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Laser ablation for finishing of porous ceramics in 3D surfaces

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Abstract

High precise slumping of thin glass (< 0.5mm) is a big challenge, especially in dimensions larger than 100 x 100mm and for optical applications like X-ray telescope mirrors.

In the current R&D project "PräBieD" a process chain included its hardware is being developed.

The applied slumping process of thin glass is vacuum supported using an open-porous ceramic mold. The core process of shaping this hard material requires a sequence of milling and laser ablation in one clamping operation. Therefore a combined 5axis milling and laser machining center FocusFlex 5x® has been developed, manufactured and installed in a temperature-controlled laboratory.

This femtosecond laser finishes the precise hyperbolic shape of its contact surface to the thin glass of the developed ceramics Cesic® and Pormulit® by ablation. Matched parameter sets smoothen the surface to the final shape, remove subsurface damages and remaining micro particles from the pores simultaneously.

Keywords: Ceramic, porosity, cleaning, roughness, figure deviation, puls duration

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1. Company profile of stoba

Stoba is located in Memmingen close to Munich and has been founded in 2007. Its core business is the development and production of customized electrochemical machines and fine cleaning. The second growing business division and competence is the micro-precision CNC-axis milling combined with the femtosecond laser machining of different materials.

Both procedures are aimed at automation for very stable mass production.

Fig. 1. Machine for electrochemical machining

2. Introduction and motivation

2.1. Application

The combination of milling and laser ablation in one clamping system was born for the R&D project "PräBieD", which works on precision slumping of thin glass (< 0.5 mm) in the dimension of 100x100 mm for the application for X-ray telescope mirrors. The key advantage would be a weight reduction of the satellite at a simultaneously increasing mirror size for the collected x-ray power.

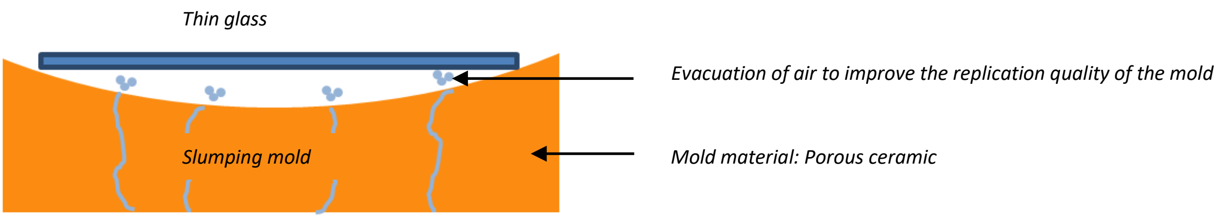


Fig. 2. Schematic view of glass slumping

Slumping of such a thin glass requires the evacuation of the remaining air volume between mold and glass due to the low weight of the thin glass to get a best case replicated mirror. This task has been solved by the project partner ECM by developing of a micro porous ceramic for the slumping mold.

2.2. Process chain

The project goal of PräBieD is the development of an optimized process chain. The laser ablation of the mold is part of the development of the mold material, milling process, metrology and slumping of the thin glass as shown in figure 3.

Therefore stoba has developed an ultra-precision 5-axis machining center for milling the ceramic mold combined with an femtosecond laser to enable a dimensional accuracy for the mold surface of less than 1,00 µm/100 mm.

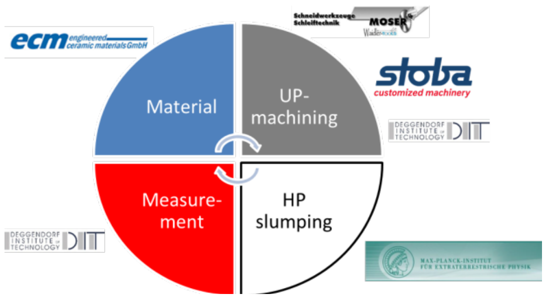


Fig. 3. process chain and project partner

3. Laser machine concept

The main features of the developed laser machine (Fig. 4 and 5) are:

- Granite frame for highest stiffness
- Cooling system to achieve temperature stability (±0,1 Kelvin) and to avoid any drifts
- Machining in one clamping unit to achieve maximum possible precision
- Z-axis1/2: Femtosecond Laser with 3D scanhead and HF milling/grinding spindle at 100.000 rpm
- A/B axis with integrated high-precision chuck system, System 3R Macro 70
- All axes are equipped with direct measurement system with highest resolution (Heidenhain & Renishaw)

