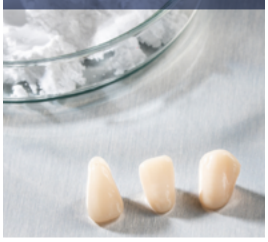
Baikowski®

Solution partner for FINE MINERALS

CERAMIC 3D PRINTING POWDERS & SLURRIES

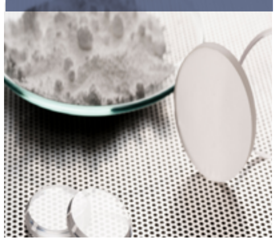
HIGH PURITY ALUMINA, ZIRCONIA, ZTA & SPINEL ADVANCED SOLUTIONS

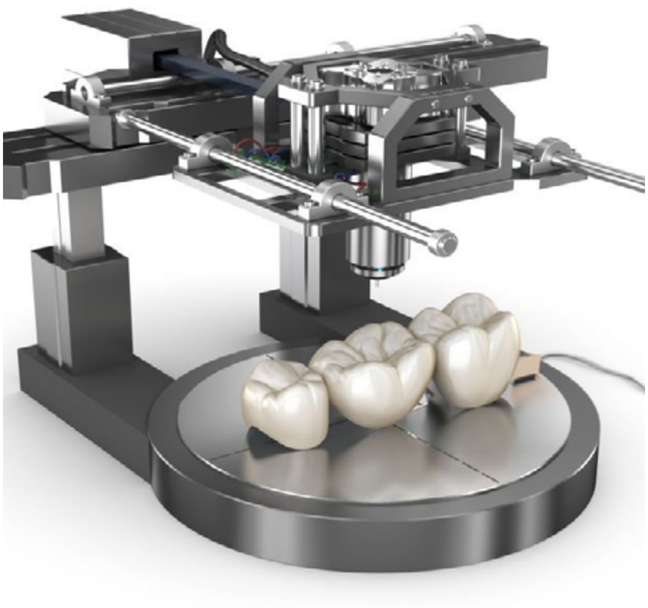
POWDER



SLURRY

SPRAY-DRY





Explore the future of ceramic manufacturing: the power of 3D printing powders and slurries for enhanced precision and customization!

> Ceramic 3D printing is a revolutionary manufacturing process that combines the precision of 3D printing with the unique properties of ceramics.

> Unlike traditional manufacturing methods, which often involve subtractive processes like cutting, ceramic 3D printing is based on **an additive approach** that opens up new possibilities and **reduce waste**.

> As a matter of fact, ceramic conventional manufacturing with molds have several limitations such as the production of **highly complex geometries, large customization options,** that 3D printing allow to overcome.

> **Ceramic slurries and powders have played a determinant role** in the development of this technology by offering enhanced compatibility with the different printing processes.

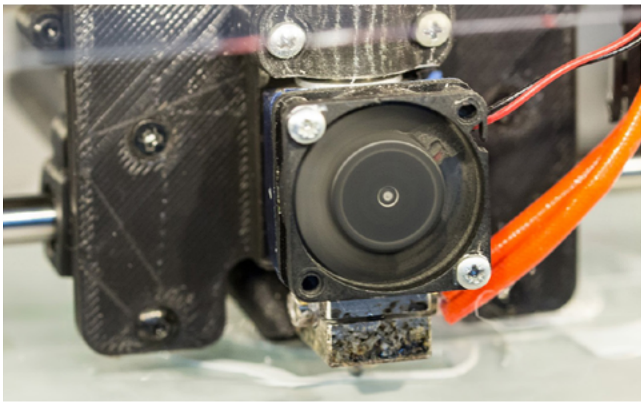
> By leveraging the offerings of Baikowski®, along with the flexibility of tailored solutions, a wider range of ceramics can be successfully printed. Our high purity, ranging from **3N to 5N**, and extremely **fine particle solutions** of alumina, spinel, zirconia, ZTA address many markets, including specific and challenging applications such as aerospace and defense parts.

