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Effects of the Nozzle Tip Clogging and the Scanning Direction on the Deposition Process During Laser Metal Deposition of Alloy 718 Using a Four-Stream Discrete Nozzle

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Abstract

Depending on the configuration of the LMD system, the nozzle tilting is necessary to be able to manufacture parts with complex geometry. In these cases, the use of discrete coaxial nozzles is recommended. With this type of nozzle, the powder can clog the internal tips of the nozzle streams due to an inappropriate shape, size distribution, humidity or temperature conditions of the powder particles during the deposition process. This undesired effect can be an opportunity depending on the combination of the activated powder tips for coating complex surfaces when the geometry of the substrate acts as a barrier for the powder stream.
This work presents for first time the effect of the scanning direction and the stream clogging on the deposition process in terms of powder efficiency, Material Deposition Rate (MDR) and clad geometry and dimensions, when Alloy 718 is deposited by LMD using a four-stream discrete coaxial nozzle.

Keywords: Laser metal deposition; coatings; geometrical characteristics; Alloy 718; discrete nozzle; stream clogging

1. Introduction

Laser Metal Deposition (LMD) technology is an Additive Manufacturing process that employs a laser beam to create a melt pool in a metallic substrate, where a material is injected most commonly as a powder form. The added

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material is fused and solidified creating a high-quality metallurgical union between the substrate and the added material. The desired part is created layer by layer, thus, allowing to manufacture complex geometries.

When manufacturing complex shape geometries, it is usually necessary to tilt the LMD nozzle or the substrate [1-2], resulting that most of the machines dedicated or including the LMD process, are based on a 5-axis configuration [3]. Since the manufacturing of complex geometries by LMD require tool-paths with multiple direction, the discrete and the continuous coaxial nozzles [4] are recommended for this kind of applications [5], rejecting the lateral nozzles [6] due to their dependence on the motion direction. However, depending on the kinematic configuration of the LMD system, the tilting of the substrate is not possible, thus, the LMD nozzle needs to be tilted. In these cases, the use of discrete coaxial nozzles is more suitable to avoid the gravity effects on the powder stream. Despite this advantage over other nozzle designs [7], the discrete coaxial nozzles present several disadvantages as lower efficiency than the continuous coaxial nozzles [8-9] and the possibility of the stream clogging [10].

Other undesirable situation in the laser cladding process is the deviation of the powder stream due to the complexity of the geometry when repairing or coating a surface [11-12]. In this case, the discrete coaxial nozzle can be a solution to focus all the powder due to the possibility of clog the stream of powder than cannot reach the melt pool.

The present work is focused on the quantitative evaluation of the effect of clogging different streams of a 4-stream discrete coaxial nozzle in the powder mass flow and in the clad geometry when depositing Alloy 718 at different feed rate direction.

2. Materials and Methods

2.1. Materials

The material used in the experimental tests as filler and substrate material has been the nickel-based Alloy 718. The filler material consisted on powder with a granulometry range between 45 and 150 µm, from Flame Spray Technologies (FST), whereas the substrate material was in an annealed state. Table 1 presents the Chemical composition of the powder and the substrate materials. This Nickel-based alloy presents excellent properties at high temperature applications (useful up to 980°C) and oxidation and corrosion properties, and it is widely used in the aeronautical sector.

Table 1. Chemical composition of Alloy 718 (Powder and Substrate)

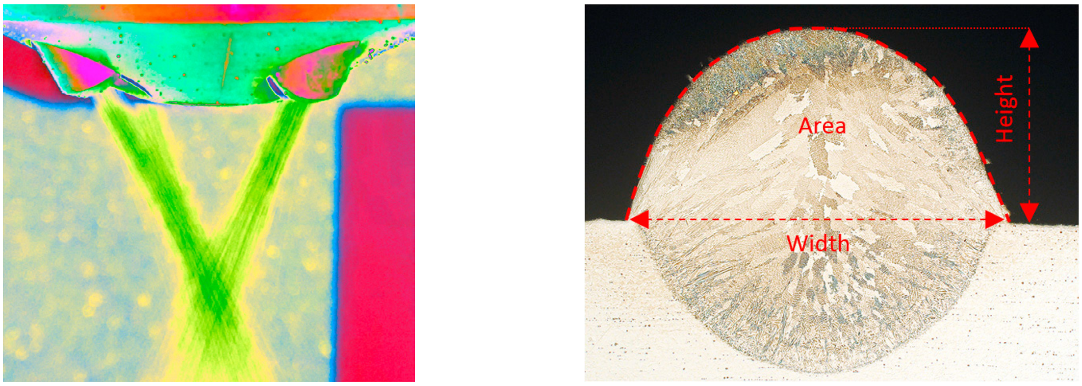
	Ni	Cr	Fe	Nb+Ta	Mo	Ti	Al
Powder	52.8	18.5	18	4.8	3.5	0.75	0.3
Substrate	53.5	18.7	17.7	5	2.9	0.94	0.58

