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Improvement of the mechanical properties of AISI 316L steel samples made with Directed Energy Deposition with high mass flow by the Laser Shock Peening process

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Abstract

The Directed Energy Deposition (DED) Process with high mass flow enables Additive Manufacturing Technologies to achieve improved productivity. Notwithstanding, the higher the mass flow is, the more abrupt the heating and cooling rates in the consolidated material are. Laser Shock Peening (LSP) applies high-intensity laser pulses on the material's surface, generating compressive residual stresses up to 1 mm depth, resulting in a global enhancement of the mechanical properties of the treated sample. A set of samples for different mechanical test has been manufactured in AISI 316L steel by the DED Process, considering different relative dispositions between the samples' length and the laser tracks. Optimized LSP treatments have been applied as post-processing technique. Microstructural and mechanical characterization of both, original and treated samples, highlights the potential of LSP technology as an benefitial post-processing technique, enhancing the properties of the additively consolidated material.

Keywords: Directed Energy Deposition; Laser Shock Peening; Mechanical Properties; Microstructure; Stainless Steel

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1. Introduction

The Directed Energy Deposition process constitutes one of the main technologies within the Additive Manufacturing techniques for metal. In this process, a jet of metal powder interacts with a coaxial or obliquus high-power laser beam to create layers of consolidated material (Ahn.,2021). The productivity of the process, thus, its efficiency, is directly related with the height of the layers, which, in turn, is dependent of the mass flow rate of the injected metal powder. Nevertheless, the higher the injected mass flow is, the more complex the dynamic of the process becomes, requiring a more accurate control of the process parameters. In addition, the microstructure of the consolidated material becomes more texturized, due to the high cooling rates, leading to anisotropic behavior of the consolidated material, and, with some porosity due to the limited interaction time preventing part of the dragging and protection gas to escape from the melt pool.

Some post-processing techniques might alleviate part of the intrinsic limitations of the additive manufacturing samples with high mass flow. Laser Shock Peening (LSP) applies short and high intense laser pulses resulting in a shockwave from the surface of the treated material, as described in Ocaña et al. 2013. The LSP process is modulated throughout the treated area and the overlap distance between pulses. The combination of a suitable election of both factors is able to create a beneficial state of compressive residual stresses with potential to enhance the hardness of the treated surfaces, due to the cold-working effect, and to limit the prejudicial effect of the possible porosity or micro-porosity in regions under the treated superface.

The present work presents a microstructural and mechanical characterization of the AISI 316L steel consolidated with DED with high mass flow; then, some samples have been treated with the LSP treatment, and its microstructure and hardness have been checked, offering a general vision of the potential of the LSP technic as a post-process for additive manufacturing samples.

2. Material and methods

The powder used in this analysis was gas atomized AISI 316L, supplied by Höganäs, with a particle size value between 44 and 106 µm. The corresponding chemical composition is listed in Table 1

Table 1. Chemical composition (wt.%) of the 316L stainless steel.

material	**C**	**Cr**	**Ni**	**Mn**	**Mo**	**Si**	**Fe**
AISI 316L	0.02	17	12	1.5	2.5	0.8	Balance

The samples were manufactured by a high-power fiber laser IPG YLS-6000 (λ = 1070 nm), with a 5 mm diameter.

In the present investigation, laser power was varied within the range of 2600 to 3000 W, while process speed ranged from 10 to 17 mm/s. Throughout the study, the powder flow rate was maintained at 25 g/min, while the shielding gas and carrier gas were kept constant at 8 L/min and 4 L/min, respectively.

The samples undergoing the LSP treatment are irradiated with a pulsed Nd:YAG laser with pulse duration of 10 ns and pulse frequency of 10 Hz, with a spot diameter of 1,5 mm, applying a on the treated surfaces a treatment density of 1500 pulses/cm^2.

The samples were prepared for microstructural characterization using conventional metallography techniques, including grinding and polishing. Once the samples were mirror-polished, the surface underwent an etching process using V2A acid, a specific reagent suitable for stainless steel. This etching method was employed to unveil and visualize the microstructure of the samples.

