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Feature-based characterisation of evolving surface topographies in finishing operations for additive manufacturing

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Abstract
Finishing operations play a fundamental role in the additive manufacture of components. Conventional surface metrology solutions allow for the characterisation of surface roughness through texture parameters, but are not fully suitable to capture the evolution of individual surface topographic formations as they undergo changes as a result of finishing operations. Feature-based characterisation of topography offers a new perspective in the investigation of surfaces. The approach consists of the identification, isolation, and dimensional characterisation of surface topography formations (surface features). In this work an original feature-based solution is proposed for the quantitative comparison of topographies before and after a finishing operation: the approach is based on the registration of areal topography datasets and quantitative analysis of shape and size differences pertaining to the relevant topographic features. A variety of finishing operations are investigated on metallic samples manufactured via powder bed fusion.

Surface texture, surface finishing, additive manufacturing, surface topography

1. Introduction

Finishing operations are applied for a variety of reasons to additively manufactured (AM) components, such as for the removal of supports, part accuracy improvements and other surface texture improvements [1]. Operations, such as shot peening [2], grinding [3] and laser polishing [4], are often applied to improve the surface quality of AM parts. It is known that finishing operations applied to a surface leave a characteristic fingerprint related to the operation itself. Examples are shot craters (as a result of shot peen size and shape), the uncovering of sub-surface features and creation of tool marks (as a result of the grinding process removing the upper surface, until the bulk material is reached), the appearance of weld tracks and re-melt features (as a result of the re-melt laser strategy) [4].

Commonly, areal surface texture parameters, such as those given in ISO 25178-2 [5, 6] are used to describe a change in surface topography as a reduction or increase in nominal value. However, texture parameters only quantify an overall change of textural properties, and are often not suitable to capture the changes that individual surface topography formations (surface features) undergo during the modification process.

In the literature on finishing operations applied to AM surfaces, qualitative assessments of changes pertaining to surface features are often performed through visual observation of, for example, images taken via optical or scanning electron microscopy. However, rigorous, quantitative techniques to perform such assessment from measured data, other than computing texture parameters, are currently lacking.

Topography measuring instruments are now capable of acquiring areal topography information to an unprecedented level of detail [6], so that geometrical and dimensional information pertaining to individual topography features can now, at least in theory, be processed. Algorithms for feature identification, extraction and quantitative characterisation are currently being developed, and new application opportunities are being explored [6-9].

In this work, the possibility to apply feature-based characterisation to the investigation of topography modifications occurring as a consequence of finishing operations in AM processes is investigated through the development of an original approach. The approach consists of the following steps:

- A sample specimen is designed, featuring one or multiple custom surface features designed to survive the finishing process with minimal modifications. These features are designed to act as relocation landmarks.
- The sample is manufactured, measured as-is, subjected to the finishing operation, and then re-measured.
- The landmark features are used to relocate the two measured datasets with respect to each other.
- Feature-based characterisation is used to identify and isolate the topographic formations of interest, and track their evolution through the modification process.

The approach is illustrated as it is applied to investigate the topography evolution of samples fabricated via electron beam powder bed fusion (EB-PBF) and laser powder bed fusion (L-PBF), and subjected to a variety of finishing processes, including shot peening, grinding and laser polishing.

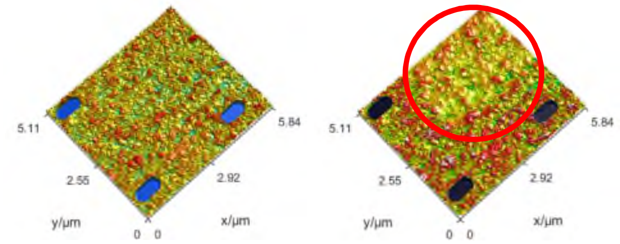
2. Methodology

2.1. Samples

Titanium alloy (Ti-6Al-4V) and nickel super-alloy (Inconel 718) samples were fabricated by EB-PBF with an Arcam A2X, and L-PBF with a Renishaw AM250. The blocks were built at multiple orientations, to include effects due to building direction in the investigation. A 30° angled titanium alloy EB-PBF block subjected to finishing by shot peening is presented in the figures 1, 2 and 3.

