MICROSTRUCTURAL STABILITY AND WEAR PERFORMANCE OF A Ni BASED ALLOY PTA COATING

Karin Graf
Universidade Federal do Paraná - R: Francisco H. dos Santos, s/No. , Centro Politécnico,CEP 81531-990 - Caixa Postal 19011
karin@demec.ufpr.br

Ana Sofia Clímaco Monteiro D'Oliveira
Universidade Federal do Paraná - R: Francisco H. dos Santos, s/No. , Centro Politécnico,CEP 81531-990 - Caixa Postal 19011
sofmat@demec.ufpr.br

Abstract. Surface engineering is important to select the most appropriate coating material and deposition process for a given working condition. Surface welding is large used to produce thick coatings on materials submitted to extremely aggressive environments like several components of an oil refinery plant. Plasma transferred arc (PTA) welding arises as a technique with an excellent reliability, producing deposits with low dilution, strong metallurgical bond and microstructure control. The Ni based alloy (Ni-Cr-Mo-W) is known by its excellent corrosion resistance and high temperature stability. The aim of this work is to relate Ni based alloy coatings deposited on two different substrates, stainless steel 304L and low-carbon steel 1020, obtained by Plasma Transferred Arc (PTA) ,to their wear behavior. Coating characterization was done using optical and scanning electronic microscopy, and Vickers microhardness profiles were done under 500g load. High temperature structure stability was evaluated by accelerated aging tests with temperatures ranging from 650ºC to 1200ºC. Results revealed that under extreme conditions significant microstructural changes occur, as carbides precipitation. The wear resistance was determined using a pin-on-disk machine. Sliding was performed between the disk and pins cut from the as deposited and aged samples. Results are discussed regarding the applications on petrochemical industry, such as valve and other sliding components.

Keywords. Ni based alloy, hardfacing, PTA, accelerated aging.

1. Introduction

Nickel and Nickel-Based alloys are recognized of their characteristics to withstand a wide variety of severe operating conditions involving corrosive environments, high temperatures, erosion or even a combination of these factors (Klarstrom, 1992). Nickel and its alloys offer a wide range of corrosion resistance, like the stainless steel. However, Nickel can accommodate larger amounts of alloying elements, chiefly Chromium, Molybdenum, and Tungsten, in solid solution than iron. Therefore, Nickel-based alloys, in general, are used in more severe environments than stainless steels, specially in situations that involve high temperature. Service performance requirements dictate not just the material selection but also the process technique to obtain coatings which best meet these service needs and which presents the best relationship cost/benefit.

According to literature, coatings obtained by plasma transferred arc (PTA) present a very good alternative to other surface welding processes, such as conventional techniques or more recent ones such as laser cladding (D'Oliveira et al, 2002). A significant advantage of PTA surfacing over traditional surface welding techniques arises from the fact that the consumable material used is in powder form. This fact enables a wide range composition for coating materials and even mixtures of different material powders. During PTA processing, the powder is usually feed into the melting pool on the substrate through the plasma arc space by a specially designed powder feeder. (Xibao et al, 1998). Among the many advantages of PTA, it can be mentioned high quality of deposited metal with low dilution, minimum losses of coating material and low distortions as a consequence of the lower heat input.

The main purpose of this work is to evaluate high temperature performance of a Ni based alloy coatings obtained by PTA known to exhibit a good wear behavior at temperatures up to 600ºC. The deposition parameters of the process were optimized in order to obtain good surface appearance coatings, free of macroscopic defects like porosity or cracks and also to obtain the lowest dilution that guarantees coating characteristics most similar to the powder ones.

As wear is strongly dependent on microstructure, in this study, after characterization of as deposited features and sliding wear behavior, coatings were submitted to accelerated aging test to evaluate microstructure stability at high temperature and, as a consequence, the expected wear behavior.

2. Experimental Procedures

In this work the Ni-based alloy (Ni-Cr-Mo-W) known as Nistelle C, commercially available product by Delloro Stellite Ltd., was PTA single layer deposited on stainless steel AISI 304 (100mm x 80mm x 7mm) and carbon steel AISI 1020 (100mm x 80mm x 7mm) plates. As-received chemical composition of coating material and substrates is presented in Tab.(1).

Table 1. Chemical composition of the as-received coating powder and substrates.

	C	Si	Mn	P	S	Cr	Ni	Fe	W	Mo	V
Ni based alloy	0,12	0,90	0,90	0,40	0,30	16,40	Balance	5,50	4,5	17,50	-
AISI 304	0,08 (max)	1,00 (max)	2,00 (max)	0,045 (max)	0,03 (max)	18,00/20,00 (max)	8,00/10,5 0	Balance	-	-	-
AISI 1020	0,18 0,23		0,30 0,60	0,04 (max)	0,050 (max)	-	-	-	-	-	-

The PTA equipment is a 300M Stellite and processing conditions for PTA deposits were as follows:

- Plasma gas flux: Ar 2,0 l/min;
- Shielding gas flux: Ar 15 l/min;
- Feeding gas flux: Ar 2,0 l/min;
- Distance torch/base material: 7 mm;
- Deposition rate: 24g/min (1,44 Kg/h)
- Welding speed: 10 cm/min.
- Main arc current: 150A

Coating characterization was done on transverse cross section of as deposited specimens. Hardness profiles were determined by Vickers microhardness under 500 g load. Specimen were ground and polished before ultrasonic cleaning. Electrolytic etching used a solution of 10% Acidum Oxalicum Cryst $(COOH)_2$, $2H_2O$ and distilled water under tension of 9V. Optical and scanning electronic microscopy were used to evaluate microstructural features. Semi-quantitative chemical analysis was done by EDS. The amount of the base material participating on the coating, dilution, (Hállen et al, 1991) was determined by quantitative metallography. Figure (1) and Eq.(1) show procedures adopted to determine dilution levels.

