SLS surfaces, Gelsight and ISO-25178 digital post-processing

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Abstract
Additive manufacturing (AM) is a set of technologies that produce parts in a layer-by-layer fashion. The layers can consist of various basis materials, ranging from polymers to ceramics. These successive layers are bound together using different techniques that go from melting through laser irradiation or polymerizing through UV lamps. The present work investigates the surface characteristics of parts produced by the Selective Laser Sintering (SLS) of polymers. The surfaces are characterized using a Gelsight benchtop apparatus that recreates 3D height maps employing a photometric stereo-algorithm and a novel type of sensor. Depending on the orientation of the surface during the processing, different surface roughness are expected. These surfaces are post-processed according to the ISO 25178-series for areal surface texture. The different surfaces are characterized using a varying range of nesting indices to separate form, waviness and roughness.

Keywords: Selective Laser Sintering, Surface, Gelsight, ISO-25178

1. Introduction

1.1 Surfaces of Selective Laser Sintering parts
It is common knowledge in the AM community that Selective Laser Sintering and Melting (SLM) parts exhibit coarse surface textures. The combination of powder as basis material, the layer-wise construction method and the laser scanning strategy lead to rough surfaces [1, 2]. Various research groups have identified ways to alleviate the roughness as for example by diminishing the layer thickness [3], orienting the parts in a certain way [4] or varying the laser scanning parameters for the outline [5]. The orientation of the surface in the building chamber is decisive as the side faces, vertical to construction plane, are rougher than top- or bottom-facing surfaces. However, despite the numerous tentative to optimize SLS surfaces, the roughness of parts coming out of SLS equipment is still not satisfactory. It may be in the fact that these surfaces could not be correctly characterized.

1.2 The Gelsight device
As a matter of fact, the characterization of surface texture for SLS parts was based on profilometry and most of the literature presents R-values. However, in the recent years, the amount and quality of surface texture characterization devices has increased ranging from confocal microscopy to stereo scanning electron microscope (stereo-SEM). Unfortunately, most of these non-contact methods are either not accurate enough for the reflective and white SLS surfaces or too costly to be performed on a daily basis [6, 7]. The Gelsight enables a rapid and true reproduction of surface texture notwithstanding the optical properties of said surface. It was shown to be effective and reliable for SLS surfaces with reproducibility and repeatability testing [6, 8]. This device was developed by Johnson [9, 10] and is based on a transparent elastomeric sensor covered on one side with a reflective coating. The sensor is pressed onto the surface and successively illuminated from 6 different directions and consecutively photographed as can be observed in Figure 1.

Figure 1. Gelsight benchtop setup to determine the areal roughness of textured surfaces; 1 - Live image of surface; 2 - High resolution camera; 3 - Reflective pad illuminated from the side and pressed onto the sample – illustrated on the right

Figure 2 presents a 3D height-map of an investigated PA12 surface; it is calculated on the basis of the grey scale pictures using a special photometric stereo algorithm developed by Gelsight. Depending on the magnification set up on the camera, the field of view and the resolution vary in a broad range, enabling the observation of micrometric to centimetric features.

Figure 2. Height-map of a vertical PA-12 surface taken with Gelsight and optical objective 3x, the field of view is 7.5 x 5 mm² with a resolution of 1.45 µm/pixel.
Because the Gelsight pads are produced out of soft matter, the investigation of surfaces with sharp edges or stiff and tall peaks can deteriorate the pad by cutting or stabbing. The surface state inside cavities (tubes, hollow cubes, undercuts...) cannot be measured as the pad cannot be pressed into such features. Moreover, depending on the geometry of the investigated surface, the pressure of the benchtop apparatus might not reach to force the gel to conform down to the deepest valleys or might not render properly a steep step at right angle. However, compared to other surface characterization devices, the amount of information gathered from Gelsight investigation is still important even when taking the drawbacks into account.

1.3. Post-processing according to ISO 25178

The standard series “ISO 25178: Geometric Product Specifications (GPS) – Surface texture area” [11] is a collection of standards for the analysis of 3D areal surface texture. The post-processing flowchart proposed by the ISO 25178 is well depicted by Digital Surf [12] as seen in Figure 3.

