JMEPEG (2018) 27:14–20
https://doi.org/10.1007/s11665-017-2843-z

1059-9495/$19.00

Additive Manufacturing of Ceramic Heat Exchanger: Opportunities and Limits of the Lithography-Based Ceramic Manufacturing (LCM)

Uwe Scheithauer, Eric Schwarzer, Tassilo Moritz, and Alexander Michaelis

(Submitted November 5, 2016; in revised form February 16, 2017; published online August 1, 2017)

Additive manufacturing (AM) techniques allow the preparation of tailor-made structures for specific applications with a high flexibility in regard to shape and design. The lithography-based ceramic manufacturing (LCM) technology allows the AM of high-performance alumina and zirconia components. There are still some restrictions in regard to possible geometries. The opportunities and limits of the LCM technology are discussed in the following paper using the example of ceramic heat exchangers. Structures are presented which combine a large surface for heat exchange with a small component volume and low pressure drop. This paper concludes summarizing the essential remarks.

Keywords additive manufacturing, alumina, ceramics, heat exchanger, lithography-based ceramic manufacturing, stereo-lithography

1. Introduction

Additive manufacturing (AM) is a manufacturing process where objects are built up layer-by-layer. Formerly, AM was also referred to as rapid prototyping (RP) or solid freeform fabrication (SFF). In popular science, the term 3D printing is used as synonym for additive manufacturing. According to ASTM, additive manufacturing is a "process of joining material to make objects from 3D model data, usually layer upon layer" (Ref 1). Today, additive manufacturing of polymers is state of the art. In the field of metals, more and more materials can be processed as well. For processing ceramic materials, the technical application of AM technologies has been limited so far. However, ceramic materials have been studied in additive manufacturing processes ab initio with the development of the different AM technologies since about 25 years (Ref 2, 3). All established AM technologies have also been tested for ceramic materials (Ref 4-28). AM technologies can be classified according to the state of the material that is used (powder materials, liquid materials, and solid materials) (Ref 29, 30) and the deposition of the material (direct, indirect) (Ref 31). Direct means that the material is directly deposited only in the position giving the desired shape of the final object. These technologies like fused filament fabrication (FFF), direct inkjet printing (DIP), or thermoplastic 3D printing (T3DP) stand out due to the possibility to the AM of multi-material components (Ref 32, 33). The lithography-based ceramic manufacturing (LCM) is part of the indirect technologies (Ref 31).

Using AM as shaping technology increases the flexibility in regard to the design of components and enables innovative and maybe more effective structural designs, which could not be realized by conventional shaping. Until now, constructers design and develop components based on what is possible to produce and not based on the optimal desired functionality. However, with AM another strategy could be chosen in generating new functional- or structural-oriented components, e.g., catalyst supports, micro-reactors, static mixers (Ref 34), or heat exchangers. Looking at heat exchangers the process conditions, the fluids used, the temperature, and the pressure applied rule the used materials and their supports. Ceramics stand out based on an excellent reliability in regard to high temperatures, abrasion, and extreme chemical environments. Another important point is the ratio of heat exchanger surface area, the pressure drop within the structure, and the volume of the whole component. AM can be seen as door opener to produce complex geometries and channel systems in order to minimize the required volume and in order to increase the heat transfer surface. Simultaneously, the flow behavior inside the components can be optimized to avoid a high pressure drop.

We chose a simple example for a heat exchanger challenge: A hot fluid (e.g., hot aggressive chemical) runs through a pipe with an inner diameter of 10 mm, an outer diameter of 11.5 mm, and a length of 25 mm. This pipe has an outer surface of about 903 mm^2 which can be used to transfer the heat to the surrounding fluid (e.g., air or water).

A common way to increase this heat transfer surface is by adding some rips to the outer surface. First, we chose eight rips with a constant cross section of 1 mm thickness and 9.25 mm height (Fig. 1, right). The resulting heat transfer surface is about 4452 mm^2. But the heat flow within the single rips depends on the thermal conductivity of the used material and if this is too low the tops of the rips stay cold because the heat is transferred to the surrounding fluid in the lower areas. The

This article is an invited paper selected from presentations at "Recent Development in Additive Manufacturing: Process and Equipment Development and Applications," held during MS&T'16, October 23–27, 2016, in Salt Lake City, UT, and has been expanded from the original presentation.

Uwe Scheithauer, Eric Schwarzer, Tassilo Moritz, and **Alexander Michaelis**, Fraunhofer Institute for Ceramic Technologies and Systems IKTS, Winterbergstrasse 28, 01277 Dresden, Germany. Contact e-mails: uwe.scheithauer@ikts.fraunhofer.de and eric.schwarzer@ikts.fraunhofer.de.

