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Influence of process parameters for Selective Laser Melting on the roughness of 3D printed surfaces in Co-Cr dental alloy powder

A M Baciu[1], C Bejinariu[2], A Corăbieru[2], E Mihalache[2], M Lupu–Poliac[2], C Baciu[2,*] and E R Baciu[3]

[1] "S.C. Colorcontrol S.R.L, Cluj – Napoca, 25A, Orăștiei Street, Cluj – Romania
[2] "Gheorghe Asachi" Technical University of Iasi, 63, Prof. dr. Dimitrie Mangeron Blvd., 700050, Iasi - 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. Modern technologies of Additive Manufacturing type allow for the obtaining of the metal components specific to medical prosthetics in the best conditions. Selective Laser Melting (SLM) method is frequently used in dental medicine since there is an obvious trend to replace the classical casting techniques especially for non-noble Co-Cr alloys. According to the values of processing parameters (SLM) there will be parts having different roughness of the exterior surfaces. The conducted studies analysed the influences exercised by three process parameters (laser power – P, scan speed – v_{scan} and exposure time – t_e) on roughness amplitude expressed by value (Ra). By combining the three distinct values adopted for each parameter we made nine sets of lamellar samples on whose non sandblasted surface, surface sandblasted once and surface sandblasted in two successive stages we carried out roughness measurements. Based on the results obtained for (Ra) parameter we formulated some recommendations for the technological parameter values that may provide surface roughness adequate to the subsequent destination of the processed parts (SLM).

1. Introduction

Selective Laser Melting represents a fast prototyping method that has been developed ever since the end of the 1980s and it applies to a large number of alloys [1-4]. SLM technology for the processing of metal powders is recommended to obtain parts with high density without the need for a subsequent thermo mechanical processing [5]. During SLM processing the powder particles of the alloy are completely melted by means of a laser beam having different energy/power values [6]. After that the solidification of the metal bath from liquid phase takes place thus resulting physical-chemical and mechanical characteristics dependent on the processing technological parameters [7-10]. SLM technology allows for the obtaining of metal parts with complex geometries [11-13] due to the CAD/CAM character of processing [14,15]. For CAD component, the 3D design and the creation of (.stl) file of the final part is necessary whereas the CAM component refers to the actual processing of the part on a piece of special equipment [16-18]. In these conditions, 3D printing or RP (Rapid Prototyping) technology is recommended in the manufacturing of parts for diverse industrial domains,

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including the metal components intended for medical prosthetics, in general, and implicitly in dental prosthetics [19-22].

The surface quality and the mechanical properties of metal parts will be influenced by the technological parameters specific to SLM processing: laser beam power, scan speed, and exposure time [23-26]. The values of these parameters require an optimization process in order to obtain the best functional and durability characteristics in the use of the products obtained [27, 28]. Consequently, laser processing parameters will require a rigorous control that will also allow for the obtaining of the most favorable values of roughness for the resulted surfaces. This way, some finishing operations applied after SLM processing will be eliminated partially or totally [29, 30].

The goal of these experimental researches is determined by the study of the influences exerted by three technological parameters of SLM processing, namely laser power (P), scan speed (vscan) and exposure time (t_e) on the roughness of exterior surfaces in non sandblasted state (NS), sandblasted once (1S), or sandblasted in two successive phases (2S).

