LUCIDEON

Commercialisation of Enabling Technologies for Advanced Ceramics

Introduction

The demand for materials to withstand harsher environments is continuously increasing. From reusable launch vehicles withstanding rentry multiple times, to nuclear fusion reactor development for global energy security, materials are needed to withstand cryogenic and high temperatures, radiation exposure, corrosive and abrasive environments and many more. Existing materials cannot meet the requirements and advanced ceramics are a potential solution.

Advanced ceramics are historically known for high operating temperature characteristics, high hardness and wear resistance, as well as a high strength-to-weight ratio. However, they are also known for their brittleness, machining challenges, and energy-intensive steps. Addressing these challenges through materials and process development can provide a step change in performance and generate novel technologies, however, it's as important to prove to industry that these technologies are scalable and reliable.

Lucideon is a materials development and commercialisation company that bridges the gap between academia and industry by scaling up technologies on industrially relevant processes. Lucideon hosts and manages the UK's Centre of Excellence for Advanced Ceramics, named the AMRICC Centre. This is an advanced ceramic pilot scale facility specifically designed to work from TRL 1-5. Combining the capabilities at The AMRICC Centre and the expertise at Lucideon provides the academia and industry bridge and forges an easier route for the commercialisation of advanced ceramics.

This poster explains four of the many ways of how Lucideon is scaling up novel technologies for applications within the Aerospace and Nuclear sectors.

Ceramic Matrix Composites (CMCs)

CMCs address the brittle behaviour exhibited in monolithic ceramics by incorporating fibres into a ceramic matrix. This is an enabling technology for materials in structural environments that need to withstand higher temperatures as well as a high strength-to-weight ratio than current materials can withstand.

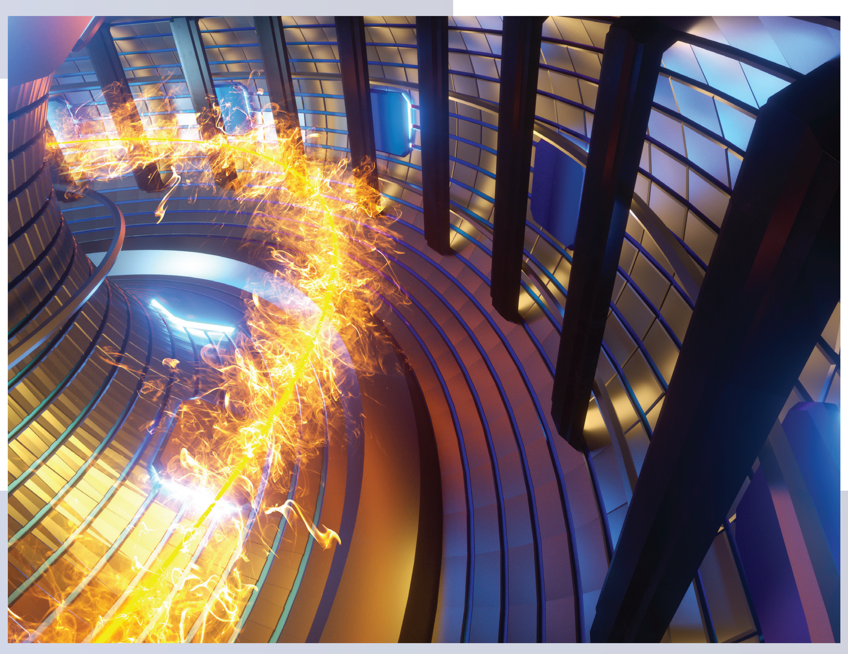
Ox/Ox, SiC/SiC and UHTCMCs are different types of CMCs, ranging in operating temperature from 1200°C, to 1600°C, to over 2000°C, respectively, and exhibit other useful properties such as resistant to oxidation, high radiation hardening resistance, and good chemical stability, respectively.

Lucideon has the capability to work with all types of CMCs through each of the process steps from material selection, matrix formulation development, forming, densification, to sintering.

Applications:

- Turbine components
- Nuclear fusion reactors
- Reusable heat shields

Lucideon is developing a range of Geoceramic MIDAR® Composites that bridge the temperature performance gap between metals and high-end Ox/Ox CMCs. Their curing temperature of <100°C makes them a cost-effective alternative to Ox/Ox CMCs and a lighter alternative to metals, ideal for fire-resistant, battery encapsulation, and extreme short-term applications.



