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EFFECTS OF HEAT TREATMENT ON THE PROPERTIES OF SLM Co-Cr-W ALLOY

BY

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Abstract. Selective Laser Melting (SLM) enables the fabrication of complex Co–Cr-based alloys with promising applications in biomedical and engineering fields. However, as-built microstructures often present residual stresses and heterogeneities that affect mechanical performance. In this study, Co–Cr–W–Mo–Si alloys were produced by SLM and subjected to various heat treatments in order to evaluate their microhardness response. The results indicate that solution treatments moderately increased hardness, while combined solution and ageing treatments yielded the highest improvements, with average values above 470 Kgf/mm². Nonetheless, heat-treated samples exhibited greater variability, highlighting the importance of optimizing thermal cycles to balance hardness enhancement and microstructural stability.

Keywords: SLM, Co-Cr-W Alloy, Additive Manufacturing, Printing Parameters, Heat treatment.

1. Introduction

Selective Laser Melting (SLM) has emerged as one of the most advanced additive manufacturing techniques, enabling the production of complex metallic

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components with high precision and tailored microstructures. Co–Cr-based alloys are among the most widely used materials in SLM due to their combination of high strength, corrosion resistance, and biocompatibility, making them suitable for applications in biomedical implants, dentistry, and aerospace components (Liu *et al*., 2016; Mutua *et al*., 2018; Yap *et al*., 2015). However, the rapid solidification associated with SLM often results in non-equilibrium microstructures, high residual stresses, and microstructural heterogeneities that may compromise mechanical performance (Li *et al*., 2019; Kok *et al*., 2018).

Heat treatment is therefore essential for tailoring the final properties of SLM-fabricated Co–Cr–W–Mo–Si alloys. Solution treatments can relieve residual stresses and promote homogenization, while ageing treatments may enhance hardness through precipitation hardening and grain refinement (Prashanth *et al*., 2017; Sun *et al*., 2019). Previous studies have shown that optimized thermal cycles can significantly improve wear resistance and extend the service life of such alloys, though they may also induce local microstructural inhomogeneities if not properly controlled (Popovich and Sufiiarov, 2016; Chen and Thouas, 2015).

In this context, the present study aims to investigate the effects of various heat treatment conditions on the microhardness of SLM-produced Co–Cr–W–Mo–Si alloys. The results are expected to provide insights into the relationship between thermal processing, microstructural evolution, and mechanical performance, with potential implications for industrial applications requiring both high hardness and microstructural stability.

Furthermore, recent investigations on the influence of corrosion on thermo-mechanical fatigue under rolling conditions with low amplitude sliding have highlighted the critical interplay between surface degradation and mechanical loading, underlining the need to consider both microstructural stability and environmental effects when assessing the performance of Co–Cr-based alloys (Mistreanu *et al*., 2024).

2. Materials and Methods

For the present experiments, a 5 kg batch of Starbond CoS Powder 55 (S&S Scheftner, Mainz, Germany) was employed. According to the manufacturer, the chemical composition was 59Co–25Cr–9.5W–3.5Mo–1.0Si (wt.%), with a particle size distribution of +10/−55 μm. The powder particles exhibited a predominantly globular morphology.

The powders were processed using a Realizer SLM 50 system, operating with a maximum laser power of 100 W and a beam diameter in the range of 0.2–0.4 μm. The general aspect of the SLM-processed 1 cm^3-volume samples. The processing parameters applied in the SLM experiments are summarized in Table 1. At the end, three types of samples were obtained, designated by A, B and C.

Table 1
Summary of the processing parameters applied in the SLM fabrication of Co–Cr–W–Mo–Si samples

Sample	A	B	C
Laser power, W	60	80	100
Scanning speed, mm/s	333	500	1000
Exposure time, μs	60	40	20

These types of samples were subjected to heat treatments, as can be seen in Table 2.

Table 2
Summary of the heat treatment parameters applied to the three SLM-processed Co–Cr–W–Mo–Si sample states.

Sample		Solution treatment		Ageing	
		T, °C	t, min	T, °C	t, min
A	A1	1200	30	-	-
	A2	1200	30	815	4
	A3	1200	30	830	6
B	B1	1200	45	-	-
	B2	1200	45	815	6
	B3	1200	45	830	2
C	C1	1200	60	-	-
	C2	1200	60	815	2
	C3	1200	60	830	4

For analysis, the samples were prepared by grinding and automatic polishing using a METKON FORCIPOL 1V machine, with metallographic papers of progressively finer grit (P180 to P1200) under continuous water flow.