![Figure 3](Image)

**Figure 3** The flowchart for areal surface post-processing following ISO 25178 as presented by Digital Surf.

The characterization of areal texture parameters depends on the kind of filters used for separating the form, waviness and roughness of surfaces. The “ISO 25178-3 Specification operators” recommends extracting the evaluation area with its side length corresponding to the filtration nesting index. The filters given in Figure 3 are categorized as follows:

- S-filters remove the short-scale components
- F-Operator is the form removal operation
- L-filters remove the long-scale components

The nesting index for the S-filter-division depends on the resolution of the measuring device. The nesting indices for F- and L-filtrations are recommended to be chosen so that they are roughly 5 times higher than the coarsest feature and taken from the following series:

...
0.1 mm; 0.2 mm; 0.25 mm; 0.5 mm; 0.8 mm; 1.0 mm; 2.0 mm;...

While investigating SLS and SLM surfaces with confocal microscopy, Grimm [13] used a 0.8 mm L-nesting index to isolate the roughness from the waviness components of the surface. Triantaphyllou [14] identified an L-nesting index for SLM surfaces of 2.5mm to be sufficient to cover the wavelengths of interest. Both articles mentioned above [13, 14] are part of the few scientific publications taking into account areal surface texture parameters and the “ISO-25178” post-processing routine. For this reason, the present investigation tries to determine the impact of post-processing on the surface roughness characterization of SLS surfaces for different inclinations and materials.

The surface texture parameters taken into account for the present study are taken from the “ISO 25178-2 Terms, Definitions and surface texture parameters” and are the root mean square height of the scale-limited surface $S_a$

$$S_a = \frac{1}{A} \iint z^2(x,y) \, dx \, dy ,$$  
**Eq. 1**

the skewness of the scale-limited surface

$$S_{sk} = \frac{1}{S^3} \frac{1}{A} \iint z^3(x,y) \, dx \, dy ,$$  
**Eq. 2**

and the kurtosis of the scale-limited surface

$$S_{ku} = \frac{1}{S^4} \frac{1}{A} \iint z^4(x,y) \, dx \, dy ,$$  
**Eq. 3**

where $z$ is the ordinate value and $A$ the evaluation area. The texture aspect ratio parameter of the scale-limited surface, $S_{ar}$, and the developed interfacial area ratio of the scale-limited surface, $S_{dr}$ are considered as well for the investigation of nesting index effect on the post-processing of SLS surfaces.

There exist different kind of filters that are presented in details in the “ISO 16610: Geometrical product specifications (GPS) – Filtration” [15]. The present work is based on the Robust Areal Gaussian Filter (FARG) that enables the generation of a plane that is not disturbed by any local or random feature of the surface profile. The FARG filter is described in “ISO 16610-71 Robust areal filters: Gaussian regression filters”.

2. Experimental Part

The following experiments are planned and currently in execution. However, the results will be presented at the conference. Three different commercial SLS materials will be used to build cubes of 20x20x20 mm$^3$:

- Duraform PA12 on an EOS P760
- Duraform HST on a DTM Sinterstation 2500 High
- iCoPP on a DTM Sinterstation 2500 Vanguard

All materials will be processed with conventional production parameters. The surface characterization will be performed using the benchtop Gelsight system with objective 3X magnification and iron oxide reflective pads of 38.1 mm diameter. The investigated surfaces are the top – side – bottom of the cubes as shown in Figure 4.

![Figure 4](Image)

**Figure 4** Fileted cube for Gelsight surface characterization. The cube's dimensions are 20 x 20 x 20 mm$^3$ and produced out of different commercial SLS materials.

The obtained height-maps will subsequently be post-processed using different nesting indices from the list mentioned above and the effect of the evaluation area is investigated at the same time. The digital post-processing is performed using the Mountains Map software from Digital Surf [12]. The effect of nesting indices and evaluation areas will be observed based on the parameters presented in Section 1.3.
4. Outlook

Based on the results obtained from this investigation, the optimization of the SLS process regarding surface finish should advance further. By understanding the order to magnitude of different mechanisms behind the rough surface state of SLS parts, specific counter-measures can be considered to effectively alleviate their effect on the surface texture. Moreover, a rapid, reproducible and relatively cheap surface characterization method could enable investigate more into details and correlate part performances with surface texture. The Gelsight could be used for determining the impact of different surface post-processing methods existing for the SLS process.

References