HIERARCHICAL CLASSIFICATION INFLUENCING FACTORS IN POWDER BED FUSION ADDITIVE MANUFACTURING FOR QUALITY ENHANCEMENT

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Abstract: PBF AM is a key metal manufacturing technology capable of producing complex geometries with high precision. However, the process is highly sensitive to multiple interacting parameters, which significantly affect part quality. This study presents a hierarchical classification of process influencing factors and analyzes their role in improving processing quality. The framework is based on established understanding of laser based PBF systems and emphasizes structured grouping of parameters for better process control, defect reduction, and optimization efficiency [1].

Keywords: PBF AM, classification, factors, process parameters, material properties, environmental factors, machine and system factors.

1. Introduction. Powder Bed Fusion is a layer wise process in which a laser melts metal powder to form solid parts. Despite its advantages, it is highly sensitive to process conditions, where part quality depends on the interaction of energy input, material, machine, and environmental factors [1]. Minor variations in parameters can cause defects such as porosity, lack of fusion, and residual stresses. Therefore, structured classification of influencing factors is essential for ensuring process stability and quality.

2. Hierarchical Classification of Influencing Factors. 2.1 Process Parameters. Process parameters are directly controlled inputs defining energy delivery and melt behavior: laser power, scanning speed, hatch spacing, layer thickness, scan strategy. These parameters determine volumetric energy density and melt pool stability. Improper balance between them can result in incomplete melting or overheating, leading to defects [1].

2.2 Material Properties. Material related factors influence powder behavior during melting: particle size and formation**,** powder morphology**,** flow ability**,** absorptivity**, c**hemical composition. Powder characteristics significantly affect layer uniformity, packing density, and melt pool formation. High-quality powder improves density and reduces porosity formation [2].

2.3 Machine and System Factors. Machine related conditions also strongly affect process stability: laser beam quality and focus, calibration accuracy, temperature control. Even with optimized parameters, machine instability may cause inconsistent layer deposition and geometric errors. Equipment precision is therefore essential for repeatability [3].

2.4 Environmental Conditions. Environmental factors influence thermal behavior and oxidation: oxygen concentration in chamber, gas flow conditions, ambient temperature, humidity. Poor shielding gas control can lead to oxidation, spatter formation, and reduced surface quality [4].

3. Impact of Classification. Classification separates factor effects and clarifies defect mechanisms; for instance, porosity is mainly linked to insufficient energy input [1]. It also enables structured optimization by prioritizing energy-related parameters before material and machine factors, reducing experimental effort and improving repeatability [2]. Furthermore, hierarchical classification enhances statistical and machine learning models by reducing complexity, leading to more accurate predictions of porosity, surface quality, and mechanical properties [4].

4. Conclusion The hierarchical classification of process influencing factors provides a structured approach to understanding and improving Powder Bed Fusion Additive Manufacturing. By grouping parameters into process, material, machine, and environmental categories, it becomes possible to better analyze defects, optimize parameters, and improve production reliability. This structured approach enhances both experimental efficiency and predictive modeling capability, contributing to improved industrial application of PBF AM technology.

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