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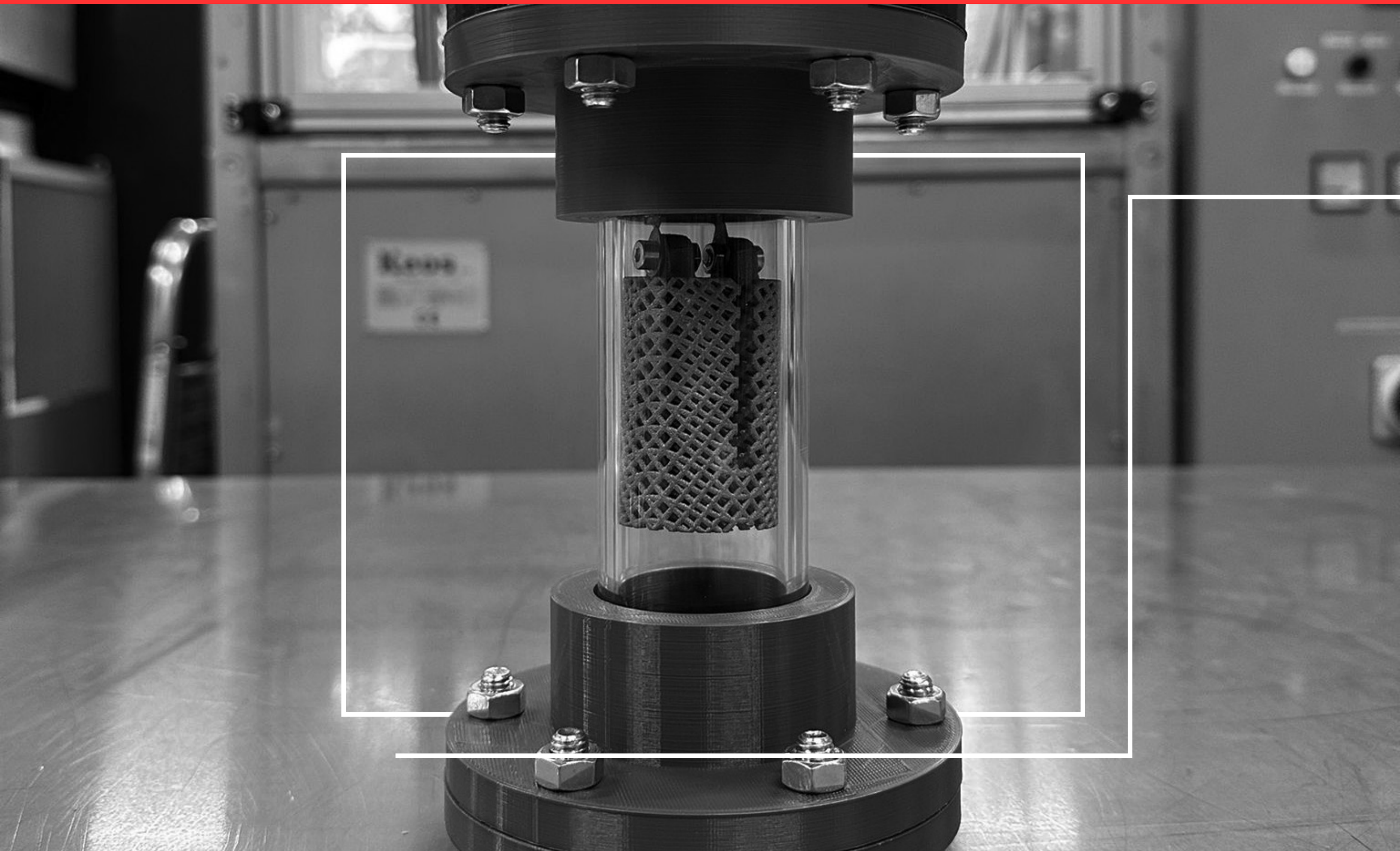
CASE STUDY

Binder Jetting of Graphite with Highly Engineered Geometry

SUPSI uses the Innovent X™ to 3D print a graphite-based electrode that support direct heat generation in reactors, contributing to a more sustainable production of solid carbon and hydrogen



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Graphite is a highly conductive material, both of heat and electricity, and it has the highest natural strength and stiffness of any material. It maintains its strength and ability to high temperatures and is very resistant to chemical attack.