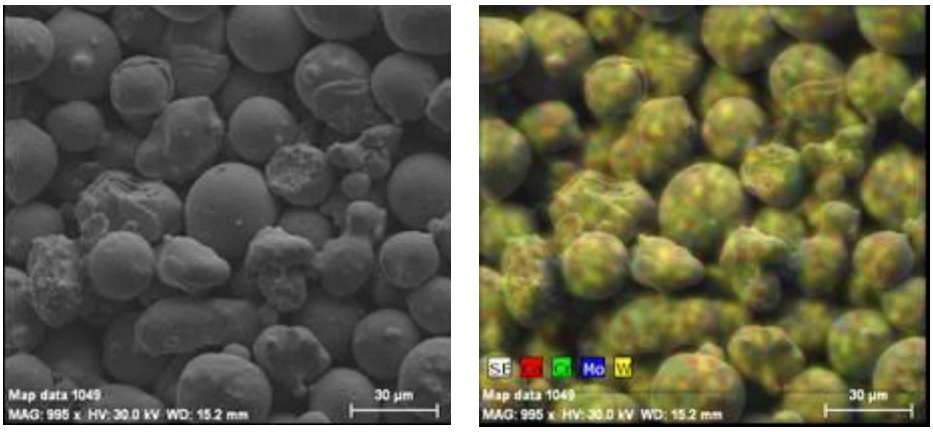
2. Experimental determinations

The samples required for experimental determinations were obtained by the SLM processing of the Co-Cr alloy powder [31], on a SLM 50 equipment (Realizer GmbH, Germany) [32]. The manufacturer has indicated the chemical composition for this metal powder in Tabel 1. The same table shows the percentage values obtained by SEM-EDX analysis.

Table 1. The chemical composition of the Co-Cr alloy powder.

Chemical composition	Nominal values of alloy composition, [%]					
	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	59.20	27.50	9.10	4.00	-	0.20

The experimental determinations were carried out with a Brucker analyzer installed on the Tescan Vega III electronic microscope, thus being recorded the distribution of the chemical elements onto the micro-area of interest (Figure 1) and the EDS spectrum of the Co-Cr alloy powder particles (Figure 2).



a) b)

Figure 1. The distribution of chemical elements onto the analysed micro-area: a – morphology of powder particles; b – micro-area for chemical analysis.

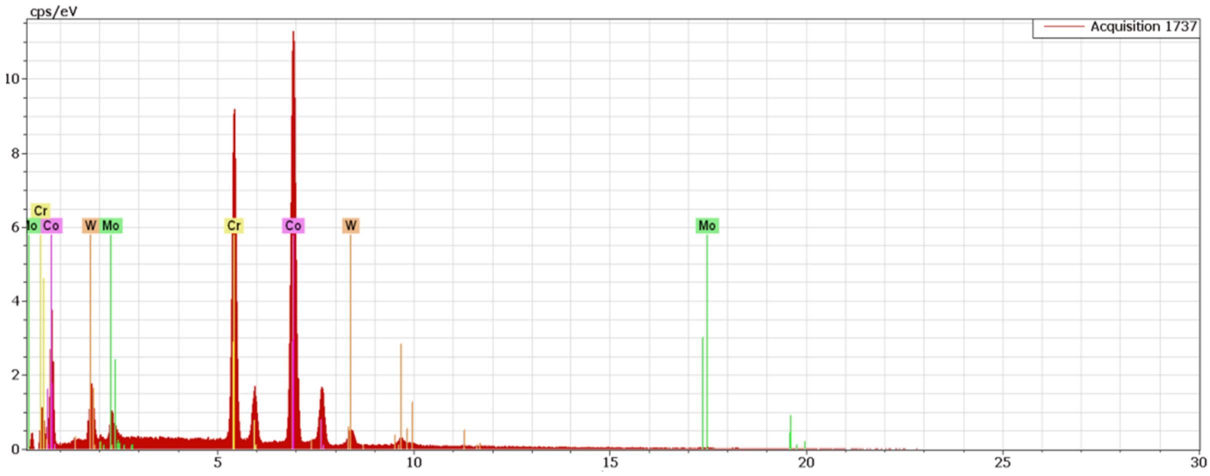


Figure 2. The EDS spectrum of the Co-Cr alloy powder particles.

The analysis of SEM images has allowed the morphological characterization of the shape and size of the used metal powder particles, Figure 3.

It has been found that, mainly, the "Splat Cap" morphology particles are present, characterized by considerable protuberances. "Satellited" particles with numerous protrusions of different size were also observed at the level of the outer surface. In terms of shape and size, spherical and spheroidal particles are predominant, having the following size values:

$l_{max} / l_{min} = 1,0…1,2$, for spherical particles and;

$l_{max} / l_{min} = 1,5…2,2$, for spheroidal particles.