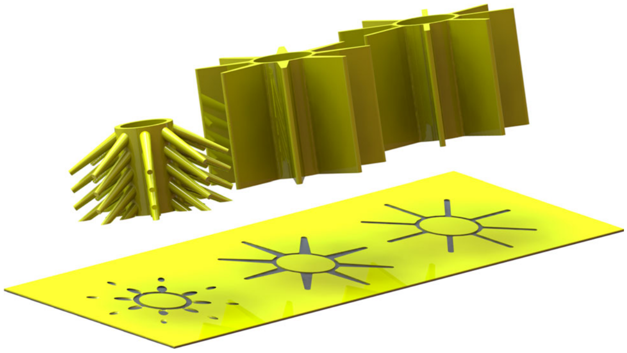

Fig. 1 CAD models of heat exchanger geometries and contact area to vat bottom during the building process—right sample 2, pipe with eight rips with constant cross section; middle: sample 3—pipe with eight rips with trapezoidal cross section; left sample 4—pipe with frustums instead of rips

surface at the tops of the rips is not used for the heat transfer, and not the whole available surface is used for the heat exchange.

But it is possible to change the geometry of the rips to a trapezoidal cross section (Fig. 1, middle). Then more heat is transferred to the tops of the rips, and the whole available surface (about 4284 mm^2 for eight rips with a height of 9.25 mm, a bottom thickness of 2 mm, and a top thickness of 1 mm) can be used for heat exchange. This surface is a little bit smaller than in the previous example, but more heat is transferred to the tops of the rips.

All these structures had a constant cross section for the whole component and can be manufactured with a technology like extrusion, slip casting, or injection molding (IM), which all have a very high productivity compared to other ceramic shaping technologies.

To increase the heat transfer surface further, we can separate the single rips into different frustums (Fig. 1, left). If each of these 96 frustums (8×12) has a height of 9.25 mm, a diameter of 2 mm at the bottom, and a diameter of 1 mm at the top, a heat exchange surface of about 4783 mm^2 results. This surface is about 11.7% higher than the surface of the example with the trapezoidal rips. The production of this structure is more complicated. If extrusion is used, a machining step is needed afterward. For IM or slip casting, the geometry is very complex and therefore is likely to include some defects in the frustums in case not all channels in the used mold can be filled perfectly. Furthermore, the demolding of these structures is very complicated.

AM technologies make it possible to manufacture structures like this. But to utilize the opportunities of AM technologies, the geometry was designed more complex. Figure 2 shows a possible structure with thin bent frustums which are connected to each other by other added frustums. We calculated a resulting heat transfer surface of about 7441 mm^2 which is more than eight times higher than the surface of the simple pipe and about 56% higher than the surface of the structure with the frustums.

2. Experimental

2.1 LCM Technology

We used the LCM technology (Ref 31, 35, 36) (LCM machine: CeraFab 7500, alumina suspension Lithalox 350, both of Lithoz-GmbH, Vienna, Austria) to manufacture all structures except the simple pipe.

The LCM technology differs from the well-known stereolithography by some features. A blue light source with a wavelength of 465 nm and a digital light processing (DLP) projector is used instead of UV light laser to cure a photosensitive suspension which mainly consists of monomers, photoinitiators, and homogenous dispersed ceramic particles. The upside-down setup of CeraFab 7500 is a big advantage, because the non-cured suspension runs back into the suspension reservoir and can be used for the production of the next layer. This means that only a small volume of suspension is necessary as well as that the cleaning process of the parts is easier because only a small amount of non-cured suspension remains in the manufactured part during the building process. The exposure of the first deposited layer to light occurs by backward located LEDs, inserted to the building platform. This cured layer is completely adhered to the building platform and guarantee fixation during the complete manufacturing time of the component. All subsequent layers are irradiated from the bottom below the building platform by DLP irradiation throughout the glass bottom of the rotating vat. We described the LCM process in a former paper in detail (Ref 34).

