Exploring Metal Additive Manufacturing Processing Parameters in Ansys Granta EduPack

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Summary

Laser Powder Bed Fusion (LPBF) revolutionizes metal 3D printing by using a powerful laser to precisely melt and fuse metal powder layers, enabling the creation of intricate, custom metal parts. Optimizing LPBF processing parameters, including laser power, scanning speed, hatch spacing, and powder layer thickness, is crucial for minimizing flaws such as porosity. Ansys Granta EduPack facilitates this exploration, offering a user-friendly platform with 35 datasheets for alloys like Inconel 625, SS316L, AlSi10Mg, and Ti64. Laser energy density (LED) emerges as a key factor influencing material properties and porosity, with careful control necessary to strike a balance between optimal fusion and avoiding defects.

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1. Introduction

Laser Powder Bed Fusion (LPBF) is an advanced method in metal 3D printing that uses a powerful laser to precisely melt and fuse metal powder layers. This technique allows for the creation of detailed and custom metal parts. The key to producing top-quality components with minimal flaws, like porous areas, lies in optimizing the processing parameters of LPBF.

Important factors such as laser power, scanning speed, hatch spacing, and powder layer thickness directly affect how the metal powder melts and solidifies. Controlling these parameters carefully is crucial for minimizing porosity, which can weaken the structure of the final product.

To improve the LPBF process for each material, the optimization process starts by melting individual tracks under different processing conditions on a layer of powdered material. Analyzing the resulting melt pools provides an initial assessment. Parameters that affect melt pool depth, width, and length give insights into potential issues like lack of fusion, keyholing, and balling. This step helps in narrowing down the range of processing parameters being investigated, as the parameters sets that result in significant defects can be discarded going forward.

The next step involves applying the remaining processing parameters to create small-scale specimens, often in cube form. Examining the porosity in these specimens helps identify the best processing parameters for the specific material. This method not only narrows down the parameters under consideration but also ensures that the chosen set produces minimal or no porosity during the manufacturing process.

This approach can also be adapted to address other structural issues, such as micro-cracks, or to find processing parameters that result in a desired microstructure. In essence, achieving optimal additive manufacturing involves systematically exploring processing parameters to create flawless and high-quality metal components.

2. LPBF processing parameters and their effects

2.1 Laser Power

The rate at which energy is emitted from a laser source. Laser power is a fundamental processing parameter in LPBF. It refers to the amount of energy delivered by the laser beam to the metal powder bed during the melting process. The laser power typically ranges from a few hundred watts to several kilowatts in LPBF applications, depending on the machine being used. The laser power directly affects the heating and melting rates, as well as the temperature distribution within the powder bed. Higher laser power leads to increased energy input, resulting in faster heating and higher temperatures. This can influence the melt pool size, solidification behavior, and thermal gradients within the material. Proper control of laser power is crucial for achieving desired material properties, controlling porosity, and ensuring optimal part quality in LPBF.

2.2 Laser Speed

Laser scanning refers to the velocity at which the laser beam scans over the metal powder bed during the melting process. The scanning speed typically ranges from a few hundred millimeters per second to several meters per second in LPBF applications. The scanning speed directly influences the energy deposition rate and the time available for heat transfer and solidification. Higher scanning speeds result in shorter exposure times at each location, leading to reduced heat input and a faster cooling rate. This can affect the size, shape and temperature profile of the melt pool, the microstructure of the material, possible element evaporation loss, fluidity and viscosity of the molten metal, grain morphology and the overall part quality.

2.3 Hatch Spacing

The distance between adjacent laser scan tracks during the fabrication of each layer. It determines the overlap and spacing between the melted regions, impacting the quality and properties of the manufactured parts. The range of hatch spacing values typically used in LPBF varies depending on factors such as the material, laser power, and scanning speed, but commonly falls within the range of 50 to 200 micrometers. Optimizing the hatch spacing can influence part density, surface roughness, residual stresses, the occurrence of defects like porosity and warping, and production speed. Large hatch spacing can lead to insufficient overlap between adjacent melt tracks, resulting in reduced part density and increased porosity. It can also cause surface roughness and decreased dimensional accuracy. On the other hand, using a small hatch spacing can enhance part density and surface quality by promoting better fusion between adjacent melt tracks. However, it may also increase the risk of balling and excessive heat accumulation, leading to higher residual stresses and potential distortion in the manufactured parts.