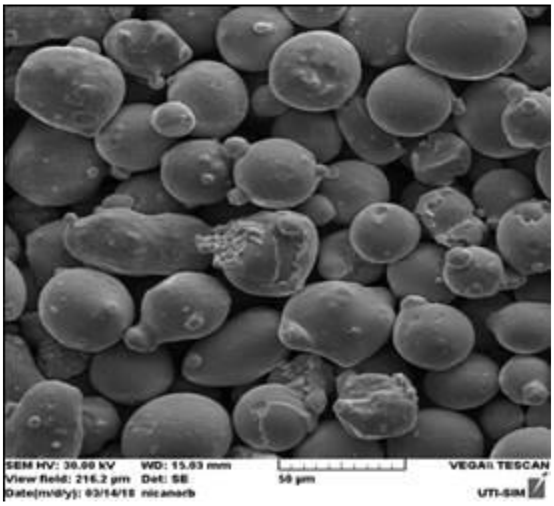


Figure 3. Morphology of Co-Cr alloy powder particles.

These characteristics of the powder particles will influence the contact between the outer surface of the samples and the working table of the Hobson-Taylor equipment. Obviously, an incorrect contact between the two surfaces will result in roughness measurement errors.

The paper addresses the influence of some technological parameters (P, v_{scan} and t_e) on the roughness of surfaces obtained by Selective Laser Melting processing. Three distinct values were established for each technological parameter under study (Table 2).

The thickness of the metal powder layer was maintained at the constant value: g_{strat} = 25 µm. Based on these values we adopted nine sets of processing technologic parameters (Table 3).

Table 2. Values of SLM processing technological parameters.

P, [W]	P1 = 100	P2 =80.30	P3 = 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

Table 3. Sets of technological parameter values.

Nr. crt	01	03	05	07	09	11	13	15	17
P, [W]	100	100	100	80.30	80.30	80.30	60.61	60.61	60.61
v_{scan}, [mm/s]	500	1000	333	500	1000	333	500	1000	333
t_e, [μs]	40	20	60	40	20	60	40	20	60

For each set of technological parameters, we made three lamellar samples having the sizes of (40 x 3 x 0.5 mm):
- a control sample marked (NS);
- a sample subsequently sandblasted with white electro-corundum marked (1S);
- a sample successively sandblasted with white electro-corundum and glass balls marked (2S).

Sandblasting was conducted on Renfert BasicEco equipment (Renfert, Germany) [33], by using white electro-corundum with F100 granularity and working pressure p = 3.5 ÷4 bar and glass balls (d=70...110 μm) for a pressure p =2.5 bar. Sandblasting was applied to reduce and to render the roughness of initial surfaces uniform (after SLM processing).

Measurements of surface roughness were conducted on a special piece of equipment (Taylor Hobson) fitted with a 2 μm nose radius feeler [34-36].

The conditions in which these determinations were conducted were:
- sampling length: λ_c =0.8 mm;
- profile assessment length: $I_n = 5\cdot\lambda_c$=4 mm;
- profile scanning speed: v_{scan} = 0.5 mm/s.

Roughness parameter was Ra [μm] and it was an amplitude parameter representing the Arithmetical Mean Height of the evaluated profile which can be calculated with the equation:

$$Ra = \frac{I}{I_r}\int_0^{I_r} |z(a)|dx \quad (1)$$

Which written in discrete form becomes:

$$Ra = \frac{\sum_{i=1}^{n}(R_{pi})}{n} \quad (2)$$

Where: (R_{pi}) – is the height of profile in discrete points (i);
n – number of discrete points

3. Experimental results

Roughness measurements were carried out on two distinct lines on the surface of each sample. Average values of experimental determinations are given in Table 4.

The analysis of experimental values was conducted through their grouping:

Ra= f(P), vscan = 500 mm/s and te = 40 μs corresponding to sample sets (01, 07 and 13);
Ra = f(P), vscan = 1000 mm/s and te = 20 μs corresponding to sample sets (03, 09 and 15);
Ra = f(P), vscan = 333 mm/s and te = 60 μs corresponding to sample sets (05, 11 and 17).

Table 4. Average values of roughness (Ra) measured on exterior surfaces.