1. Ceramic 3D printing principle

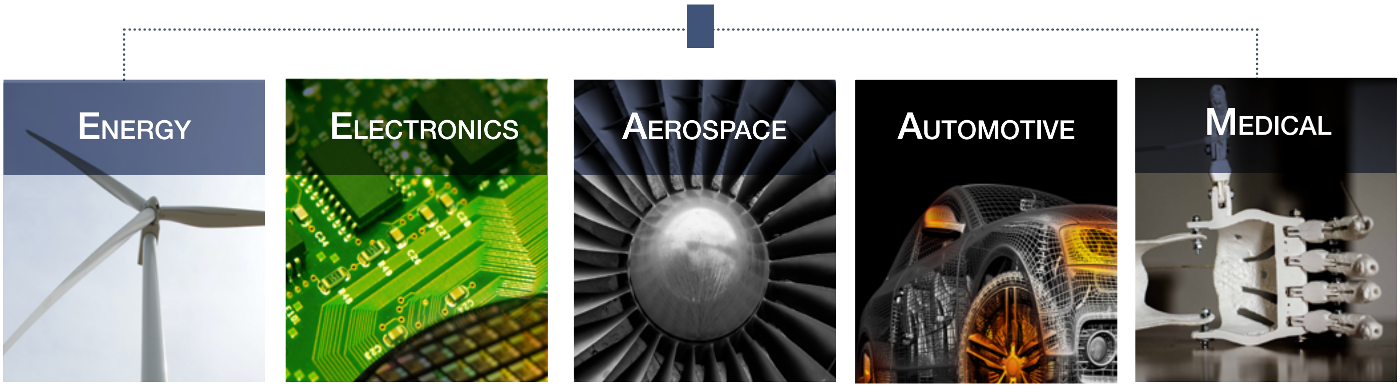
> The principles behind ceramic 3D printing involve **precise control of material deposition,** layer thickness, curing and sintering processes.

> A printer follows the digital model in a controlled manner to achieve the desired shape and structure.

> Once the printing is complete, the object undergoes post-processing steps such as drying, debinding, and sintering to enhance its mechanical properties and achieve the desired level of density.



2. Applications



> Nowadays, the latest advances in materials and computer sciences have allowed the development of 3D printing technologies for the manufacturing of **complex ceramic parts with outstanding properties** such as turbine blades, fuel cells, but also at an early stage of development, ceramic-based semiconductors and dental implants.

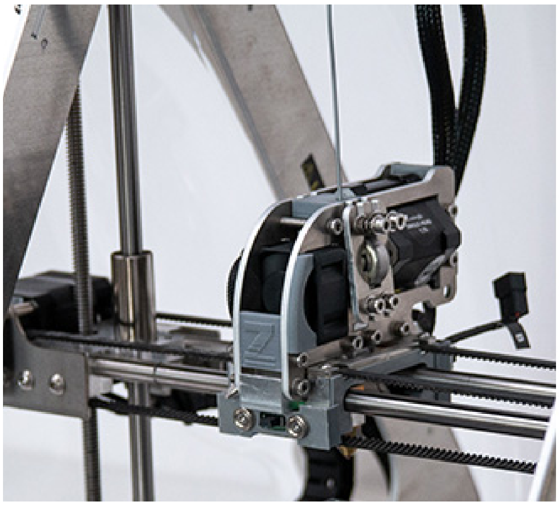
> **The combination of 3D printing and nanotechnology** has also paved the way to various applications such as nanocomposites, which are used in electrical systems, sensors, piezoelectric materials, and energy storage. Indeed, this technology enables complex nanosized structures, while nanoparticles enhance the properties of 3D printed materials.

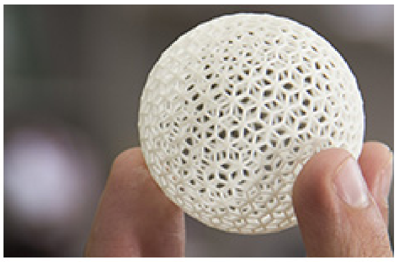
> Furthermore, the burgeoning field of **bioprinting** has sparked considerable interest in the realm of biotechnological applications. Nanomaterials integration into 3D bioprinted scaffolds have provided enhanced scaffold design specificity, elevated cell attachment, improved cell-material interactions, and facilitated tissue development.

> However, the degree of scalability and commercial availability for each application may vary and R&D are constantly expanding the capabilities in these fields.

3. Main technologies

> Depending on the **feedstock forms, slurry and powder**, we distinguish the non-fusion-based methods such as binder jetting and stereolithography (SLA) from the fusion-based methods such as laser powder bed fusion (LPBF). Other related technologies such as Direct Light Printing (DLP) technology are also used.





> These newer and promising technologies offer good control over the details, resulting in ceramics with excellent mechanical properties. However, every method has its particularities when it comes to the achievable material properties.