3. Experimental characterization and analysis

The microstructure of the consolidated material has been studied. Fig. 1 shows a cross section of the consolidated material. At the left, a more columnar growth pattern can be seen, whereas, at the right, a more cellular-like pattern is observed. Depending on the thermal gradient and the local heating and cooling rates the growth pattern can evolve from one scenario to the other, according to the phenomena described in Li et al. 2021.

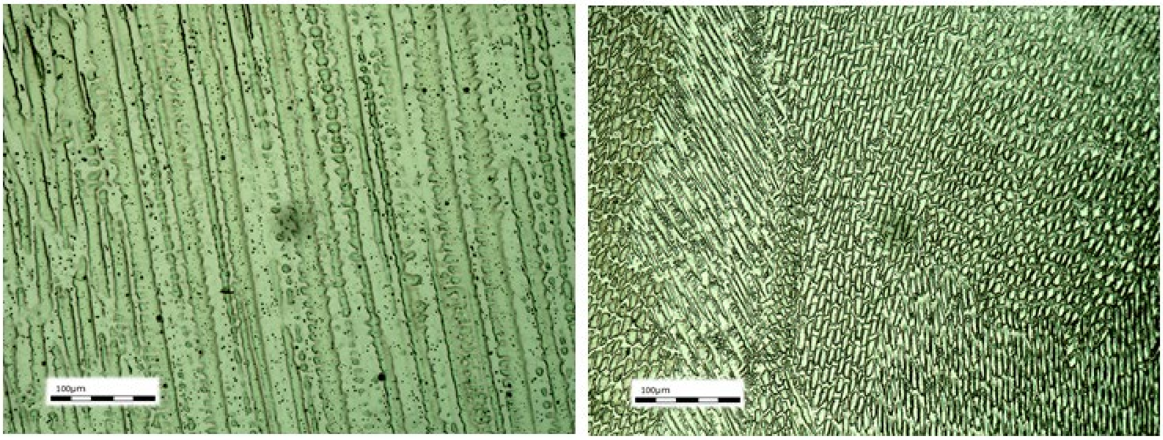

Fig. 1. Columnar growth pattern of the consolidated material (left) and cellular growth pa.

Fig. 2 shows with different magnifications (a more general view at the left and a more detailed view at the right) the effect of the LSP treatment on the microstructure of the consolidated material.

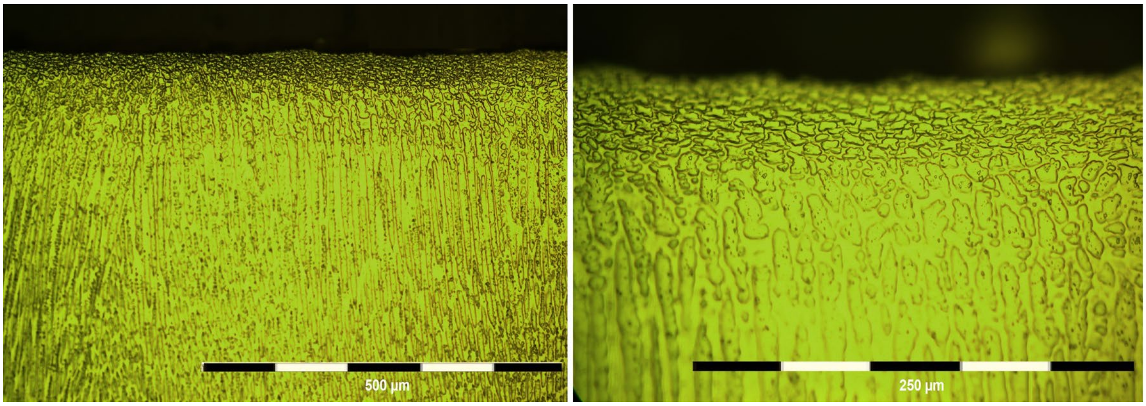

Fig. 2. Effect of the LSP treatment on the microstructure of the DED consolidated material. More general view to the left, detailed view to the right

From Fig. 2 it can be seen the effect of the LSP treatment on the microstructure, where, along several micrometers under the treated surface, the original columnar dendrites have been discomposed into smaller and more equiaxial grains. It highlights the capability of the LSP technique to affect such microstructure as the one obtained by the DED process.

