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# INFLUENCE OF POWDER PARTICLE SIZE IN THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF INCONEL 718 COMPONENTS PRODUCED BY LASER- POWDER DIRECTED ENERGY DEPOSITION

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**Abstract.** Additive manufacturing technology Laser Powder - Directed Energy Deposition has gained significant attention in industry due to its ability to produce components with complex geometries and to repair worn parts. This method uses metal powder as a raw material, which is one of its main attractions. This is especially relevant for material with excellent mechanical properties that are difficult to machine in conventional processes. One of material that has aroused great interest thanks to this characteristic of LP-DED process is Inconel 718. This alloy is widely used in industries such as nuclear and aerospace due to its outstanding heat and corrosion resistance. This paper focuses on the investigation of how the particles size of Inconel 718 powder influences the microstructure and mechanical properties of components produced through the LP-DED process. The powder particles were classified into three groups: 45-62, 63-90 and 45-90  $\mu\text{m}$ . The fabrication of beads and cubes was carried out. The results show how the particle size influences the selection of process parameters, as well as the porosity and hardness of the manufactured components. This underscores the importance of considering the particle size range when using LP-DED process, especially when working with demanding materials such as Inconel 718

**Keywords:** lp-ded, inconel 718, powder size, microstructure

## 1. INTRODUCTION

Additive Manufacturing (AM) technologies, also known as 3D printing, have revolutionized the manufacturing of industrial components. The most widely used AM technologies are Directed Energy Deposition (DED), a process in which a laser or electron beam melts material layer by layer onto a substrate or a pre-manufactured part; and Powder Bed Fusion (PBF), a process in which a roller deposits a layer of a powder and laser melts it, successively, to form the desired geometry. Brandt (2004). AM allows the use of any metal powder material, which is very attractive for use of materials that are difficult to use in conventional manufacturing processes. Due to it, Inconel 718, a nickel-based alloy, has been one of the most studied materials in AM process. This is because it is a material with high demand in industry, with aerospace and energy applications, due to high heat and corrosion resistance Hosseini and Popovich (2019).

In AM processes that use powder as raw material, spherical-shaped feedstock is preferred to obtain optimal material flowability, improve layer distribution and loose powder packing, especially in processes such as PBF. The DED process is more tolerant of satellites or fragmented-shaped powder, as long as the powder feed system has the capability to maintain the feed rate Anderson *et al.* (2018). Although the LP-DED and PBF processes use metal powder as raw material, LP-DED requires larger particles (45-150  $\mu\text{m}$ ) to achieve effective material feeding Toyserkani *et al.* (2004). One of the challenges facing LP-DED is the porosity of large-sized powders. Porosity can range from 10% to 90% of the particles size, and is caused by trapped atomization gas within the particles production, and in this way, porosity problems can occur in LP-DED manufactured components, which will directly affect their micro-structure and mechanical behaviour Rabin *et al.* (1990). Porosity can also be caused by satellite particles. These imperfections hinder the flowability and uniform packing of powder during deposition, which promotes the formation of larger pores Ning *et al.* (2022). The variability in the properties of powder particles can lead to a range of issues, such as particle flow resistance, instability, among others. Therefore, it is necessary to establish quality criteria to ensure that the raw material meets the requirements for the necessary applications. These criteria should consider particle morphology, flowability, size and distribution, as well as criteria accepting defects Barroqueiro *et al.* (2019). To investigate the influence of particles size and its effects on mass flow in a LP-DED process, Iams *et al.* (2022) used UNS S32101 powder material with particle size of 53-106  $\mu\text{m}$ , as well

as UNS S32205 and UNS S32705 with particle size between 53-105  $\mu\text{m}$ . The results revealed that UNS S32101 required a feed rate that was 45% higher than UNS S32205 and 65% higher than UNS S 32750. The authors concluded that small variations in the particles size distribution of the metal powders can reduce the mass flow feeding capacity in the LP-DED process.

