3D-Printing: From Multi-Material to Functionally-Graded Ceramic

Fields such as medicine, electronics and aerospace are using 3D-printing to overcome problems that require innovative new technology to make further progress past their already established applications. Multi-material in 3D-printing is one area that is garnering widespread attention due to the wide range of possibilities that it provides to make parts which are more functional and have improved properties. Lithoz, the global market and technology leader in ceramic additive manufacturing, has been developing ground-breaking multi-material 3D-printing technology and will review its work on this fascinating topic in this article.

Fig. 1
The CeraFab Multi 2M30: Lithoz's multi-material 3D-printing technology

Introduction

Rapid development of Additive Manufacturing technologies is no longer restricted to single-phase materials. Multiple materials can already be used simultaneously to manufacture parts. By expanding the design space to different materials, multi-material 3D-printing establishes the possibilities of manufacturing 3D-parts with enhanced properties and altered material compositions and structures from one section of the component to another. Structures combining highly complex shapes with different materials without the need for joining or assembly can be directly manufactured, allowing for the replacement of assemblies with printed parts. This opens the door to numerous applications, in fields ranging from electronics and embedded sensors to biomedical implants and devices, as well as aerospace, automotive and energy storage systems [1, 2].

Keywords
multi-material 3D-printing technology, swivel platform assembly

This article introduces the CeraFab Multi 2M30, developed by Lithoz for multi-material 3D-printing and functionally graded ceramics, and gives ideas for potential uses and applications for a variety of scientific fields.

The CeraFab Multi 2M30

Powered by industry-leading LCM technology, the CeraFab Multi 2M30 (Fig. 1) is Lithoz's new multi-material 3D-printing machine which allows for the manufacturing of multi-functional components.

The assembly of the CeraFab Multi 2M30 (Tab. 1) consists of two rotating vats (Fig. 2) filled with photocurable resin/suspension. Two separate vats mean ceramics can be combined with other ceramics, polymers or metals. These vats move over the projecting system as needed, curing the respective layer. The vat's bottom is transparent, allowing the light source to expose suspensions from below. The building platform is mounted on an axis and moves up and down during the 3D-printing process.

Sebastian Geier, Isabel Potestio
Lithoz GmbH
1060 Vienna
Austria

E-mail: ipotestio@lithoz.com

The innovative two-vat system enhances the speed, accuracy and effectiveness of a clean material switch between and within layers while the fully automated cleaning step avoids cross contamination during material changes. Very little slurry is used and no material recovery operations or pumping systems are required to keep the slurry circulating, making it attractive in terms of cost and resource efficiency. The swivel platform assembly allows for huge innovation potential. Vats can be switched out for other systems with customized software written independently, allowing for greater customer development and opportunities for research. An essential step in the production of composite materials is successful co-processing and co-sintering of the selected powders. Developments in the sintering of different classes of materials into one component aim to match shrinkage behaviours of different materials to make functional components [3].

Lithoz is investigating ways to guarantee the successful co-sintering of multi-material components. The shrinkage behaviour of various components is determined by tuning powder fractions in the slurry and by adapting the particle size distribution or shape.

Expanding design space for different materials

The CeraFab Multi 2M30 allows for accurate designs and gradual alterations to a material's composition to achieve a desired functionality. The powerful CeraFab Control software can combine several materials within a layer, while special types of advanced composites with varying compositions and/or microstructure, known as Functionally Graded Materials (FGMs) and Functionally Graded Structures (FGSs), can be produced. Possible combinations for unlocking new functional applications as shown in Fig. 3 include: a) two materials combined in one layer b) a dense material combined with a secondary porous material c) two or multi-phase materials with gradual variation in material composition d) and e) combination of these (i.e. with gradual variations in both density and material composition).

Fig. 2
View of the CeraFab Multi 2M30's flexible modular assembly

Tab. 1
Technical properties of the CeraFab Multi 2M30

Technical Properties	
Lateral resolution	40 µm (635 dpi)
Layer thickness	10–100 µm
Number of pixels (X, Y)	1920 x 1080
Build volume	76 mm x 43 mm x 170 mm (x/y/z)
Data format	.stl (binary)
Number of vats	2
Light source	LED
Build speed	up to 100 slices per hour
Size (L x W x H)	1,8 m x 0,85 m x 1,78 m
Weight	560 kg

The technology can process any sinterable powder. Many different powders have been processed with particle sizes ranging from around 10 nm to 100 µm. There is no limit to the particle size of the powder used and the open material system makes it easy to develop customized materials and combinations thereof.

There must be good layer bonding between each phase to obtain a distinct boundary between combined materials. Lithoz recently combined alumina with zirconia toughened alumina (Fig. 4). After sintering, clear boundaries and good layer bonding between the two were visible at the interface (Fig. 5).

Another study focused on 3D-printing a dual-color ring, combining white and two-

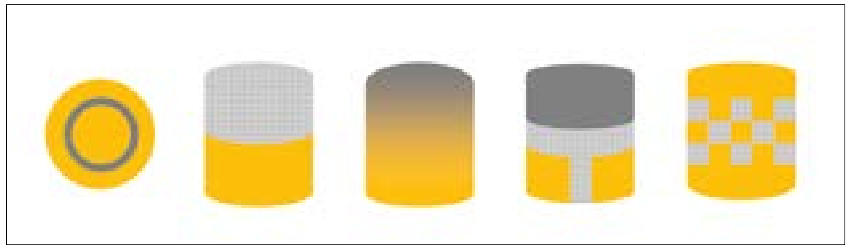

Fig. 3
Possible compositional and/or structural combinations facilitated by the CeraFab Multi 2M30

Fig. 4
ZTA–Al_2O_3 composites green part manufactured on the CeraFab Multi 2M30

colored alumina for luxury applications. The sintered ring, consisting of a voronoi structure, is shown in Fig. 6.