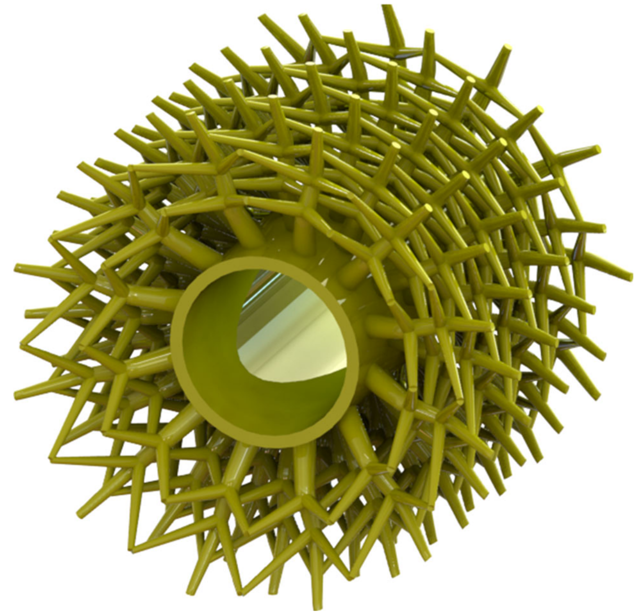

Fig. 2 Heat exchanger—sample 5—possible heat exchanger structure only producible with AM; CAD model

Table 1 Used debinding regime

Heating rate, K/min	Temperature target, °C	Dwell time, h
0.208	75	21
0.167	115	70
0.375	205	24
0.375	430	0
1.306	900	0
−1.823	25	0

Table 2 Used sintering regime

Heating rate, K/min	Temperature target, °C	Dwell time, h
2.667	200	0
0.667	600	0
1.528	1150	0
0.833	1600	2
−0.833	1200	0
−1.597	50	0

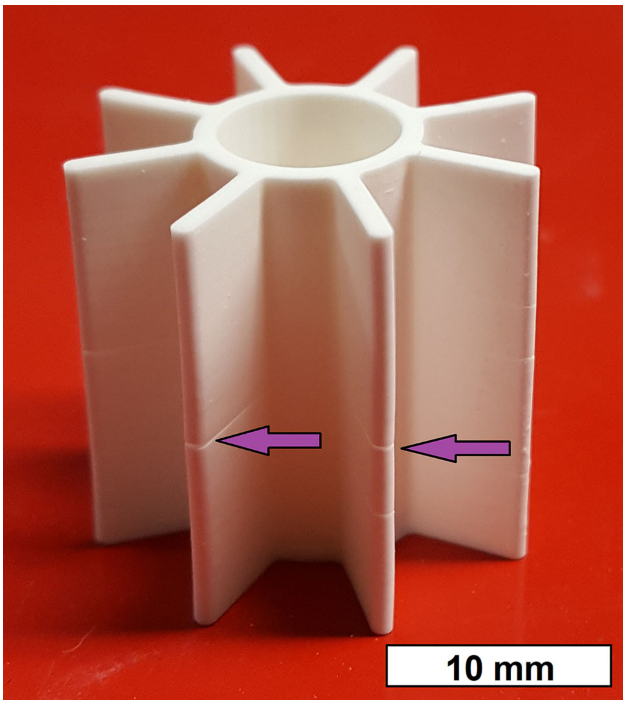

Fig. 3 Heat exchanger—sample 2—pipe with eight rips with constant cross section; sintered alumina component with typical defects

Because of the high resolution (635 dpi, pixel size 40 × 40 μm^2) and the adjustable layer thickness (5-100 μm), a very good surface quality (compared to other AM technologies) and very thin structures (minimal wall thickness 100 μm) can be realized.

2.2 Necessary Design Changes

The pipes with the rips were manufactured with the same designs which were used to calculate the heat exchanger surfaces. But for the pipe with the frustums a little change in the design was necessary to avoid supporting structures between the frustums of one row. This was realized by changing the orientation of the frustums a little bit. The angle between the rotational axes of the inner pipe and the frustums was changed from 90° to 60° (Fig. 1, left).

For the last, very complex structure we added a support structure below the first frustums to support these during the printing process and to increase the connection between the whole structure and the building platform. These supporting structures were removed from the green components after the manufacturing process.

Last but not least, all edges were rounded to avoid crack formation in the ceramic components.

