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Feature-based characterisation of laser powder bed fusion surfaces

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Abstract
A novel algorithmic pipeline for the automated identification and dimensional/geometric characterisation of topographic formations of interest (surface features) is proposed, specifically aimed at the investigation of signature features left by laser powder bed fusion of metallic surfaces. Unmelted and partially-melted particles, as well as spatter formations and weld tracks, are automatically identified and extracted from topography datasets obtained via state-of-the-art areal topography measurement instruments, and then characterised in terms of their size and shape properties. Feature-based characterisation approaches, such as the one proposed in this work, allow for development of new solutions for the study of advanced manufacturing processes through the investigation of their surface fingerprint.

Feature-based topography characterisation, laser powder bed fusion, surface metrology, manufacturing process fingerprint.

1. Introduction

The investigation of manufacturing processes through the signature they leave on the fabricated surface plays an important role in process development and optimisation, especially for those manufacturing technologies that are still at an early stage of industrialisation, such as additive manufacturing of metals via laser powder bed fusion (LPBF) [1,2]. Recent advances in areal topography measurement [3] now allow an unprecedented level of detail in the acquisition of topographic information at micrometric and sub-micrometric scales. However, conventional topography data analysis and characterisation methods are still strongly rooted in the computation of areal texture parameters (in particular, the set of areal parameters defined in ISO 25178-2), and thus, are conceptually oriented towards capturing the properties of the entire measured region into a series of summary indicators (texture parameters). An opportunity is, therefore, missed in fully exploiting the acquired topographic information, pertaining to individual topographic features [4].

The focus of this work is on LPBF of metals. First attempts at the identification of topographic features in LPBF surfaces are found in recent works by the authors [5] and elsewhere [6,7]. In this work, an approach is presented for that allows for a comprehensive identification and characterisation of the most relevant signature topographic features of LPBF surfaces. An original algorithmic approach to automated identification and characterisation of the signature features is proposed, which can be applied to topography datasets normally obtainable from current state-of-the-art topography measurement instruments.

2. Methods

A Ti6Al4V sample (40 mm × 14 mm × 10 mm) fabricated via LPBF using a Renishaw AM250 selective laser melting machine with the manufacturer's recommended build settings is selected as a test specimen. An Alicona InfiniteFocus G5 focus variation (FV) microscope is used for measurement (20× magnification objective: NA 0.4, single field of view (FOV) of (0.808 × 0.808) mm, pixel width (0.439 × 0.439) µm). The top layer is investigated in the as-built conditions, i.e. with no post-processing, to retain as many topographic formations as possible; useful to investigate the signature of the process. Several regions are measured using a single FOV with no stitching, located sufficiently far from the sample borders to be considered representative of steady-state manufacturing process conditions (i.e. avoiding unconventional thermal effects typical of edge regions). The measurement results in a height map of 1840 × 1840 points.

The targeted topographic features (attached particles, spatter formations, weld tracks) are summarised in figure 1.

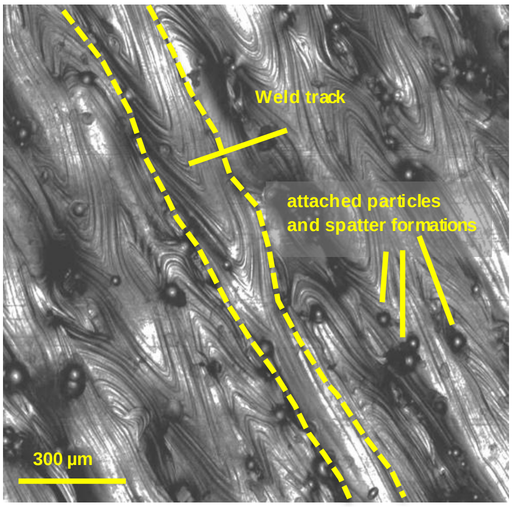

Figure 1. Main topographic formations visible on the LPBF surface (top layer). Focus-stacked image taken with a confocal microscope (FOV (1.78 × 1.78) mm, pixel width (0.625 × 0.625) µm).

2.1. Pre-processing of the topography datasets

The feature identification algorithmic pipeline consists of a first pre-processing step of the entire topography, comprised of levelling by least-squares mean plane subtraction, and replacement – by weighted interpolation of valid neighbours – of non-measured points (voids) and localised spike-like measurement artefacts identified via local outlier detection.

2.2. Identification and characterisation of attached particles and spatter formations

Attached particles and spatter formations are processed through the same algorithmic procedures as they are both seen as protruded singularities; the main discriminating factor being size (the spatter formations are larger, resulting from coalescence of multiple melted particles). The shape of the protruded singularities is approximately spherical, except when multiple particles are clustered together, so shape/size-related considerations can be used for further discrimination, once generic protruded singularities have been isolated. To isolate the features, the topography is first filtered using a high-pass Gaussian filter (ISO 16610-61) to remove the underlying, larger-scale waviness, then height-based segmentation is performed via k-means clustering [8] to obtain a coarse identification of the features. Shape/size post-processing on the two-dimensional feature footprint (blob analysis via image moments) leads to further discrimination between individual particles (unmelted or partially-melted particles), spatter formations (approximately circular footprint but projected area larger than a single particle) and particle clusters (large projected area, non-circular footprint and low isoperimetric quotient). Attributes such as particle numerosity, aspect ratio, size and localisation within the FOV can be determined once the features have been individually extracted.