3.1 Ceramic slurry-based technology

3.1.1 Stereolithography (SLA)

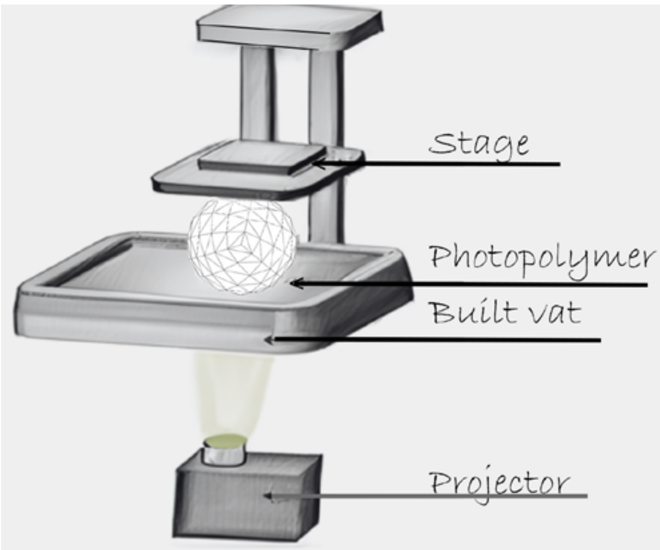
> The SLA technology uses slurry which consists of a mixture of photosensitive resins and a solid load of ceramic powder. Ceramic components are constructed layer by layer with the use of a UV laser that polymerizes the resin.

> The parts are then subjected to a heat treatment which eliminates the resin (debinding) and densifies (by sintering) the ceramic.

> It is an accurate method that allow the creation of complex shape geometries thanks to the photopolymerization process but it can be time-consuming.

> The alumina slurry should not only possess **low viscosity and uniformity,** but also be able to complete the photocuring process. It's worth noting that alumina **high purity and chemical stability** are crucial criteria. In fact, impurities in the process could adversely affect the final printed parts' mechanical properties, density, and sintering behavior.

3.1.2 Digital Light Processing (DLP)

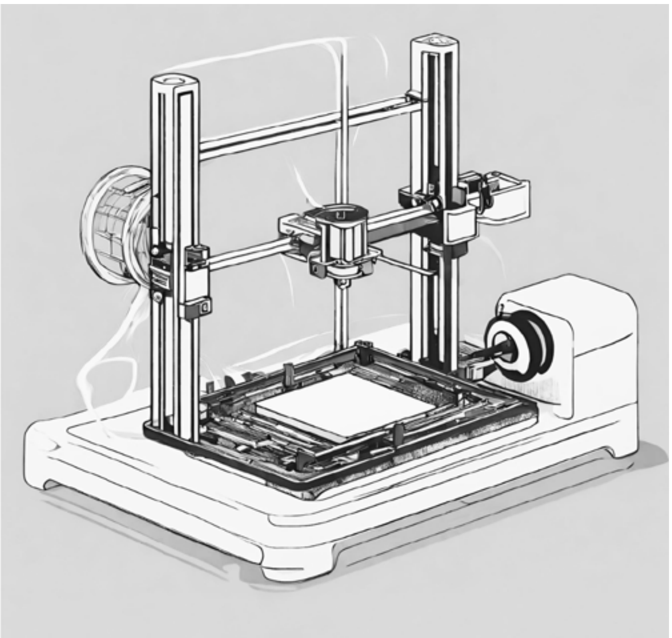


> The Digital Light Processing is similar to SLA. However, the light source is different as it uses a UV projector able to cure a complete layer of resin at a time, enhancing the process speediness.

> Originally designed for use with pure resins, recent advancements have unveiled its potential for polymerizing ceramics. **Slurry optimization** has been a crucial step for successful ceramic 3D-printing and combined with the proper debinding and sintering techniques, DLP can now manufacture components with **high precision.**

> Such flexibility increases the potential of the technology across various fields, ranging from bone scaffolds to smart biomaterials for robotics and microfluidic devices.

3.1.3 Direct ink writing (DIW)



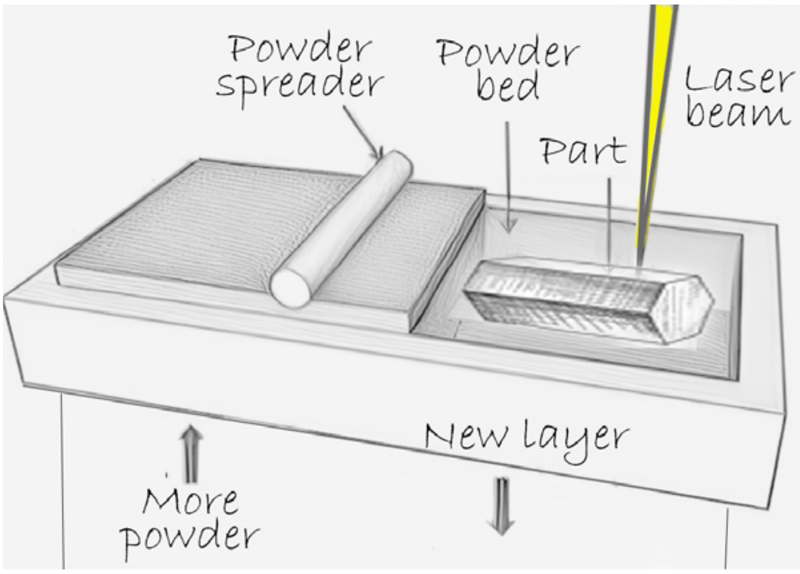
> Direct ink writing, also entitled robocasting, is a printing technique that operates by accumulating layers of material. Ceramics are one of the more difficult materials to fabricate into complex morphologies and are challenging to employ for fine surface robocasting.

