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Application fields for different Direct Energy Deposition beads geometries

Daniel Andres Rojas Perilla
Johan Sebastian Grass Nuñes
São Carlos School of Engineering - University of São Paulo (EESC-USP). Avenida Trabalhador São Carlense, 400 - Parque Arnold Schimidt. São Carlos - São Paulo
darojasp@usp.br; jsgrassn@usp.br

German Alberto Barragan de los Rios
Grupo de investigación en Ingeniería Aeroespacial, Universidad Pontificia Bolivariana, Medellín, Colombia. Circular 1 # 70-01. Medellin, Colombia
german.barragan@upb.edu.co

Reginaldo Teixeira Coelho
São Carlos School of Engineering - University of São Paulo (EESC-USP). Avenida Trabalhador São Carlense, 400 - Parque Arnold Schimidt. São Carlos - São Paulo)
rtcoelho@sc.usp.br

Abstract. *Metal Additive Manufacturing (AM) has generated a breakthrough in component manufacturing and repair processes. One of the most prominent processes is Direct Energy Deposition (DED), applying between other products for aeronautical, automotive, medical, and oil pipeline industries. The process has shown versatility and efficiency. DED operations require a correct set of process parameters involving a considerable parametrization process according to the work that needs to be done, the machine, and the material employed. Nonetheless, a lack of information about the possible uses of the different geometry beads generated by a commercial DED technology. Therefore, the dimensional characteristics of different deposited beads associated with mass flow variation values were analyzed in the present work. The experimental procedure was conducted keeping fixed parameters such as laser power, travel speed, and standoff. Some industrial applications were proposed, and significant improvements were identified for specific process parameter results.*

Keywords: Direct Energy Deposition, Additive manufacturing, Deposition beads, Geometry results.

1. INTRODUCTION

Additive manufacturing (AM), related to the construction of 3D objects layer upon layer, has rapidly emerged, allowing the fabrication of components directly from its digital model (Zhang., et al 2018). Between the different classifications of the MA process, Direct Energy Deposition (DED) uses metallic material in powder form with a laser source for fabrication (Bourell, 2020). The DED process has caused an industrial and academic revolt, breaking the paradigms of conventional manufacturing methods (Schmidt., et al 2017). Introducing unique operations such as the fabrication of new geometries starting above an existing one that acts as a substrate, using unique materials mixture and metal gradient constructions while reducing cost, materials, and tools requirements (Ahn, DG., 2021). DED process attracts attention in various areas such as aeronautics, automotive, energy, medicine, and mold industry to improve and make the manufacturing and repair service of customized products more affordable (Molitch-Hou, M., 2018).

Three central systems are involved in DED machines: Motion, Powder feed, and the energy source. In this process, a CNC machine or arm robot permits the movement (Barragan, et al 2021). The material delivery is carried out utilizing a distribution unit, a transport gas, and a nozzle. Coaxial nozzles have been extensively employed for powder material delivery as an efficiency tool that provides a continuum powder stream. Different energy sources have been employed; between them, Lasers are considered the most popular (Barragan, et al 2021), standing out CO_2 and Nd:YAG types.

During DED operations, the powder stream interacts with the laser at a determined standoff distance between the nozzle exit and the substrate. On the surface of the substrate, the laser creates a melt pool where it catches a percent of the material that interacted with the laser, having absorbed a part of the laser energy (Takemura et al., 2019). In this interaction, the metal powder that reaches the melting point transported by the gas and that manages to overcome the surface barrier of the melt pool joins it to generate the material track, as shown in Figure 1.

The relationship between process parameters and bead geometries has been studied in the literature (Kiani et al. 2020). For its part Shim et al. (2016), describes that the relationship of the bead dimensions height, width, and depth in deposited
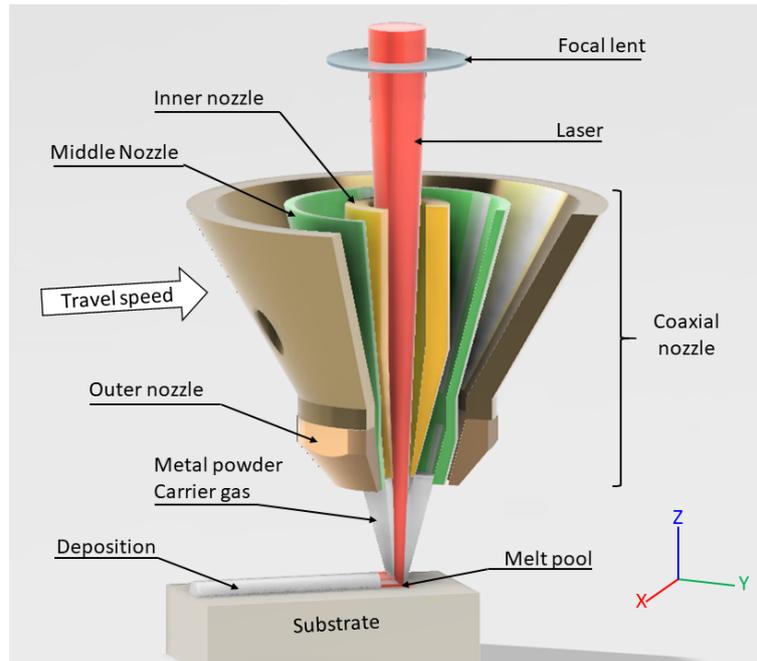
Figure 1. Schematic of the DED process with the Hybrid D800 ROMI.

