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DEVELOPMENT OF PURE IRON PROCESSING PARAMETERS FOR MEDICAL APPLICATIONS USING L-PBF: A FOCUS ON POROSITY

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1 INTRODUCTION

Biodegradable metals, such as zinc (Zn), magnesium (Mg), and iron (Fe) have gained significant attention in biomedical applications, particularly for the production of bone scaffolds and implants. These metals offer the unique advantage of degrading within the body over time, eliminating the need for secondary surgeries to remove implants. Pure iron has been demonstrated considerable potential due to its excellent biocompatibility and biodegradability [1,2].

Despite its advantages, pure iron has certain limitations that must be addressed for optimal use in biomedical applications. Its traditional biodegradability rate is too slow, which does not align with the desired rate of bone regeneration. Furthermore, the mechanical properties of pure iron are significantly higher than those of natural bone, potentially leading to issues such as stress shielding [2].

Metal additive manufacturing, particularly Laser Powder Bed Fusion (L-PBF), provides a solution to these challenges [3]. This technique allows for the creation of porous bone implants, layer by layer, with tailored lattice structures, resulting in a higher biodegradation rate, ensuring that the material resorbs at a rate more compatible with bone healing [3]. Additionally, porous structures can mimic the mechanical properties of bone, reducing the risk of stress shielding and promoting integration with the surrounding tissue.

This study used the L-PBF technology to develop process parameters for additive manufacturing of pure iron for future biomedical applications. A total of 206 parallelepipedal samples (5 x 5 x 7 mm^3) were printed with a pre-defined laser power value of 300 W.

2 PROCESS PARAMETERS

In the first phase, 84 samples were printed considering various parameter combinations, and visually inspected to evaluate overmelting or undermelting. The parameters tested in this first Design of Experiments (DoE) are shown in Table 1.

Table 1 - Pure iron L-PBF parameters tested in DoE 1.

Parameter	Range	Step:
Scanning Speed (mm/s)	500 – 1400	300
Spot Size (µm)	100 – 200	50
Hatch Spacing (mm)	0.05 - 0.2	0.025

Based on these observations, a refined set of parameters was chosen for the second phase, where an additional 120 samples were manufactured for detailed porosity analysis. The parameters tested in the second DoE can be observed in Table 2.

Table 2 - Pure iron L-PBF parameters tested in DoE 2.

Scanning Speed (mm/s)	500	800	1100	1400
Spot Size (µm)	100 – 200; step: 25			
Hatch Spacing (mm)	0.15 – 0.20 step: 0.01	0.125 – 0.175 step: 0.01	0.10 – 0.15 step: 0.01	0.10 – 0.15 step: 0.01

To quantify the porosity, the upper part of each sample (3 mm) was cut by electric discharge machining, ground and polished with a grinding wheel, and microscopically analyzed. Porosity measurements were conducted using ImageJ software.

3 RESULTS

The results, as displayed in Figure 2, revealed that samples processed with an energy density between 55 and 70 J/mm^3 and an energy intensity between 13,000 and 40,000 W/mm^2 exhibited optimal density levels approaching 100% relative density. These findings offer valuable insights into parameter optimization for pure iron in L-PBF, contributing to advancements in porous iron manufacturing for biomedical applications.

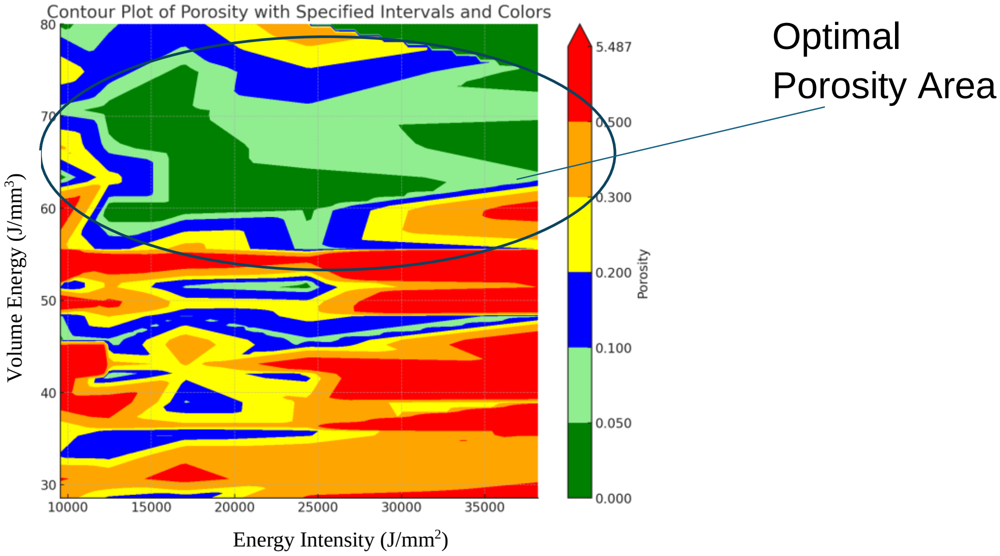

Figure 1 - Contour plot of porosity as a function of energy intensity (J/mm^2) and volume energy (J/mm3) during L-PBF processing of pure iron.

REFERÊNCIAS

[1] Pawan Sharma & Pulak M Pandey. 'Morphological and mechanical characterization of topologically ordered open cell porous iron foam fabricated using 3D printing and pressureless microwave sintering'. In: Materials & Design 160 (2018), pp. 442–454.

[2] Huafang Li, Yufeng Zheng & Ling Qin. 'Progress of biodegradable metals'. In: Progress in Natural Science: Materials International 24.5 (2014), pp. 414–422.

[3] Qin et al. 'Additive manufacturing of biodegradable metals: Current research status and future perspectives'. In: Acta Biomaterialia 98 (2019), pp. 3