Customer
The University of Applied Sciences and Arts of Southern Switzerland (SUPSI)

Location
Lugano, Switzerland

Industries
Research and Development

Material
Graphite

Machines
Innovent X™

Website
www.supsi.ch/en/research-innovation-overview

Graphite: A valuable resource for today's high-tech applications

Graphite is one of the many forms of carbon known for its exceptional chemical and physical properties, including chemical stability, resistance to high temperatures, and resistance to thermal shock.[1] These properties of graphite make it a desirable material for a wide range of modern, high-tech applications. It is especially useful for producing and storing electrical energy, such as thermochemical heat storage for heating buildings in winter, which collects its energy from solar thermal energy in summer.[2]

As the global demand for high-purity, carbon-based materials continues to grow, the current production processes are facing increased environmental scrutiny due to their greenhouse gas emissions.[3] Researchers worldwide, including those at the Department of Innovative Technologies (DTI) of the University of Applied Sciences and Arts of Southern Switzerland (SUPSI), are working to develop more sustainable solutions to meet this demand. They have even made successful attempts in this area.

The path to more sustainable carbon production

The Institute of Mechanical Engineering and Materials Technology (MEMTI), one of six research institutes under the DTI, carries out applied research and knowledge transfer to industry in the manufacturing and energy sectors. The institute is equipped with six state-of-the art laboratories. One of these, the Hybrid Materials Laboratory (HML), is a leading research facility specializing in studies related to the field of materials science and technology, including the carbon-based, and porous ceramic materials.

> "Most state-of-the-art production processes for carbon black and both natural and synthetic graphite have a very high environmental impact. Thus, one of our research initiatives aims to find a more environmentally sustainable approach to producing high-purity carbon-based materials,"
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> **Riccardo Balzarotti, one of the researchers at SUPSI's Hybrid Materials Laboratory**

Several research projects have been conducted in this field. One of these projects, funded by Innosuisse (the Swiss Innovation Agency), involved producing a special graphite-based electrode (electric conductor) in the form of periodic open cellular structures (POCS). These are highly engineered geometries made up of repeating, specifically defined, geometric unit cells arranged in a periodic pattern to achieve predictable, uniform material properties. These cells are open with interconnected pores that allow for fluid flow or heat transfer.[4]

Graphite-based POCS can be used in many applications, including heat exchangers, energy systems, and lightweight aerospace and automotive components.[2] SUPSI's research team investigated using these graphite structures to support direct internal Joule-heating in reactors (see figure 1). These reactors are used to produce carbon-based materials and hydrogen structures via the methane cracking process. The graphite POCS were printed using the Innovent X™, a metal binder jetting system from Arc Impact, and consolidated through precursor infiltration pyrolysis (PIP).

The graphite-based POCS play an important role in a reactor's heat generation process, as confirmed by Balzarotti. "The POCS reduce the heat demand of the methane cracking process due to its carbon composition. In this process, graphite serves as a catalyst."

