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Macro-pore free sub-surface PBF-LB/M components through laser polishing

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Abstract

Despite notable improvements in the laser-based powder bed fusion of metals (PBF-LB/M) in recent years, residual porosity is still an issue. Near surface pores can affect the functional properties of PBF components, such as their fatigue life, yield strength, or corrosion behavior. To help address the challenge, this work shows that laser polishing decreases the surface roughness while also creating a highly dense sub-surface region of PBF parts with only microscale pores remaining.

Keywords: Laser beam machining, polishing, metals, pores

1 Introduction

High process related design flexibility of metal components is one of the key characteristics of laser-based powder bed fusion. These components find applications ranging from medical technologies, aerospace segments, and more. However, despite the advantages of the process, PBF-LB/M parts face challenges in terms of surface quality based on surface roughness and pores close to or connected to the parts' surface. Near surface pores can affect the functional properties of the components, such as fatigue life, yield strength, or corrosion behavior. These pores have various formation mechanisms like dissolved gas porosity, residual porosity within powder, lack-of-fusion porosity due to processing, spatter induced lack-of-fusion porosity and keyhole porosity [1]. A porosity of 1 % according to the Archimedes method decreased the fatigue limit of Ti6Al4V down to 100 MPa from an initial value of 350 MPa at nearly 0 % porosity [2]. When it comes to the surface roughness of PBF-LB/M parts, the resulting surface roughness is commonly smoothed using conventional, mechanical processes such as sand blasting. Liang et al. [3] demonstrated that ns-pulsed laser polishing is capable of simultaneously reducing the surface roughness while also decreasing the porosity of Ti6Al4V. Panov et al. showed a decrease in porosity of 90 % due to cw-laser remelting of PBF 316L which is also referred as pore healing or densification [4]. These results confirm the findings of Yasa et al. [5].

To further understand the mechanism of reducing the near-surface porosity of PBF-LB/M parts made of Co-Cr with a focus on micropores, this work studied cw-laser polishing as a post processing technique for PBF-LB/M specimen and analyzed the porosity size distribution following polishing.

2 Methods

The PBF-LB/M specimens (10 mm x 10 mm x 4 mm) were printed using a TruPrint 1000 by Trumpf with Celsit-21P (Co-Cr-alloy) powder. The PBF-LB/M build process used a laser power of 120 W and a scanning velocity of 900 mm/s. The hatching distance was set to 50 µm while the layer thickness was 20 µm. The post-process laser polishing used a JK 400 fiber laser with a circular beam and a gaussian intensity profile. Polishing was performed with a laser power of 35 W, scanning velocity of 120 mm/s, and variable path overlap percentage. The specimens were shielded with Argon gas to prevent chemical reactions during processing. The pores and their position were examined in cross sections perpendicular to the scanning direction using scanning

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electron microscopy (SEM). Since different hatch spacings i.e., overlapping degrees of the scanning paths were chosen parts of the scanning paths, were remelted different number of times, as Fig. 1 depicts.

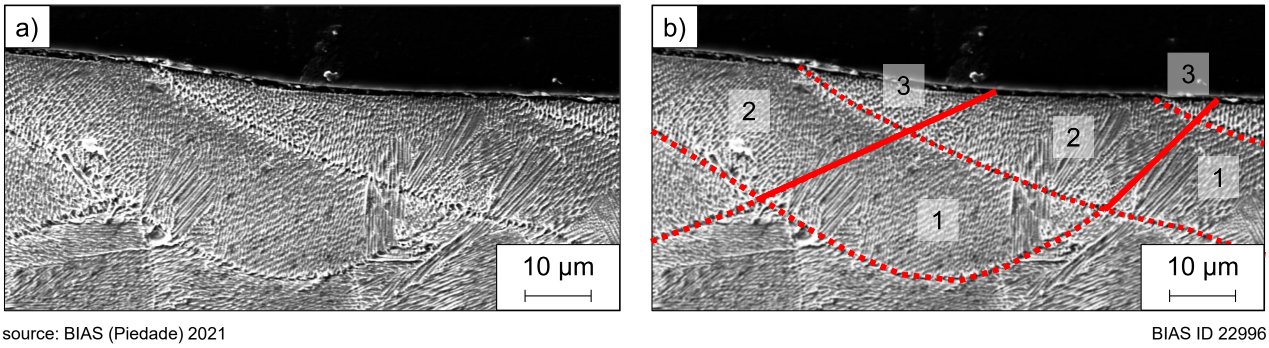

Fig. 1: a) Cross-sectional SEM image and b) visible melt line marked as red dashed line and extrapolation of former melt lines marked as red solid line. Numbers indicate the number of remelting events.

The horizontal position of a pore was defined as the smallest distance to seam center that is perpendicular to the surface and located at the deepest point of the melt path. The vertical position of a pore was described as the smallest distance of it to the surface of the specimen. In terms of the cross-sectional size of pores, those were considered ideal circular, resulting in an approximated pore cross section area. The detected pores were categorized into different sizes classes. Fig. 2 gives a schematic description of the measurement procedure in term of the pores' position.

