

Innovative Powder Reuse Strategy in the Selective Laser Sintering Process using a Fluidized Bed System

Daniele Sofia*, Rossella Girimonte

Department of Computer Engineering, Modeling, Electronics and Systems, University of Calabria, Via P. Bucci cubo 44/a Rende (CS), 87036, Italy
daniele.sofia@unical.it

This study introduces an innovative method for the recovery and reuse of unsintered powder in the Selective Laser Sintering (SLS) process, widely used in additive manufacturing for creating complex components with a broad range of powder materials. The main challenge in this process is the effective management of unsintered powder, particularly the separation of aggregates formed during the sintering phase, to avoid compromising the properties of the reused material. The proposed fluidized bed system employs a gas flow to fluidize the powder, effectively separating the aggregates and restoring the powder's granularity to a quality similar to its original state. This process not only improves material efficiency by reducing waste but also maintains the desired properties of the powder for continuous reuse in the SLS process.

Experimental results demonstrate that the powder recovered through this method retains its essential characteristics, such as particle size distribution and flow properties, enabling its direct reuse in the SLS process work chamber. This approach represents a significant step toward sustainability and economic efficiency in additive manufacturing, providing a viable solution for powder reuse and reducing the environmental impact associated with the production of new powder.

1. Introduction

Selective Laser Sintering (SLS) stands today as one of the most advanced and versatile technologies in the field of additive manufacturing. This technique enables the production of highly complex and customized components, utilizing a wide range of powder materials and making it possible to create geometries that would be impossible with traditional manufacturing methods (GU et al, 2012). Thanks to its ability to produce detailed, robust parts without the need for additional support structures, SLS has found widespread application in numerous industrial sectors, including automotive, aerospace, biomedical devices, and consumer goods (Ojala et al, 2016).

However, behind the clear advantages of this technology lie important challenges—one of the most critical being the effective management and recovery of unsintered powder. During the printing process, not all of the powder is fused by the laser. A significant portion remains unused, accumulating in the build chamber. Reusing this leftover powder is essential for maintaining the economic and environmental sustainability of the process. Yet, reuse is not straightforward: the high temperatures and laser exposure during printing can lead to the formation of aggregates and alter the physical properties of the powder, compromising its quality. If this “spent” powder is not properly treated, it can result in defective parts characterized by undesirable porosity, surface irregularities, or, in the worst cases, structural weakness (Luo et al, 2014).

Traditionally, mechanical methods such as sieving and filtration have been employed to recover and separate unused powder. While these methods are well-established and relatively simple, they come with notable limitations. Their effectiveness drops significantly when dealing with particles of very similar sizes or when trying to remove small but cohesive aggregates. Moreover, these techniques often require considerable manual intervention, which increases processing times and reduces overall production efficiency (Liu et al, 2007).

To overcome these limitations and address the challenges of powder separation more effectively, research has increasingly focused on alternative, more advanced approaches.

Among these, fluidized bed separation has emerged as a particularly promising solution. This technique uses a flow of gas to fluidize the powder, creating a dynamic environment in which particles behave like a fluid. In this state, heavier aggregates can be effectively separated from finer, more uniform powder particles without the need for manual handling or complex mechanical operations. The continuous and automatic operation of a fluidized bed system not only reduces production downtime but also ensures consistent quality in the recovered material.

Adopting a fluidized bed system for powder separation in the SLS process is more than just a technological upgrade—it represents a meaningful step toward more sustainable and economically viable additive manufacturing. By reducing the need for purchasing new powder and minimizing waste, manufacturers can lower production costs and shrink the environmental footprint of their operations, addressing key priorities in an era of growing sustainability awareness.

In light of these considerations, the aim of this study was to design, develop, and validate a fluidized bed system capable of efficiently recovering unsintered powder from the SLS process. The goal is to enable the reuse of powder without compromising its essential properties, such as particle size distribution and flow characteristics, and without introducing defects into the final printed parts. This work seeks to provide a concrete solution to one of the key challenges in additive manufacturing, helping to establish a more sustainable, efficient, and resource-conscious production model.

