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Effect of Processing on Microstructure and Properties of CoCrMoSi Alloy

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CoCrMoSi alloys microstructure is affected by processing and their properties have been associated with the high volume fraction of Laves phase. However, not much has been reported on the effect of structure refinement and morphology on the properties of these alloys. This paper evaluates a CoCrMoSi alloy processed by centrifugal casting and Plasma Transferred Arc (PTA) hardfacing, aiming to understand the correlation between microstructure and properties at room temperature in the as-processed condition and following exposure at 600 °C. Characterization was carried out using scanning electron microscopy, X-ray diffraction, hardness and wear tests. The cooling rates associated with each of the processing techniques used account for the developed microstructures and associated hardness, a 626 $HV_{0,5}$ cast alloy and 649 $HV_{0,5}$ deposited alloy, the former exhibiting a coarser microstructure. Wear behavior was determined by the dispersion of solid solution areas in the microstructure and as a consequence temperature exposure aggravated the poorer wear resistance of the cast alloy. The finer phase dispersion formed in coatings overlapped the deleterious effects of dilution and account for the stable wear behavior after temperature exposure.

Keywords: *CoCrMoSi alloy, microstructure, plasma transferred arc, centrifugal casting, wear behaviour*

1. Introduction

Bearings used to support the sink roll in the processing equipment for continuous hot-dip galvanizing (HDG) lines are supplied in the cast condition. They operate in hostile environment involving the effects of abrasive wear, molten metal attack and temperature. Galvanizers have been worked in order to extend the service life of pot hardware, in particular bearings, reducing line stops and improving the quality of galvanized products[1-5]. The continuous search for materials that can withstand such harsh demands led to the use of Laves phase reinforced Co-based alloys, the CoCrMoSi alloy system.

Cast CoCrMoSi alloy bearings show a mean service live of 30 days in traditional galvanizing bath at 460 °C. This behaviour has been attributed to the ability of the alloy to retain hardness at operating temperature[6,7]. An even more demanding service condition is presented in the hot dip galvanizing lines where the pot hardware operates in molten 55AlZn bath at 600 °C. The interaction between a complex set of factors, including higher operation temperature, hard intermetallic dross particles, and reactivity to the 55AlZn molten bath[2, 6-9], results on a reduced bearing life that does not exceed 7 days (168 h).

Plasma transferred arc (PTA) coated bearings can be produced as an alternative for conventional centrifugal cast and the deposition of CoMoCrSi alloy on stainless steel substrate is attractive by the control and refinement of the coatings microstructure. On other hand, the iron content increase due to dilution and higher cooling rates experienced by coatings can affect the temperature stability and wear behavior at operating temperature.

Although enhanced wear resistance has been achieved, further understanding on the relationship between the microstructure features and their response to temperature is required to better optimize the CoCrMoSi system. So, this work evaluated the effect of temperature exposure at 600 ^{0}C for 168 h on Co-based alloy as a way to isolate one important degradation factor on bearings for hot-dip galvanizing with 55AlZn molten bath. This study aimed at establishing the relation between the processing microstructures of a CoCrMoSi alloy and their response after temperature exposure.

1.1. *Experimental procedures*

The chemical composition of CoCrMoSi alloy used in this work is shown on Table 1. The centrifugal cast bearings were supplied by one of the manufacturer and the hardfaced alloy was processed by PTA. Deposition was carried out with the atomized CoCrMoSi alloy on AISI 316L stainless steel plates with $100 \times 100 \times 12{,}5$ mm^3, without pre-heating the substrate or torch oscillation. Processing parameters are shown on Table 2.

The cast bearings and the coatings were first analyzed by visual inspection for their soundness regarding the presence of cracks or other processing defects. Dilution, as the amount of the base material participating on the coating and Laves phase fraction was determined by quantitative metalography on single layer deposits. The Laves phase fraction was counted using an image analyzer which is accopled to the scanning electron microscope. Samples

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cut out from the transverse section of the alloy processed with both techniques were prepared following standard metalographic procedures. Microstructure was characterized by scanning electron microscopy, X-Ray diffraction analysis using $K_{\alpha}Cu$ from 20 to 120° with time of exposed channel of 3s and Vickers hardness under 0,5 kgf load.

Temperature stability of cast and coating alloy was assessed comparing samples in the as-processed condition and following exposure at 600 °C for 7 days (168 h) in an air furnace. Temperature and soaking time were selected considering the mean service live of 7 days (168 h) reported by literature[9].

