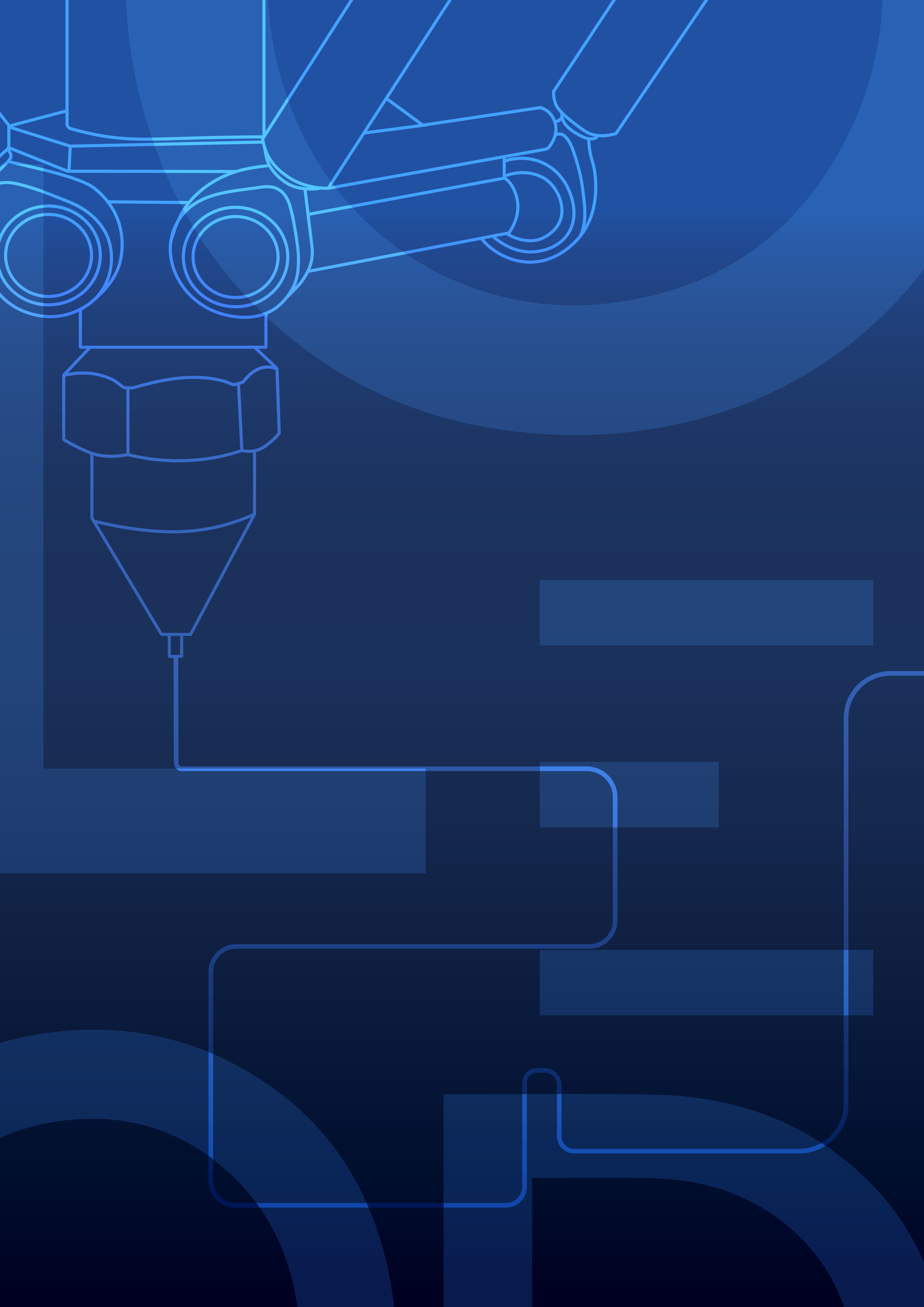
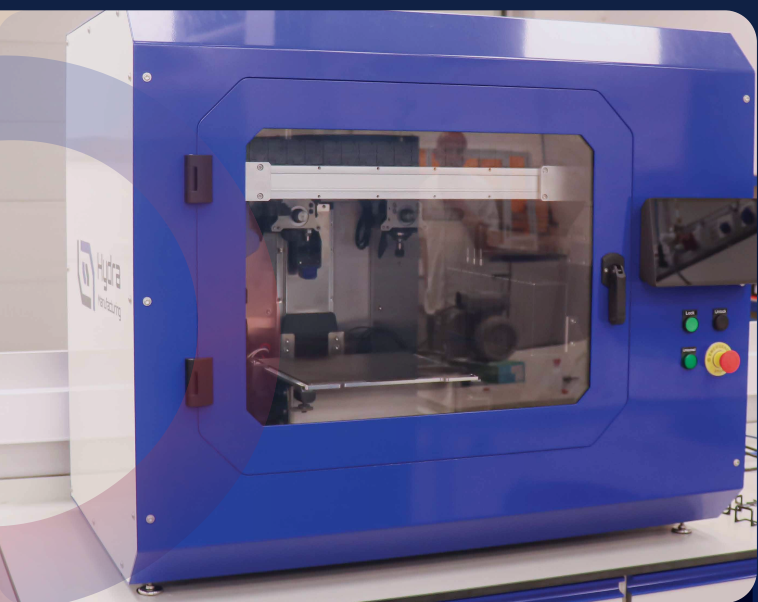
AMRICC INSIDE

