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Improving surface and porosity analyses of laser powder bed fusion parts through CT-based three-dimensional metal powder characterization

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Abstract

X-ray computed tomography (CT) can be used to perform three-dimensional (3D) measurements of both size and shape of metal powder used as feedstock material in laser powder bed fusion (LPBF). Such powder characteristics – which can be altered when employing particles recovered after being used although not processed in previous processes – are known to have a significant influence on typical LPBF process issues and product flaws, such as the presence of internal defects and complex surface texture. This work investigates the possibility to exploit the CT-based 3D powder characterization to guide and improve the evaluation of surface texture and internal pores by aiding the identification of surface features due to unstable process conditions and the discrimination between pores caused by insufficient fusion and voids caused by the presence of spatter formation.

X-ray computed tomography, additive manufacturing, powder measurement, surface metrology, porosity

1. Introduction

Laser powder bed fusion (LPBF) is successfully used for the production of metal parts in high-added-value industrial sectors, such as aerospace, automotive and biomedical [1]. However, the quality of LPBF products is still often penalized by the presence of internal defects and surface texture complexity with high roughness [1]. The geometrical characteristics of the input metal powder are known to have a significant influence on such possible issues [2]. Even if powder particles are generated to have size distribution and shape promoting an acceptable flow and spreading during the coating operation as well as a high powder bed density, the recovery of used powder – which is beneficial for instance to improve the process sustainability – can lead to altered conditions of powder characteristics [3]. Previous works demonstrated that X-ray computed tomography (CT) can be used to perform sufficiently complete and accurate three-dimensional (3D) measurements of both size and shape of metal powder used in LPBF, and that 3D powder measurements might bring important advantages with respect to bi-dimensional (2D) measurements, such as those performed by scanning electron microscopy [4,5]. This work extends a previous study by the authors [5] and focuses on the possibility of exploiting the CT-based 3D powder characterization to guide and improve the evaluation of surface texture and internal pores. In particular, prior knowledge about the processed powder can aid the identification of surface features due to unstable process conditions and the discrimination of pores caused by insufficient fusion and voids caused by the presence of process by-products, such as spatter formations.

2. Materials and methods

This section briefly illustrates the materials and methods used for: the fabrication of parts by LPBF of different materials (Sect. 2.1), the powder measurements (Sect. 2.2), and the characterization of surfaces and internal porosity (Sect. 2.3).

2.1. Fabrication by laser powder bed fusion

Different powder materials were used in this work, including Ti6Al4V, AlSi10 and FeSi. Only recovered powders (i.e., powder particles remained unprocessed during previous fabrications and sieved before being reused) were employed. A Sisma MYSINT100 LPBF machine was used for the manufacturing.

2.2. Three-dimensional powder measurements

The powder batches were evaluated using a metrological micro X-ray CT system (Nikon Metrology MCT225; X-Tek Nikon Metrology, UK) following the methodology presented in [5]. The CT scanning parameters were specifically set for each powder material and sample design, while the voxel size was equal to 3 µm in all cases. Fig. 1 shows the 3D reconstruction obtained for a set of powder particles of the two investigated materials (i.e., Ti6AlV in Fig. 1a and AlSi10 in Fig. 1b). After performing a local-adaptive surface determination in the software VGStudio Max 3.2 (Volume Graphics Gmbh, Germany), the equivalent spherical diameter and the sphericity ratio were measured on a number of powder particles for each investigated materials.

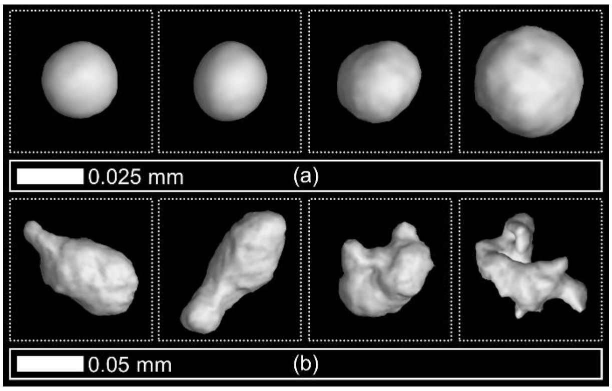

Figure 1. Examples of 3D CT reconstructed powder particles made of Ti6Al4V (a) and AlSi10 (b).

2.3. Surface and porosity characterization

The surfaces and internal porosities of fabricated parts were characterized by means of CT scans and feature-based analyses [6]. In particular, a procedure was developed and implemented using the software VGStudio MAX 3.2 and ImageJ (National Institutes of Health, USA) for segmenting and measuring the features belonging to the surfaces or included within pores. The sphere-based wall thickness analysis in VGStudio MAX 3.2 was initially used to identify a region containing only the features of interest. Such region was then exported as an image stack and elaborated in ImageJ to segment the individual features using a watershed algorithm. The features were measured in terms of equivalent spherical diameter and sphericity ratio (same measurands as per the powder particles; see Sect. 2.2).

