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The effects of x-ray computed tomography filament degradation on extracted areal surface texture data.

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Abstract

The addition of x-ray computed tomography (XCT) to the arsenal of available surface metrology methods has proved particularly advantageous due to its ability to perform areal surface analysis of surfaces with no line-of-sight (optical or contact stylus). This technique has particular application for parts manufactured by additive manufacturing techniques (AM). The combination of the use of XCT for dimensional checks and extraction of surface topography has led to significant interest in XCT as a metrology tool. Recent research has led to the development of validation of the methods by which useable areal surface texture data can be extracted from XCT scans. Various factors effecting the values obtained from this process were highlighted previously. The paper highlighted a significant change to data following a filament change, this may be attributed to the filaments not being dimensionally identical, not being seated in the same position or possibly degrading during their useful life. Filament changes are a regular maintenance procedure carried out when using XCT machines this is due to the consumable filaments reaching the end of life. At the point where a filament has reached end of life its diameter will have decreased by approximately 5-6% [1]. This paper reports on a research program which has investigated the statistically significant changes to the measured surface texture data from a known surface, throughout the lifetime of an XCT filament. The results are presented in terms of changes to extracted areal texture parameters per ISO 25178-2 and show that during the filament lifetime the effects of filament degradation needs to be taken into account and a maintenance/validation checks need to be regularly carried out.

Keywords: x-ray computed tomography, filament, areal surface texture data, ISO 25178

1. X-ray computed tomography

The use of X-ray computed tomography machines as a metrology tool has allowed users to perform data extraction from previously inaccessible surfaces, with new methods having been developed to meet existing ISO standards regarding this field [2].

It is however important to understand the limitations of these machines and possible sources of error, the hypothesis of this paper is that the degradation of the filaments used in XCT is a source of error.

2. X-Ray computed tomography filaments

Filaments are a consumable used in XCT machines. In use a high current is passed through a tungsten filament which then emits a stream of electrons due to the increase temperature. These electrons then strike a target material generating x-rays, these are then used for imaging.

Filament life as monitored on the authors system (Nikon XT H 225) varies dependent on usage, historically this has ranged from 20 to 200 hours. During the useful life the diameter has been found to decrease by 5-6% [1]. It is hypothesised this change in diameter will have a significant effect on any data taken.

The present work concentrates on the effect of filament life on extracted areal surface texture parameters. This work should provide a basis for developing correction methods, for any changes noted to this data throughout a filament's life.

3. Data collection methods

Two methods of data collection were used to provide both accurate results as well as results that accommodate the random usage of the XCT machine by third parties. Both methods used the settings displayed below (*Table 1*).

Areal surface texture parameter data was gathered from a sample of additively manufactured Ti6Al4V. Prior to the beginning of each measurement a filament change was performed.

Table 1 *Parameters used for data collection*

Voltage (kv)	160	**Current (w)**	9.9
Gain (dB)	12.0	**Magnification**	10.4
Filter thickness (mm)	1	**Filter Material**	Copper
Exposure time (ms)	4000		

3.1. Consecutive scan data gathering

The first method of data gathering used took consecutive scans of the artefact, this batch scan took a measurement of the artefact repeatedly for approximately 120 hours using an identical set of variables. With each individual measurement taking approximately 3.3 hours to complete.

This method was devised to minimise external influences on the surface data collected, as it is unknown what effect variation of acquisition parameters may have on filament life.

3.2. Accounting for multiple users

It is common for XCT machines to have multiple users, especially in research and engineering institutions where various projects are often run concurrently. With this being the case it is recognised that the variation in the relevant settings could alter the results gathered throughout the life of a filament.

Variation such as this was accounted for by taking a measurement approximately every 20 hours during the normal working life of a filament. Starting with a measurement at 0 hours, with measurements taken every 20 hours for 100 hours. As projects finish times varied measurements could not be taken at exact 20 hour intervals. This resulted in scans being taken as close to 20 hour intervals as possible.

4. Areal surface texture data processing

Data processing has been carried out in accordance with the methodology developed by Townsend et al. [2] This procedure facilitates the extraction of surface topography information from the raw XCT point cloud. XCT point clouds contain re-entrant features which cannot be analysed by comerical packages such as Surfstand of Mountains.