2. Materials and Methods

In this study, we adopted an innovative approach for the recovery and reuse of unsintered powder in the Selective Laser Sintering (SLS) process, leveraging the unique capabilities of the Sintratec Kit SLS apparatus and Sintratec PA12 Powder polymer, combined with the use of a fluidized bed column for effective separation of aggregates from the powder. Below, we provide a detailed description of the materials and methods used.

2.1 Materials

Sintering (SLS) 3D printing, widely used in industrial additive manufacturing. Known for its exceptional mechanical strength, durability, and precision, it is ideal for creating both functional prototypes and end-use parts (Bertrand P. et al, 2007). PA12 Powder's key advantages include its ability to withstand significant mechanical stress, impact, and fatigue, making it suitable for demanding environments. It also maintains integrity under high temperatures and resists a variety of chemicals, ensuring longevity and reliability. The powder offers excellent dimensional stability and precision, producing parts with tight tolerances.

While SLS parts typically have a rough surface texture, PA12 parts can be post-processed for a smoother finish if needed (Kahrizangi S. et al, 2015). The material's versatility makes it suitable for various industries such as automotive, aerospace, consumer goods, and medical devices. It enables the creation of complex designs without support structures, reducing waste and increasing efficiency.

PA12 is used extensively for durable components like hinges and gears in the automotive and aerospace sectors, custom prosthetics and surgical instruments in medical fields, and consumer products like protective cases and sports equipment. Its robustness and versatility make it a valuable material for innovative and reliable 3D printing solutions (Lupo M. et al, 2023).

Table 1: Characteristics of PA12 Powder.

Materials	T_m (°C)	ρ_B (kg/m ³)	ρ_P (kg/m ³)	d_{10} (µm)	d_{50} (µm)	d_{90} (µm)	$d_{3,2}$ (µm)	$d_{4,3}$ (µm)
PA12	210	525	1130	15	46	91	20	50

Sintratec PA12 Powder is a cornerstone material in SLS 3D printing, offering a harmonious balance of performance, durability, and versatility. Its widespread adoption not only drives innovation in design and product development but also promotes sustainable manufacturing practices by optimizing material use and minimizing waste (Lupo M. et al, 2019). This material is truly at the forefront of advancing the capabilities and applications of additive manufacturing.

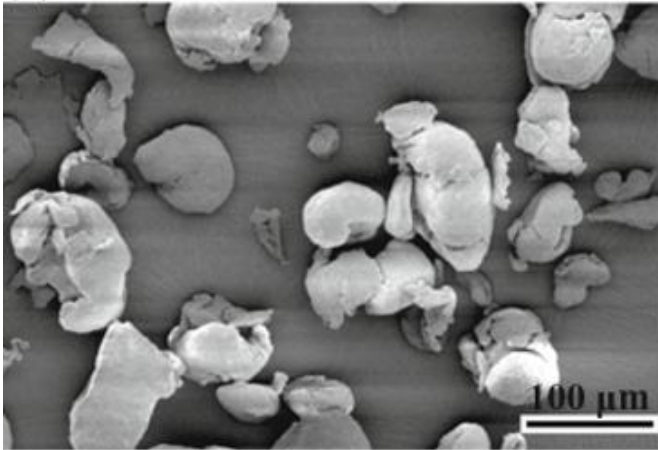


Figure 1. Electron microscopy of PA12 powder.

2.2 SLS apparatus

For this study, we used the Sintratec Kit SLS apparatus, chosen for its innovative design and research-friendly features. This system is particularly advantageous because of its open parameter settings, which allow precise adjustments to key printing parameters such as laser speed and temperature. These adjustments are crucial for tailoring the SLS process to various materials and experimental needs.

The Sintratec Kit offers a maximum print volume of 110 x 110 x 110 mm, providing ample space for diverse experimental designs. However, for optimal results, we recommend a print volume of 90 x 90 x 90 mm. The laser speed is highly adjustable, ranging from 5 to 600 mm/s, enabling fine-tuning to suit different materials and desired print qualities. Layer height can be set between 100 and 150 μm , which facilitates the creation of detailed and precise layers. The overall dimensions of the apparatus are 520 x 520 x 360 mm, making it compact yet powerful. Weighing 36 kg, the unit is stable during operation, ensuring consistent performance.

