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Laser powder bed fusion of high-density glass

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Abstract

Glass as a material poses a challenge for laser powder bed fusion (L-PBF) due to the comparably high viscosity even at high temperatures and low absorption for laser wavelengths in the visible and near infrared spectrum. As its superb optical properties, low thermal and electrical conductivity and chemical properties makes it desirably for various applications, several alternative approaches were developed for making the additive manufacturing of glass feasible. Here we demonstrate the printing of glass parts obtaining densities above 99% directly from the powder bed without the need for thermal post processing by using suitable process parameters and heating of the powder bed. Although not completely free of bubbles, with the advantages of the L-PBF process, the realization of almost any desired geometry impossible to create with common molding or subtractive processes is within reach.

Keywords: Additive manufacturing; L-PBF; Glass; Density; Porosity; Soda Lime; CO2-Laser

1. Introduction

L-PBF of glass is a promising field of research, as glass possesses desirable material properties such as low thermal and electrical conductivity, chemical properties and good to superb optical properties for potential applications from free shape insulators, microfluidics [Kotz et al. 2018] to optical applications. This comes at the cost of a high viscosity which is typically several orders of magnitude higher than those of molten metal [Fluegel 2007]. This negatively affects the fusion and movement of the molten glass and results in low achieved relative density of parts produced [Seyfarth et al. 2020]. This limits the application due to a lack in stability, transparency and leak proofness. Even though there are alternative approaches to additive

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manufacturing of glass capable of producing dense, high-resolution parts [Kotz et al. 2017], this comes with the need of necessary thermal post processing. Here, we present the L-PBF of Soda Lime, a glass with a low glass transition temperature and a steep temperature dependence of the viscosity making it a promising material for investigations on the influence of various process parameters on the resulting density of the produced parts.

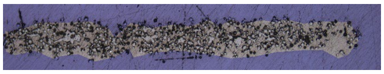
2. Experimental setup and material used

The experiments were realized using a semi-custom machine from Aconity3D. It is equipped with a CO2-Laser with a maximum laser power of 245 W which gets focused to a spot on the surface of the powder bed with a diameter of 650±20 µm. In the process chamber a flow of protective nitrogen gas is adjusted to ensure a well-defined process environment. The building platform was heated to 500 °C. As a material, spherical Soda Lime glass powder with a size distribution from 1 to 38 µm was used, a silica glass with fractions of 10…15% sodium oxide and calcium oxide each. The relatively low glass transition temperature of 560 °C and the low viscosity (compared to other glasses) leads to a good processability. The influence of the comparably high coefficient of thermal expansion and therefore the tendency to form cracks at strong temperature changes can be mitigated by using a preheated building platform mentioned above.

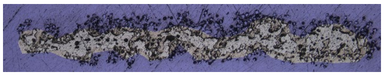
3. Results and Discussion

Parameter tests were performed by melting single walls with a layer height of 50µm and an overall height of 500µm. The samples were embedded upright in epoxy resin, grinded and polished and analyzed via light microscopy.

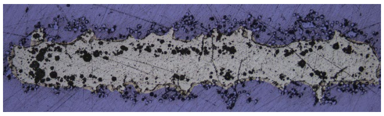
- For very low line energies (<40 J/m), the powder is loosely sintered together without significant melting. The instability of these lines leads to partial removal of particles due to the grinding and polishing.
- Increasing the line energy up to 80 J/m, a connected, molten track forms in the middle of the wall, increasing the overall stability. Nevertheless, the appearance is dominated by sintered particles at the periphery.
- A medium regime is characterized by stable, molten lines. A densification at the middle of the melt track is noticeable.
- For high line energies above 2000 J/m, the fluctuation of the width of the walls increases. The visible scratches are a result of residual powder particles which get released in the process of grinding and polishing.