Wear performance considered a pin-on-disc sliding test apparatus. Pins with a square transverse section of 4 mm were slide against silicon carbide paper (#320) assembled on a 60 HRC hardness metal disc. An axial load of 1 kgf and a tangential speed of 1,5 m/s were applied. Mass loss rate due to the abrasive sliding distance was determined by weighting pins before the test and after each 250 m sliding distance up to 1500 m at room temperature.

2. Results and Discussion

2.1. *As-processed alloy*

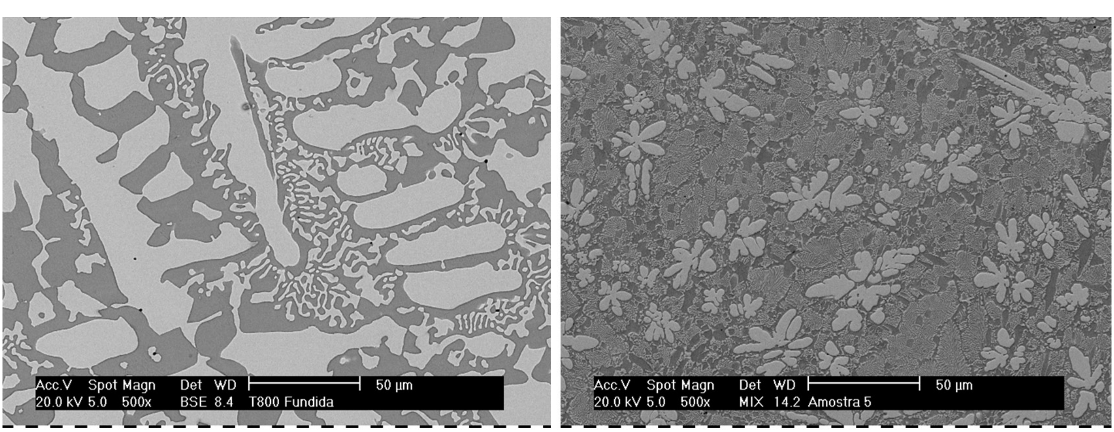
Visual Inspection of the as-received cast alloy and as-deposited coatings did not revealed cracks or porosity. The wall thickness of cast alloy was 12 mm and the PTA overlay 3 mm. Coatings dilution of 9% is within the expected 5 to 15% range mentioned for PTA coatings[10,11]. The solidification rates associated with each of the processing technique determined the characteristics of the microstructure and a coarse structure developed in the cast alloy, Figure 1a. Cast samples showed dendritic primary Laves phase and coarse interdendrictic microstructure composed by lamellar structure and large areas of Cobalt

Table 1. Chemical Composition (wt%).

Alloy / Element	Co	Cr	W	Mo	C	Fe	Ni	Si	Mn
PTA Co-Alloy	Bal.	17,1	....	28,9	0,02	0,4	0,5	3,1	....
Cast Co-Alloy	Bal.	17,5	----	28,5	< 0,08	< 1,5	< 1,5	3,4	....
Substrate	%C	%Mn	%Si	%P	%S	%Cr	%Ni	%Mo	%Al
AISI 316L	0,020	1,350	0,430	0,026	0,008	16,780	10,120	2,126	0,002

Table 2. Plasma Transferred Arc processing parameters.

Parameters	Conditions
Shielding gas (l/min)	2
Protection gas (l/min)	15
Powder feeding gas (l/min)	2
Main arc current (A)	150
Powder feed rate	Constant in volume
Travel speed (mm/min)	100
Distance torch / substrate (mm)	10
Electrode diameter (mm)	3,125



(a) As Cast (b) As Deposited

Figure 1. Microstructure of the CoCrMoSi alloy in as produced condition.

solid solution. Coatings exhibited a dendritic primary Laves phase, refined interdendritic lamellar structure and small areas of Cobalt solid solution, Figure 1b. However, the total fraction of Laves phase (primary and lamellar) was very similar following the two processing techniques (54% in cast and 56% in coatings) which agrees with the small differences in chemical composition and hardness. The higher cooling rate involved in the processing of coatings induced a faster advancing solidification front promoting an overall structure refinement and changes on distribution of interdendritic microstructure.