Methane cracking is a process that breaks down methane (CH4) into hydrogen gas (H2) and solid carbon without producing carbon dioxide (CO2). In theory, this process is a better choice for the environment than the usual ways of making solid carbon and hydrogen. This process also produces solid carbon, which is easier to store, sell, or use in, e.g. carbon black or graphite applications. Besides, the hydrogen purity from the methane cracking process is higher than from the traditional methods.[3]

However, the methane cracking process requires a lot of energy. There are different process configurations to run the process. The SUPSI research team investigated the heating methods from inside the reactor (internal reactor heating) to meet the process's energy needs. They decided to move heat generation from outside the reactor to inside because it has been shown that this can overcome the limitations of external heat generation and transfer.[3]

Nevertheless, effectively implementing the direct heating approach is complex. The direct Joule heating mechanism, which has recently been implemented in various fields of industrial catalysis, lacks sufficient information on its effective implementation. Joule heating generates heat locally by applying an electrical current to a medium with limited conductivity. Therefore, the research team at SUPSI aimed to address this issue by conducting an experimental investigation of 3D-printed, Joule-heated POCS for use as structured internals in the methane cracking process. The feasibility tests of this innovative process and technology yielded positive results.[3]

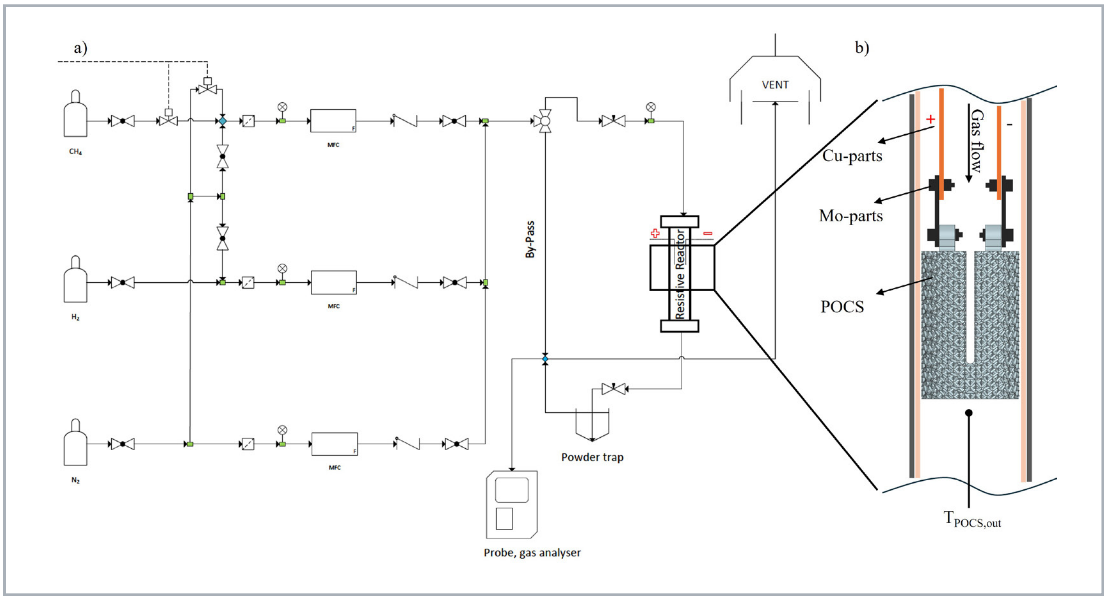

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Figure 1:
A visualization of a rotated cube POCS inside a reactor used for methane cracking. (a) A schematic representation of the rig setup, (b) the reactive zone of the electrified reactor. The figure is courtesy of the Hybrid Materials Laboratory at SUPSI.[3]

Challenges in processing graphite with complex geometries

According to the HML team, the production of carbon/graphite-based structures is a well-known challenge. In addition to the environmental concerns associated with processing the material, graphite is difficult to machine or form with traditional methods. Additionally, graphite cannot be melted, rendering AM techniques that involve melting materials ineffective for its processing.

The geometric complexity of the POCS also poses significant production challenges. These structures are reticulated, featuring interconnected cylindrical bars that create a network-like configuration. These thin, porous features are difficult to manufacture using conventional methods due to their fragility, which can lead to breakage or deformation during machining or mold removal. “It’s nearly impossible to produce these complex graphite parts conventionally without laborious or complicated manufacturing processes,” confirmed Balzarotti.

