euspen's 16th International Conference & Exhibition, Nottingham, UK, May 2016

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On characterising surface topography of metal powder bed fusion additive manufactured parts

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Abstract

Inherent to the somewhat uncontrolled nature of the additive process, the surfaces of metal powder bed fusion additively manufactured components tend to be very rough. Large isolated 'bumps', as one of the major defect features, are often present due to partially melted particles attached to the surface. An enhanced watershed segmentation method is proposed to separate these 'bump' features from the underlying surface texture such that the 'bumps' and underlying surface can be quantitatively analysed. The results show that the amplitude roughness parameters of the underlying surface are significantly less than the un-segmented surface and spatial roughness parameters differ between two surfaces. Characterising the extracted underlying surface and 'bumps' independently allows better correlation between surface measurements and additive system performance and hence aids in process optimization.

Surface metrology, additive manufacture, watershed segmentation

1. Introduction

Additive manufacturing (AM) processes have the potential to produce highly complex, customisable and multifunctional parts at lower material and energy costs and with lower environment pollution than conventional (subtractive) manufacturing techniques. However the commercialisation of AM has been beset by a number of technological issues, wherein uncontrolled process and lack of precision in product are identified as major hurdles [1]. There is an urgent demand for accurate methods of measuring and evaluating AM surface quality.

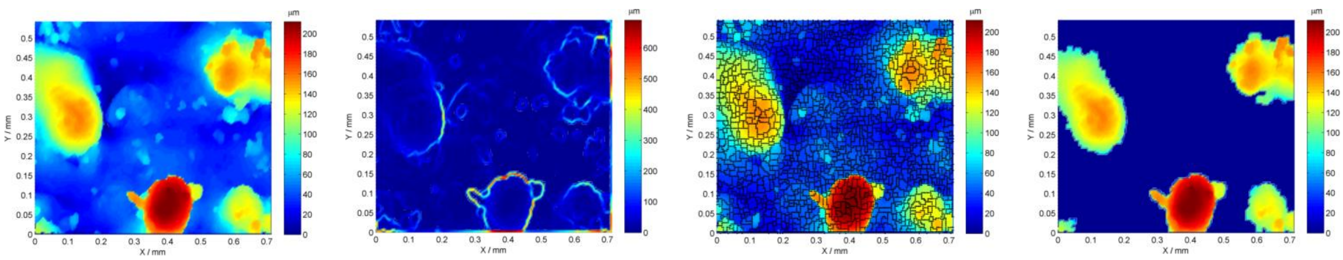
The complex nature of powder AM processes tends to produce component surfaces that are very rough, showing significant defect features, including large isolated 'bumps' due to partially melted particles attached to the surface, repeating steps generated by successively adding layers, surface pores and re-entrant features. To achieve a good surface finish post-processes, such as grinding, polishing and sand blasting, are performed to remove these protruding 'bumps'. Such processes however will also deteriorate the underlying surface and other defect features which may contain critical evidence concerning the additive process. Thus it is of critical importance to extract the pertinent features in order to facilitate the further study of the origin of individual defects and their relevance to the process optimisation.

As the AM surface topography is often dominated by the presence of 'bump' features, this paper presents the use of the watershed segmentation method for separating the 'bumps' and the underlying surface texture such that they can be quantitatively analysed.

2. Enhanced watershed segmentation

Figure 1a presents a 0.71x0.54 mm^2 surface measured from the side surface of a solid cube produced by selective laser melting using AlSi10Mg powder (no post processing). The surface was measured using an Alicona G4 focus variation instrument with a 20x magnification objective lens. Significant 'bumps' are clearly present on the surface topography while the underlying surface shows relatively better surface quality. To separate the 'bump' features from the underlying surface, an extraction method based on the watershed segmentation technique [2, 3] has been developed. The watershed method, originated from geography, which naturally segments a landscape into a number of catchment basins, is well qualified for the extraction of 'bumps' on the metal AM surface by viewing them as the Maxwell hills.

The 'bump' topography elements feature a high gradient at their geometrical boundary and high surface height in comparison to the neighbouring surface. Edge enhancement is required to reinforce the feature boundary and enable the subsequent segmentation analysis to obtain a more