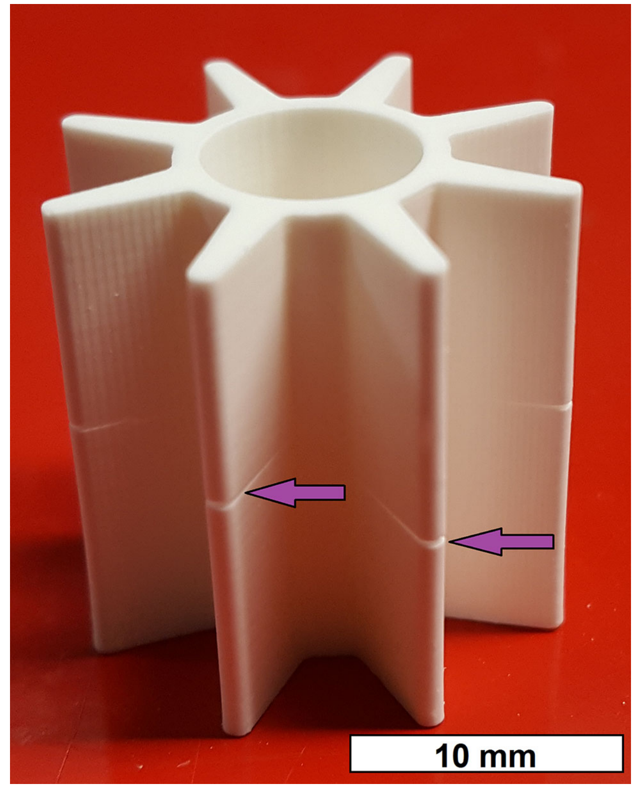

Fig. 4 Heat exchanger—sample 3—pipe with eight trapezoidal rips; sintered alumina component with typical defects

2.3 Building Process

For the building process, the parameter set given by Lithoz for 25 μm layer thickness and "middle" thick structures with 3.7 s exposure times were applied. The velocity for removing the cured layer from the tube bottom was decreased by 30%.

2.4 Cleaning, Debinding, and Sintering

For cleaning we used the cleaning fluid of Lithoz combined with compressed air. The non-cured suspension was removed, which remains on the structures because of the cohesiveness. For the thermal debinding, we followed the instructions given by Lithoz with different dwell times at 75, 115, 205, and 430 °C and a maximum temperature of 900 °C (Table 1). This temperature is necessary for first pre-sintering processes to increase the mechanical strength of the structures. The sintering happened at a temperature of 1600 °C with a dwell time of 2 h (Table 2).

3. Results

Figure 3, 4, 5, 6, and 7 show the different sintered alumina structures. Delamination defects in the rips between two layers were not visible after the manufacturing process. After debinding first little defects became visible and during the sintering process these defects increased further (Fig. 3 and 4; defects marked by arrows). The structure with the frustums as well as the pipe with the complex AM structure was sintered defect free and showed no delamination (Fig. 5, 6, and 7).

Fig. 5 Heat exchanger—sample 4—pipe with frustums instead of rips; defect-free sintered alumina component

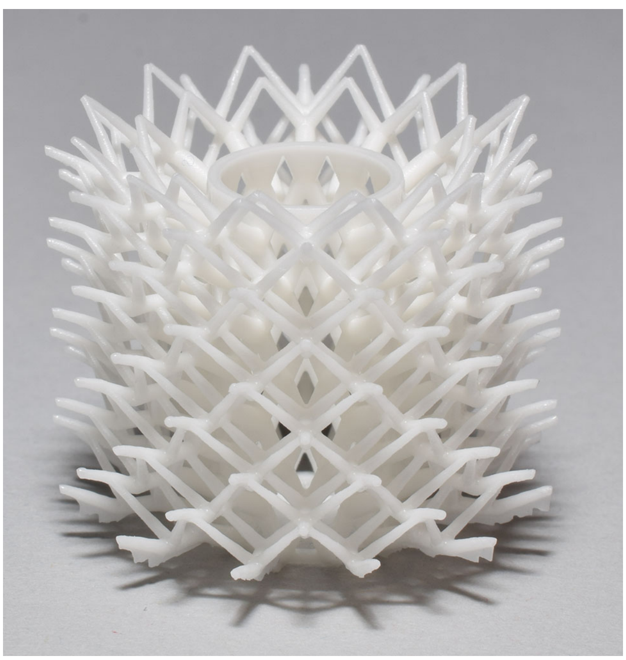

Fig. 6 Heat exchanger—sample 5—pipe with complex AM structure; defect-free sintered alumina component—horizontal view

4. Discussion

4.1 Designing and Manufacturing Process

It is not possible to manufacture all geometries with AM technologies. For each AM technology, different limitations exist. Compared to powder bed-based processes which can use the powder bed as support, all cured areas of the manufactured layer have to be connected to the building platform/the last manufactured layer for the LCM technology or within the cured layer. Overhangs can be realized up to 60°, and outstanding

Fig. 7 Heat exchanger—sample 5—pipe with complex AM structure; defect-free sintered alumina component—top view