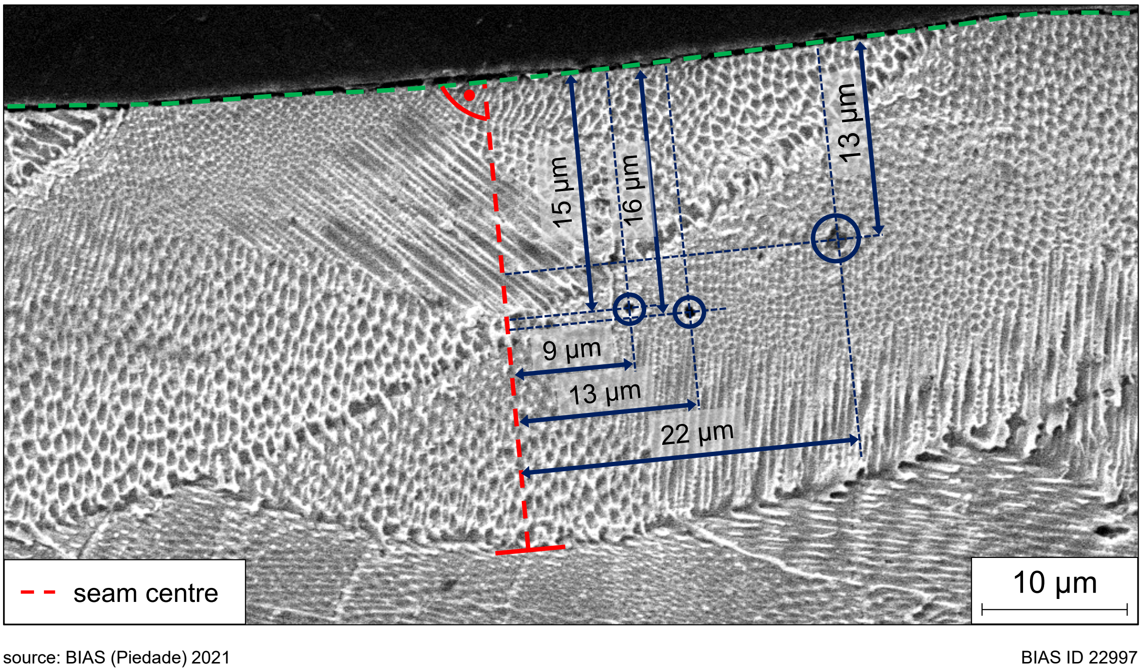

Fig. 2: Schematic depiction of pore position determination.

3 Results and Discussion

The evaluation of the distance of pores to the surface and the seam center as a function of different path overlaps leads to the results depicted in Fig. 3. As shown, depending on the path overlap, the areas are remelted between one to three times. Thereby, no clear tendency of the path overlap and hence the resulting number of remelting events on the distances of the pores to the surface and to the path center are noticeable. Therefore, the mechanism that gas moves to the surface on each case within the time when the molten pool is liquid and moves through the solidification fronts towards the center during solidification does not seem to play a significant role here.

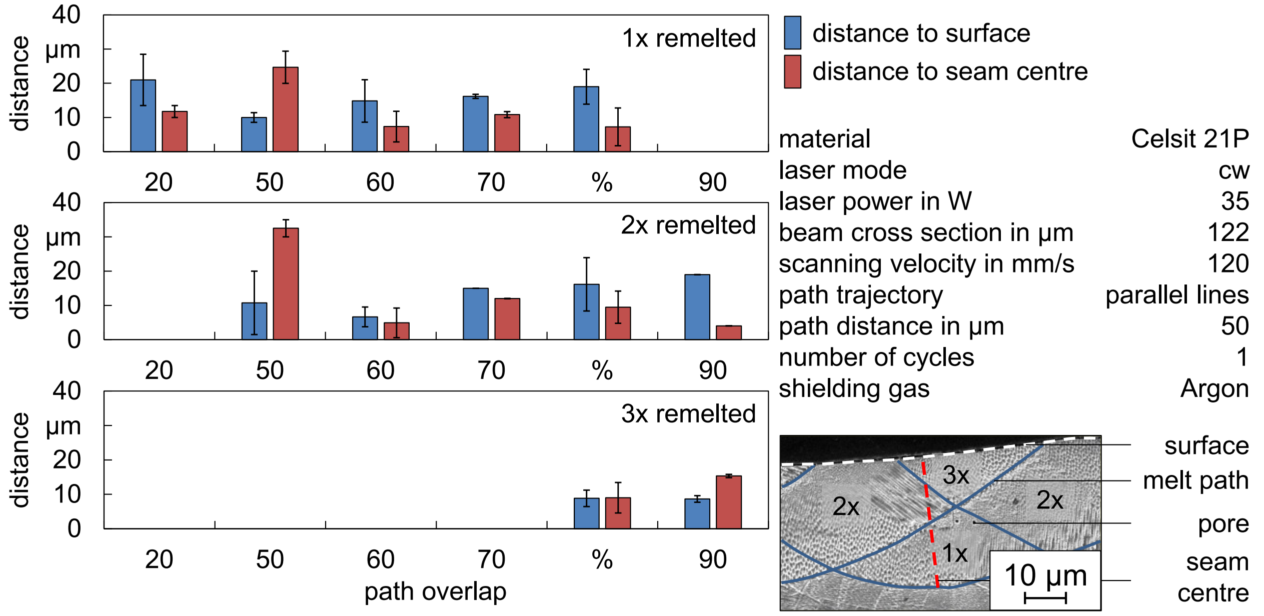

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Fig. 3: Distances of pores to the surface and to the seam center in dependency of the path overlap.