2.4 Layer Thickness

The height of each printed layer, typically in tens of micrometers. The optimal range of layer thickness depends on factors such as the metal material, desired resolution, and system capabilities. Additionally, the particle size of the metal powder used in LPBF plays a role in deciding the appropriate layer thickness, as finer powders allow for thinner layers and potentially finer microstructures in the final part. Thicker layers result in faster build times but may compromise surface finish and fine details. Conversely, thinner layers enhance precision and surface quality but increase build time. The choice of layer thickness also impacts the material properties of the manufactured part, as it influences factors like grain size, microstructure, and residual stresses.

3. Laser energy density and porosity

Continuing the investigation of crucial parameters in Metal Laser Powder Bed Fusion (LPBF), Laser Energy Density (LED) emerges as a key factor measuring the energy delivered to the powder bed, and it provides a comprehensive understanding of how the above-mentioned parameters' interplay contributes to the overall optimization of LPBF. This fundamental metric, essential to LPBF additive manufacturing, is defined in three ways: 1D LED, considering laser power and scan speed; 2D LED, incorporating hatch spacing; and 3D LED, adding layer thickness into the calculation.

1D LED (J/mm) = P/v [laser power / laser speed]
2D LED (J/mm2) = P/(v.h) [laser power / (laser speed) (hatch spacing)]
3D LED (J/mm3) = P/(v.l.h) [laser power / (laser speed) (layer thickness) (hatch spacing)]

Within LPBF, LED can significantly affect the material properties and characteristics of the final product. Higher LED values raise temperatures and extend exposure times for the molten material, allowing more thorough melting and fusion. This extended cooling and solidification process can significantly influence the microstructure and properties of the end product. Engineers control these critical aspects by adjusting laser energy density, influencing factors like grain size, solidification microstructure, and residual stresses.

Regarding porosity, LED plays a distinctive role in forming various types, including lack of fusion, balling, and keyholing. Lack of fusion porosity, resulting from insufficient energy delivery, can be reduced with higher LED values, promoting better fusion and bonding. Higher LED values increase the likelihood of balling as excessive melting and resolidification can lead to the accumulation of molten material in undesired regions. Keyholing porosity, resulting from vaporization and void formation, is encouraged by higher LED values, creating deeper and wider melt pools.

Understanding the intricate relationship between LED and porosity types is crucial for optimizing process parameters. Selecting an appropriate LED range aims to find a balance between sufficient energy input for complete fusion and avoiding excess that leads to balling and keyholing. This optimization process is vital for minimizing porosity and ensuring the production of flawless, high-quality metal components in LPBF. It requires careful consideration of material properties and scan strategy to achieve optimal results.

4. Exploring LPBF processing parameters vs Porosity

In Ansys Granta EduPack, part of the Materials Science and Engineering database, you'll discover a handy section called Property-Process Profiles. This resource acts as a do-it-yourself kit, allowing students to explore how different processes influence the properties of chosen metals, polymers, and ceramics. Inside this section, you can locate the "8. Additive manufacturing: metal powder bed fusion" folder, containing 35 datasheets. These datasheets are tailored to examine the effects of laser power, laser speed, and laser energy density on the melt pool sizes and porosities of four specific metallic alloys: Inconel 625, SS316L, AlSi10Mg, and Ti64.