Microhardness measurements were performed using an HVT-1000 tester (Shanghai Daheng Optics and Fine Mechanics Co., Ltd.) under a load of 300 gf applied for 15 s. For each sample surface, seven microhardness measurements were performed under identical testing conditions.

3. Results and Discussion

Figure 1 shows the microhardness of printed samples that did not undergo any heat-treatment. Figure 2 shows the average hardness of heat-treated samples. It is obvious that all of the heat-treated samples were harder than the initial as-fabricated ones. This could be related to the fact that the aged samples had smaller grains as compared to the SLM as-fabricated ones.

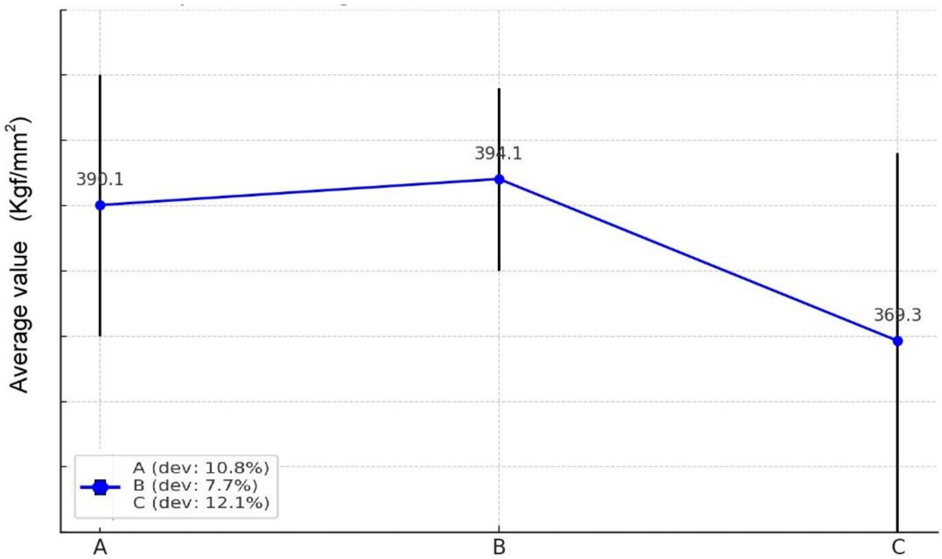

Fig. 1 – Micro-hardness values were determined on SLM as-fabricated samples, as an average of seven measurements.

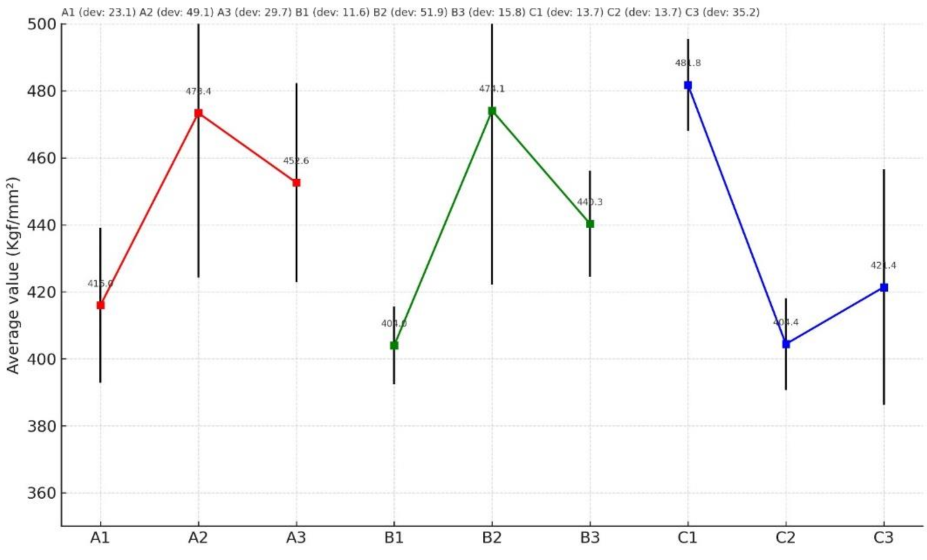

Fig. 2 – Micro-hardness values were determined on heat-treated samples.

The microhardness analysis revealed clear differences between the as-fabricated and the heat-treated samples. For the SLM-processed states (A, B, C), the average values ranged between 369 and 394 Kgf/mm², with sample B showing slightly higher hardness compared to A and C. This trend can be attributed to the processing parameters, as the higher laser power and scanning speed in sample B favor a more homogeneous microstructure with fewer residual defects.

