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Comparison of mechanical properties and microstructural characterization of CoCrMo alloy obtained via selective laser melting (SLM) and casting technique

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Abstract

Advances in processes using the powder metallurgy techniques are making this technology competitive compared to the other traditional manufacturing processes, especially in medicine area. The additive manufacturing technique – selective laser melting (SLM) was applied in a biomaterial of CoCrMo alloy (ASTM F75), to study the mechanical properties and microstructural characterization in comparison between the conventional technique – lost wax casting. Yet there is an important knowledge of performance properties, dimensional, mechanical and microstructural of this sintered alloy compared to casting, as reported recently (MERGULHÃO et al., 2015a, 2015b; PODESTÁ et al., 2015). The aim of this study is to demonstrate the mechanical properties and microstructures of specimens manufactured by powder metallurgy techniques using the SLM, using the Co-Cr-Mo alloy in the form of particulate matter.

Materials and Methods

The Co-Cr-Mo alloy gas atomized (H.C Starck® Company) was provided by the HighBond company in three different particle sizes (granulometric range), respectively by terminologies D1 < 15 µm, D2 15-45 µm and D3 76-106 µm. The confirmation of the chemical composition by fluorescence spectrometer X-ray energy dispersive of powders is presented in Table 1.The flow chart of the process of this study is showed in Figure 1.

Table 1 – Chemical composition (weight %) of Co-Cr-Mo powder and the standard reference ASTM F75.

	Cobalt	Chromium	Molybdenum	Iron
Powder	63,86 ± 0,07	28,96 ± 0,04	7,02 ± 0,01	0,16 ± 0,01
Cast	62,601 ± 0,06	27,998 ± 0,04	6,02 ± 0,01	0,213 ± 0,01
ASTM F75	Balance	30,00 - 27,00 ± 0,30	7,00 - 5,00 ± 0,15	0,75 ± 0,03

