IMIiB
Instytut Materiałów Inżynierskich i Biomedycznych
Zeszyt nr 4
Gliwice 2017
WYDZIAŁ MECHANICZNY TECHNOLOGICZNY
POLITECHNIKA ŚLĄSKA
ZESZYTY STUDENCKICH KÓŁ NAUKOWYCH

Lithography-based Ceramic Manufacturing: 3D printing of ceramics

P. Gwiaździńska [a], S. Żołnierczyk [a], T. Tański [b]

[a] Students of Silesian University of Technology, Mechanical Technological Faculty
email: pola.gwiazdzinska@gmail.com, sandra.zolnierczyk@gmail.com

[b] Politechnika Śląska Wydział Mechaniczny Technologiczny, Instytut Materiałów Inżynierskich i Biomedycznych, email: tomasz.tanski@polsl.pl

Abstract: Lithography-based Ceramic Manufacturing (LCM), defined as a rapid production of ceramic finished objects from a 3D printer, is in present the only technology in industry, that allows to create ceramic parts – and still with only a few possible materials. The rapid manufacturing technologies of metals and polymers start to become common with a wide range of applications. LCM technology, however, promises all capabilities of rapid manufacturing with advantages characterized only ceramic materials such as high chemical resistance, high hardness and stiffness or heat-resistance.

Keywords: Lithography-based Ceramic Manufacturing, 3D printing technology, Ceramics, Zirconium Oxide, Aluminum Oxide

1. INTRODUCTION

The main purpose of the additive manufacturing methods is obtaining a three-dimensional solid objects of virtually any shape from a digital model. The additive processes have a big advantage – they reduce the material loss in opposite to the subtractive processes such as conventional milling or turning, where the material is removed. In this techniques components are built-up gradually in layers by solidyfing or binding a line, until the final geometry is obtained. There are various methods of additive manufacturing, which have differences between the way of produced layers and used materials. However, the production of ceramic materials by the additive methods is still not so common in the industry and considered to be expensive method [1-2].

The LCM method appears not a long time ago and still is developed. Against the background of other technologies of lithography-based additive manufacturing, it seems to be still the only method, which achieves the highest accuracy of ceramic details. The development of additive manufacturing methods in time shows the timeline (fig.1).

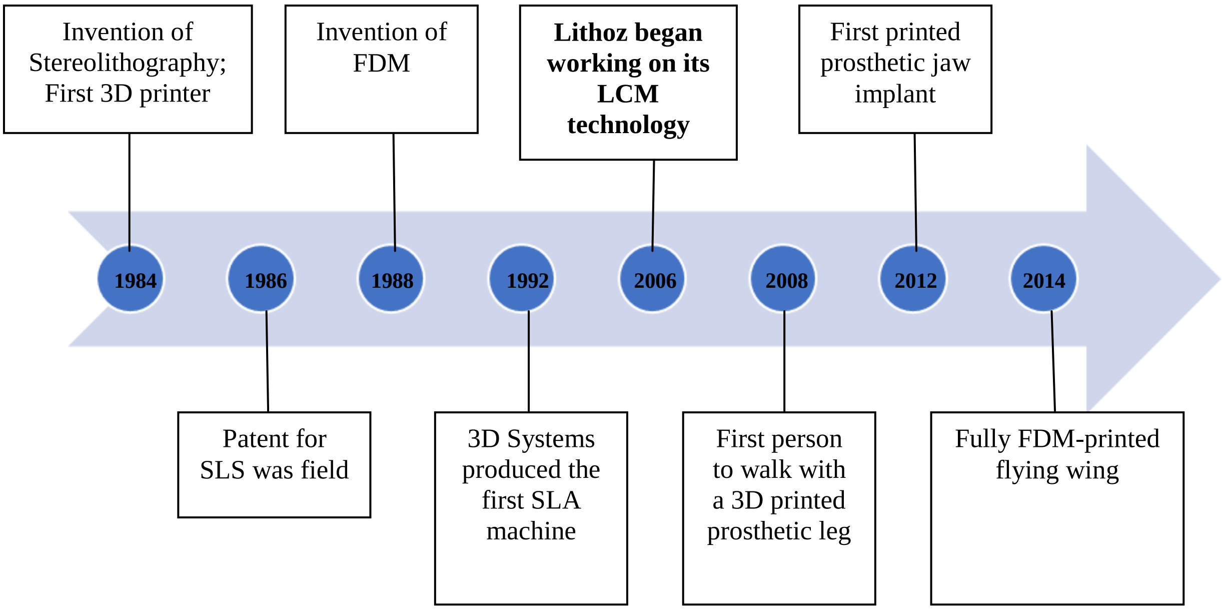

Figure 1 The timeline of additive manufacturing [13-15]

3D printing of ceramics is a huge challenge. Ceramics possess a number of unique properties unmatched in other material groups. Creation of technical ceramics is very difficult due to the high thermal shrinkage of ceramics during firing or sintering and the difficulty of forming shapes and maintaining the correct dimensional accuracy. Until recently, there was no 3D printing technology that allowed for the production of technologically sophisticated parts made of ceramic materials. Only LCM technology has allowed for quick construction of almost any complex technical as well as medical ceramic materials.