Ceramic Additive Manufacturing at LUCIDEON



Contents



Why Ceramics?

Advanced ceramics are renowned for their:

- High operating temperatures
- Low thermal conductivity for thermal insulation and heat shielding
- High strength-to-weight ratio
- High hardness and wear resistance
- Biocompatibility for medical implants

However, their exploitation can be restricted due to:

- Brittleness resulting in flaw sensitivity, and therefore limited design stress with large factors of safety
- High cost of production, due to energy-intensive processing methods and high material cost

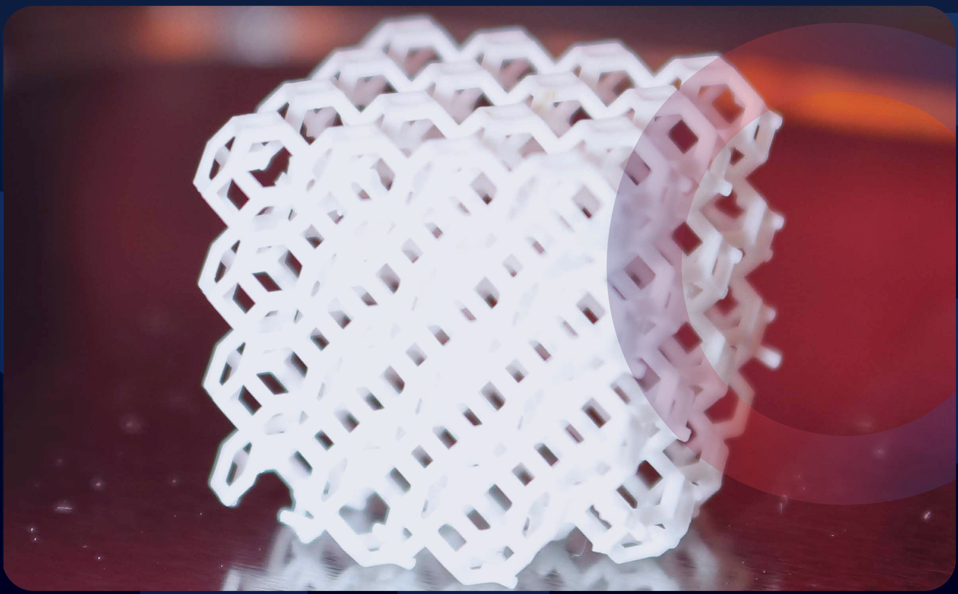
These materials exhibit massive potential for innovative applications if their limitations can be addressed through the development of workable and scalable solutions for industry.

Applying Additive Manufacturing

Ceramic Additive Manufacturing (AM) is an emerging technology area with applications across sectors including healthcare (orthopedic and dental), aerospace, and energy. Novel materials and printing technologies are under development, but currently require scale-up support and validation to progress towards full commercialisation.

AM enables the printing of complex geometries that conventional forming methods cannot achieve. This presents opportunities for small run production of complex parts, part shape optimisation – such as lightweighting or integration of cooling/heating channels – and the development of personalised parts.

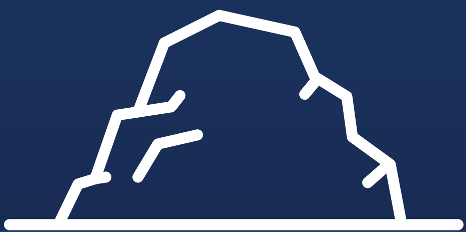
Lucideon's role is to support companies on this journey through comprehensive consultancy, bringing next-generation materials technology closer to realisation for partners and end users around the world.