Temperature control is another critical feature of the Sintratec Kit. The chamber temperature can be adjusted between 30 and 145 $^{\circ}\text{C}$, which is essential for maintaining optimal conditions for various materials. Additionally, the surface temperature can be set from 80 to 180 $^{\circ}\text{C}$, providing further control over the printing process.

These specifications make the Sintratec Kit highly versatile and efficient under a wide range of conditions. The ability to adjust parameters like laser speed and temperature allows for extensive experimentation with different materials, optimizing the printing process to achieve the best possible results. This flexibility is essential for advancing SLS technology and exploring new possibilities in additive manufacturing.



Figure 2. Sintratec Kit SLS Apparatus.

2.3 Method

The study embarked on an innovative journey to explore the recovery and reuse of unsintered powder in the Selective Laser Sintering (SLS) process, leveraging the unique capabilities of the Sintratec Kit SLS apparatus

and the high-performance Sintratec PA12 Powder, alongside a fluidized bed column for effective aggregate separation (Macri D. et al, 2020). This methodical approach aimed to enhance the sustainability and efficiency of SLS manufacturing processes. Here's how the study was meticulously structured to achieve its objectives:

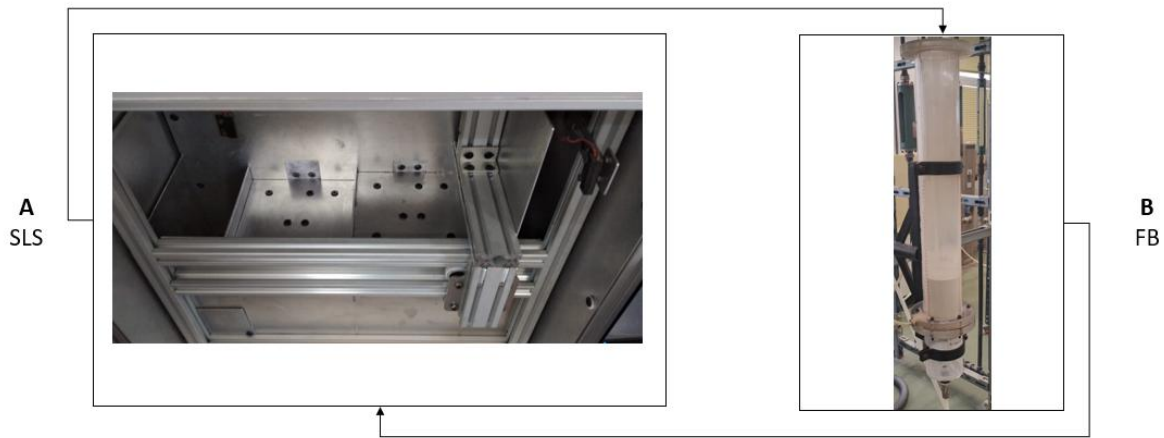


Figure 3. Process scheme.