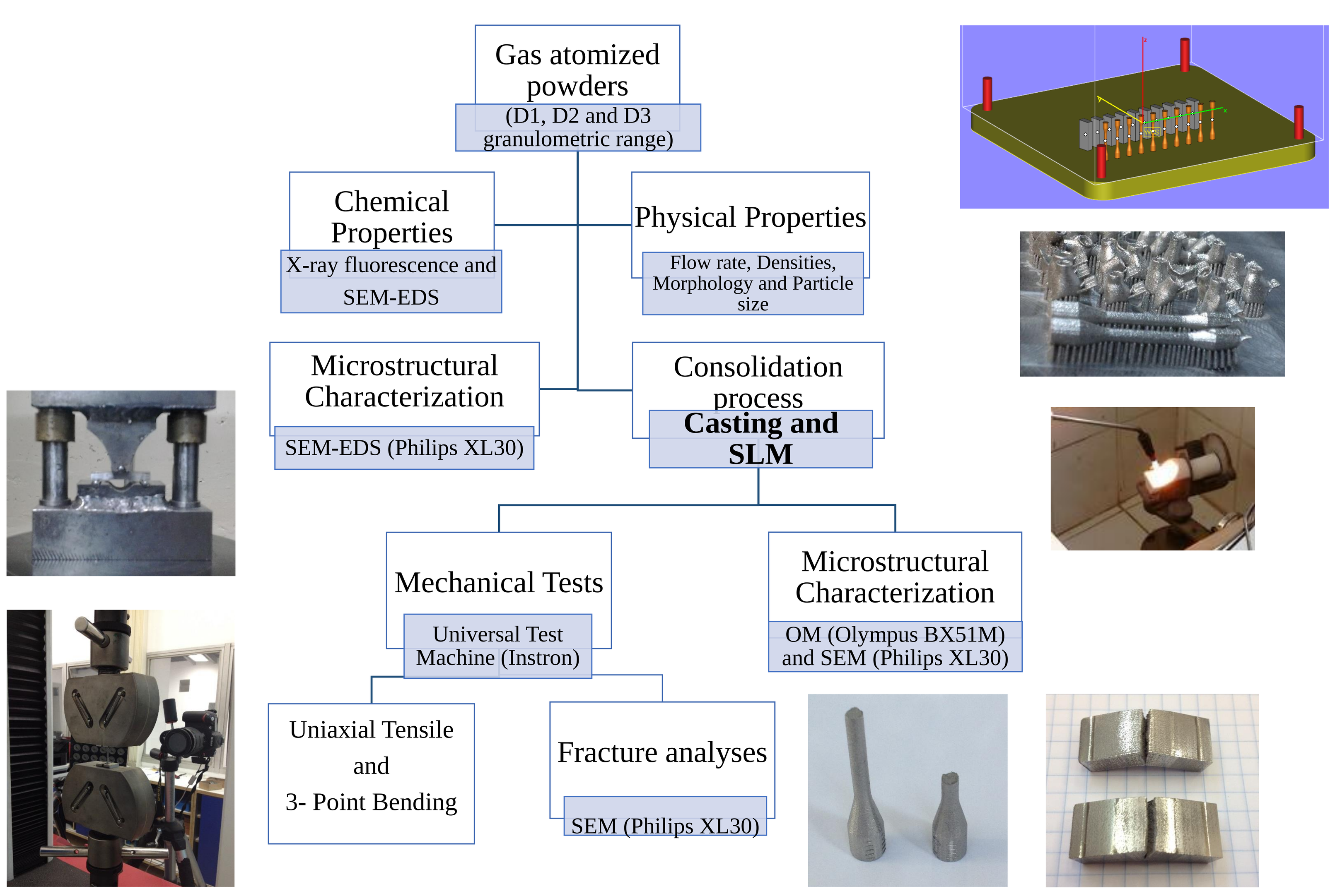

Figure 1 – Flow chart of the process of this study and images of tests and specimens.

Results

The results of all physical properties are showed at the Table 2 and the spherical powders analysed by SEM-EDS in Figure 2. The spherical powders presented satellites and the cross-sectioned powder a dendritic characteristic morphology of gas atomization.

Table 2 – Physical properties of Co-Cr powders.

Physical Properties		Powder		
		D1	D2	D3
Granulometric Distribuition [µm]	Diameter 10%	5,67	20,88	-
	Diameter 50%	12,73	31,11	-
	Diameter 90%	19,64	46,10	-
	Medium Diameter	12,76	32,36	92,81
Flow Time [s/50g]		-	15,85 ± 0,11	22,89 ± 0,03
Apparent Density [g/cm³]		4,12 ± 0,01	4,51 ± 0,01	4,55 ± < 0,01
Tap Density [g/cm³]		5,00 ± 0,02	5,26 ± 0,05	5,09 ± 0,02
Theorical Density (g/cm³)		8,37		
Pycnometer Density by Helium (g/cm³)		8,28 ± 0,001	8,30 ± 0,001	8,27 ± 0,001
Specific Surface (m²/g)		0,66757	0,01114	0,35287

