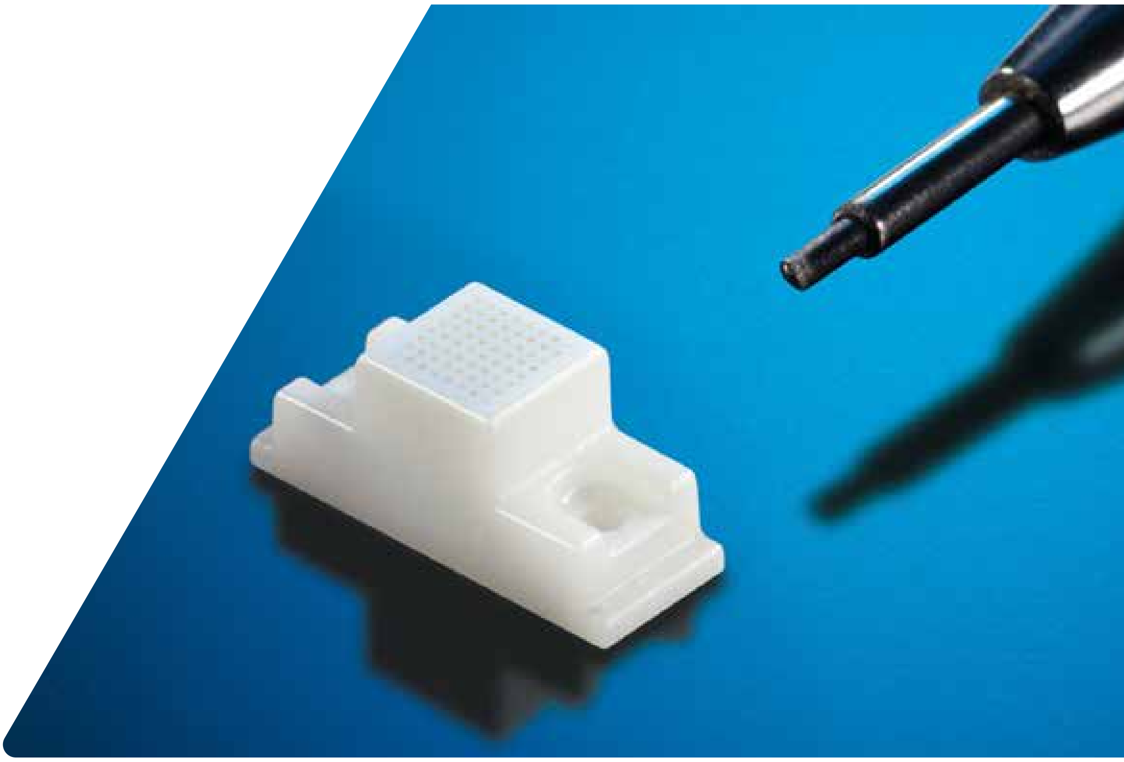
How AM complements conventional ceramic parts manufacturing

Introduction

The demand for ceramic components continues to grow across various industries due to their unique combination of properties, which enable improved performance, reliability, and sustainability in diverse applications. Especially the demand for small and complex components is increasing because of the trend to miniaturization, environmental considerations to replace plastics and market growth in key industries like healthcare and electronics.

Ceramic shaping methods, like powder pressing & sintering in combination with hard machining or Powder Injection Moulding (PIM) have long been serving these markets. However, in the current rapidly evolving environment, small parts require more complex geometries, more design freedom and shorter lead times. Geometries that challenge today's standard shaping methods create new opportunities for the equally fast emerging Additive Manufacturing (AM) technologies. What are the opportunities for AM to complement PIM?



Market requirements for technical ceramics

Small and complex ceramic components are increasingly demanded in several markets due to their unique properties and advantages. Some of these markets include:

Electronics and Semiconductors

The electronics industry relies on ceramic components for various applications such as insulating substrates, capacitors, resistors, and semiconductor packaging due to their high electrical insulation, thermal stability, and resistance to corrosion.