The study was designed to develop an integrated, systematic approach for recovering and reusing polyamide PA12 powder used in Selective Laser Sintering (SLS) 3D printing a process known to generate significant material waste if effective recycling strategies are not implemented. It began with the careful preparation of Sintratec PA12 powder, a thermoplastic chosen for its high mechanical strength, thermal stability, and proven compatibility with SLS systems. The powder was precisely weighed and evenly distributed inside the Sintratec Kit SLS apparatus, ensuring a flat, uniform layer critical for avoiding fusion defects and achieving proper layer-by-layer bonding during sintering. The actual printing process was conducted using specifically tuned laser parameters power, scan speed, and layer thickness designed to fully exploit the material's properties and produce uniformly dense, high-quality parts while minimizing partially fused or thermally degraded powder. After printing, all unsintered powder was recovered using an automatic suction system designed to minimize loss and ensure complete collection of even the finest particles or aggregates formed due to secondary heat exposure or ambient humidity. This recovered powder typically exhibited less controlled particle size distribution and included solid agglomerates that could compromise the mechanical properties and surface quality of new parts if reused without treatment. To address this, the collected powder was processed in a purpose-built fluidized bed column with an internal diameter of 100 mm and a total height of 1000 mm, dimensions chosen to balance particle residence time, stable fluidization regimes, and sufficient batch-processing capacity. Fluidization was carried out at ambient temperature (20 °C) using an adjustable air flow rate between 50 and 150 NL h⁻¹, allowing precise control of the fluid velocity to optimize separation based on the characteristics of each powder batch. Air was uniformly distributed at the base of the column through a porous plate or diffuser, suspending finer, lighter particles in a turbulent pseudo-fluid regime while heavier, malformed aggregates tended to settle or be diverted away. This process exploited differences in particle terminal velocities and the balance between drag forces and gravity, enabling effective physical classification and removal of undesired solid lumps or partially fused contaminant particles. The fluidized bed's effectiveness also supported in the literature (Girimonte et al., 2018) lay in its ability to break weakly bound agglomerates through turbulence and recover a powder fraction whose size distribution approached that of virgin material, restoring its suitability for reuse in SLS printing. At the end of this treatment, the regenerated powder was carefully collected in sealed containers, analyzed to verify particle size distribution and residual aggregate content, and subsequently reloaded into the Sintratec Kit SLS apparatus for further print cycles thus closing the production loop with a circular approach. This entire protocol, structured in interdependent phases careful powder preparation and loading, controlled SLS printing, complete recovery via automated suction, regeneration in a fluidized bed column with well-defined parameters (100 mm internal diameter, 1000 mm height, 20 °C operating temperature, and 50–150 NL h⁻¹ air flow rate) was designed to minimize waste, optimize additive manufacturing efficiency, and improve environmental sustainability by demonstrating the technical feasibility of a closed-loop recycling system for polymer powders in 3D printing.

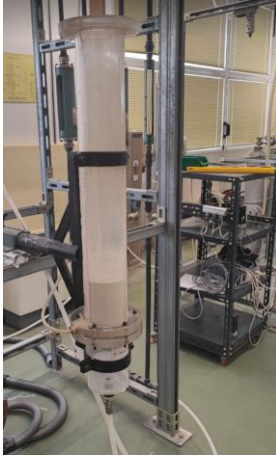


Figure 4. Fluidized bed's

3. Results and discussion

The study results showed that the upper layers of the fluidized bed column contained less mass, with a higher concentration of finer particles at the top. Consequently, it is necessary to recover the powder from the top of the bed to avoid the formation of aggregates, which tend to accumulate at the bottom of the column.

This observation suggests that the powder recovered from the upper layers, being finer and more homogeneous, can be further processed in the SLS apparatus using automated suction systems. This technique improves the efficiency and quality of the sintering process while ensuring the sustainability of powder reuse. As evident in Fig. 4, the automated recovery of powder from the upper layers of the fluidized bed can be integrated into the workflow to optimize production.

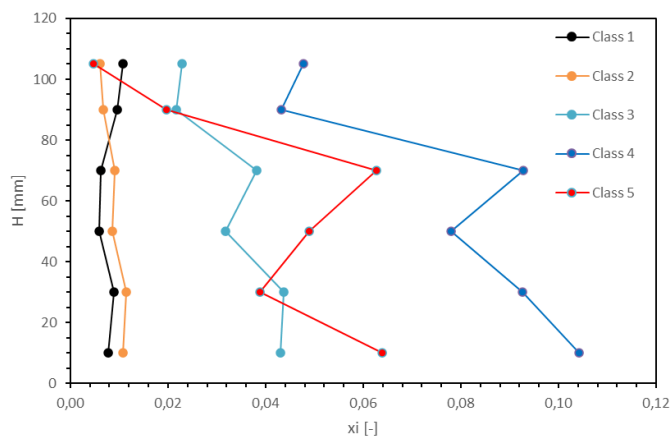


Figure 5. Particle size class profiles versus column height.

4. Conclusions

The findings of this study highlight the importance of an effective powder recovery strategy in the Selective Laser Sintering (SLS) process to enhance material efficiency and sustainability. Through the integration of a fluidized bed separation system, it has been demonstrated that unsintered powder can be successfully recovered and reused without compromising its properties. The recovered powder maintains a consistent particle size distribution and flowability, making it suitable for multiple reuse cycles in the SLS process.

