Elucidation of spatter formation mechanism with high-speed observation of melt pool in metal powder bed fusion

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KEYWORDS: Metal additive manufacturing, Spatter, Laser, Image analysis, High-speed observation

Metal additive manufacturing is a process in which a laser beam is irradiated onto a layer of metal powder, causing the irradiated area to melt and solidify, this is then repeated in layers. However, this method has a problem in that spatter generated during laser irradiation reduces the strength and surface quality of the fabricated object. Since the detailed mechanism of spatter generation has not yet been clarified, understanding this issue will be effective in realizing high-quality products in metal 3D printers. In this study, we constructed the experimental system using a pulsed laser, a processing laser, and a high-speed camera, observed the melt pool in-situ during laser irradiation, and used image analysis to quantitatively examine the mechanism of spatter generation. As a result of the experiment, spatter due to recoil pressure scattered from the front region of the melt pool at about 12 m/s was observed at 1,000,000 fps. By using image analysis on the obtained images, the velocities of the plume and spatter was visualized. The close proximity of these speeds suggests that the spatter was driven by the plume.

1. Introduction

Metal additive manufacturing is a method of fabricating complex shapes by repeating the process of melting and solidifying the irradiated portions of a metal powder layer by irradiating it with a laser beam. However, this method has problems such as a decrease in the strength of the fabricated object due to spatter generated during laser irradiation, etc. A study by Yang et al. found that the tensile strength and fracture strain of tensile specimens made from spatter-containing metal powders were lower than those made from spatter-free metal powders [1]. To solve such defects in fabricated specimens, it is important to understand the mechanism of spatter generation. Wang et al. observed the behavior of spatter generated by scanning a laser beam in a linear direction across a metal powder of SUS316L steel on the order of milliseconds and identified spatter as: i. metal vapor emitted by recoil pressure, ii. Liquid spatter emitted by convection in the melt pool, iii. Powder spatter scattered by the blast [2]. According to a study by Sonny Ly et al., the mechanism of spatter generated from melt pools is such that spatter is observed to be generated from the tip of the convexity after the convexity is formed [3]. As described above, various mechanisms of spatter generation are currently proposed. While such studies have been conducted, the mechanism of spatter generation has not been clarified quantitatively.

In this study, as a foothold to solve the aforementioned problems in metal additive manufacturing, we conducted in-situ observation of laser irradiation on the order of μm and μs using a pulsed laser and a high-speed camera, and investigated the spatter generation mechanism quantitatively from the obtained images.

2. EXPERIMENTAL PROCEDURE

The experimental system shown in Fig. 1 was used to observe the powder layer surface, melt pool, and spatter when the sample was irradiated with a continuous wave laser (SPI Lasers, redPOWER R4 CW). The sample was a SUS316L metal plate with a 50 μm-thick SUS316L metal powder (Sanyo Special Steel Co., Ltd., PSS316L) layer. The continuous wave laser irradiation conditions were set to 200 W output, 50 μm spot diameter, and 90 μs irradiation time. The sample was placed on a moving stage with a speed of 100 mm/sec, and spot irradiation was performed while the stage was scanning. Real-time observation was performed by using a pulsed laser illuminator (CAVILUX HF, Cavitar Ltd.) with a wavelength of 640 nm, a bandpass filter matched to the wavelength, and a high-speed camera (Hyper Vision HPV-X, SHIMADZU CORPORATION). While the sample stage was scanned, the filter was used to suppress scattered light and plume light from the continuous-wave laser. The frame rate of the high-speed camera is 1 million fps and the exposure time is 200 ns. A 10X objective lens (N Plan Apo NIR 10X, Mitutoyo) was used for observation from an angle of 11°. The continuous wave laser, pulsed laser illuminator, and high-speed camera used in this experimental system were controlled using a delayed pulse generator (DG645, Stanford Research Systems). Velocity vectors were displayed on the obtained videos using a Python based optical flow method on each video frame.