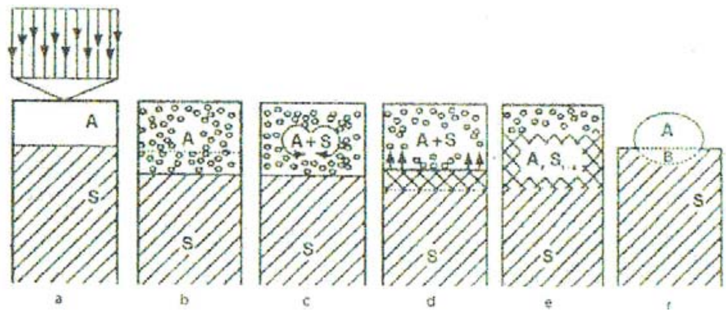


Figure 1. Schematic draw showing areas used to determine dilution.

$$Dilution = \frac{B}{A+B} \times 100 \qquad (1)$$

Sliding wear was measured using pin-on-disk tests under 500g load and a rotation of 350 rpm. Pins of 3mm diameter were cut out from the coatings by eletro-discharge, resulting on a contact pressure of 0,69MPa. Both pins flat surfaces were ground in order to guarantee parallelism between the planes. The stationary pin was rubbed against a rotating (52HRC) VC-131 quenched and tempered disc without lubrication, at room temperature. Pins mass loss curve was determined after sliding distances of 0,5; 1; 2; 4 and 8Km.

High temperature stability was evaluated by accelerated aging tests. As time and temperature are two dependent variables, related by Ahrrenius equation, temperature stability was determined submitting specimen to higher temperatures in order to simulate long time exposure at 600ºC. Specimen were first submitted to different times at 1100ºC to identify the presence of a peak aging. Coatings were then exposure to different temperatures for the time interval corresponding to the peak aging (two hours). For this procedure coatings were cut in 7,2mm slices, which were then submitted to the different temperature treatments.

3. Results and Discussion

3.1 As deposit Features

Coatings exhibited a good surface appearance, free of macroscopic defects like porosities or cracks. For the parameters used to process the samples, dilution levels were identical for both substrates reaching 18%. It is interesting to notice that this result does not follow previous trends measured on Co-based alloy coatings deposited on substrates of different chemical compositions (Santos et al, 2003). Dilution values are known to be directly affected by processing parameters, like current intensity and also by the chemical composition of the substrate (D´Oliveira et al, 2002;Deuis et al, 1998; Davis, 1993).

As deposited microhardness profiles for both substrates used are shown on Fig. (2). Coatings exhibited a constant hardness through thickness (250HV) for the two different substrates. Hardness profiles are coherent with the identical dilution levels measured for both substrates.