> However, DIW enables the printing of **precursor ceramic structures** that can be post-processed into dense ceramic structures with complex morphologies.
This advantage provides the freedom to create intricate 3D ceramics, as long as the ceramic formulation (i.e., the ink) is workable. With its precise control over ceramic part porosity, the process is particularly useful in applications such as filtration, fluid transport, and tissue engineering.

> DIW has been greatly expanded by the introduction of 3D-printed slurries. To ensure a smooth extrusion during the process, the slurry must possess **excellent fluidity**. Additionally, sufficient **viscosity** is required to maintain the desired shape in the post extrusion modeling stage, as well as good **strength and elastic modulus** to ensure a stable morphology after extrusion.

3.2 Ceramic powder-based technology

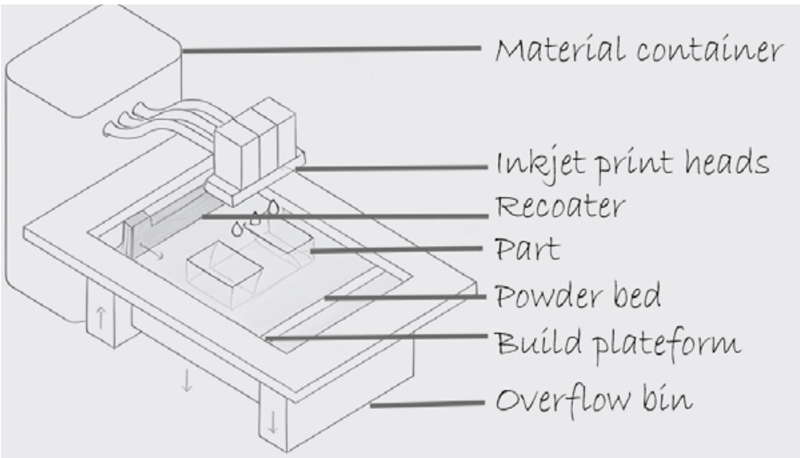
3.2.1 Laser powder bed fusion (LPBF)



> The powder bed fusion method uses a high-energy laser beam to interact directly with the ceramic powder. The laser's precise control allows the creation of complex geometries and intricate internal.

> The parts produced with this method and High Purity Alumina are **dense, high-strength, lightweight** and offer **high chemical stability**. As a result, it has a wide range of uses in different sectors, including industrial, aerospace, automotive, and medicine.

3.2.2 Binder jetting (BJ)



> The process uses a powder bed and inkjet technology to create objects. A liquid binder is used to bond the powder particles together, and the layers are applied using a rotating roller and print head.

> Even if the presence of the binder can contribute to a relatively lower material density than the fusion-based-method, binder jetting is increasing in popularity because of its ability to produce parts **without support structures and relatively high build rates.**

Powder decisive factors are a **narrow particle size distribution, the particle shape and a low specific area.**

4. 3D printing technology current benefits and limitations

Feedstocks	3D Printing technologies	Benefits	Limitations
Slurry	Stereolithography (SLA)	• Highly accurate in terms of geometry and dimension • Smooth surfaces	• Time-consuming. • The ceramic density strongly depends on the slurry formulation
	Digital Light Processing (DLP)	• Dense ceramic components	• Faster printing rate than SLA. • The detail degree depends on the slurry formulation, debinding and sintering techniques
	Direct ink writing (DIW)	• Precise control over ceramic part porosity	Ceramic-based porous structures give difficulties in • shaping intricate geometries on a larger scale • fine-tuning pore morphologies on the smaller micro- and nano-scales
Powder	Laser powder bed fusion (LPBF)	• Enhanced design flexibility • Lightweight complex geometry parts • High dense and strength ceramics	• Time-consuming. • Limited build size • LPBF optimized parameters can be a challenge to reduce residual stresses within ceramics
	Binder jetting (BJ)	• Ability to produce ceramics without support structures • High build rates	• Lower material density than the fusion-based-method