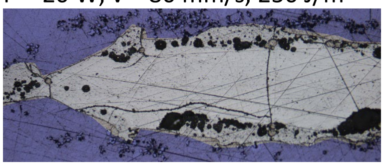
P = 14 W, v = 640 mm/s, 22 J/m



P = 7 W, v = 160 mm/s, 44 J/m



P = 20 W, v = 80 mm/s, 250 J/m



P = 56 W, v = 10 mm/s 500 µm

Fig. 1. Printed glass lines (white) embedded upright in epoxy resin (blueish) and grinded and polished afterwards.

Different regimes were identified as seen in Fig. 1, corresponding to the line energy which is defined as laser power divided by scanning speed. For all these walls, sintered powder remains at the periphery of the lines build.

In order to realize extended 3D structures, suitable parameter sets for two-dimensional parameter scans were derived from the line parameter tests and limited by the thermal load of the Soda Lime building platforms used. Produced samples were embedded upright in resin, grinded and polished afterwards and an analysis based on reflected light microscope images was performed. There, the brightness contrast between remolten glass and sintered particles and pores was used for determining the relative density respectively porosity of the samples. It was found that, especially the hatch distance between neighboring lines turned out to have a significant influence on the porosity respectively relative density of the parts produced, as shown in Fig. 2.

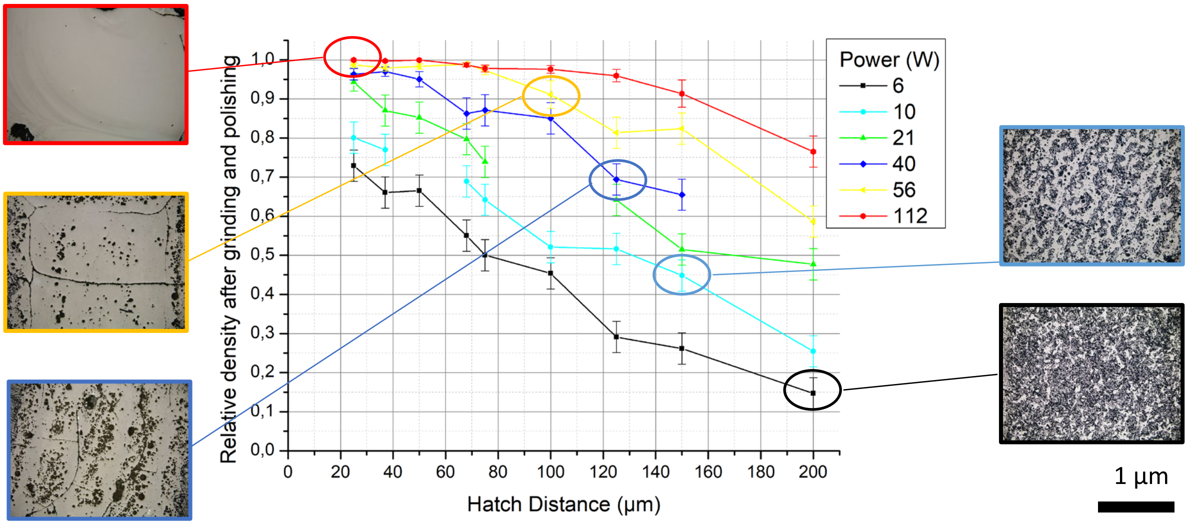


Fig. 2. Relative density of Soda Lime glass samples depending on the hatch distance and the laser power with exemplary reflected light microscope images. For hatch distances of 50 µm and below, relative densities of >99% respectively porosities of <1% are reached, with highest values >99,9%. The test samples have a size of 3x3 mm, were produced by a scanning speed of 320 mm/s and a layer height of 50 µm on a platform heated to 500°C. The samples were embedded upright in resin, grinded and polished and inspected via light microscopy.

4. Conclusion

In this work we presented the L-PBF of Soda Lime glass by variying the laser power, scanning speed and hatch distance while heating the powder bed up to 500°C. Soda Lime turned out to be a suitable and sensitive specimen for studying the influences of these process parameters with respect to the achievable relative densities. With the knowledge obtained from the experiments, glass samples with a relative density of >99,9% were produced without mechanical or thermal postprocessing. This is an important step towards increasing the stability, transparency and leak proofness of glasses shaped by the L-PBF-process.

References

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