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# EFFECTS OF THE VARIATION OF SELECTIVE LASER MELTING PRINTING PARAMETERS ON THE PROPERTIES OF CO-CR-W ALLOY

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***Abstract:*** *Additive manufacturing technologies such as selective laser melting (SLM) are increasingly applied in industrial sectors due to their ability to obtain parts with complex geometries and high precision. This study investigates how variations in SLM printing parameters affect the properties of a Co-Cr-W alloy. The powder particle size was +10/55 μm, which was deposited in successive layers of 25 μm. Three sets of technological parameters were established, involving changes in laser power (P), scan speed ($s_{speed}$) and exposure time ($t_{exp}$). The results demonstrate significant correlations between the process parameters and the properties of the resulting materials, providing insights for optimizing the manufacturing of Co-Cr-W components.*

***Key words:*** *SLM printing, Co-Cr-W alloy, particle size, technological parameters, microhardness, electrochemical behavior.*

## 1. INTRODUCTION

Over the past two decades, Selective Laser Melting (SLM) has become an advanced additive manufacturing process, particularly for the production of metal components with complex geometries and high density [1]. Its ability to transform CAD models directly into functional parts - with fine control over shape and internal structure - has opened up new possibilities in key sectors such as aerospace engineering, medical engineering and high-precision machining tools [2]. In this context, attention is focused on the Co-Cr-W alloy, a ternary alloy system that attracts interest due to its well-balanced combination of mechanical strength, corrosion resistance and biocompatibility [3, 7]. These properties recommend it for applications where long-term performance and structural reliability are essential, including medical implants and dental restorations [4].

A 2014 study on laser additive manufacturing of Co-Cr alloy found that it is possible to refine the microstructure if the process parameters are optimized [5]. Thus, laser power, powder feed rate and scanning speed allow for excellent mechanical, tribological and electrochemical properties. For other material systems (e.g. stainless steels and ceramics) changing these parameters affects porosity, grain size distribution and residual stresses [6]. In the specific context of Co-Cr-W alloy, understanding these relationships is essential for optimizing the process in order to achieve superior performance in demanding jobs.

In this paper, the basic SLM process and its technological parameters are presented, the specific microstructural changes of the Co–Cr–W alloy are investigated, and the mechanical properties of the alloy are evaluated. Each issue will be critically examined, with reference to relevant research findings and existing data from the literature, thus providing an integrated picture of how changes in SLM parameters affect the overall properties of parts manufactured from the Co-Cr-W alloy [9, 10].

## 2. EXPERIMENTAL PROCEDURE

### 2.1 Experimental equipment

The samples were fabricated by SLM using a Realizer SLM 50 system, which can reach a laser power of $P_{max}$ = 100 W, laser beam diameter

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d = 0.2 ÷ 0.4 µm, with the recommendation that the metal powder particles have to be between 20 ÷ 50 µm and the thickness of the printed metal layer g = 25 µm. The metal powders that can be used are: Ti alloys, Co – Cr alloys, 316 L stainless steels, Ni-based alloys (Inconel 725) and gold-based alloys.

Under these conditions, three sets of technological parameters for SLM processing were established and are presented in Table 1.

*Table 1*

**Technological parameters adopted for SLM processing of Co-Cr-W metal powder.**

| Technological parameters | | | | |
|---|---|---|---|---|
| **Set No.** | **Sample mark** | **P [W]** | **$S_{speed}$ [mm/s]** | **$T_{exp}$ [µs]** |
| 1 | A | 60 | 333 | 60 |
| 2 | B | 80 | 500 | 40 |
| 3 | C | 100 | 1000 | 20 |

The printing was achieved by selectively melting the metal powder layer by layer in the vertical build direction (bottom to top). Each layer was deposited linearly, with an orientation of 90° to the previous layer, in order to improve the adhesion between the layers and reduce possible defects, such as delamination or porosity, as highlighted in Fig. 1.