2.3. Identification and characterisation of weld tracks

Once deprived of particles and spatter (masked out as non-measured points), the topography is fitted to a smoothed approximation via local non-parametric regression (Lowess – locally weighted scatterplot smoothing [9]). Morphological segmentation into hills with Wolf and area pruning (ISO 25178-2 and [10]) is then applied to isolate the weld tracks. Once the individual tracks have been isolated, their shape/size properties (thickness, width and cross-sectional shape) can be investigated by slicing each track along their respective axes, found via blob analysis of the weld track footprint.

3. Results

The identification results for the attached particles are shown in figure 2, as obtained on one of the test datasets. The identified features are rendered in false colour.

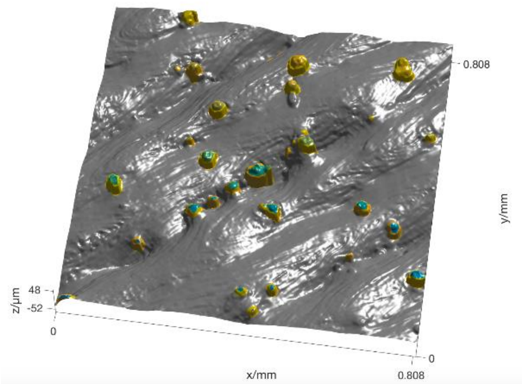

Figure 2. Results of the algorithmic identification of attached particles for one of the test datasets.

In figure 3, feature post-processing via blob-analysis is shown as a means to further discriminating the protruded singularities into individual particles, spatter formations and particle clusters.

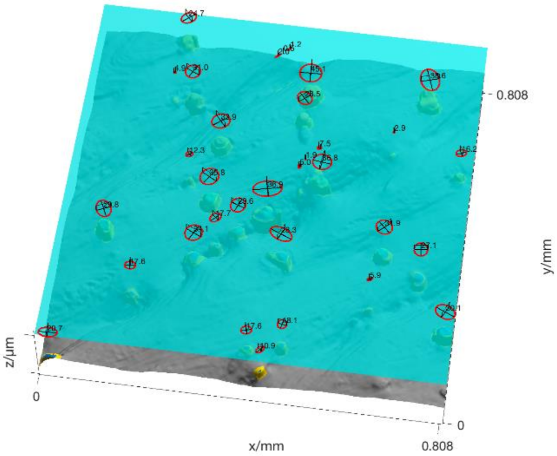

Figure 3. Feature post-processing via blob-analysis.

The identification results for the weld tracks are shown in figure 4, for the same test dataset shown in figure 2 and figure 3. In figure 5, an extracted weld track is shown, along with the results of weld track slicing and local weld track width computation on the cross-sections.

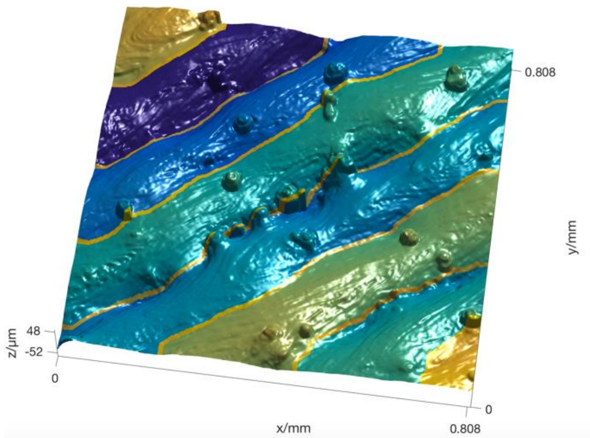

Figure 4. Results of the algorithmic identification of the weld tracks for the same test dataset shown in figure 2 and figure 3. Each track is rendered in different colour.

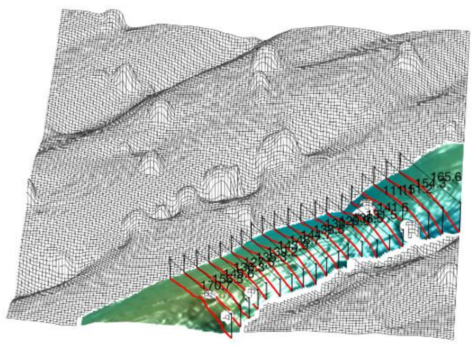

Figure 5. Extraction, cross-sectioning and local width computation for one of the identified weld tracks.

4. Conclusions

An algorithmic pipeline has been implemented which allows for both the automated identification and the dimensional/ geometric characterisation of localised topographic features of interest, starting from areal topography datasets. The pipeline has been designed to target signature features left by the LPBF process on the top surface of metal parts, and allows the investigation of the manufacturing process fingerprint.

The results promote the approach of feature-based characterisation as a viable alternative to the summary description of topographic properties via computation of areal field texture parameters (e.g. roughness parameters), and allows a more direct targeting of the geometric and size properties of topographic features left by the manufacturing process under investigation.

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