SURFACE IMPROVEMENT OF AN ADDITIVE MANUFACTURED LAYER THROUGH LASER REMELTING

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Abstract. *Before selecting a component for critical applications, is important to assure its integrity. Recently, additive manufacturing has been used for fabrication of medical and aerospace parts, but many issues still not understood, regarding the surface quality and voids. Although post-processing methods are available, aiming at providing integrity, these techniques show limitations. The propose of this work is to analyze the Laser Remelting (LR) as an alternative of post-processing components made by Directed Energy Deposition with Laser (DED-L), a typical additive manufacturing process. Surface images were acquired with the Scanning Electron Microscope (SEM), before and after remelting, and the transversal images of the layer formed by adjacent bead were done with an Optical Microscope (OP). The average roughness (Ra) was measured with a 2D profilometer. The results pointed that LR contributes for eliminating non-melted particles adhered at the surface, which resulted in a 53% reduction of Ra, and also a decrease of lack of fusion area, simultaneously. Therefore, the fatigue strength could be improved.*

Keywords: *3D printing, Directed Energy Deposition, Roughness, Porosity, Lack of fusion.*

1. INTRODUCTION

Additive manufacturing has increased its presence in different industrial sectors. Although initially directed to prototyping, today is widely used for functional metallic components. For example, in the medical field, it is possible to build customized prosthesis, with similar bone properties (Moiduddin, K. et al, 2017). In the aerospace sector, 20 pieces components have turned to 1 piece, made layer by layer (Rockstroh, T. et al., 2013). Many benefits were accounted such as the possibility of building complex structures, the reduction of material waste and the higher productivity level (Gibson, I., 2010).

However, there still a series of limitations that hinders its implementation in large scale. The component integrity can be highlighted. It must be ready for application requirements (Griffiths, B., 2001). Two characteristics contribute for integrity: the surface roughness profile and the voids level (pores and lack of fusion).

Chan et al. (Chan, K. S. et al., 2013) studied the surface roughness influence on the fatigue resistance and found that non-melted particles can favor stress concentration, which contributes for crack initiation. With respect to voids level, Yadollahi e Shamsaei (Yadollahi, A. and Shamsaei N., 2017) concluded that large and irregular voids, near the surface, are the main factors that limit the fatigue strength.

There are a wide range of post-processing techniques available to deal with the covered problems. The manual polishing constitutes the most common method to attenuate the surface roughness. Nonetheless, it does not guarantee uniformity and presents low productivity (Gora, W.S. et al., 2018). The Hot Isostatic Pressing (HIP) is used to close internal pores, but is not capable to remove open voids, those connected to the surface (Atkinson, H.V. and Davies, S., 2000).

The Laser Remelting (LR) is also a viable alternative. The process starts after the formation of a molten pool on the metal surface, due to laser radiation. Differently from subtractive processes, the material redistributes due to capillary pression, which attenuates the surface (Gora, W.S. et al., 2018) and extinguishes the voids simultaneously (Demir, A. G. and Previtali, B., 2017).

A few works have investigated the application of the LR as a post-processing method for additive manufactured structures. In order to fill this gap, the present work proposes to study the influence of LR on the surface characteristics and voids level after an iron layer deposited through the Directed Energy Deposition with Laser (DED-L) process.

2. EXPERIMENTAL PROCEDURE

The experiments were executed with an IPG Photonics® fiber laser source, model YLS 10000, coupled with an YW52 Precitec optical head, and a feeding nozzle designed by the Fraunhofer Laser Technology Institute (ILT). A powder feed GTV and a Siemens SINUMERIK 840D SL CNC system with three movement modules were also used.

The laser focus was located 15 mm above the surface, with a diameter of 800 µm. Argon was used as shielding gas. Iron powder was selected as the feeding material. One layer was deposited over an A36 material workpiece, with 400 mm (length) x 20 mm (width) x 9,53 mm (thickness) dimensions.

For the DED-L process, power P=450 W, scanning speed V=600 mm/min, powder feeding rate f =11,23 g/min and overlap ratio of OR=30% input parameters were applied. For the laser remeltin process, the power was also set at P=450 W and the scanning speed at V=600 mm/min.

The surface was assessed with a Taylor Robson 2D profilometer, with 5 mm sample length, 0,8 mm cut off, 2 µm stylus radius, 1,5 mN force and 0,5 mm/s speed. The stylus was positioned perpendicularly to the layer deposits. The average roughness (Ra) was selected for comparison.