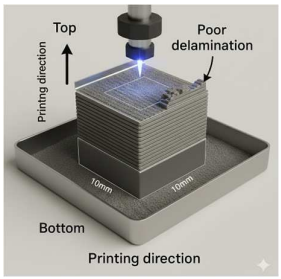


**Fig. 1.** An example of SLM printing, layer by layer

The preparation of the surface to be investigated was carried out on a grinding and polishing machine (Metkon Forcipol 202) with metallographic paper of different grain sizes while the polishing was performed with suspended alumina.

The microhardness was measured using the Vickers hardness (HV) method using an HVT-1000 type equipment (Shanghai Daheng Optics and Fine Mechanics Co., Ltd.), applying a force of 300 gf for 15 seconds.

Energy Dispersive Spectroscopy (EDS) analysis was performed with a Tescan Vega III electron microscope in order to determine the average chemical composition. To assess the spatial distribution of elements and to record the EDS spectra of the powder particles, a Bruker analyzer was used.

Optical Microscopy (OM) observations were carried out on an Optika Italy microscope equipped with a Sony CMOS IMX334 sensor camera.

## 2.2 Materials

In the present experiment, the powder used was Starbond CoS Powder 55 (S&S Scheftner C, Germany). The chemical composition of the powder is presented in Table 2.

*Table 2*

**Chemical composition of Starbond CoS Powder 55 (S&S Scheftner C, Germany).**

| | **Co [wt%]** | **Cr [wt%]** | **W [wt%]** | **Mo [wt%]** | **Si [wt%]** |
|---|---|---|---|---|---|
| Values indicated by the manufacturer | 59.0 | 25.0 | 9.5 | 3.5 | 1.0 |
| Average values determined by EDS | 59.83 | 25.99 | 9.54 | 3.48 | 1.16 |

Notes:

- the average values were calculated based on 10 experimental determinations;
- the values obtained do not indicate major differences that could majorly influence the processing technology and the resulting transformations.

The distribution of chemical elements, determined on each area of interest, as well as the EDS spectrum of the powder particles, are presented in Fig. 2.

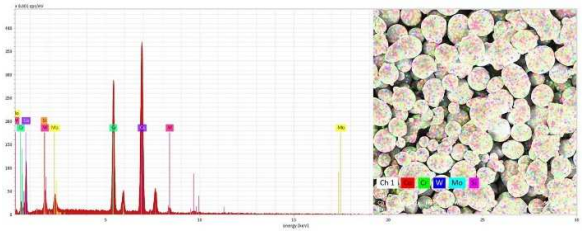

**Fig. 2.** Elemental chemical analysis and EDS analysis

The technical data sheet of the metal powder Starbond CoS Powder 55 presents to following values of physical and mechanical properties:

- density: 8.8 g/cm3;
- elastic limit: Rp 0.2 = 720 ÷ 1130 MPa;
- tensile strength: Rm = 990 ÷ 1250 MPa;
- tensile elongation: A = 2 ÷ 10%
- longitudinal modulus of elasticity: E = 195 ÷ 200 GPa;
- Vickers hardness: HV = 345 ÷ 490 HV;
- melting temperature range: 1305 ÷ 1400 °C;
- coefficient of linear thermal expansion (for the range 20 ÷ 600 °C): α = 14.4 10-6 K-1.

Three types of samples were SLM printed taking into account the parameters established in Table 1. Each sample has a cubic shape with dimensions of 10 x 10 x 8 mm.

The samples were ultrasonically cleaned in alcohol for 5 minutes to remove any impurities or traces of grease resulting from the manufacturing process or from handling. The samples were sanded with SiC paper up to P2500 under a water jet and polished on felt discs and alumina in suspension. The grain boundaries were highlighted by chemical etching, using a mixture of hydrogen peroxide ($H_2O_2$) and hydrochloric acid (HCl) in a ratio of 1:2, the sample being immersed for one hour.

