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Opinion article

Interdependent Influences of the Laser Power and Printing Pattern on Residual Stresses in Laser Powder Bed Fusion Additive Manufacturing

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Abstract

The finite element method is a powerful tool to investigate the effect of additive manufacturing parameters for high-quality part fabrication. In this study, the interdependent influences of the printing pattern and laser power on residual stresses in laser powder bed fusion process are evaluated. The residual stress is calculated using thermo-mechanical simulation. The line heat input model with the mesh coarsening technique is applied to reduce the computational time. The models are developed with four different sets of printing patterns and laser powers. Simulation results show that the laser power has a weak direct and strong indirect influence on residual stress. For instance, increasing the laser power strengthens the impact of the printing pattern on residual stresses.

Keywords: Laser powder bed fusion; Finite element modelling; Laser power; Printing pattern; Residual stress

Introduction

Laser powder bed fusion (LPBF) is an additive manufacturing process where a laser is used to locally consolidate powder into a desired geometry [1]. The LPBF process is especially important for high gamma prime nickel-based superalloy materials, which are good candidates for high-temperature environments in aerospace applications. However, there are many challenges during the building process due to the complex material-process relationship [2-5]. An optimum combination of laser scanning parameters, such as laser power, hatch spacing, and printing pattern, is required to construct near net shape high-quality parts. Each parameter can have direct or indirect effects, depending on the strength of the inter-parametric influences, on the final part quality [6]. A finite element (FE) model can be used to determine a set of laser parameters to reduce the number of defects and experimental iterations desired for part construction [7]. Bo Cheng & Kevin Chou [8], discussed the interdependent influences of different printing parameters using simulation. In this evaluation, it was reported the higher laser power and lower scan speed increases the melt pool size. This necessitates using larger island scan sizes to obtain a stable melt pool size. A beam-scale model was used to simulate the process for a few tracks, which limited the analysis to a single layer [8]. Simulations of larger components require the development of larger heat input models to reduce the number of elements and increments [9]. Tangestani et al. [10] performed process simulations to capture the thermal and mechanical results for a few layers. The model was developed using the line heat input model and mesh coarsening technique to improve computational efficiency. This approach is beneficial to evaluate the effect of laser power and printing pattern on residual stress. While the direct impact of each parameter was reported, the inter-dependent influences of each parameter were not considered. In other words, increasing the value of one parameter could affect the contribution of another parameter to the residual stresses.

In this study, the LPBF process was simulated to evaluate the direct and interdependent influences of the laser power and printing pattern on residual stresses. The line heat input model and mesh-coarsening technique were used to achieve a feasible computational time. The printing parameters include two different laser powers and scan patterns, allowing the comparison of four different parametric combinations.

Model Description

The finite element software, Abaqus, was used to simulate the process for a 30-layer part made of high gamma superalloy RENÉ 65 (R65). The part domain is 5 × 0.5 × 1.2 mm (length × width × depth) on a 5 × 0.5 × 4 mm substrate as shown in Figure 1(A). A series of two different laser powers and printing patterns are studied. The two laser powers are 180 W and 220 W, and the two printing patterns, at 90° and 45° rotation angles, are demonstrated in Figure 1(B). Similar material properties as reported in [7,10] were used in this study.

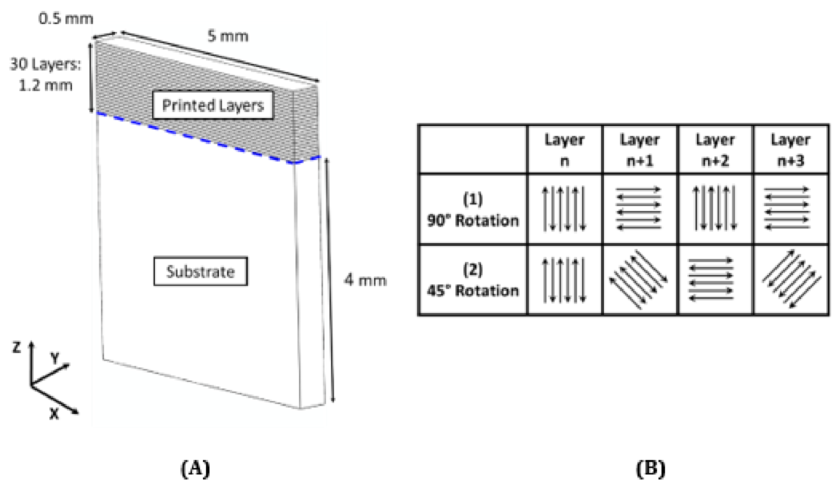

Figure 1: (A) The 30-layer part was used to simulate the LPBF builds. The dashed blue line shows the border between the printed layers and the substrate. (B) Two different printing patterns (90° and 45° rotation angles) were used to study the interdependent influences of laser power and printing pattern.