Set No	Surface status	Ra, [μm]	Set No	Surface status	Ra, [μm]	Set No	Surface status	Ra, [μm]
	NS	7.07		NS	8.10		NS	9.65
01	1S	5.00	07	1S	4.50	13	1S	5.81
	2S	4.50		2S	4.14		2S	5.3
	NS	8.63		NS	8.81		NS	9.66
03	1S	5.91	09	1S	6.00	15	1S	7.45
	2S	5.00		2S	5.40		2S	6.14
	NS	7.13		NS	7.40		NS	9.42
05	1S	4.76	11	1S	4.16	17	1S	5.74
	2S	4.28		2S	3.87		2S	5.13

The phase evolution of roughness profiles and the values of roughness variations measured on the non sandblasted samples, sandblasted once (1S) or twice (2S) – Figure 4 allowed us to determine the variations of (Ra) parameter through the application of the following calculation formulae:

$$Ra_1 = Ra_{NS} - Ra_{1s};\ [\mu m] \tag{3}$$

$$Ra_2 = Ra_{NS} - Ra_{2s};\ [\mu m] \tag{4}$$

$$\Delta Ra_1 = \frac{Ra_{NS} - Ra_{1S}}{Ra_{NS}} \cdot 100;\ [\%] \tag{5}$$

$$\Delta Ra_2 = \frac{Ra_{NS} - Ra_{2S}}{Ra_{NS}} \cdot 100;\ [\%] \tag{6}$$

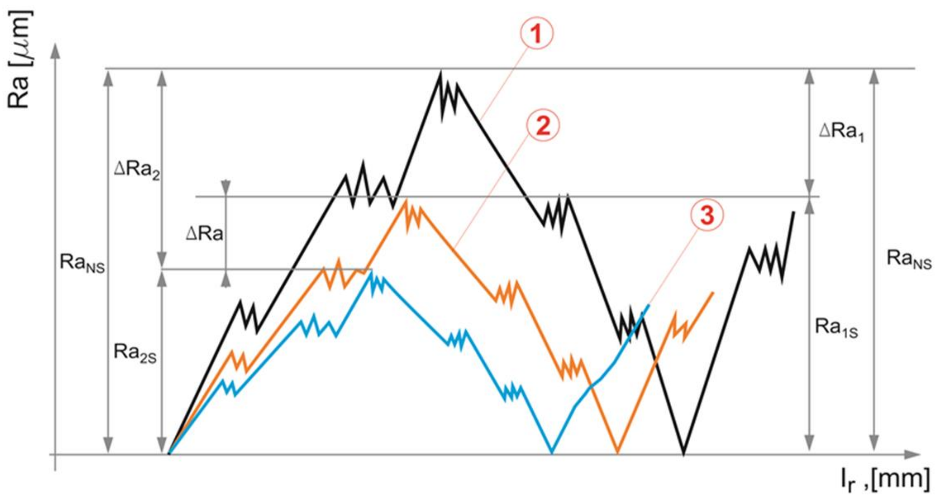


Figure 4. Evolution of roughness profiles of exterior surfaces of the (SLM) processed parts; 1–roughness profile for non-sandblasted surface (Ra_{NS}); 2–roughness profile for the surface sandblasted with white electro-corundum (Ra_1); 3–roughness profile for the surface sandblasted successively with white electro-corundum and glass balls (Ra_2).

Based on the experimental results presented in Table 3 we traced the variation curves Ra = f(P) for all (SLM) processed samples: non sandblasted (NS) – Figure 5, subsequently sandblasted (1S) – Figure 6 and successively sandblasted (2S) – Figure 7.

Tables 5, 6 and 7 give the values of ΔRa_1 and ΔRa_2 variations calculated for the three groups of sample sets.

Table 5. Reduction of roughness values through sandblasting (1S) or (2S) after (SLM) processing.

Sample set	Surface status	Reduction of roughness values			
		ΔRa_1		ΔRa_2	
		[μm]	[%]	[μm]	[%]
	NS	0	0	0	0
01	1S	2,07	29,28	-	-
	2S	-	-	2,57	36,35
	NS	0	0	0	0
07	1S	3.60	44.44	-	-
	2S	-	-	3,96	48,88
	NS	0	0	0	0
13	1S	3,84	39,79	-	-
	2S	-	-	4,34	44,97