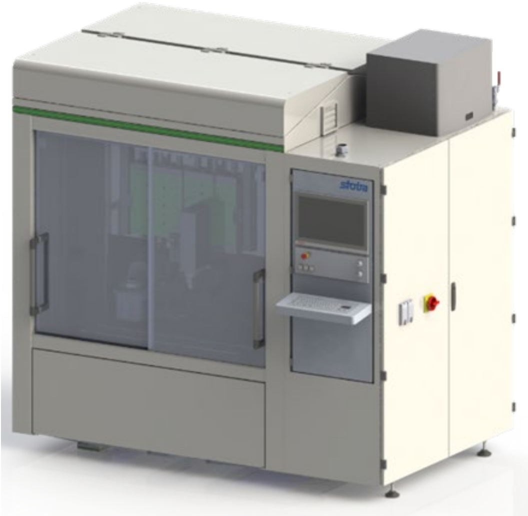


Fig. 4. CNC 5-axis laser machine

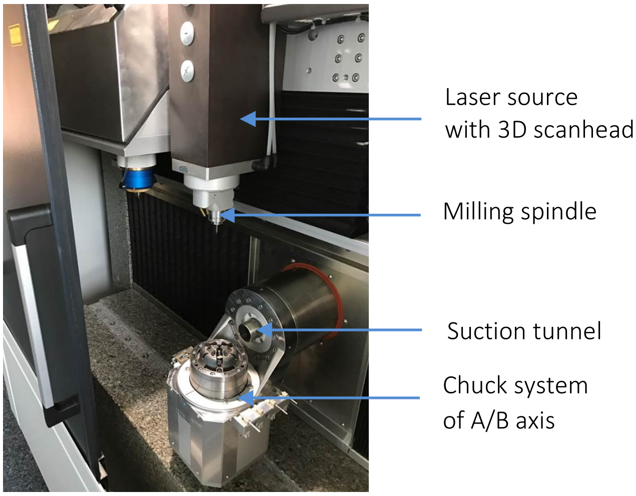


Fig. 5. inside view of stoba laser system

4. Trials and results

4.1. Feasibility tests with non-porous HB-Cesic®

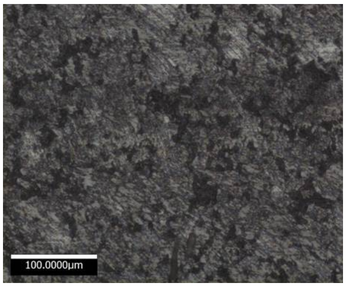


Fig. 6. grinded surface of HB-Cesic®

The initial condition of the ceramic surface was a grinded surface before laser ablation of dense HB-Cesic® with roughness of

Ra: 0.26 µm or Rz: 2.40 µm

In order to differentiate the influence of pores on the milling process and the laser ablation we have started the first trials with nonporous ceramic and the parameters described in Table 1:

Table 1. Process parameter of laser ablation

Process parameter	
Laser source	Spectra Physics Spirit
3D Scanner	Arges Precision Elephant
Material Ablation	8-20 µm*
Wave length	1040 nm
Pulse length	790 fs
Pulse energy	146 µJ
Feed rate CNC	0.5 m/min
HSC op. mode2	0.002

*… ablation depends on the grinding direction

Preliminary results:

- Laser ablation of ceramic is possible in principle.
- Different material compositions show different absorption behavior of silicon, silicon carbide and carbon.
- The surface quality after grinding has a direct influence on the roughness after laser ablation.
- By laser ablation „smeared“ abrasive particles were removed (Laser-cleaning).

Fig. 7. laser ablated surface of HB-Cesic®

Laser ablation in parallel to the grinding direction of dense HB-Cesic® intensified the roughness to

Ra: 0.58 µm or Rz: 5.60 µm

by the cleaning effect as described above.

Fig. 8. laser ablated surface of HB-Cesic®

Laser ablation vertical to the grinding direction of dense HB-Cesic® gave better results of roughness:

Ra: 0.46 µm or Rz: 3.70 µm

Fig. 9. laser ablated surface (left) *vs* *grinded surface of HB-Cesic® (right)*

Figure 9 shows at the right side areas of silica which have been removed with the detected parameters of the laser ablation at the left side.