2.2. Machine

All tests have been performed in an IBARMIA ZVH45/1600 Add+Process hybrid machine. This multiprocess machine combines the LMD technology with 5 axis milling and turning capability. This machine is equipped with a Precitec YC52LMD coaxial head with a 4-stream coaxial discrete nozzle, a Sulzer Metco TWIN-10-C Powder Feeder and an Yb-Fiber Rofin FL030 Laser generator of 3 kW with a continuous wavelength of 1.07 µm.

2.3. Experimental Testing

The experimental tests have been divided in two steps. First, the convergence distance of the powder mass flow (Fig.1.a) and the distribution of the powder at different combination of activated and disabled streams of the 4-stream nozzle have been studied. Secondly, once the convergence distance has been obtained, single clads have been deposited for each nozzle set up, measuring subsequently the height, width and area of the cross section of each clad (Fig.1.b).



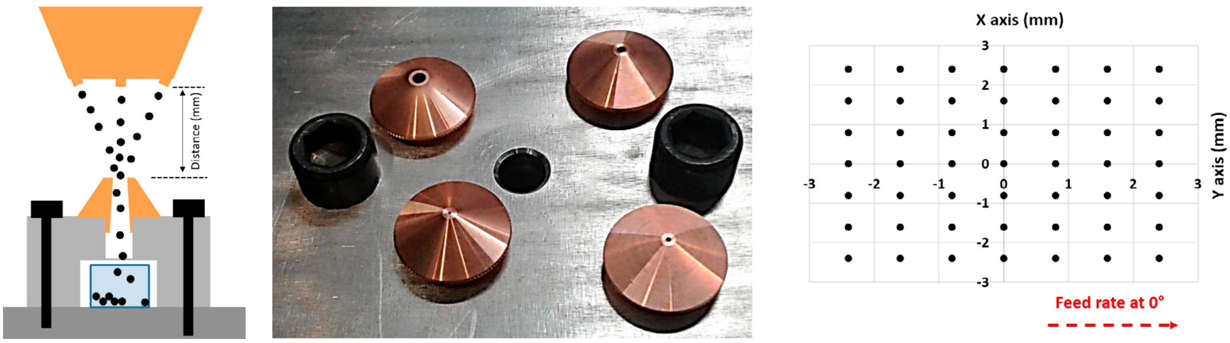
a) *b)*

Fig. 1. (a) 4-stream convergence point; (b) single clad cross section characteristics

2.3.1. Study of the convergence distance and powder mass flow distribution

To study the convergence distance a container with exchangeable nozzles of different inlet diameter (Fig.2.a and b) has been designed. The deposited powder has been weighted to obtain the percentage regarding to the powder injected at different distances, separated by 1 mm in the range of 10.5 to 17.5 mm, using the same methodology as that used by Tabernero et al [13]. Following this methodology, the distribution of the powder mass flow in the convergence point can also be obtained if the powder mass flow presents a circular symmetry respect the center point. Thus, to evaluate the shape of the distribution for the different stream configurations analyzed, the powder deposited in the container has been weighted at different distances from the center point in the convergence distance with an inlet nozzle of 0.8 mm (Fig.2.c).

For the study, the powder mass flow ($\dot{m}_p$) has been kept constant at 18 g·min^{-1}. The carrier and protective gas flow have been 4.5 and 17 l·min^{-1} respectively. The powder is carried from the powder feeder to the nozzle by an only tube that is divided twice using two-way fitting until obtain 4-stream. To obtain each set up it only has been needed to change a two-way fitting for one-way one when has been necessary.



a) *b)* *c)*

Fig. 2. (a) Scheme of the container; (b) inlet nozzles of different diameters; (c) points measured with an inlet nozzle of 0.8 mm.

