Powder spreading effects on laser powder bed fused parts quality

Effets de distribution de la poudre sur la qualité des pièces fusionnées sur un lit de poudre laser

Fatima-Ezzahrae Jabri[1], Aissa Ouballouch[2], Larbi Lasri[3], Rachid El Alaiji[4]

[1] Laboratory of Innovative Technologies (LTI), ENSA, Abdelmalek Essaâdi University, Tanger,Morocco,fatimaezzahrae.jabri1@etu.uae.ac.ma,
[2] Laboratory of Mechanics, Productics and Industrial Engineering (LMPGI), EST, Hassan II University, Casablanca, Morocco, a.ouballouch@gmail.com
[3] Systems Engineering and Innovation Laboratory, Mechanics and Systems Engineering Team, ENSAM, Moulay Ismail University, Meknes, Morocco, Lasrilarbi@yahoo.fr
[4] Laboratory of Innovative Technologies (LTI), ENSA, Abdelmalek Essaâdi University, Tanger,Morocco, relalaiji@uae.ac.ma

ABSTRACT. Laser powder bed fusion (LPBF) is an additive manufacturing technique whose efficiency and quality depend largely on a consistent and precise powder spreading procedure. This article examines the crucial role of powder spreading in influencing the quality of 3D-printed parts. Through case studies and experimental results, the article demonstrates in detail the impact of parameters such as: powder flowability, spreading speed, layer thickness, and recoater type on powder uniformity during spreading. In addition, the paper presents a comparison between types of recoaters in order to obtain optimum surface finish, mechanical properties, and reduced defects. This paper reviews the most appropriate powder spreading techniques to maintain the flowability and uniformity of the powder. Therefore, the primary objective of this work is to present an in-depth review of the impact of powder spreading dynamics in LPBF. In addition, it aims to demonstrate to the reader the various factors influencing powder spreading and the methodologies employed to optimize this crucial process.

RÉSUMÉ. La fusion laser sur lit de poudre (LPBF) est une technique de fabrication additive dont l'efficacité et la qualité dépendent largement d'une procédure de distribution de poudre cohérente et précise. Cet article examine le rôle crucial de la distribution de la poudre dans l'influence de la qualité des pièces imprimées en 3D. À travers des études de cas et des résultats expérimentaux, l'article démontre en détail l'impact de paramètres tels que : la fluidité de la poudre, la vitesse de distribution, l'épaisseur de la couche et le type de recouvreur sur l'uniformité de la poudre pendant la distribution. En outre, l'article présente une comparaison entre les types de recouvreurs afin d'obtenir une finition de surface optimale, des propriétés mécaniques et une réduction des défauts. Ce document passe en revue les techniques de distribution de poudre les plus appropriées pour maintenir la fluidité et l'uniformité de la poudre. Par conséquent, l'objectif principal de ce travail est de présenter un examen approfondi de l'impact de la dynamique de la distribution de la poudre dans le LPBF. En outre, il vise à démontrer au lecteur les différents facteurs qui influencent la distribution de la poudre et les méthodologies employées pour optimiser ce processus crucial.

KEYWORDS. Additive manufacturing, laser powder bed fusion, powder spreading and spreading parameters.
MOTS-CLÉS. Fabrication additive, fusion de lit de poudre laser, distribution de poudre et paramètres de distribution.

1. Introduction

Laser Powder Bed Fusion (LPBF) additive manufacturing has emerged as a revolutionary technology for producing complex, high-performance parts with unprecedented design freedom [NOU 21]. At the heart of this process lies the precise manipulation of powders to build up intricate geometries layer by layer. Among the various stages of LPBF, powder spreading plays a pivotal role [MUS 21, OBE 22], laying the foundation for subsequent laser melting and solidification processes. A number of critical steps are involved in this process, such as powder recoating, deposition, laser melting, and the repetition of these steps for each layer. In this regard, the quality and uniformity of powder spreading directly influence the final properties and performance of 3D printed parts. Several factors need to be considered to ensure the effectiveness of powder spreading dynamics in the LPBF process. One of these is the characterization of powder properties, including particle size distribution, morphology, and flowability [GUO 24]. These properties directly affect the density, surface finish, and mechanical properties of the 3D printed parts. In addition, the design and calibration of the recoating mechanism [BEI 19, ZHA 20] are crucial, as they control the even distribution of powder layers and minimize defects such as uneven spreading and powder segregation. In this context , the powder spreading mechanism uses a blade or roller [AMA 21 ,PAR 16] to carefully displace a thin layer of powder from the feed bed to the print bed. The main objective of the spreading mechanism is to ensure uniform distribution and a constant thickness of each successive powder layer [MUS 21]. Any change in the thickness or distribution of the powder layer leads to part defects, including porosity, surface irregularities, or a lack of fusion [ZHA 20]. Hence, the main goal of this article is to provide a comprehensive exploration of the impact of powder spreading dynamics on the quality of LPBF parts. As well as, it gathers valuable insights and guidance for optimizing powder spreading techniques, drawing from experimental results and numerical simulations based on literature studies. So, this article is structured as follows: Section 2 highlights the key factors that influence the effectiveness of powder spreading. Section 3 explores the implications of powder spreading on surface finish and porosity of 3D printed parts. The conclusion summarizes the key findings and emphasizes the significance of accurate powder spreading.