5. Pushing boundaries with advanced ceramic powders & slurries

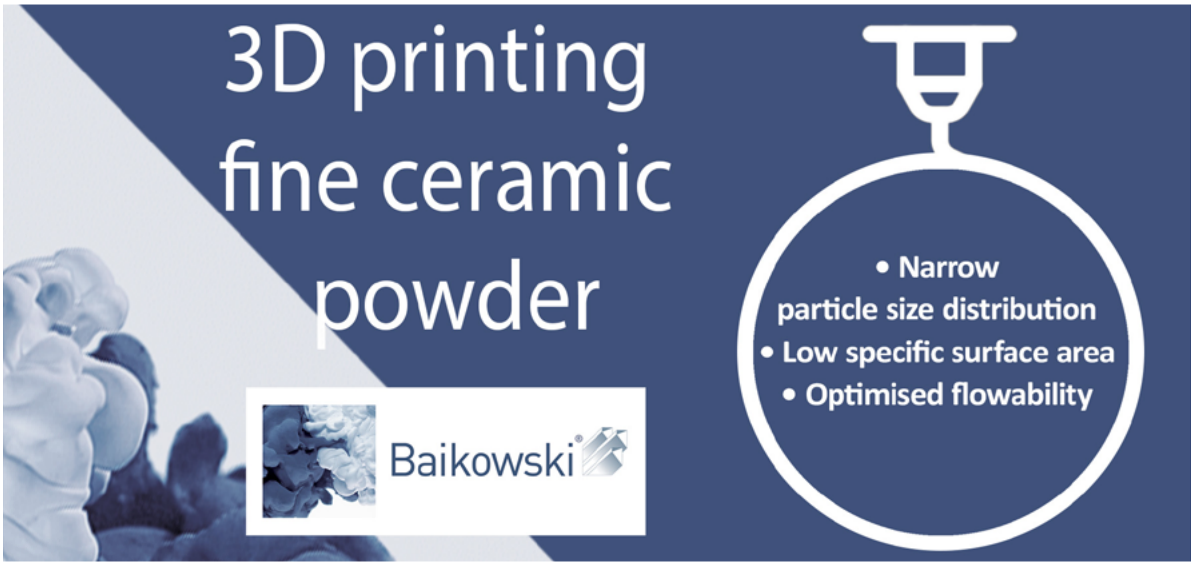
> The development of advanced ceramic materials specifically designed for 3D printing has contributed to **faster printing speeds and part quality.** Among them, we can mentioned:

- Ceramic powders with optimized flowability
- Low viscosity ceramic slurries

5.1 Ceramic powders with optimized flowability

> An ideal powder for 3D printing should possess grains with a well-rounded shape and a particle size distribution close to a monomodal one in order to guarantee a sufficient **flowability,** which is a prerequisite for the successful execution of the 3D printing process.
Indeed, carefully controlling these criteria allows a **smooth and consistent powder spreading** and with **a good processability,** the manufacturing of complex geometries and reliable printing results are becoming possible.

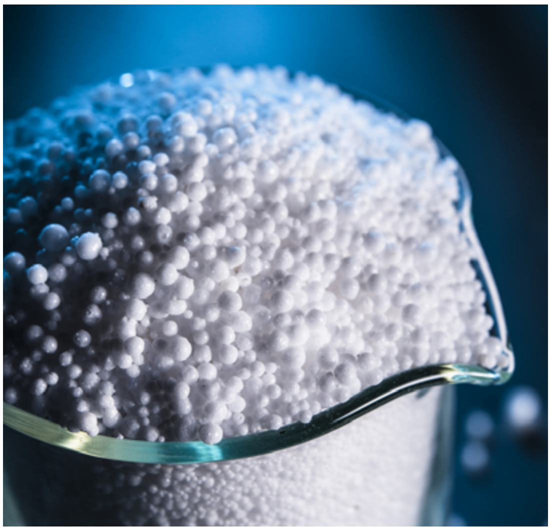
Additionally, **a low specific surface area** is helping the powder incorporation in the feedstock.