The study provides compelling evidence that this method significantly reduces material waste, addressing one of the major challenges in additive manufacturing. By ensuring that high-quality powder is available for subsequent printing cycles, this approach not only minimizes production costs but also contributes to environmental sustainability by limiting the need for new raw materials. The ability to recycle and reuse powder without a loss in quality or efficiency marks a substantial advancement in sustainable manufacturing practices.

Additionally, the automated nature of the fluidized bed system presents a practical solution for industrial applications, reducing manual intervention and streamlining the powder recovery process. The reduction in downtime and material wastage further enhances the economic feasibility of this method, making it a viable solution for large-scale manufacturing environments.

Future research should focus on optimizing process parameters to further improve the efficiency of the powder recovery system. Investigations into the behavior of different powder materials under fluidized bed conditions and the impact of extended reuse cycles on mechanical properties will provide valuable insights for broader applications. Furthermore, integrating real-time monitoring technologies could enhance process control, ensuring consistent powder quality and system performance over time.

Overall, this study presents a robust and effective method for improving the sustainability and efficiency of the SLS process. By addressing key challenges related to powder reuse, this work contributes to the ongoing advancement of additive manufacturing technologies, paving the way for more resource-efficient and cost-effective production methods.

This study demonstrates that integrating a fluidized bed separation system within the SLS process enhances powder reuse, reduces material waste, and improves cost efficiency. The findings indicate that powder recovered from the upper layers of the fluidized bed column is of high quality and suitable for reuse, ensuring sustainable additive manufacturing practices. Future research will focus on optimizing process parameters to further enhance powder recovery efficiency.

References

- Bertrand, P., Bayle, F., Combe, C., Goeriot, P. and Smurov, I. (2007) 'Ceramic components manufacturing by selective laser sintering', *Applied Surface Science*, 254, pp. 989–992. doi:10.1016/j.apsusc.2007.08.085.
- Girimonte, R., Formisani, B. and Vivacqua, V. (2018) 'The relationship between fluidization velocity and segregation in two-component gas fluidized beds: Density- or size-segregating mixtures', *Chemical Engineering Journal*, 338, pp. 63–73.
- Gu, D.D., Meiners, W., Wissenbach, K. and Poprawe, R. (2012) 'Laser additive manufacturing of metallic components: materials, processes and mechanisms', *International Materials Reviews*, 57, pp. 133–164. doi:10.1179/1743280411Y.0000000014.
- Kahrizangi, S.H., Sofia, D., Barletta, D. and Poletto, M. (2015) 'Dust generation in vibrated cohesive powders', *Chemical Engineering Transactions*. doi:10.3303/CET1543129.
- Liu, C., Xia, Z. and Czernuszka, J.T. (2007) 'Design and development of three-dimensional scaffolds for tissue engineering', *Chemical Engineering Research and Design*, 85, pp. 1051–1064. doi:10.1205/cherd06196.
- Luo, X., Liu, Y., Gu, C. and Li, Z. (2014) 'Study on the progress of solidification, deformation and densification during semi-solid powder rolling', *Powder Technology*, 261, pp. 161–169. doi:10.1016/j.powtec.2014.04.001.
- Lupo, M. et al. (2019) 'Calibration of DEM simulation of cohesive particles', *Chemical Engineering Transactions*. doi:10.3303/CET1974064.
- Lupo, M. et al. (2023) 'Experimental metrics of the powder layer quality in the selective laser sintering process', *Powder Technology*. doi:10.1016/j.powtec.2023.11834.
- Macri, D. et al. (2020) 'Characterization of the bulk flow properties of industrial powders from shear tests', *Processes*, 8(5), p. 540. doi:10.3390/PR8050540.
- Ojala, L.S., Uusi-Kyyny, P. and Alopaeus, V. (2016) 'Prototyping a calorimeter mixing cell with direct metal laser sintering', *Chemical Engineering Research and Design*, 108, pp. 146–151. doi:10.1016/j.cherd.2015.11.015.