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Melt pool sensing and size analysis in laser powder-bed metal additive manufacturing

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ABSTRACT

Process temperature measurement for selective laser melting (SLM) can provide critical information such as melt pool dimension for real-time part quality control. In this study, a LumaSense MCS640 thermal imager with a spectral range of about 670 nm wavelength was utilized to collect process radiant temperature information during SLM fabrication using Inconel 718 powder. Sharp transition of cooling curve in collected radiant temperature profile along scanning direction was considered as material phase transition, and it was identified by minimum secondary derivative values of each camera pixel from fitted polynomial functions. Obtained liquidus-solidus transition was used to calculate melt pool size. Speed effect on melt pool dimension has been investigated. The major findings are as follows. (1) At a beam power of 180 W, typical melt pool has average dimensions of about 0.39 mm and 0.23 mm in length and width for 400 mm/s scanning speed. (2) Similar melt pool sizes were observed at different build heights for a given scanning speed. (3) Melt pool width decreases with the increase of scanning speed while the trend for melt pool length is unclear; no significant difference was observed for melt pool length at different scanning speeds under a beam power of 180 W.

1. Introduction

Selective Laser Melting (SLM) based on additive layered fabrication can build complex structures such as lattice and internal features. SLM technology utilizes a high energy laser beam to scan predefined cross sections. Fabricated part defects such as porosity may result from incomplete melt under different process conditions. To improve part quality, a thorough understanding of real time process thermal characteristics is needed. Thermal imaging technology is adopted to monitor the transient thermal response in SLM process. The main part of thermal imaging system is an infrared (IR) camera with special wavelength and frame rate, it is usually used to record in-situ build surface temperature distribution. However, the thermal camera may not be able to present true temperature measurement results; it gives radiant temperature information based on material emissivity. The material emissivity can vary with temperature, material state (powder/solid/liquid), or camera view angle [1]. Such variation makes the accurate measurement of true temperature to be extremely difficult. Instead of trying to capture true temperature, some of the comparatively easy-to-identify characteristics of the temperature profile can be utilized to digest useful information from collected data. The liquidus-solidus transition, happened during material liquid to solid phase transformation, would cause a sharp change in temperature profile (plateau) due to latent heat of fusion effect. This discontinuity may be used as a threshold point for melt pool dimension measurement [2].

Due to insufficient understanding of the physical process, there are still challenges in SLM process such as quality variation of build part, which is a major factor that hinders the widespread application of SLM components. Thus, the process thermal characteristic measurement such as real-time temperature collection may provide vital information to link part quality and process variables. There are limited literature that investigated temperature measurement methods using thermal imaging system in SLM process. Kolossov et al. [3] utilized an IR camera, with a spectral band filter from 3 up to 5 μm, to record the top powder surface temperature distribution in selective laser sintering (SLS) process. The recorded thermal information was used for numerical model validation. Fischer et al. [4] also used an IR camera to measure the SLS temperature distribution for laser irradiating with continuous wave radiation and with pulsed radiation. It was found that the pulsed laser sintering had the advantages of stronger consolidation, which could be due to lower average temperature and much higher peak skin temperature. Yadroitsev et al. [5] employed a Charge-coupled

