Evaluation of the influence of selected parameters of Selective Laser Sintering technology on surface topography

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Abstract. The paper presents the preliminary research results of studies of the influence of basic technological parameters of the additive technology, Selective Laser Sintering (SLS), on the quality of geometric surface texture. Microstructural studies included the determination of two-dimensional as well as three-dimensional parameters of surface texture. The study includes the influence of technological parameters such as the orientation of the models on the virtual building platform, the energy density transmitted to the sintered powder layer and the building layer thickness. The results confirm that the above mentioned parameters have a significant influence on the geometrical surface texture. The most favorable variants of the location of the models on the building platform, the value of layer thickness and energy density applied to sintered powder were determined.

1. Introduction

Additive manufacturing (AM) technologies have revolutionized the manufacturing industry over the last few years. Because of the layered nature of the building process and possibility to manufacture models directly from 3 dimensional CAD files, AM allows production of unique models with almost unlimited shapes, especially with complex internal dimensions. Generative technologies are successfully found in many kinds of industries as both prototype and fully functional applications. The ever-expanding branch of both the production of more accurate machines and modern construction materials used in the layered technologies shows that these technologies are becoming more competitive in some applications than conventional manufacturing methods [1] such as machining, forging or casting.

Selective Laser Sintering of polyamide powders is one of the most important additive manufacturing technologies. Due to the use of material in a form of powder which is based on construction polyamide (PA), SLS technology has great application potential [2]. This applies both to the production of prototype models [3,4] and fully functional components of machines and equipment, for example technical seals or bearing arrangements [5,6,7]. In this technology there is no need to build support structures, which significantly increases its production potential. The recent trend in the development of additive technologies demonstrates that these technologies will continue to evolve dynamically in the direction of hybrid machines (combination of CNC machining centres and additive machines) and with the development of the so called “overprinting” to obtain composite elements [8].

With the development of technology and consequently the complexity of construction of machines implementing layered technologies, a significant problem has arisen. There is an increase in the
number of process parameters which influence the properties of manufactured elements. These include, especially, dimensional accuracy and mechanical properties, which directly influence performance characteristics such as abrasive wear processes [9]. Therefore, it is crucial to determine the impact of process parameters on the above mentioned properties. This is particularly true of the surface texture quality due to its strong influence on the correct co-operation of the associated machine elements. Experimental research is focused on both mechanical properties [10,11,12] and accuracy as well as mathematical analysis of the surface texture [13,14,15,16,17]. These papers describe the influence of process parameters on mentioned phenomena.

The paper [14] presents the research results, which consisted of determining the influence of selected process parameters on the microstructure of the examined surface. In addition further laser surface treatment for samples made of metal powder manufactured by SLS technology were included. Research has shown that it is possible to improve (reduce) the value of the surface texture parameters by laser treatment, and the key technological parameters are laser power and energy density.

Preliminary studies conducted by the authors of the paper [9] have shown that the “printing” direction on the platform during manufacturing and the building layer thickness affect the abrasive wear process. The research was carried out on the well-known polyamide PA 2200 using a tribometer (ring on disc type).

Research conducted in the work [16] was based on the influence of selected process parameters such as laser power, scan spacing, bed temperature and hatch length on 2D geometric surface parameters: $Ra$, $Rz$ and $Rq$. The material used for the construction of the samples was Dura-form polyamide. Research has shown significant impact of the aforementioned technological parameters on the measured quantities, in particular the laser power, where, with increasing its value, the roughness parameters decrease.

The important scientific topic of the influence of technological parameters of selective laser sintering technology on the dimensional accuracy of the models, especially technological surface texture is discussed in the presented paper. Further research will involve the extension of research especially the impact of process parameters on the more complex 3D surface texture parameters, the mass of building models and stress relaxation during compression testing.

2. Research and Methodology

Cylindrical samples with a diameter of 13 mm and 6.3 mm high were designed in SolidWorks, CAD software. These dimensions are in accordance with the ISO standard [18] for specimens designed to determine stress relaxation during uni-axial compression tests. By using EOS Formiga P100 machine, which is a selective laser sintering technology printer, physical models of the sample with predefined technological parameters have been manufactured. Each type of sample was made in 3 pieces. Three characteristic variants of positioning of models on the machine building platform, i.e. at 0 °, 45 ° and 90 °, were selected. The building layer thickness was equal to 0.1 and 0.2 mm. All type of sample was produced with three specified values of energy density i.e. 0.032 J/mm², 0.056 J/mm² and 0.08 J/mm². Material used to construct the samples was polyamide PA 2200 which is based on the well-known construction material polyamide PA 12. Measurements of the surface texture were carried out at the Laboratory of Computer Measurement of Geometric Quantities at the Kielce University of Technology using the Taylor Hobson TalySurf CCI Lite. This devise uses coherence correlation interferometry measurement technique (CCI). This precision optical measurement profilometer is characterized by a measuring range of 2.2 mm, with a vertical resolution of $Z = 10$ pm and optical resolution (X, Y) of 0.4-0.6 μm [19]. The parameters of primary profile ($Pa$, $Pz$) and surface ($Sa$, $Sz$) were obtained after leveled processes. To compare research results further filtering operation was not necessary. Surface geometry studies were carried out at the top surface of the sample (Fig.1) using the magnification equal to 20, where the measured area was 0.8 x 0.8 mm. The geometric parameters [20] of the primary 2D profile ($Pa$ and $Pz$) and 3D geometric parameters ($Sa$ and $Sz$) were determined for the comparison of the research results (with different technological parameters).
3. Results
The results of the studies presented in the table 1 show the mean values of the three measured samples for each type. The table includes both 2D and 3D surface texture parameters and manufacturing technological parameters where: $LT$ - layer thickness, $PD$ – printing direction, $ED$ – energy density.