The main goal of the LSP treatment on the DED samples is to improve the initial residual stresses status of the as-build material, with unfavorable tensile stresses, as shown in Fig. 3, to get, after the LSP treatment, a beneficial compressive stress profile, under the treated surfaces, as it can be seen in Fig. 4.

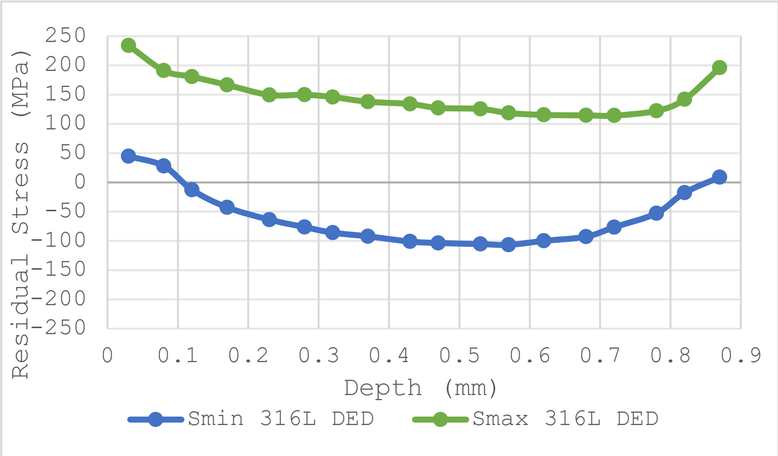

Fig. 3. Residual stress profile of the DED sample as built.

Fig. 4 shows the residual stress profile after applying the LSP treatment on the surface of the DED samples.

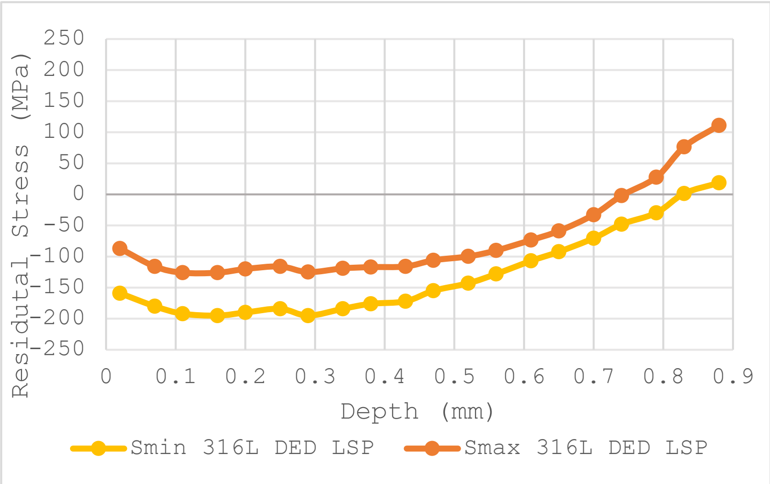

Fig. 4. Beneficial compressive residual stress profile after the treatment of the surface of the DED sample.

From Fig. 4 it can be seen that the LSP treatment has achieved a considerable status of compressive residual stress under the irradiated surface, despite the initial tensile status. This result is considered as a sign of the potential of the LSP technology as post-processing technique to mitigate the effect of the intrinsic defects associated to the Additive Manufacturing technologies for metal components.

4. Conclusions

- The microstructure and characteristics of the material consolidated with the DED process with high mass flow is characterized by a texturized microstructure, with a certain level of porosity.
- The growth pattern of the metallic grains is dependent of the local conditions of thermal gradient and heating and cooling rates of each part of the manufactured sample.
- The LSP technique is able to modify the microstructure of the DED consolidated material along several micrometers under the treated surface.
- The application of the LSP treatment on the surface of the DED samples is able to generate a profile of compressive residual stress up to 0.5 mm under the treated surface.
- The capability of the LSP technique to induce compressive residual stresses into material consolidated by means of the DED process allows the LSP process to be considered as viable post-processing to enhance the mechanical behavior of metal Additive Manufacturing samples.

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