The HML team has assessed several production methods for graphite-based applications with reticular structures. For instance, the hybrid production technique that combined powder bed fusion with the infiltration of pre-ceramic polymers was evaluated. However, they found the process to be too complex. The team also explored the use of fused deposition modeling to produce these structures. However, this option was not determined to the most suitable due to concerns regarding quality and process reliability.

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Big POCS for methane cracking

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Big POCS for methane cracking
(rotated view)

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POCS with copper-plated pins
(rotated cube unit cell)
Cell size: 4 mm Strut size: 1 mm

After careful consideration, the decision was made to use binder jetting technology for 3D printing the graphite architectures. “We worked closely with Arc Impact’s Binder Jetting Adoption Center to assess the technology’s capabilities in processing different carbon, graphite materials with complex geometries. We‘ve concluded that the binder jetting method is the most reliable one for producing the graphite POCS,” said Balzarotti.

Binder jetting of graphite-based POCS

The 3D design for binder jetting of the POCS with rotated cube was created using a specific algorithm by an in-house designer at the HML team who specializes in complex geometries. The POCS are exceptionally small, with cell sizes down to 4 mm and strut sizes down to 1 mm. This makes production with conventional methods challenging.

A mixture of graphite powder and carbon black was used for the preparation of the powder bed for 3D printing the POCS. A phenolic binder was used as injection binder into the powder by the print head.

The green parts, or preforms, were printed using the Innovent X™, the world’s most widely researched binder jetting system. It is known for its broad material compatibility, tight tolerances, and excellent surface finish.

In the binder jetting process of the POCS, the print head selectively deposited the liquid binder onto the bed of graphite powder. This process was repeated layer-by-layer until the final parts were complete. Afterwards, the job box, containing the printed POCS and the unbound powder, was heat-treated in a drying oven. This step was essential for removing the solvent present in the binder and pre-curing the phenolic resin to ensure sufficient mechanical resistance for handling the part. Then, excess powder was removed using a soft brush and a low-pressure air gun for the inner surface.

Post-Process: Precursor Infiltration and Pyrolysis (PIP)

Two post-processing steps followed binder jetting to achieve the desired final properties of the parts produced. First, the printed graphite preforms were infiltrated with a carbon-rich precursor (in this case furan resin) to fill the material pores. This process is called precursor infiltration. The second process was pyrolysis, which converted the precursor material into a solid form through heating.

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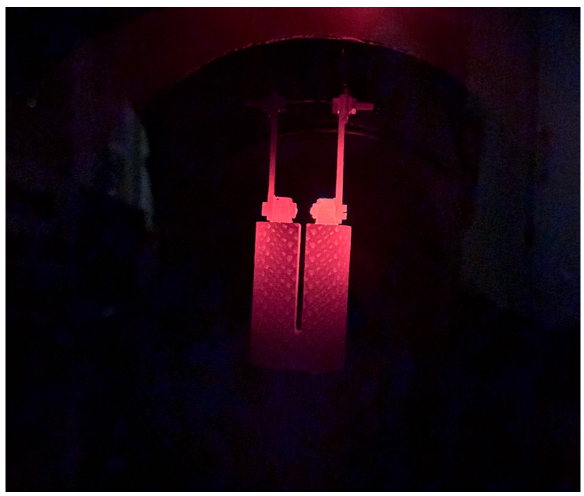
Davide Viganò, Research Assistant, at the Hybrid Materials Laboratory (HML) at SUPSI uses the Innovent X™, the world's most research binder jetting system, in numerous R&D projects related to the field of materials science and technology.

The strengths of binder jetting

The research team at SUPSI was very proud to have successfully used binder jetting technology to 3D print graphite-carbon material with few millimeter size periodic open cellular structures, followed by infiltration and pyrolysis. “So far, we haven’t found anyone publishing on the topic of 3D-printed graphite or its application,” stated Giovanni Bianchi, senior researcher at the HML. This is an innovative process which has the potential to enable the sustainable production of solid carbon and pure hydrogen.