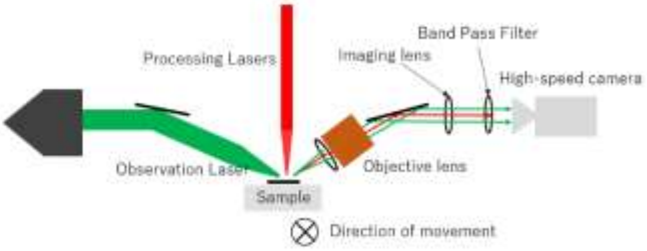

Fig. 1 Schematic of the experimental system

3. Results and discussion

Fig. 2 shows the observation results. Spatter was observed to be generated from the melt pool.

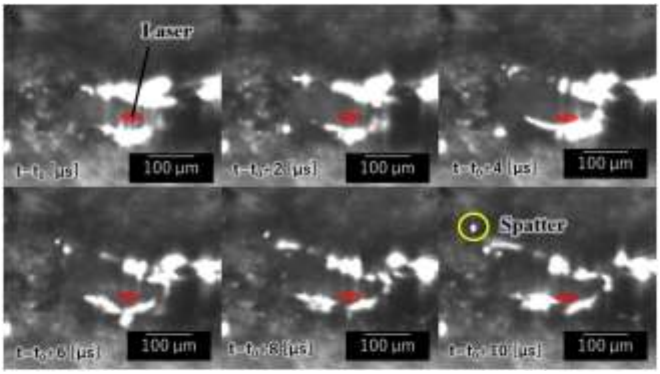

Fig. 2 Schematic of the experimental system

Fig. 3 shows the results of the analysis done by the image processing program.The green arrows represent the velocity vectors which are combined with the original image so that the flow can be visualized.

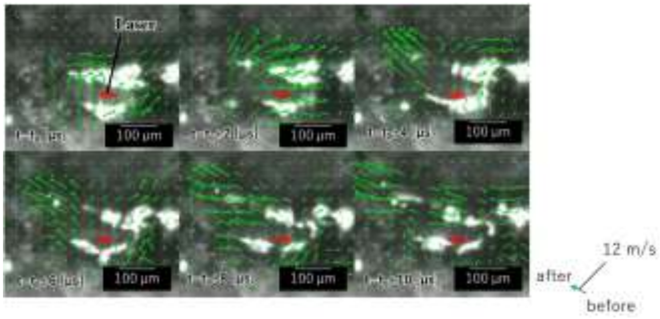

Fig. 3 Vector field of velocity

The velocity of the spatter and the velocity of the surrounding gas obtained as a result of image analysis are shown in Fig. 4.

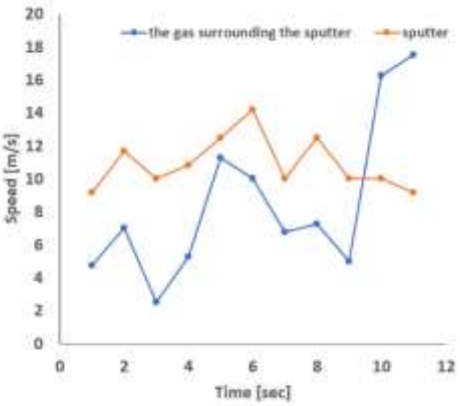

Fig. 4 Speed of spatter and gas surrounding the spatter

Image analysis was used to visualize the velocity of the gas surrounding the spatter. From the analyzed images, it was found that the velocity of the surrounding air was similar to that of the spatter at the moment when the spatter was generated. This analysis suggests that the spatter is caused by the influence of the surrounding gas. The instantaneous generation of strong metallic vapor from the keyhole generates a large shear force on the keyhole surface. As a result, a convexity grows from the keyhole, and spatter is observed to be generated from the tip of the convexity. Before 9 µs, the spatter always had a higher velocity than the surrounding air, but after 10 µs, the surrounding gas always has a velocity 6 m/s faster than the spatter. The reason why the spatter is not accelerated here is thought to be due to the shape of the spatter when it is scattered as droplets. Since the scattered spatter has a circular shape, shear force is less effective than when it is forming a convex hull, and as a result, it is less likely to be accelerated.

5. Conclusion

In this study, in-situ observation on the order of µm and µs during laser irradiation was performed using a pulsed laser and a high-speed camera, and the mechanism of spatter generation was quantitatively investigated from the images obtained and it was found that shear forces are exerted on the melt pool by the metal vapor and that spatter is generated from the melt pool.

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