3D Inkjet Printing of Optics

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Abstract

Established additive manufacturing technologies such as Fused Deposition Modeling (FDM), stereo lithography (SLA) and Polyjet are commonly used in the creation of functional 3D prototypes. The disadvantage of these technologies is the formation of visible layering, which only can be removed by labor intensive technique such as polishing.

We have developed an inkjet based process that is able to 3D print fully transparent products with high smoothness. No post-processing is required, which makes the technology suitable for rapid manufacturing and small series production of optics.

In this paper we provide an overview of the manufacturing process in general, as well as some technical details of the inkjet printer and optical material.

Introduction

Manufacturing techniques such as diamond turning, milling, injection molding and extrusion are commonly used for optics production. The complexity in design geometry and order size are leading factors in the choice of manufacturing technology. For example, optics manufactured by injection molding are often of low complexity, but require a high amount of parts to be cost effective. On the other hand, high complexity optics are often diamond turned. This can be very expensive, so it is only used for low volume series.

Additive manufacturing or 3D printing is very suitable for prototyping complex parts. However, typical 3D printed products are not transparent and have an extremely high surface roughness. Moreover, the typical production rate of these products is very low, so high volume manufacturing is not possible.

Luxexcel has developed a 3D inkjet printer that produces smooth and transparent polymer optics, which do not require any post-processing after manufacturing. As the printer is based on inkjet technology, the complexity of the design can be very high and the productivity of the system can be scaled up with relative ease.

The core competence and knowhow of Luxexcel is the specification and development of inkjet based 3D printing systems. These systems require unique system configurations, custom made materials, unorthodox print methods and dedicated software development tools, which ultimately results in the possibility to 3D print complex optics at a high throughput.

From 3d design to product

3d design & image processing

The production process starts with a digital 3D design. The design needs to be inspected to make sure the product can be printed. Typical inspections are dimensions, shape complexity, wall thickness, manifold errors and absence of overhanging structures. Most of these checks can be done with the support of automatic software tools, but manual inspection is often required.

If the design is theoretically suitable to be printed, the 3D file will be nested with other customer designs onto a single build platform. The designs will then be sliced into several thousands of image files, depending on the height of the object. The thickness of the layers is variable however and may be adjusted to the specific product design requirements. Typically the layer thickness is between 5 and 15 µm.

Depending on the shape and complexity of the product, the image files can be manipulated to improve print quality. Ongoing research has shown thus far that this method of compensation is required to print optical components that are either very small or have very high complexity.

Together with the image file, a data file is generated which contains the processing information of the print job. The specific processing settings are dependent on the requirements of the printed product. Typical product parameters that are tuned are surface smoothness, shape accuracy, light transmission and printer productivity for large quantity orders.

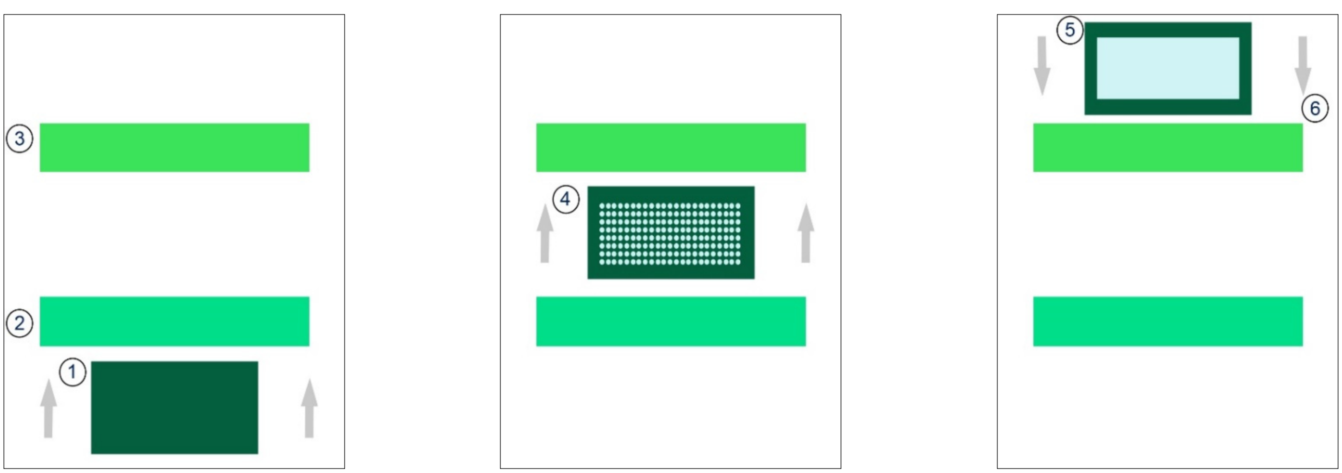

Figure 1: *General overview of the 3D printing process*

Figure 2: *Example of 3D printed optics*

Printing process

The general 3D printing process is illustrated in figure 1. A substrate is placed on the vacuum stage (1) and is transported under multiple industrial print heads (2). Millions of droplets of UV-curable fluid are jetted (4) on the substrate material and cured within (milli) seconds to a solid layer (5) using UV radiation (3). The next layer of material will be deposited on the previous layer of material (6). This process will be repeated layer by layer until a smooth 3D object is manufactured. Lastly, the printed material is removed from the substrate material. Product examples are shown in figure 2.