The research team was very satisfied with the results of the heat transfer performance and catalytic activity tests of the 3D-printed POCS for methane cracking. Thus, these binder jetted POCS can be used as direct, internal, Joule-heated supports in a reactor to produce solid carbon and pure hydrogen via the methane cracking.



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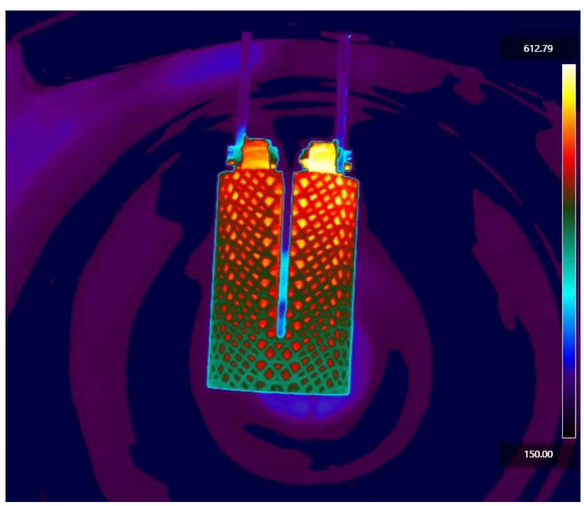
Joule Heating



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Joule Heating

They highlighted several key strengths of the Innovent X™ binder jetting system in regards to 3D printing of these graphite structures.

Balzarotti pointed out that the binder jetting process is simple. “Binder jetting is a very straightforward process. The green body is already 90% of what would be the final product. With other methods, your structure will shrink significantly.”

Binder jetting offers material flexibility, making it ideal for custom research projects, as Bianchi explained. “It is really easy to work with the initial material. You have to find the right powder, but with binder jetting, you can choose any material. That’s why we found it easy to start working with binder jetting to produce graphite parts. Of course, there were many trials in the beginning to select the correct graphite grade and to find the right binder combination. Once we found the right parameters, though, binder jetting became a very reliable technique. You can start working on the geometries you want, or take on applications to understand how changing the geometry of the heating element influences the performance of the heat exchanger or the reactor.“

There is a great freedom of geometry with binder jetting. The technology enables the creation of parts with intricate internal geometries, such as reticulated structures, which traditional manufacturing processes cannot achieve. It also produces parts with exceptional precision, accuracy, and detail. “At the moment, binder jetting is the most interesting, suitable technique to produce complex geometries like the reticulated structures. It simplifies the manufacturing of complex designs,” added Bianchi.

Another significant advantage of the binder jetting process is its rapid printing speed. Balzarotti pointed out: “With other techniques, the overall production time would be longer due to the additional steps or post-processing needed. Even if the production time for the green body were the same for both binder jetting and the hybrid method, for example, the hybrid method would require much more post-processing”.

The research team has also benefited from the repeatability of binder jetting technology. This technology can produce parts with consistent results across multiple printing jobs due to its low-thermal, digitally controlled, mechanically stable process. The printed graphite parts also retained their complex shapes after post-processing.

Lastly, binder jetting is a scalable additive manufacturing method, making it easy to increase production volumes or transition to industrial-scale production. “The next step is to scale up this more sustainable process of cracking methane. It is important that we transition to more industrially relevant conditions. It’s great that larger binder jetting systems are already available. We’ve partnered with Arc Impact’s Binder Jetting Adoption Center to 3D print a higher volume of samples using the X25Pro™ binder jet system. This is our first step toward industrial-scale production,” explained Balzarotti

Continuous research and development with binder jetting

Over the past years, the team at the Hybrid Materials Laboratory at SUPSI has conducted numerous research and development projects involving challenging materials, including silicon carbide, tungsten carbide, and carbon-based materials like graphite. The team has also successfully developed several high-performance applications with these materials using the Innovent X™ binder jetting system, some of them in partnership with Arc Impact's Binder Jetting Adoption Center.