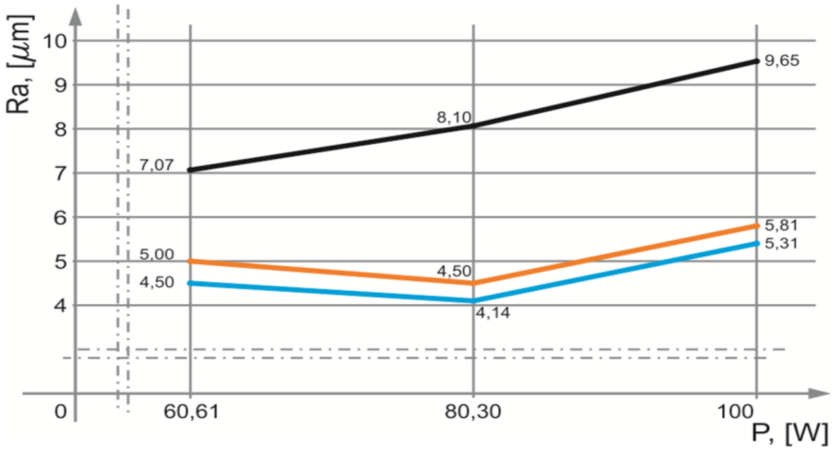


Figure 5. Roughness variation (Ra) for sample surfaces obtained by (SLM) processing – NS or subsequently sandblasted (1S) and (2S); sample sets (01, 07 and 13).

Table 6. Reduction of roughness values through sandblasting (1S) or (2S) after (SLM) processing.

Sample set	Surface status	Reduction of roughness values			
		ΔRa_1		ΔRa_2	
		[μm]	[%]	[μm]	[%]
	NS	0	0	0	0
03	1S	2,72	31,51	-	-
	2S	-	-	3,63	42,06
	NS	0	0	0	0
09	1S	2,31	31,89	-	-
	2S	-	-	3,41	38,70
	NS	0	0	0	0
15	1S	2,21	22,88	-	-
	2S	-	-	3,52	36,43

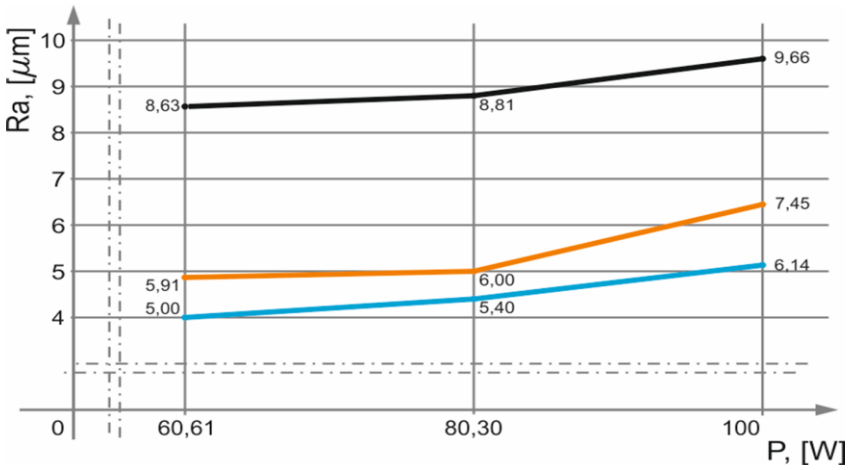


Figure 6. Roughness variation (Ra) for sample surfaces obtained by (SLM) processing – NS or subsequently sandblasted (1S) and (2S); sample sets (03, 09 and 15).

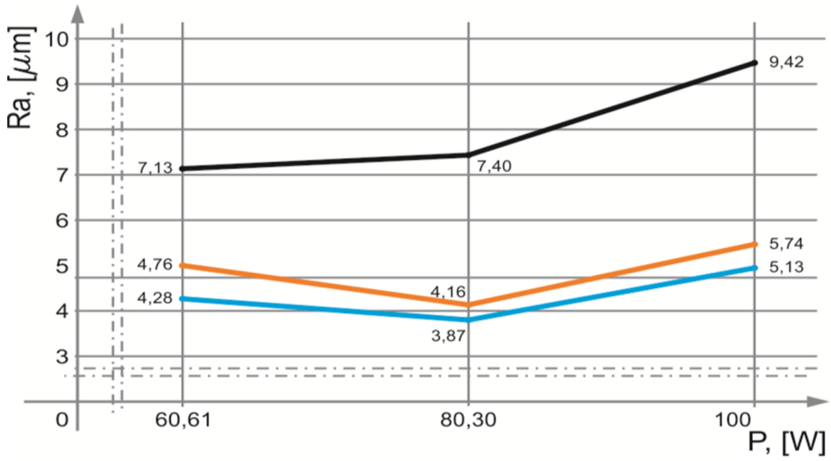


Figure 7. Roughness variation (Ra) for sample surfaces obtained by (SLM) processing – NS or subsequently sandblasted (1S) and (2S); sample sets (05, 11 and 17).