Offerings

1. Feedstock Processing Development

2. AM Techniques



3. Materials Development

4. Sintering Optimisation

5. Analysis and Evaluation

6. Computational Techniques

1. Feedstock Processing Development

Why is material development required?

In ceramic additive manufacturing the boundaries of printer capability are always expanding, and many printing technologies are just breaking into the commercial world. As a result of their complexity, printers are sensitive to the form and quality of their input material, feedstock.

Through appropriate preparation methods, particle size distribution, viscosity, rheology, and other properties can be tuned for the desired product requirements, verified through characterisation, and tested on an end-to-end process.

Lucideon's role

This is where Lucideon's core expertise and capabilities lie. We are experts in powder processing and characterisation. Drawing from a network of materials supplies, our consultants and scientists can formulate and test feedstocks for a variety of AM processes, considering both printability and end materials performance.

With access to the pilot-scale equipment located at The AMRICC Centre, a Centre of Excellence for Advanced Ceramics that Lucideon hosts and manages, these feedstocks can be produced in kilogram scale batches and put through the full AM, debinding, and sintering process.

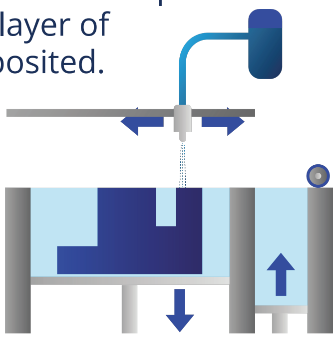
Lucideon can develop and optimise formulations aimed at tailoring viscosity and solids loading, improving material suitability for AM printing as reliably as possible for a given process. With a wide variety of milling and mixing processes to hand, we can develop and optimise feedstock production.

2. AM Techniques

Ceramic AM encompasses a wide range of processing and techniques, all with characteristic benefits and limitations. Lucideon's work encompasses many of these methods, including:

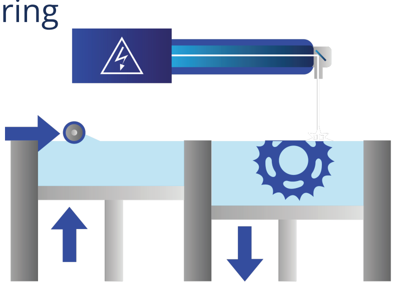
Binder Jet

Binder jetting is one of the fastest AM methods. Firstly, a ceramic powder is deposited. The inkjet applies a binder into the layer for the desired shape and then another layer of powder is deposited. This process is repeated until the shape is complete. The green body is then subjected to excess powder removal and sintering.



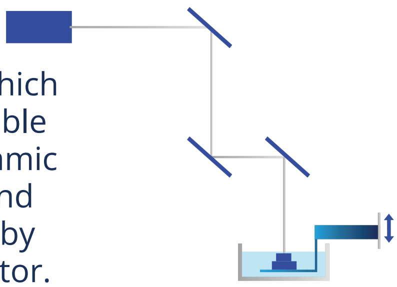
Powder Bed Fusion

Powder bed fusion is suitable for the manufacture of complex parts. Following ceramic powder deposition, a heat source is used to fuse the powder layer-by-layer, forming a solid part. The two main methods for ceramic powder bed fusion processing are Selective Laser Sintering (SLS) and Electron Beam Melting (EBM).



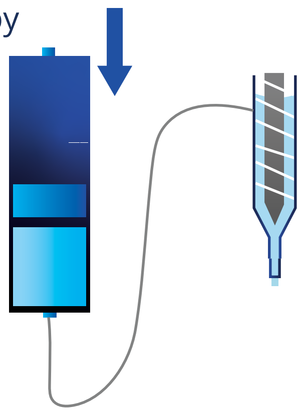
Stereolithography (SLA)

Stereolithography is a vat polymerisation technique through which layers of a photocurable resin mixed with ceramic powder are spread and selectively hardened by a laser or light projector.



