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Comparison of X-ray computed tomography and conventional methods for the geometrical characterization of metal powder for additive manufacturing

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Abstract

Among additive manufacturing technologies, laser powder bed fusion (LPBF) has experienced extensive interest in recent years from a wide range of industrial sectors, including aerospace and biomedical. One important aspect influencing the performances of processes and products is the quality of the feedstock material. In particular, metal powder used in LPBF should have shape and size promoting good flowability and packing behaviour, which have a direct impact on density, surface finish and mechanical properties of the fabricated parts. X-ray computed tomography (CT) is an advanced technique that enables holistic three-dimensional characterizations of metal powder, with simultaneous measurement of size and shape. The geometrical measurement accuracy of X-ray CT powder characterization is investigated and enhanced in this work, starting from the comparison with laser diffraction and scanning electron microscopy.

X-ray computed tomography, laser powder bed fusion, metal powder, geometrical metrology

1. Introduction

Laser powder bed fusion (LPBF) is increasingly used to produce metal components for advanced industrial applications [1]. The quality of metal powder used as raw material is important as it is strongly connected to the process performance as well as to the quality of the fabricated parts [2]. However, the metal powder is typically recovered and reused after the LPBF process for sustainability and cost-related reasons [3], leading to larger average size, more complex morphologies and properties degradation [4].

This work focuses on the required geometrical characteristics of metal powders, and particularly on shape and size distribution, which should promote good flowability, powder bed consistent packing and, as a consequence, final parts with acceptable density, surface finish and mechanical properties [5].

Two techniques that are commonly used for the evaluation of such powder characteristics are scanning electron microscopy (SEM) and laser diffraction (LD) [6]. The first technique is based on the analysis of bi-dimensional (2D) images of a single side of powder particles, in which the 2D nature of images limits the capability of well representing the three-dimensional (3D) morphology of powder, especially for particles with complex shape. The second technique can evaluate the size distribution, but not the shape of particles. X-ray computed tomography (CT) enables the measurement of both powder size and full morphology, based on the 3D reconstruction of powder particles [7].

This paper is part of a wider work aimed at investigating and enhancing the accuracy of CT metal powder measurements. In particular, X-ray CT measurements are compared here with characterizations obtained by SEM and LD methods.

2. Metal powder and characterization methods

Three powder batches of different materials were investigated in this work: Ti6Al4V, CuCrZr, and AlSi10. All batches are composed of powders recovered after being used, but not processed, in an actual LPBF process.

The powder batches were characterized using three different methods: X-ray computed tomography, SEM image analysis and laser diffraction.

X-ray CT scans were conducted using a metrological X-ray CT system (Nikon Metrology MCT225, X-Tek Nikon Metrology, UK), equipped with micro-focus X-ray tube (minimum focal spot size equal to 3 µm) and 16-bit flat panel detector composed by 2000×2000 pixels. SEM analyses were performed with a FEI Quanta 400 scanning electron microscope (FEI Company, USA). Laser diffraction was executed with a Malvern Mastersizer 2000 instrument (Malvern Panalytical Ltd, UK).

To adequately compare X-ray CT with SEM image analysis, a number of particles were attached to the top surface of a polymeric pillar, with a diameter equal to 5 mm, as schematically illustrated in Figure 1a. The pillar was designed to enable CT scanning of the powders with voxel size equal to 3 µm by the CT system described above. The pillar allowed also mounting on the SEM rotary table, to collect images of the powder particles in two different configurations. In the first configuration, the table was kept horizontal and the powder was imaged from above (as seen in Figure 1a). In the second configuration, the table was tilted by 60° and rotated around its axis to collect different images of the powder particles from lateral views (see Figure 1b). On their top part, Figures 1a and 1b show examples of SEM images of a CuCrZr powder particle obtained in the two configurations described above. The comparison of CT and SEM analyses was done considering both 2D and 3D CT measurements, aligning CT volumes according to the acquisition direction of SEM images.

In order to compare X-ray CT with laser diffraction, a higher number of powder particles were inserted into a thin polymeric cylinder with a diameter of 5 mm (see Figure 1c). Also in this case, CT scans were conducted with a voxel size of 3 µm. An example of a cross-section extracted from the CT 3D reconstruction of a sample made of Ti6Al4V powder is shown in Figure 1c. A 3D region of a CT reconstruction is instead visible in Figure 2a. Four examples of CT reconstructed individual powder particles with different morphology are shown in Figure 2b.

