Considerations on the surface roughness of SLM processed metal parts and the effects of subsequent sandblasting

M A Bernevig-Sava, C Stamate, N-M Lohan, A M Baciu, I Postolache, C Baciu and E-R Baciu

1 “Gheorghe Asachi” Technical University of Iasi, 63, Prof. dr. Dimitrie Mangeron Blvd., 700050, Iasi - Romania
2 “S.C. Colorcontrol S.R.L, Cluj – Napoca, 25A, Orăștiei Street, Cluj – Romania
3 “Gr. T. Popa” University of Medicine and Pharmacy of Iasi, Romania, Faculty of Dental Medicine, 16 University Street, 700115, Iasi – Romania

E-mail: constantin_baciu@yahoo.com

Abstract. Selective Laser Melting is an Additive Manufacturing technology based on 3D scanning of successive layers of metal powder. Three distinct values were determined for each of the three technological parameters (P – the power of the laser, V\text{scan} – scanning speed and t\text{e} – exposure time), therefore resulting nine sets for the “layer by layer” processing. After SLM processing, the samples were sandblasted simply (1S), sandblasted successively (2S), or left unsandblasted (NS). The roughness (Ra) of the outer surfaces was measured for all the samples, and there was found a decrease in the height of the micro-irregularities and the uniformisation of the roughness profile along with the intensification of the sandblasting process. For some samples, there were found uncertainties regarding the accuracy of the experimental results’ values, determined by the presence of the adherent particles identified by the SEM analysis of the outer surfaces. The number and size of these particles have affected the manner in which the samples were placed on the roughness tester’s plate, as well as the accuracy of the measurements. Under these conditions, the tip of the roughness tester’s diamond stylus has recorded the specific values of the surface’s secondary profile, which is affected by the existence of the formations adhering to the primary profile of the SLM processed samples.

1. Introduction
Selective Laser Melting is a modern technology, of the Additive Manufacturing type, with important applications for the manufacturing of metal components specific to dental medicine [1-5]. Given the CAD/CAM character of the processing [6-8], SLM technology allows the execution of prosthetic elements with complex outer shapes. The quality of the surfaces, of the parts made using this rapid prototyping method (RP) is determined by both the specific technological parameters: laser beam power, scanning speed, exposure time, direction of construction, etc. [9-12], and the characteristics of the metal powder used: particle size, physicochemical, mechanical, thermal properties, etc. [13- 15]. The values adopted for these process variables will ensure the quality and continuity of the melting/solidifying processes of the particles under the laser beam [16, 17], but also the presence of forms of manifestation of defects specific to the internal structure (e.g. ”balling”) or the shape of the outer surfaces (e.g. adhesion of particles in the immediate vicinity) [18-20]. These aspects require the correct choice of the values of the working parameters in order to obtain the most favourable profile of
the outer surfaces of the SLM processed parts, [21- 23]. The shape of the roughness profile can be improved by the subsequent application of sandblasting (simple or successive) using different sandblasting materials and different values of the specific technological parameters [24, 25].

2. Materials and methods

The research samples were made by SLM processing of Co-Cr alloy powder [26], on a SLM 50 equipment (Realizer GmbH, Germany) [27, 28]. The chemical composition of the Co–Cr dental alloy powder is presented in Table 1. The prescribed values are indicated by the powder manufacturer and the determined values correspond to the analyses carried out by spectrometry with an EDS Bruker detector.

| Table 1. Nominal values for the chemical composition of the metal powder. |
|-------------------------------------------------------------|
| **Percentage values, [%]** | **Identified chemical elements** |
| Co | Cr | W | Mo | Si | Other elements: C, Fe, Mn |
|---|---|---|---|---|---|
| Prescribed | 59,00 | 25,00 | 9,50 | 3,50 | max.1 | max.1,5 |
| Determined | 62,33 | 28,91 | 9,66 | 4,21 | - | - |

Three distinct values were determined for each of the three selected process parameters (P, v_{scan} and t_e), Table 2.

| Table 2. Values adopted for SLM processing technological parameters. |
|-------------------------------------------------------------|
| **P, [W]** | P_1 = 100 | P_2 = 80,30 | P_3 = 60,61 |
| v_{scan}, [mm/s] | v_1 = 333 | v_2 = 500 | v_3 = 1000 |
| t_e, [µs] | t_1 = 20 | t_2 = 40 | t_3 = 60 |

Note: P – laser beam power; v_{scan} – speed of scanning the powder layer; t_e – time of exposure of the powder particle to the action of the laser beam.