2.3.2. Single clad testing

To determinate the clogging effect, clads of 60 mm in length have been manufactured at different activated stream set up and feed rate direction (Fig.3). The feed rate (v) direction has been selected taking into account the symmetry of each stream configuration. The process parameters have been obtained from previous works where clads with the characteristics that are shown in Table 2 were manufactured. These clad characteristics have been selected as a control value to obtain the evolution of the characteristic as a percentage of the control. The distance to the substrate has been the convergence distance measured above for each case. For analyzing the clads, the average value of the height (h), width (w) and area (A) of 2 cross sections at different positions have been obtained, avoiding the first and the last 10 mm of the clads, thus, avoiding process instabilities due to the start and stop conditions [14]. Samples have been measured by employing Motic SMZ-143 microscopy and the Clemex Captiva® software.

As at the same process parameters and material density (ρ), the efficiency (η_p) and the MDR are proportional to the area value (*eq.1* and *eq.2*), the evolution of the value of these parameters have been the same than the area regarding to the control.

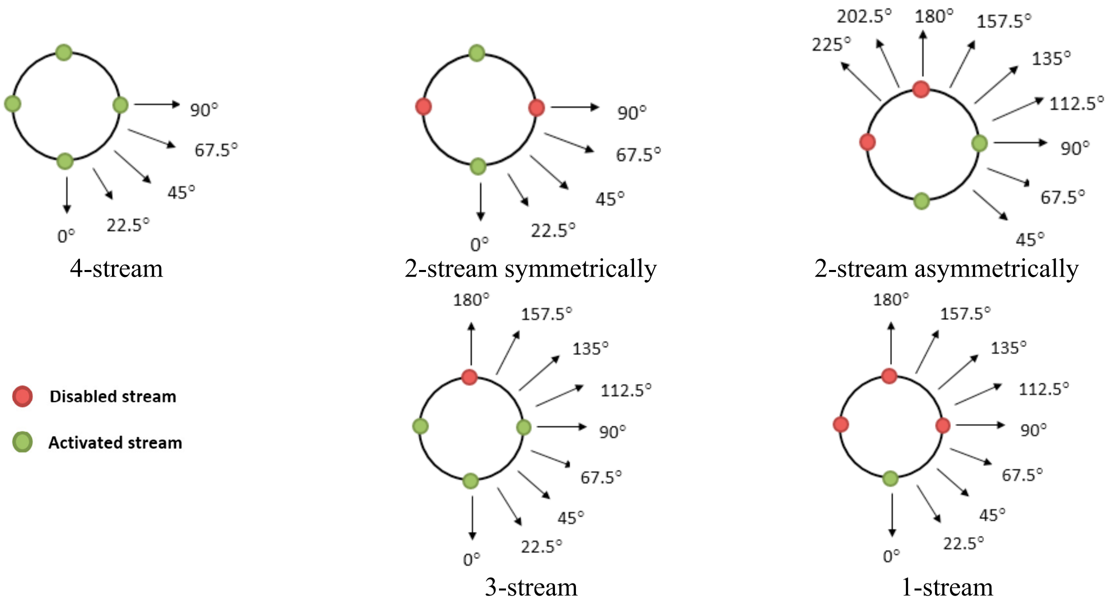


Fig. 3. Activated streams configurations and selected direction of the feed rate for each case.

$$MDR = A \cdot \varphi \cdot v \tag{1}$$

$$\eta = \frac{MDR}{\dot{m}_p} \tag{2}$$

Table 2. Parameters and characteristics with 4 activated streams at 14.5 mm distance.

Process Parameter		Clad Characteristics			
P (W)	2500	h (mm)	0.82	η (%)	56.7
v (mm·min^{-1})	700	w (mm)	3.23	MDR (kg·h^{-1})	0.61
$\dot{m}_p$ (g·min^{-1})	18	A (mm^2)	1.78	Aspect ratio	3.94

3. Results and discussion

3.1. Study of the convergence distance and powder mass flow distribution

The convergence distance varies from 14.5 mm with the 4 streams activated to 13.5 mm in the other cases (Fig.4.a-b). This is due to the increase of the carrier gas flow feed rate (v_F), based in the continuity equation of the fluids flow (eq.3), since the powder injecting stream area (A_F) is reduced with the same carrier gas flow (Q) when a stream is disconnected. The percentage of the injected powder at different distances and inlet diameters is a second-degree equation in all cases.

