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Spatter formation in selective laser melting process using multi-laser technology

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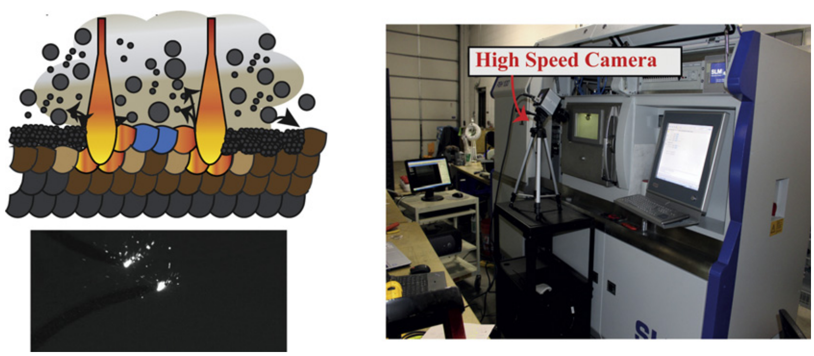
HIGHLIGHTS

- High-speed photography is utilized to observe the formation mechanism of spatters.
- An image analysis framework is developed to assess the distribution of induced spatters.
- Spatter particles are detrimental type of defects on mechanical properties of SLM parts.

GRAPHICAL ABSTRACT



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ABSTRACT

This study demonstrates the significant role of recoil pressure in selective laser melting (SLM) process using multi-laser technology. High-speed photography is utilized to observe the formation mechanism, and also the behavior of spatter particles during SLM fabrication. A computational image analysis framework is developed to assess the size and the number of induced spatters. The morphology and the composition of spatters and their influence on the surface of the fabricated parts are determined. Unmelted regions, resulting from spatter deposition into the powder or the solidified layer, are found to be a detrimental type of defects on mechanical properties of SLM parts. This is followed by a discussion on demand for developing a meaningful process parameters optimization to enhance the mechanical properties of SLM products.

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1. Introduction

During the past decades, additive manufacturing (AM), particularly metallic AM, has drawn extensive attention due to its unique ability for layer-by-layer fabricating parts of various complexities [1,2]. Selective laser melting (SLM) as a novel metallic AM process has demonstrated a promising future [3]. The SLM technology allows fabrication of high-density metallic parts (up to 99.9%), exhibiting extremely fine microstructures with very complex geometries that cannot be easily

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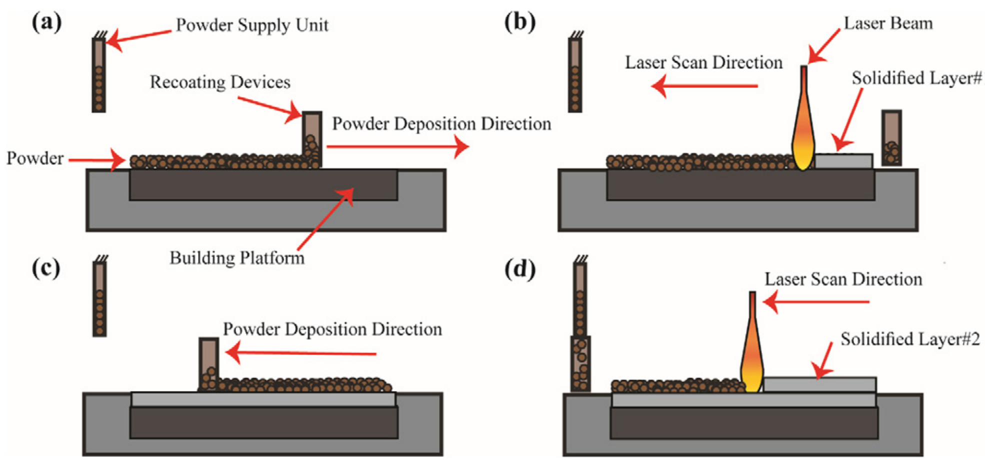

Fig. 1. Schematic representation of the fabricating sequences in SLM 280HL machines. (a) Bi-directional recoating devices deposit the powder on the building platform. (b) The laser beam melts selectively the powder based on the CAD model. (c) The recoating devices deposit the powder on the solidified layer. (d) The laser beam fuses the next layer and the powder supply unit fills the recoating devices.

fabricated by conventional methods [4–9]. However, widespread adoption of SLM with metallic parts depends on whether the final products meet the requirements of engineering quality standards [10]. This includes reducing the defects induced by spatters, which can adversely affect the mechanical properties.