Due to the Widespread use of the PBF process, a growing number of studies have been conducted on this technology. It has been found that particles size distribution plays a critical role in the density, surface quality, and mechanical properties of components Spierings *et al.* (2011). In components manufactured by PBF, the use of spherical particles has been shown to improve powder flowability, facilitating powder compaction and preventing issues such as porosity and lack of fusion, while also enhancing the geometric and mechanical characteristics of the components Brika *et al.* (2020).

Due to the Limited number of researchers focusing in the influence of particles size in the LP-DED process, the object of this paper is to analyse how different groups of Inconel 718 particles affect the process. An evaluation will be conducted on various aspects, ranging from the flowability of the particle groups, cross-sectional geometry, as well as the dilution and porosity resulting from bead and cube depositions.

## 2. MATERIALS AND METHODS

The tests were carried out using a ROMI D800Hybrid machine with printing surface of 800 \* 650 \* 500 mm. This machine is equipped with a deposition head and a coaxial nozzle, as well as 1500Kw Nd-Yag-laser with wavelength of 1080 nm. The deposition height is 10 mm, the spot size is 2 mm, and it uses a material feed using a rotating disk to apply the material powder on the melt pool.

### 2.1 Particle sieving

Commercial grade, gas atomized Inconel 718 powder from the same batch produced by Hogan was selected. Sieving was performed using 45,63,90 and 103  $\mu\text{m}$  meshes. This process was repeated several times, sieving 1 kg of material each time, until 1 kg of each of the groups selected. Table 1. The LP-DED feed system allows for operation with a small quantity of raw material, so this amount was considered enough. Image 1

Table 1. Powder groups

GROUP	SIZE ( $\mu\text{m}$ )
A	45-62
B	63-90
C	45-90

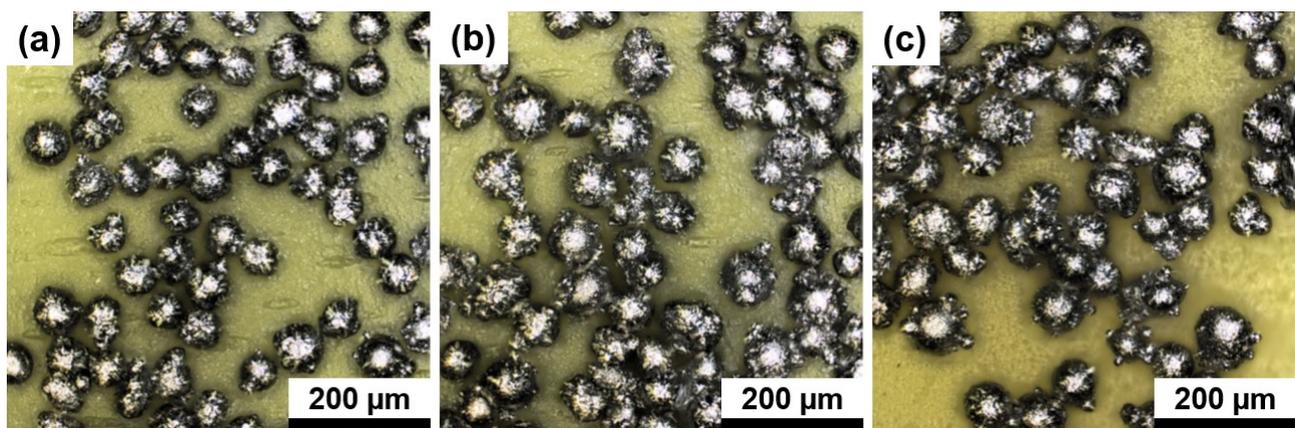


Figure 1. Optical micrograph of the powders: groups (a) A, (b) B, and (c) C.

### 2.2 Flowability test

To avoid larger particles from interfering with experiments involving smaller particles, the feeder was thoroughly cleaned with isopropyl alcohol and compressed air before switching to the next group of particles. The feeder was reassembled and left empty, and the system was purged with high-volume gas flow for 3 minutes to remove any remaining powder particle.

Due to the operation of the feeding system, powder was collected using different rotation speeds (RPM). In order to en-

sure the stability of the gas-powder flow, the powder was captured in a beaker with water for three minutes. subsequently, it was weighed on a precision balance to determine the mass flow obtained at each RPM.