In the convergence distance, at different inlet diameters of the container, the distribution of the powder has been quite similar in all cases except with only one stream activated (Fig.4.c-d). In this case, the concentration of the powder has been lower (Fig.4.c). If the distribution of the powder had been circular, these results would be enough, but the shape of the distribution has changed as a function of the employed stream set up.

The results obtained weighting the powder deposited in the convergence distance at different positions from the center point with an inlet nozzle of 0.8 mm in the container have been used to plot 3D graphs of the powder distribution in each case. Fig.5 shows the obtained graphs for two different configurations (4-stream and 2-streams symmetrically activated) where the different colors (Fig.5.a-b) represent the weighted powder in each position. Since all the results have been obtained using the same small inlet area, the weight obtained in each point can be considered proportional to the powder distribution. The 4-activated stream case presents a circular distribution (Fig.5.a), thus, in this case, the previous results of calculating the convergence distance could be used to determinate the distribution of the powder mass flow. However, the other cases present different distribution comparing with the circular one (Fig.5.c-d) so the results related to the convergence distance are not useful to determinate it.

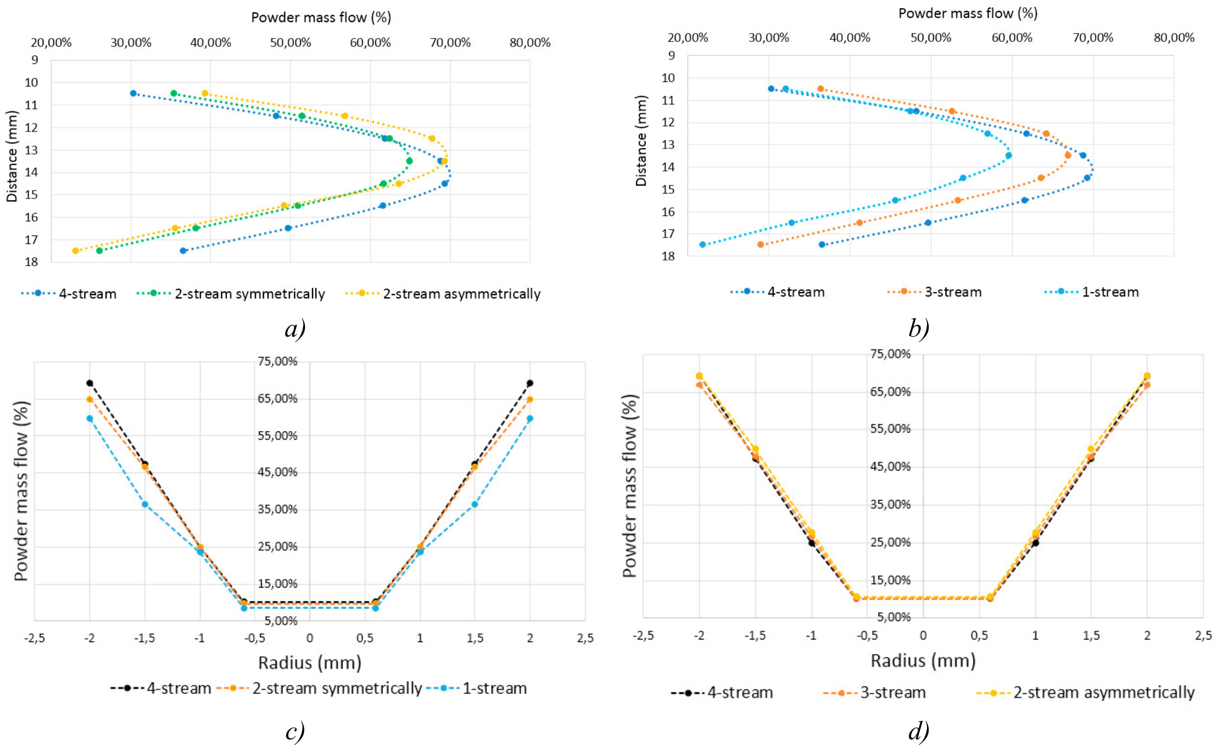


Fig. 4. (a-b) powder percentage deposited with an inlet diameter of 4 mm; (c-d) Powder distribution at the convergence distance

