

Midlands Advanced Ceramics for Industry 4.0

CASE STUDY

REF No: 2506005

WS7 - Scale up EXTRUSION-BASED ADDITIVE MANUFACTURING OF PRESSURELESS SINTERED SILICON CARBIDE USING VISCOUS PASTES ON THE HYREL HYDRA 21

MODELLING
& DESIGN

RAW
MATERIALS
PROCESSING

FORMING

DRYING &
SINTERING

ANALYTICAL

THE CHALLENGE

Additive manufacturing is a process that enables the creation of complex geometries and detailed internal structures by depositing material layer by layer. Robocasting, a type of extrusion-based method of additive manufacturing which involves building objects by extruding viscous paste out of a nozzle. Robocasting of technical ceramics is challenging as the paste needs to be formulated with a high solids loading to achieve dense parts whilst achieving appropriate rheological properties and suitable drying time to produce optimal print quality. In addition, a minimum concentration of binder is required to produce suitable green strength for handling and removing parts from the build plate without failure. Meeting these criteria is challenging, as formulation components often enhance one property while compromising another, necessitating multiple

iterations. Higher solids loading also results in a more viscous, stiffer paste that some robocasters are not equipped to handle. As part of efforts to expand in-house additive manufacturing capabilities, the Hyrel Hydra 21 printer was commissioned and evaluated for ceramic paste extrusion. Its high-torque extrusion heads make it suitable for processing highly loaded formulations, such as those required for robocasting. To demonstrate and validate this capability, paste formulations were developed for the production of solid-state sintered silicon carbide (SiC). SiC is a non-oxide advanced ceramic with applications across the automotive, aerospace, and defence sectors. Demonstrating the ability to produce dense, intricate near-net-shape components from SiC represents a valuable addition to the AMRICC Centre's manufacturing capabilities.

HYREL HYDRA PRINTER

The Hyrel Hydra 21 is a versatile 3D printer with multiple, exchangeable print heads, allowing users to work with a wide range of materials, including store-bought and homemade filaments, as well as clays and technical ceramic pastes. The printer offers multiple benefits, including large, heated printing bed and ability to extrude paste with viscosity up to 2,000 PaS.

Figure 1
Hyrel 21 3D
printer housed
within an enclosed
built environment



Lucideon developed a silicon carbide paste with a high solids loading (45 vol%) and low binder content (2.0 wt%), which was successfully printed using the Hyrel Hydra 21 printer and sintered in an argon atmosphere to produce high-density (~90%) components featuring intricate internal lattice structures.

WHAT WE DELIVERED

Multiple iterations of the paste were produced and tested, optimizing dispersant concentration to maximize solids loading while experimenting with various binders, plasticizers, and rheology modifiers to create a paste with optimal printability for pressureless solid-state sintering. Utilising the optimized formulation, the paste displayed good printability with no slumping or cracking as shown in Figure 2. Using the refined paste, a series of successful prints have been produced and sintered, resulting in demonstration parts, as seen in Figure 2.