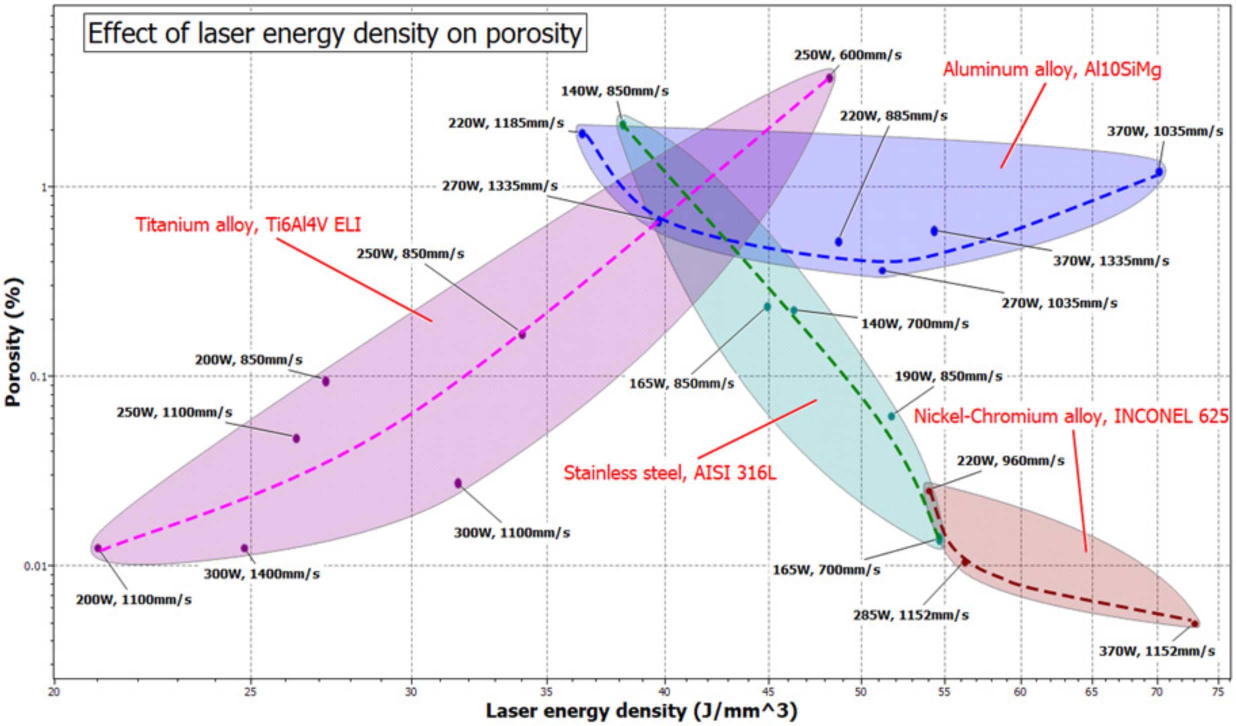

Figure 1 - The interplay between laser energy density and the resulting porosity in laser powder bed fusion of AlSi10Mg, Ti64, INCONEL 625 and SS316.

The presented figure 1 provides a comprehensive overview of how variations in laser energy density influence porosity for four distinct metallic alloys. Notably, in the cases of Inconel 625 and SS316L, a discernible trend emerges, showcasing a reduction in porosity as laser energy density increases within the depicted range. This outcome is intricately tied to the effective elimination of lack of fusion porosity. Essentially, the heightened energy input enhances the fusion and bonding between layers, mitigating the risk of incomplete melting and subsequent porosity formation.

Contrastingly, the alloy Ti64 exhibits a contrasting response to changes in laser energy density. Here, an elevation in laser energy density correlates with an upswing in porosity. This phenomenon is associated with the augmented formation of keyholing porosity, particularly at higher energy density values. The intricate interplay between laser energy and material characteristics underscores the need for a nuanced approach to optimize the manufacturing process. In the case of Ti64, careful consideration is imperative to strike a balance, avoiding excessive energy input that could inadvertently lead to heightened porosity.

AlSi10Mg showcases a unique dual-effect scenario in response to laser energy density variations. Initially, an increase in energy density proves beneficial by eliminating lack of fusion porosity. However, as energy density levels continue to rise, a subsequent contribution to the formation of keyholing porosity becomes evident. This nuanced relationship underscores the complexity of the manufacturing optimization process, urging engineers to tread carefully in selecting the most suitable energy density levels for AlSi10Mg. This comprehensive understanding of how laser energy density impacts porosity provides invaluable insights for refining the laser powder bed fusion process and achieving optimal outcomes in the fabrication of high-quality metal components.

5. Reality check

In Laser Powder Bed Fusion (LPBF), laser energy density plays a pivotal role not only in influencing porosity but also in shaping other critical defects within the final product. One significant defect to consider is the formation of micro-cracks. Elevated laser energy density levels can contribute to the development of micro-cracks in the manufactured components. The intense energy input may induce rapid heating and cooling cycles, leading to thermal stresses that manifest as microscopic cracks within the material. The careful control of laser energy density becomes essential to strike a balance that ensures thorough melting for fusion without inducing excessive thermal stresses that promote micro-crack formation.

Another defect influenced by laser energy density is spattering, which refers to the ejection of molten material particles during the LPBF process. Higher laser energy density can result in increased spattering, especially in cases where the energy input surpasses the optimal level required for controlled melting and solidification. This phenomenon can compromise the precision of the fabrication process and lead to irregularities on the surface of the manufactured part. Hence, engineers need to carefully manage laser energy density to mitigate spattering-related issues, ensuring a more controlled and precise additive manufacturing process.

Moreover, the interaction between laser energy density and cooling rates during the LPBF process can impact the formation of residual stresses. Excessive energy input, often associated with higher laser energy density, can lead to prolonged exposure times for the molten material, affecting the cooling and solidification rates. These variations in cooling rates can result in the accumulation of residual stresses within the final product, influencing its mechanical properties. Hence, a nuanced approach to optimizing laser energy density becomes crucial in managing not only porosity but also these additional defects, contributing to the overall quality and structural integrity of the metal components produced through LPBF.

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