| No. | $LT$, mm | $PD$, $^\circ$ | $ED$, J/mm$^2$ | $Sa$, µm | $Sz$, µm | $Pa$, µm | $Pz$, µm |
|-----|----------|----------------|----------------|-----------|-----------|-----------|-----------|
| 1   | 0.1      | 0              | 0.032          | 13.534    | 108.347   | 13.175    | 74.976    |
| 2   | 0.1      | 0              | 0.056          | 13.692    | 94.598    | 13.359    | 77.8      |
| 3   | 0.1      | 0              | 0.08           | 13.637    | 115.013   | 13.04     | 74.692    |
| 4   | 0.1      | 45             | 0.032          | 14.276    | 116.467   | 13.44     | 76.695    |
| 5   | 0.1      | 45             | 0.056          | 17.258    | 139.527   | 16.404    | 92.979    |
| 6   | 0.1      | 45             | 0.08           | 14.088    | 106.948   | 13.444    | 75.078    |
| 7   | 0.1      | 90             | 0.032          | 12.925    | 101.493   | 12.584    | 72.251    |
| 8   | 0.1      | 90             | 0.056          | 14.121    | 110.733   | 13.285    | 77.487    |
| 9   | 0.1      | 90             | 0.08           | 14.554    | 117.37    | 13.981    | 79.12     |
| 10  | 0.2      | 0              | 0.032          | 12.964    | 108.383   | 12.574    | 73.444    |
| 11  | 0.2      | 0              | 0.056          | 13.179    | 107.707   | 12.765    | 75.886    |
| 12  | 0.2      | 0              | 0.08           | 12.019    | 97.205    | 11.619    | 68.076    |
| 13  | 0.2      | 45             | 0.032          | 19.937    | 126.673   | 19.421    | 96.458    |
| 14  | 0.2      | 45             | 0.056          | 13.67     | 106.983   | 13.113    | 76.005    |
| 15  | 0.2      | 45             | 0.08           | 14.445    | 121.017   | 13.532    | 77.689    |
| 16  | 0.2      | 90             | 0.032          | 18.706    | 122.097   | 18.017    | 91.491    |
| 17  | 0.2      | 90             | 0.056          | 13.708    | 106.747   | 13.01     | 74.286    |
| 18  | 0.2      | 90             | 0.08           | 16.149    | 123.037   | 15.328    | 84.884    |
Fig. 2. 3D view of tested surfaces, samples 1-9: a) 0°, b) 45°, c) 90°
**Fig. 3.** 3D view of tested surfaces, samples 10-18: a) 0 °, b) 45 °, c) 90 °
Quantitative analysis of the research results, shows that the technological parameters significantly affect the quality of the surface geometry. There is a noticeable effect on the thickness of the building layer and the position on the platform “printing direction” as well as the density of energy transmitted to the sintered layer.

Surface texture views made using the optical profilometer shown in Figures 2 and 3 indicate a phenomenon of the so called stairs-step effect. This phenomenon is noticeable in Figures 2b and 3b, where samples were manufactured with a positioned at an angle of 45°. This indicates a large area of valleys and peaks at the contact points of the layers being built.

Samples from 1 to 9 manufactured with a layer thickness of 0.1 mm and with the lowest value of energy density equal to 0.032 J/mm² have the lowest values of GPS parameters. In this variant of layer thickness, one can notice the significant influence of the orientation of the models on the building platform. Samples manufactured with an angle of 0° do not show significant influence of the energy density on the surface texture, differences are around 1%. Samples prepared in the direction on the building platform equal to 45° are influenced much more by the energy density. When comparing sample numbers 4 and 5 you can see a significant reduction in 2D and 3D parameters (about 17%) when using an energy density of 0.032 J/mm² instead of 0.056 J/mm² (0.056 is recommended value by the machine producer). In the case of the 90° sample placement, the use of a similarly lower value of energy density results in a reduction in the aforementioned parameters values of approximately $Sa$ and $Sz$ around 8%, $Pa - 5\%$, and $Pz - 6\%$. Taking into account the influence of the “printing” direction with the same level of $ED$, it can be concluded that in almost all cases the GPS parameters have the highest values for the angle of 45°.

Analyzing the second type of samples, i.e. those manufactured with a specified layer thickness of 0.2 mm, we can observe similar changes in the GPS parameters. There is no impact of energy density on samples with an angle of 0°. It can be said that the increase in $ED$ in the case of sample number 12 has reduced the value of parameters by about 10%. As in other variants, here also the positioning of the samples at 45° is the least preferred variant. It is interesting to note that in the case of decreasing the value of $ED$, the GPS values increase by approximately 30% and 40% for sample numbers 16 and 13 respectively.

4. Conclusion
Analyzing the research results presented in this paper, the following general conclusions can be formulated.

The orientation of the models on the virtual platform directly affects the quality of the surface texture. The location of the examined plane at an angle of 45° to the building platform results in an unfavorable increase in the value of geometric surface parameters.

The impact of the energy density parameter is related to the thickness of the layer being built. When the thickness of the layer is equal to 0.1 mm, the lower value of the energy density advantageously affects the quality of the surface texture. Samples prepared with a specified layer thickness of 0.2 mm and reduced values of the energy density are characterized by unfavorable increases in GPS parameters.

The increased thickness of the layer (up to 0.2 mm) influenced the manufacturing time, but the average value of parameters increased by up to 5% ($Sa$) in this case. Particularly noticeable is the increases in GPS parameters for the location at a given angle of 90° and layer thickness of 0.2 mm.

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