2.1. Relocation landmarks

Three slots were fabricated via micro-milling on each sample. Each slot is shaped as a (1.0 × 0.5) mm rectangle with rounded corners and 300 µm depth. The slots are arranged as shown in figure 1.



(a) (b)

Figure 1. Measured surface before and after shot peening showing the slots acting as relocation landmarks and the shot peened region (b – red circle).

2.2. Measurement strategy

A focus variation microscope [10] (Alicona IF G5) was used to measure the surfaces using a 20× objective (NA 0.4; field of view (0.81 × 0.81) µm). A (5 × 5) mm stitched measurement area was acquired to include both the relocation landmarks and an area (2.5 × 2.5) mm wide for evaluation (figure 1). The measurement set-up involved a 3.51 µm lateral resolution, 12 nm vertical resolution (resolution as defined by the instrument manufacturer), and the use of ring light. Measurements were performed before and after the finishing operations with the same set-ups. Relocation was performed in Digital Surf MountainsMap [11] using the landmarks as fiducials.

2.3. Finishing operations

Finishing parameters shown in table 1 were used.

Finishing operation	Key parameters and values
Shot peening	ASH110 cast steel shot approx. 280 µm Ø, Almen intensity 0.2 mm to 0.25 mm A, 200% coverage, 0° impact angle
Grinding	P80 grit flap wheel , 100 mm/s spindle speed, 0° attack angle, 12 N contact force, 3 passes
Laser Polishing	500 W 1090 nm laser, 350 µm spot size, 225W laser power, 30 µm hatch, 500 mm/s scan speed, 0° angle from nominal, argon shielding

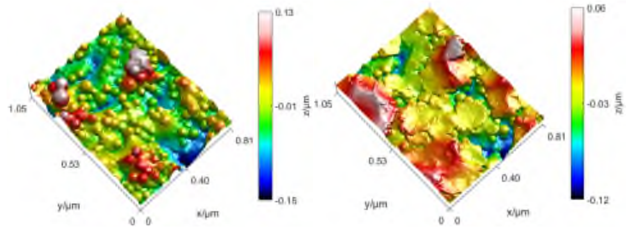
Table 1. Finishing parameters

2.4 Feature-based evaluation of surface topography

After alignment, custom algorithms were applied to the surface topographic data to identify and isolate relevant features on the AM as-built and finished surface. Feature attributes, such as number of instances, footprint area and volume were computed as indicators of topography evolution.

3. Results

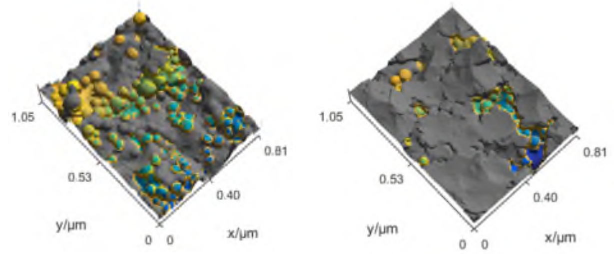
An extracted, aligned region of an angled EB-PBF titanium alloy surface before and after shot peening is shown in figure 2.



(a) (b)

Figure 2. Aligned and extracted (0.81 × 1.05) mm regions of the (a) as-built and (b) shot peened, 30° angled titanium EBM surface.

Spatter features have been algorithmically identified (Figure 3). The feature-based analysis allows to track both the instances that underwent modification as a consequence of the finishing operation, and those that survived the process basically unchanged.



(a) (b)

Figure 3. Identified spatter formations in the as-built surface (a) and surviving unaltered the finishing operation (b).

4. Conclusions and future work

An original method has been presented for the investigation of evolving topographies as a consequence of finishing operations. The method has been applied to AM parts. The method is based on combining topography registration based on fiducials, with feature-based characterisation for the identification of relevant topography formations, and to track how they change as a consequence of the finishing operation.

Further work will apply this methodology to other finishing operations, AM processes and orientations to offer further understanding of the evolution of the features on the AM surface.

Acknowledgements

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