Additive manufactured cerium oxide foils, used as pads for polishing processes of brittle-hard materials

Christian Schulze[1,*], *Sebastian* Henkel[1], *Denise* Schultheiß[1], *Dominique* Pipiorka[1], *Jens* Bliedtner[1], *Albert* Kerber[2], *Edda* Rädlein[3]

[1]Ernst-Abbe University of Applied Sciences Jena, Carl-Zeiss-Promenade 2, 07745 Jena, Germany
[2]QSIL Ceramics GmbH (formerly SiCeram GmbH), Am Nasstal 10, 07751 Jena, Germany
[3]Technische Universität Ilmenau, Ehrenbergstrasse 29, 98693 Ilmenau, Germany

Abstract. A new concept for polishing pads for flat and spherical surfaces is introduced which comprises additive manufactured polishing pads made of cerium oxide. By using additive manufacturing technologies, polishing processes with polishing slurry can be substituted with tools containing bonded grain. The bonded polishing pads can be fabricated using rolling processes. The pad geometries can be adjusted by using laser cutting. Furthermore, surface modifications of the pad can be applied with laser processes to favour quality and economic factors of the polishing procedure. First results from the experimental setup are showing, that **lapped surfaces with a roughness Rq of ~ 500 nm can be improved to approx. Rq = 30 nm roughness by polishing with bonded grain cerium oxide foils**. Further approaches for future investigations and applications are proposed.

1 Motivation

Polishing is often considered as a final processing step in the production chain for optical components of high quality. Due to the various geometries and sizes of processed samples as well as applied kinematics, polishing slurries, tools and machines, polishing can be described as a complex processing step with many influencing parameters. Many of these parameters can be user-dependent or variable over time. This complicates meeting requirements of polishing processes like surface quality, shape deviation, repeatability as well as economic aspects.[1] The applications of micro-optical systems in the fields of refractive and diffractive optics have increased tremendously. Due to the growing demands on the optical components, adjustments to the processes or new processes are necessary to meet these requirements.[2][3]

This paper reports on an experimental study using a new type of additive manufactured cerium oxide foils for polishing processes of brittle-hard materials.

2 Approach

Typical polishing processes are realized by a tool consisting of a tool body and a polishing pad, that follows specified pathways using a polishing slurry as lubricant. When applying polishing slurry, the concentration can be user-dependent concerning the concentration ratio of polishing powder, additives and water. Furthermore, in CNC polishing the concentration ratio is varying due to evaporation, dilution and deposition of polishing slurry inside the machine. The polishing slurry itself can be a time dependent variable too, since the abrasion of individual polishing grains results in a lower removal rate over a longer period of time.

The presented approach is to use bonded cerium oxide grains with an average grain size of 2µm instead of loose grain in a slurry, comparable to conventional grinding tools. This would offer several benefits: the concentration and concentration ratio remain constant and can be adjusted by the tool design and manufacturing process. Tool dressing can easily be done by using tools that are also applied for dressing conventional grinding tools such as galvanic, metal bonded tools or ceramic bonded tools. Instead of applying a slurry which can fluctuate in concentration and grain size, only water is needed as a lubricant. This can widen the range of machines capable of polishing samples, either for prototype manufacturing or regular production. Moreover, similar to other additive manufactured tools, this method offers major flexibility in terms of geometry, shape and possible surface modifications.

Fig. 1. a) Cerium oxide polishing powder with an average grain size of 2 µm b) Cerium oxide foil out of polishing powder, 100mm x 40mm x 1mm

* Corresponding author: Christian.Schulze@eah-jena.de

3 Realization and first results

To manufacture a thin foil, a roller processing is needed. Since the cerium oxide grains itself are to brittle to form a stable layer, a support structure is necessary. To produce the foil, the polishing powder is mixed with various organic components (~13%) by kneading. The product is then rolled to the required thickness and finally, the plasticizers are extracted in acetone. The density of the produced foils is about 3.4 g/mm³ after the extraction of plasticizers. The amount of organic components after extraction is ~4%, the amount of plasticizer < 1%. The manufactured foils are then cut out using a fiber laser (λ=1064 nm), enabling a wide range of tool designs. Figure 2, shows a flower-like shape with micro joints to ensure better handling as an example that is used in synchro-speed polishing processes. The foils can be applied to flat as well as spherical tool bodies, since the foil can be adjusted to be flexible enough to be bended into a spherical shape. Further modification to the surface can be made. Fig. 3c pictures an example of a laser applied cross shaped groove structure with depth of about 400 µm with a line spacing of 1 mm.

