

- The viscosity of the slurries were characterized using a cone and plate apparatus and shear rates varying from 1 to 200 s−1.
- In general, slurry viscosity increased with solids loading and decreased Isobam-104 content.
- However, viscosity varied within these parameters depending on slurry batch size, time elapsed between mixing and pouring, and temperature of the slurry.

Sintering

Isobam-104	Solids Loading	Green Density	Sintered Density
1.2 vol.%	46 vol.%	54 %	95.4 %
1.2 vol.%	50 vol.%	54 %	96.8 %
1.4 vol.%	46 vol.%	50 %	95.1 %
1.4 vol.%	48 vol.%	53 %	95.4 %

Cracking Modes After Sintering

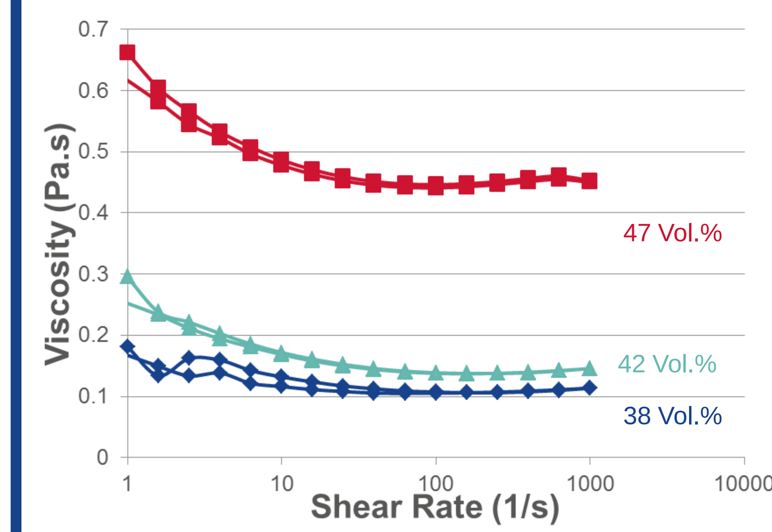
- The highest sintered density achieved was 96.8 % using a 50 vol.% loaded slurry with 1.2 vol.% Isobam-104.
- Parts with 1.2 vol.% Isobam-104 were crack free after sintering, whereas parts with 1.4 vol.% content experienced two modes of cracking.
- Cracking attributed to burnout and drying defects.

3D Printing

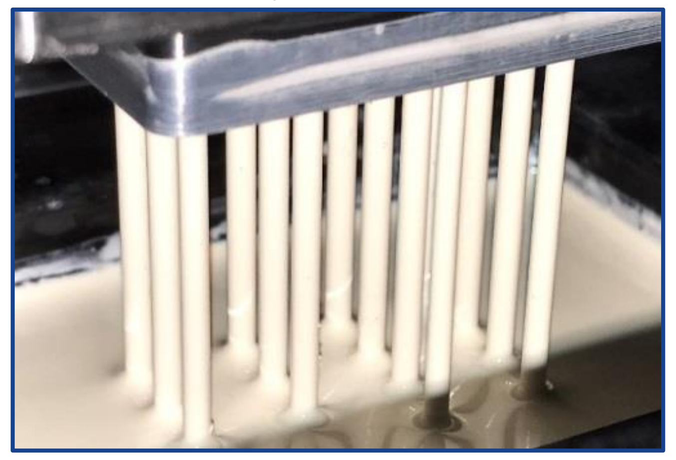
Overview

- 3D Printing inks were formulated using MMA powder, a UV curable binder, a photo initiator, and a dispersant.
- The highest sintered density achieved was 96% at 47 vol.% solids loading.
- Continuous 3DP does not meet requirements with current platform because of the flexible membrane and viscosity of 47 vol.% loaded slurry.

