Comparison of Additive Manufacturing techniques regarding mechanical and optical properties

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This article examines whether optical and mechanical components can be additively manufactured with net shape properties. Furthermore various Additive Manufacturing techniques are investigated regarding the suitability for an integrated process. Hence, the possibility of producing multimaterial components and optomechanical systems without the necessity for assembly and adjustment is evaluated.

1 Introduction

With focus on optical technologies, Additive Manufacturing is especially used for manufacturing optomechatronics [1]. However, the scope of application extends mainly to individual components based on polymers and partial researches regarding glass materials [2]. Most of the optical components, which are additively manufactured, have to be reworked in a post-process in order to fulfil the requirements [3]. These additional steps preclude the production of optomechanical systems in a single process. The assembly and adjustment effort cannot be minimized accordingly. In order to quantify the post-processing effort, the properties of the additively manufactured components has to be known and may already be sufficient depending on the application.

This paper describes which mechanical and optical properties can be achieved without post-processing an additive manufactured component. Therefore, different demonstrators are manufactured using various commercial systems and are compared afterwards. Statements are summarized whether unprocessed components are suitable for mechanical and optical functions, and whether optomechanical systems can be realized with Additive Manufacturing in one process.

2 Evaluated Additive Manufacturing techniques

In order to compare materials from one material class, technologies for processing polymers are considered. The associated processes of Additive Manufacturing are Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Stereolithography (SLA) and Poly-Jet Modelling (PJM). Since the technologies process different polymers in different initial states - here powder and polymer bath - a comparison of the properties is only plausible to a certain extent. With the exception of Selective Laser Sintering, only transparent materials are investigated as a trade-off. Following the mechanical properties such as tensile strength, Brinell hardness and optical properties are analysed.

3 Measurement setup

The analysis of the mechanical properties were carried out by means of the standards DIN 50125 (tensile strength) and ISO 6506 (Brinell hardness), whereby the sample geometries were designed accordingly. The optical properties transmittance and reflectivity were identified via plane-parallel plates. The plates were positioned at a 45° angle to the beam path. The beam path is thus split into a transmitted and reflected section and each is measured simultaneously with spectrometers. The light source is a white light LED that covers most of the visible spectrum, which is used for a wide range of applications for illumination optics.

4 Results

Regarding the mechanical properties components manufactured with PJM have the highest tensile strength and Brinell hardness (see figure 1). Furthermore, PJM offers the lowest standard deviation and thus the best reproducibility of the results.

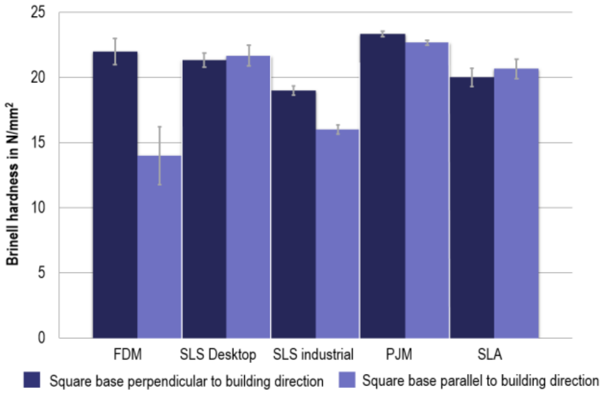

Fig. 1: Brinell hardness of additively manufactured polymer components for different building directions

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It is also notable that the building direction has no effect on the Brinell hardness as long as it is manufactured with PJM. The same applies to the tensile strength values at which the PJM components also performs best. However, the building direction gains a significant influence on these values.

The measurements of the optical properties show that the transmittance values vary considerably based on the manufacturing process. PJM achieves the best results with a minimum of 26% at 440 nm. The transmission increases significantly for larger wavelengths and reaches values above 50%. Figure 2 shows this behaviour in comparison to differently manufactured plane-parallel plates (*d*=0.5 mm) whose transmission values are below 5%.

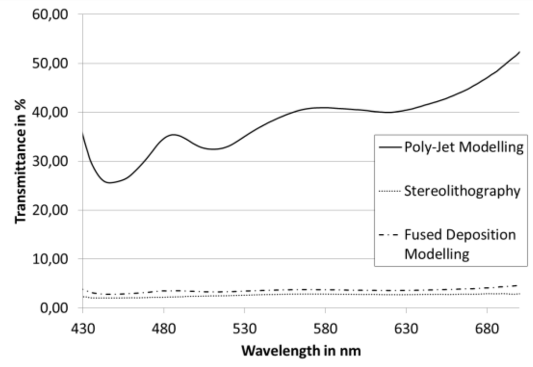
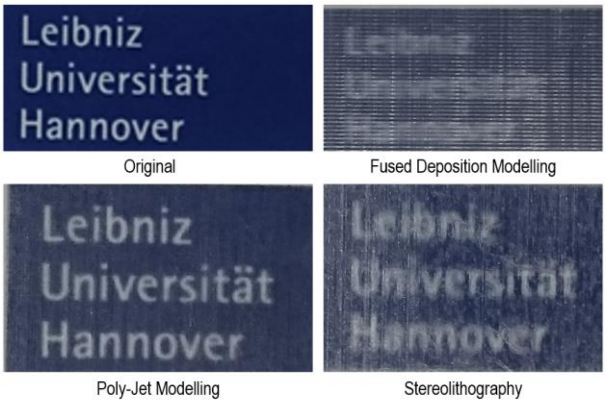


Fig. 2: Transmittance of plane-parallel plates (thickness 0.5 mm) for three different Additive Manufacturing techniques

The fact that the transmission is somewhat defined by the manufacturing processes can be seen in figure 3.



Original

Fused Deposition Modelling

Poly-Jet Modelling

Stereolithography

Fig. 3: Comparison of different transparent samples and their imaging quality

For FDM, a layered structure remains visible. With SLA, many inhomogeneities arise, which in particular affect the surface. With PJM, the material was processed most homogeneously.

5 Discussion

For the mechanical and optical properties can be concluded that components manufacturing with PJM have the highest quality features. Regardless of the direction in which the components are manufactured, the lowest standard deviations for mechanical properties are achieved, which leads to the greatest repetition accuracy. These properties approximately reflect the literature values as solid material. Therefore most of the additively manufactured components can be used for mechanical purposes.

Such a general statement cannot be given for the analysis of the optical properties. The differences between the transmittance and reflectivity values are clear. Based on Figure 3, it can be assumed that processes with liquid starting material can generate optically more homogeneous components, since the layer structure can be clearly seen in FDM. In contrast to PJM, SLA components should be positioned obliquely in the building space in order to achieve better results. Nevertheless, impurities on the surface are to be expected.

However, especially with regards to the optical properties, the components do not offer sufficient quality to be used for precise, high-efficiency imaging optics. Post-processing techniques like grinding and polishing can be used in order to remove surface structures and hence reduce the scattering on the surface. Regarding optics for pure illumination applications, PJM can already offer a solution without post-processing effort as long as the efficiency of the system represents no priority.

6 Outlook

Additive Manufacturing processes require extensive optimization, especially with regard to the optical properties of the manufactured components. However, the manufacturing processes themselves are bound to physical limits, which are associated with topology and homogeneity of the components. Integrated post-processing techniques can provide the necessary optical quality for lenses, waveguides, etc. in one process, thereby enabling the fabrication of optical systems.

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