In terms of the cross-sectional size of pores, Fig. 4 presents this size as a function of the path overlap. There seem to be only a slight size decrease with increasing overlap degree, but the variability on pore size decreases with increasing overlap distance. For the applied polishing and Argon shielding conditions, using a path overlap between 60 % and 90 %, only pores with an approximated pore cross section area smaller than 15 µm² were observed. Hence, laser polishing can lead to a nearly full dense sub-surface layer with remaining micropores only, which is not the expected condition directly after the PBF process, even if a direct correlation of the pore reduction in micrographs is not possible. Such small micropores are further difficult to measure with micro x-ray computed tomography to compare the PBF and polished state directly. Large pores with cross-section areas in the range of hundreds or thousands µm² as observed in laser polishing of PBF-LB/M with high mean laser power [6] were not detected. The results are in line with the findings in [7] and [3] showing that laser polishing can lead to a nearly full dense sub-surface layer. Further investigations are necessary to understand the acting mechanism which could be the elimination of pores due thermocapillary force as observed during PBF-LB/M [8].

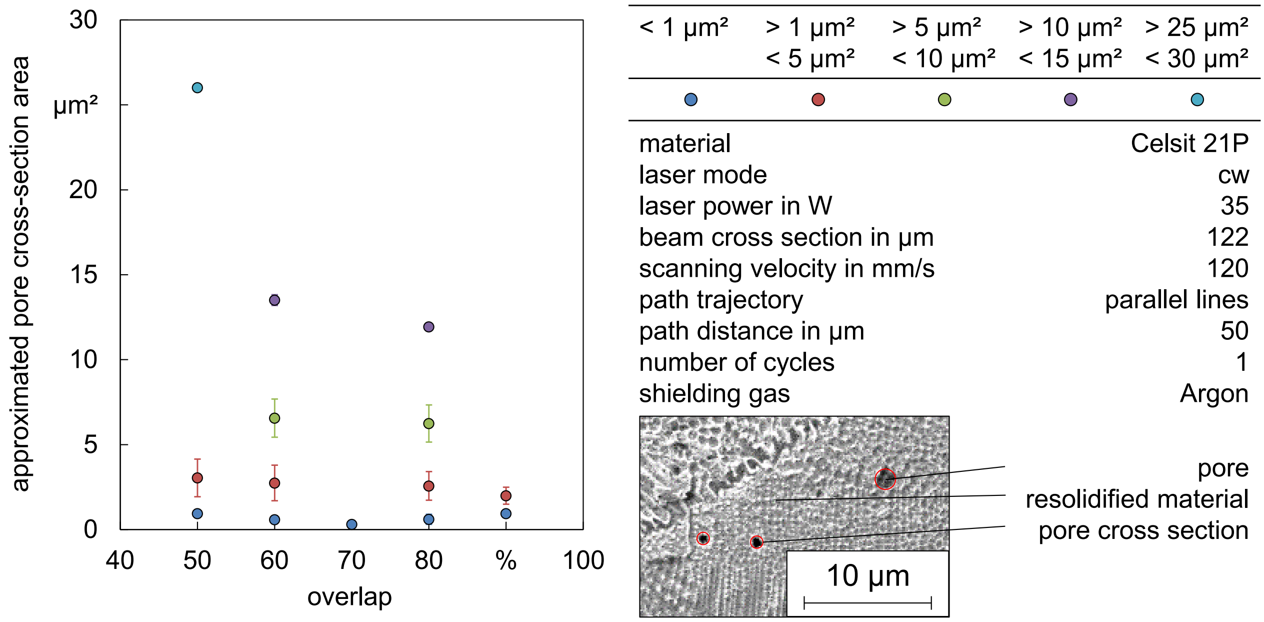

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Fig. 4: Mean pore cross-sectional sizes in dependency of the path overlap.

4 Summary

In this work PBF-LB/M Co-Cr parts were laser polished with varying path overlaps resulting in regions being molten up to 3 times. For each case, cross sections of these molten paths were investigated in terms of occurring pores and their cross-sectional areas. No correlation between the number of remelting events and the pore distribution could be observed but the variability in pore size decreases with increasing overlap distance. Thus, the presumed mechanism that higher degrees of overlap, resulting in multiple melted areas, lead to a significantly increased reduction of the pores cannot be confirmed. A trend regarding a pore's size and its ability to be removed or reduced by the melt pool during laser polishing through remelting appears to be present and must be further investigated. The results show that laser polishing can lead to a nearly full dense sub-surface layer with only micropores remaining, whereby it is assumed that such a condition did not exist directly after the PBF process.

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