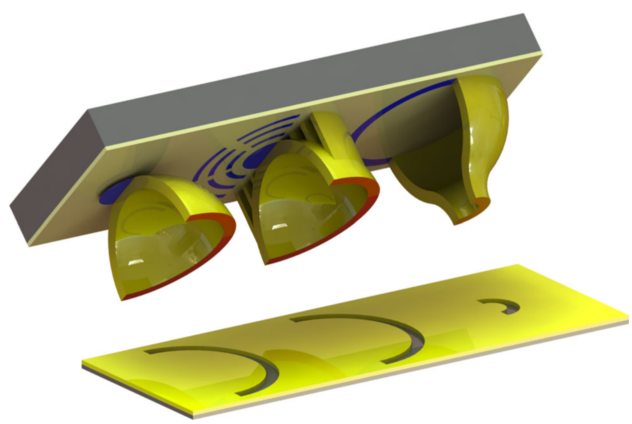

Fig. 8 Connection to building platform (blue) vs. connection to vat bottom (red)

structures are critical. But it depends on the size of the overhanging area and the distance between the connection points.

Figure 3 and 4 show typical defects of LCM components. The cracks are orientated parallel to the manufactured layers. The probability of generating these cracks increases with the thickness of the manufactured structures.

A possible explanation could be that for bigger structures the contact area between the vat bottom and the manufactured layer is bigger than for fine structures (Fig. 1). During the detaching process of the manufactured layer from the vat bottom, mechanical stress is induced into the structure and this stress increases with the size of the contact area because of the significant higher adherence on the vat bottom. This initiation of mechanical stress happens for every layer, and if this induced mechanical stress is too high, some non-visible delaminations

Fig. 9 Heat exchanger—sample 7—alternative heat exchanger structure; defect-free sintered alumina component

Fig. 10 Heat exchanger—sample 7—alternative heat exchanger structure; defect-free sintered alumina component; top view

are possible, which become visible after debinding and/or sintering.

The contact area between the vat bottom and the manufactured layer is significantly smaller for the structure with the frustums compared to the structure with the rips. The induced mechanical stress is lower, and no defects were initiated.

Possible solutions could be to decrease the exposure time to decrease the adherence between the structure and the tube bottom (this should be possible for these thick walls) or to slow down the detaching velocity.

Another challenge is the stable connection between the components and the building platform. The mechanical stress which is induced during the detaching process can result in tearing the components off the building platform. To avoid this defect, the contact area between the building platform and the first layer of the component and the support structure should be larger than the contact area between the cured area of the manufactured layer and the tube bottom but at most of the same size. Figure 8 shows three different configurations. The left one is a very critical one, because of the small contact area to the building platform and the big one to the vat bottom. By adding a support structure (middle), the connection to the building platform can be increased significantly. The example on the right shows a non-critical component.

For the manufacturing process of the support structure, the very same material has to be used as for the component. Therefore, the removing of the support structure from components with fine structures is very critical. If possible supporting structures should be avoided by changing the orientation of the component in regard to the building platform or changing the component design to realize functional geometries which work as supporting structure as well (e.g., the rips of the component in Fig. 9 which acts as supporting structure and later as heat exchanger surface).

The LCM technology allows the AM of components with very fine structures and very good surface qualities. We have manufactured honeycomb structures with a wall thickness of 100 µm and a channel cross section of $0.9 \times 0.9\ mm^2$ as structure with the thinnest walls.

Holes with very small diameters (<200 µm) tend to clocking. The non-cured suspension remains in this area and is cured during the manufacturing of the next layers because of scattering light. This material cannot be removed during the cleaning process and is sintered like surrounding suspension material.

A critical point is the manufacturing of components which combine fine and thick structures in one layer. To cure very small areas and very big areas in one layer, different process parameters ought to be used. Small areas have to be cured with a high intensity and long exposure time, for big areas the used energy has to be lower to avoid overexposure, geometry deviation, and strong adherence to the vat bottom.

But this is not possible with the current device, and such geometries should be avoided.

4.2 Cleaning

The biggest challenge during the cleaning process is to remove the non-cured suspension completely. Most but not all can be removed with compressed air but also a cleaning fluid can be used. But if too much cleaning fluid is used or the component is exposed to the cleaning fluid for a prolonged time (>5 min), swelling occurs and defects are introduced to the components. New cleaning procedures are required for the future, to prevent swelling and defects introduction during cleaning. Another challenge is the handling of complex components to avoid any defects during the cleaning process.

4.3 Debinding and Sintering

The debinding regime given by Lithoz needs about 6-7 days for the alumina suspension depending on the realizable cooling rate. This time could be reduced by intensive investigation of the debinding behavior.