beads is considerably affected by the parameters used (laser power, mass flow, advance speed). An in other cases, the better process parameters combination was explored to be employed in different applications, such as the work of Torsten et al (2016), which describes the use of various combinations of parameters in the beads to generate cylinders also using various strategies with the beads to reconstruct missing sections in a turbine burner.

According to the requirements and final application, the beads of material deposited with the DED can be generated. The depositions formed can meet dimensional specifications with various sizes (height, width, and penetration). This work demonstrates various uses that can be given to the deposited beads according to their solidified volume, size, and the conditions of their cross-section.

2. Materials and Methods

2.1 Materials

For this work, the materials used were Gas Atomized AISI 316L powder fabricated by LPW company as additive material feedstock and AISI 1020 bar with dimensions 70mm x 40mm x 10mm for the substrate. Figure 2 shows the external morphology of the AISI 316L powder.
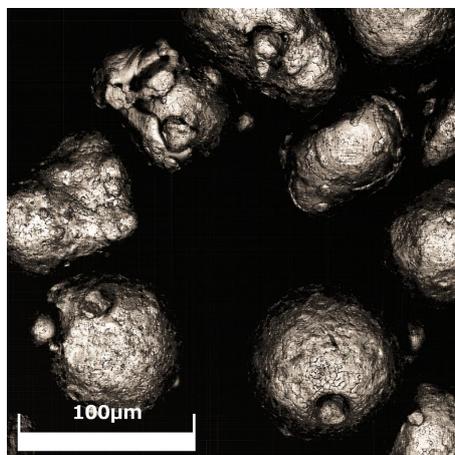

Figure 2. Shape of the AISI 316L powder

The powder has primarily spheric morphology with low satellite and porosity formation with an average grain size between 45–106 m. The nominal chemical composition of the employed materials is presented in Table 1.

Table 1. Chemical composition of the powder and substrate materials (Matweb, 2021)

(wt.%)	Fe	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N	O
AISI 316L	Bal	0.02	0.64	1.04	0.010	0.004	17.8	13.0	2.4	0.02	0.1	0.001
AISI 1020	99.53	0.023	-	0.60	0.040	0.050	-	-	-	-	-	-

2.2 Methods

The experimental depositions were performed on the ROMI D800-Hybrid machine. This equipment is located at the Advanced Processes and Sustainability Laboratory (LAPRAS), located at the São Carlos School of Engineering - University of Sao Paulo (EESC-USP). This machine has a Yb: YAG laser fiber system with a maximum capacity of 1500 W.

Single tracks were fabricated to analyze the deposited beads of AISI 316L. It was employing different hopper rotation velocities that are related to different mass flows quantities. The velocity was increased in intervals of 20 RPM in a range between 20 to 120. The laser power, the travel speed, and the standoff distance were constant in 800W, 350mm/min, and 10mm, respectively. The flow of the gases was fixed in "nozzle of 4 L/min", "carrier of 5 L/min," and "Shield of 8 L/min".

The substrate components with the deposited beads were cut in the cross-section, embed in Bakelite, polished, and etched with Aqua regia to be analyzed by traditional metallographic procedures. In addition, the effect of the employed process parameters has been studied considering the dimensions of the beads height, width, and dilution as output, see figure 3. The deposition images were obtained by laser microscopy (Olympus LEXT OLS4100).
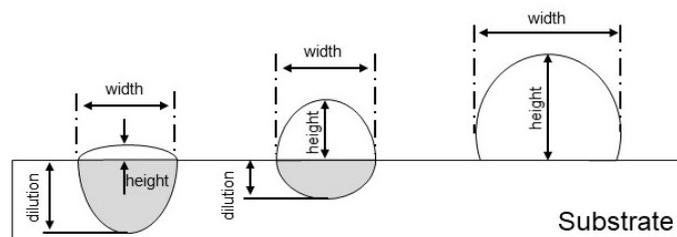

Figure 3. Schematic of dimension measurement for different deposition tracks.

3. Results and discussions

Figure 4 shows the cross-section of the deposited beads obtained during the experimental procedure.

Figure 4. Cross-section of experimental depositions variety the mass flow.