The effect of the solidification rate in the refinement of coatings microstructure overlaps the deleterious effects expected to follow dilution. In a Co-based alloy, the higher the dilution measured by the amount of Fe in the coatings relative to that of the original alloy, the larger the decrease in

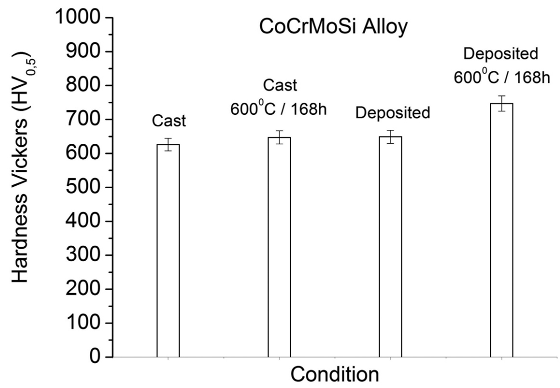


Figure 2. Hardness for as processed and after temperature exposure conditions.

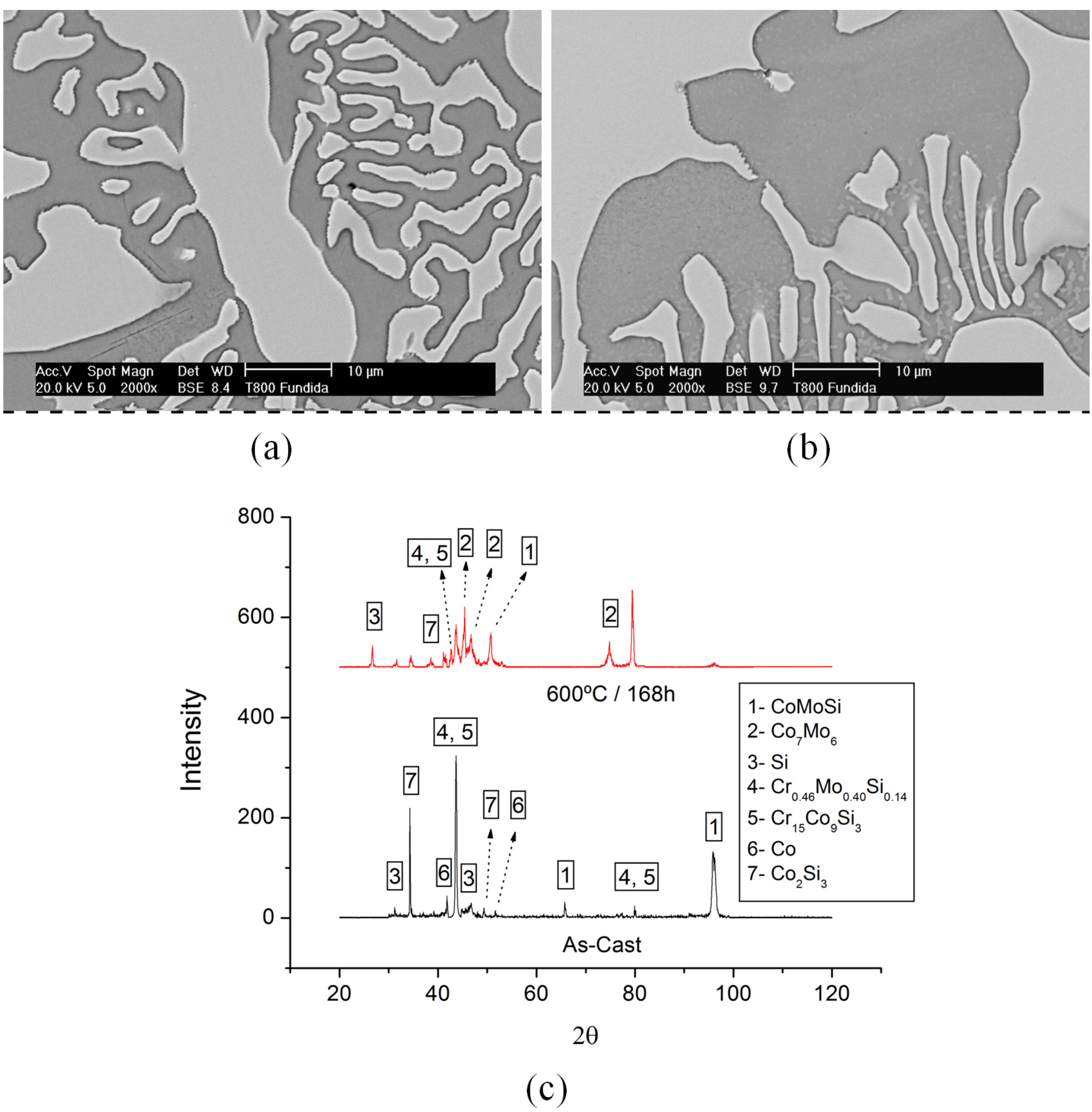


Figure 3. Microstructure of the Cast CoCrMoSi alloy (a), exposed to 600 °C for 168h (b) and new phases formed by temperature exposure (c).

