Binder evaporation during powder sheet Additive Manufacturing

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Abstract

Several Additive Manufacturing methods are well established and found access into regular production in multiple sectors. For processing metals, typically wire or powder is used as feedstock. Wire processing is typically used for comparably large structure building, while powder processes offer, in general, a more precise metal application. For Powder Bed Fusion processes, very fine powder is used (typical 20 µm to 65 µm), while for Directed Energy Deposition powders are in the range between 50 µm and 160 µm. Such fine powders can be a health risk for humans (aspiration, skin integration). Avoiding contact with the powders in a production environment can be a big effort or not avoidable. Therefore, an alternative process was developed that provides the powder not as free powder particles but in form of powder sheets. For enabling the necessary bonding between the particles, a binder is used. In order to understand the impact of the binder during laser processing of the powder sheets, single pulse and line treatments were produced and recorded with high-speed imaging. Recordings show the vaporization of the binder and the related ejections of powder particles. At lower energy input, the binder evaporation led to less spattering, which indicates that a binder heating at low heating rates induces less pressure on the powder particles.

Keywords: Powder sheet processing, laser materials processing, vaporization, spatter

Introduction

Laser powder Additive Manufacturing (AM) is an establish technology used by many actors in industry. Most established is the Laser Powder Bed Fusion with a laser beam of metals (PBF-LB/M), where a laser melts pre-placed powder layer by layer to produce complex structures (e.g. a combustion chamber [1]). Another technology is the Directed Energy Deposition with a laser beam of metals (DED-LB/M), where the powder is applied through a powder nozzle with gas assist, while the laser beam produces the melt pool, in which the powder particles incorporate (e.g. [2], [3]). Also wire-based processes are established, which have the advantage of high build-up rates at minimum material loss but are typically more useful for larger structures (e.g. [4]).

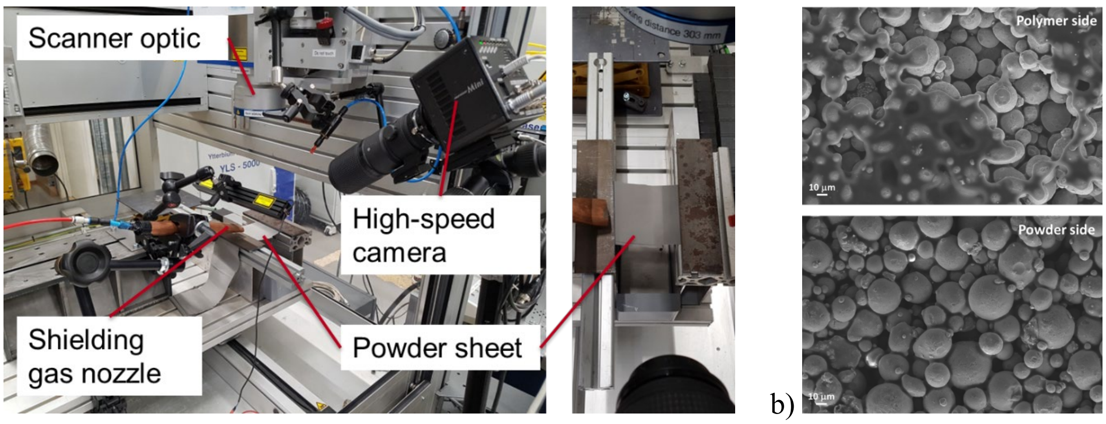
Powders for laser AM are typically in the size range of 20 µm and 65 µm for PBF-LB/M and 50 µm and 160 µm for DED-LB/M. Such fine powders are efficient to form the powder layers or to be fed through the feeding systems but denote a health risk for humans during handling or exposure. Aspiration of powders can lead to lung diseases and fine powder particles can even access the human body through skin pores. In particular in production facilities, it is required to make the necessary precautions for human safety and minimize human exposure to powder particles. However, handling requires human interaction and powder transfer in the air cannot be completely avoided. In order to reduce the exposure of metal particles to humans working in production facilities, a new approach is suggested in this work that promises limit extraction of loose powder.