Table 7. Reduction of roughness values through sandblasting (1S) or (2S) after (SLM) processing.

Sample set	Surface status	Reduction of roughness values			
		ΔRa_1		ΔRa_2	
		[µm]	[%]	[µm]	[%]
5	NS	0	0	0	0
	1S	2,39	31,51	-	-
	2S	-	-	3,63	42,06
11	NS	0	0	0	0
	1S	3,24	43,78	-	-
	2S	-	-	3,53	47,70
17	NS	0	0	0	0
	1S	3,68	39,06	-	-
	2S	-	-	4,29	45,54

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The effects of sandblasting in two phases (2S) on the roughness of (SLM) processed samples may be seen by calculating variation (ΔRa).

$$\Delta Ra = \Delta Ra_2 - \Delta Ra_1;\ [\mu m] \quad (7)$$

$$\Delta Ra = \frac{\Delta Ra_2 - \Delta Ra_1}{\Delta Ra_2} \cdot 100;\ [\%] \quad (8)$$

4. Discussions

From the analysis of presented results we have noticed the highest values of roughness (Ra) were obtained after (SLM) processing with the parameter set P =60.61W; v_{scan} = 1000 mm/s, and t_e = 20 μs (set 15).

Through white electro-corundum sandblasting after (SLM) processing the height of surface profile decreased very much, an effect seen in the reduction by 44.44 % of the initial value of roughness (ΔRa_1, for the set 07). After the application of successive sandblasting with white electro-corundum and glass balls after (SLM) processing we obtained the most significant reduction of initial roughness (ΔRa_2 = 48.88 %, for the set 07).

(SLM) processing of Co-Cr powder by using the medium values of technological parameters helped obtaining the best sandblasting effects thus registering the highest values for ΔRa_1 and ΔRa_2. The adoption of combinations formed with extreme parameter values (v_{scan} =1000 m/s and t_e = 20 μs) determines the reduction of sandblasting effects while noticing that ΔRa_1 and ΔRa_2 variations are lower than for other used sets.

The analysis of values of ΔRa_1 and ΔRa_2 variations highlight the fact that the first sandblasting phase (white electro-corundum sandblasting) results in the significant reduction of height of roughness profile whereas the second phase (ball sandblasting) mainly produces a uniformization of surface roughness. The confirmation of these aspects results from the calculation of roughness value (ΔRa) registered between sandblasting phases, and the values obtained are given in Table 8.

Table 8. Reduction of roughness value (ΔRa) after successive phase sandblasting.

Sample set	Values of (SLM) processing parameters		Reduction of roughness values after sandblasting phases					
	v_{scan}, [mm/s] t_e, [μs]	P, [W]	ΔRa_1		ΔRa_2		ΔRa	
			[μm]	[%]	[μm]	[%]	[μm]	{%}
01	v_{scan} = 500 mm/s t_e = 40 μs	100.00	2.57	36.38	2.07	29.28	0.50	19.45
07		80.30	3.96	48.88	3.60	44.44	0.36	9.09
13		60.61	4.34	44.97	3.84	39.79	0.50	11.52
03	v_{scan} = 1000mm/s t_e = 20 μs	100.00	3.63	42.06	2.72	31.51	0.91	25.06
09		80.30	3.41	38.70	2.31	31.89	1.10	32.26
15		60.61	3.52	36.43	2.21	22.88	1.31	37.21
05	v_{scan} = 333 mm/s t_e = 60 μs	100.00	3.63	42.06	2.39	31.51	1.24	34.15
11		80.30	3.53	47.70	3.24	43.78	0.29	8.21
17		60.61	4.29	45.54	3.68	39.06	0.61	14.21

Significant reductions of roughness values after sandblasting with white electro-corundum were obtained for (SLM) processing with medium or low values of the technological parameters (ΔRa_1= 3.84 μm – for the set 13, and ΔRa_1 = 3.68 μm for the set 17). The use of high values for the three parameters (sets 1 and 15) reduces the efficiency of the first sandblasting (ΔRa_1= 2.07 μm – for the set

1, and ΔRa_1 = 2.27 µm for the set 15). This aspect may be explained through the hardening effect of the surface likely to appear during (SLM) processing with high powers of the laser beam (P= 100W) or high values of the scan speed (v_{scan} = 1000 mm/s) and short exposure time (t_e = 20 µs).