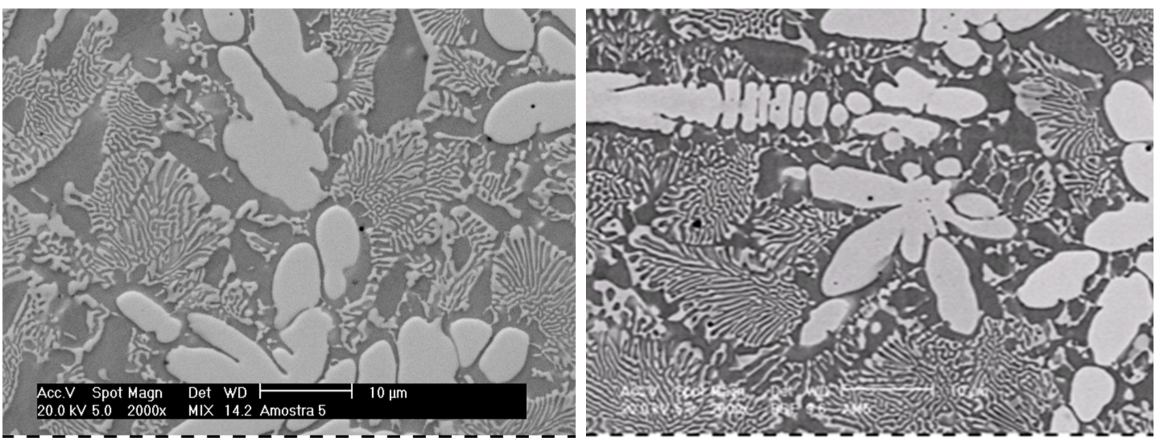
hardness[12]. However, despite the dilution with the substrate, the contribution of the structure refinement to coating hardness was more significant.

2.2. *Temperature exposure*

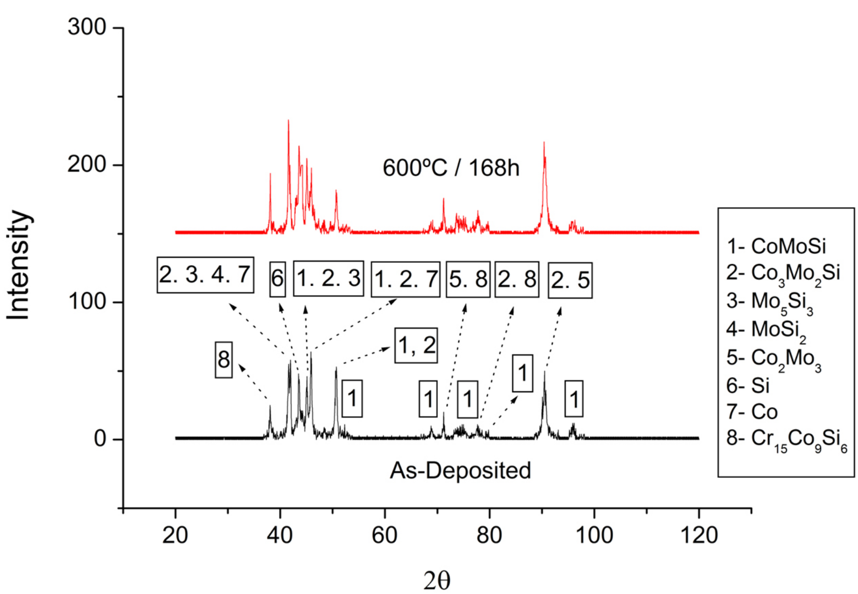
Temperature exposure induced a hardness increase regardless of the processing technique used although a more significant increase was measure on coatings (Castings Δ20HV vs coatings Δ100HV), Figure 2. It interesting to notice that, although the temperature increase tends to magnify the deleterious effects of dilution on the coating hardness, the CoCrMoSi coatings showed an increase on hardness[13]. The analysis of the microstructure revealed coarsening of the structure of the cast alloy and a fine precipitation along primary Laves phase boundaries and within the lamellar structure. Also the depleting Mo from solid solution contributed to form Co_7Mo_6, as identified by XRD after temperature exposure, Figure 3c.