Integrated Materials & Processing Advanced Computational Technique (IMPACT™)

Determining the optimal formulations or relevant processing parameters through trial and error can be time consuming and expensive due to the extremely large number of combinations available. However, recent development through Industry 4.0 proves computational modelling and machine learning can offer a solution.

Lucideon's IMPACT™ technology platform encompasses the following techniques alongside an extensive knowledge in advanced ceramics and pilot-scale equipment to provide a unique offering to market:

1. **First Principles Guidance**
The exploration of novel materials and optimisation of existing materials at a fundamental level through a physics-based approach. Understanding the chemical and structural characteristics of advanced ceramics through expertise and experimental methods can validate and guide model development, ensuring results are reliable and optimal.

2. **Finite Element Analysis**
Creating accurate and reliable simulations of legacy and advanced materials to predict structure property relationships as well as processability and thermal properties. Combining FEA and Lucideon's characterisation suite, this capability can be used to recognise deformation or failure of materials under a wide variety of conditions without wasting material and equipment time.

3. **Machine Learning**
ML covers various topics, such as automated quality control via the use of Computer Vision and controlled feedback, process optimisation and enhanced design of experiments. Lucideon can utilise historical data to predict pertinent material properties, create real-time dashboards for process monitoring, and much more.

For example, Lucideon is developing a Computer Vision software to identify, model and predict the distortion and shrinkage of ceramics during the sintering process. Due to the high temperatures involved, identifying the edges of parts during this process is challenging, however, Lucideon is developing a real-time monitoring software integrated with cameras that will ultimately enhance the quality control process when implemented into industry.

Applying IMPACT™ to development programmes drives forward the commercialisation of advanced ceramic technologies, through accelerated materials discovery, to parameter and process optimisation.

Conclusion

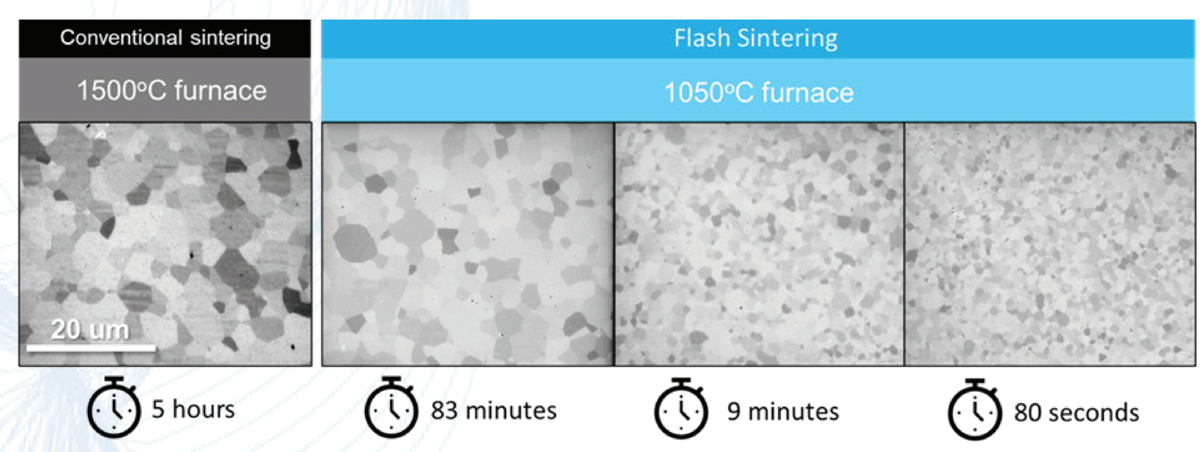
The demand for advanced ceramics continues to increase, particularly since existing materials cannot meet the requirements for the new applications. Industry needs reliable technologies to commercialise and therefore, needs a bridge for developing these from academia.

It's shown that Lucideon is developing novel material and process technologies related to advanced ceramics however, the list is not exhaustive. For example, Lucideon is developing geopolymer formulations for construction and nuclear waste encapsulations, another key technology platform.

Future work for Lucideon continues in these areas mentioned above as well as novel coatings and sintering techniques, novel joining technique development, and ceramic armour.

Flash Sintering

Flash Sintering is an advanced sintering technology that works by directly applying an electric field to a ceramic body. Conventional sintering can be inefficient due to the heat loss to the surrounding furnace however, with Flash Sintering, materials can be sintered quicker and at a lower furnace temperature than those conventionally sintered. In addition, Flash Sintering can provide the function of microstructural control, a key property for improving performance for specific applications. For example as shown in the image below, Flash Sintering, at a furnace temperature 1050°C in 83 minutes can generate a similar microstructure to which conventional sintering would produce at a furnace temperature of 1500°C for 5 hours. Conversely, when optimised field settings are applied for 80 seconds, a smaller grain size is retained within the part, maintaining the same density.