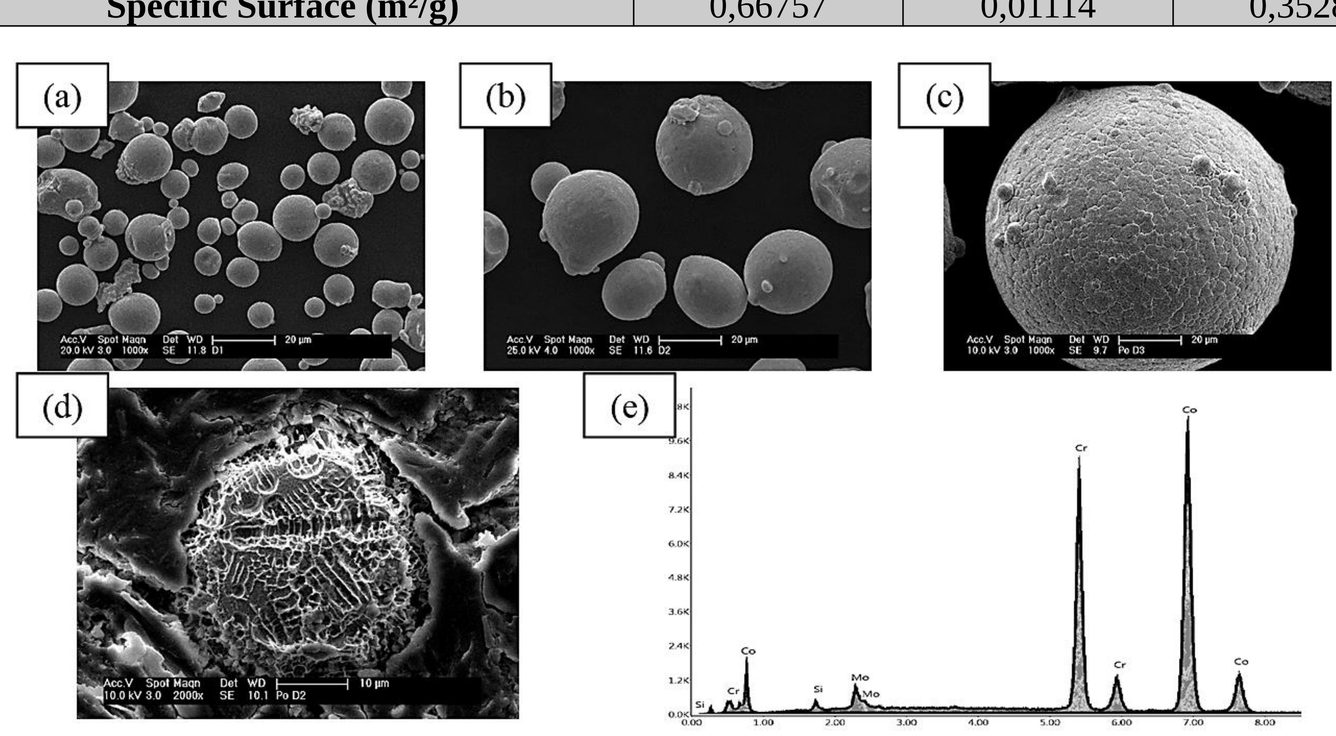

Figure 2 – a) to c) SEM micrographs of atomized powders, respectively D1, D2 and D3 granulometric distribution , d) SEM micrograph of cross-sectioned powder etched and e) EDS of powder gas atomized.

Mechanical curves of uniaxial stress are presented at Figure 3 and for more explanations about the mechanical properties values is apresented at the Table 3.

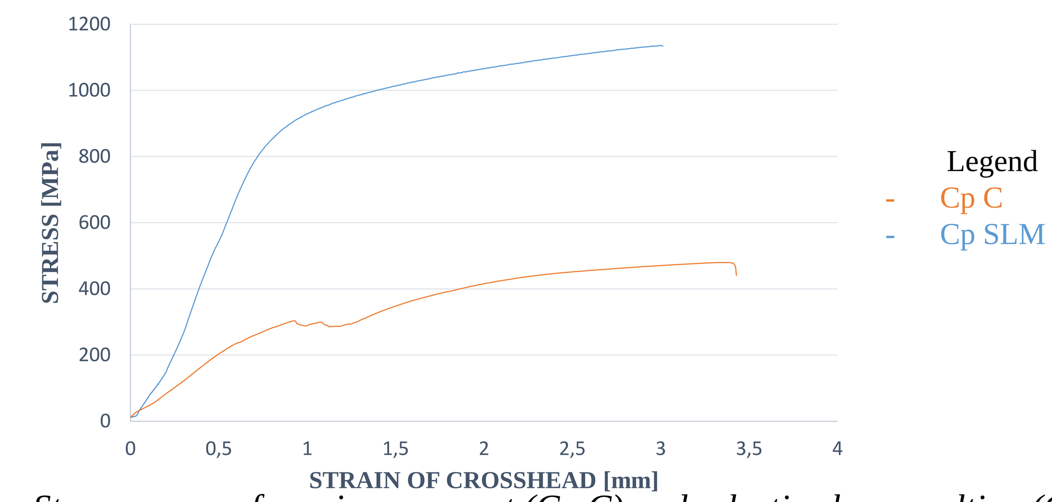

Figure 3 – Stress curves of specimens – cast (Cp C) and selective laser melting (Cp SLM).