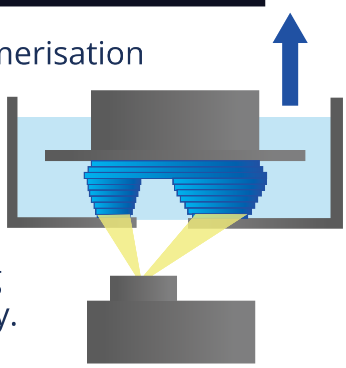
Robocasting

Robocasting, or robotic material extrusion, is an AM technique analogous to direct ink writing and other extrusion-based 3D-printing techniques.
The technique consists of the extrusion and deposition of ceramic-based pastes or fused ceramic/polymer filaments.
This method includes selective deposition of a ceramic paste/filament by movement of the extruder head or build platform in x-y directions, as well as moving in z-axis after depositing each layer.



Digital Light Processing

This is another vat polymerisation technique, similar to SLA. With DLP, a digital projector screen is used to flash an entire photosensitive resin layer from below, curing all points simultaneously.



AM Techniques

Robocasting - CHAMP

Hydra Manufacturing and Lucideon are collaborating on the development of robocasting, a ceramic AM process technology. The CHAMP printer combines the AM concept with in-situ green machining, giving it new design freedoms via layer-by-layer machining. The system is designed to allow for the production of high-density parts with increased product complexity, and is being developed into an in-situ quality control (QC) system that can detect and remove defects during the printing process.

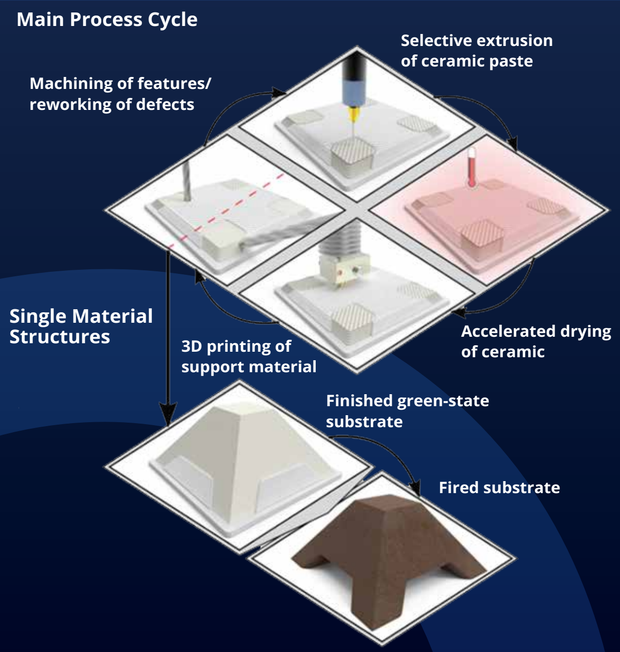
Standout features of robocasting include the ability to produce thick-walled components and perform debinding and sintering of outputs in under 24 hours.

Lucideon can develop novel printable ceramic ink formulations, tailoring the properties for given applications.

We work with oxides such as alumina, non-oxides such as silicon carbide, and nitrides including silicon nitride.

Lucideon's extensive knowledge in materials development pairs with Hydra's printing technology to enable the cost-efficient manufacture of complex high-resolution parts.

Build Volume	300 x 300 x 200 mm
Max Traverse Speed	110 mm/s
Machining resolution	1 µm



AM Techniques

Robocasting - WASP

Lucideon has access to WASP robocasting printers, from small lab-scale up to prototype scale, through The AMRICC Centre. With the ability to rapidly iterate parts through the conveyor belt addition on the prototype scale printer, this technology is easily scalable and cost-effective. Lucideon can develop and optimise aqueous materials formulations for a given application up to prototype level scale and demonstration.

Build volume	400 mm x 1000 mm
Nozzle size	0.6 - 6 mm
Layer resolution	0.5 - 4 mm

Build volume	100 x 100 x 100 mm
Laser	300 mW UV laser
Laser thickness	0.02 - 0.125 mm

Stereolithography (SLA)

Lucideon uses a 3D Ceram SLA C101 Lab to trial prints of extremely intricate geometry parts. This printer is compatible with a variety of printable resins, ranging from alumina for aerospace applications to hydroxyapatite for healthcare applications.

These trials allow our customers to discover whether SLA is appropriate for their parts, and get a head start on designing parts to take advantage of its unique strengths.

Lucideon can also undertake parameter optimisation for the post-processing of AM parts. The precise temperature and atmosphere control capabilities of our equipment allow for the refinement of the debinding and sintering processes on a part-by-part basis, ensuring your product is at its top performance.

