Abstract

Laser additive manufacturing (LAM), such as Laser Directed Energy Deposition (L-DED) process, often encounters challenges in maintaining uniformity, quality and repeatability of microstructure and hence properties, throughout the layer-by-layer builds, which limits its use to critical component fabrication. This study attempts to address this issue through online monitoring of the thermal history and its subsequent application in feedback control during LAM processes. To understand the process parameter–property relationship, a single-spot monochromatic pyrometer was initially employed to monitor the thermal signals during the laser pre-placed cladding process. Cooling rate, rather than peak temperature, proved to be a more effective thermal characteristic for correlating with deposition features like microstructure and morphology. Gradation of process parameters during thin wall deposition helped in maintaining the uniformity of cooling rate during the deposition process and this contributed towards better and more uniform mechanical properties. Since cooling rate dictated the microstructural characteristics, a monitoring system for the cooling rate was developed employing two pyrometers in tandem. Further, a feedback control system using this setup was developed to maintain the cooling rate of the process at a pre-defined level. Employing this control system, thin walls of Inconel 718, each having 120 layers, were built both with and without adaptive control. Results revealed that feedback-controlled walls had superior geometry, microstructure, and mechanical properties. The system thus could effectively fabricate adaptively controlled LAM structures with large layer numbers by simultaneous control of laser scan speed and powder feed rate. Moreover, the higher cooling rates maintained by the adaptive control of laser process parameters led to finer, discrete Laves phase, which was more easily dissolved by solution annealing. This facilitated a more even distribution of strengthening phases after aging, resulting in higher strength with the application of feedback control. Another novel monitoring system using a single pyrometer oscillating along and across the laser track during deposition was developed to monitor the cooling rate and track width respectively in real-time. The successful demonstration of the above two control systems based on pyrometers can be used for real-time adaptive control during LAM of large layer numbered structures to ensure repeatability of the geometrical features and microstructure in the built parts.