Following heat treatments, a significant increase in hardness was observed in almost all cases. The solution-treated samples (A1, B1, C1) displayed moderate improvements, while the specimens subjected to combined solution and ageing treatments (A2, A3, B2, B3, C2, C3) exhibited the highest hardness values. For instance, samples A2 and B2 reached values above 470 Kgf/mm², markedly higher than the corresponding as-fabricated states. This behavior is consistent with grain refinement and precipitation phenomena typically promoted by ageing treatments in Co–Cr–W alloys.

Another important observation concerns the standard deviations associated with each state. Heat-treated samples generally presented larger scatter in microhardness values, particularly A2 and B2, suggesting that local microstructural inhomogeneities were introduced during the thermal cycle. This variation may be linked to incomplete homogenization or the presence of residual internal stresses. Conversely, as-fabricated samples showed more uniform distributions, although at lower hardness levels.

Overall, the results indicate that heat treatment significantly enhances the hardness of SLM Co–Cr–W–Mo–Si alloys, especially when ageing is combined with solution treatment. However, the increase in hardness is accompanied by a higher variability, which may affect the predictability of mechanical performance. These findings highlight the importance of optimizing thermal cycles not only to maximize hardness but also to ensure microstructural stability and reproducibility across different processing states.

3. Conclusion

The experimental results demonstrate that heat treatment has a marked influence on the mechanical response of SLM Co–Cr–W–Mo–Si alloys. Solution treatments led to moderate hardness increases, whereas combined solution and ageing treatments yielded the highest improvements, with average values exceeding 470 Kgf/mm². Nevertheless, the enhanced hardness was accompanied by higher variability, suggesting microstructural heterogeneities induced during the thermal cycle. These findings emphasize the need for optimized heat treatment protocols that maximize hardness while ensuring uniformity and reproducibility, thereby improving the reliability of Co–Cr-based components in demanding engineering and biomedical applications.

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REFERENCES

Chen Q., Thouas G.A., *Metallic implant biomaterials: current status and future perspectives*, Materials Science and Engineering R, 2015.

Kok Y. et al., *Anisotropy and heterogeneity of microstructure and mechanical properties in metal additive manufacturing*, Materials & Design, 2018.

Li X. et al., *Residual stress and microstructure of SLM Co–Cr–Mo alloys*, Journal of Alloys and Compounds, 2019.

Liu Y.J. et al., *Microstructure and mechanical properties of selective laser melted Co–Cr–Mo alloy*, Materials Science and Engineering A, 2016.

Mistreanu S., Tudose-Sandu-Ville F., Munteanu C., Cimpoeșu R., Luțcanu M., Științbu I., Manole V., Stamate C., Rusu O., Cimpoeșu N., *Influence of Corrosion on Thermo-Mechanical Contact Fatigue in Rolling Conditions with Low Amplitude Sliding*, Archives of Metallurgy and Materials, 1-18, 2024.

Mutua J. et al., *Optimization of selective laser melting parameters and influence on microstructure and mechanical properties of Co–Cr alloy*, Journal of Materials Processing Technology, 2018.

Popovich A., Sufiiarov V., *Metal additive manufacturing of high-performance alloys for aerospace engineering*, Russian Journal of Non-Ferrous Metals, 2016.

Prashanth K.G. et al., *Effect of heat treatment on microstructure and mechanical properties of SLM alloys*, Additive Manufacturing, 2017.

Sun S.H. et al., *Precipitation behavior and mechanical properties of Co–Cr alloys subjected to ageing*, Journal of Materials Science, 2019.

Yap C.Y. et al., *Review of selective laser melting: Materials and applications*, Applied Physics Reviews, 2015.

EFECTELE TRATAMENTULUI TERMIC ASUPRA PROPRIETĂȚILOR ALIAJULUI Co-Cr-W

(Rezumat)

Topirea selectivă cu laser (SLM) permite fabricarea de aliaje complexe pe bază de Co-Cr cu aplicații promițătoare în domeniile biomedicale și inginerești. Cu toate acestea, microstructurile construite prezintă adesea tensiuni reziduale și heterogenități care afectează performanța mecanică. În acest studiu, aliajele Co-Cr-W-Mo-Si au fost produse prin SLM și supuse diferitelor tratamente termice pentru a evalua răspunsul lor la microduritate. Rezultatele indică faptul că tratamentele de punere în soluție au crescut moderat duritatea, în timp ce tratamentele combinate de punere în soluție și îmbătrânire au produs cele mai mari îmbunătățiri, cu valori medii peste 470 Kgf/mm². Cu toate acestea, probele tratate termic au prezentat o variabilitate mai mare, subliniind importanța optimizării ciclurilor termice pentru a echilibra creșterea durității și stabilitatea microstructurală.