2. TECHNOLOGY

LCM technology (Lithography-based Ceramic Manufacturing) patented by Austrian Company Lithoz GmbH allowed for fast manufacture of complex shape elements for technical and medical applications made of ceramic. LCM method is similar to Stereolithography process based on DLP chips using blue light. The LCM machine is composed of three basic parts: the building platform, where the head can move in the Z axis, the rotating vat for the input material and the light source (fig.2). It can be also equipped into the coating blade if is necessary [3,5,9].

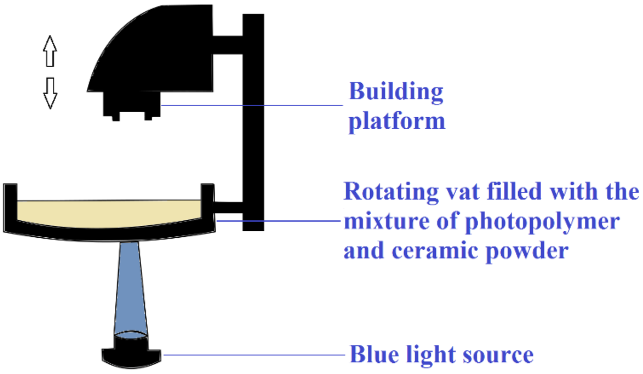

Figure 2 The schema of the LCM process [9,10,16,17]

The process uses as an input material a suspended matter consisting of a photo-curable resin with ceramic particles dispersed therein and at least one photoactive component in the form of photoinitiator. It is necessary to initiate the polymerization reaction by forming the free radicals by the photoinitiator and then decomposed them by the absorption of blue light photons. The photopolymers need to be used as a binder for ceramic particles, allowing precise forming of the shape. The constructing of the component is obtained by stacking up layers of an input mixture. All regions of a layer, which are necessary for creation the desired object are cured simultaneously. This way of work can increase the productivity of this method in comparison to the other techniques using laser beam for dot-wise exposure, such as stereolitography. Selective curing takes place in a room temperature to avoid creating of thermal stresses in the material. The most important is the proper mixing of the suspension between the forming of following layers, what allows to keep a homogeneity. After curing the bottom layer in the bottom of the vat containing the suspension, the component is raised by a distance corresponding to the thickness of the next layer. The next suspension layer can be applied by a coating blade [4,5,10,11,16].

The most meaningful things during LCM process are [3]:

- Composition of photopolymer with ceramic nanopowders,
- The way of resin homogenization and layer hardening,
- Burning and sintering processes.

This technology can produce parts with high accuracy. It is possible to obtain a layer thickness below 200 microns with the slice thickness between 25-100 µm and lateral resolution up to 40 microns. The differences between slice thickness are regulated by the speed of the process – fast and less precisely parts can have thickness about 100 µm and slow, but more precisely achieve thickness of 25 µm. Possibility of creating complex shapes of parts, also implementation of undercuts and cavities causes that this technology is considered as a method with almost no geometrical limitations. A possibility of modification of the light source allows for optimize the curing process for each pixel of the exposed layers[6,10].

The printed objects should require additional support from the native material. In all technologies of additive manufacturing the printed parts are building up from the bottom in layers. The higher resolution of the object is, the thinner layers are made. In such a case, the more complex parts could be unstable, what can be solved by building also layers of support material from the ground up for overhanging sections. The supports should be easy to access or else they cannot be removed during re-process, still before the burning [3-4].

3. COMPARING LCM TO SLA

The narrow range of possible 3D printing methods for obtaining ceramics is caused by a lot of complications. It is hard to achieve precise layer deposition by spreading fine powder layers during the process or to ensure that the following layers are uniform, coated by highly viscous ceramic suspension, what is demanded in SLA method. In addition, there often can be noticed an effect called "staircase", which is a result of slicing of a contoured surface. Reducing the thickness of the layers or the whole component can eliminate that effect, but it is not always possible. In that cases, a grinding or polishing operations can be performed additionally, but it takes also time and costs. The LCM method usually can avoid that problem, because of better resolution in comparing to other methods producing ceramic components. As the SLA was considered as a method, which allows for the best surface finish, now the LCM dominates in this area [17].

