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Results from an interlaboratory comparison of areal surface texture parameter extraction from X-ray computed tomography of additively manufactured parts

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Abstract
This paper presents the results of the CT-STARR (CT-Surface Texture for Additive Round Robin) interlaboratory comparison. The study compares the results obtained for the extraction of areal surface texture data per ISO 25178-2 from five X-ray computed tomography (XCT) volume measurements from each of four laboratories. To reduce the number of process variables, all participants utilise a Nikon XCT machine, either an XT H 225 industrial CT or an MCT22S metrology CT. Measurement process parameters, such as physical X-ray filtering, acceleration voltage and filament current, are set at similar values for all machines. All data processing and computation to extract, align, crop, filter and generate surface texture parameter information and deviation analysis results from the measurement volumes is performed by one participant. Two Ti6Al4V ELI (extra low interstitial) components are included in each of the XCT acquisitions. The first component is an additively manufactured cube built on an Arcam Q10 electron beam melting machine. Surface texture data is extracted from XCT scans of this part. The second component is a machined artefact designed for XCT scaling and surface determination analysis and verification. The data extracted from XCT measurements of these components is compared with measurements from coordinate measuring machine, focus variation and stylus instruments. The effect of scaling correction and XCT surface determination on extracted surface texture data, as well as measurement repeatability and reproducibility, are discussed.

Additive manufacturing, areal surface texture data, interlaboratory comparison, X-ray computed tomography, metrology, ISO 25178.

1. Introduction

Additive manufacturing (AM) methods enable the manufacture of components with features that are not possible to manufacture using conventional subtractive techniques. However, the freedom to manufacture components with complex internal features presents manufacturing challenges. Currently the principal method available for imaging the internal features of metal AM components is X-ray computed tomography (XCT). The importance of areal surface extraction from XCT is discussed elsewhere [1, 2] but, until recently, the only reported research detailing the extraction of surface information from XCT was the extraction of profile data from lattice structures [3]. A novel methodology for the extraction of areal surface texture data per ISO 25178-2 [4] from metal AM components has been reported [5]. The results showed a 2.5 % difference between the mean measurements obtained using XCT when compared to a focus variation (FV) instrument in measurement of an AlSi10Mg AM component. The potential industrial and research applications of this technique have prompted development of a round robin to assess the variation of results between XCT laboratories. The current work reports on Stage 1 of the CT-Surface Texture for Additive Round Robin (CT-STARR).

Stage 1 is designed to be a tightly controlled, expeditious round robin with a limited number of participant laboratories (four) using similar XCT machines with defined measurement settings. The results of measurements and analysis of Stage 1 data will then be used to guide a second, expanded round robin (Stage 2).
maintain an air gap between all measured surfaces and the fixture (see figure 1).

Figure 1. Artefacts within the fixture

The fixture development process is reported elsewhere [7]. The artefacts were not removed from the fixture during five XCT measurements performed by each round robin laboratory.
Post round robin measurements included further measurements of surface and dimensions using FV and stylus, together with a repetition of the CMM measurements. The participants and the XCT machines used are shown in Table 1.

Table 1. Round robin participant laboratories

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Responsible</th>
<th>XCT machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Huddersfield, UK</td>
<td>Andrew Townsend</td>
<td>Nikon XT H 225</td>
</tr>
<tr>
<td>University of Nottingham, UK</td>
<td>Richard Leach</td>
<td>Nikon METROSURF</td>
</tr>
<tr>
<td>National Physical Laboratory, UK</td>
<td>Peter Woolliams</td>
<td>Nikon MCT225</td>
</tr>
<tr>
<td>Nikon Metrology, UK</td>
<td>David Bate</td>
<td>Nikon MCT225</td>
</tr>
</tbody>
</table>

All extracted surface data was aligned to one of the FV measurements. The FV and XCT data was processed per the methodology introduced in [5]. The surfaces were levelled and filtered with an L-filter nesting index of 8 mm and an S-filter nesting index of 0.025 mm per ISO 25178-3 [8]. Data was extracted and values for parameters per ISO 25178-2 were generated.

3. Results

Results reported here are for one set of measurements from the University of Huddersfield (XCTHUD) and one set of measurements from the University of Nottingham (XCTNOT). Table 2 shows the mean and standard deviation (SD) values of ISO 25178-2 parameters computed for the FV and XCT measurements.

Table 2. ISO25178-2 parameter values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean FV</th>
<th>SD FV</th>
<th>Mean XCTHUD</th>
<th>SD XCTHUD</th>
<th>Mean XCTNOT</th>
<th>SD XCTNOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sq/μm</td>
<td>32.40</td>
<td>0.001</td>
<td>30.77</td>
<td>0.036</td>
<td>32.03</td>
<td>0.252</td>
</tr>
<tr>
<td>Ss/μm</td>
<td>25.33</td>
<td>0.001</td>
<td>24.05</td>
<td>0.031</td>
<td>25.07</td>
<td>0.241</td>
</tr>
<tr>
<td>Sz/μm</td>
<td>33.59</td>
<td>0.306</td>
<td>32.77</td>
<td>2.889</td>
<td>32.70</td>
<td>1.644</td>
</tr>
<tr>
<td>Ssk</td>
<td>0.246</td>
<td>&lt;0.001</td>
<td>0.08</td>
<td>0.016</td>
<td>0.202</td>
<td>0.008</td>
</tr>
<tr>
<td>Sku</td>
<td>3.70</td>
<td>&lt;0.001</td>
<td>3.67</td>
<td>0.009</td>
<td>3.66</td>
<td>0.040</td>
</tr>
<tr>
<td>Sdr/%</td>
<td>39.90</td>
<td>0.013</td>
<td>28.26</td>
<td>0.123</td>
<td>41.92</td>
<td>1.080</td>
</tr>
</tbody>
</table>

Figure 2 shows the results of the FV, XCTHUD and XCTNOT for SQ and Sz, showing the 95 % confidence interval for the mean. The XCTHUD Sq and Sz are approximately 5 % and 2.5 % less than the FV values. The XCTNOT Sq and Sz are approximately 1.1 % and 0.9 % less than the FV values. Figure 3 shows the charts for the dimensional artefact OD, ID and length measurements taken on the CMM and both XCT machines. The OD, ID and length dimensional measurement errors for the XCTHUD were -0.27 %, -0.83 % and -0.54 % respectively. If a surface determination correction of 4.1 μm is applied, moving the calculated surface into the part, the errors become -0.55 %, 0.55 % and -0.54 %.

A global (x,y,z) dimensional scaling compensation of +0.55 % can then be applied. The effect of these compensations on the AM surface parameters will be investigated as part of future work.

4. Conclusion

The round robin results of ISO 25178-2 areal surface data extraction from XCT scans of a Ti6Al4V ELI component have been reported for two of the round robin participants. The results for SQ for the XCTHUD and XCTNOT measurements are mean 30.77 μm (SD 0.036 μm) and mean 32.03 μm (SD 0.252 μm) respectively; these mean values are within 5 % and 1.1 % of the FV results (FV mean 32.40 μm [SD 0.001 μm]). Analysis of the differences in standard deviation values for the initial XCTHUD and XCTNOT surface parameters, together with the final results for all four participants will be presented at conference and in a later journal. This round robin, an extension of a novel technique to extract quantitative areal surface texture data reported in [5], validates the parameter extraction process, provides useful repeatability and reproducibility data and provides baseline information for an expanded, Stage 2, round robin.

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References