euspen's 16th International Conference &
Exhibition, Nottingham, UK, May 2016
www.euspen.eu

Diamond machining of AM metal parts with high-build eNiP-layers on complex free form shapes

L. Autschbach [1], D. Ewert [1], M. Schüle[1], C. Niederle [1]

[1]*Carl Zeiss Jena GmbH, Oberkochen, Germany*

lutz.autschbach@zeiss.com

Abstract
The worldwide optic market is a fast growing one. More and more optic designs change from standard optics with a few spheres to very complex free from shapes. In this way optics can be either adapted to special needs like illuminating distinct areas, or stark reductions of installation space can be achieved, like in optics for mobile devices. These optics often have to be high-end as well as high volume. The solution usually is found in complex plastic optics with form accuracies < 5 µm and roughness < 3 nm. One typical process chain for such mass production is injection moulding using ultra precision machined metal moulds. Today such process chains are characterized by classical material removing mould production steps like milling, grinding, polishing e.g. of block material. Challenges are often the implementation of cooling channels, embedded structures and installation of sensors etc.
To overcome challenges of functional integration e.g. activities were started in additive manufacturing of metal parts as well as plating of high-build eNiP-layers with thicknesses > 500 µm. With respect to first positive results these activities were extended to achieve best effort curvatures etc. The actual results are showing the potential of this process chain and production solution provided from one source.

Keywords: high-build eNiP-layer, additive manufacturing, diamond machining, free forms, alternative process chain, one supplier solution

1. Introduction

The markets for high-end as well as for high volume optics and opto-electronics are strongly increasing. Typical for these markets are complex plastic optics with surface geometries like regular spheres, aspheres, cylinders as well as free forms and/or microstructures. One process chain for mass production of these optics is injection moulding. Ultra precision diamond machined metal moulds made of nickel-phosphorous (NiP) plated steel are typically used. Today such process chains are well known and characterized by classical material removing mould production steps like milling, grinding, polishing e.g. of block material. Additive manufacturing (AM) could be an alternative process chain for generating moulds. On the one hand AM opens the possibilities for new designs, functional integration etc. – on the other hand it is questionable if AM is able to generate semi-manufactured surfaces in acceptable quality, low enough porosity, high stability e.g. and if plating with NiP for a later diamond machining is possible. The goal was to develop and establish these process chains for a variety of customer markets and achieve a one supplier solution at Zeiss for in-house projects as well as for external customers.

2. Additive manufacturing

Additive manufacturing started in the 1980s as "a system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed", based on the technology of inkjet printer heads [1]. Laser-melting / -sintering of metals and the development of STL (stereolithography) file-formats were pursued in the following decades and were just recently established as consumer friendly machine solutions. Around 2005 industrial production started to focus more and more on AM also.

AM-knowledge level varies depending on the different markets and products. For medicine technology and tooling AM is in the status of full-rate production, followed by aerospace and automotive, where first demonstrators are published. But for optics industry AM is just starting to be evaluated. According to market research AM expertise here is just at the level of technical validation for jigs and adapters, optics themselves are only at basic concepts (see figure 1).

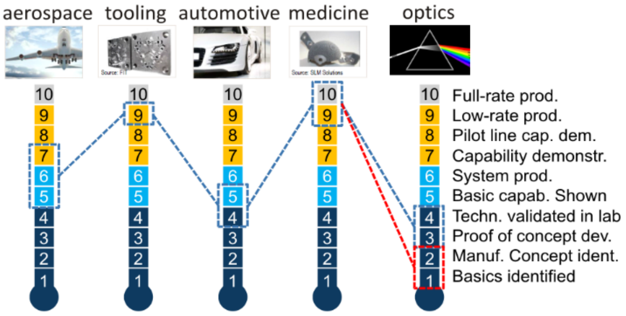

Figure 1. AM-level for different industrial markets [2,4]. The list to the right shows a short description of each level, the graph to the left shows the evaluation where the different markets stand.

For this project the focus was on 3D printing / SLM (selective laser melting) of new metal mould generations. For this pursue the design and construction of the moulds had to be adapted, new software solutions and measurement technology were involved, e.g. CT-technology as well as reverse-engineering software. The starting point was to provide a new AM laboratory considering e.g. fire / explosion protection when dealing with heated metal powder. Figure 2 shows the laboratory with a metal printer as well as a platform with additive manufactured test parts on it. These parts were used for identifying mechanical strength properties, porosity values e.g.


Figure 2. AM-lab at Zeiss and platform with additive manufactured test parts.

With the knowledge of found material characteristics mould geometries were (re-) designed. First tests were done to develop inner and outer structures for realisation of adapted stiffness as well as joining conventional constructed moulding parts. With these new cooling channel geometries and layouts it was for example possible to eliminate process steps like hard-soldering of separate machined parts.

