Potentials and challenges of additive manufacturing using highly transparent silicone materials

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The research in additive manufacturing using highly transparent silicone for optical applications is still in its early stages. This contribution is aiming to investigate potentials and challenges in additive manufacturing using silicone and to identify a suitable manufacturing concept to fabricate highly transparent optical elements.

1 Motivation

While additive manufacturing technologies for conventional polymers have been industrially available for many years, additive manufacturing with silicone materials is still under development [1]. For the design of optical elements, additive manufacturing offers a great potential to produce individually adapted freeform optics with high design complexity. In this paper the potentials and challenges, as well as a possible technical concept for the additive manufacturing of optical elements with highly transparent silicone materials will be shown.

2 Potentials

Additive manufacturing is suitable to produce complex and cost efficient freeform geometries. Due to its high adaptability and short process time, additive manufacturing is suitable for rapid prototyping of optical elements [3]. For additive manufacturing of transmissive optical elements mainly thermoplastic polymers are used [1]. In comparison silicone materials show a high resistance to UV, environmental and temperature influences, which allows the application as transmissive optics in vehicle headlights. Due to the widespread use of highly transparent silicones in the fabrication of optical elements, a wide range of materials with varying optical properties is available. A further advantage is the reversible deformability of silicone materials. Combined with the possibility of functional integration that comes with the additive manufacturing process, this enables production of adaptive optics with a high degree of design freedom [4]. In addition, due to their biocompatibility, specific silicones can be applied in the field of biomedical engineering.

3 Challenges

The challenges in additive manufacturing of optical elements can be divided into three categories, which are geometry, volume and surface.

Geometry

The main points that influence the macroscopic geometry of the optical elements are resolution, shape accuracy and tolerances. In order to fulfill the function of the optical element, the most accurate reproduction of the ideal geometry is required. Particularly for imaging optical elements, deviations in the micrometer range can lead to severe impairment of functionality and performance. Even for non-imaging illumination optics, the most exact reproduction of the calculated geometry is necessary.

Volume

At inclusions, inhomogeneities and interface layers of the optical element, scattering, reflections and interferences can occur which impair the optical function and reduce the transmission [2]. To improve the optical function, the occurrence of these volumetric effects must be reduced.

Surface

The achievable surface roughness of the manufacturing processes is of high relevance for the production of optical elements, since especially reflections and scattering must be reduced to assure a high transmission rate. The production of complex geometries requires the use of support structures in most processes. These support structures must be removed mechanically in the post-process, which leads to a reduction of surface quality. The layer-by-layer build-up of additive manufacturing processes leads to the staircasing effect shown in Fig. 1, which results in a deviation from the ideal geometry.

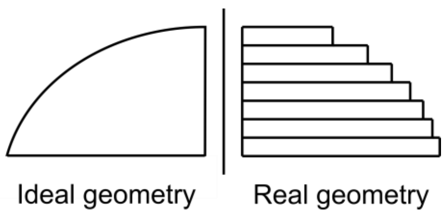

Fig. 1 *Staircasing-effect in additive manufacturing*

4 Manufacturing concept

The depicted challenges within the additive manufacturing of optical components shall be addressed with the development of a suitable manufacturing concept. Material extrusion, material jetting, photopolymerization and freeform-reversible-embedding (FRE) can be used for additive manufacturing with silicone materials [5]. Of these processes, only the FRE process offers the possibility of manufacturing complex geometries without support structures, which ensures low post-processing efforts and smooth surfaces [5,6]. The confirmed minimal resolution of the FRE process is 30 µm in lateral and 100 µm in vertical direction. The planned FRE machine concept is shown in Fig. 2. A UV-curable silicone is injected into a support material by using a thin injection needle. Afterwards the silicone is cured using a UV radiating light source.

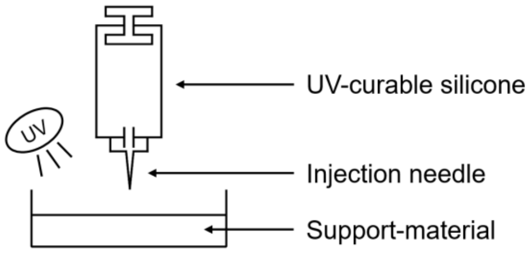

Fig. 2 *Freeform-Reversible-Embedding principle*

In order to avoid rough surfaces caused by the staircasing-effect shown in Fig. 1, the parts to be manufactured are not sliced along the Z-axis. As shown in Fig. 3, the non-planar slicing is optimized for achieving the best surface quality [3].

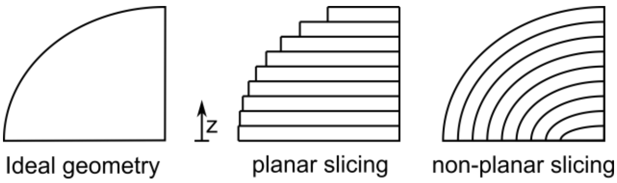

Fig. 3 *Planar and non-planar slicing methods*

Slicing can be adjusted according to the optical function of the component so that interface effects and interference phenomena can be reduced [3]. Since non-planar slicing requires the print head to be in a lower z-position than the already printed silicone material, it is necessary that the print head can be tilted as shown in Fig. 4 to prevent collisions.

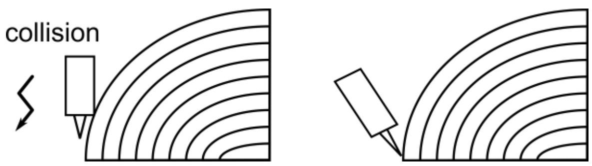

Fig. 4 *Collision of printing head with printed material*

5 Conclusion

In this paper we presented the potentials of additive manufacturing with highly transparent silicone materials for the fabrication of optical elements. Approaches to solve the general challenges in additive manufacturing of optical elements described in section 3 were demonstrated. The proposed process enables the additive manufacturing of optical elements with a high resolution and fast printing speed. Since no support structures are required, a significantly better surface quality can be achieved without any post-processing. Non-planar slicing, combined with the ability to tilt the injection needle prevent the staircase effect, which drastically improves surface quality and also enable to control the orientation of the interface layers in the optical element.

6 Acknowledgement

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