During the sintering process, deformations could occur for complex or thin structures. Possible supporting structures and changes in geometry have to be implemented during the designing process.

4.4 Costs

The production costs for LCM components depend on the number of components, which are produced. The costs, which have to be considered and have to be spread across the number of components which should be manufactured, are:

- time for investigation of optimal machine parameters (curing parameter, detaching velocity) and supporting structure
- time for generation of specific machine file (array and orientation of parts, supporting structure, process parameters)
- machine costs
- utilization of the building area (the time needed for the production of one layer does not depend on the area which has to be cured → the building platform should be fully loaded if possible)
- height of parts, selected layer thickness (the time needed to manufacture one layer is about 40-60 s depending on the selected process parameters)
- time and energy for debinding and sintering → utilization of the kiln

Additionally, the variable costs, nearly similar for each part, have to be considered:

- time for cleaning
  - effort depends on part geometry—outer surfaces much easier to clean than inner channels, big channels easier than thin ones
- costs for cleaning equipment
- suspension costs
  - suspension needed for the manufacturing of the part(s)
  - loss of suspension depends on part geometry—much more non-cured suspension remains in thin channels and complex geometries than on outer smooth surfaces

If a high number of parts should be processed, the development of handling aids and cleaning strategies could be reasonable. With these additional efforts, especially the time for cleaning and the number of defects can be reduced significantly.

For mass production the production costs of the LCM technology will always be higher than for conventional shaping technologies. Fast production of low quantities is suitable. But the future of this technology will be the production of components with very complex geometries.

5. Conclusion

AM technologies allow the realization of components with a complex design which cannot be produced with any other technology. For the AM of ceramic components, the LCM technology stands out because of the very good component properties, the high sinter density, and the high resolution (smallest wall thickness about 100 µm).

To use the new degree of flexibility in design, a mind-changing process has to be initiated and simulation tools have to be used to design the components to function (flow, heat transfer, mechanical strength, etc.). But the opportunities of the known CAD tools are limited and further developments are needed to realize a designing tool which allows easy designing and changing of complex structures according to the simulation results. At the end a modification of the CAD model is necessary to optimize the geometries for the AM process. Preferably this necessary step is implemented into software tools which consider the specific restrictions of the chosen AM technology.

If these challenges could be solved, the AM technologies are one key for functionalization and miniaturization of ceramic components. Figure 9 and 10 show a possible heat exchanger structure manufactured by the LCM technology and an alumina suspension. A heat transfer surface of more than 3500 mm^2 could be realized in a structure with an outer diameter of 26 mm, a height of 13 mm, and an inner diameter of the pipe of 2.2 mm. The surface can be increased further by adding rips or other structures to the top of the structure. The rips at the bottom were used as remaining support structure which connects the component to the building platform during the building process and which works as heat exchanger surface after sintering.

For AM of ceramic components using the LCM technology, the following statements can be made:

- during the design process of the component, the following things should be addressed to avoid any defects:
  - minimal wall thickness is about 0.1 mm
  - the minimal diameter of a hole depends on the aspect ratio, but holes with a diameter of 0.2 mm can be realized
  - thinner structures have small contact areas to the vat bottom and debinding can happen faster
  - significant differences in wall thicknesses should be avoided in one layer because of the homogenous exposure of all selected areas
  - the connection area to the vat bottom should be the same or smaller than the connection area to the building platform
  - check if functional structures can be used as supporting structures to avoid the removing step
- during the manufacturing process:
  - for thin structures more exposure time and intensity are needed than for thicker structures
  - the velocity of the detaching process has to decrease with increasing size of the cured areas
- during the cleaning process:
  - use compressed air for cleaning and reduce the usage of solvents (Ref 37)
- debinding and sintering process:
  - check the real temperature distribution of the used kiln and modify the used temperature regime if necessary
  - the needed timeframe for debinding and sintering can be reduced by thermal analytics and adjustment of the temperature regimes

- costs:
  - the costs per part decrease with the number of parts
  - compared to other technologies like ceramic injection molding:

  - the costs for a small number of parts (< 50) are significant lower
  - the costs for a large number of parts are significant higher
  - the breakeven point depends on the component size, the used ceramic material, and the material used for the mold

Acknowledgments

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement No. 678503.