Figure 3 shows additive manufactured moulds and structures. The achievable porosity with < 0.2 % was less than in conventional metal parts, which is an important requirement for homogeneous plating later on. Structures were melted to thin walls or rods down to only a few layer thicknesses. The minimum achieved diameter in a lattice structure of Inconel steel was < 0.3 mm.

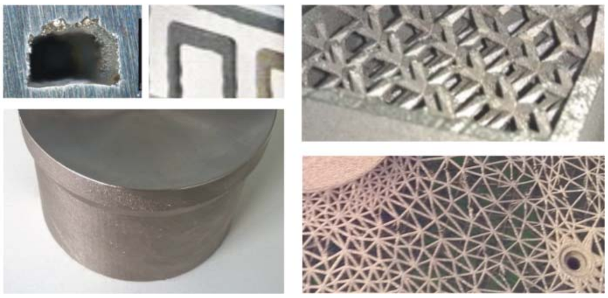
Figure 3. Additive manufactured mould (left bottom), cooling channels (left top) and examples of possible inner (right top) and outer (right bottom) structures.

3. Mould preparing and plating of high-build eNiP-layer

The positive results in additive manufacturing of the metal moulds with their low porosity e.g. laid the basis for a new process chain. The next evaluated process steps considered the machinability with respect to achievable quality of fittings, surface roughness as well as the dependency / interaction on AM layer orientations e.g. Milling and turning of the AM generated moulds with (typical) conventional well known process parameters and cutting tools were investigated and qualities in the typical IT-classes were achieved without any problems.

Last step before finishing the optical relevant surfaces with diamond machining was plating with electroless nickel-phosphorous-layers (eNip). In the past several mould manufacturers tried to plate AM generated moulds but failed generally on issues often resulting from binding materials, high porosity e.g. With the new laser melting machines, metal powders and process strategies positive results in eNiP-plating were achieved. Important for this success was the development of the correct boundary phase and low plating rates of only a few microns per hour to avoid stress. In particular for plating of a high-build layer with several hundreds of microns a low and homogeneous stress-level was vital.

Typical layer thickness for eNiP-plating is starting from 10 µm up to 300 µm. In this project layer thicknesses close to 1 mm were achieved. The challenge to reach the maximum thickness is the controlling of the plating process during the long process time, often it has to be manually monitored at times.

4. Diamond machining of free forms and structures

Diamond machining of non-ferrous metals like eNiP is in general well known and an established process for years [3,4]. The challenges in machining free forms are the details of the processes, starting from the data handling, the needed high-end quality of the monocrystalline diamond tools, the setup, ultra precision-machining strategies as well as metrology. For complex shapes and (structured) free forms e.g. here multi-axes planning and fly-cutting were used. An example for circumferential milling of a mould with a discontinuous free form is shown in Figure 4. The tool path is generated by using different software CAD-CAM solutions while every single intersection point of the tool was programmed. As for the monocrystalline diamond tools only tools with a controlled waviness of the cutting edge < 50 nm were accepted. Machining strategies were varying using several pre- and finish cuts depending on the curvatures. The machining time was up to several days per surface and planning was the most time consuming process. Form accuracies < 1 µm and roughness < 20 nm Rq at a calculated Rtkin < 2 nm were achieved for the mentioned process chains.

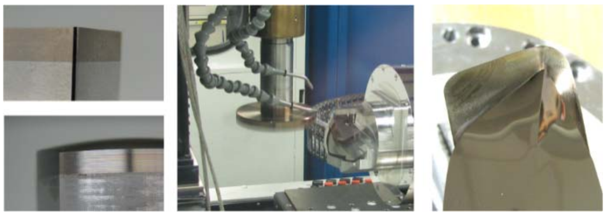
Figure 4. Steel moulds with high-build eNiP-layer, up-fly cut setup and up-machined structured free form

5. Summary and conclusion

The focus of this work was the manufacturing of complex metal parts for injection moulding in optical quality. The work includes investigations in additive manufacturing, high-build eNiP-plating in combination with diamond machining. The actual results are showing the potential of this process chain and production solution provided from one source as one supplier solution for in-house projects as well as for external customers.

Further AM-work will focus on other metal powders, new design-strategies for adapted moulds as well as process combination of additive and material removing machining setups. Besides the AM-supported process chains of metal adapter / optics also investigations in new AM-process chains for plastic optics are planned, for glass optics AM solutions might be forthcoming within the next 5 years.

References

[1] Hull, Charles W. (Chuck): 3D Systems, 1984
[2] Langenfeldt Dr. Bernhard: Industrialization of Additive manufacturing – Key success factors for serial production, Vortrag Euroforum-Konferenz “Industrielles 3D-Drucken”, Stuttgart, 2014
[3] Photonics in Germany, 2015, ISSN 2191-7191
[4] Wohlers Report: www.wohlersassociates.com/2015report.htm