$$Q = A_F \cdot v_F \tag{3}$$

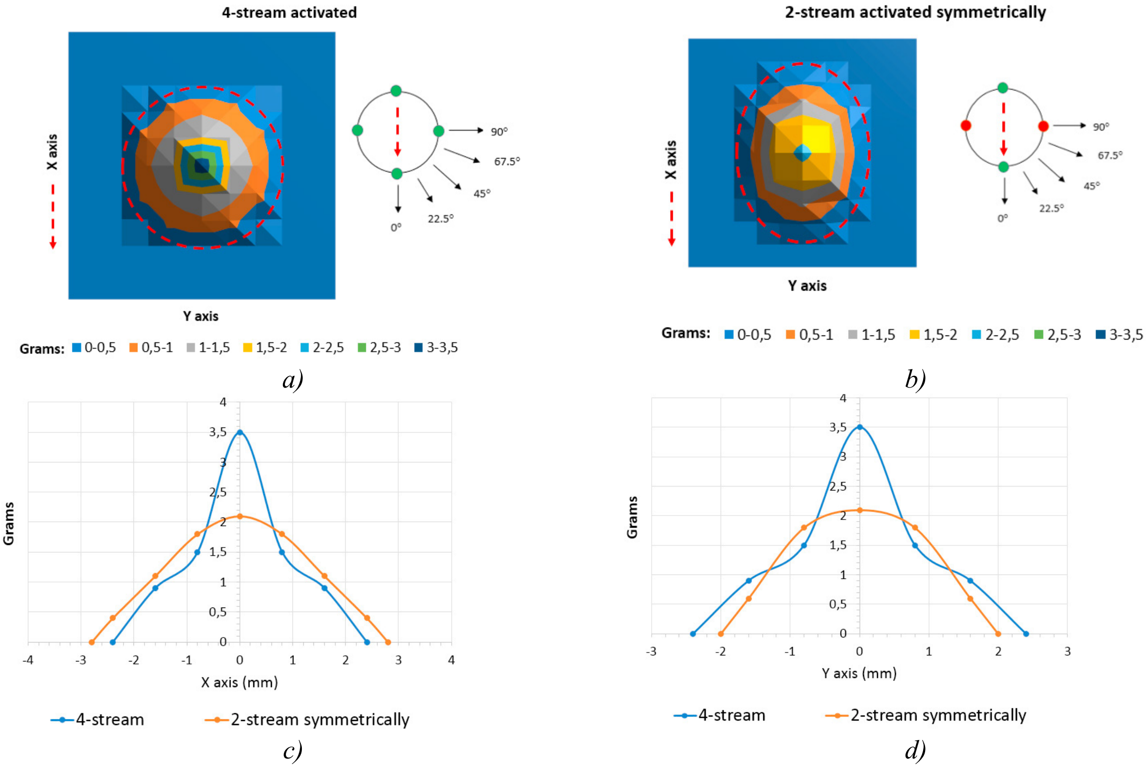


Fig. 5. (a) 4-stream circular distribution; (b) 2-stream elliptical distribution; (c-d) Cross section of (a) and (b) at different axis;

3.2. Single clad testing

The single clad characteristics have presented different values regarding to the control (Fig.6). At higher number of streams disabled, the difference of the minimum and maximum value of each characteristic has been higher, and the effect of the feed rate direction has been sharpest. In all cases the width has been the characteristic that has presented lower changes. These differences have been due to the concentration of the powder that has been different depending the direction.

With 4-stream activated (Fig.6), has been measured similar values at different feed rate directions. In this case, the variability of the characteristics can be explained with low differences in the powder mass flow rate when injecting powder. As has presented a circular distribution of the powder, the feed rate direction has not had effects in the clads characteristics.

At 3- stream (Fig.6.d-f), The height and the area have reached lower values while the width has presented similar trend to the 4-stream case. The influence of the feed rate direction is higher at 180° reaching values lower than 80 % regarding to the height and area of the control clad.

