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Additive Manufacturing of glass: post process surface treatment of DLP parts

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Abstract

There is a high demand for new manufacturing technologies in the production of technically functional glass objects and complex glass shapes. Optical components such as complex light guiding structures, adapted, miniaturised lenses and mirrors as well as components for optical data processing require high optical transparency. To address this demand, within the Glass3D project research is being conducted on production of optically transparent glass objects using Additive Manufacturing (AM).
In a part of this study, objects are first additively manufactured using stereolithography/DLP (Digital Light Processing) and then sintered in order to remove binder and fuse the glass particles together.
The material used, FP20, is a rapidly crystallising glass in which undesirable crystals form on the surface during the sintering process. These crystals must be removed post AM process by mechanical grinding and subsequent polishing. However, complex, thin walled geometries with curved surfaces or undercuts, as they are possible to be created by AM, cannot be processed using conventional grinding and polishing wheels. Thus, those processes are not applicable for complex shaped parts. Commonly applied sandblasting is very limited in reproducibility due to the manual control of the abrasive media nozzle.
A possible alternative is automated particle blasting to remove the crystalline layer and reduce the surface roughness. Automated abrasive blasting enables processing of complex workpieces with controllable movement between particles and parts and therefore reproducible kinetic energy and process time. This study investigates feasibility of automated particle blasting to post-process glass objects from DLP material with high brittleness. Kinetic energy of the particles and the processing time are varied. The evaluation of the results by means of confocal microscopy showed that an improvement of the surface roughness (Rz) could be achieved.

Additive Manufacturing, Stereolithography, DLP, Particle Blasting, Surface Finishing, Glass

1. Introduction

Stereolithography/Digital Light Processing (DLP) enables the production of complex shaped glass bodies. In the Glass3D project, fluorophosphate glass (FP20), $(20Sr(PO_3)_2–80[AlF_3, MgF_2, CaF_2, SrF_2])$ was explicitly chosen for its usability in optical applications. It is the first attempt to process FP20 glass with the DLP process. Compared to silica, which is used in similar AM processes [1,2], FP20 tends to surface crystallise, which affects the post-processing sintering process. Removal of the crystals is not possible with conventional grinding and polishing wheels for complex geometries, and conventional manual sandblasting is difficult to reproduce. Therefore, in this study the feasibility of automated particle blasting for DLP glass objects is investigated by varying the kinetic energy and the processing time, with the aim of reducing the surface roughness of the parts. Determination of the achieved surface finish and roughness is carried out optically by confocal microscopy.

2. Specimen production made of fluorophosphate glass

In this study, FP20 is additively processed using stereolithography/DLP. The FP20 glass with $20Sr(PO_3)_2$ - $30AlF_3$ - $10MgF_2$ - $22CaF_2$ - $18SrF_2$ was produced by conventional melt quenching as e.g. described in [3].

Initially, FP20 glass produced by melt quenching was crushed into fine glass particles of a size of 32-125 µm and mixed with the DLP resin. Specimens are fabricated by pouring the resin into moulds of 15x7x2 mm³, followed by UV curing. The samples are then heated to 500 °C to remove the organic components. Finally, to obtain a glassy transparent specimen, sintering was carried out above the crystallisation temperature of the glass with a fast heating rate of 20 K/min. The fast heating rate prevents the internal nucleation and growth of crystals during sintering. Nevertheless, surface crystallisation occurs during sintering, enveloping the workpiece with its transparent glass body. Due to the so far imperfect DLP process with FP20, the samples used for the tests show pores and cracks in addition to the expected and most likely unavoidable crystalline layer with an average thickness of 370 µm. Both can be seen in fig. 1.

Figure 1. Cross section of the sintered, unprocessed sample

The surface crystals must be subsequently polished or etched in order to obtain a transparent glassy workpiece after sintering. An already known possibility to remove surface crystals is ion blasting. Whether particle blasting with glass itself as abrasive material is another option was examined in this study.

3. Glass blasting process

Particle blasting is a mechanical surface treatment in which an abrasive media is accelerated and targeted onto the surface of the workpiece to be treated. The process depends on the abrasive material used and the kinematics of the particles. Abrasive blast cleaning is used to remove foreign matter and cover layers, as well as to clean and roughen the surface [4].