From previous experience, it was possible to determine a linear correlation between the programmed speed of the rotary disk (RPM) with the delivered mass of powder. As previously related, the travel speed (v) and the laser power (P) were kept constant. In the figure, it is possible to observe a significant variation in the bead geometry. An increase in its related dimensions appears with the increase of mass flow. However, for a high mass flow rate, the dilution is significantly reduced that phenomena could be explained by the reduction of the laser energy reaching the substrate due to the powder scattering phenomenon.

The deposition tracks A and B employ low mass flow (20% RPM and 40% RPM) and generate a large dilution zone with the applied power (800W). The effect of this material quantity and the available energy is reflected in the low height reached by the bead. Already for a medium mass flow (60% RPM and 80% RPM), as shown by depositions C and D, they expose the loss of laser efficiency to penetrate the material (800W), forming a low fusion zone and dilution on the substrate. In comparison, the solidified material over the substrate increases its size. Depositions E and F high mass flow (100% RPM and 120% RPM) show zero o minimum penetration on the substrate. It can be related to enough power for melt pool generation. Nevertheless, in contrast, the bead volume and high are the biggest. The results obtained from the dimensions in the cross-sections of the depositions are represented in Figure 5.
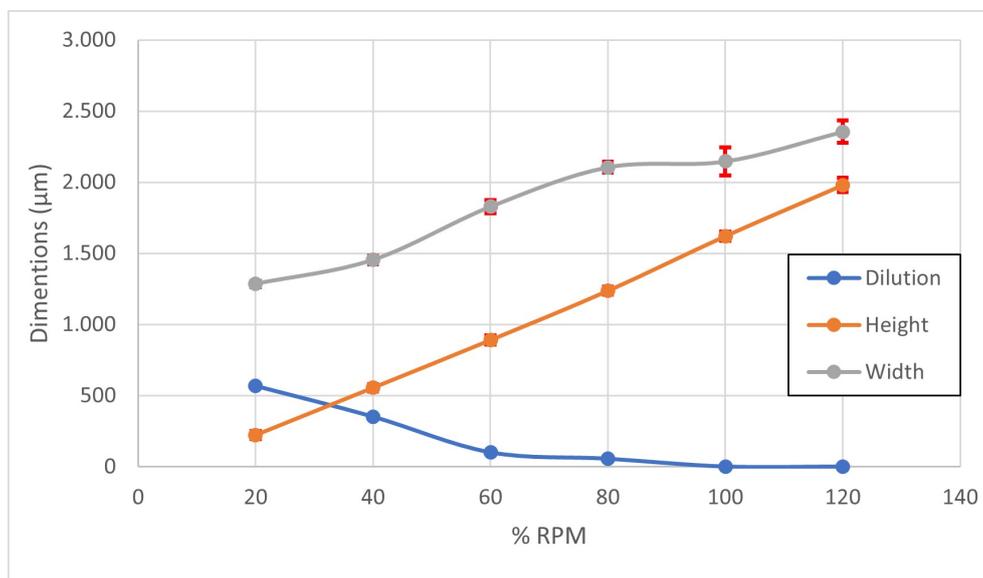

Figure 5. Dimensions of cross-section from single bead.

The maximum deviation obtained between a series of experiments and two repetitions of each deposition was $0.02 \mu m$ for dilution, $51.56 \mu m$ for height, and $97.74 \mu m$ for width. In addition, it is observed how the effect of the mass flow of the powder constantly increases in the same way that the heights of the depositions do as it increases. In the case of width, it can be deduced that its dimension also increases with a greater quantity of material with a superior limited related to the maximum laser spot dimension. The size of the melt pool decreases with a more significant amount of dust released, which reduces the amount of energy delivered by the laser to the substrate to form the melt pool with the interaction of the current of material (Shim et al, 2016).

The process parameters combination showed different geometries that could be fabricated. An additional step is to identify the possible uses of each of them and consider some related elements are defined as follows. First, medium dilution is optimum for component construction, and the ideal condition is to allow the maximum building rate possible. Second, tracks with high dilution could be employed for coating or repairing procedures were a significant mixture of the feedstock elements and substrate improves the corrosion resistance of the substrate. The last case tracks with very low or no dilutions are acceptable as an initial layer during a construction process because they can help in an easy and quick component substrate remotion, which leaves significant improvements in terms of lead time during the fabrication process.

4. Conclusions

The variation in mass flow delivery while the other principal parameters were constant to modify the dimension and size of the deposited beads. As a result, height and width increase over the substrate with the mass flow rate increase, and the dilution area within the substrate can is reduced.

Therefore, it can be said that the depositions presented in this work can be used to:

• Compared to the height gained on the substrate, high dilution beads offer a potential use in coating. Compared to

the height gained on the substrate.

- A thinner bead allows its use for repairs or construction in thinner sections with improved accuracy.

- High dilution beads present a large volume without fusion to the substrate, generating a base layer. The no presence of high dilution and connection with the substrate allows its use for quick component remotion.

5. ACKNOWLEDGEMENTS

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