Examples of applications developed by the SUPSI research team using challenging materials with the Innovent X™ binder jet platform and subsequent post-processing are as follow:

- Reusable active heat shields (Si-SiC)
- Compact heat exchanger for high temperatures (Si-SiC)
- Latent heat thermal storage (Si-SiC)
- Porous burners (Si-SiC)
- High-temperature and high-pressure chemical reactors (SiC)
- Seasonal thermochemical heat storage (Graphite)
- Radiotherapy X-Ray Collimators (Tungsten Heavy Alloy)

Further binder jetting research projects are currently under discussion. "One possible application is printing molds for metal or other composite material castings instead of making complex molds that are not feasible or hardly feasible with conventional machining from large blocks of graphite," said Balzarotti. "We are also exploring the potential to engineer heating elements with specialized shapes that can be used in applications requiring graphite heating systems."

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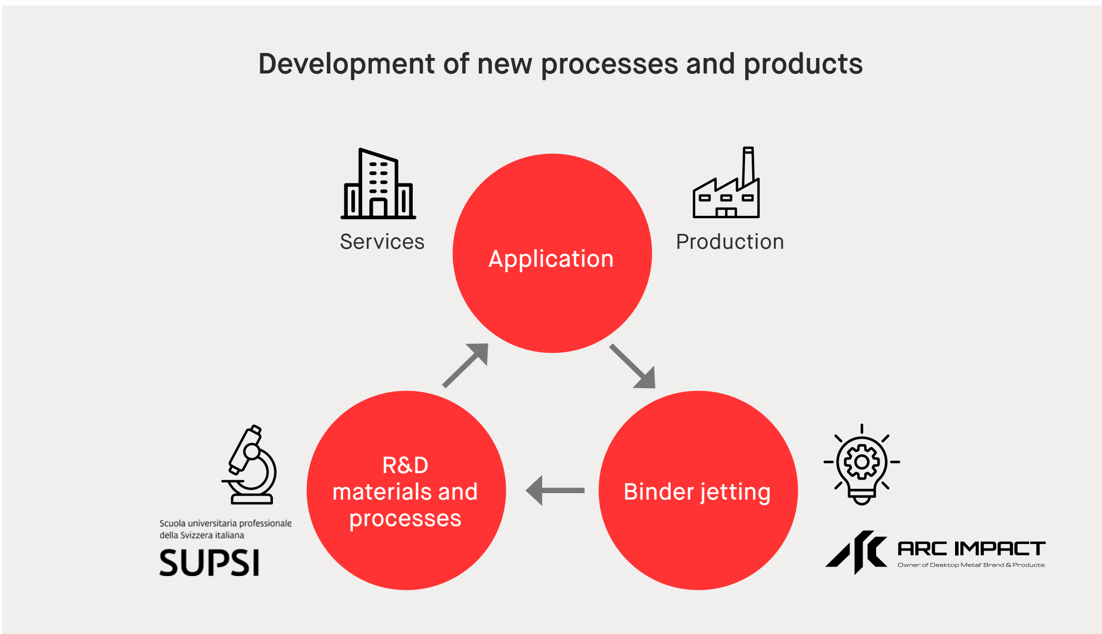
Another possible application of 3D-printed graphite: Crucible for casting

Partnership with Arc Impact Binder Jetting Adoption Center

The team at the Hybrid Materials Laboratory at SUPSI has established a solid partnership over the past few years with the Arc Impact Binder Jetting Adoption Center. They have been exploring the potential of binder jet 3D printing to solve the needs and challenges of industrial applications in the production and services sectors, including in the automotive, aerospace, healthcare, and energy sectors. These industries regularly encounter demands for lighter, stronger, more complex, or more sustainable components. However, such demands often exceed the capabilities of traditional manufacturing methods, prompting the exploration of innovative solutions. Consequently, the industries are continually seeking out enabling technologies that can address these needs