4.2. Feasibility tests with open-porous Cesic®

The open-porous Cesic® have been laser-ablated with the determined parameters for dense Cesic® (Table 1).

Table 2. Overview of different open-porous Cesic® ceramics

Overview of Cesic® materials				
Grinded		**MI9-2**	**MI9-3**	**MI9-4**
optical	R_a	0.14	0.06	0,14
min/max	Pore Ø	34 – 72 µm	26 – 30 µm	25 – 63 µm
min/max	Pore depth	12.1 – 33.5 µm	17.4 – 17.8 µm	10.1 – 31.1 µm
Laser ablated		**MI9-2**	**MI9-3**	**MI9-4**
optical	R_a	0.62	1.06	0,35
min/max	Pore Ø	20 – 59 µm	34 – 36 µm	21 – 52 µm
min/max	Pore depth	8.0 – 35.8 µm	6.2 – 8.3 µm	3.9 – 23.3 µm

Table 2 compares the surface quality before and after laser ablation of different open-porous Cesic® samples.

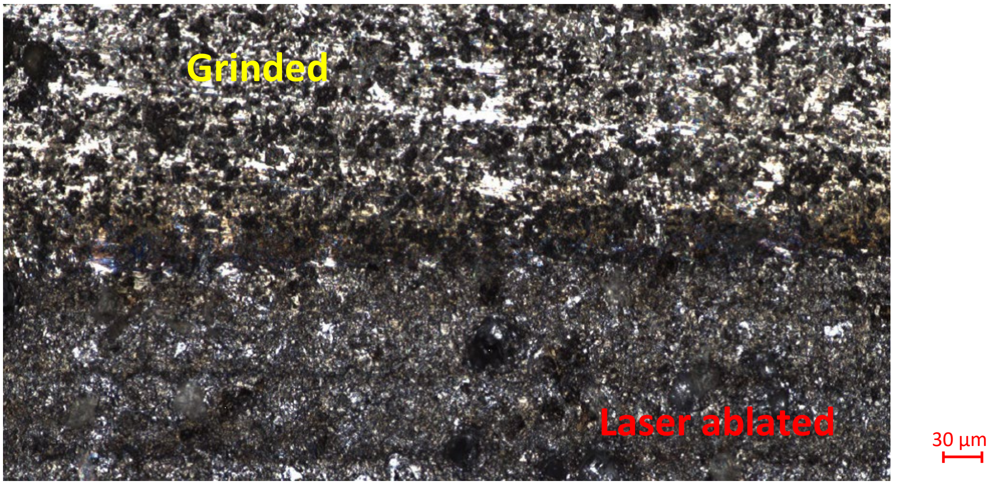


Fig. 10. laser ablated surface of open-porous Cesic®

Figure 10 shows the cleaning effect of the surface of open-porous Cesic® bevor and after ablating

It has been noticed, that

- The surface roughness increased, but this has no effects on the mold accuracy. This is caused by the following cleaning effect of the laser ablation.
- The laser ablation opens the pores by ablating of abrasive particles, dust and silicon.
- An additional positive effect of laser-cleaning the surface is the avoidance of any contamination with thin glass during slumping and improves the quality of replication.

4.3. Feasibility tests with open-porous Pormulit-grün®

Table 3. Overview of different open-porous ceramic Pormulit-grün compared to Cesic®

Overview ceramics				
name	Cesic®	Cesic®	Cesic®	**Pormulit-grün***
type	MI9-2	MI9-3	MI9-4	
status		Open-porous		
Pore diameter	20-50 µm			**0.73 µm**

*… evaluation stage

The alternative ceramic Pormulit-grün has been ablated with the following process parameter of table 4.

