PREDICTING SURFACE ROUGHNESS IN LASER POWDER BED FUSION PARTS AFTER LASER POLISHING: A MULTI-PHYSICS SIMULATION APPROACH

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Abstract

Laser powder bed fusion (L-PBF) uses a controlled laser beam to melt specific regions of a metal powder bed in a layer-by-layer fashion to fabricate parts with an intricate geometry. However, due to the stochastic nature of the L-PBF process, many defects may occur during the build process, including distortion, porosity, and high surface roughness. A poor roughness of the upper surface is frequently associated with impaired mechanical properties and a lower corrosion resistance. Thus, laser polishing (LP) is commonly employed to smooth the surface of the component following the build process. The present study proposes an integrated framework based on discrete element method (DEM) and computational fluid dynamics (CFD) simulations which takes account of all of these factors to predict the final surface morphology and roughness of L-PBF components following LP processing. The validity of the simulation model is confirmed by comparing the calculated mean surface roughness of the polished components (S_a) with the experimental values. It is found that the maximum error of the simulation results for different initial surface morphologies and LP processing conditions is less than 6.8%.

Keywords: Surface Generation Model, Surface Morphology, Laser Polishing, Laser Powder Bed Fusion, Computational Fluid Dynamic (CFD)

1.Introduction

Laser Powder Bed Fusion (L-PBF) utilizes laser radiations to selectively fuse a metal powder layer bed layer-by-layer in such a way as to gradually build up a 3D component with a specified size and geometry. A high top surface roughness is one of the most common defects in AM. One of the main reasons for this high surface roughness is the “layering” effect which occurs during the build process, in which the surface roughness of the current layer is superimposed on top of that of the previous layer such that the surface roughness gradually accumulates as the build process proceeds [1]. The surface roughness of the top layer is further degraded by the build-up of powder particles on the surface, incomplete melting of the powder particles , spatter formation, and variations in the laser power, scanning speed, and other printing factors [2-4]. Experimental studies have shown that the surface roughness of L-PBF parts adversely affects their mechanical properties [5] and fatigue life [6].

The present study proposes a novel simulation model including an algorithm to simulate surface morphology and a CFD simulation model to predict the surface roughness of LP-processed L-PBF parts as a function of the as-received L-PBF surface roughness and the LP processing conditions. In the proposed method, the surface profile of the as-received L-PBF part is calculated experimentally, and the characteristic values of the surface roughness are determined mathematically. The surface roughness parameters are processed by a surface generation model and discrete element method (DEM) simulations to reconstruct the surface morphology of the as-built sample. CFD simulations are then performed to model the impacts of the surface tension force, recoil pressure, and Marangoni convection on the surface morphology of the LP-processed part.

2.Methodology

Figure 1 presents a flowchart of the proposed integrated simulation methodology. The process commences by measuring the surface morphology of the as-built sample and extracting the characteristic parameters of interest, namely S_a, S_q, Cl_x and Cl_y, where S_a is the arithmetic mean deviation of the surface from a defined centerline; S_q is the root-mean-square deviation of the surface from the centerline; and Cl_x and Cl_y are the variations of the surface height in the lateral and vertical directions, respectively [7]. Based on the extracted surface parameters, a mathematical model consisting of a surface generation model and DEM simulations is applied to simulate the surface morphology of the as-built L-PBF part. The simulated surface is then imported into a CFD simulation model to predict the surface morphology of the as-built part following laser polishing with specific processing parameters. The findings from the simulation are validated by comparing the computed value of S_a for the polished surface profile with that obtained from experimental measurements.