In spite of the higher hardness increase and the higher cooling rate experienced by coatings under the conditions tested, a stable microstructure without coarsening and phase changes after temperature exposure was observed. Eventual changes in the volume fraction of phases may account for the measured hardness variations, Figure 4. Also, a more significant segregation occurs which can accounts for the Mo silicites identified by X-ray diffraction in the coatings.

The wear behavior of CoCrMoSi alloy has been referred to be a consequence of the volume fraction of the hard Laves phase[14], together with the similar hardness measured following the two processing techniques, one could have



(a) (b)



(c)

Figure 4. Microstructure of the Coating CoCrMoSi alloy (a), exposed to 600 °C for 168h (b) and no new phase formed after exposition (c).

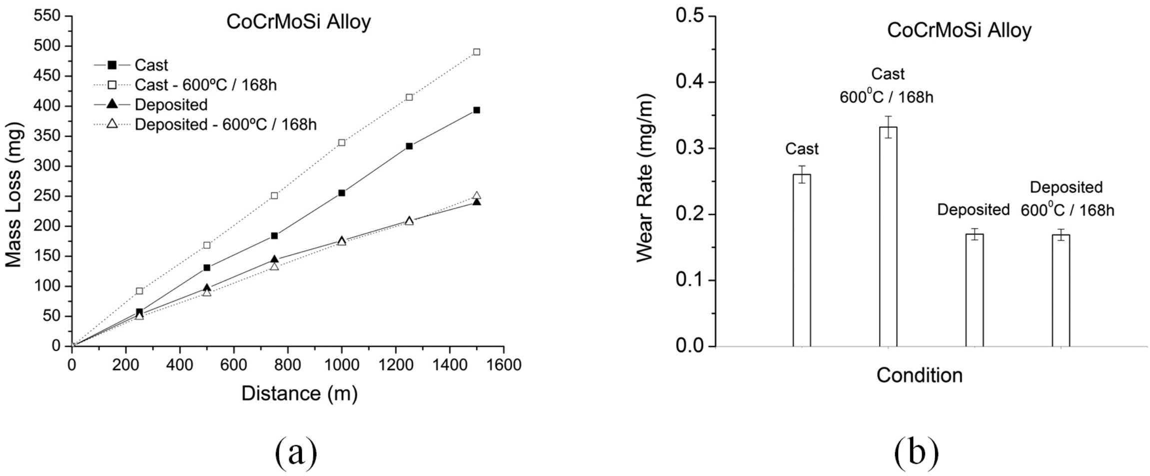


Figure 5. Pin-on-disc wear test: (a) Mass Loss to Distance and (b) Mass Loss Coefficient.

expected for the wear behavior at room temperature to be similar. Mass loss variation with the sliding distance for the CoCrMoSi alloy processed with both techniques is shown in Figure 5. The mass loss rate at room temperature of cast alloy was 0,2603 mg/m, 53% higher than the 0,1700 mg/m rate for coatings. Detailed analysis of the transverse section of pins revealed that the mass loss rate of the alloy was dictated by the wear out of the Cobalt solid solution region (intermetallic free areas) which is the softer region in the microstructure. Therefore, the coarser the structure the larger the areas of Cobalt solid solution and the less wear resistant is the structure. In contrast, the distribution of the interdendritic microstructure as well as a refined lamellar morphology formed in the coatings act as a reinforcement of these solid solution areas, the result being an enhanced wear behavior.

Temperature exposure induced an increase of 27,6% in the wear mass loss rate of cast alloy, following the poor structure stability. In agreement with the thesis that the Cobalt solid solution areas accounted for the measured wear behavior, the coarsening of the cast structure together with its depletion in Molibdenum occurred after temperature exposure, compromised even further the wear resistance of the cast alloy. An attractive behavior was exhibited by coatings in spite of the hardness variation following temperature exposure, it wear rates measured were not altered. Again the refinement and distribution of the lamellar interdendritic microstructure altered the Cobalt solid solution (intermetallic free) exposed areas, dictating the stability and the reduced wear mass loss rate for coatings.

3. Final Remarks

For the conditions evaluated in this study, regarding the influence of processing technique on microstructure and response to temperature of a CoCrMoSi alloy, the main contributions are as follows:

- The faster solidification rates of the PTA hardfacing technique account for the finer structures overlapping the eventual deleterious effects of dilution;
- The finer distribution of the Laves phases can contribute to the observed temperature structure stability and wear resistance;
- The wear behavior of CoCrMoSi alloy is dictated by the amount of Cobalt solid solution areas (intermetallic free) resulting in poor wear resistance for the cast alloy aggravated following temperature exposure.

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