Fig. 2. Laser-cut polishing tools with a diameter of 25 mm and micro joints for better handling

First polishing tests were successfully conducted by using a lever machine. Flat N-BK7 samples with a diameter of approx. 40 mm could be polished using a cerium oxide foil with a diameter of 25 mm, applied to a flat aluminum tool holder with glue as pictured in Figure 3. While the sample rotates, the tool performs a linear movement.

Fig. 3. Tool with cerium oxide foil, diameter of 25 mm a) pad applied to a tool body using glue b) 200x magnification of foil surface before polishing c) structured foil in a cross shaped pattern with line spacing of 1 mm and a depth of 400 µm

With an initial roughness Rq = 500 nm from lapping with SiC F600, the final roughness could get reduced to approx. Rq = 30 nm. This was realized by using the lever kinematic, with the sample rotating at approx. 100 rpm and the tool above the sample executing a linear oscillation of roughly 40 rpm, while using additional weight of 20 N. Figure 4 shows a visual comparison of the initial and final roughness of the N-BK7 sample.

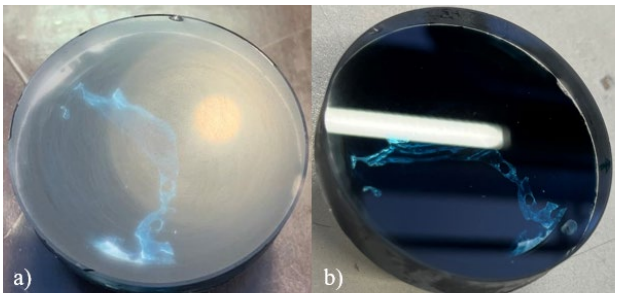

Fig. 4. N-BK7 sample, diameter of 40mm a) initial lapped surface (F600 SiC), roughness Rq = 500nm b) polished surface, Rq = 30 nm

4 Outlook and conclusion

Further investigations on additive manufactured cerium oxide polishing tools are planned. One approach is to convert the polishing powder into a filament to include well known techniques like FLM printing. This would enable complex 3D tool geometries, benefiting polishing of freeform optics or correcting polishing processes in addition to flat and spherical polishing processes. Similar attempts were successfully made for filaments containing diamond grains instead of polishing powder for fine-grinding processes of flat surfaces made of fused silica and N-BK7.[4]

In conclusion, cerium oxide polishing foils, a novel bonded grain kind of polishing pads, have been developed and successfully tested on N-BK7 samples during first experiments. Through the conversion from loose to bonded grain, those foils offer a promising alternative to conventional polishing pads for a wide range of polishing applications of brittle hard materials. The feasible applications in terms of diameter, smallest radii processable, long-term stability, shape durability as well as industrial applicability are currently under investigation.

References

1. J. Bliedtner: Optiktechnologie, ISBN 978-3-446-45850-5 (2022)
2. T. Suratwala: Materials Science and technology of Optical Fabrication, ISBN 9781119423775, DOI:10.1002/9781119423775 (2018)
3. G. Ghosh, A. Sidpara, P.P. Bandyopadhyay: Fabrication of Optical Components by Ultraprecision Finishing Processes, *Micro and Precision Manufacturing, Springer International Publishing, pp 87–119* (2018)
4. J. Bliedtner, S. Henkel, M. Knauf et al: Development and application of additive manufactured fine grinding tool for the processing of fused silica, *The European Physical Journal Conferences 287, DOI: 10.1051/epjconf/202328709016* (2023)