The following can be combined:
- porous | dense;
- bioresorbable | bioinert;
- hard | ductile;
- electrically conductive | electrically insulating;
- heat conductive | heat insulating;
- magnetic | non-magnetic;
- colors.

Multifunctional properties and applications
Medical applications benefit from introducing multi-material 3D-printing technology. Bone microstructures vary from dense and stiff external structures to lighter porous internal structures, providing biological adaptations and tailored tribological properties at different positions [4]. A mandibular cage implant was 3D-printed using two different materials and structures, mimicking the hierarchical structures and gradients of bone (Fig. 7).
The high-strength zirconia outer shell gives support during the healing phase. The implant's volume is made of bioresorbable materials such as porous Hydroxyapatite (HA) and Tricalcium Phosphate (TCP) mixture. This enables bone regrowth and will be bio-absorbed by the body, ensuring complete healing [5].
Recent developments focus on material combinations in one printing process through multi-material LCM printing. TCP/HA and zirconia combinations are used for bones and open up a new market for designing permanent implants in the future.
Many applications can benefit from 3D-printing metal-ceramic structures, including printed circuit boards, piezoelectric stacks, electronic and telecommunication components as well as Low and High-Temperature Co-Fired Ceramics (LTCC and HTCC). These are routinely made by stacking green dielectric layers upon which printed circuitry has been inscribed, followed by co-firing to make a dense 3D-circuit. A significant advantage of applying multi-material 3D-printing here is that it uses conventional ceramic powders and reduces the steps involved in the manufacturing process, minimizing fabrication costs [3]. More complex structures can be realized which have great potential from prototypes to serial production.
Another area to be explored using the CeraFab Multi 2M30 is producing ceramic-polymer composites. Polymer serves as a sacrificial support, generating tailored porosity and cavities in the component once it is burnt out during the subsequent firing process with sizes pushing the limits of any existing AM process.
Targeted combinations, such as hard and ductile, electrical or heat-conducting/insulating and magnetic or non-magnetic, give new scope for designing new composite components [6]. The CeraFab Multi 2M30 therefore creates new possibilities for creating multi-material parts in the future.

Development platform powered by Lithoz
Lithoz's new CeraFab Multi 2M30 allows for different material properties to be combined into one single, digital-driven production step. The multi-material 3D-printing technology can be applied to accurately design and gradually alter a material's composition and organization within a component in order to achieve multiple functionalities.
The swivel platform assembly allows for huge innovation potential. Changes and additions of own devices can be easily made and control software adapted for a full customization of the machine.
Three-dimensional combinations of material properties and structures open the door to the design of new components that can greatly benefit many industries - with applications in fields ranging from electronics, printed circuit boards and embedded sensors to biomedical implants and devices, as well as aerospace, automotive and energy storage systems.
With its wealth of experience in ceramic additive manufacturing, materials and software, Lithoz is an important partner to many industrial manufacturers as well as research-based institutions.

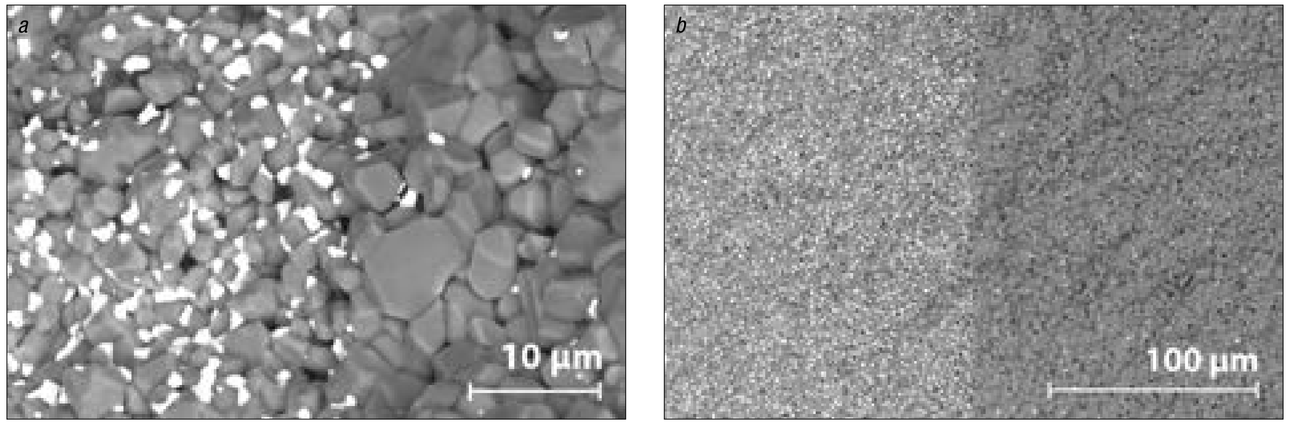

Fig. 5 a–b
SEM-image of a sintered ZTA/Al_2O_3; multi-material sample manufactured on CeraFab Multi 2M30

Fig. 6
Dual-coloured alumina ring (as fired) 3D-printed on the CeraFab Multi 2M30

Fig. 7
Mandibular cage made of zirconia with a three-dimensional interconnected pore network made of HA/TCP; material combination in one printing process is under development

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