The clads deposited with 2-stream symmetrically (Fig.6.a-c) have presented higher differences than the 3-stream case. The width has presented higher values at 0°, 90°,180° and 270° reaching the 90 % of the control clad value but its value has never been lower than 80 %. The influence of the feed rate direction has been higher at 90° and 270° reaching values lower than 70 %, in the case of the height, and 60 %, in the case of the area, regarding to the control clad. At 0° and 180°, the results have presented higher value than the control clad.

The clads deposited with 2-stream asymmetrically (Fig.6.a-c) have presented different trend than the 2-stream symmetrically case. In this case, the width has presented values in the range of the 90-100 % of the control clad. The influence of the direction of the feed rate has been higher in the range of 180° to 270° reaching values higher than the control clad. in the case of the height and the area, and similar width to the control at 225°.

Finally, the characteristics of the clads deposited with 1-stream (Fig.6.d-f) have presented the highest differences regarding to the control excepting the width that has shown values near to the 90 % in all cases. The influence of the feed rate direction in the height and the area has been similar to the 2-stream symmetrically but presenting higher values to the control only at 180°.

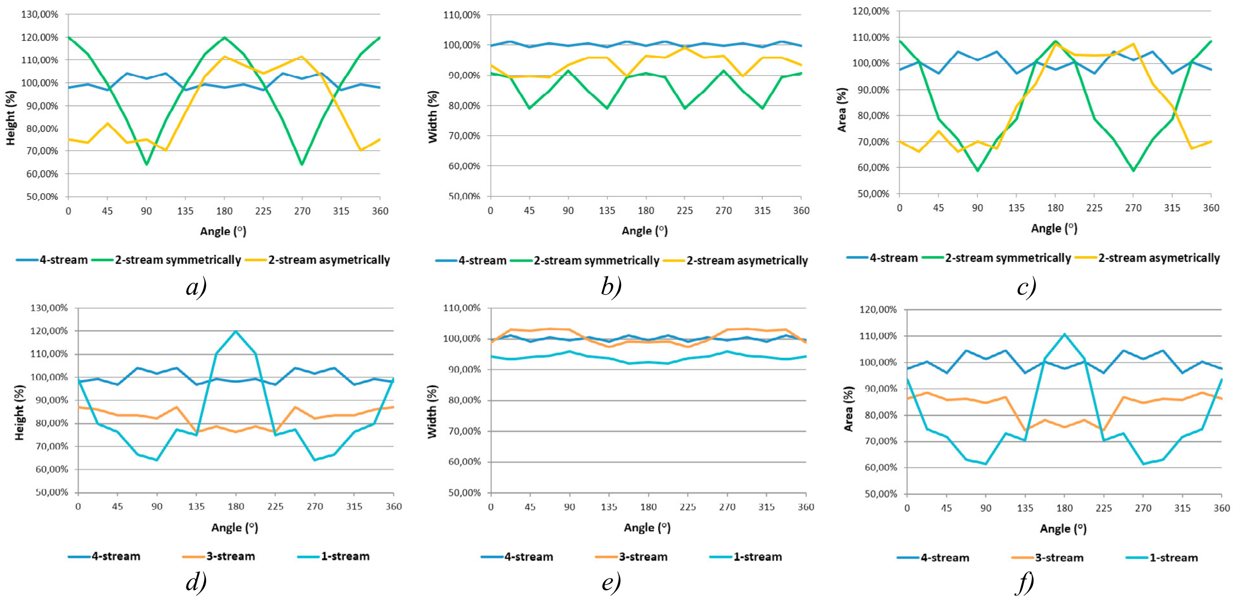


Fig. 6. Evolution of the clads characteristics regarding to the control and the direction of motion.

4. Conclusions and future work

The results of the present work have demonstrated that the only set up that can obtain a circular distribution, in the convergence distance, is the 4-stream one. With the other stream set ups, this fact changes the amount of powder in the melt pool depending on the feed rate direction, changing the clad characteristics at difference direction of motion regarding to the 4-stream set up.

The convergence point changes from 14.5 mm at 4-stream to 13.5 mm in the other cases due to the increases of the carrier gas feed rate.