2. Factors affecting powder spreading

The LPBF powder spreading process is affected by a number of variables, including the recoater type, layer thickness, powder flowability, and spreading speed [XIA 22]. In this regard, powder flowability is determined by factors such as the shape and size distribution of particles, as well as their surface morphology and density [GUO 24]. In addition, uneven dispersion and surface defects may result from a movement that is executed too quickly, whereas a movement that is executed too slowly may lengthen the process time and reduce output. Therefore, improving the effectiveness and dependability of the LPBF technology requires an awareness of and control of spreading speed. Besides, one important metric to consider is the thickness of each layer of powder. In this context, [CHE 19] noted that printing resolution is improved with thinner layers, but production time is increased, whereas manufacturing efficiency is improved and costs are reduced with thicker layers. Moreover, various recoaters, such as blades or rollers, can have different effects on the powder spreading process. Regarding distributing uniformity, speed, and the capacity to manage various types of powder, every type possesses its own set of benefits and drawbacks. Specifically for cohesive powders, the load on the underlying part and the accuracy of powder deposition are greatly affected by the shape of the spreader. Table 1 emphasizes the critical role played by these factors in determining the quality of powder spreading of LPBF process. With this knowledge, producers can regulate the powder spreading process more precisely, leading to more consistent and high-quality LPBF products.

Ref.	LPBF type	Material	Variable & Constant Parameters	Outputs
[CHE 17]	SLM	Metal	-Particle density: 7.8 kg/ m3 -Particle radius R : 9-140 µm -Layering height : 2-14R -Layering speed : 25–75 mm/s	- Decreasing the size of particles to less than 21.8 µm enhances the flowability of the powder and increases the quality of the bed.

[PAR 16]	SLS	PA12	-Translational velocity of the roller : 20 and 180 mm/s -Roller diameter: 2.5 mm - Particle material density : 1000 kg/m3	- Increased processing speed results in less dense packing, more space between particles, and a more irregular surface. -Substantial fluctuations in load during the coating process as a result of non-uniform interparticle interactions.
[DRE 18]	LMS	PA12	-Laser power : 6-33 W -Scan speed : 800-3300 mm/s -Coating speed : 100-450 mm/s -Particle diameter: 60 µm	-Higher coating rates lead to lower elongation and mechanical properties. - Lower coating speeds are associated with improved mechanical properties.
[ZHA 20]	SLM	Al2O3 ceramic	-Roller's translational speed : 40-160 mm/s -Roller's rotational speed : 40-320 rpm -Roller's diameter: 3-8 mm -Particle density : 3820 kg/m3	-Increasing roller translation speeds leads to a decrease in powder bed density, while using larger diameter rollers improves it.
[CHE 19]	SLM	316L stainless steel	-Layer thickness : 60-180µm -Particle size : 20-100µm -Material density: 7.8*10^3 kg/m3 -Spreading velocity: 100 mm/s	-Larger layers reduce the impact of both static and dynamic wall effects, leading to higher packing densities.
[HEC 20]	SLS	PA6	-Recoating Speed : 168-288 mm/s -Layer Thickness: 100-140 µm -Laser Power : 16-36 W -Scanning Speed Fill : 10.16 m/s -Hatch distance : 0.15 mm	-Anisotropic mechanical characteristics and part performance can be improved by slightly increasing fibre alignment in the recoating direction through reducing layer thickness. - Mechanical performance was unaffected by recoating speed.
[CHE 22]	SLS	CF/ PA12	-Spreading speed : 50–150 mm/s -Rotation speed : 0–4.8π rad/s -Layer thickness: 100 µm -Roller diameter: 10 mm -Particle size distribution : 30–70 µm	-Higher rotation rates in the counter-rotating roller are detrimental to powder bed stability, while forward-rotating rollers improve packing density and surface morphology in comparison to non-rotating and counter-rotating modes.