References

1. ASTM-Standard F2792 -12a: Standard Terminology for Additive Manufacturing Technologies. March 1, 2012, ASTM International Distributed under ASTM license by Beuth Publisher
2. U. Lakshminarayan, S. Ogrydiziak, and H.L. Marcus, Selective lasersintering of ceramic materials. *Proceedings of Solid Free-Form Symposium*, 1990, p. 16–26
3. A. Lauder, M.J. Cima, E. Sachs, and T. Fan, Three dimensional printing: surface finish and microstructure of rapid prototyped components, *Mater. Res. Soc. Symp. Proc.*, 1992, **249**, p 331–336
4. K. Pham-Gia, W. Rossner, B. Wessler, M. Schäfer, and M. Schwarz, Rapid Prototyping of high-density alumina ceramics using stereolithography, cfi/ Ber, *DKG*, 2006, **83**, p 36–40
5. T. Chartier, C. Duterte, N. Delhote, D. Baillargeat, S. Verdeyme, C. Delage, and C.J. Chaput, Fabrication of millimeter wave components via ceramic stereo- and microstereolithography processes, *J. Am. Ceram. Soc.*, 2008, **91**, p 2469–2474
6. M.L. Griffith and J.W. Halloran, Freeform fabrication of ceramics via stereolithography, *J. Am. Ceram. Soc.*, 1996, **79**, p 2601–2608
7. A. Licciulli, C.E. Corcione, A. Greco, V. Amicarelli, and A. Maffezzoli, Laser stereolithography of ZrO_2 toughened Al_2O_3, *J. Europ. Ceram. Soc.*, 2005, **25**, p 1581–1589
8. Y. de Hazan, M. Thänert, M. Trunec, and J. Misak, Robotic deposition of 3d nanocomposite and ceramic fiber architectures via UV curable colloidal inks, *J. Europ. Ceram. Soc.*, 2012, **32**, p 1187–1198
9. R. Felzmann, S. Gruber, G. Mitteramskogler, P. Tesavibul, A.R. Boccaccini, R. Liska, and J. Stampfl, Lithography-based additive manufacturing of cellular ceramic structures, *Adv. Eng. Mater.*, 2012, **14**, p 1052–1058
10. R. Lenk, A. Nagy, H.-J. Richter, and A. Techel, Material development for laser sintering of silicon carbide, cfi/ Ber, *DKG*, 2006, **83**, p 41–43
11. P. Regenfuss, R. Ebert, and H. Exner, Laser Micro Sintering—a versatile instrument for the generation of microparts, *Laser Tech. J.*, 2007, **4**, p 26–31
12. Y.-C. Hagedorn, J. Wilkes, W. Meiners, K. Wissenbach, and R. Poprawe, Net shaped high performance oxide ceramic parts by selective laser melting, *Phys. Proced.*, 2010, **5**, p 587–594
13. Y. Wu, J. Du, K.-L. Choy, and L.L. Hench, Laser densification of alumina powder beds generated using aerosol spray deposition, *J. Europ. Ceram. Soc.*, 2007, **27**, p 4727–4735
14. R.D. Goodridge, J.C. Lorrison, K.W. Dalgarno, and D.J. Wood, Comparison of direct and indirect selective laser sintering of porous apatite mullite glass ceramics, *Glass Technol.*, 2004, **45**, p 94–96
15. U. Gbureck, T. Hoelzel, I. Biermann, J. Barralet, L.M. Grover, Preparation of tricalcium phosphate/calcium pyrophosphate structures via rapid prototyping J. Mater. Sci.: Mater. Med. **19**, 1559–1563 (2008)
16. H. Seitz, W. Rieder, S. Irsen, B. Leukers, C. Tille, Three-dimensional printing of porous ceramic scaffolds for bone tissue engineering. Biomed. Mater. Res. Part B: Appl. Biomater. **74B**, 782–788 (2005)
17. A. Khalyfa, W. Meyer, M. Schnabelrauch, S. Vogt, and H.-J. Richter, Manufacturing of biocompatible ceramic bone substitutes by 3D-printing, cfi/ Ber, *DKG*, 2006, **83**, p 23–26
18. U. Deisinger, F. Irlinger, R. Pelzer, and G. Ziegler, 3D-printing of HA-scaffolds for the application as bone substitute material, cfi/Ber, *DKG*, 2006, **83**, p 75–78
19. F. Dombrowski, P.W.G. Caso, M.W. Laschke, M. Klein, J. Guenster, and G. Berger, 3-D printed bioactive bone replacement scaffolds of alkaline substituted ortho-phosphates containing meta- and di-phosphates, *Key Eng. Mater.*, 2013, **529–530**, p 138–142