Figure 2
Manufacture
of Cube with
100% Infill Using
Optimized SiC
Paste

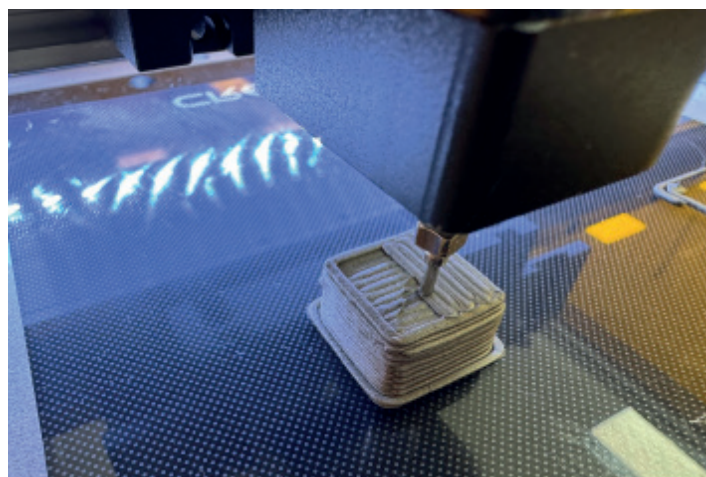
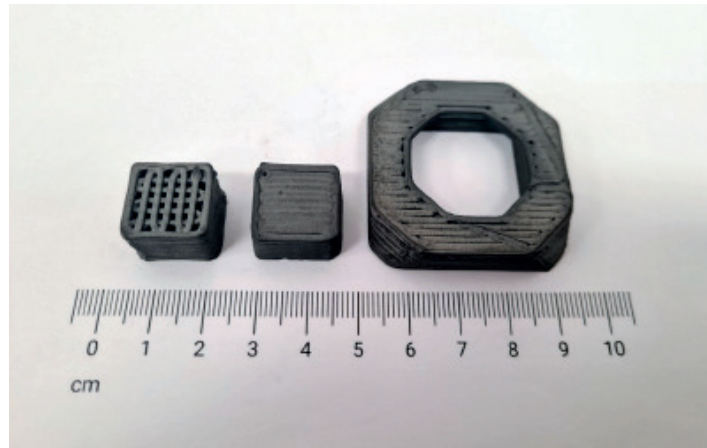


Figure 3
Sintered SiC
Demonstration
Parts



The rheological properties of the silicon carbide paste were characterised by conducting a frequency sweep in the linear viscoelastic region as shown in Table 1. These results reveal strong shear-thinning behaviour, with complex viscosity decreasing by over three orders of magnitude as frequency increases. This indicates the paste behaves as a viscoplastic material with a high resistance to flow at low stress and readily flows under applied force—ideal for extrusion-based 3D printing. The sharp drop in viscosity also suggests the presence of a yield stress, supporting structural integrity during deposition while allowing smooth flow through the nozzle.

Table 1
Frequency Sweep
Rheology Test
in the Linear
Viscoelastic
Region

Angular Frequency (rad s ⁻¹)	Complex Viscosity (Pa S)
0.1	439,206
1.0	45,577
10	3,435
100	326

The maximum sintered density achieved was 89.7% of the theoretical density, with some porosity present in the material, as shown in Figure 4. Larger pores are visible in the optical micrograph at 50x magnification, highlighting defects related to the printing process. These defects can be further minimized by optimizing the printing parameters. Additional porosity is visible under higher magnification, which could be decreased further by formulation optimization for higher solids loading and lower binder content.