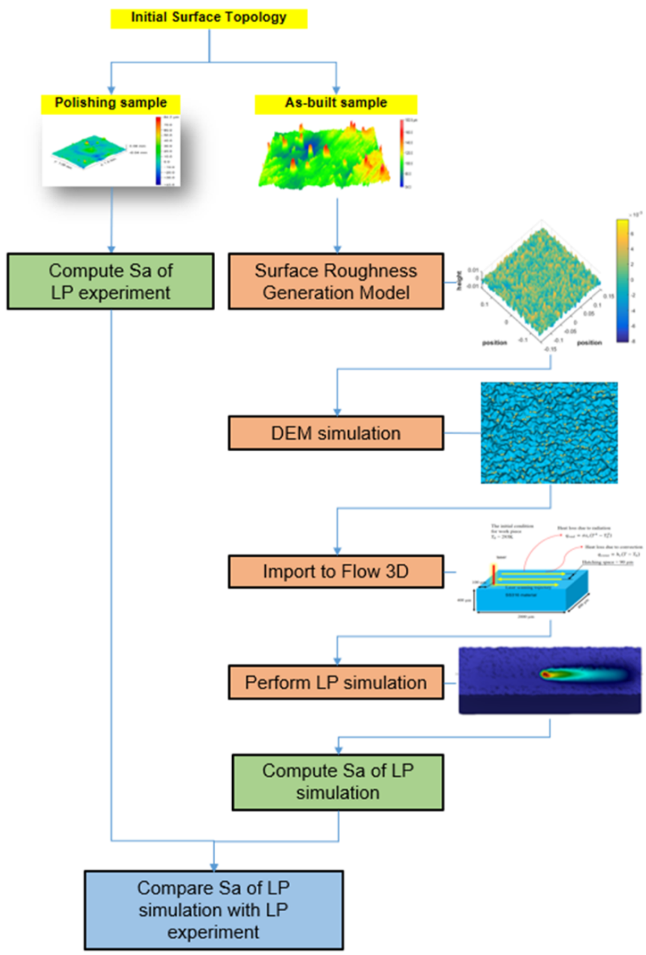

Figure 1 Workflow of proposed simulation framework

Figures 2(a) and (b) show the initial and polished surface roughness profiles of two samples with initial S_a values of 12 μm and 17 μm, respectively. (Note that the LP processing parameters are 239 W and 976 mm/s in both cases.). The LP process reduces the surface roughness of the two samples to 8.5 μm and 12.8 μm, respectively.

For the sample with an initial S_a value of 12 μm, the surface roughness improved by approximately 29% to 8.5 μm after the LP process. Similarly, for the sample with an initial S_a value of 17 μm, the surface roughness improved by about 25% to 12.8 μm after LP. These results indicate that the LP process effectively reduces the surface roughness of both samples. Therefore, it is indicated that a smoother initial surface, as evidenced by the lower initial S_a value, results in a more significant improvement in surface roughness after polishing.

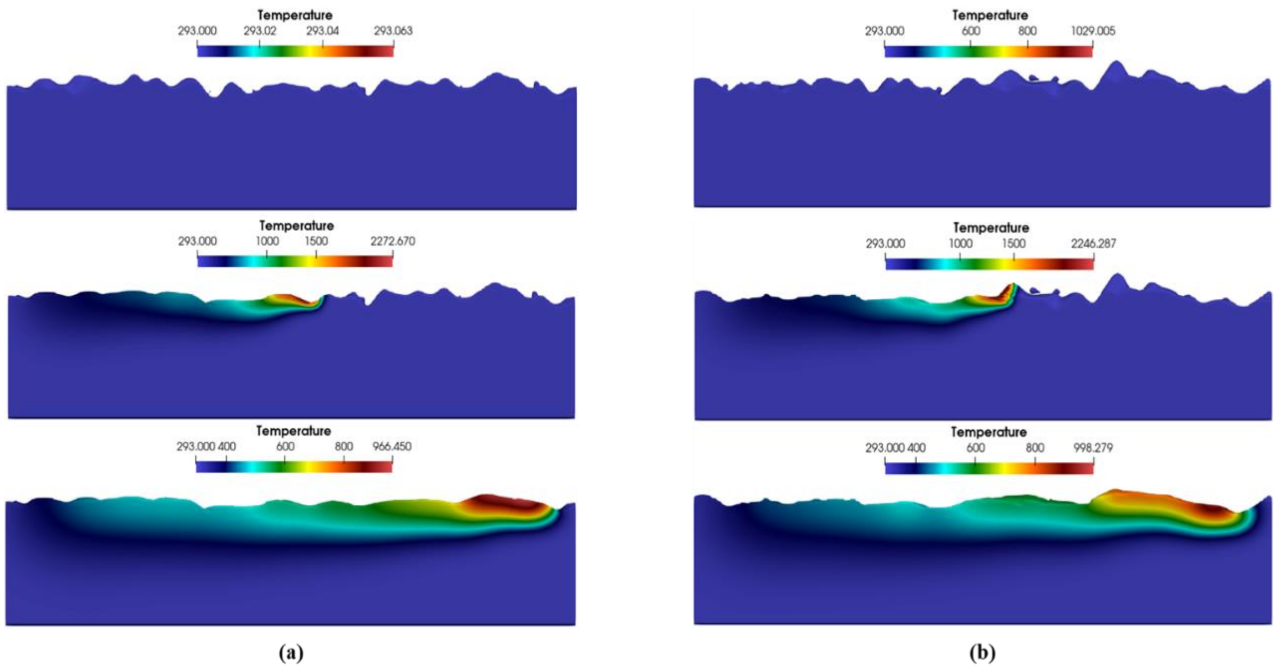

Figure 2 Effects of initial surface roughness on final surface roughness after LP processing: (a) initial surface roughness of 12 μm, and (b) initial surface roughness of 17 μm.

3.Conclusion

This study has developed an integrated simulation framework to predict the surface roughness of L-PBF samples following LP with specific processing parameters. The following are the main study achievements and conclusions. The CFD model takes proper account of the effects of evaporation, surface tension forces, and recoil pressure on the surface morphology of the laser-polished samples. The simulated values of S_a after LP processing with different energy densities lie within 6.8% of the experimental values. For a rougher initial L-PBF surface morphology, the peaks and valleys act as barriers, which slow the speed of the molten metal in the LP process and thus reduce the smoothing effect.

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