## 3. RESULTS AND DISCUSSION

The 21 Vickers hardness measurements were performed on 3 sets of samples obtained by SLM processing, according to the parameters established in table 1 and denoted by A, B and C. Seven determinations were performed on each set of samples [8] and their values are presented in Fig. 3.

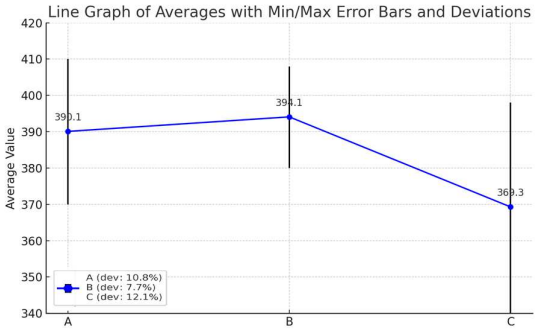


**Fig. 3.** Vickers microhardness values for SLM processed samples from Co-Cr-W metal powder

It was observed that the average microhardness values ranged from 369.3 HV to 394.1 HV. The set of samples marked with B presents the highest average microhardness, followed by those marked with A, and the lowest values are found in the set of samples marked with C. The differences are not very large, in absolute values (approximately 25 HV between maximum and minimum), but they are relevant for evaluating the uniformity and efficiency of the manufacturing process.

The min - max ranges are shown by the vertical error bars: for the set of samples marked A - the values vary between 370 HV and 410 HV, for the set marked B - the values vary between 380 HV and 408 HV, and for the set of samples marked C - the values range between 340 HV and 398 HV. A greater dispersion was noted for the sample set marked C, with a considerable extension of the values (58 HV between minimum and maximum), which may indicate an inhomogeneity of the microscopic structure or a lack of optimal control over the process parameters. In contrast, set B has a narrower dispersion range and a higher mean, which suggests better homogeneity of the structure and, possibly, a more complete and consistent melting of the powder particles during SLM processing.

Information on the percentage deviations of the mean values is 10.8% - for set A, 7.7% - for set B and 12.1% - for set C and they reflect the degree of dispersion of the measurements from the mean of each sample confirming the previous observation: sample B has the lowest dispersion, which recommends it from the point of view of mechanical stability. In contrast, sample C is the most unstable, also having the lowest average hardness, which in real applications may raise problems related to wear resistance and mechanical fatigue.

These differences can be directly correlated with the applied manufacturing parameters. For example, a high scanning speed and too short powder exposure time can lead to incomplete melting, porosities and non-uniform microstructures, as appears to be the case for the sample set marked C. In contrast, a balanced energy input, as is likely the case for the sample set marked B, leads to a controlled solidification

and a fine and uniform microstructure, reflected in high and uniform hardness values.

The SLM technological parameters will influence the final microstructure of the deposited layers and this will determine the values of the investigated physical-mechanical properties. A high scanning speed and a short exposure time of the metal powder particles will cause incomplete melting, the formation of a dimensionally non-uniform microstructure, characterized by a high pore density.

Figure 4(a) shows a microstructure characterized by non-uniform grain size and a lack of crystallographic orientation. Solidification defects such as pores are highlighted in large numbers, which will negatively affect the continuity of the microstructure and will diminish the values of the analyzed physical-mechanical properties.

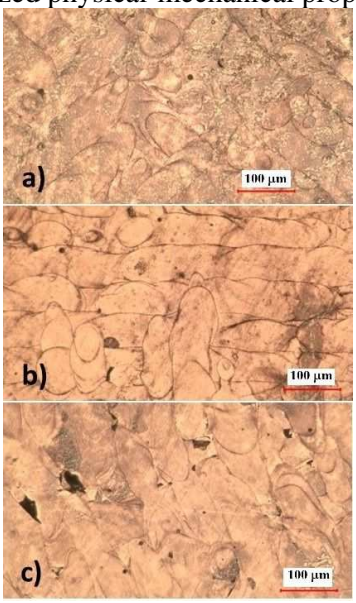


**Fig. 4.** Optical microscopy images of samples obtained by SLM, respecting the parameters from Table 1: a) sample from set A, b) sample from set B, c) sample from set C

Fig. 4(b) highlights a microstructure with elongated grains in the direction of heat dissipation during the solidification process. There are also some grains, few in number, with other crystallographic orientations. At the grain boundaries, there are defects specific to the printing process, such as voids, which will characterize the porosity of the obtained microstructure. The metallographic appearance indicates that the solidification of the successively deposited layers was continuous because there are no separation surfaces between them.