Regarding to the single clad study, the clog of a stream changes the obtained characteristics of the clad. This effect is more notorious at higher number of streams disabled. However, depending on the stream set up and the feed rate direction, is possible obtain higher efficiency than in the 4-stream case excepting with the 3-stream set up.

The results of the 2-activated stream symmetrically set up suggest, as future work, the application of this set up to coating and repair slots where only the stream injected in the same direction than the feed rate could reach the melt pool.

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References

[1] Torims, T., Pikurs, G., Ratkus, A. et al. Development of Technological Equipment to Laboratory Test In-situ Laser Cladding for Marine Engine Crankshaft Renovation. Procedia Engineering, 100 (2015) 559-568. DOI: https://doi.org/10.1016/j.proeng.2015.01.405.

[2] Tabernero, I., Calleja, A., Lamikiz, A. et al. Optimal Parameters for 5-axis Laser Cladding. Procedia Engineering, 63 (2013) 45-52. DOI: https://doi.org/10.1016/j.proeng.2013.08.229.

[3] Cortina, M.; Arrizubieta, J.I.; Ruiz, J.E. et al. Latest Developments in Industrial Hybrid Machine Tools that Combine Additive and Subtractive Operations. Materials, 11 (2018) 2583. DOI: https://doi.org/10.3390/ma11122583

[4] Ramiro, P., Ortiz, M., Alberdi, A. et al. (2018). Characteristics of Fe-based powder coatings fabricated by laser metal deposition with annular and four stream nozzles. Procedia CIRP, 74, 201-205. DOI: https://doi.org/10.1016/j.procir.2018.08.094

[5] Toyserkani, E., Khajepour, A. and Corbin, S.F. (2004). Laser claddingCRC press.

[6] Ur Rahman, N., Capuano, L., Van der Meer, A. et al. Development and characterization of multilayer laser cladded high speed steels. Additive Manufacturing, 24 (2018) 76-85. DOI: https://doi.org/10.1016/j.addma.2018.09.009.

[7] Lamikiz, A., Tabernero, I., Ukar, E. et al. Current Designs of Coaxial Nozzles for Laser Cladding. Recent Patents on Mechanical Engineering, 4 (2011) 29-36. DOI: https://doi.org/10.2174/2212797611104010029.

[8] Ramiro, P., Ortiz, M., Alberdi, A. et al. Optimization of the efficiency of the laser metal deposition process applied to high hardness coatings by the analysis of different types of coaxial nozzles. DYNA, 93 (2018) 613-619. DOI: http://dx.doi.org/10.6036/8836

[9] Ramiro, P., Alberdi, A., Ortiz, M. et al. Characteristics of Fe-, Ni- and Co-based powder coatings fabricated by laser metal deposition without preheating the base material. Procedia CIRP, 68 (2018) 381-386. DOI: https://doi.org/10.1016/j.procir.2017.12.099

[10] Liu, S., Zhang, Y. & Kovacevic, R. Numerical Simulation and Experimental Study of Powder Flow Distribution in High Power Direct Diode Laser Cladding Process. Lasers Manuf. Mater. Process. (2015) 2: 199. DOI: https://doi.org/10.1007/s40516-015-0015-2

[11] Nikam S.H., Jain N.K. (2017) Laser-Based Repair of Damaged Dies, Molds, and Gears. In: Gupta K. (eds) Advanced Manufacturing Technologies. Materials Forming, Machining and Tribology. Springer, Cham. DOI: https://doi.org/10.1007/978-3-319-56099-1_6

[12] Leunda, J., Soriano, C., Sanz, C. et al. Laser Cladding of Vanadium-Carbide Tool Steels for Die Repair. Physics Procedia, 12 (2015) 345-352. DOI: https://doi.org/10.1016/j.phpro.2011.03.044.

[13] Tabernero, I., Lamikiz, A., Ukar, E. et al. Numerical simulation and experimental validation of powder flux distribution in coaxial laser cladding. J Mater Process Technology, 210 (2010) 2125-2134. DOI: https://doi.org/10.1016/j.jmatprotec.2010.07.036

[14] Ocelík, V., Eekma, M., Hemmati, I. et al. Elimination of Start/Stop defects in laser cladding. Surface and Coatings Technology, 206 (2012) 2403-2409. DOI: https://doi.org/10.1016/j.surfcoat.2011.10.040.