### 2.3 Deposition beads

Bead and cubes deposition was used Inconel 718. Table 2 parameter. A 304L SS plate with dimensions of 100 \* 30 \*10 mm and a sandblasted surface was employed as the substrate to enhance laser absorption. Table 3 describes the chemical composition of powder and Table 4 chemical properties of substrate.

Table 2. parametros

PARAMETER	VALUE
Laser power (Kw)	950
Mass flow (g/min)	5
Scan speed (mm/min)	500
Gas nozzle (l/min)	4
Gas carrier (l/min)	3
Gas shield (l/min)	6

Table 3. Chemical composition of inconel 718. Matweb (2022)

Chemical Composition (Wt %)					
Element	Min.	Max.	Element	Min.	Max.
Ni	50	55	Mn		0.35
Cr	17	21	Cu		0.30
Nb	4.75	5.5	Ta		0.05
Mo	2.8	3.3	P		0.015
Ti	0.6	1.2	S		0.015
Al	0.2	0.8	B		0.006
C	0.002	0.006	O		0.030
Co		1	N		0.025
Si		0.35	Fe balance		

Table 4. Chemical composition of SS 304L.Matweb (2023)

Chemical Composition (Wt %)		
Element	Min	Max
C		0.035
Cr	18	20
Mn		2
Si		1
P		0.045
S		0.030
Ni	8	12
Fe balance		

### 2.4 metallography test

For the analysis of the cross-sectional areas, the samples were prepared as follows:

- Cutting: The samples were cut using a cut off machine with fluid to lubricate and cool the specimen.
- Sanding: The samples were sanded using a sequence of sandpapers with grid sizes from 80 to 1500.
- The samples were polished with alumina to achieve a smooth and shiny surface.
- Chemical etching: The samples were etched with a marble solution to highlight the microstructural detail.

After chemical etching, the samples were analyzed with a Scanning Electro Microscope (SEM) to evaluate the bead geometry, dimensions, dilution and porosity. Microhardness was subsequently measured and the wear test was performed

### 2.5 Micro-abrasive waer test

Resistance to abrasive wear was evaluated using the free ball calotest micro-abrasive test. Samples were prepared by sanding with SiC sandpaper from 800 to 2000 mesh, followed by polishing in alumina suspension with 0.05  $\mu\text{m}$  grain size. The abrasive solution was 0.3 g/mL SiC (400 mesh) diluted in distilled water. AISI 52100 steel spheres (quenched and tempered, 25.4 mm diameter, 60 HRC hardness) were rotated in contact with the samples (400 rpm) while the abrasive solution was dripped onto the contact point (1 drop every 15 s). A normal load of 0.22 N was applied by the weight of the sphere. Test times were 5, 10, 20, and 40 minutes, corresponding to sliding distances of 160, 320, 640, and 1280 m, respectively. Tests were performed in triplicate on each sample at 28 °C and 45% relative humidity. The test produced a worn region in the form of a cap, whose average diameter was used to calculate the removed volume using equation 1, where V is the removed volume, d is the average cap diameter, and R is the ball radius (12.7 mm).

$$V = (\pi \cdot d^4) / (64 \cdot R) \quad (1)$$

### 3. RESULTS

The figure 2 shows that the particles with a size smaller than 64  $\mu\text{m}$  have better flowability than larger particles. This is due to smaller particles have a lower tendency to form satellites, which hinder their flow. As a result, smaller particles allow for a greater mass flow available for deposition. In contrast, the use of particles from 45 to 90  $\mu\text{m}$  reduces the availability flow by 12% for the LP- DED process.

