Performance Prediction and Process Optimization of 316L Stainless Steel Produced by Selective Laser Melting Based on Response Surface Methodology

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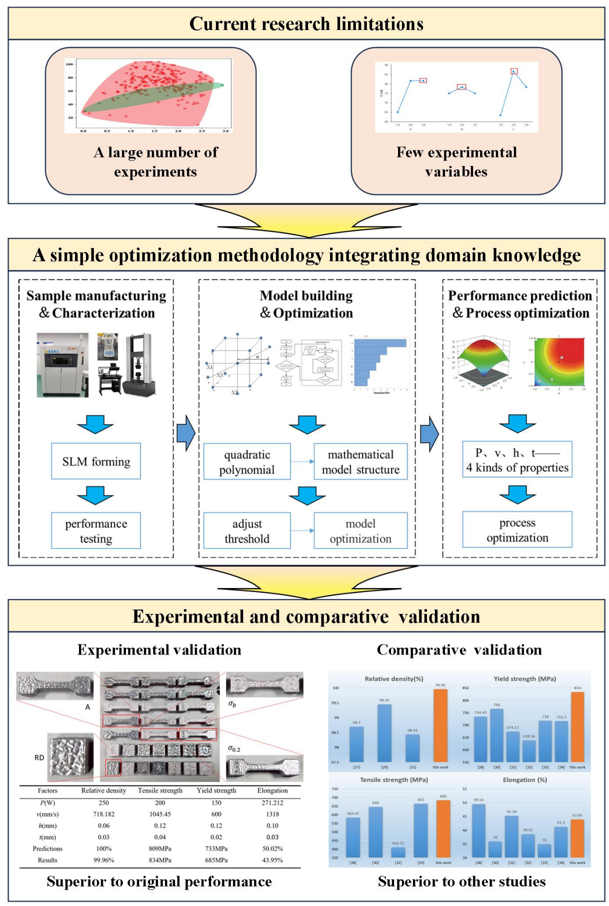
Abstract: A key aspect in 3D printing is studying how different process settings in Selective Laser Melting (SLM) affect part quality. Optimizing SLM requires a model that predicts part performance based on these settings. Therefore, we conducted a study using 316L stainless steel as an example, manufacturing and testing 31 sets of specimens to investigate the influence of different process parameters on forming performance. Initially, we employed response surface methodology to design and carry out four-factor printing experiments, which considered laser power, powder thickness, scanning speed, and hatch space. Subsequently, the specimens were tested for density and mechanical properties. Based on statistical analysis, we established four predictive models that depicted the relationship between four process parameters and properties like relative density, tensile strength, yield strength, and elongation. We also calculated the optimal response value and its corresponding process parameter combination. The established models exhibited good fitting and prediction capabilities, with all four models achieving R2 values of 85.56%, 82.19%, 90.08% and 91.72% respectively. After process optimization, the formed parts demonstrated a relative density of 99.96%, tensile strength of 834 MPa, yield strength of 685 MPa, and elongation of 43.95%. This method can obtain good optimization results with fewer experiments.

Keywords: Selective laser melting; Process parameters; Properties; Response surface methodology; Predictive model; 316L stainless steel

1 Introduction

Selective laser melting (SLM) is one of the most widely used additive manufacturing metal materials methods.

SLM is widely used in aerospace, automotive industry, biomedical and defense fields [1] due to its pollution-free [2], high precision [3], freedom design of shape and short manufacturing cycle.



Graphical Abstract

This paper presents a method merging domain knowledge with response surface methodology for optimizing process parameters using fewer, high-quality experiments. It uses 316L stainless steel as a case study, examining laser power, powder layer thickness, scanning speed, and hatch space in printing experiments.

2 Experimental procedure

The 316L stainless steel samples were formed by SLM with a four-factor central composite design (CCD) in the response surface methodology, and the parameters varied as presented in Table 1. Relative density is tested with drainage.