Digital Light Processing (DLP)

Lucideon's Zortrax Inkspire 2 provides the opportunity to print novel formulations. Lucideon can provide not only access to this equipment, but also sintering parameter optimisation to ensure the part meets the desired performance requirements.

Build volume	192 x 120 x 280 mm
Laser	Integrated LED panel (wavelength 405 nm)
Laser thickness	25, 50, 100 μm

3. Materials Development

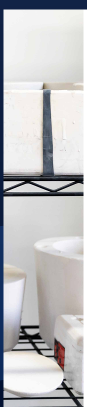
Material selection and development is a critical area for the maturation of the Ceramic AM as a technology. Lucideon has the ability to offer our clients support and consultation in trialling robocasting processes for the following materials:

Alumina

One of the most widely used ceramic materials, alumina is an oxide ceramic that can withstand temperatures up to 1600 °C. Due to its high operating temperature and oxidation resistance, it has a wide range of applications that capitalise on its high-performance characteristics. Within ceramic AM, this includes lattice structures and thermal management systems.

Silicon Carbide

The market need for silicon carbide is growing, due to both its operating temperature of up to 1600 °C and its chemical resistance. It also displays high hardness, low weight, high thermal conductivity, and a resistance to thermal shock. Lucideon has completed development trials using both solid-state and liquid-phase silicon carbide. These materials display high mechanical strength and enhanced densification benefits, respectively.



Nitride-bonded Silicon Carbide

Nitride-bonded silicon carbide can be formed with negligible shrinkage at low temperatures through direct nitridation, reducing the need for surface finishing and production costs. This material also displays excellent characteristics for certain applications such as kiln furniture because of its high strength at high temperature, excellent thermal shock resistance, and good oxidation resistance.

We are also capable of operating additive manufacturing development programmes incorporating novel materials.

The following materials are promising candidates for further development:

Ultra-High Temperature Ceramics

This category includes materials such as hafnium carbides and zirconium diborides, which operate at performance temperatures of up to 2500 °C. By using additive manufacturing techniques, UHTC properties can be enhanced through the application of complex geometries to achieve suitability for extremely high temperature applications, which conventional manufacturing processes and materials cannot replicate.

Silicon Nitride

Silicon nitride is known for its thermal stability and dielectric properties that make it suitable for applications in extreme environments. AM of silicon nitride displays potential applications for custom electronics with complex geometries as well as applications in the aerospace and defence sectors.

Aluminium Nitride

Aluminium nitride has an extraordinary combination of high thermal conductivity and low electrical conductivity allowing for thermal management without electrical conduction, and making it a useful material for electronic substrates and packaging. Lucideon has previous experience in ultra-high temperature ceramics and silicon nitride and are seeking opportunities to progressing this alongside the AM market.

If you are interested in developing AM techniques for specific performance requirements or materials, get in touch with us to discuss further.

4. Sintering Optimisation

What is sintering?

Sintering is the consolidation of ceramic material into one part through heating and/or pressurising a green body (unfired ceramic), causing it to form a single, solid mass.

This is the most energy-intensive processing step for manufacturing ceramics, and therefore efficiency at this stage is key for reducing energy wastage. Solutions here are not one-size-fits-all; the sintering process for each product requires individual optimisation and can vary depending on material formulation, kiln type, part geometry, number of parts within a kiln, and many more parameters.

Lucideon's role

Combining our decades of experience in ceramic processing alongside the advanced ceramic pilot-scale facility that Lucideon manages and hosts, we help our clients to optimise sintering parameters for any given additively manufactured part.

Through access to the equipment at The AMRICC Centre, Lucideon can sinter at up to 3000 °C in vacuum and can carry out both liquid silicon reaction bonding of silicon carbide and polymer pyrolysis.

We operate a hot isostatic press for top-of-the-range densification capabilities, and our equipment is capable of completing debinding and sintering processes within one furnace. As a materials science consultancy, Lucideon also supports the development of novel sintering techniques that could improve product performance.