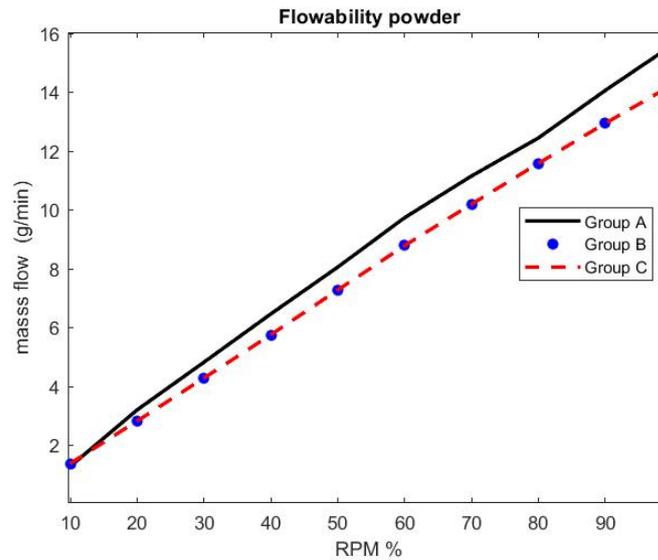


Figure 2. Flowability

The figure 3 A. Describes the bead deposited by the set of particles in group A. A slightly irregular cross-section with a considerable level of porosity can be observed. Due to the small size of the pores, this defect can be associated with porosity induced by the raw material and the satellites is presents DebRoy *et al.* (2018), as can be seen in 3A The small satellites can cause imperfections in the bead, as the smaller the particle are, the easier they will have to fuse.

Figure 3 B. illustrates how the particles from group B from a bead with low porosity. This phenomenon suggests that this granulometric range facilitates a complete fusion of the material, which is advantageous in terms of the quality of the components manufactured with particles of this size.

In the image 3 C, it can be observed that the particle in group C exhibit a deposition with a good quality cross-sectional view. However they also display pores of considerable size, which suggest the need to adjust the parameters. It would be advisable to consider increasing the laser power or reducing the mass flow in order to thereby decrease or prevent the formation of porosity in the deposition.

As can be observed in figure 4, it was observed that the bead deposition by the group B exhibited a favorable aspect ratio between the bead and dilution areas. This suggest that the use of particles within a size a range of 63-90  $\mu\text{m}$  would allow achieving depositions with outstanding dilution, which would be reflected in an exceptional mechanical performance of components manufactured with particles within particle size range.

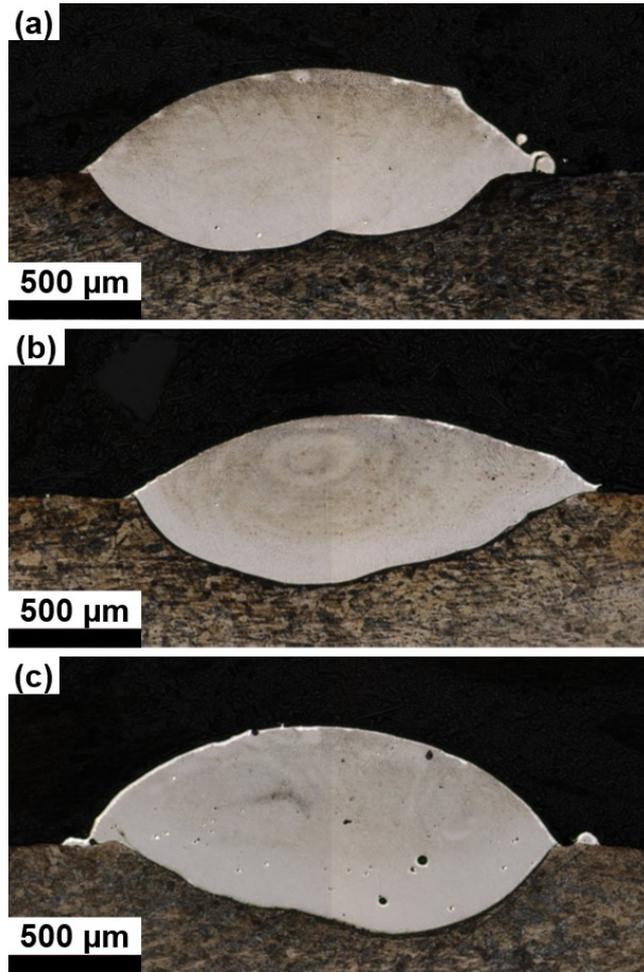


Figure 3. Optical micrographs of the cross-sectional views of the deposited beads for powder groups (a) A, (b) B, and (c) C.