Table 1 Design of Experiments for CCD

Factors	Axial point1	Lower level	Central point	Upper level	Axial point 2
P (W)	150	200	250	300	350
v (mm/s)	600	825	1050	1275	1500
h (mm)	0.06	0.075	0.09	0.105	0.12
t (mm)	0.02	0.03	0.04	0.05	0.06

3 Result and discussion

3.1 Properties prediction

Four prediction models for material properties (relative density, tensile, yield strengths, tensile strain) were developed via RSM with variables P, v, h, t (Equations 1-4). Stepwise regression optimized these models by adjusting α to maximize R-sq (prediction), employing a hierarchical model structure in the process.

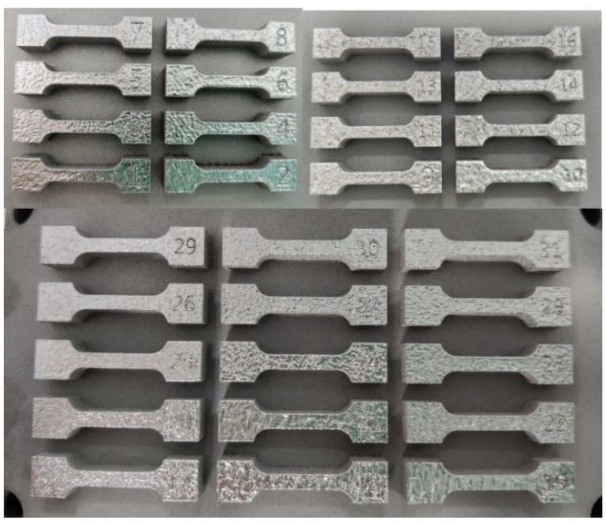


Fig. 1 Samples of SLM SUS 316L

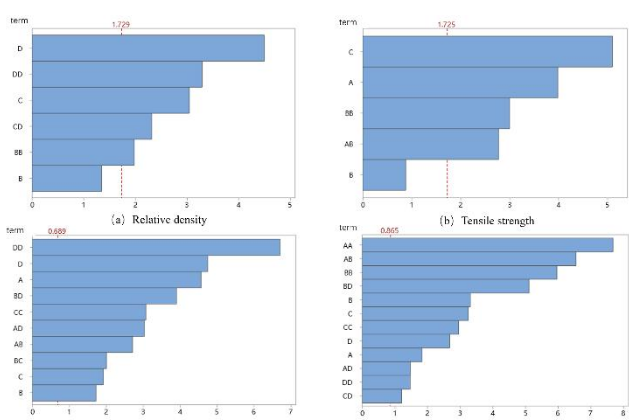


Fig. 2 Pareto plot of the normalized effects of each model

The effect of prediction models' terms on properties is ordered as shown in Fig. 2.

3.2 Parameters optimization

Validation tests were done to verify effectiveness. For the density-response surface model, the optimal value of the response (density) reaches 99.96% , the optimal value of the response (tensile strength) reached 834 MPa.The results of yield strength are up to 685 MPa and the elongation is up to 43.95%.

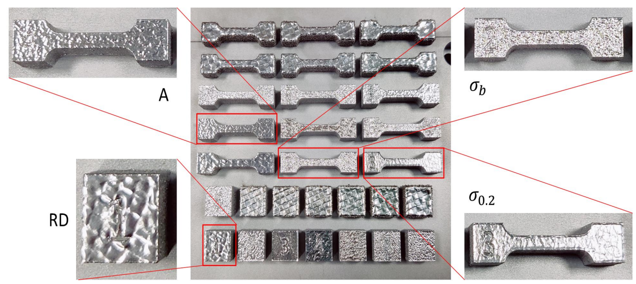


Fig. 3 Verification samples

4 Conclusions

(1) 4 good fitting ability properties prediction models are constructed based on a domain knowledge-based and response surface methodology fusion methodology.

(2) the relationship prediction model between the four process parameters and the density, tensile strength, yield strength and elongation are established

(3) Process parameters optimization of SUS316L is realized in selective laser melting.

Acknowledgments

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