5. Analysis & Evaluation

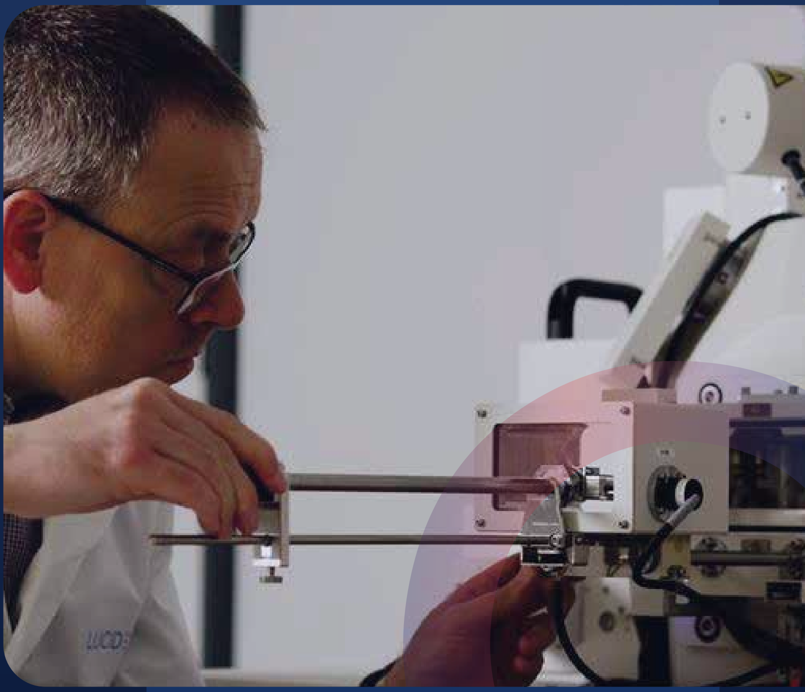
Why is Analysis & Evaluation important for AM?

The use of AM parts in live industrial operation faces delays in implementation due to quality control and validation requirements, and so thorough testing and characterisation are vital for these parts to become widely accepted and commercially available. Lucideon can provide custom complex testing to simulate the various environments to which the parts could be exposed, reducing the inherent uncertainty that comes with the uptake of novel technology.

Lucideon's role

Lucideon has expertise in the characterisation and testing of advanced ceramic materials with our offering covering microstructural, chemical, thermal analysis, and mechanical testing.

Through our world-class equipment suite, we offer physical testing capabilities, ranging from cryogenic (-196 °C) to elevated temperature (1600° C), a variety of microstructural characterisation equipment such as XRD, XRF, SEM and optical microscopy for assessing grain size and pore size, thermal analysis equipment such as TGA and dilatometry, and more.



Scan for a full list of specific characterisation techniques that can be applied to our clients' projects

6. Computational Techniques

How does data science advance Ceramic AM?

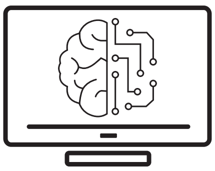
Ceramic AM requires a high degree of optimisation for developing, designing, and producing 3D-printed parts. Since the number of experimental parameters can be colossal, it can be challenging to isolate the significant factors that will allow you to fabricate the optimal part time- and cost- effectively.

Lucideon's role

Lucideon combines computational, experimental, and synthesis methods to expand the solution toolbox and support overall material and process development efficiency.
The capabilities range across the following areas:

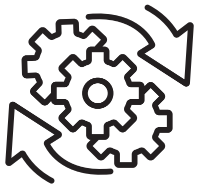
Machine Learning

We can use ML techniques to carry out Design of Experiments, improve the quality of the data collected, and identify the optimal conditions for achieving desired material properties. For example, we have used the Random Forest Regressor method to train generated AM data sets to suggest parameter subspaces for high quality printed parts.



Computer Vision

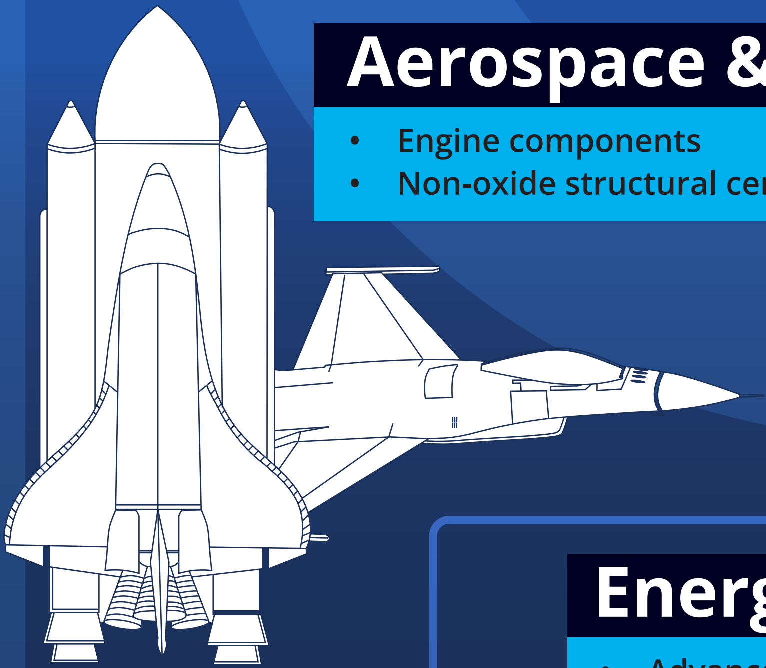
We can model furnaces to predict optimal sintering locations of parts. We can utilise the testing characterisation facilities at Lucideon to create accurate and robust simulations of materials. We can simulate the deformation and failure of materials under different conditions. It's essential to have both data and material science expertise for applications like this, and Lucideon's years of expertise in both is what makes our offering so unique.



