Influence of Selective Laser Melting Processing Parameters of Co-Cr-W Powders on the Roughness of Exterior Surfaces

M A Baciu¹, E R Baciu², C Bejinariu³, S L Toma³, A Danila⁴ and C Baciu*³
¹S.C. Color control S.R.L., Str. Orastiei 25A, Cluj-Napoca, Romania
²Faculty of Dental Medicine, Grigore T. Popa University of Medicine and Pharmacy Iasi, 16 Universitatii St., Iasi 700115, Romania
³“Gheorghe Asachi” Technical University from Iasi - Romania, Faculty of Materials Science and Engineering, Blvd. Dimitrie Mangeron, No. 71A, 700050, Iasi- Romania
⁴S.C. LAMAS MICROTÉCH S.R.L. Bucureşti, str. Aron Cotrus, no.51-59, Sector 1, Bucuresti, Romania

E-mail: constantin_baciu@yahoo.com

Abstract. Selective Laser Melting (SLM) represents an Additive Manufacturing method widely used in medical practice, mainly in dental medicine. The powder of 59% Co, 25% Cr, 2.5% W alloy (Starbond Co S Powder 55, S&S Scheftner C, Germany) was processed (SLM) on a Realizer SLM 50 device (SLM Solution, Germany). After laser processing and simple sanding with Al₂O₃ or two-phase sanding (Al₂O₃ and glass balls), measurements of surface roughness were conducted. This paper presents the influences exercised by laser power (P = 60 W, 80 W and 100 W), the scanning speed (vscan = 333 mm/s, 500 mm/s and 1000 mm/s) and exposure time (te = 20 µs, 40 µs and 60 µs) on the roughness of surfaces obtained by SLM processing. Based on the experimental results obtained for roughness (Ra), some recommendations regarding the choice of favorable combinations among the values of technological parameters under study in order to obtain the surface quality necessary for subsequent applications of the processed parts (SLM) have been made.

1. Introduction

The construction of parts through “layer by layer” technique while using Selective Laser Melting (SLM) method represents a modern processing technology CAD/CAM of Co-Cr alloys for diverse components specific to dental prosthetics [1].

The roughness of exterior surfaces obtained through SLM processing depends on numerous factors keeping both to metal powder and the technical features of the equipment. To improve the surface quality, two research directions have been approached: the study is influences by the technological processing parameters; the identification of some new technological processing possibilities that may turn the technical characteristics of the equipment used to good account.

Yasa, E. et al [2, 3] analysed the influences of hatch strategy on roughness by carrying out processing techniques “with two areas” also including a laser surface for the remodeling of the border area between the two successive passes of the laser beam. In their papers, Delagordo et al [4] studied the influence of construction direction on the resistance to bending and elongation. Krauss, H. [5] investigated workability through SLM method following the characterization of the unique lines corresponding to the melting/solidification layout followed by the laser. Smurnov, I et al. [6] analysed the influence of thermal conductivity of the alloy used on the layer construction of parts. The exposure strategy of powder particles to the action of laser beam and the manner of distribution of heat in the molten metal bath represented lines of research for Fateri et al. [7]. The impact of alloy elements on
the “bulling” effect has been analysed by Kruth et al. [8, 9]. They also studied the role of phosphorus additions on the superficial tensions existing at the contact between liquid metal and solidified metal. Gebhardt, A., [10] and afterwards Strano et al [11] investigated the influence of “stair stepping effect” in relation to the construction direction on the roughness of exterior surfaces.

2. Experimental method
To obtain the specimens we used Starbon CoS Powder 55 (S&S Scheftner C, Germany) metal powder having the chemical composition given in Table 1 and the particle size of 10…55 µm.

Table 1. Chemical composition of Starbon CoS Powder 55.

| Chemical composition [% mass] |
|-----------------------------|
| Co  | Cr  | W  | Mo | Si | Other elements: C, Fe, Mn |
| 59.0% | 25.2% | 9.5% | 3.5% | max. 1% | max. 1.5 |

We may notice the absence of beryllium. The sizes of the 54 specimens were 40x30x0.5 mm, as they are going to be used in other experimental researches as well. Specimens were obtained on a Realizer SLM 50 device (SLM Solution Germany). The technological parameters for laser beam processing were as follows: laser power: $P_1 = 60$ W; $P_2 = 80$ W; $P_3 = 100$ W; scanning speed: $v_1 = 333$ mm/s; $v_2 = 500$ mm/s; $v_3 = 1000$ mm/s; exposure time: $t_1 = 20$ μs; $t_2 = 40$ μs; $t_3 = 60$ μs; powder layer thickness: $g = 25$ μm; hatch spacing: $h = 60$ μm; spot diameter: $d = 50$ μm. By combining these values 9 sets of technological parameters have been established:

Table 2. Parameter sets.

| Parameter sets. |
|-----------------|
| $P_1$ | $P_2$ | $P_3$ |
| $v_1$ | $v_2$ | $v_3$ |
| $t_1$ | $t_2$ | $t_3$ |

After SLM processing, all specimens were subjected to a thermal treatment by stress relief ($T_{\text{max}} = 700^\circ$C, $t = 45$ min) as recommended by the power manufacturer. 3 specimens were made for each set of parameters used: the first specimen remained non sandblasted - marking (NS), the second specimen was sandblasted only with aluminum oxide powder ($d = 125$ μm) – marking (1S) while the third specimen was sandblasted in two phases: once with aluminum oxide and then with glass balls ($d = 25…50$ μm) – marking (2S).

3. Experimental results
Roughness measurements were conducted on three distinct lines of the surface of each specimen. Average values of experimental researches are given in Table 3.

Table 3. Roughness of SLM surfaces processed with different laser beam powers.

| Surface state | Technological parameters | $P_1$, [W] | $v_{\text{scan}}$, [mm/s] | $t_{\text{e}}$, [μs] |
|---------------|-------------------------|----------|---------------------|-------------|
| Roughness     | 60                      | 80       | 100                 |             |
| Ra, [μm]      | NS                      | 8.80     | 6.43                | 8.99        |
|               | 1S                      | 4.04     | 4.17                | 4.81        |
|               | 2S                      | 3.56     | 3.67                | 4.95        |
| Roughness     | 60                      | 80       | 100                 |             |
| Ra, [μm]      | NS                      | 3.56     | 5.23                | 5.55        |
|               | 1S                      | 5.23     | 5.36                | 3.80        |
|               | 2S                      | 4.62     | 3.80                | 3.60        |
| Roughness     | 60                      | 80       | 100                 |             |
| Ra, [μm]      | NS                      | 8.28     | 7.14                | 7.85        |
|               | 1S                      | 5.62     | 7.14                | 4.93        |
|               | 2S                      | 5.36     | 4.06                | 4.85        |
According to these results, we drew the variation curves $Ra = f(P)$ for non sandblasted specimens (NS) – Figure 1, sandblasted once (1S) – Figure 2 and sandblasted twice (2S) – Figure 3.

Figure 1. Variation curves $Ra=f(P)$ for non sandblasted specimens (NS).

Figure 2. Variation curves $Ra=f(P)$ for specimens sandblasted once (1S).

Figure 3. Variation curves $Ra=f(P)$ for specimens sandblasted twice (2S).
4. Discussions

Based on the data in Table 3 and Figure 1 – 3 we may notice as follows:

- the maximum extension intervals for roughness (Ra) are:
  \[ \Delta R_{a_{\text{max}}} = 11.34 - 5.55 = 5.79 \mu m \text{ – for (NS)} \text{ specimens;} \]
  \[ \Delta R_{a_{\text{max}}} = 5.60 - 3.79 = 1.83 \mu m \text{ – for (1S)} \text{ specimens;} \]
  \[ \Delta R_{a_{\text{max}}} = 4.62 - 3.15 = 1.76 \mu m \text{ – for (2S)} \text{ specimens;} \]
- the efficiency of sandblasting after SLM processing is highlighted through the reduction of interval for roughness values (\(\Delta R_a\));
  - by 31.60\% after the first sandblasting;
  - by 48.72\% after the two sandblasting phases.

A first variant for analysis of the experimental data may take into account laser power (P) and scanning speed (v\(_{\text{scan}}\)), a case where we may notice as follows:

- the lowest values of roughness for the non sandblasted specimens (NS) were obtained by SLM processing with cu P = 80 W or P = 100 W and v\(_{\text{scan}}\) = 333 mm/s and P = 80 W or P = 100 W and v\(_{\text{scan}}\) = 500 mm/s;
- the most recommended values of technological parameters for sandblasted specimens (1S) and (2S) are: P = 60 W or P = 80 W and v\(_{\text{scan}}\) = 333 mm/s, and P = 80 W or P = 100 W and v\(_{\text{scan}}\) = 500 mm/s. There is also the variant P = 80 W and v\(_{\text{scan}}\) = 1000 mm/s.