Aerospace and Defense

Aerospace and defense applications utilize ceramic components in aircraft engines, thermal protection systems, missile guidance systems, and armor due to their elevated temperature resistance, mechanical strength, and lightweight properties.

Medical and Healthcare

Ceramic materials are used in medical devices and equipment such as dental implants, orthopedic implants, surgical tools, and diagnostic equipment due to their biocompatibility, resistance to wear, and ability to withstand sterilization processes.

Energy and Power Generation

Ceramic components are used in energy production and power generation systems such as gas turbines, fuel cells, solar panels, and nuclear reactors due to their thermal stability, corrosion resistance, and ability to withstand extreme operating conditions.

Automotive

The automotive industry utilizes ceramic components in engine components, exhaust systems, brake systems, and sensors due to their high temperature resistance, wear resistance, and lightweight properties, contributing to improved performance and efficiency.

Chemical Processing and Industrial Applications

Ceramic components find applications in chemical processing equipment, pumps, valves, and heat exchangers due to their corrosion resistance, chemical inertness, and ability to withstand hot temperatures and abrasive environments.

Where conventional shaping methods like Ceramic Injection Moulding limit these applications due to their design restrictions and slow development cycles, the opportunities that 3D printing of ceramic materials nowadays offer is becoming increasingly popular. There is a growing need for flexibility in design and functional prototyping during the product development cycle. AM technologies for ceramics now offer these possibilities with multiple materials, reliable material properties and accurate dimensional control. And this also automatically makes available the possibility for far-reaching integration of functionality and complexity that AM technology offers in general. Now the ceramic manufacturing industry experience an increasing shift towards AM, becoming a real complementary manufacturing technology for ceramic components.

A case study - part of a surgical instrument

This particular product covers a part of a surgical instrument designed to guide a wire. Typically, iterations in design were performed using pure resin models. These only supply answers for geometrical fitting tests, the resin does not have the further specifications such as the designed ceramic or metal product. With additive manufactured parts, three evaluative steps were executed before a final design was frozen for functional testing. A further 25 parts were printed for this testing purpose. After approval, the design was still open to either Injection Moulding or Additive Manufacturing.

Yearly production quantities were forecasted at 10.000, expected to rise to 25.000 in the years to come. Product life cycle was set at five years, however this was based on current models of mould life expectations, it was not driven by innovation, nor marketing desires.

Comparing PIM and AM in this case, Injection Moulding would require a four cavity mould with one slider, commercially quoted at € 18.000 for the required tolerances and a shot guarantee of 150.000 parts. Price per part would be € 0,45 at a minimum ordering quantity of 5000 parts, while production capacity due to cycle time and four-cavities would be 3840 parts per day. That is in case of production without automation for unmanned night production. Typical throughput time for the tool was 8-12 weeks.

Example materials suitable to use in both PIM and AM

Some common ceramics that are injection molded or 3D printed include:

Alumina
A commonly used ceramic material known for its high strength, hardness, and chemical resistance. It finds applications in industries such as aerospace, electronics, and medical.

Zirconia
This ceramic material is renowned for its mechanical properties, such as high strength, toughness, and wear resistance. It is often used in dental applications, aerospace components, and industrial machinery.

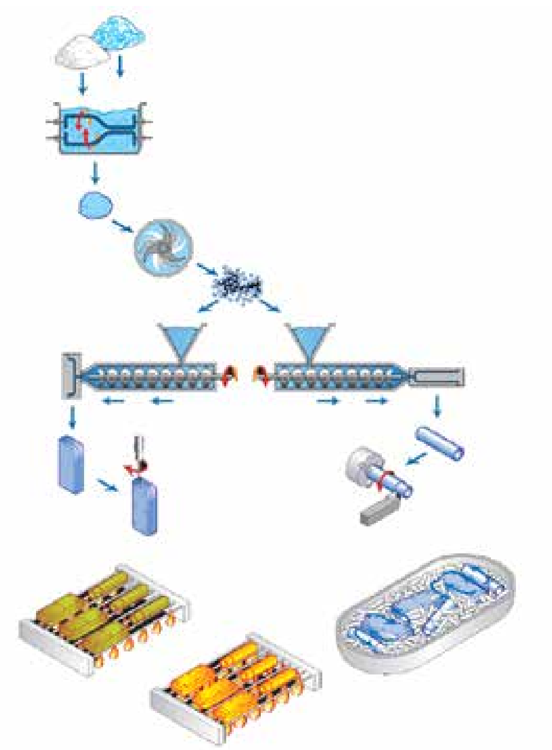
Silicon Carbide
Known for its excellent thermal conductivity, low thermal expansion, and high strength, silicon carbide is used in high-performance applications like aerospace, automotive, and electronics.