Process Optimisation

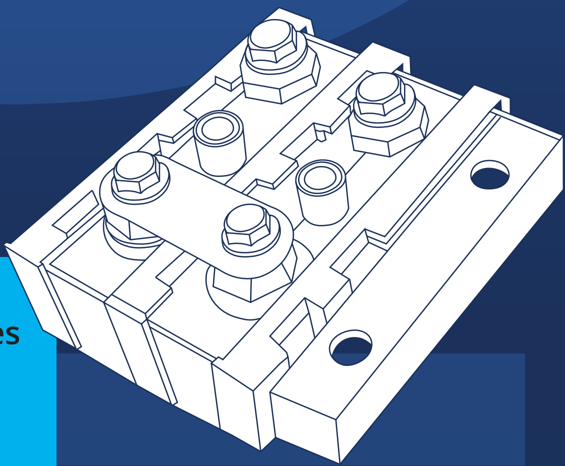
We can record processing data and identify failures or improvement areas to ultimately enhance manufacturing productivity.

Sectors and Applications



Aerospace & Defence

- Engine components
- Non-oxide structural ceramics



Energy

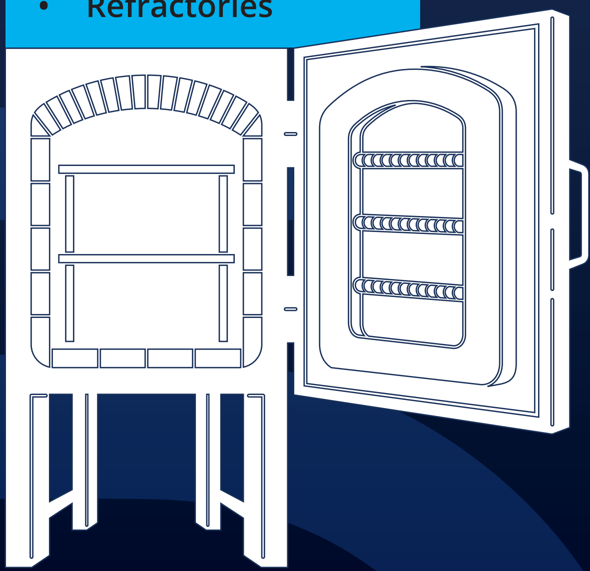
- Advanced batteries & supercapacitors
- Solid Oxide Fuel Cells