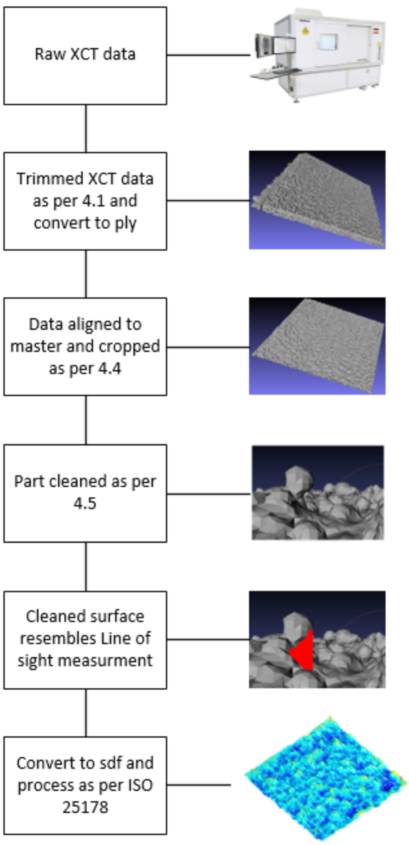

Figure 1 *Step by step process showing re-entrant features.*

Through this process these features are removed leaving a surface which is line of sight. Imagery of various steps can be seen in figure 1.

4.1. Trim Data

XCT scan data comprises of a full 3D model of the part, as only one face was being studied the other surfaces were cropped to reduce the time taken for data analysis. Care was taken to assure these surfaces were a minimum 9 mm x 9 mm centred from the original surface.

4.2. Convert stl to ply

Stl (Sterolythography) and ply (Polygon File Format) are common forms 3D mesh file formats. Ply file format contains only vertices not the triangle mesh information.

The file size is also approximately 30% the size of an stl allowing for faster data analysis.

4.3. Align surfaces

A focus variation measurement was used as a master sample; this sample was not trimmed allowing for the largest possible area to be used during the alignment process.

All remaining surfaces were aligned to this surface using a least squares function in cloudcompare.

4.4. Crop to 8.4 mm x 8.4 mm

Post alignment all surfaces excluding the master were cropped to 8.4 mm x 8.4 mm using an identical coordinate system, these were then saved to ply.

4.5. Clean mesh

In order to perform the next step accurately the XCT mesh needs to be cleaned removing any non-viable re-entrant features as seen in figure 1. The surface was cleaned then repaired in meshlab to create a continuous mesh.

4.6. Convert ply to sdf

The XCT data files were then converted to a height map (Standard Data File) from a point cloud using linear interpolation, and projection onto a plane. A 2.5 µm grid spacing was used to mirror existing standards. Sdf files allow for areal texuture parameters to be generated using Surfstand.

4.7. Crop to 8mm x 8mm

The surfaces were the cropped per ISO 25178-3 to 8 mm x 8 mm and saved as a SDF file.

4.8. Filter in line with ISO 25178-3

Filtering was performed on all surfaces again in line with ISO 25178-3 using a Gaussian Regression L-filter index of 8 mm and an S-filter index if 0.025 mm

4.9. Generate parameter data per ISO 25178-2

Surface data was generated per ISO 25178-2.

Table 2 *Average surface texture data measurements at time given*

Filament Life (Hrs)		0	20	40	60	80	100	120
Scan Set 1	Sa (µm)	9.752	9.800	9.696	10.201	9.900	9.768	9.803
	Sq (µm)	12.693	12.814	12.618	13.255	12.936	12.783	12.831
	Sz (µm)	143.239	142.613	153.503	154.242	149.280	143.362	149.080
Scan Set 2	Sa (µm)	10.234	10.309	10.505	10.255	10.219	10.237	10.282
	Sq (µm)	13.293	13.353	13.635	13.318	13.305	13.249	13.380
	Sz (µm)	170.994	171.392	162.819	154.614	154.509	170.532	160.630
Scan Set 3	Sa (µm)		10.151	10.407	10.063	10.171	9.906	
	Sq (µm)		13.248	13.549	13.146	13.308	13.004	
	Sz (µm)		149.057	121.956	154.188	155.544	154.691	