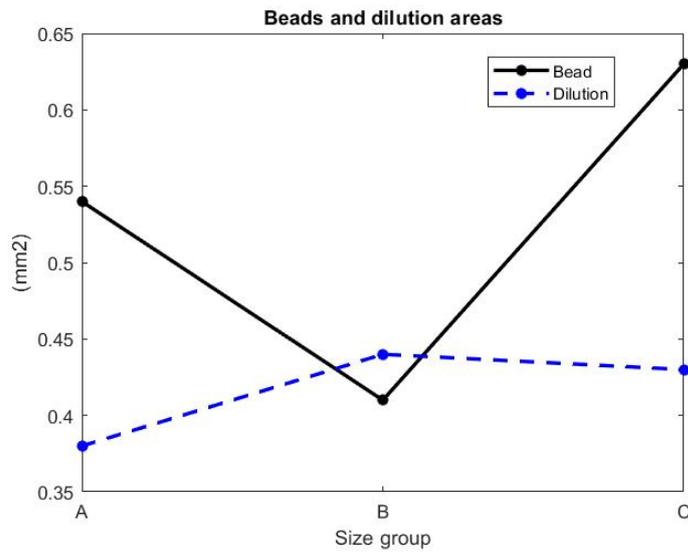


Figure 4. Dilution and bead areas

In figure 5, it can be observed in great detail how the particle size influences the quality of the parts manufactured by LP-DED process. Figure 5A shows a cube deposited with the smaller particles ( group A), where despite its small size, it exhibits significant porosity. In figure 5B, a cube with considerably lower porosity is observed, confirming the hypothesis that particle group B has an optimal grain size distribution for producing high-quality components. Finally, figure 5C shows a low porosity compared to the porosity level exhibited by the deposited bead with particle group C. This indicated that during the manufacturing process, the laser power has a significant influence on reducing porosity Svetlizky *et al.* (2021). briefly, these results highlight the importance of considering the size and morphology of the particles for the manufacturing of Inconel 718 components with optimal characteristics in their microstructure