Moreover, both methods – LCM and SLA use very expensive and a limited range of raw materials – photosensitive resins. While SLA allows the use of wide range of ceramic materials available in powder form, the LCM has very limited possibilities in this area. However, despite that disadvantage, still using the LCM leads to many benefits mentioned in this paper [11,17].

4. MATERIALS

There is one condition, which is need for efficient curing of the binder photopolymer by exposure to blue light - the ceramic particles dispersed in the binder must not absorb the radiation. For that reason, dark ceramic powders are strongly limited for use in this process. The most common materials for LCM method are Zirconium Oxide (ZrO_2) and Aluminum Oxide (Al_2O_3). This materials are prepared directly for Lithography-based Ceramic Manufacture. They are characterized by the trade name, because are not these pure chemical compounds, but composites with addition of the resins, which are obtained after the process, also after burning. These two materials has very good properties that allows to obtain parts and elements with very good accuracy and high quality. There is also a possibility of use the tricalciumphospate as a biomaterial in this method [7,8,11].

4.1. Zirconium Oxide

Lithoz Company offers Zirconium Oxide material called LithaCon 3Y 610 Purple. This Zirconium Oxide has unique hardness and strength values. It can be used for mechanical and tribological parts. This material can be also used for biomedic and prosthetic applications. LithaCon 3Y 610 Purple allows to produce parts with very high accuracy and quality [7].

The most meaningful properties of LithaCon 3Y 610 Purple are such as:

- Very high crack resistance,
- Very good tribological properties,
- Low thermal conductivity,

- High tensile and bending strength,
- High corrosion and abrasion resistance [7].

Tabel 1 Technical data [7,18]

Material	**ZrO_2**
Bending strength (4P method)	**650 MPa**
Density	**> 6.01 g/cm^3 (99.11%)**
Roughness (Ra)	**~ 0.6 µm**
Hardness Mohs	**~ 7**
Young module (E)	**~ 2·10^5 N/mm**
Thermal conductivity	**~ 3 W/m·K**
Thermal expansion	**~ 11·10^{-6} K**
Thermal shock resistance	**good or very good**

4.2. Aluminum Oxide

Lithoz Company offers Aluminum Oxide material called LithaLox HP 500.. This Aluminum Oxide is one of the most meaningful ceramic oxides. Because of its high density this material has good mechanical chemical and electrical properties which allows to use it for many applications [8].

The most meaningful properties of Litha Lox Hp 500 are such as:

- Corrosion resistance,
- Temperature resistance,
- Abrasion resistance,
- High hardness,
- High tensile strength [8].

Tabel 2 Technical data [8,18]

Material	**Al_2O_3**
Bending strength	**430 MPa**
Density	**> 3.96 g/cm^3 (99.4%)**
Roughness (Ra)	**~ 0.4µm**
Hardness Mohs	**~ 9**
Young module (E)	**(3,5÷4)·10^5 N/mm**
Thermal conductivity	**~ 30 W/m·K**
Thermal expansion	**~ 7,5·10^{-6} K**
Thermal shock resistance	**average**

4.3. Applications

Costs of materials used in Lithography-based Ceramic Manufacturing are not cheap. One kilogram of suspension made of ceramic nanoparts and photopolymeric resin can be in the range of few thousands zlotys. For this reason, LCM technology is not widely used. Great properties of materials that are used in this technology and properties of parts after printing could allow for using them in many areas such as:

- Automotive,
- Medicine,
- Dentistry and prosthesis,
- Aerospace,
- Military
- Electronics,
- Chemistry.

Further developments in materials could help to reduce the costs. This would allow extension of the scope of application [3, 4, 7, 8 ,12].

5. CONCLUSION

Since the invention of the first 3D printer, many years have passed. So far, the most developed are the printing of metals and polymers. In the area of 3D printing in ceramics there are still many solutions to be developed, mainly in terms of materials that can be used. Over the next few years or so, this area should expand.

Currently on the market of printing of ceramics, forefront the Lithoz company which developed its Lithoghraphy-based Ceramic Manufacturing technology. Very good parameters of printed elements and the wide ability of LCM Lithoz's printers should be the driving force of the process of developing new combinations of ceramic materials that could be used.

Today, the material is the most expensive component of ceramics printing process. Developing of new materials would make it possible to reduce costs and consequently disseminate technology.

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