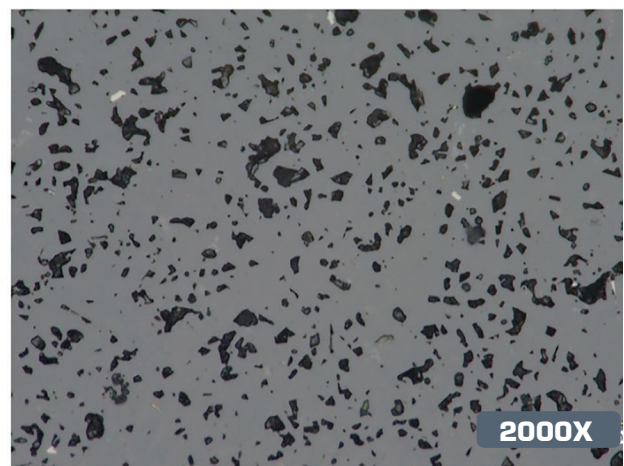
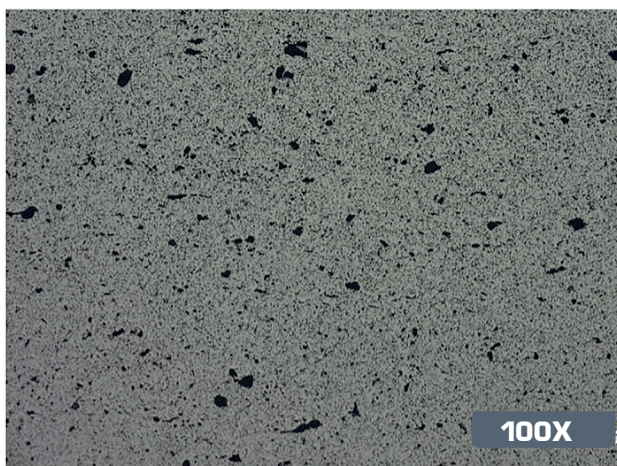
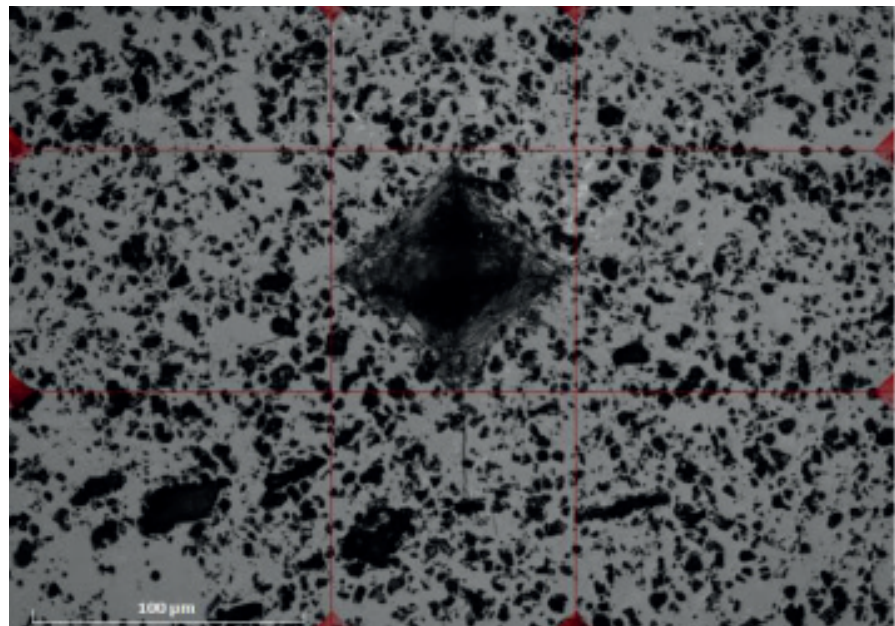


Figure 4 Optical Micrographs of Sintered SiC, 100X Magnification (left) and 2000X Magnification (right)

The average Vickers hardness measured was 1605 +/-233 HV when a 5-kilogram force was applied to the sample. Porosity throughout the sample introduces crack-initiation sites thus reducing hardness of the samples.

Figure 5
Vickers Hardness Testing Using Diamond Indenter



IMPACT

Lucideon formulated a paste with a high concentration of silicon carbide powder exhibiting excellent rheological properties for robocasting. This paste was robocasted using the Hyrel Hydra 21 producing complex shapes that can be sintered using pressureless sintering to moderately high density.

To enhance performance, further formulation trials could focus on increasing solids loading, reducing binder content, more effective de-airing to eliminate entrapped air, and evaluating different concentrations of sintering aids. In addition, the formulation could be designed to exhibit reduced viscosity upon heating, enabling the use of the heated canister during printing to maximise solids loading.

The versatility offered by the Hyrel Hydra 21 can be further exploited for a wide range of ceramic materials, making it a valuable platform for developing and testing advanced formulations. Its capability to accommodate a dual nozzle system enables the fabrication of multi-material components, which opens opportunities for creating functionally graded materials, integrated support structures, or components combining different ceramic properties within a single part. This flexibility supports innovation in ceramic additive manufacturing, particularly in applications requiring tailored mechanical, thermal, or electrical performance.

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