[BEI 19]	SLS	PA12	-Laser Speed : 550 mm/s -Layer thickness : 120 µm -Hatch distance : 0.3 mm -Blade geometries: Flat/Round/Sharp	-The uniformity and density of powder beds were best achieved with flat-bottom blades because of the broader horizontal contact zone they provided.
[HAE 17]	LPBF	PEEK	-Recoater geometries: Blade/Roller -Roller speed : 0.03-0.06 m/s. -Particle Density : 1300 kg/m3 -Layer thickness (before spreading) 10*10^ (-4) m	-The use of rollers, as opposed to flat-bottom blades, improved powder bed quality by avoiding particle dragging, lower roller speeds further improved these results.
[DRU 15]	LMS	PA12	-Recoater geometries: Rake/Roller -Laser power : 7.8-32.9 W -Scanning speed : 780-3290 mm/s -Coating speed : 125-500 mm/s -Particle size of d3,50 : 60 µm	- An optimal spreading speed of 250 mm/s was found for both blade and roller systems.

Table 1. *Impact of Parameters on Powder Spreading Quality in LPBF process*

3. Influence of powder spreading on part quality

Laser powder bed fusion (LPBF) relies heavily on the precision of powder spreading to specify the optimum properties of 3D printed parts. This section investigates the direct impact of powder layer uniformity on a number of critical quality criteria, including surface roughness and the presence of defects such as porosity. In a study conducted by [PET 19] pointed out that a higher roller speed resulted in a rougher powder bed surface. As well as, [WAN 22], underline that rougher surface finishes result from less particle deposition and higher shape variances between part cross-sections as the layer gap increases. In addition, [BUD 13] tried out recoaters like the blade and other rollers. They found that the counter-rotating roller with a 22mm diameter was the most efficient in producing high bulk density and outstanding surface quality. However, the effect of different powder compression ratios and laser re-melting regimes on the density and surface roughness of stainless steel 316L components was recently studied by [OBE 22]. By increasing the powder compression ratio and doing laser double passes over each layer, with density increases of up to 3%. As a result, a notable decrease of 50% in surface irregularity was detected through the implementation of laser dual pass processing. Besides, uneven distribution of powder can result in areas lacking material, which can cause incomplete melting and the formation of pores. According to [BER 07], the density of the powder bed can be increased by the use of roller compression. Also, [LU 08] pointed out that irregular powder layering leads to porosity formation caused by cohesion forces like Van der Waals' force. Conversely, [PAL 19, XIA 16] have shown that combining particles with varying sizes can increase the packing density of powders and decrease the porosity of the manufactured parts. Another approach is suggested by [NGU 18, SAL 17],which entails increasing the packing density by compressing the powder bed with a rigid roller. The goal of this approach is to reduce porosity and voids in the material structure of LPBF-produced parts.

4. Conclusions

In conclusion, laser powder bed fusion (LPBF) effectiveness depends on powder spreading quality. Our review on powder spreading and 3D printing component quality emphasizes the necessity of precision and consistency in this essential step. The efficacy of powder distribution influences every aspect of part quality, including surface quality, mechanical properties, and porosity. The main findings:

- The use of a forward-rotating roller to spread CF/PA12 composite powder in SLS improves powder bed compaction and surface morphology compared to traditional methods.
- Recoaters that are angled or rounded on the spreading process enhance the efficiency of powder deposition.
- Increased powder flowability (particle size and shape) leads to better surface quality and reduced porosity.
- Too high a recoater speed leads to uneven powder distribution, increasing surface roughness, while lower speeds improve mechanical properties by maintaining better thermal conditions in the powder bed.
- Thinner layers enhance surface quality but lower density and mechanical strength, while thicker layers enhance powder bed compaction and boost mechanical characteristics.
- Rollers generate a better powder bed than blades, lowering roughness and porosity.
- Recoater shape and rotation mode have an impact on powder compaction and deposition efficiency.

In summary, optimizing the qualities of the final part requires meticulous control of the powder spreading process, which in turn depends on the quality of the powder spreading.

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