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Abstract

Effect of temperature on the powder flow properties and their dispersion in Selective Laser Sintering (SLS) process

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Abstract

Understanding the flow properties of powders is paramount in industries reliant on powder-based processes, as it directly impacts production quality, efficiency, and ultimately, the bottom line. Powder flow properties play a pivotal role in ensuring optimal processing conditions across various stages of manufacturing, from handling and transportation to blending and deposition. One of the primary reasons why powder flow properties are critical lies in their influence on process quality and speed. In industries such as pharmaceuticals, food processing, and additive manufacturing, where powders are extensively used, the ability to control and predict powder flow behavior is indispensable. Poor flow properties can lead to inconsistencies in feed rates, uneven distribution of materials, and even equipment malfunction, all of which can significantly impede process efficiency and increase production costs. Furthermore, the impact of powder flow conditions extends beyond the manufacturing process itself to the final properties of the manufactured materials. Given the critical importance of powder flowability, it is essential to identify and understand the key parameters that influence it. Moreover, advancements in analytical techniques, such as powder rheology and particle characterization methods, have facilitated more accurate assessment and prediction of powder flow behavior. These tools enable manufacturers to not only evaluate powder flow properties under various conditions but also to tailor formulations and process parameters to achieve desired flow characteristics and enhance product quality and performance.

Additive Manufacturing (AM), often synonymous with 3D printing, offers numerous advantages that extend well beyond traditional manufacturing paradigms. Its capacity for flexible design allows for the creation of complex geometries and structures that were previously considered impractical or impossible with subtractive manufacturing methods. This flexibility empowers designers and engineers to innovate without the constraints of conventional fabrication processes, leading to more efficient and performance-optimized products. The on-time production capabilities of AM align perfectly with the modern demand for rapid turnaround and lean manufacturing practices. By significantly reducing the lead time from design to finished product, companies can respond more swiftly to market changes and customer needs, ensuring a competitive edge in fast-paced sectors. This agility also supports customized production at scale, a trend that is increasingly popular in industries such as consumer electronics and personalized medical devices. Rapid prototyping is another hallmark of additive manufacturing, enabling the quick realization of ideas into tangible models. This accelerates the development cycle, allowing for more iterative testing and refinement stages, which in turn enhances the final quality of the product. High final quality is further ensured through advancements in AM technologies, including improved materials, precision, and repeatability of processes. The adoption of additive manufacturing across diverse industries like automotive, aerospace, and biomedical reflects its transformative potential. In the automotive sector, AM is revolutionizing the production of lightweight, complex components, contributing to more fuel-efficient vehicles. The aerospace industry benefits from the technology's ability to manufacture parts that reduce aircraft weight without compromising strength or integrity, leading to significant savings in fuel and emissions. In the biomedical field, additive manufacturing is facilitating the creation of customized prosthetics and implants tailored to individual patient anatomy, improving outcomes and patient quality of life. As the costs associated with additive manufacturing continue to

decrease, thanks to improvements in technology and material science, its accessibility and viability as a mainstream manufacturing option are expected to rise. This cost reduction, coupled with ongoing research and development, promises to unlock even more applications and drive widespread adoption across various sectors. Future advancements may include the integration of AM with other technologies, such as artificial intelligence and the Internet of Things, further enhancing its capabilities and applications. The evolution of additive manufacturing represents not just an alternative to traditional manufacturing methods, but a fundamental shift towards a more innovative, efficient, and customized production future.

One of the Laser-based AM methods is selective laser sintering (SLS). SLS is one of the new manufacturing methods which allows fabricating 3D products by adding powders layer by layer. Every layer plays a crucial role in final product properties and needs a uniform powder layer formation per run. In other words, high flowability and spreadability of powders in each layer are necessary. This step of powder delivery is affected by the properties of the powders, namely the particle size distribution and morphology, and by process conditions, such as the blade velocity and the preheating temperature. In particular, the temperature can significantly affect the flowability of powders by changing the intensity of cohesive inter-particle forces like van der Waals forces. Consequently, increasing cohesion could cause particle aggregation and, thus, a non-homogeneous powder layer formation. In addition, the temperature is a key parameter to improve the quality of the sintered specimens because it can reduce thermal stresses and the formation of cracks, improve the final artefact density due to the improved wetting of the fused phase, or reduce the laser energy demand for sintering. On the other hand, powder preheating to high temperatures can reduce powder flowability and impair the powder bed preparation strategy. It is therefore required to understand the suitability of powder materials in the SLS process and to identify the best operating conditions to obtain high-quality layers in the powder spreading process.