Quality control

The huge advantage of 3D printing is the freedom in product design. From a technical perspective this can be problematic, as it is inevitable that some parts may have geometries that prove difficult to manufacture. To make sure the parts have the dimensional tolerances required by our customers, the printed optics are scanned using an ATOS triple scan system from GOM Metrology.

Before the samples may be scanned, a thin coating of titanium dioxide is applied using an airbrush. This is required for the measurement method, because blue light is projected on the part and needs to be reflected into the camera system. The sample is tilted and rotated during measurement to make sure the full geometry of the part is digitized.

As a final step the digitized part is compared with the original 3D design. Standardized metrology methods are used to identify any geometric deviations (figure 3). If the quality check is within tolerance, the products that haven't been scanned can be shipped to the customer. A typical time between order placement and delivery of the parts is 5 working days.

Printing process in detail

Printer

Two single pass inkjet 3D printers are currently available at Luxexcel. The systems are designed to give a high motion system accuracy (±3µm) at high printing speed (1000mm/sec), in combination with possibility to change print heads, UV sources and printing methods relativity easily. There are several compensation methods built into the printer to compensate for missing nozzles and droplet volume variations. Both systems have a very similar process window, but each system is used for a different purpose.

The first printer has a small build platform of 60x60x80 mm and contains multiple industrial piezo print heads. The system is exclusively used for research and development. This system has been designed specifically to accelerate process optimizations and implementation of new printing materials. In some cases it is also used to print complex optical parts that have proven to be difficult to manufacture under standard processing conditions.

The second printer has a build envelope of 400x200x80 mm and is a scaled up version of the research and development printer. As the typical build speed is about 10 to 20mm print height per hour, the ink throughput can be as high as 1.5 liter ink per hour. This allows for extremely high productivity in comparison with other 3D printing systems. For example, 250 products of 20x20x5mm can be printed per hour.

Material

The OPTICLEAR material currently used in the printing process is based on the principle of radical polymerization of acrylate monomers using UV radiation. Typical UV curable ink jet fluids would consist of a variety of acrylate monomers and oligomers, combined with a variation of photo-initiators and additives.

Acrylate monomers are commonly used in inkjet processes, due to their low viscosity and potentially high reactivity. As there is a large variety of monomers available, the material properties before and after curing can be tailored to the requirements of the process and application of the products.

Figure 3: *Design (left), measured 3D optic (middle), deviation from geometry (right)*

From a liquid state perspective, the OPTICLEAR material has been optimized to give excellent and stable droplet formation at high jetting frequency with a low droplet volume. High boiling point monomers have been used to limit evaporation, allowing for stable jetting performance, even after multiple hours of downtime. From a solid state perspective, the monomers were selected to give a high visible light transmission, optical stability at elevated temperatures, high mechanical strength and a very low surface tack.

Another important part to consider in the formulation process is the selection of photo-initiator types and concentration. Multiple variations of the OPTICLEAR material have been developed to match different lamp configurations and therefore different emission spectra and curing speed requirements in the process.

As mentioned before, after printing the material is removed from the substrate. This was one of the most difficult parameters to optimize during the ink formulation, as the adhesion of the printed material to the substrate had to be perfect. More specifically, if there is too much adhesion, the part could not be removed from the substrate. On the other hand, if there is too less adhesion, the part would release from the substrate during printing, due to the high printing velocity.

Conclusion

It is possible to manufacture smooth and transparent polymer optics using inkjet technology. Our unique combination between machine, material and software allows for very high productivity and removes the need for post processing such as sanding and polishing.

Biography

Ricardo Blomaard has received his BS in chemistry at the HZ University of Applied Science in 2012 and joined Luxexcel in the same year. His work is focused on the development of optical materials and optimization of printing processes.

Joris Biskop has been at Luxexcel for 5 years, where for the last two years he has been the CTO. He brought two generations of inkjet printers to market and led pioneer work in optimizing acrylic materials for use in inkjet technology. He's the author and inventor on 5 patents.