3. Results

Fig. 2 shows the particle size distribution (PSD) cumulative curves related to Ti6Al4V and AlSi10 alloys. D10, D50 and D90 values are 22.4, 31.3 and 41.3 µm for Ti64AlV and 24.8, 35.4 and 50.3 µm for AlSi10. The maximum measured equivalent diameters are reported in Fig. 2 as well: 53 µm for Ti64AlV and 66 µm for AlSi10. Moreover, the average sphericity ratio was determined equal to 0.9 for Ti6Al4V and 0.65 for AlSi10. Such a difference is illustrated by way of example in the images shown in Fig. 1. The obtained CT measured values were used to guide the feature-based analyses performed as described in Sect. 2.3.

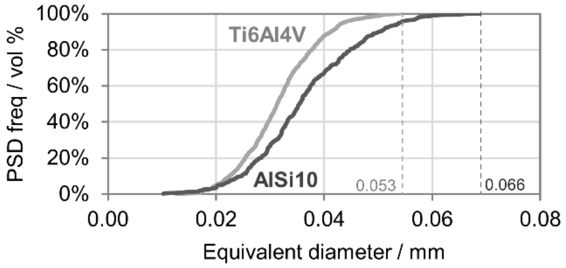

Figure 2. Cumulative PSD curves for Ti6Al4V and AlSi10 powder.

Among the surface features identified and segmented in the Ti6Al4V surface, 95 % were found to have shape and size in the same ranges as the initial powder, while the remaining 5 % were characterized by larger size. The former can be either individual particles or small clustered sintered powders attached onto the investigated surface; the latter can be due to spatter particles or to larger clustered sintered powders. In the case of the AlSi10 surface (see an example of reconstructed surface topography portion in Fig. 3), a significantly higher number of surface features larger than the powder particles (41 %) and with a sphere-like shape was found, indicating a higher process instability with respect to the Ti6Al4V case. Fig. 3a shows the overall result of the feature-based analysis. The features are illustrated distinguishing between spatter formations/large powder clusters and powder particles/small clusters respectively in Fig. 3b and Fig. 3c. From the presented result, it can be concluded that during the LPBF process of AlSi10 a more severe spatter formation occurred, which in this case was determined to be caused by a high volumetric energy density and low inert gas flow. Preliminary experiments were conducted also for lack-of-fusion (LOF) porosities in parts made of FeSi, which can be caused either by an insufficient volumetric energy density or by the presence of spatters fallen onto the powder bed before the laser action because not completely removed by the action of gas flow. LOF voids are typically characterized by the presence of entrapped powder with size and shape in the same range as the initial powder (see the example in Fig. 4a). When LOF voids are instead irregular and surrounding a spherical large particle (see Fig. 4b), they are typically caused by a spatter. Hence, the interpretation of porosity analyses and the study of their process-related causes can be improved based on the knowledge gained through the advanced CT characterization of powder particle geometry. This will be further investigated in future developments of this research.

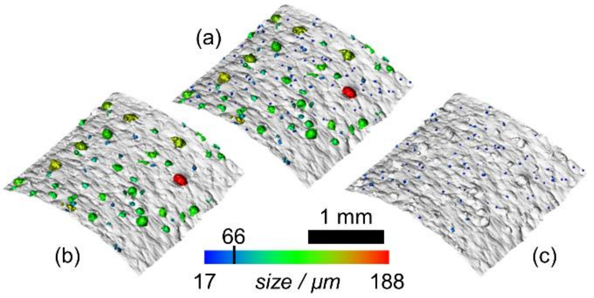

Figure 3. Example of AlSI10 surface topography obtained from CT data. Feature-based characterization (a), with further analyses distinguishing between spatter particles/large powder clusters (b) and powder particles/small powder clusters (c) sintered onto the surface.

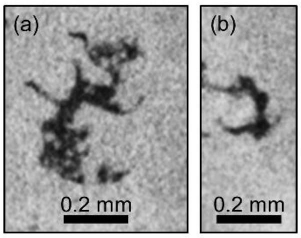

Figure 4. Examples of CT cross-sections of FeSi parts with internal LOF pores characterized by entrapped powder particles (a) and spatters (b).

4. Conclusions

In this work, 3D CT-based measurements of powder geometrical characteristics are exploited for aiding advanced surface topography of LPBF parts. In particular, it was shown how the prior knowledge gained from CT-based 3D geometrical measurement of powder can enable an advanced surface characterization, improving the discrimination between different types of process-induced surface features. Similar experiments were also proposed to discriminate between lack-of-fusion pores caused by insufficient melting (i.e., including entrapped powder particles) and by the presence of spatter particles. Such considerations are particularly relevant to improve the precision of the LPBF process by increasing the understanding of the process-related causes leading to defects. Future applications of the proposed approach can aid optimizing the percentage of recovered powder in the batch according to the printing conditions.

References

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