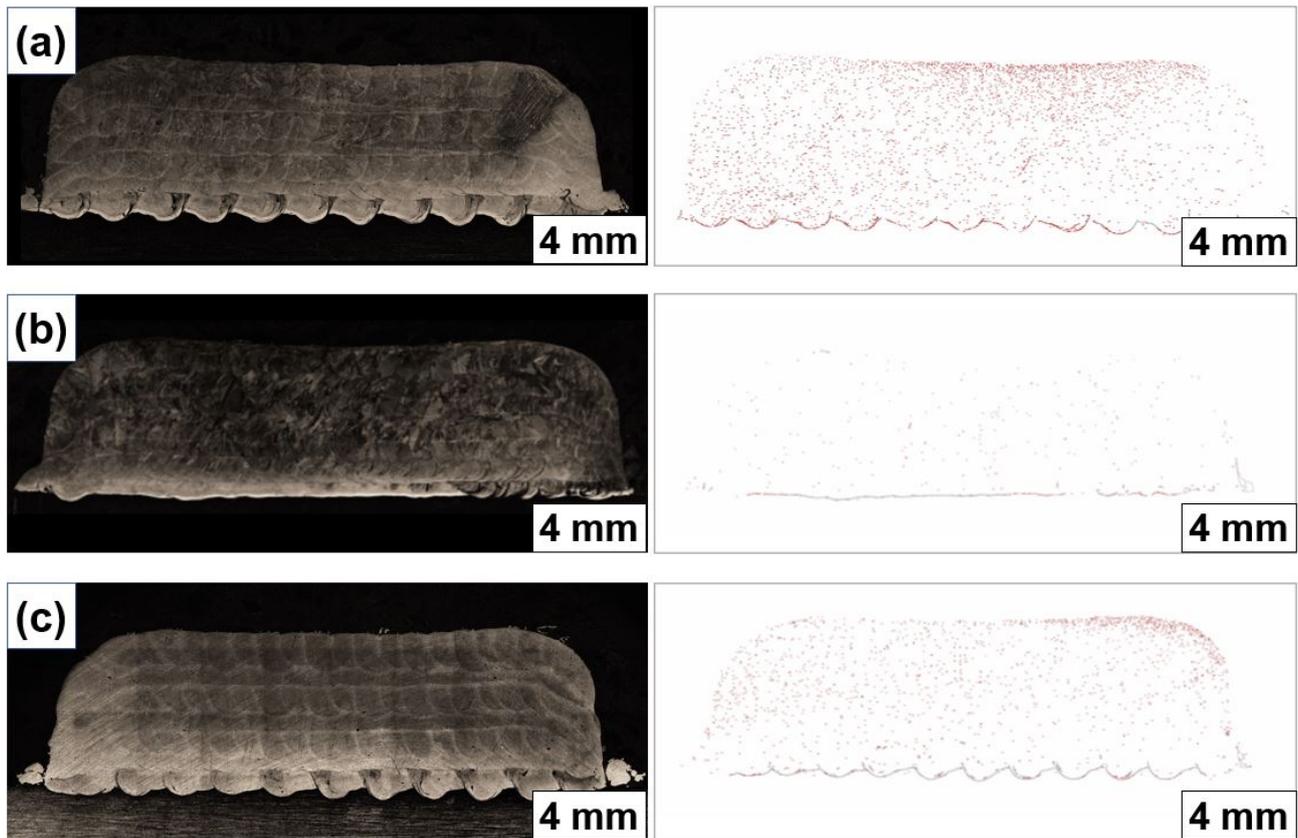


Figure 5. Optical macrographs of the cross-sections of the deposits, along with quantitative porosity analysis, for powder groups (a) A, (b) B, and (c) C

Figure 6 presents the Vickers microhardness profiles obtained in the cross-sectional areas of the deposits. It is evident that average hardness values of  $262.1 \pm 2.8$  HV5.0,  $261.6 \pm 3.5$  HV5.0, and  $261.1 \pm 3.14$  HV5.0 were recorded for groups A, B, and C, respectively. These findings suggest that the deposits exhibited similar hardness values, suggesting that the powder granulometry had no influence on the quality of the LP-DED deposits. When examining the microhardness profiles, we can observe that the hardness remained relatively consistent from the surface to the interface, indicating the high quality of the deposits. The average hardness of the AISI 304 substrate measured  $219.8 \pm 2.1$  HV5.0.