Therefore, a new methodology was successfully tested, called MAPS (Metal Additive manufacturing using Powder Sheets) [5]. This approach includes the pre-production of powder sheets. Regular powder material of nearly any powder size distribution and shape is mixed with a polymer binder and formed with a metal-polymer-solvent mixed solution, which is poured on a flexible Teflon sheet. This is followed by the solvent evaporation from the mixture and the metal powder in conjunction with the polymer binder to solidify to form a flexible powder sheet. It is expected that the additional steps to incorporate powder particles into sheets will not significantly increase the powder prices, but significantly increase the production worker´s health. Processing with a laser beam in a similar way to PBF-LB/M processing allows to form layer-by-layer structures.

However, the process is not fully understood. In particular, the effect of the binder on the processing and metal transfer are unknown. Therefore, this work uses high-speed imaging in order to observe the laser interaction with the powder sheet in order to identify process characteristics.

Methodology

Powder sheets were produced using 304L stainless steel powder (Carpenter Additive, powder size of 15-45 µm) forming powder sheets of 137 µm thickness (Fig. 1b). From the powder sheet production, the lower sheet side shows a flat binder/polymer surface (here called binder side) and the upper side, which is rougher, dominated by the powder (here called powder side).
In order to process the powder sheets, a test setup (Fig.1a) was established using a scanner optics (Jenoptic) leading the laser beam from an IPG fiber laser (300W max power) to the free hanging powder sheet. The process zone was shielded by an Argon gas flow (18 L/min).



a) b)
Figure 1. a) Setup of the testing equipment and b) microscopic pictures of a powder sheet

For observation of the laser impact, a high-speed camera (Photron) including illumination (Cavitar) was installed. The camera was positioned in horizontal position for the pulse experiments and in a 45° angle for the processing experiments (Fig. 1a). The impact of processing parameters was analyzed by varying the laser power and processing speed. In addition, the processed powder side was varied.

Powder sheets, before and after laser-material interaction, were characterized by means of a Zeiss Sigma 500 field emission scanning electron microscope (FE-SEM) equipped with an Oxford Instruments Ultim Max detector for energy dispersive X-ray (EDS) analysis.

Results and Discussion

First, laser pulsing experiments were conducted by applying a 0.5 s pulse on different sides of the powder sheet. A pulsating vapor outflow to the top side was observed with a few small hot particle ejections. On the bottom side of the powder sheet, a vapor channel was established, which transports small powder particles and spatters in a more divergent way compared to the vapor stream (Fig. 2). Those tests show that a metal transfer should be possible with the ejected material, while the binder material vaporizes on the sheet top side.

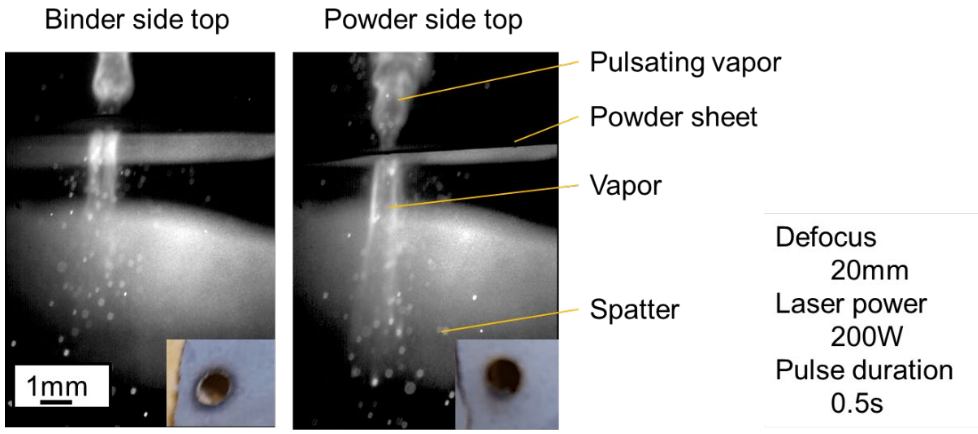


Figure 2. Representative high-speed frames of a pulsed laser impact on the powder sheet (horizontal camera position) and photograph of the powder sheet after processing

Micrographs acquired on the area subjected to laser pulsing experiments showed the formation of some deposits enriched in C and O on the bottom side of the powder sheet. These deposits are present in a region approximately 300 µm around the hole left by the laser pulse. The investigation about the exact composition of the layer is ongoing. Several samples gave similar results regardless of the processed powder sheet side. The origin of such deposits is under current investigations.