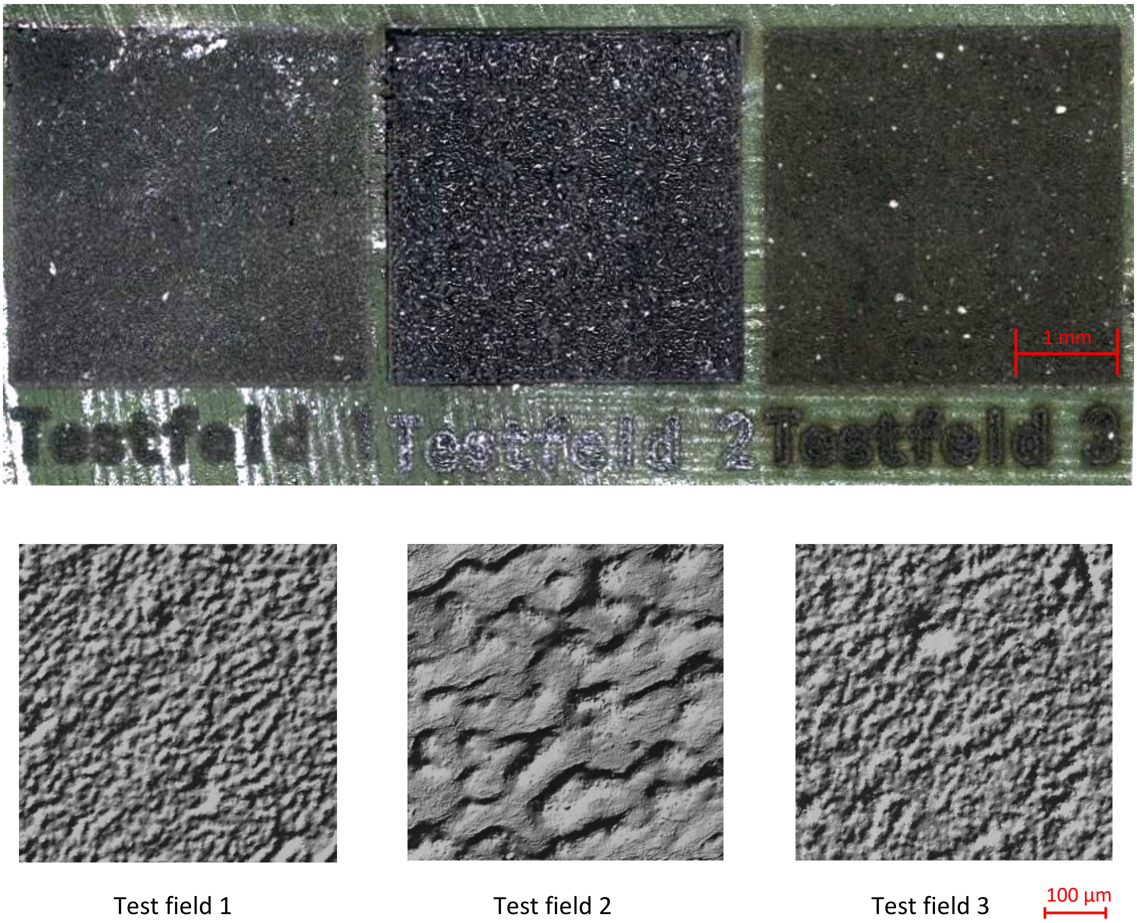
Table 4. Best-case (set 3) of process parameter of laser ablation

Process parameter	
Laser source	Spectra Physics Spirit
3D Scanner	Scanlab precSYS
Wave length	1040 nm
Pulse length	790 fs
Pulse energy	146 µJ
Feed rate CNC	0.8 m/min
HSC op. mode2	0.0026

Preliminary results:

- Laser ablation also of Pormulit-grün is basically possible.

Figure 11 compares the surface of three test fields in the development of the process parameter for laser ablating of Pormulit-grün.



Test field 1 Test field 2 Test field 3

Fig. 11. Surface structures of laser ablated Pormulit-grün as function of process parameters

Table 5. Surface quality of laser ablated Pormulit-grün of process parameter of laser ablation

Pormulit-grün			
Test field	1	2	3
Measuring machine	Keyence VK-X 250		
Measurement principle	Laser-scanning microscope		
Ra [µm]	2,0	5,2	2,0
Rz [µm]	11,7	22,9	9,8

This process for Pormulit-grün is still in development.

Applying of parameter set 3 for laser ablation of Pormulit-grün (best-case) resulted in the smallest roughness of surface.

Summary

- Different material compositions show a different absorption behavior.
- The surface quality after grinding has a direct effect on the roughness after laser ablation.
- An increased surface roughness has been detected but without negative effects for the mold accuracy.
- The laser ablation reopens the pores. Abrasive particles, dust and silicon will be removed.
- Additional positive effect: laser-cleaning of the surface avoids any contamination with thin glass during glass slumping and improves the slumping quality of the thin glass.

Acknowledgements

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References

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