Ink Formulation and Rheology



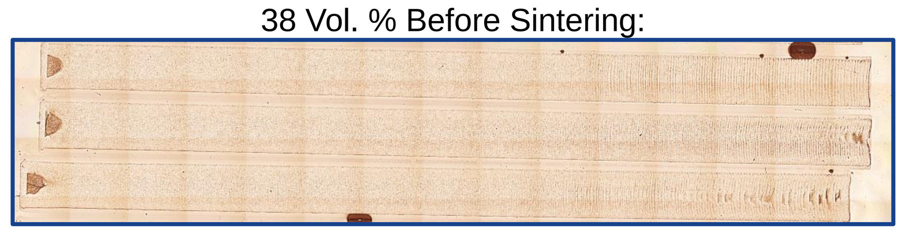
1 cm/h, 38 vol.%



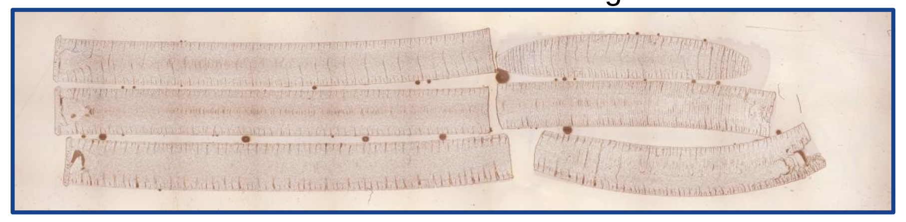
- 38 vol.% rods show minimal layer defects towards the start of the print.
- Larger defects can be seen towards the end of the print (right in photos) which are related to settling of the slurry.
- Cracking due to combined issues of layer defects, settling of slurry, low density, and binder burnout.

Solids Loading	Sintered Density Continuous 3DP	Sintered Density Cast
38 vol.%	90% with cracks	93%
42 vol.%	Unable to print	93%
47 vol.%	Unable to print	96%

38 Vol. % Before Sintering:

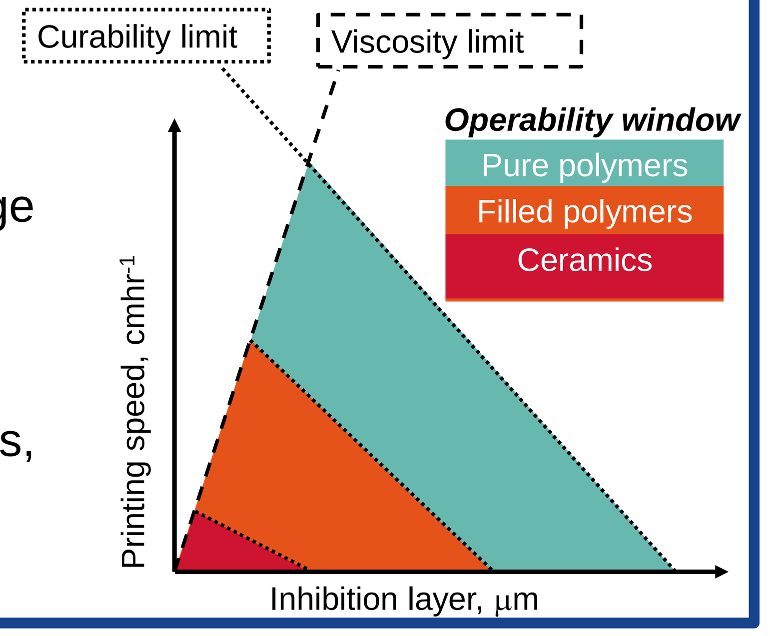


38 Vol. % After Sintering:



Operability Limits

- Current platform is not suitable for large components and UV absorbing and scattering materials
- Continuous 3DP has limitations with respect to materials, object dimensions, viscosity, settling, and solids loading



Next Steps

Gelcasting

- Further rheological characterizations of slurries to understand temperature and time dependence.
- Investigate secondary dispersant to decrease the Isobam-104 content and theoretically increase the solids loading and lengthen the working time.
- Optimize sintering cycle to eliminate cracking.
- Determine design constraints by increasing the complexity of cast parts.

3D Printing

- Complete installation layer by layer platform with open control parameters by August 1st.
- Achieve 95% relative density rods printed from a >47 vol.% loaded slurry with new platform.
- Address cracking during sintering by drying out powders for acrylate base slurry and investigating potential of water base slurries.

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