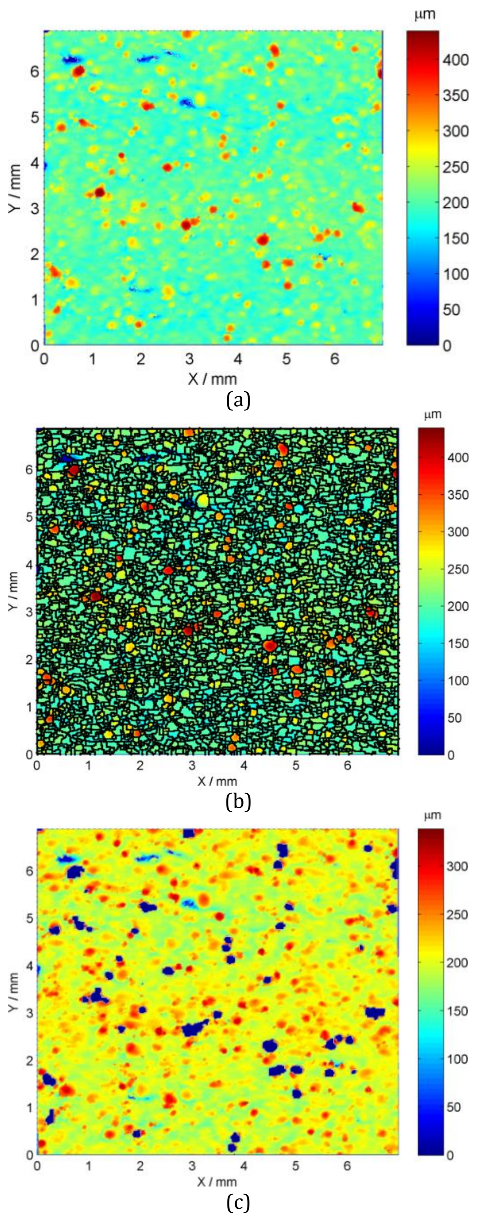
(a) (b) (c) (d)

Figure 1. Extraction of 'bump' features from a 0.71x0.54 mm^2 AM surface: (a) Original surface; (b) Gradient map; (c) Watershed segmentation; (d) Extracted 'bumps'.

representative extraction. This is achieved by applying the Gaussian filtering to suppress measurement noise and smooth topographical features followed by application of the Sobel operator [4] to yield a gradient map of the processed surface data. Figure 1b shows the resultant gradient map of the surface.

The watershed segmentation is applied to the gradient surface to generate a sequence of small segments. These segmented surface patches designate local surface hills. Figure 1c presents the resulted segments superimposed spatially on the original measured surface. To extract the 'bumps', an estimated threshold 100 µm is applied to the local surface hill height. Those surface patches with their height above this threshold are extracted and regarded as the bump features. See Figure 1d for the extracted 'bumps'.

Figure 2a presents a large surface measured from the same part and by the same measurement instrument but with 10x magnification objective lens. The surface is 6.88x6.98 mm^2, which is a much larger surface area than that shown in Figure 1 and thus is more meaningful for the comprehensive evaluation of the surface topography. The developed method is applied to the measured surface with a systematically defined height threshold of 321 µm, which is three standard deviations above the mean height of the underlying surface excluding 'bumps'. Figure 2b illustrates the result of the watershed segmentation and Figure 2c shows the final extracted underlying surface. The 'bump' features are marked by the blue areas.



(a) (b) (c)

Figure 2. Extraction of 'bump' features from a 6.88x6.98 mm^2 AM surface: (a) Original surface; (b) Watershed segmentation; (c) Underlying surface texture.

3. Results and discussion

The values of areal parameters per ISO 25178-2 [3] were extracted from the underlying surface and the un-segmented surface. In the case of the surface presented in Figure 2, the amplitude parameters Sa and Sq and the spacing parameter Sal are given in Table 1. It is clearly observed that the values of Sa and Sq for the underlying surface texture are significantly less by around 16% and 17% compared to the un-segmented surface and the Sal values of the two surfaces are different as well.

Due to the presence of significant 'bumps', the parameter results of the un-segmented surface evidently differ from that of the underlying surface. Efficient separation of defect features enables independent characterisation of different surface components and thus offers a more accurate analysis of complex AM surface topography.

Table 1 Surface texture parameters of un-segmented surface and the underlying surface.

Parameters	Un-segmented surface	Underlying surface
Sa	22.16 µm	18.72 µm
Sq	37.45 µm	30.88 µm
Sal	0.112 mm	0.129 mm

Feature extraction facilitates further characterisation of the 'bump' areas and the result for the surfaces measured is given below, which can also be useful for detecting process malfunction.

- Total 'bump' areas: 0.92 mm^2
- 'bump' area percentage to the whole surface: 1.92%
- Total 'bump' volume: 0.069 mm^3

In the present case the extraction of 'bump' features is determined by thresholding the local surface heights. Other potential judgement criteria include segment volume or the projected segment surface area.

4. Conclusion

The topography of AM surfaces contains various types of defect features pertinent to the additive processes, wherein large isolated 'bumps' are caused by partially melted particles attached to the surface. It is proposed to use the watershed segmentation method with appropriate enhancement to separate the 'bump' features from the underlying surface texture, thus allowing a more accurate analysis of AM surface topography.

Future work includes the improvement of segmentation method and the analysis of other types of defect features, such as step markings and surface pores.

Acknowledgement

The authors gratefully acknowledge the UK's Engineering and Physical Sciences Research Council (EPSRC) funding of the EPSRC Centre for Innovative Manufacturing in Advanced Metrology. The authors would like to thank the University of Nottingham EPSRC Centre for Innovative Manufacturing in Additive Manufacturing for supplying the AM sample.

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