> Moreover, Baikowski® **spray-dried powders** offer several advantages to unlock new possibilities and advancements in ceramic 3D printing technology for superior performances such as:

- A better dispersion of the slurry
- The improvement of the flowability and spreading
- Finest layers

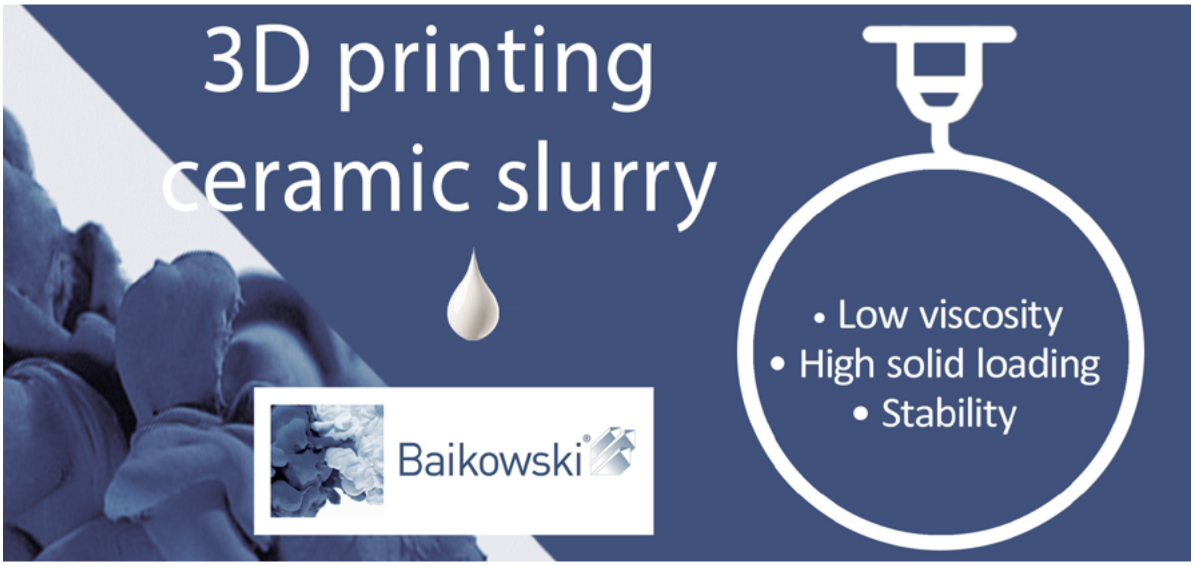
> Note that in some cases a binder formulation can provide better adhesion and uniform coverage of the alumina powder and led to reduce surface irregularities and improved overall surface quality.



5.2 Low viscosity ceramic slurries

> The slurry must possess the appropriate **viscosity and rheological** characteristics to smoothly exit the nozzle and adhere to the build platform. Subsequently, it should rapidly transform from a fluid-like consistency to a solid-like state, enabling the addition of the next layer.

Therefore, **high solid loading and low viscosity** are key parameters for a ceramic slurry, but the type and concentration of dispersant used can also impact its rheological properties and stability.



> Precise parameters may differ based on particular application and the printing method employed. In consequence, it is necessary to fine-tune these parameters with our R&D teams to meet your specific requirements.

6. Process monitoring point : thermal stability

> Alumina has a high melting point, making it important to consider the **thermal stability** of the material during the 3D printing process.

The printing parameters, such as laser power and scanning speed, should be carefully controlled to avoid excessive heat exposure that could lead to undesirable thermal effects or distortion in the printed parts. As a result, proper thermal management ensures accurate and dimensionally stable alumina parts.

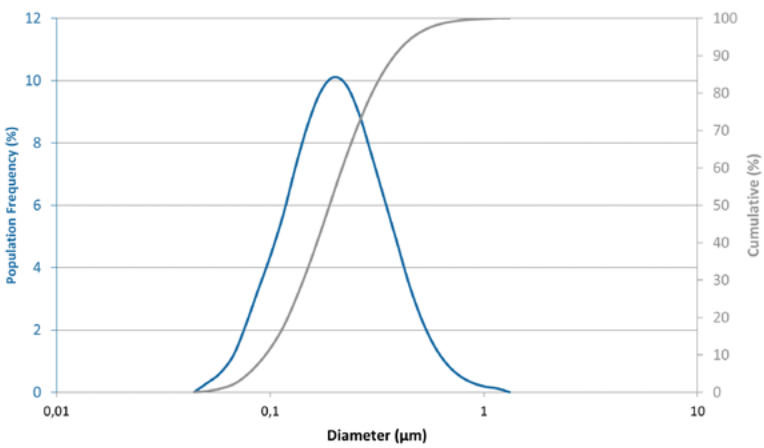
7. Baikowski® ceramic 3D printing solutions

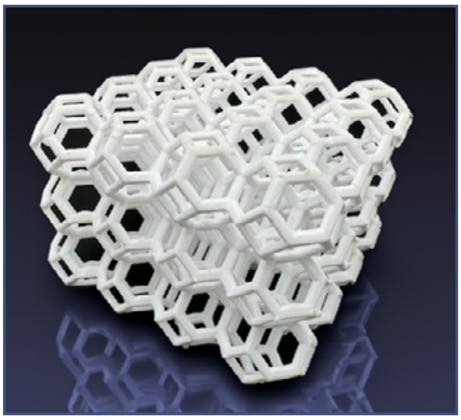
> High Purity α alumina powders

(Including spray dried powders) with a **narrow particle size distribution and a low specific surface area**