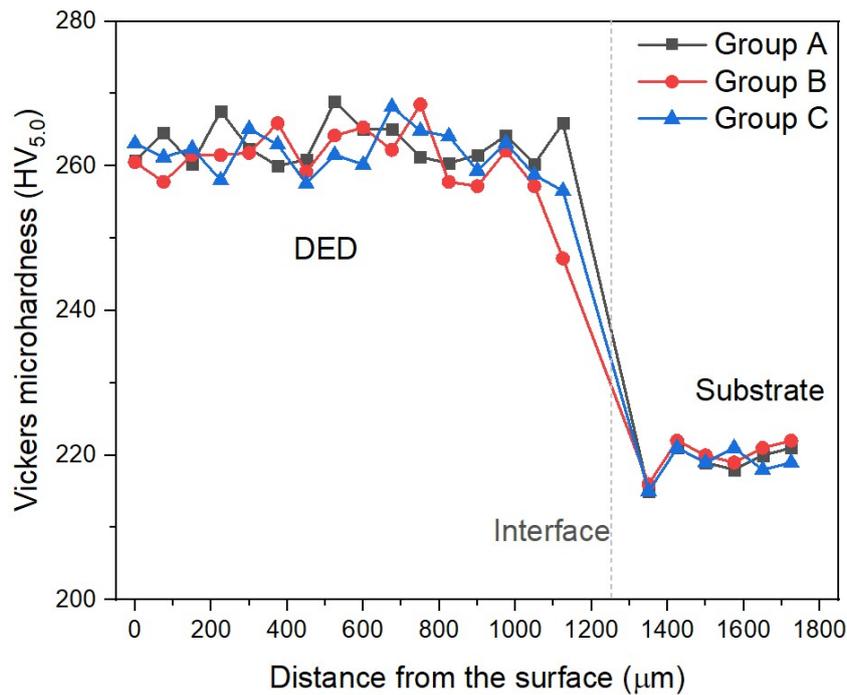


Figure 6. Vickers microhardness profiles obtained for the deposits

Figure 7 shows the calotest micro-abrasive wear test results for the deposits. No significant variations in the removed volumes were noted when comparing deposits from different samples. These findings align with the Vickers microhardness results, which similarly exhibited uniform characteristics across the various samples. This implies that the hardness and wear properties remained constant, irrespective of the powder granulometry utilized as the raw material.

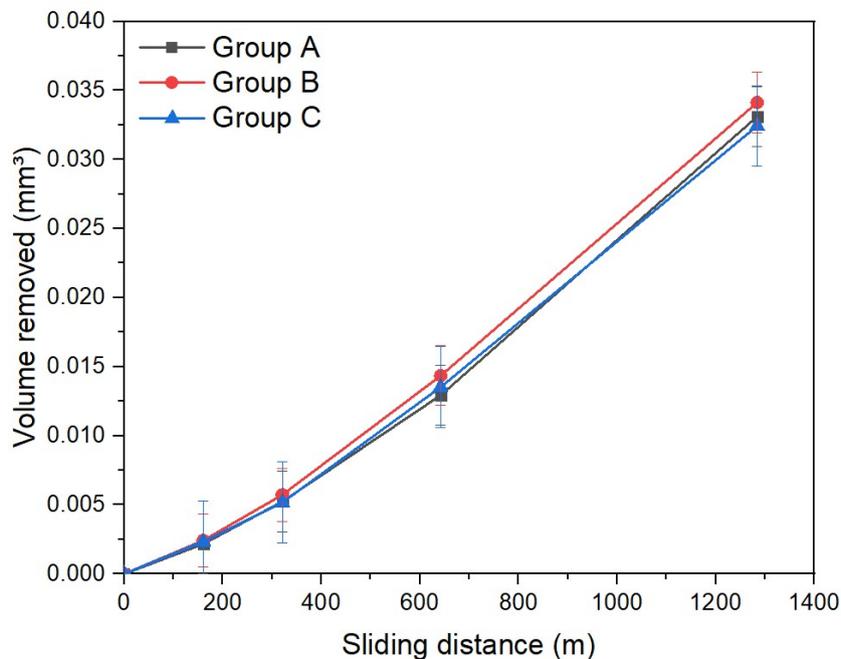


Figure 7. Graphs of the micro-abrasive wear tests.

#### 4. CONCLUSIONS

- An analysis was conducted on the influence of particle size on various aspects such as flowability, porosity and cross-sectional area. The results revealed that the relationship between particle size and porosity does not always follow a linear trend, thus challenging the theory that smaller particles inevitably result in a reduction of porosity. Additionally, it was observed that small variations in particle size have a significant impact on the parametrization

process in the LP-DED process using inconcel 718.

- The problem porosity in group A can be explained by the fact that the particles are smaller, resulting in a higher mass concentration at the convergence diameter. This prevents the laser from completely melting all the material concentrated at that point, which in turn induces porosity in the depositions. On the other hand, in group B having larger particles means that less mass is concentrated at the convergence point, allowing for more effective utilization of the laser power. Finally, group C, despite having the same flowability characteristics as group A, would face the issue of mas concentration at the lase focal point.
- Based on the consistency of the removed volumes in the depositions of the different samples, as well as the similarity of the Vickers microhardness results between them, we can conclude that the variations in the deposition conditions did not have a significant impact on the evaluated properties. This suggests a stability in the deposition process and in the quality of the analyzed samples, regardless of the granulometric variation of the powders used as raw material.

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