\( g_{\text{sat}} = 50 \mu m \) was the value selected for the thickness of the metal powder layer.

The sets of values of the SLM processing parameters are presented in Table 3.

| Table 3. Sets of values of SLM parameters. |
|-------------------------------------------|
| **Set no.** | **P, [W]** | **v_{scan}, [mm/s]** | **t_e, [µs]** |
|---|---|---|---|
| 02 | 100 | 500 | 40 |
| 04 | 100 | 1000 | 20 |
| 06 | 100 | 333 | 60 |
| 08 | 80,30 | 500 | 40 |
| 10 | 80,30 | 1000 | 20 |
| 12 | 80,30 | 333 | 60 |
| 14 | 60,61 | 500 | 40 |
| 16 | 60,61 | 1000 | 20 |
| 18 | 60,61 | 333 | 60 |

Three lamellar samples (40 x 3 x 0.5 mm) were made for each set of parameters, amongst which some were sandblasted once with white electrocorundum (granularity F100, \( p = 3.5÷4 \) bar) – marking (1S), others were successively sandblasted with white electrocorundum and glass beads (d = 70…110 \( \mu m \), \( p = 2.5 \) bar) – marking (2S) and the rest were left unsandblasted – marking NS. A Renfert
BasicEco equipment [29] was used for sandblasting. Roughness (Ra) measurements were carried out on the surface (40 x 3 mm) of each sample, using a Taylor Hobson equipment [30], provided with a diamond stylus with the radius \( r = 2 \) \( \mu \)m. Determinations were carried out under the following conditions: sampling length: \( \lambda_c = 0.8 \) mm; profile assessment length: \( I_m = 4 \) mm; profile scanning speed: \( v = 0.5 \) mm/s. The process of adhesion of the metal powder particles to the outer surfaces of the samples played an important part in determining the roughness values. The investigations on the evolution of adhesion on the three surface types (NS, 1S and 2S) were performed by SEM electronic microscopy, on a Tescan Vega LMH2II equipment [31-34].

3. Experimental results

Roughness measurements were performed on two distinct lines on the surface of each sample. The mean values of the experimental determinations are presented in Table 4.

| Item no. | Surface condition | Ra, [\( \mu \)m] | Item no. | Surface condition | Ra, [\( \mu \)m] |
|---------|-------------------|-----------------|---------|-------------------|-----------------|
| 02      | NS                | 8.62            | 12      | 1S                | 9.00            |
|         | 1S                | 7.93            |         | 2S                | 6.66            |
|         | 2S                | 6.66            |         | NS                | 10.99           |
| 04      | NS                | 10.99           | 14      | 1S                | 10.01           |
|         | 1S                | 10.62           |         | 2S                | 10.32           |
|         | 2S                | 10.32           |         | NS                | 9.36            |
| 06      | NS                | 8.48            | 16      | 1S                | 14.35           |
|         | 1S                | 7.04            |         | 2S                | 6.55            |
|         | 2S                | 6.55            |         | NS                | 10.04           |
| 0,8     | NS                | 9.40            | 18      | 1S                | 11.68           |
|         | 1S                | 7.26            |         | 2S                | 6.26            |
|         | 2S                | 6.96            |         | NS                | 5.23            |
| 10      | NS                | 12.59           |         | 1S                | 12.09           |
|         | 1S                | 12.09           |         | 2S                | 11.85           |

4. Discussions

The analysis of the results presented in Table 4 shows that the values corresponding to roughness (Ra) are close for the surfaces of samples NS, 1S and 2S of sets 04, 10, 14 and 16. This observation is also confirmed by the appearance of the curves of the gross roughness profile, Figure 1.