20. A. Zocca, C.M. Gomes, E. Bernardo, R. Müller, J. Günster, and P. Colombo, LAS glass–ceramic scaffolds by three-dimensional printing, *J. Europ. Ceram. Soc.*, 2013, **33**, p 1525–1533
21. Z. Sadeghian, J.G. Heinrich, and F. Moztarzadeh, Direct laser sintering of hydroxyapatite implants by Layerwise slurry deposition (LSD), cfi/ Ber, *DKG*, 2004, **81**(12), p E39–E43
22. B. Cappi, E. Oezkol, J. Ebert, and R. Telle, Direct inkjet printing of Si_3N_4: characterization of ink, green bodies, and microstructure, *J. Europ. Ceram. Soc.*, 2008, **28**, p 2625–2628
23. J. Ebert, E. Özkol, A. Zeichner, K. Uibel, Ö. Weiss, U. Koops, R. Telle, and H. Fischer, Direct Iinkjet printing of dental prostheses made of zirconia, *J. Dent. Res.*, 2009, **88**, p 673–676
24. M. Allahverdi, S.C. Danforth, M. Jafari, and A. Safari, Processing of advanced electroceramic components by fused deposition technique, *J. Europ. Ceram. Soc.*, 2001, **21**, p 1485–1490
25. S. Bose, J. Darsell, H. Hosick, L. Yang, D.K. Sarkar, A. Bandyopadhyay, Processing and characterization of porous alumina scaffolds. J. Mater. Sci.: Mater. Med. **13**, 23–28 (2002)
26. T. Schlordt, S. Schwanke, F. Keppner, T. Fey, N. Travitzky, and P. Greil, Robocasting of alumina hollow filament lattice structures, *J. Europ. Ceram. Soc.*, 2013, **33**, p 3243–3248
27. K. Cai, B. Roman-Manso, J.E. Smay, J. Zhou, M.I. Osendi, M. Belmonte, and P. Miranzo, Geometrically complex silicon carbide structures fabricated by robocasting, *J. Am. Ceram. Soc.*, 2012, **95**, p 2660–2666
28. D. Polsakiewicz and W. Kollenberg, Process and materials development for functionalized printing in three dimensions (FP-3D), refractories. WORLDFORUM, **4**, 1–8 (2012)
29. T. Chartier, A. Badev, Rapid Prototyping of Ceramics. in *Handbook of Advanced Ceramics* (Elsevier, Oxford, 2013)
30. N. Travitzky, A. Bonet, B. Dermeik, T. Fey, I. Filbert-Demut, L. Schlier, T. Schlordt, and P. Greil, Additive manufacturing of ceramic-based materials, *Adv. Eng. Mater.*, 2014, **16**, p 729–754
31. A. Zocca, P. Colombo, C.M. Gomes, and J. Günster, Additive manufacturing of ceramics: issues, potentialities, and opportunities, *J. Am. Ceram. Soc.*, 2015, **98**(7), p 1983–2001
32. U. Scheithauer, A. Bergner, E. Schwarzer, H.-J. Richter, T. Moritz, Studies on thermoplastic 3D Printing of steel-zirconia composites. J. Mat. Res. **29**(17), 1931–1940 (2014)
33. U. Scheithauer, T. Slawik, E. Schwarzer, H.-J. Richter, T. Moritz, A. Michaelis, Additive manufacturing of metal-ceramic-composites by thermoplastic 3D-printing. J. Ceram. Sci. Tech. **06(**02), 125–132 (2015)
34. U. Scheithauer, E. Schwarzer, G. Ganzer, A. Körnig, W. Beckert, E. Reichelt, M. Jahn, A. Härtel, H.-J. Richter, T. Moritz, and A. Michaelis, Micro-reactors made by Lithography-based Ceramic Manufacturing (LCM). in P*roceedings of 11th International Conference on Ceramic Materials and Components for Energy and Environmental Applications 2015*, Vancouver, Ceramic Transactions, 2016, 258, The American Ceramic Society
35. U.K. Fischer, N. Moszner, V. Rheinberger, W. Wachter, J. Homa, and W. Längle, Lichthärtende Keramikschlicker für die stereolithographische Herstellung von hochfesten Keramiken (light curing ceramic suspensions for stereolithography of high-strength ceramics), european patent EP 2404590A1, published 11.01.2012
36. J. Homa, Rapid Prototyping of High-Performance Ceramics Opens New Opportunities for the CIM Industry. Powder Injection Mould. Int. **6**(3) (2012)
37. E. Schwarzer, M. Götz, D. Markova, D. Stafford, U. Scheithauer, T. Moritz, Lithography-based Ceramic Manufacturing (LCM)—Development of a possible process chain for the additive manufacturing of personalized medical products. J. Eur. Cer. Soc. (submitted for publication in 2017)