The sets made of:

- high or medium values of parameters (P) and (t_e) combined with a low value for (v_{scan}), or
- low values of parameters (P) and (t_e) combined with a high value for (v_{scan})

helped obtaining the most important effects for two-step sandblasting:

ΔRa = 37.21 % - for the 15, ΔRa = 34.15 % - for the set 05 and ΔRa = 32.26 % - for the set 09.

5. Conclusions

The action of SLM processing technological parameters P, v_{scan} and t_e on the roughness of exterior surfaces obtained in the processing of Co-Cr metal powder was studied in this paper. Among the parameters specific to roughness amplitude we considered the arithmetic mean of the profile under evaluation (Ra).

Based on the values of experimental results we may formulate the following conclusions:

- SLM processing was carried out with three distinct values for each technological parameter P, v_{scan}, t_e. After SLM processing, the obtained surfaces were sandblasted once (1S), in two successive phases (2S), or they were not sandblasted at all (NS).
- for each sandblasted sample we calculated roughness variations (ΔRa_1) and (ΔRa_2) in relation to nonsandblasted surfaces. The analysis of values obtained for parameters (ΔRa_1) and (ΔRa_2) showed that the use of a high power of the laser beam (P = 100 W) in combination with high scan speed (v_{scan} = 1000 mm/s) and short exposure time (t_e = 20 µs) resulted in a surface with high roughness.
- the use of glass ball sandblasting after white electro-corundum sandblasting produced supplementary reductions of the height of the exterior surface relief. The highest total variations of roughness were ΔRa_2 = 4.29 µm – for the set 17 and ΔRa_2= 4.34 µm – for the set 13. These results show that the efficiency of double sandblasting increases for the SLM processed samples with low values of laser power and medium values of the other two parameters (v_{scan}) and (t_e).
- conducting micro-hardness measurements on the transversal section of the samples would allow for the identification of a potential process of hardening of the material once with the increase of value of SLM processing parameters, a fact that might considerably diminish the sandblasting effects.
- double sandblasting helps obtaining the lowest roughness values, a fact that will contribute to the subsequent reduction of the quantity of ceramic material applied on the exterior surface provided that an adequate value of adherence between the ceramic layer and the metal sub-layer is ensured.
- Implications and influences

The performed research aimed at identifying the influence of sandblasting on the roughness of surfaces obtained by SLM processing. The study follows the evolution of the values obtained for the Ra parameter, after SLM processing, after simple sandblasting with white electrocorundum (1S) and after successive sandblasting with white electrocorundum and glass beads (2S). We found that simple sandblasting had the effect of significantly reducing the roughness profile, while the second step of the sandblasting produced a rounding of the asperities peaks, without significantly affecting their height ($\Delta Ra_2 < \Delta Ra_1$). These influences will be further developed, when the adhesion between the ceramic layer and the metal substrate will be analysed within the stage of ceramic plating of dental prosthesis components.

The performed experiments made it possible to determine the most favourable value combinations of the technological SLM processing parameters capable of providing, after sandblasting processing, an optimal roughness for the outer surfaces of the metal substrate. 9 sets of values were used for the SLM processing parameters (P, v_{scan}, t_e) and two sandblasting variants were applied: simple (1S) with white electrocorundum and sequential (2S) with white electrocorundum and glass beads. The measurements of roughness (Ra) have shown the efficiency on the surface quality of each stage in the sandblasting process. In this way, in the future, it will be possible to choose the most favourable technological conditions for both SLM processing and sandblasting, which will allow for optimum roughness for an efficient ceramic plating.