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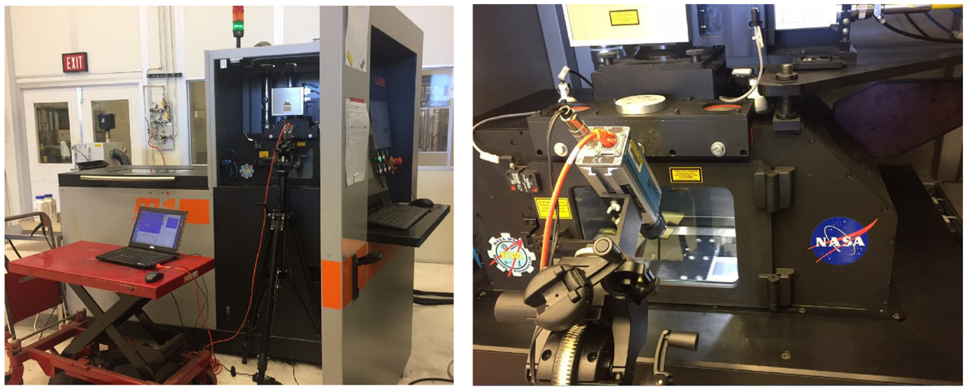
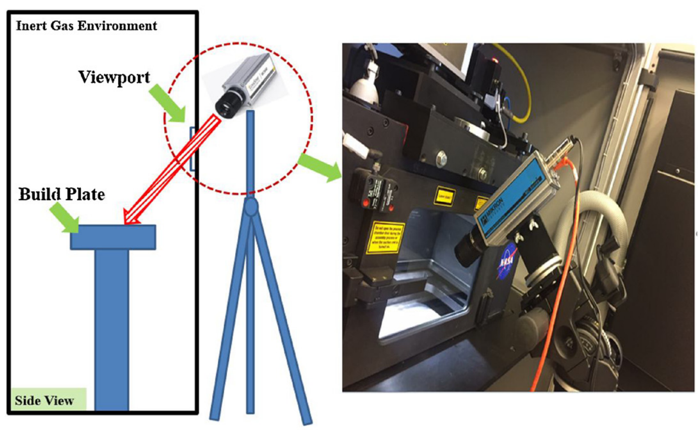


(a) Overview of experimental setup



(b) Camera setup

Fig. 1. Schematic plot for experimental setup.

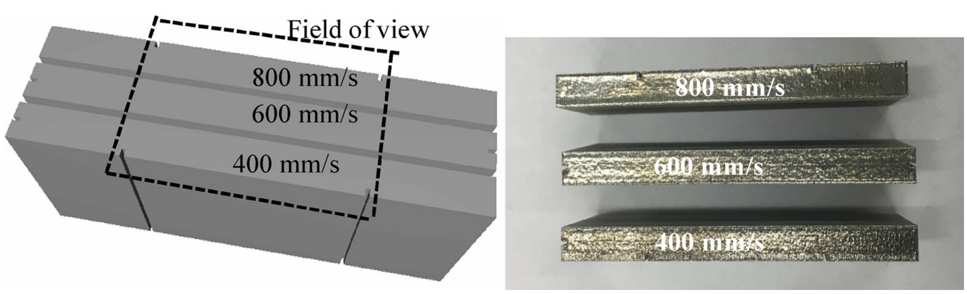


Fig. 2. CAD model for build samples.

Device (CCD) camera to measure SLM process temperature. They calculated true temperature in melt pool based on measured solidification temperature. Wegner and Witt [6] integrated a thermal imaging system (InfraTec Jade III MWIR) into a laser sintering machine, the melt region and unmelted region could be determined by this system. Gao et al. [7] used IR thermography method to obtain the point temperature information in SLS process, the collected thermal information has been applied for simulation comparison purposes. A thermal imaging system for temperature measurement in SLM process was developed by Krauss et al. [8] with an uncooled microbolometer detector. The feasibility of flaw detection has been investigated, especially for the artificial flaws in the range of 40 μm–500 μm. They were able to identify flaws up to ~ 100 μm by checking the temporal evolution and spatial irradiance distribution shortly after the exposure. Chivel and Smurov [9] developed an optical temperature monitoring system for SLS/SLM process. The spatial distribution of build surface temperatures as well as temperature profiles could be obtained. It was possible to optimize SLS powder bed porosity with this developed system. With high speed IR camera and pyrometer, Bayle and Doubenskaia [10] were able to observe the laser-powder interaction in SLM process. The ejected liquid droplets can be observed around scanning path using high acquisition frequency e.g., from 2031 Hz up to 3556 Hz. Heigel and Lane [11] utilized a high speed IR camera (1800 frames per second) to record the thermal information in SLM process. The authors have investigated the effect of different combinations of the laser speed and power on melt pool length when laser beam scanning on a bare Inconel 625 plate. The melt pool length was obtained by identifying the liquid-solidus transition discontinuity. Due to observed vapor plume and reflection around the melt pool width direction, no meaningful melt pool width could be reported. The authors have found that melt pool length would decrease slightly with increase of scanning speed, e.g., from 200 mm/s to 800 mm/s, under lower power (122 W); while melt pool length was similar when a higher