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Detecting microscale impurities on additive surfaces using light scattering

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Abstract

Additive manufacturing (AM) is a fast-growing method that allows the production of complex geometries by reducing the need for traditional cutting tools and fixtures. A common metal AM technique, known as laser-based powder bed fusion (PBF-LB), uses laser beams to melt and fuse powder layer-by-layer into 3D parts. Despite efforts to improve the process, achieving consistency and reliability in PBF-LB remains a challenge, necessitating the development of comprehensive quality assessment systems tailored to PBF-LB. Microscale impurities that are formed on individual layers can significantly impact the overall part quality, and are the most common features across various materials. Hence, there is a need to establish a measurement system for their detection to create a quality assessment method for PBF-LB. This research introduces a light scattering technique designed for the detection of microscale surface impurities on PBF-LB components. Following the design of the experimental setup, a corresponding scattering simulation model, which is based on the Beckman-Kirchhoff approximation, has been developed to simulate the experimental conditions. This simulation model can be utilised for future use in generating scattering data faster and simpler than through experimentation. The paper presents preliminary results of both the experimental setup and simulation model. Our findings affirm that the proposed methodology, utilising both experimental and simulated approaches, can be used to detect microscale surface impurities. This advancement contributes to the establishment of a quality inspection system for the overall part assessment of PBF-LB.

Keywords: Laser-based powder bed fusion, light scattering, surface impurity detection

1. Introduction

Additive manufacturing (AM) is the method of building three-dimensional (3D) components by depositing materials such as metals, polymers and ceramics in a layer-by-layer fashion [1]. Among metal AM techniques, laser-based powder bed fusion (PBF-LB) stands out as the most widely used and developed technique [2]. It employs a high-power laser source to selectively melt and fuse layers of powdered material based on the geometric specifications of the parts.

Despite advancements in PBF-LB, determining the optimal process parameters for a specific material and geometry remains challenging due to insufficient stability, robustness and repeatability in the manufacturing processes [3]. This challenge can result in anomalies, defects and non-uniformities during fabrication, emphasising the need to assess fabrication quality to ensure product quality.

The assessment of PBF-LB fabrication quality can be achieved through measurement and monitoring methods utilising in-situ and ex-situ approaches [4]. This paper proposes an ex-situ inspection method, which holds potential applicability as an in-situ approach with further improvements, within both experimental and simulation frameworks.

The proposed approach utilises a light scattering technique for the detection of microscale surface impurities that may detrimentally impact the overall quality of the fabricated part. This method offers notable advantages, such as a rapid processing speed and the capability to detect impurities smaller than 100 µm in our case. Although the simulation model will be further utilised in subsequent research, this paper presents the outcomes of both approaches and validates their alignment.

In section 2, the experimental setup and simulation model to obtain the scattering pattern are detailed. Section 3 then presents the outcomes obtained through these methodologies. Section 4 provides a summary of the paper and the future work.

2. Methods

In this work, the surface is illuminated with a laser light source, and the resulting scattered light generates a distinct scattering pattern on a plane/screen. The surface topography determines the angle of the scattered light, and as a consequence, the scattering pattern contains information about surface topography, enabling impurity detection and surface quality evaluation [5].

The experimental setup (Figure 1) used in this study includes a diode laser with a central wavelength of 635 nm to illuminate the surface. The beam diameter of the laser source was reduced from the initial size of 1.1 mm to around 90 µm by a converging lens (with a focal length of 75 mm and a diameter of 50.8 mm) to enhance the detection capability of microscale impurities. The scattered light projected onto a screen is recorded by a digital single-lens reflex camera (with a field of view of (160 × 106) cm and a (6000 × 4000) pixels sensor). A microscopy system is used to confirm the illuminated area. Figure 2 a) and b) display microscopy images highlighting circular areas depicting illuminated regions with and without impurities, respectively.

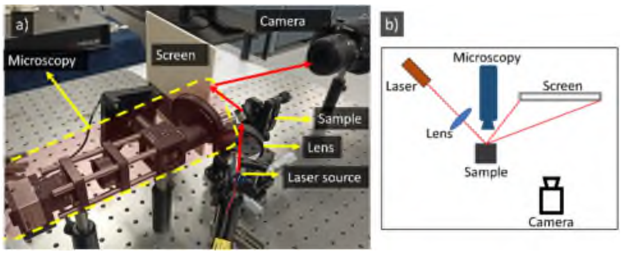

Figure 1. a) Experimental setup of the light scattering technique and itsb) schema.