6. References

[1] Sapate K D and Tejashree Apte U 2017 *IJCET* **7(1)**
[2] Yap C Y, Chua C K, Dong Z L, Liu Z H, Zhang D Q, Loh L E and Sing S L 2015 *Appl. Phys. Rev.* **2(4)** 041101
[3] Puchades J R B 2012 *Master thesis* (Valencia: Universitad Politecnica de Valencia)
[4] Kruth J P, Badrossamay M, Yasa E, Deckers J, Thijs L and Van Humbeeck J 2010 *International Symposium on Electromachining, Shanghai*, China
[5] Koutiri I, Pessard E, Peyre P, Amlou O and De Terris Th 2018 *J. Mater. Process. Tech.* **255** 536
[6] Prashanth K, Scudino G, Maity S, Das T and Eckert J 2017 *Mater. Res. Lett.* **5(6)** 386
[7] Wen–Hou Wei and Shen J 2018 *Int. J. Mater. Res.* **109(5)**
[8] Lin-Zhi W and Wen-Hou W 2018 *Acta Metall. Sin.* **31(8)** 807
[9] Gu H, Gong H, Deepankar P, Khalid R, Starr TH and Stucker B 2013 *24th, Annual international solid freeform fabrication symposium; an additive manufacturing conference, proceedings Austin* TX **474**
[10] Han J 2015 *Rapid Prototyping J.* **23(2)** 217
[11] Goutianos S 2017 Adv. *Mater. Res-Switz.* **219**
[12] Poprawe R, Hînke Ch, Meiners W, Schrage J, Bremen S and Merkt S 2014 *Lect. N. Prod.* **49**
[13] Mager V, Bâlc N, Leordean D, Dudescu M C and Fockele M 2013 *Appl. Mech. Mater.* **371** 280
[14] Kim H R, Jang S H, Kim Y K, Son J, Min B K, Kim K H and Kwon T Y 2016 *Materials* **9(7)** 596
[15] Figliuzzi M, Mangano F and Mangano C 2012 *J. Oral. Maxillofac. Surg.* **41** 858
[16] *Additive Manufacturing products*, https://www.renishaw.com/en/additive-manufacturing-products--17475
[17] *Manufactures and Developers of Additive Systems and Materials*, https://wohlersassociates.com/manufacturers-and-developers html
[18] *Systems and Equipment for Metal Manufacturing*, https://www.eos.info/systems_solutions/metal/systems_equipment
[19] Rajúková V, Polacek I, Toth T, Zivcak J, Izarikova G, Kovacevic M, Somos A and Hudak R 2016 *Lekar a technika* **46(4)** 102
[20] Dikova T, Dzhendov Dz, Simov M and Katreva I 2015 *Journal of IMAB* **21(4)**
[21] Dzhendov Dz and Dikova Ts 2016 *Journal of IMAB* **22(4)** 1414
[22] Takaichi A, Suyalatu A, Nakamoto T, Joko N, Nomura N, Tsutsumi Y, Migita S, Doi H, Kurosu S, Chiba A, Wakabayashi N, Igarashi Y and Hanawa T 2013 *J. Mech. Behav. Bionned. Mater.* **21** 67
[23] Baciu M A, Baciu E R, Bejinariu C, Toma S L, Dănilă A and Baciu C 2018 *IOP Conference Series*: *Materials Science and Engineering* **374 (1)**
[24] Hong M H, Kim B K and Kwon T Y 2016 *Applied Sciences* **6(12)** 401
[25] Fox J C, Moylan S P and Lane B M 2016 *Proc. Cirp.* **45** 131
[26] Yadroitsev L and Smarov I 2011 *Physcs. Proc.* **12** 264
[27] Perevoshchikova N 2016 *Rapid Prototyping* J. **23(5)** 881
[28] Li Z, Kucukkoc I, Zhang D Z and LiU F 2016 *Rapid Prototyping* J. **24(1)** 150
[29] Lober L, Flache Ch, Petters R, Uta Kuhn J 2013 *Rapid Prototyping* J. **19(3)** 173
[30] Seifi M and Satko D 2018 Proceedings of the 9th International Symposion on Superalloy **718** 515
[31] Scheftner Dental Alloy CoS Line, S&S Scheftner GmbH Germany 2018, https//www.Scheftner.dental/cocr-based.html
[32] SLM Solution GmbH Germany, www.slm-solution.com
[33] Renfert BasicEco (Renfert, Germany), www.renfert.com/usa-en/Company

[34] *Taylor-Hobson Talysurf, Ametek Instruments,* www.taylor-hobson.com
[35] Vizureanu P, Perju MC, Galusca DG, Nejneru C, and Agop M 2013 *Metalurgia International* **15** 59-64
[36] Cerempei A, Muresan EI, Cimpoesu N, Carp-Carare C and Rimbu C 2016 *Industrial Crops and Products* **94** 216-225

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