Tooling System for Diamond Turning of Hardened Steel Moulds with Apsheric or non Rotational Symmetrical Geometries

Fritz Klocke[1], Olaf Dambon[1], Benjamin Bulla[2]
[1]*Fraunhofer IPT, Germany*
[2]*Son-x GmbH*

benjamin.bulla@ipt.fraunhofer.de

Abstract

The direct machining of hardened steel, conventionally not possible due to high tool wear, can be enabled by applying an ultrasonic assisted process. In this publication a unique system, working with a frequency of 80 kHz will be applied to manufacture industrially relevant geometries in order to prove the potential of the process.

1 Introduction

Ultra precise moulds with optical surface qualities and complex shaped geometries are required for modern optics fabrication e.g. in plastic injection molding or precision glass molding processes.

Nowadays optical molds for injection molding are made of steel and coated with a nickel layer, in order to be able to machine the surface with diamond tools. Directly machining the steel parts would decrease the total production time of the mold, making the coating step unnecessary. Besides, the hardness and the durability of the moulds can be significantly increased. Therefore the potential and benefit of directly machining steel with single crystal diamonds is exceptionally high.

Diamond machining is conventionally limited to non ferrous, a few crystalline and plastic materials. The affinity between the carbon (diamond) and the iron (work piece) leads to excessive tool wear in conventional machining of steel. The ultrasonic assisted technology enables the direct manufacturing of steel components with single crystal diamond tools [3]. This technology has been investigated over years within the Fraunhofer IPT and has proven its potential [1,2]. The results of the manufacturing of two aspherical steel molds and one large spherical mold will be presented in the following in order to demonstrate the high potential of the system. The applied system works with a unique frequency of 80 kHz reaching never before achieved accuracies and surface qualities.

2 Manufacturing of Steel Molds

For the presented experiments one large sphere applicable for illumination optics and sun glasses and two aspherical geometries applicable for micro optics, such as cameras were defined in order to prove the feasibility of manufacturing geometries directly into steel applying ultrasonic assisted diamond turning (Figure 1).

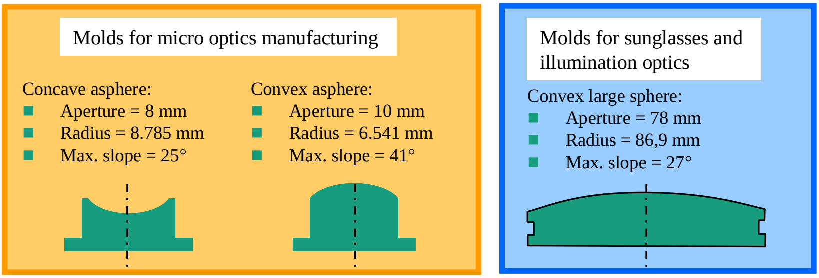

Figure 1: Specifications of the geometries, two aspheres (l.) and one large sphere (r.)

2.1 Aspherical steel molds

The aspheres were manufactured by ultrasonic assisted diamond machining in hardened steel (53HRC). The convex mold had an aperture of 8 mm with a depth (sag) of approximately 1 mm and a maximum slope of 25 degree. The convex mold has an aperture of 10 mm and a height of approximately 4 mm. The maximum slope of this curve is approximately 41 degree. The geometries were derived from a commercial plastic optic. The desired form accuracy is P V < 300 nm and a surface roughness of Ra < 10 nm for each mold.

Figure 2 shows the geometry of the manufactured aspherical parts (left) and the form accuracy (right) that could be achieved applying the ultrasonic assisted process. The shape accuracy that was reached was under P-V < 150 nm for the concave mold and P-V < 210 nm for the convex mold, which was beyond the initial goal. This high accuracy was reached through an iterative process applying an on machine measurement and correction system (Moore Nanotech 350 FG with WEC). Also an optical surface roughness of Ra = 4 to8 nm could be achieved. Six iteration steps were required respectively in order to reach the high accuracies demanded in this application.