The selected printing parameters ensured the temperature and time conditions required for proper melting and solidification.

The microstructure in fig. 4(c) presents an advanced degree of dimensional inhomogeneity, with insufficiently developed grain boundaries. An oriented arrangement of the crystals in accordance with the direction of heat evacuation during the solidification process cannot be identified. The density of the formed structure is reduced and the presence of large pores is noted. This type of microstructure will characterize a material with non-uniform physical-mechanical properties.

The corrosion parameters include the corrosion potential (E(I=0)), corrosion current density ($j_{cor}$), corrosion rate ($v_{cor}$), polarization resistance (Rp), and anodic and cathodic Tafel slopes (α and β). Corrosion studies were performed in 0.9%NaCl solution, respecting the parameters in Table 3.

*Table 3*

**Corrosion process parameters.**

| Sample mark | E(I=0) [mV] | $j_{cor}$ [µA/cm²] | $v_{cor}$ [µm/an] | Rp [ohm.cm²] | $\beta_a$ [mV/dec] | $-\beta_c$ [mV/dec] |
|---|---|---|---|---|---|---|
| A | -126 | 68.99 | 957.4 | 339 | 151 | 152 |
| B | -147 | 33.14 | 460.2 | 847 | 183 | 172 |
| C | -187 | 27.83 | 386.49 | 914 | 146 | 145 |

The comparative analysis of the electrochemical behavior of the SLM-processed Co–Cr–W samples revealed significant differences, Fig. 5, which are correlated with the microstructure and microhardness values obtained.

Sample A, although it has a high average hardness (390.1 HV), records the highest corrosion current density (68.99 µA/cm²) and the highest corrosion rate (957.4 mm/year), behavior explainable by the non-uniform microstructure and the presence of porosities observed through microscopic images.

Sample B presents the most balanced behavior: hardness slightly higher than the general average value (394.1 HV), a homogeneous microstructure with continuous

solidification and a significantly reduced corrosion rate (460.2 mm/year), accompanied by a high polarization resistance (847 Ω·cm²), which indicates the formation of a stable passive film.

Sample C, although it has the lowest hardness (369.3 HV) and a microstructure with obvious defects, presents the lowest corrosion rate (386.5 mm/year), which can be attributed to a higher electrochemical reactivity, which favors the rapid formation of a protective passive layer.

Thus, the results obtained indicate that the process parameters corresponding to sample B offer the best correlation between mechanical properties and corrosion resistance, being the most appropriate for applications involving simultaneous mechanical and chemical stresses.

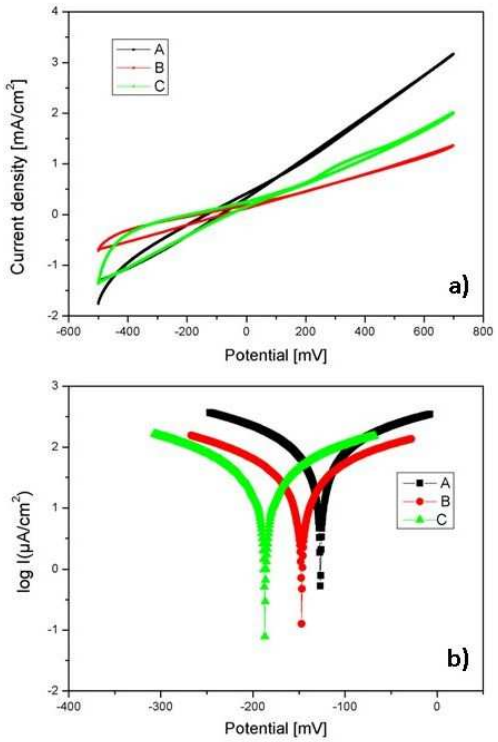


**Fig. 5.** Comparative analysis of electrochemical behavior: a) Cyclic diagrams in 0.9%NaCl solution; b) Tafel diagrams in 0.9%NaCl solution