The shape of the curves of the gross profile indicates that during the roughness measurement process the samples were not placed on a flat surface. Figure 2 shows, schematically, the possibility of a process of adhesion of the particles that are close to the outer wall of the molten metal bath.
Figure 1. Gross roughness profile of the surfaces of some SLM processed samples: a) sample 50 – 04 – 2 (after simple sandblasting); b) sample 50 – 10 – 3 (after successive sandblasting); c) sample 50 – 14 – 2 (after simple sandblasting); d) sample 50 – 16 – 3 (after successive sandblasting).

Figure 2. Schematic representation of the process of adhesion of the particles to the SLM processed outer surface.

The SEM images of the outer surfaces of some SLM processed samples confirm the theoretical assumptions, Figure 3. The large number and variable size of the adherent particles have affected the direct contact between the tip of the diamond stylus and the surface analysed to determine its primary/real profile.
Figure 3. SEM images of the adhesion process: a) sample 50 – 16 – 1, unsandblasted (NS); b) sample 50 – 14 – 2, sandblasted once (1S); c) sample 50 – 16 – 3, sandblasted in two successive stages (2S).

Under these conditions, the measurements performed led to the investigation of a secondary profile characterized by measurement errors generated by the existence and shape of adherent particles, Figure 4.

The roughness value of the surface with adherent particles was amplified by the existence of "satellite" formations on the outside of the particles (see Figure 2).

Figure 4. Conditions for carrying out roughness measurements: (a) – the existence of errors in placing the sample and measurement errors; (b) – the primary profile and the secondary profile of the sample surface.

Table 5. Variations of roughness values $\Delta R_{a1}$ and $\Delta R_{a2}$, resulted after simple sandblasting (1S) or successive sandblasting (2S).

| Set no. | Roughness variation |          |
|---------|---------------------|----------|
|         | $\Delta R_{a1}$    | $\Delta R_{a2}$ |
| 02      | 1,29                | 0,09     |
| 04      | 0,03                | 0,02     |
| 06      | 0,17                | 0,06     |
| 08      | 0,22                | 0,04     |
| 10      | 0,03                | 0,01     |
| 12      | 0,26                | 0,03     |
| 14      | 0,08                | 0,06     |
| 16      | 0,04                | 0,03     |
| 18      | 0,46                | 0,16     |
Sandblasting the surfaces after SLM processing resulted in reducing the roughness by the following values: \( \Delta R_{a1} \) – after simple sandblasting, and \( \Delta R_{a2} \) – after successive sandblasting, Table 5.

The following relations were used to calculate the \( \Delta R_{a1} \) and \( \Delta R_{a2} \) values.

\[
\Delta R_{a1} = \frac{Ra_{NS} - Ra_{1S}}{Ra_{NS}} \cdot 100 \% \quad (1)
\]

\[
\Delta R_{a2} = \frac{Ra_{1S} - Ra_{2S}}{Ra_{1S}} \cdot 100 \% \quad (2)
\]

The analysis of \( \Delta R_{a1} \) and \( \Delta R_{a2} \) values shows that the sandblasting process was also affected by the presence of adherent particles because there were very small variations between the roughness values of the surfaces of samples (NS), (1S) and (2S) for sample sets 04, 10, 14 and 16.

5. Summary and conclusions

The paper aimed at studying the roughness (Ra) of the surfaces of samples made by SLM processing of Co-Cr dental alloy powder (S&S Scheftner Germany).

Given the results of experimental measurements and of electronic microscopy (SEM) analyses, the following conclusions may be formulated:

a) SLM processing was carried out with three distinct values for each technological parameter \( P, v_{\text{scan}}, t_c \). Following SLM processing, the obtained outer surfaces were sandblasted once (1S), in two successive stages (2S) or they were not sandblasted (NS);

b) roughness measurements (Ra) were performed and the variations in roughness values (\( \Delta R_{a1} \)) and (\( \Delta R_{a2} \)) were calculated for each sandblasted sample;

c) the analysis of the real roughness profile and the SEM images indicate that for some samples measurement, errors were determined due to the presence of particles adhering to the outer surfaces;

d) the number, shape and size of adherent particles affect the real conditions under which measurements are performed and the accuracy of the values recorded for the (Ra) parameter.

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