Table 3 – Mechanical properties (medium values and desviations) of the specimens manufactured by casting and SLS process. (NU= not usual)

Reference	Type	0.2% YS [MPa]	Elongation [%]	E [GPa]	UTS [MPa]	TRS [MPa]	HV [0.1mN/10s]
Co-Cr-Mo alloy	CAST	276,20 ± 43,60	8,37 ± 4,45	291,21 ± 15,22	453,62 ± 75,91	NU	365,74 ± 16,15
	SLM	731,50 ± 40,31	13,73 ± 5,32	276,70 ± 12,63	1136,95 ± 0,92	1127,91 ± 0,15	420,62 ± 21,16
ISO 22674:06	1	80	18	-	-	-	-
	2	180	10				
	3	270	5				
	4	360	2				
	5	500	2	150			
ASTM F75		450	8	-	655	-	253-327 HV

The microstructure and the fractures of the specimens were evaluated by OM and SEM-EDS as showed in Figure 4 and Figure 5.

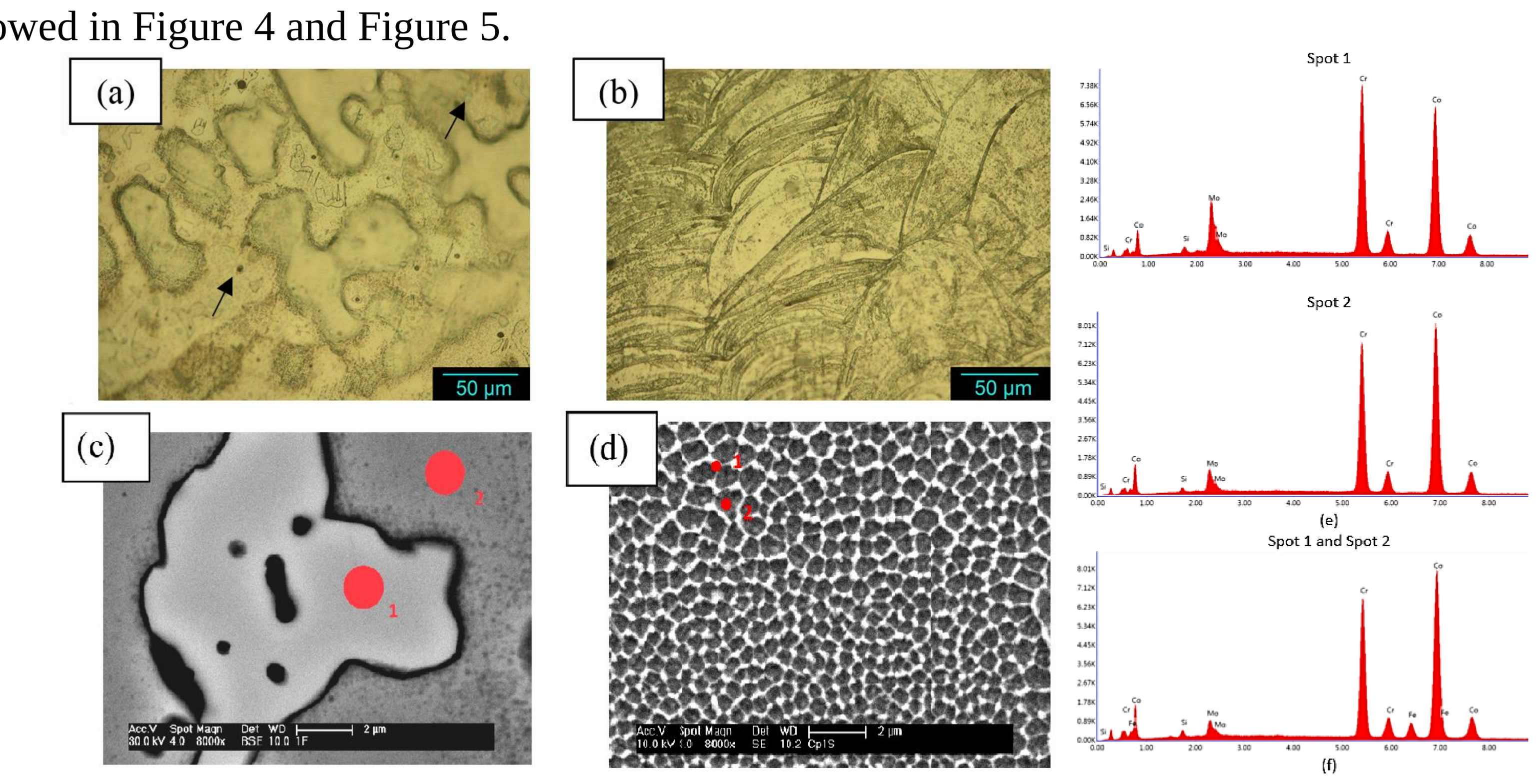

Figure 4 – OM and SEM micrographies of CoCrMo a) and b) as-cast sample, c) and d) as-SLM sample and e) and f) respectively semi-quantitative analysis by EDS of samples.

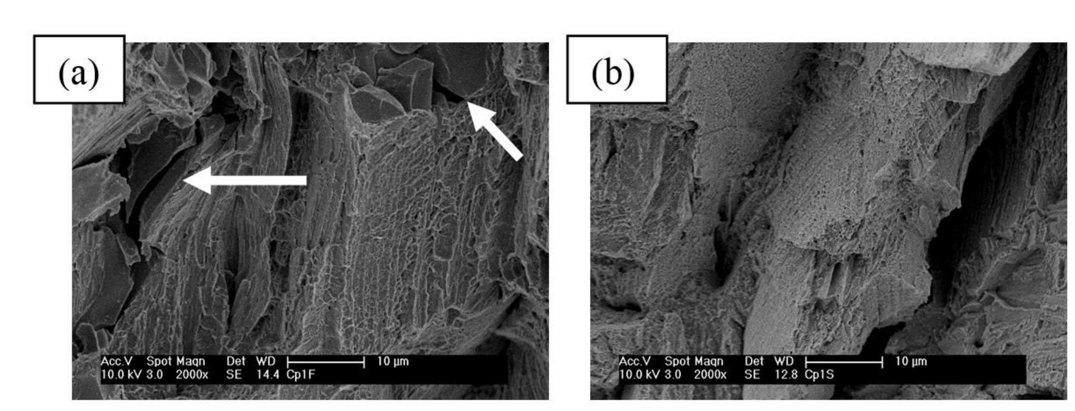

Figure 5 – SEM images of tensile fractures, a) cast sample and b) SLM sample.

To determine the porosity of the consolidated samples was established the density comparison via Helium picnometry between the theoretical density. The results of analysis are shown in the Table 3.

Table 3 –Results (mean and desviations) of porosity analysis methods applied in specimens Co-Cr-Mo.

Specimens	Density methods [g/cm³]	
	Helium Picnometry	Theorical
CAST	8,193 ± 0,007	8,37
SLM	8,244 ± 0,006	

Conclusions

The SLM technique allowed obtaining samples with superior mechanical properties of the cast technique. In this case, the yield strength and elongation were respectively 69,73% and 39,04% greater than the yield strength and elongation obtained in the cast samples.

The microstructural characterization of the casting samples showed formation of rich carbide molybdenum. The SLM allowed to obtain samples with improved chemical homogeneity over the molten sample, as discussed in the microstructural characterization of the samples and confirmed by fracture analysis.

The processing using laser sintering proved superior to casting processing technique, allowing the use of this technique in the manufacturing area of prosthetics and dental implants.

Acknowledgments
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