The Scanning Electron Microscope (SEM) HITACHI model TM3030 was used to analyze the surface before and after remelting. An Optical Microscope (OM) Olympus model BX60M was also used to understand how the remelting affects the voids level in the transversal section.

3. RESULTS

Figure 1 shows the SEM photograph of the DED-L sample, with two magnifications: (a) 100x and (b) 1000x. There are a vast number of powder particles that did not melt and got sticked on the surface. As indicated by Chan et al. (Chan, K. S. et al., 2013), these particles can act as stress concentrators and contribute to reduce the fatigue strength.
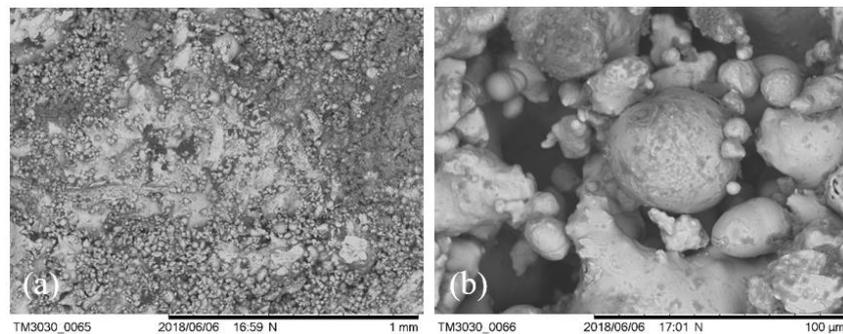

Figure 1. SEM image of the DDE-L processed surface. (a) Magnification of 100x. (b) Magification of 1000x.

However, when LR is applied, the powder particles reach the melt point, and are not noted anymore on the surface, as indicated by the SEM image of Figure 2, for the same magnifications. The dark spots are oxides that formed during processing.
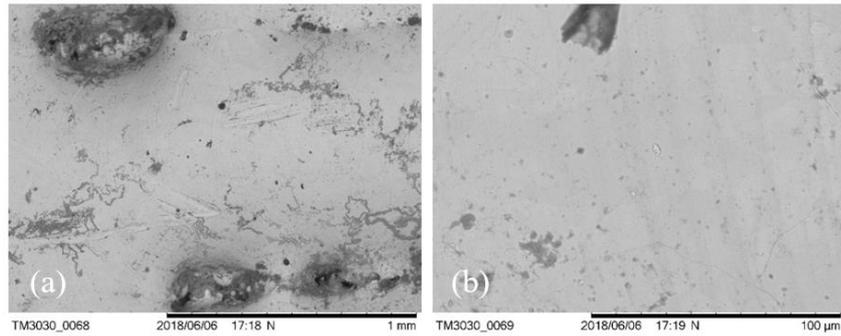
Figure 2. SEM image of the DDE-L processed and subsequent remelting. (a) Magnification of 100x. (b) Magification of 1000x.

The roughness profiles are presented in Figure 3. After the DED-L process, the surface presented oscillations, which are evidenced by the peak and valleys variations (Figure 3a). The Ra value was 19.205 µm. After application of LR, the Ra decreased to 9.030 µm (Figure 3b).
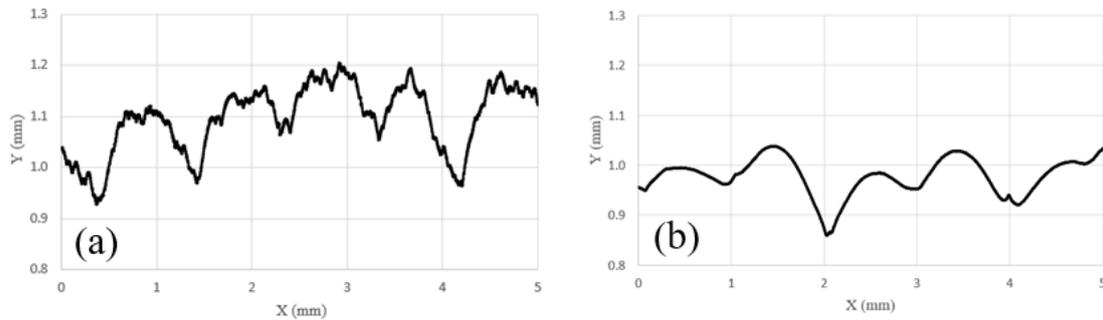

Figure 3. Roughness profile. (a) After DED-L processing. (b) After DED-L processing and subsequent remelting.