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This diagram illustrates collaborative processes between industries, SUPSI's Hybrid Materials Laboratory,and the Arc Impact Binder Jetting Adoption Center to develop new processes and products that canaddress the needs and challenges posed by industrial applications.

and challenges. "We believe that additive manufacturing with binder jetting technology has the potential to meet the industries' needs and challenges by facilitating the production of complex geometries, and lightweight structures using a variety of materials, including metals and ceramics," stated Balzarotti.

The HML team has found that implementing binder jetting for a particular application often necessitates substantial adaptation in terms of material selection, process optimization, and post-processing. Research and development institutes, such as the HML team at SUPSI, play a fundamental role in this field by studying the materials and processes involved in this AM technology. SUPSI is collaborating with industry leaders and binder jetting system manufacturers, including Arc Impact, to create customized processes that translate the industry's functional requirements into manufacturable and reliable components.

Once a suitable material-process combination is developed, it is transferred back into the binder jetting production environment, using equipment and platforms provided by AM companies like Arc Impact. Here, prototypes and initial production batches are manufactured, validating the research work.

These parts are then subjected to rigorous testing in their designated industrial applications. During this process, they are evaluated based on criteria such as performance, reliability, and adherence to design specifications. This phase not only validates the technology but also generates crucial feedback regarding limitations, process variability, or new requirements that may have emerged during real-world use.

This cycle of feedback is then passed on to the R&D department, where it is used to make improvements in material formulations, process parameters, or equipment settings. The cycle then begins anew. In this way, industry applications act as both the starting point and the ultimate validator of innovation, while Binder Jetting and research activities form the responsive core that adapts and evolves to meet those industrial needs.

This model emphasizes collaborative innovation, where industrial challenges guide research, Binder Jetting serves as the manufacturing enabler, and continuous iteration ensures that emerging products and processes are both technically sound and practically relevant.

Such collaborative innovation frameworks can often be supported and accelerated through funding from national and international research programs, particularly those dedicated to advanced manufacturing, materials innovation, or technology transfer. These programs—such as those offered by Innosuisse, Horizon Europe, or regional innovation agencies—promote collaboration between academic institutions, technology providers, and industrial partners, thereby reducing risks, facilitating knowledge exchange, and accelerating the implementation of cutting-edge solutions like binder jetting in the market.

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SUPSI

About SUPSI

About the Research and Innovation Division at the University of Applied Sciences and Arts of Southern Switzerland (SUPSI)

SUPSI, with its multiple locations throughout Switzerland, is engaged in a variety of applied research and knowledge transfer programs and projects. Its research units are dedicated to applied research with strong practical applications, aiming to offer innovative solutions that enhance both the competitiveness of companies and organizations and the quality of people's lives.

SUPSI's applied research activities are carried out by numerous institutes, competence centers, and specialized laboratories within its various departments and affiliated schools. These entities collaborate closely with local, federal, and international institutions, companies, and partners.

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Learn more: www.supsi.ch/en/memti

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About Arc Impact

Arc Impact is an application-driven, end-to-end solution provider built on deep expertise in binder jetting, materials science, powder metallurgy, and ceramics. Moving beyond the traditional hardware-only business model, we act as a true manufacturing partner dedicated to powering the return of a strong, agile industrial base. To ensure our additive manufacturing solutions seamlessly integrate into complex production environments, our focus extends far beyond simply printing to orchestrating the entire journey to the final product. Through cradle-to-grave support, we collaborate with customers on materials selection, process qualification, and downstream ecosystem integration, guiding them from initial concept through full-scale serial production to ensure long-term manufacturing success.

Learn more about Arc Impact and our #TeamDM brands at

www.desktopmetal.com