Spatter creation have been reported in several laser-assisted manufacturing works [11–16]. Some examples are the works by Low et al. [11,12] on studying the spatter formation mechanism during laser drilling and the effects of laser process parameters on spatter deposition. However, few research studies have been conducted on spatter creation mechanisms during SLM process. Simonelli et al. [15] studied oxidation reactions during the SLM process and its effect on the spatter composition. They found that the chemical compositions in spatter particles change significantly compared to the initial powder. Khairallah et al. [14] used a three-dimensional high fidelity powder-scale model to study the importance of recoil pressure and Marangoni convection in shaping spatter particle during laser bed-fusion process. Mumtaz and Hopkinson [16] used a pulse shaping technique to control the heat delivered to the laser-material interaction zone and consequently reduce the amount of induced spatter during SLM process. In another study spatter creation mechanism has been observed in single track experiments by employing 316 stainless steel powder [17]. The authors found that laser energy input affects the size, scattering state and jetting height of spatter significantly. Despite these studies on SLM technique, there is still a gap of knowledge and obvious need for a systematic analysis of spatter creation during SLM process. Current

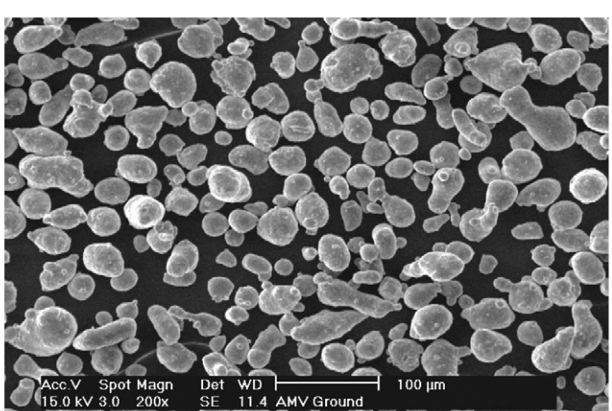

Fig. 2. Scanning Electron Microscopy (SEM) micrograph of the fresh Al-Si_{10}-Mg alloy powder. The average particle size is ranging between 30 μm to 50 μm.

developments of SLM machines using multiple powerful laser beams to accelerate the fabrication process speed, adds to the demand for investigating the spatter formation during SLM fabrication.

In the present work, high-speed photography is utilized to realize the formation mechanisms and behavior of spatter particles during SLM fabrication. A computational image analysis framework is developed and applied to obtain the size and the number of induced spatters. Spatter distribution while two laser beams are working together is compared with the one laser operation condition. It is shown that using multi-laser technology significantly increases the number and the size of induced spatter particles. The morphology and the composition of spatters and their influence on the surface of the fabricated parts are also determined in this paper. The good agreement reported between the photography results and the microscopic examination of SLM parts reveals the facts that spatter detection using a high-speed camera is a reliable method if it is applied properly. The effect of spatter formation on failure mechanisms of SLM products are studied and a discussion is made on requirements for development of a systematic process parameter optimization to enhance the mechanical properties of SLM products.

2. Materials and methods

2.1. SLM process

An SLM 280HL (SLM Solutions Inc., Lübeck Germany) machine is used for SLM fabrication. The machine is equipped with two 400 W CW Ytterbium fiber lasers and a 280 mm × 280 mm × 350 mm building chamber. The beams are directly focused on two systems of galvanometric mirrors and have beam diameters of approximately 80 mm at the focal point of lasers radiation. Fig. 1 shows the sequences of operation of SLM 280HL machines schematically. First, the bi-directional recoating devices deposit the powder with a predefined thickness on the building platform from the left end (Fig. 1a) and stops at the right end. Then, the laser beam selectively melts the powder layer based on the geometrical information of the sliced computer aided design

Table 1
Process parameters and the resulting energy input used in this study.

Effective Laser Power W	Layer Thickness μm	Scan Velocity mm/s	Hatch Space μm	Energy Input J/mm^3
300	30	1650	120	50.5

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