Silicon Nitride
This ceramic offers exceptional thermal shock resistance, high strength, and excellent wear properties. It is commonly used in automotive and aerospace components, cutting tools, and bearings.

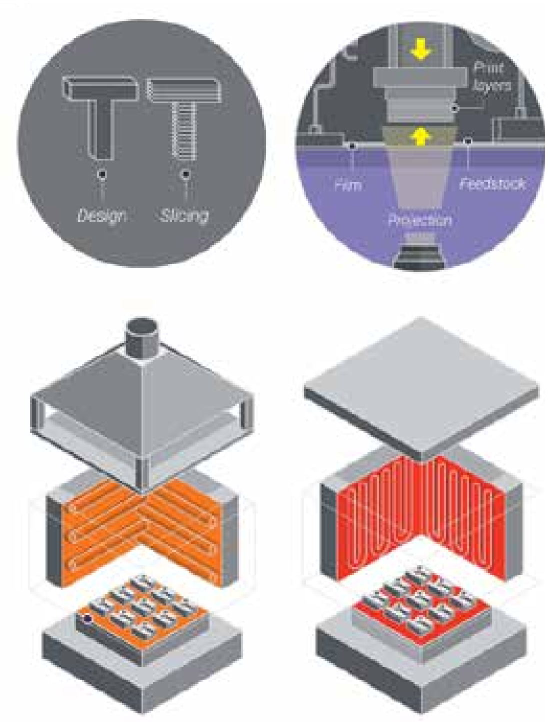
Differences Between PIM and AM

PIM and AM to produce ceramic parts use comparable production steps of shaping a “green” part, after which it undergoes thermal debinding to remove any organic binder and sintering to consolidate. Both processes can deliver full (>99%) dense parts when using appropriate powder sizes and sintering parameters.

CIM Process



AM Process



Process Overview:

	PIM	AM
Process Overview	Powder Injection Molding involves mixing ceramic powders with binders to form a feedstock, which is then injection molded into the desired shape. The molded parts are subsequently debound and sintered to achieve the final ceramic product.	Additive Manufacturing, often referred to as 3D printing, builds ceramic components layer by layer from digital designs. This is typically done through techniques like selective laser sintering (SLS) or binder jetting.
Design Flexibility	Offers high design flexibility, allowing for intricate shapes and detailed features due to the molding process.	Provides unparalleled design freedom, enabling the creation of highly complex geometries, internal structures, and customized parts without the constraints of traditional manufacturing methods
Material Properties	Produces ceramics with isotropic properties, meaning the material characteristics are consistent in all directions. This makes PIM suitable for applications requiring uniform mechanical properties.	Can yield ceramics with anisotropic properties, where the material properties vary depending on the direction. This can be advantageous for tailored performance in specific applications but may require careful consideration during design and engineering.
Production Scalability	Well-suited for large-scale production runs due to its batch processing nature, making it economically viable for mass production of ceramic components.	Often utilized for low to medium volume production or rapid prototyping due to its layer-by-layer construction method, which may not be as efficient for high-volume manufacturing.
Surface Finish and Tolerance	Typically achieves high surface finish and tight tolerances, making it suitable for applications where precision and smoothness are critical.	Surface finish and dimensional accuracy can vary depending on the specific AM technique and parameters used, requiring post-processing to achieve desired specifications in some cases.
Material Selection and Availability	Limited by the availability of suitable ceramic powders and binders that can meet the requirements of the molding and sintering process.	The process allows for a higher functionality of the materials used, i.e. different materials can be used for different layers.

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