The parts were printed with a laser speed of 1000 mm/s, layer thickness of 40 µm, beam radius of 60 µm and hatch spacing of 90 µm. The cooling time between each layer scan is 10 s, and the simulation runs for 480 seconds after the last layer is printed to allow the part to cool down to room temperature (25 °C). Following the process simulation, the boundary conditions are relaxed in the substrate to account for the stress relaxation when the part is removed from the printer. The convection and radiation heat losses were applied for all open surfaces with coefficients $20\left(\frac{W}{m^2\,^{\circ}c}\right)$ of and 0.4, respectively. The LPBF process is simulated using the line heat input model to predict the residual stresses as described in [10]. This allows the control of the increment time and element size. To enhance the computational time efficiency, the mesh-coarsening technique was used to reduce the total number of elements [10].

Results and Discussion

Figure 2 shows the von Mises stresses in the cross-sectioned parts for different laser powers and printing patterns. The von Mises stress is higher on the surface compared to the center of the part due to higher tensile stress in the longitudinal direction as reported in previous reports [1,10]. This negatively impacts the final part quality as the longitudinal tensile stresses at the surface increase the part's susceptibility to fatigue failure. The stress magnitude is lower close to the top surface as the normal stress is near zero in the last layers. The substrate constrains the part from moving in all directions, hence reducing the stress in the lower layers [11]. The direct effect of printing patterns on the residual stresses is stronger than that of laser power, which agrees well with a previous study [10]. As reported by Tangestani et al., the longitudinal and normal stresses, controlled by the laser printing pattern, play a major role in the creation of von Mises stresses [1,10]. Accordingly, the rotation angle helps homogenize the residual stresses created within the part [12]. While both laser power and printing pattern have direct impacts on the created residual stresses [13], they have interdependent influences as well. For instance, for a constant laser power of 180 W (Figures 2(A) and 2(C)), changing the printing pattern from 90° (Figure 2(A)) to 45° (Figure 2(C)) does not directly affect the residual

stresses. However, as the laser power is increased to 220 W (Figures 2(B) and 2(D)), the effect of printing pattern on the residual stresses is more pronounced, as shown in Figure 2(B) (90°) and Figure 2(D) (45°). This is highlighted by comparing the residual stress distributions for the 90° (Figure 2(B)) and 45° (Figure 2(D)) cases (black circles) For the 90° case, the residual stresses are more inhomogeneous compared to the 45° case. Therefore, increasing the laser power leads to more induced energy through the printed layers and enhances the effect of printing pattern on residual stress.

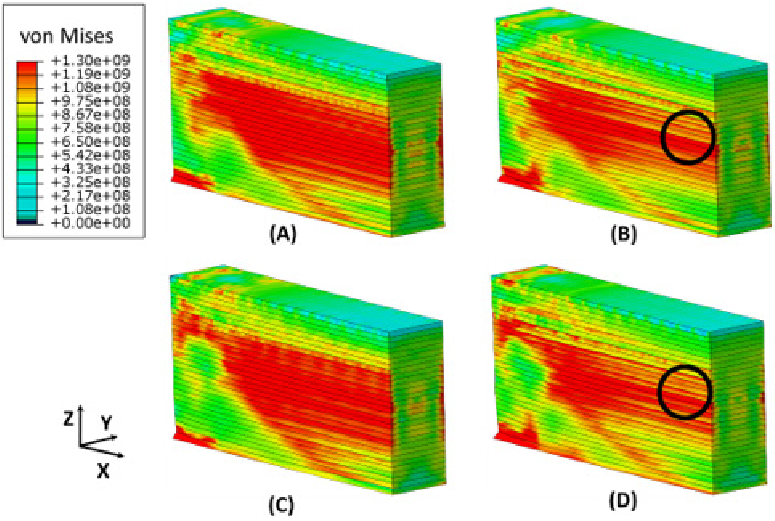

Figure 2: The residual stress following the completion of simulation. The parts are sectioned at the center along the X-direction and the laser powers and rotation angles used are (A) 180W-90°, (B) 220W-45°, (C) 180W-90°, (D) 220W-45°, respectively. The black circles highlight the regions demonstrating the effect of printing patterns on residual stress magnitude.

Conclusion

In this study, the interdependent influences of the printing pattern and laser power on residual stresses were examined using finite element simulation. It was demonstrated that the interdependent effect is higher compared to the direct effect of laser power on residual stresses. Increasing the laser power induces more energy through the printed layers and enhances the influence of printing patterns on residual stresses. Thus, it is proposed that the selection of optimum printing patterns is more significant with higher laser power.

Acknowledgement

None.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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