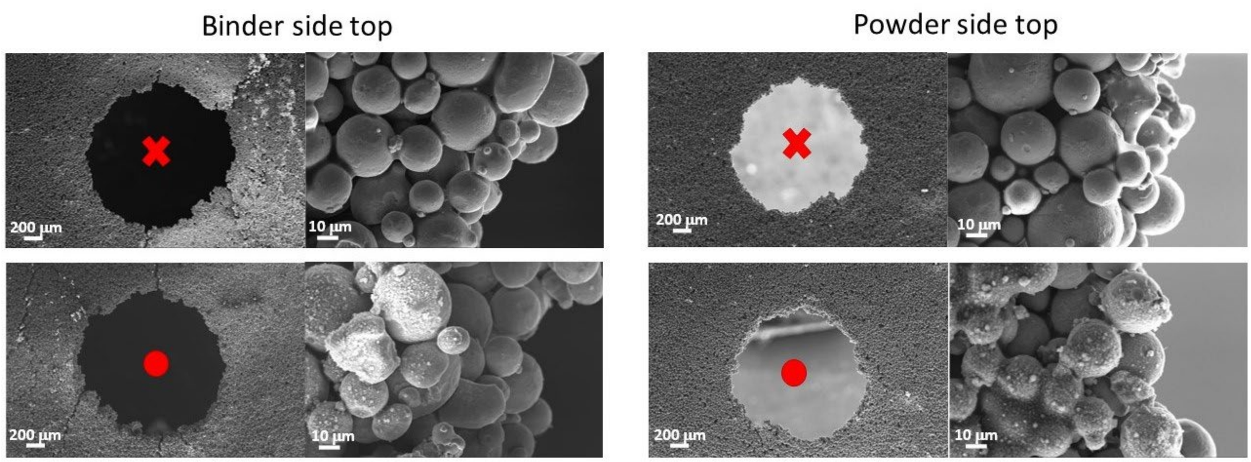


Figure 3. Representative micrographs of the sheet binder and powder side after the laser pulse. The red cross and dot on the micrographs indicate the direction of the laser beam. The cross marks the side on which the laser beam was impinging the sheet, while the dot indicates the side opposite to the laser impact.

When using line scanning on the free hanging powder sheets, different vapor and particle ejection behavior was observed (Fig. 4). When the powder side is on top, the vapor and spattering are more pronounced, indicating that the accumulated binder in the bottom part of the sheet expands and pushes powder particles upwards. In general, the vapor appearance is reduced at higher processing speeds as expected due to the lower energy input per time. However, the sheets were not completely molten, and no material was ejected to the bottom at too high speed, which indicates that the processing window has a limit towards energy input that needs to be reached to achieve the material transfer and an upper limit where extensive vaporization disturbs the processing due to spattering.

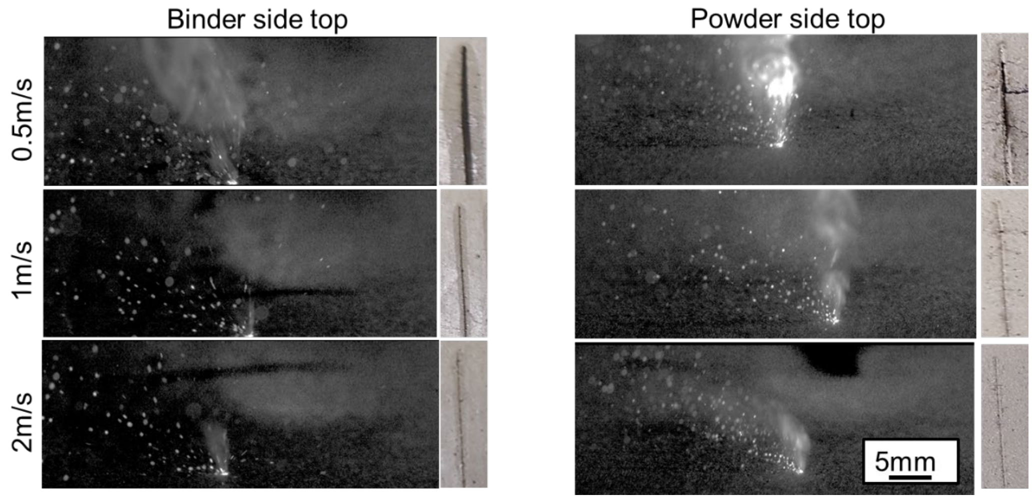


Figure 4. High-speed images and powder sheet appearances at different process conditions at 200W laser power

When processing the powder sheets with a base sheet underneath, the process was observed (Fig. 5). Since the vaporized binder cannot escape downwards, a more pronounced vapor upwards is established compared to the free hanging sheet results. More extensive spattering occurs at higher laser power. In general, it was observed that less spattering and vapor occurs at low energy input. At high laser power, material could be transferred to the base sheet forming an additively produced track.