Healthcare

- Bone scaffolds
- Dental crowns

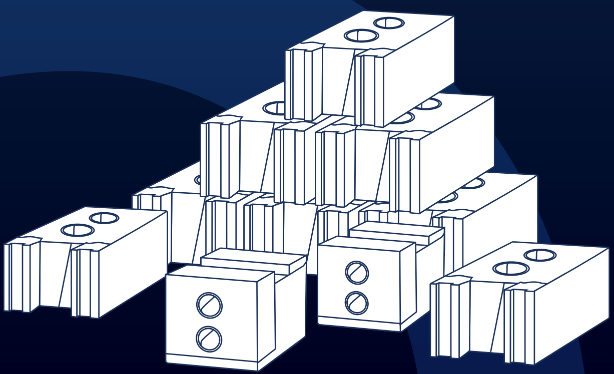
Ceramics

- Kiln furniture
- Refractories



Construction

- Structures
- Reinforced ceramic systems



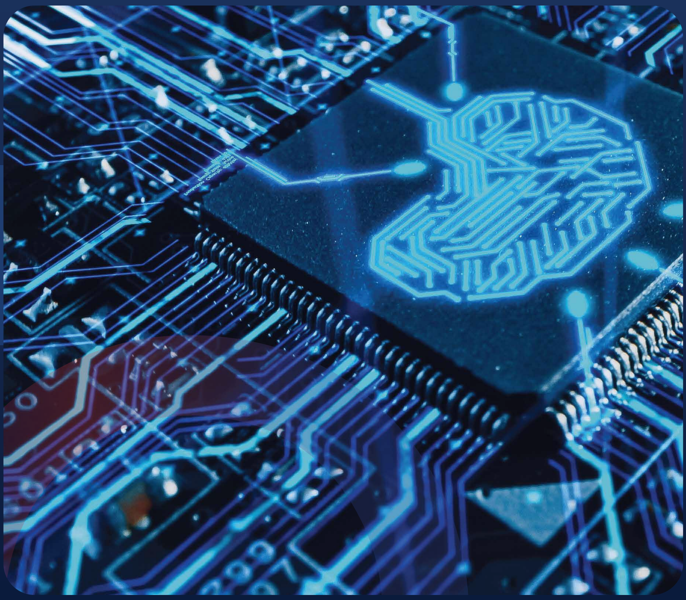
Case Study:

3D Printing Optimisation

The Challenge

For 3D printing to be used in industry, a high degree of optimisation is required to ensure parts are printed to the requisite quality. When conducting experiments to enable this optimisation, the number of experimental parameters that can be changed is extremely large.

The canonical method to understand the experimental space is Design of Experiment (DoE), a method to systematically vary each parameter value and record the result. In ceramic AM, we could, for example, vary temperature from 0 °C to 100 °C in steps of 10 °C while allowing print speed to take on 10 different values for each temperature step. For 6 parameters, where each parameter can take on 10 values, the resultant number of experiments required would be approximately 64 million, which of course is not practical. One must greatly reduce the number of experiments and yet still find the subset of parameter values that optimise final print quality.



The Solution

Lucideon applied Machine Learning (ML) enhanced DOE, using the Random Forest Regressor, to suggest a subspace that would be more likely to lead to high quality printed parts.

This new approach created parameter space heat maps, where “hot” regions point to higher probability of finding high quality prints and “colder” regions point to poor quality prints.

Lucideon’s Offering

By applying this technique, Lucideon can provide the client with the optimal print parameters for their given requirements whilst reducing the number of trials needed, ultimately reducing time and cost.

Case Study:

Silicon Nitride Bonded Silicon Carbide Kiln Furniture for Aerospace Components

The Challenge

Kiln furniture is crucial to the firing of ceramic parts. Its purpose is to securely hold parts during firing, preventing deformation. In recent years, there has been a growing demand for kiln furniture produced from advanced ceramics, due to their high temperature stability, abrasion resistance and low thermal conductivity.

For parts such as ceramic matrix composites, kiln furniture must be produced using complex geometry. This needs to be a cost-effective process, and capable of using a compatible and stable material for the parts undergoing sintering. Robocasting silicon nitride bonded silicon carbide (SNBSC) is a material that exhibits the necessary characteristics.

The Solution

The manufacture of complex geometry kiln furniture is possible via robocasting and Lucideon explored the use of SNBSC as the material choice because of its high strength at elevated temperatures, chemical inertness, corrosion resistance, and exceptional thermal shock resistance. These are vital requirements for kiln furniture material, so the green body parts do not distort or react with the surface of the kiln furniture when undergoing the sintering process.

Lucideon's Offering

Lucideon can develop, trial, and evaluate novel formulations for client applications with a view to industrial scale-up.

About

LUCIDEON

Lucideon is a materials science consultancy that solves the most complex challenges through materials development, process optimisation, and characterisation. It utilises its many years of experience in development, analysis, and assurance to provide technical consultancy to enable, enhance, and accelerate its clients' R&D activities. Its application of cross-industry insight, materials science expertise, and innovative thinking allows industry to develop and implement disruptive technology platforms, providing cost and/or product performance benefits and enabling real market differentiation.

In addition to a multi-disciplinary team of scientists, engineers, and commercial analysts, Lucideon has world-leading testing and characterisation laboratories, a combination of pilot and feasibility plant and equipment, and a management and certification division.

Lucideon has offices and approved laboratories in both North Carolina and South Carolina, as well as New York State, and Staffordshire in the UK .

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