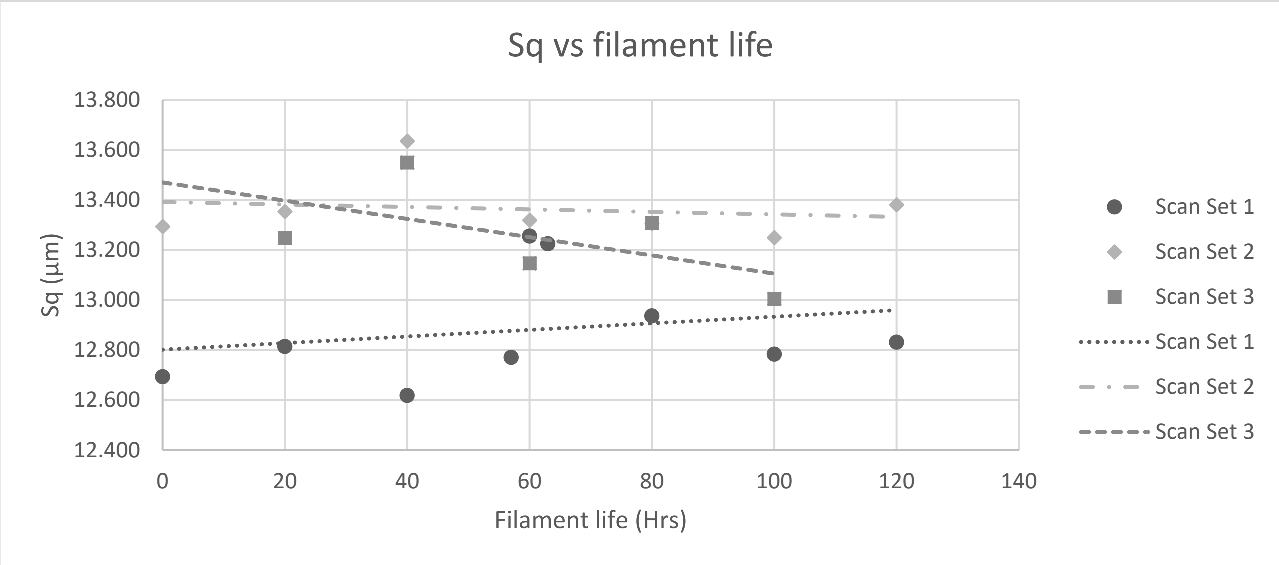

Figure 2 *Sq against filament life w/line of best fit (least squares method)*

5. Analysis of results

Three scan data sets were taken with scans 1 and 2 using the data collection method detailed in section 3.1. and scan three using the method from section 3.2.

Initial results show the variation of parameters taken does not provide a pattern correlating with the deterioration of the filament. Table 2 shows fluctuations in the data appear random in nature.

Figure 2 clearly demonstrates that the deterioration of a filament alone does not affect the extracted areal texture data. Variation is however clear from the results with an average percentage difference of -4% in Sq between scan sets 1, and 2. This is significantly higher than the differences found by Townsend et al who reported a changes of -0.97% after filament change [3].

It was noted the 60 hour scan in set 1 was significantly higher than other data sets from the same filament, as such the scans taken immediately before and after were analysed. The surface texture parameters extracted from these scans are displayed on Figure 2. They were found to partially match the already existing pattern with the scan immediately after showing very similar Sq value to the 60 hour scan.

6. Further analysis

6.1. Further data analysis

As outlined above, consecutive data collection was employed for scans sets 1 and 2. Further analysis of the data from consecutive scans will allow a hypothesis to be drawn on the cause of the fluctuation of parameters during a filaments life.

If consecutive scans show incremental changes following the trends established by the current data set it can be assumed that some small change between scans is affecting the results. However, if consecutive scans show a similarly random distribution it may show limits regarding the accuracy of areal texture data extracted from XCT scan data, understanding this limitation will affect the application of these methods.

6.2. Filament to filament variation

Areal texture data extracted from a sample can be seen to vary from filament to filament with previous results concurring with the results shown to a lesser extent. These changes whilst small may prove significant in certain applications and should be taken into consideration.

Further work should investigate the difference from filament to filament focusing on the overall change to values extracted from surfaces. A large sample number of filaments could show the window of variation and thus the range within which values are accurate.

It should be noted that a machine produced by Nikon (MCT225) has been built specifically for metrology and as such has a protocol for calibrating the system post filament change.

6.3. Filament defects

It is possible that surface defects and porosity may along with manufacturing tolerances regarding the filament diameter, be responsible for the variation seen from filament to filament.

By studying the surfaces of filament pre use and performing analysis of the areal texture data taken using these filaments, links may be found between the defects themselves and results given.

It is unlikely diameter alone has an effect on results as the deterioration of the filaments during use does not correlate to the results shown. Porosity analysis of filaments may also show hidden defects that again could affect data taken using XCT machines.

7. Comparison of data collection methods

The two methods of data collection used did not produce significant differences in the areal texture data extracted.

8. Conclusion

The hypothesis that a clear link between the deterioration of a filament throughout its working life would be reflected by a change in the extracted areal texture data has not yet been proven, though variation of extracted surface data throughout the life of an individual filament has been demonstrated.

Whether this variation is random or deterministic is the subject of continuing work. If proven to be deterministic, the sources will be isolated and methods will be developed to attempt to correct this.

In additional the results presented concur with those from past papers by Townsend et al [3], in that there is an apparent change in extracted surface texture results when comparing measurements taken using different filaments. Causes of this phenomena are currently under investigation.

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