Processability		Deagglomarated			Spray-dried	
Baikalox® products (Typical values)		**PB4-MAR**	**SMA6**	**SA8-MAR**	**GEA6-W**	**BA15-W**
Chemical purity		3N	4N	4N	4N	4N
Specific Surface Area (m^2/g) *BET*		4	7	8	6	15
PSD (µm) Particles	d_{50}	0.77	0.19	0.31	0.18	0.11
PSD (µm) Granules	d_{50}				50-60	

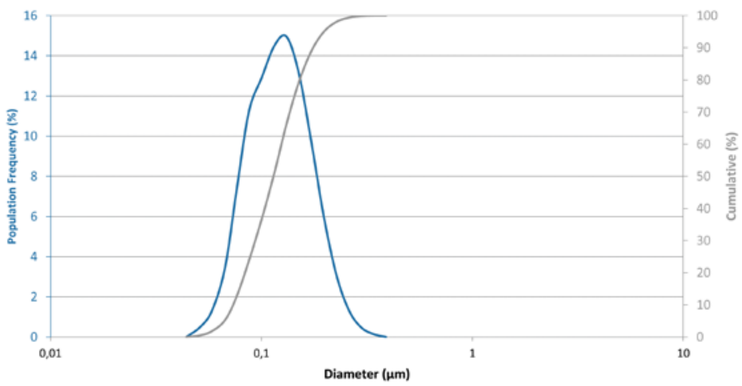
SMA6





Lattice cube - Baikowski®4N alumina SLA 3D printing process

BA15-W



Burr coffee grinder - Baikowski®4N alumina SLA 3D printing process

> ZTA80-W

Developed in a spray-dried form to offer enhanced flowability and spreading

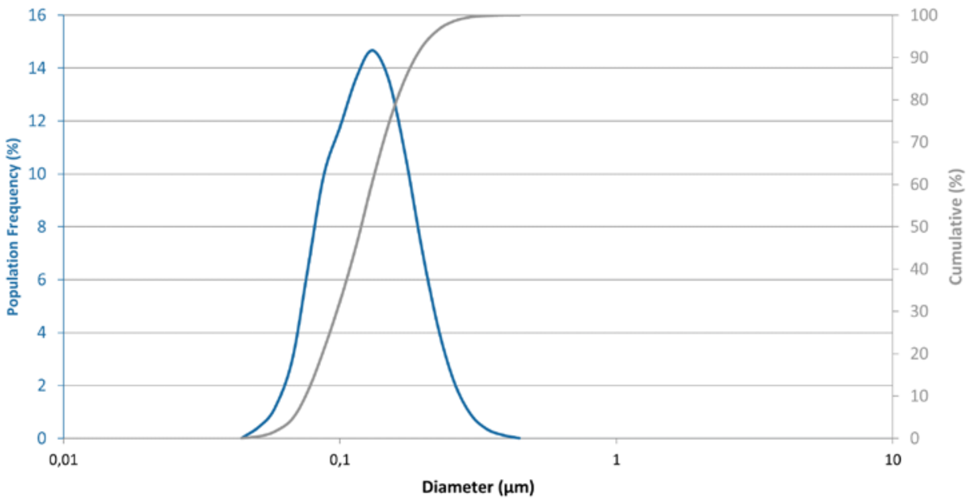
- 80% vol Al_2O_3
- High chemical purity (4N)
- Spray-dried
- Specific Surface Area 14-18 m²/g