The Twister® blasting system made by BMF GmbH, fig. 2, uses a superimposed rotating and swivelling movement of the workpiece to enable a uniform and all-round surface treatment even of complex components. Here, the workpiece holder is located on a turntable utilising a planetary gear and rotates continuously at slow speed around a central particle feed. The blasting material is accelerated onto the workpiece by means of a centrifugal wheel located in the centre.

Figure 2. Movement scheme of the Twister® [7]

To ensure uniform and reproducible process kinematics, blasting particles that are too fine are extracted and removed from the abrasive. The blasting medium must be selected according to the material and the material condition of the workpiece with regard to type, hardness and grain diameter [5]. Glass abrasive enables a low-intensity blasting process, as is necessary for thin-walled, porous parts [4].

4. Experimental procedure

The surface condition and roughness of the sintered FP20 samples were observed before and after the glass blasting process by confocal microscopy. The blasting process was carried out using spherical fine abrasive made of alkali lime glass with a particle size of 100 – 200 µm. The process was stopped as soon as no crystalline surface was visible by means of a reflected light microscope or the glass piece broke. The specimen was aligned so that the particles hit the surface as perpendicularly as possible (at an angle of 90°). The blasting parameters are shown in tab. 1.

Table 1. Blasting parameters

Particle size in µm	Time in s	Kinetic energy levels set through wheel rpm
100 - 200	Intervals of 30	4000
		7000
		9000

5. Results and discussion

As expected, the surface roughness could be reduced by the glass blasting process, see tab. 2. All samples have a evenly, matt, non-transparent surface, as the blasting process results in conchoidal spalling [6] on the glass body. Sample 3 broke prematurely during the blasting process due to the excessive kinetic energy of 9000 rpm, which may also have been facilitated by the pre-existing damage, such as cracks and pores during the sample production. As expected in samples 1 and 2, the surface crystals, visible in Fig. 3 (l), could be removed with increased process time and reduced kinetic energy, but the blasting process opened pores located directly under the crystalline layer, Fig. 3 (r), which in turn led to an undesirable increase in surface roughness. The objective of reducing the surface roughness and removing the crystalline surface was achieved. However, for an optically transparent glass body, damage such as pores, cracks and matt surfaces are not acceptable, which is why further post processing is essential for optical components made from sintered FP20 glass.

Table 2. Surface roughness Rz mean value in µm

Part	Parameters	Rz	SD (Rz)	min (Rz)	max (Rz)
1	**4000 rpm, 0 s**	113.40	48.50	41.67	226.20
1	**4000 rpm, 240 s**	87.18	49.93	23.77	189.40
2	**7000 rpm, 0 s**	97.54	62.38	17.15	300.90
2	**7000 rpm, 180 s**	33.41	6.78	18.12	49.54
3	**9000 rpm, 0 s**	66.45	35.18	21.56	180.80
3	**9000 rpm, 30 s**	84.64	35.86	37.76	226.00

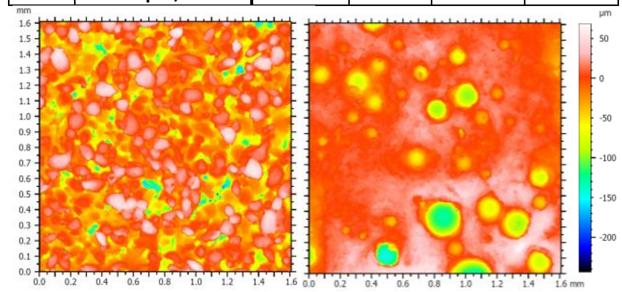

Figure 3. False colour image of surface topology before (l) and after (r) blasting, sample 2

6. Conclusion

A mechanical surface treatment of FP20 glass by means of particle blasting using glassy abrasive is possible, but the final polishing is indispensable to achieve an optically transparent workpiece. The influence of media with coarser or finer grain size distribution on surface roughness as well as a longer blasting time must be investigated, also using improved initial samples.

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