## 4. CONCLUSIONS

The present study enabled a systematic evaluation of the influence of selective laser melting (SLM) processing parameters on the microstructure, microhardness and corrosion behavior of a Co-Cr-W alloy under controlled and reproducible experimental conditions. While previous studies have primarily focused either on mechanical characterization or on comparative analyses between conventionally manufactured and additively manufactured Co-Cr alloys, the present research provides an integrated process–structure–property–corrosion correlation for SLM-fabricated Co-Cr-W components.

A significant original contribution of this work consists in the direct comparison of three distinct SLM parameter sets applied to the same powder feedstock and geometry, which allowed the isolation of the effects of energy input balance on microstructural continuity, hardness dispersion and electrochemical response. Unlike earlier investigations that reported averaged mechanical properties without detailed consideration of microstructural homogeneity, the present study demonstrates that the uniformity of the solidified microstructure and the dispersion of microhardness values represent key indicators for process optimization.

Furthermore, in contrast to studies that emphasized corrosion behavior independently of microstructural features, the present work establishes a direct link between microstructural defects induced by non-optimal SLM parameters and increased corrosion current density in physiological saline solution. The results show that high hardness values alone do not guarantee superior corrosion resistance, and that continuous solidification and reduced porosity are dominant factors governing electrochemical stability.

Among the investigated conditions, the parameter set corresponding to sample B was identified as optimal, as it ensured a dense and homogeneous microstructure, high and uniform microhardness, and a balanced electrochemical response characterized by low corrosion rates and high polarization resistance. This finding represents a practical advancement beyond previously reported data, by defining a parameter window that simultaneously satisfies mechanical and corrosion-related requirements relevant to biomedical applications.

The outcomes of this study contribute to refining the current understanding of SLM processing of Co-Cr-W alloys by demonstrating that small variations in scanning speed and

exposure time can significantly alter the balance between mechanical performance and corrosion resistance. As a result, the present work provides experimentally validated guidelines for parameter selection, which are not explicitly addressed in existing literature.

Future research will extend the current investigation toward quantitative porosity analysis, phase identification and residual stress evaluation, as well as toward the assessment of post-processing treatments aimed at further improving microstructural integrity and service performance. These developments will allow the consolidation of SLM-fabricated Co-Cr-W alloys as reliable candidates for long-term biomedical and engineering applications.

## 5. FUNDING

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## Efectele variației parametrilor de printare prin topire selectivă cu laser asupra proprietăților aliajului Co-Cr-W

Tehnologiile de fabricație aditivă, cum ar fi topirea selectivă cu laser (SLM), sunt din ce în ce mai aplicate în sectoarele industriale datorită capacității lor de a obține piese cu geometrii complexe și precizie ridicată. Acest studiu investighează modul în care variațiile parametrilor de printare SLM afectează proprietățile unui aliaj Co-Cr-W. Dimensiunea particulelor de pulbere a fost de +10/55 μm, fiind depusă în straturi succesive de 25 μm. Au fost stabilite trei seturi de parametri tehnologici, care implică modificări ale puterii laserului (P), vitezei de scanare ($s_{speed}$) și timpului de expunere ($t_{exp}$). Rezultatele demonstrează corelații semnificative între parametrii procesului și proprietățile materialelor rezultate, oferind informații pentru optimizarea fabricării componentelor din pulbere Co-Cr-W.

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