- Controlled particle size distribution

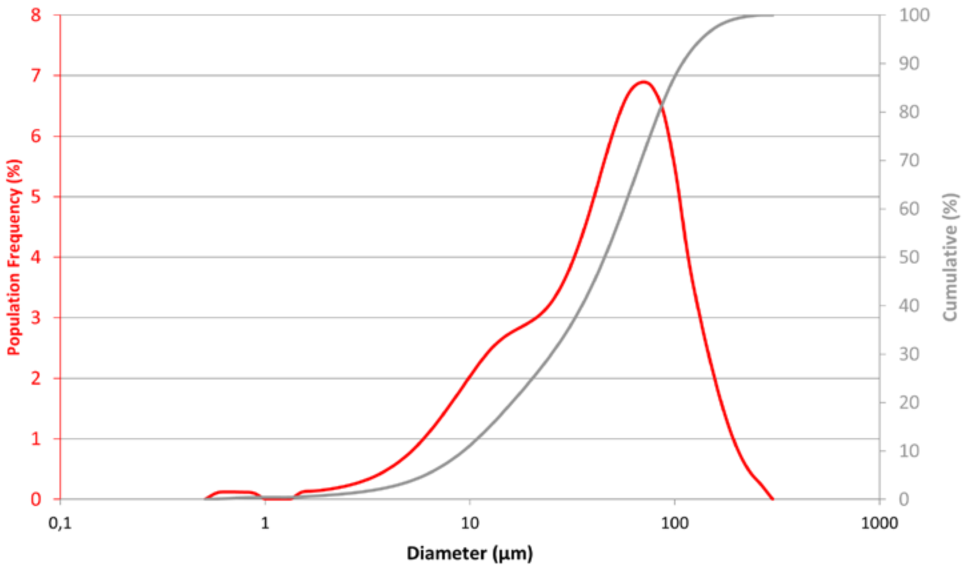
(PSD) $d_{50} \approx 0.12$µm

(GLS) $d_{50} \approx 40\text{-}50$µm

PSD



GLS



Dispersing system - Baikowski®4N alumina SLA 3D printing process

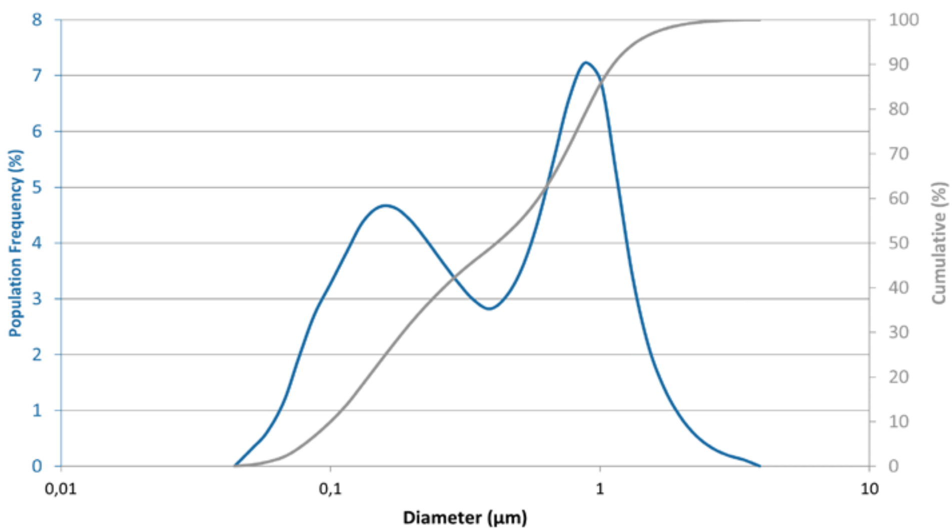
Static mixer - Baikowski®4N alumina SLA 3D printing process

> S25CR

Jet-milled spinel powders

- $MgAl_2O_4$
- High chemical purity (4N)
- Jet milled
- Specific Surface Area 22 m²/g

PSD



Baikowski®

8. Powder & slurry customization

> Adjustment of **doping and chemical composition** can be done such as:

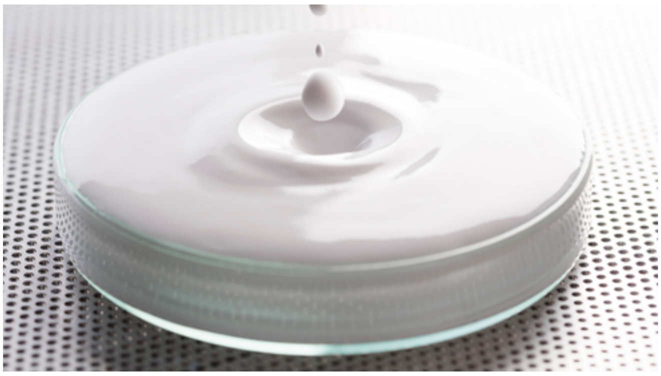
- High purity
- Sintering additives
- Nano particles
- Mixed oxides (e.g. alumina/zirconia for additional mechanical properties)

> Product **customization** examples:

- Control of particle size distribution and SSA
- Binder-free spray-dried powders (for a better processability of submicronic powders)
- Concentrated slurries

PRODUCT DESIGN

> **Contact us** and we will develop together the product that meets all your specific needs and requirements.



9. Scientific publications

> Embedded 3D printing of Multi-material composites
Baikowski® product: **SMA6**

> Transparent alumina ceramics fabricated by 3D printing and vacuum sintering
Baikowski® product: **CR10**

> See more scientific publications

Your solution partner for fine minerals

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