In the pursuit of optimizing the Selective Laser Sintering (SLS) process, the flowability and spreadability of polymeric powders have emerged as critical factors determining the efficiency and quality of manufactured parts. The investigation into these properties employed an Anton Paar Shear cell for measuring flowability and a custom-built spreading machine from the University of Salerno for assessing spreadability. Further, these empirical findings were juxtaposed with the outcomes of discrete element method (DEM)-based simulations to gain deeper insights into the behavior of polymeric powders under varying conditions. The comparative analysis of experimental data revealed a trend where, for most of the materials studied, flowability diminished as the temperature was elevated. This observation underscores the sensitivity of polymer powders to thermal conditions, which can significantly alter their behavior during the SLS process. The study of flow properties of various in general indicates a decrease in powder flowability as the temperature increased. However, specific materials displayed unique characteristics and behaviours. For instance, in the case of PA6, PA6 black, PPNAT, and PEKK powders, the flowability gradually decreased with rising temperature. This observation suggests that these materials experienced a gradual plasticization effect, resulting in deteriorated flow properties. However, as the temperature approached their respective melting points, a significant effect of temperature on flowability became evident. When the temperature approaches the melting point, the materials change their flow behaviour significantly. This change could be attributed to the substantial plastic deformation at the contact points, creating significant interparticle forces. Consequently, this led to the formation of a cohesive powder. In contrast, TPU exhibited a different pattern. The flowability of TPU powder decreased much slower with increasing temperature. This behaviour suggests that TPU materials are more resistant to temperature-induced changes in flow properties. While the flowability reduction was observed, it occurred at a relatively slower pace compared to the other tested materials. These findings highlight the material-dependent nature of flowability and its response to temperature variations. The observed trends provide valuable insights into the behaviour of different polymeric materials, aiding in the understanding and optimising of powder processing techniques. Additionally, the research involved a comparative analysis of two Zeolite powders consisting of the same material but differing in their particle size distribution and shape. It was found that the variation in temperature had a noticeable influence on the results. The combined effect of contact points and particle size distribution was estimated and accounted for in a theoretical framework in which the changes in the bulk properties and consolidation could be related to the elastic-plastic behaviour of the contacts between particles. The observed trends could be attributed to an increase in van der Waals forces, which play a crucial role in the interaction between particles. At higher temperatures, the plasticization of the contact point between particles becomes more pronounced, leading to enhanced van der Waals forces. This phenomenon contributes to the overall behaviour and performance of the materials under investigation. The obtained results are largely consistent with previous findings regarding the impact of temperature on the properties of these materials. It is believed that the ability to accurately measure and understand their behaviour at high temperatures and identify key factors influencing their performance can leverage the enhancement of powder bed-based manufacturing processes, ensuring the production of materials that meet desired specifications and exhibit improved performance characteristics. Concerning the powder spreadability experiments, the developed experimental protocol and image analysis procedure would help a quantitative assessment of the roughness of the layer surface obtained by the spreading process at various experiments conditions, involving two distinct spreading velocities (3 and 30 mm/s) and temperature ranges from 25°C to 110°C. The results indicated a general degradation in spreadability with spreading speed and temperature increase. Notably, the specific temperature at which spreadability was optimized varied based on several factors, including the particle size and shape, the polymer's melting temperature, and the chosen spreading velocity. This variability suggests that the interplay between these factors is complex and that optimal processing conditions may be highly material-specific.

Furthermore, the analysis demonstrated that the conventional flowability classification does not provide a comprehensive understanding of spreadability. This finding is significant as it highlights the necessity of considering both properties independently when optimizing the SLS process. Although flowability might give an initial indication of the powder's suitability for SLS, spreadability directly impacts the uniformity and density of the powder bed, which are crucial for achieving parts with high dimensional accuracy and mechanical properties. The DEM simulations offered a powerful tool for reproducing and understanding the powder spreading dynamics observed in the experiments. The ability of the DEM model to closely mimic the experimental results underscores its potential as a predictive and diagnostic tool in the development of SLS materials and processes. By simulating various conditions, researchers can anticipate how changes in powder characteristics or process parameters might influence the final product quality, thereby guiding the optimization of SLS operations.

This comprehensive study highlights the nuanced relationship between temperature, powder properties, and their impact on flowability and spreadability in the context of SLS. The findings emphasize the need for a multifaceted approach to powder characterization, one that incorporates both experimental and simulation techniques to tailor materials and process parameters for optimal SLS performance. As the field of additive manufacturing continues to evolve, such insights will be invaluable for advancing the capabilities and applications of SLS technology.