The synthetic analysis of this finding indicates that from roughness (Ra) viewpoint, the following value combinations are recommended for the two technological parameters (P) and (v\(_{\text{scan}}\)):

\[ \text{Table 4. Values combination.} \]

| Specimen surface | P, [W] | \(v_{\text{scan}}\) [mm/s] |
|------------------|--------|--------------------------|
|                  | 60     | 80 | 100 | 333 | 500 | 1000 |
| NS               |        |   |   |     |     |     |
|                  | •      |   |   |     |     |     |
|                  | • •    |   |   |     |     |     |
|                  | • •    |   |   |     |     |     |
| 1 S + 2 S        | • •    |   |   |     |     |     |
|                  | • •    |   |   |     |     |     |
|                  | • •    |   |   |     |     |     |

The second variant for analysis of the experimental data may take into consideration laser power (P) and exposure time (\(t_e\)), a case where we may notice as follows:

- the lowest values of roughness for the non sandblasted specimens (NS) were obtained by SLM processing with cu P = 80 W or P = 100 W and \(t_e\) = 40 \(\mu s\), and P = 80 W and \(t_e\) = 60 \(\mu s\);
- the most recommended values of technological parameters for sandblasted specimens (1S) and (2S) are: P = 80 W or P = 100 W and \(t_e\) = 40 \(\mu s\). There are also the variants: P = 60 W or P= 80 W and \(t_e\) = 60 \(\mu s\) and there is also the possibility P = 80 W or P = 100 W and \(t_e\) = 20 \(\mu s\), P = 60 W respectively.

The synthetic analysis of this finding indicates that from roughness (Ra) viewpoint, the following value combinations are recommended for the two technological parameters (P) and (\(t_e\)):

\[ \text{Table 5. Values combination.} \]

| Specimen surface | P, [W] | \(t_e\) [\(\mu s\)] |
|------------------|--------|----------------|
|                  | 60     | 80 | 100 | 20 | 40 | 60 |
| NS               |        |   |   |   |   |   |
|                  | • •    |   |   |   |   |   |
|                  | • •    |   |   |   |   |   |
|                  | • •    |   |   |   |   |   |
|                  | • •    |   |   |   |   |   |
| 1 S + 2 S        | • •    |   |   |   |   |   |
|                  | • •    |   |   |   |   |   |
|                  | • •    |   |   |   |   |   |
The experiments conducted show that for SLM processing of the Co-Cr-W powder used, values of laser power \( P < 60 \text{ W} \), scanning speeds \( v_{\text{scan}} < 300 \text{ mm/s} \) or \( v_{\text{scan}} \geq 1000 \text{ mm/s} \) and exposure times \( t_e < 40 \mu\text{s} \) are not recommended because the value of energy density \( (E_V) \) will be diminished, a fact that will negatively affect the selective melting/solidification processes of metal powder. A direct consequence of inadequate SLM processing is represented by the obtaining of some exterior surfaces with high roughness.

5. Conclusions

This scientific paper refers to the Selective Laser Melting processing method with laser beam of Co-Cr-W (Starbon CoS Powder 55, S&S Scheffner C, Germany) metal powders.

The variable technological parameters were laser power \( (P) \), scanning speed \( (v_{\text{scan}}) \) and exposure time \( (t_e) \) with whose values we made 9 different sets of specimens. Roughness \((R_a)\) measurements were conducted on the surfaces sandblasted one – 1S or twice – 2S, or non sandblasted – NS.

On the basis of exterior surface roughness, we have reached the following conclusions:

(i) the most indicated combinations of parameters for non sandblasted (NS) specimens are: \( P = 80 \text{ W or } P = 100 \text{ W and } v_{\text{scan}} = 500 \text{ mm/s} \); 
(ii) the most indicated combinations of parameters for (1S) and (2S) sandblasted specimens are: \( P = 80 \text{ W or } P = 100 \text{ W and } v_{\text{scan}} = 333 \text{ mm/s or } v_{\text{scan}} = 500 \text{ mm/s} \); the combinations: \( P = 100 \text{ W and } v_{\text{scan}} = 333 \text{ mm/s, and } P = 60 \text{ W and } v_{\text{scan}} = 1000 \text{ mm/s} \) are less recommended; 
(iii) from the viewpoint of volumetric energy density \( (E_v) \) necessary for SLM processing of Co-Cr-W powders, values of \( v_{\text{scan}} < 300 \text{ mm/s or } v_{\text{scan}} = 1000 \text{ mm/s and values of exposure time } t_e < 40 \mu\text{s} \) are not recommended as they will result in high roughness values.

6. References

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