The voids level was studied based on the transversal section. Figure 4 exhibits the overlapped deposits that formed the layer. Although the powder feed rate was fixed, the transversal area of each bead varied. This is an indicator of variation of feeding efficiency. It is also noted a series of pores inside the beads and lack of fusion areas between the deposits.
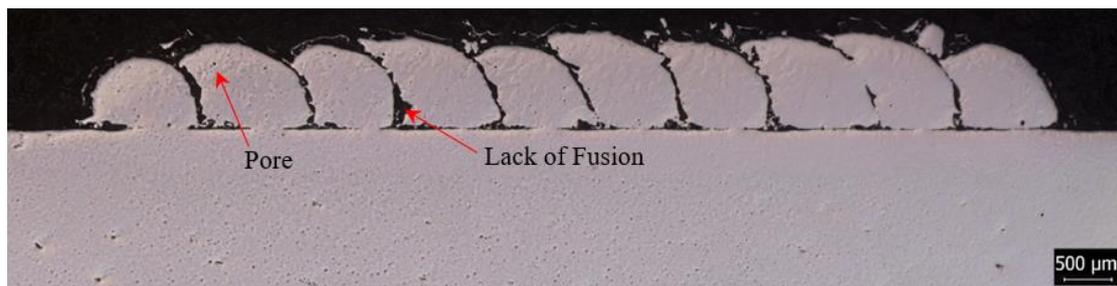

Figure 4. Overlapped deposits after DED-L processing.

When the remelting was applied over the DED-L deposit, some pores remained, with a larger diameter, but the lack of fusion area between the adjacent beads was reduced. In some points, the melting was able to join the beads. This is shown in Figure 5. Therefore, the large and irregular voids pointed by Yadollai e Shamsaei (Yadollahi, A. and Shamsaei N., 2017) as the main limiting factor of fatigue strength, could be reduced.

L. E. S. Paes, M. Pereira, F. A. Xavier, F. Ratusznei, W. L. Weingaertner, L.O. Vilarinho.
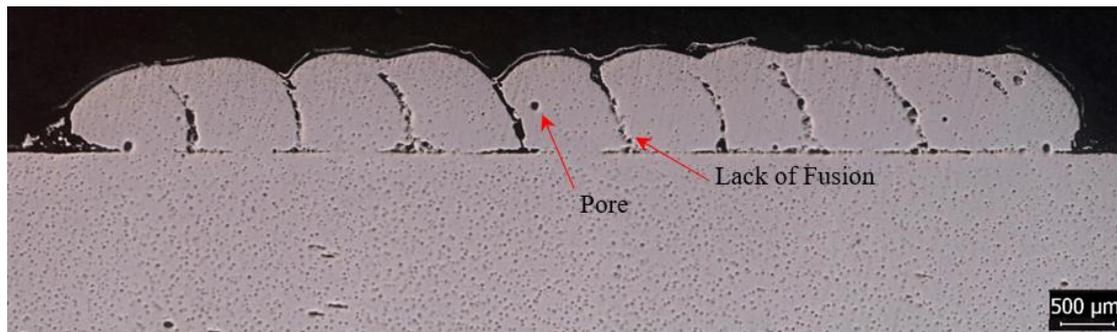Surface Improvement of AM Through Laser Remelting

Figure 5. Overlapped deposits after DED-L processing and subsequent remelting.

Based on the above results, it is possible to affirm that the LR post-processing is viable for the integrity improvement of components manufactured layer by layer, as it attenuates the surface (53% reduction of Ra) and decreases the incidence of irregular voids caused by lack of fusion. Future works should be done in order to determine the optimum parameters that minimize undesirable aspects and then allow this technology to be applied in large scale.

4. CONCLUSION

The developed work presents the following conclusions:

1 – The LR contributes for surface smoothing after the DED-L processing, as indicated by the roughness profile. The Ra reduction was 53%. After remelting, the non-melted powder particles were not seen in SEM images.

2 – The lack of fusion area between the deposits was reduced after LR. Although an increase of pore diameter was noted, the lack of fusion voids is more detrimental for fatigue strength. Overall, the LR was beneficial for the component integrity.

3 – Differently from conventional post-processing methods, LR can deal simultaneously with surface improvement and voids reduction.

5. ACKNOWLEDGEMENTS

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