For simulation of the experimental results, the Beckman-Kirchhoff theory of scattering [6] is employed. The simulation model reproduces the scattering patterns from the surface topographies obtained by a surface topography measuring instrument based on the coherence scanning interferometry (CSI) technique (Zygo Nexview NX2). The measured surface topographies cover an area of approximately (90 × 90) µm. Figure 2 c) and d) showcase examples of surface topographies of the PBF-LB surfaces with and without impurities, respectively. The PBF-LB parts examined in this study were produced from titanium alloy powder using a Renishaw 500Q machine.

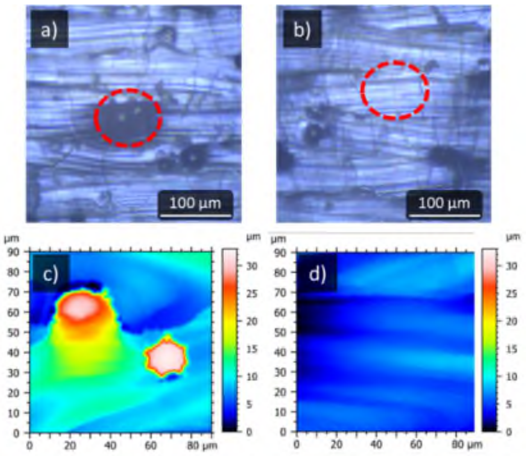

Figure 2. Example microscopy images of the PBF-LB surface a) with and b) without surface impurities. Example surface topographies of the PBF-LB surface c) with and d) without surface impurities obtained by the CSI instrument.

3. Results

Figure 3 and 4 present randomly selected scattering patterns derived from surfaces with and without impurities. Each figure displays two rows, with the top row showing experimentally acquired scattering images, and the bottom row presenting simulated scattering images. The images in Figure 3 demonstrate that surfaces with impurities produce randomly distributed scattered light patterns, whereas those in Figure 4 show that surfaces without impurities generate curved-like scattered light patterns. The observed distinction in scattering patterns produced by surfaces with and without impurities can be used for detecting such impurities, thereby affirming its potential utility in assessing surface quality.

4. Conclusion

In summary, this paper proposes a light scattering method within an experimental and simulation framework to detect microscale surface impurities. Surfaces containing impurities produce similar scattering patterns, as do surfaces without impurities. However, there are notable distinctions in the scattering patterns of surfaces with and without impurities. This indicates that the proposed method is applicable for detecting micrometre-scale surface impurities, allowing for the assessment of the quality of components produced by PBF-LB.

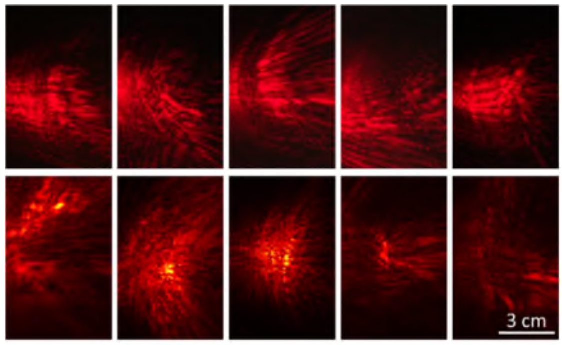

Figure 3. Scattering patterns of surfaces with impurities from the experimental (top) and simulation (bottom) models.

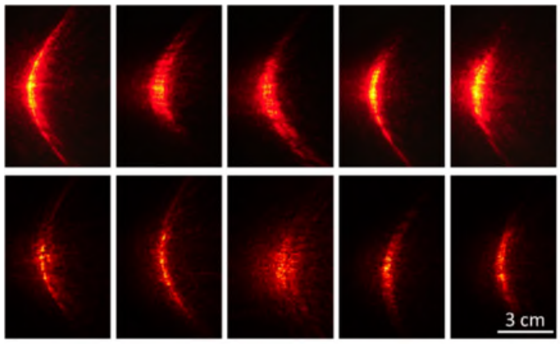

Figure 4. Scattering patterns of surfaces without impurities from the experimental (top) and simulation (bottom) models.

For future work, our plan involves training a machine learning algorithm to detect impurities from scattering images. The training process requires a substantial dataset, and the collection of a large volume of experimental data may prove challenging and time-consuming. Therefore, the simulation model emerges as a viable alternative, allowing for the generation of ample data in a more efficient and expeditious manner compared to the experimental setup.

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