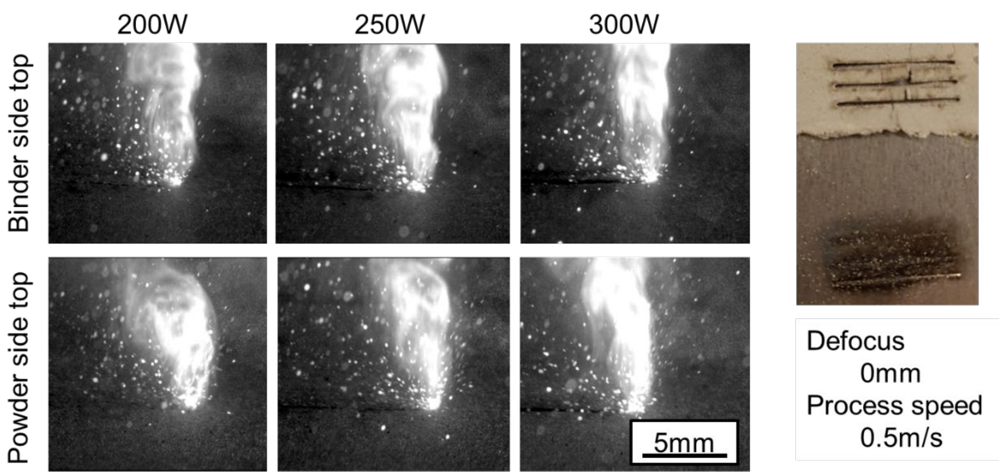


Figure 5. High-speed images, powder sheet and applied material appearances at different processing conditions

304 stainless steel samples were printed by using the fabricated powder sheet and a commercialized Realizer SLM50 system in the AMBER AR-lab in TCD (Figure 6). 70 layers of 50×6×1.5 mm3 samples were printed, which shows the capabilities of the MAPS for printing large-scale structures. First visual inspection shows that after polishing, the cross section show nearly fully dense sample was printed (Figure 6b), comparable to that of the loose powder based PBF-LB/M. Quantitative and volumetric analysis is ongoing and will be presented in future work.

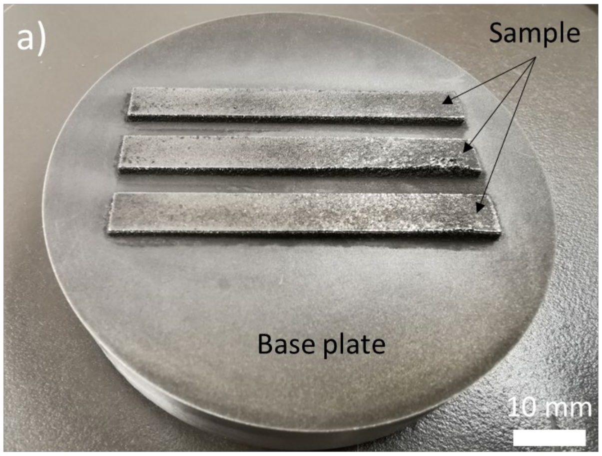


Figure 6. 304 stainless steel sample printed by using powder sheet: a) three 50×6×1.5 mm^3 samples and b) cross section of polished sample (5×5×0.6 mm^3)

Conclusions

The experimental tests of the new Additive Manufacturing technology MAPS (Metal Additive manufacturing using Powder Sheets) show the feasibility of transferring material from the powder sheets to a base material. Observations of the vapor plume in high-speed images show the binder evaporation and related spattering. At lower energy input, the binder evaporation led to less spattering, which indicates that a binder heating at low heating rates induces less pressure on the powder particles.

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