Thermal management of the process relies on Lucideon's proprietary real-time linear control software that incorporates over 20 different electric variables.

Flash Sintering's main application is the rapid sintering of nuclear fuels for plutonium disposition and MOX manufacture. Concept plant design shows increases in productivity from between 70 and 550%, based on setting utilised for sintering UO_2 pellets to full density. This results in a dramatically reduced furnace temperature, sintering below 1000°C, removing the need for water cooling on furnaces, improving the safety case for these materials manufacture.

Applications:

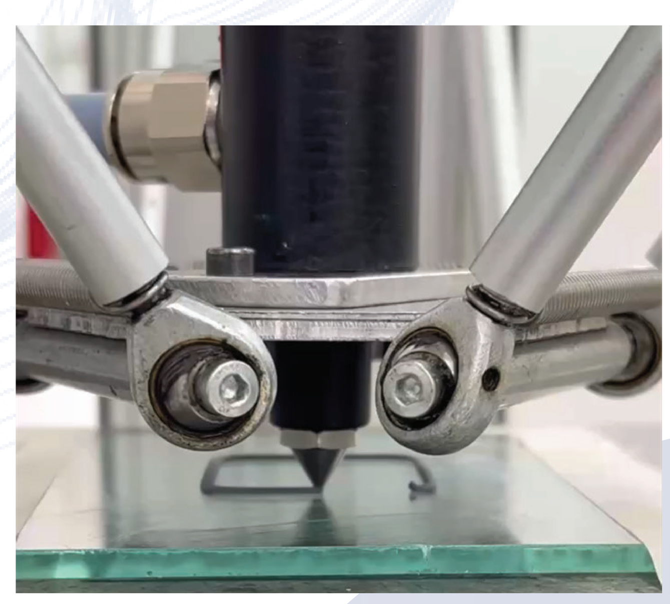
- Nuclear fuels and fuel immobilisation
- Regolith sintering
- Flash synthesis of cathode materials for next-gen batteries
- Flash Bonding – Joining of dissimilar materials.
- Contactless Flash Sintering – Environmental Barrier Coatings

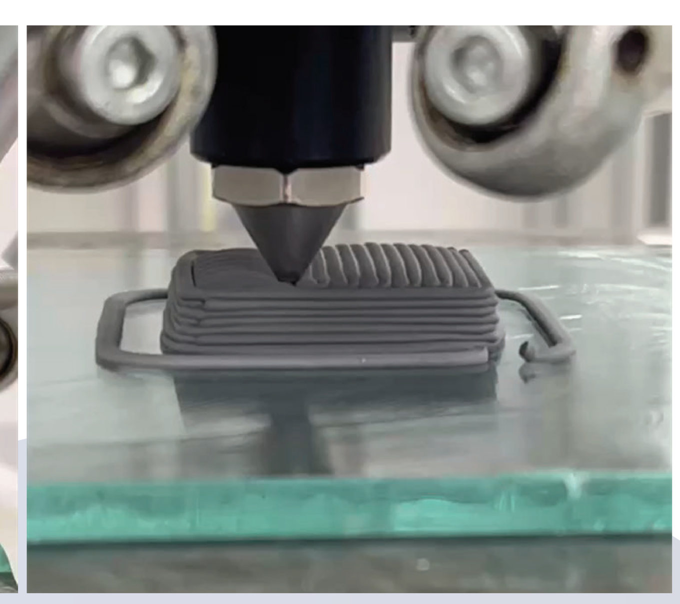
Ceramic Additive Manufacturing

Ceramic AM can produce complex, near-net-shape parts, providing an enabling forming technique that conventional forming processes cannot produce, as well as a reduction in machining and material, thus tooling and supply cost, respectively.

There are multiple techniques, ranging from vat polymerisation processes which are excellent for intricate details and high tolerances, to powder bed processes which print parts quickly. Lucideon is developing novel formulations for a 3D printing technique, named robocasting. This is a rapid, low-cost, extrusion-based technique that deposits a slurry layer by layer.

Kiln furniture is an example of a robocasting application. It's used to support ceramic parts during the sintering process and is expected to resist deformation as it's cycled through the temperature range





In addition, Lucideon has access to vat polymerisation printing capabilities, techniques that are emerging due to their excellent surface finish and high resolution.

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The AMRICC Centre