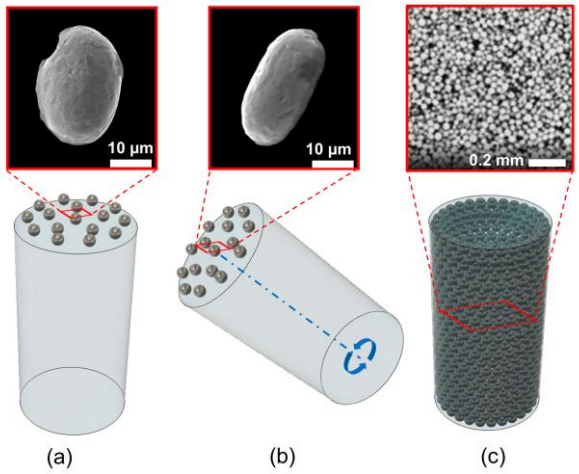

Figure 1. Bottom: schematic representations of (a) powder particles arranged above a polymeric pillar for CT and SEM analyses, (b) configuration with tilted table used for SEM analyses from lateral views, and (c) powder included in a cylindrical container for CT and LD characterization. Top: (a, b) examples of SEM images of a CuCrZr powder particle obtained in the two different SEM configurations, (c) example of cross-section extracted from a CT 3D reconstruction of Ti6Al4V powder included in a cylindrical container.

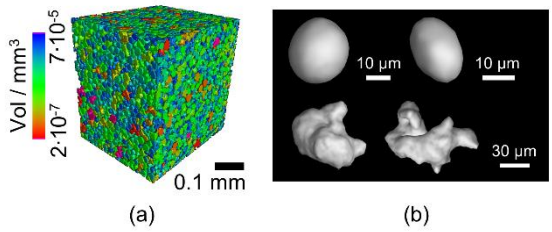

Figure 2. Examples of CT reconstruction of: (a) powder batch, and (b) individual particles with different shapes.

3. Comparison of characterization methods

This section presents the results obtained by comparing X-ray CT powder characterisation with SEM image analysis and with laser diffraction. SEM and CT images of powder particles were compared from different points of view, according to the configurations illustrated in Figures 1a and 1b. The overall shape of particles was found to be well represented by CT (see examples in Figure 2b), even if the resolution is lower than SEM. This outcome holds for Ti6Al4V and AlSi powder independently from the morphological complexity, and for CuCrZr powder particles with simple geometry. The higher X-ray attenuation coefficient of CuCrZ lead to more pronounced blurring and image artefacts, with increased difficulties in obtaining an accurate representation of particles with complex morphology. Percentage deviations between CT and SEM shape measurements were found to be 5% for Ti6Al4V, 6% for AlSi10 and 8% for CuCrZr, on average.

Concerning the measurement of the particles size, dimensional deviations between CT and SEM showed a bias. The surface determination – conducted using the local-adaptive algorithm available in VGStudio MAX 3.2 (Volume Graphics GmbH, Germany) – was then improved by optimizing the starting threshold value based on the comparison of CT with SEM. The percentage deviations determined after the threshold optimization were equal to 3% for Ti6AlV and AlSi10, and 4% for CuCrZr, on average.

The optimized threshold also allowed improving the comparison of CT with LD, as visible in Figure 3, which compares the cumulative size distribution curves obtained with CT and LD in the case of CuCrZr. CT curves obtained with non-optimized and optimized threshold are both illustrated. The obtained D10, D50 and D90 showed a maximum deviation of 1.9 µm after the optimization.

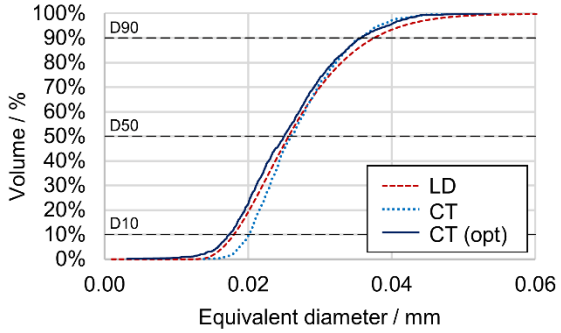

Figure 3. Cumulative size distribution curves obtained with X-ray CT and laser diffraction in the case of CuCrZr powder. CT curves obtained with non-optimized and optimized threshold are both reported.

4. Conclusions and future works

This paper was focused on the comparison of CT powder measurements with powder analyses performed by SEM and LD. Even if the spatial resolution cannot be as good as in the SEM images, CT has proven to be capable of providing a good representation of the overall powder shape and size, for different grades of powder morphological complexity. Increased difficulties were observed in the case of CuCrZr, due to more pronounced blurring and image artefacts. Despite such difficulties, after optimizing the surface determination based on the comparison of CT with SEM measurements, the comparison with LD in the case of CuCrZr powder showed a maximum deviation of 1.9 µm with regard to D10, D50 and D90 values.

Future works will further address the evaluation and enhancement of the accuracy of CT metal powder characterisation. The use of nano-focus CT devices with higher resolution is also planned for this purpose. In addition, the CT measurements will be used to study the relation between powder geometrical characteristics and the quality of LPBF parts, particularly in terms of surface texture and density.

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