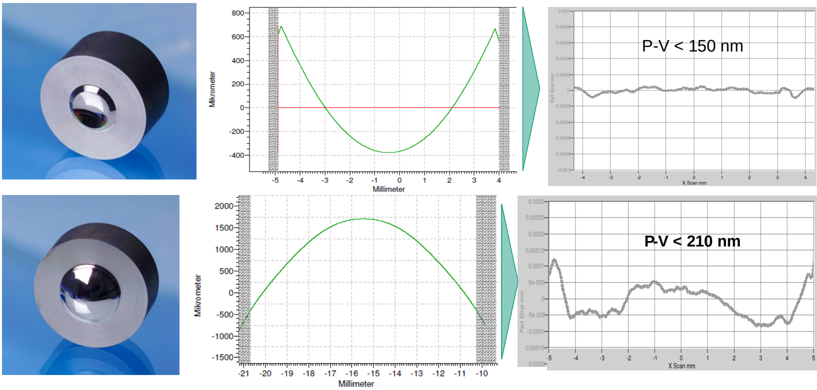

Figure 2: Aspheres shape (l.) and the reached shape accuracy (r.)

Besides the form accuracy and the surface quality, the diamond tool wear is of interest. The tool that was used for the pre machining and for the fine machining operation is shown in Figure 3. No tool wear can be detected under the SEM after the required overruns.

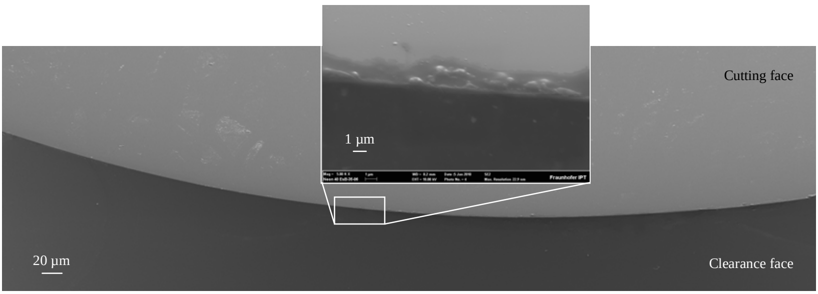

Figure 3: Single crystal diamond tool used for the pre and finish machining of concave steel asphere applying ultrasonic vibration

2.2 Large spherical steel mold

The large sphere with a diameter of 75 mm (~3 inch) was also machined in Stavax ESU with a hardness of 53 HRC applying ultrasonic assisted diamond turning. The average surface roughness that could be reached was Ra = 5 nm. The shape accuracy of the part was P V < 1.5 µm. Therefore the general objective regarding the surface and shape quality was also fulfilled. A surface roughness measurement can be seen in Figure 5 (right). On the left side the large mold is shown in comparison to the smaller aspherical molds. Though the size is much larger, the achieved quality is equal.

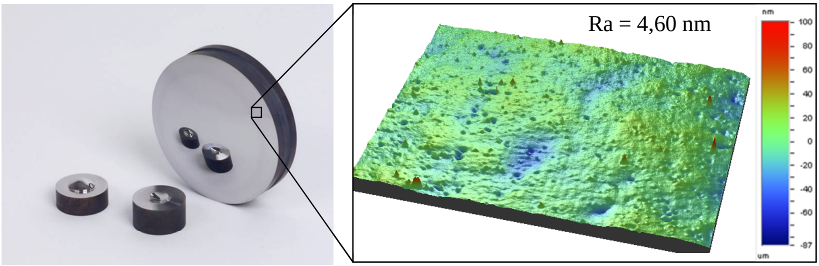

Figure 5: Diameter 75 mm mold (l.) and the surface topography of the mold (r.)

3 Summary and Conclusion

The desired shape accuracies and surface roughness values were easily reached on both aspherical geometries and on the large spherical mold. This demonstrates the capabilities of this new technology and opens the door for this technique to compete with established manufacturing processes, such as the manufacturing of nickel plated mold inserts. The ultrasonic diamond machining with 80kHz enhances several advantages, high flexibility, faster production time, stronger mold inserts, etc. and will therefore strongly improve and establish its future position on the market as a manufacturing technology for optical molds. The application of this technology on a Slow-Tool-Servo process in order to create non rotational symmetrical geometries is still being investigated. The system is commercialized through the company Son-x.

References:

[1] Klocke, F.; Dambon, O.; Bulla, B. Direct diamond turning of aspheric steel molds in ultra precise accuracy, 25th ASPE Annual Meeting, Atlanta, USA 2010

[2] Klocke, F., Dambon, O., Heselhaus, M., Bulla, B., Ultrasonic Assisted Diamond Turning of Hardened Steel for Optical Mould Manufacturing, EOS, Munich 2009

[3] Moriwaki, T.; Shamoto, E.: Ultraprecision Diamond Turning of Stainless Steel by Applying Ultrasonic Vibration, Annals of the CIRP Volume 40/1/1991