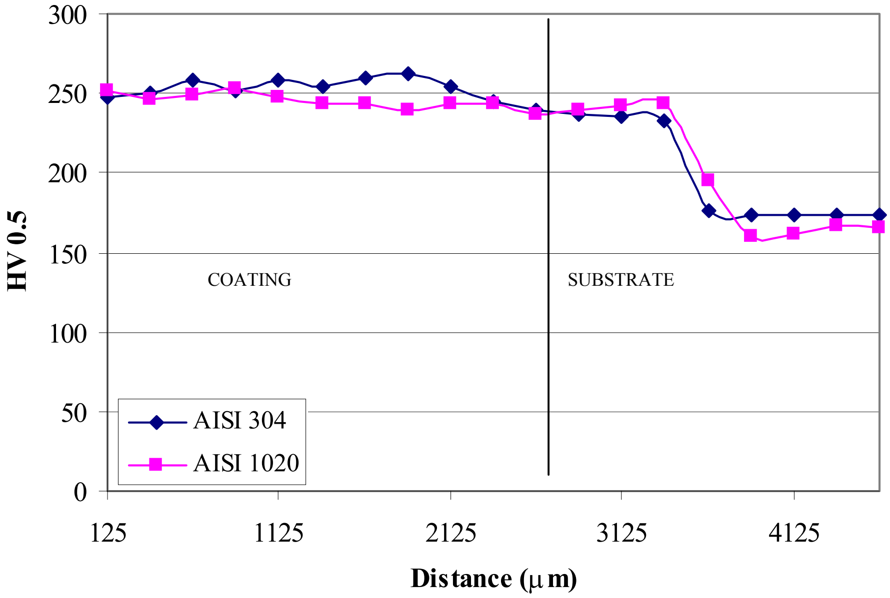
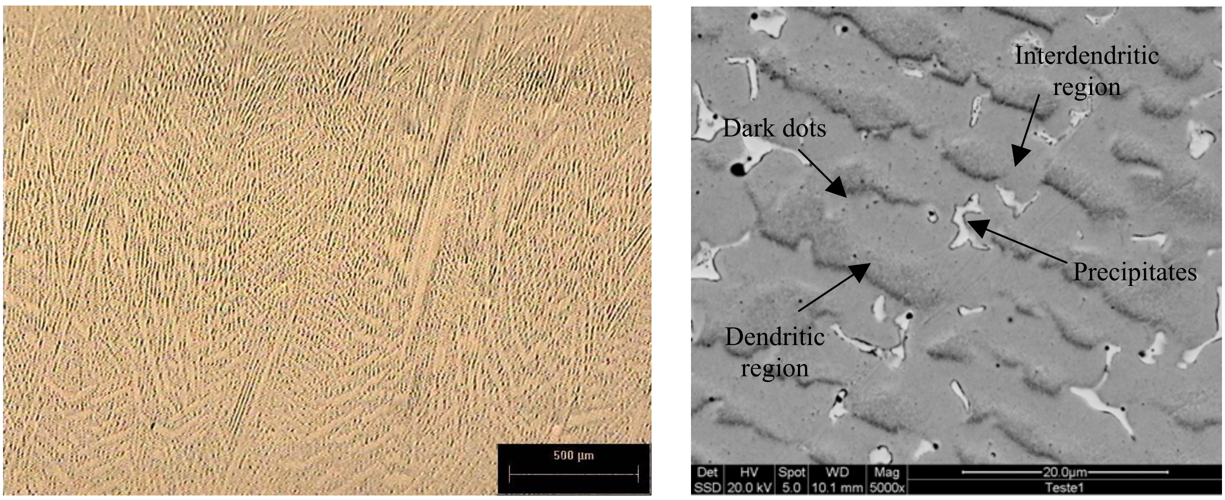


Figure 2. Microhardness profile measured on the cross-section of the as-deposited specimens for the two different substrates.

Figure (3) shows as-deposited microstructures as observed under optical and scanning electronic microscopy for both substrates: (a) low carbon and (b) stainless steel. Microstructural observation reveals a typical solidification structure for coatings deposited on both substrates. On Fig.(3b), it can be noticed interdendritic regions, richer on alloying elements like Mo and W than the matrix. In this region, the lighter areas are identified as carbides (Cr, W, Fe). Precipitates in dendritic regions, identified by dark dots, are also observed, and reveal to be rich on C, Cr, W and Fe.



(a) (b)

Figure 3. .(a) Typical microstructure of coatings deposited on carbon steel (b) Typical microstructure of coatings deposited on stainless steel.

As mentioned, wear tests run at 350rpm and each test was set on a new track in order to maintain initial test conditions constant. Therefore the tangential sliding speed changed in each test because of differences on the track radius. Plotting wear results as mass loss versus tangential sliding speed, for different sliding distances tested, it is clear the determining effect of the tangential sliding speed, increasing the mass loss as it decreases. Also, as sliding distance increases wear is more significant. It is important to bear in mind that in the latter mass loss is also influenced by the number of times the pin was through the worn track on the disk.

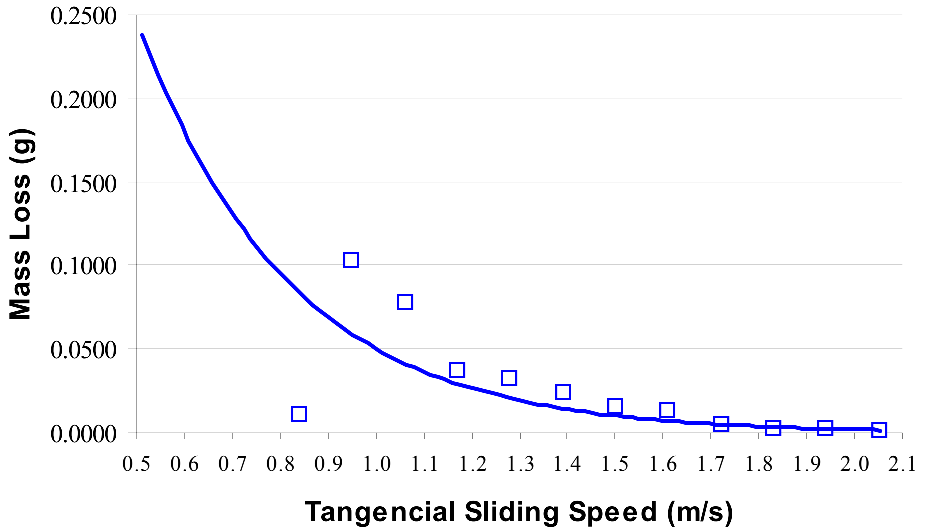


Figure 4. Material loss versus tangential sliding speed obtained from pin-on-disc tests

3.2 Accelerated aging

The properties of Ni-based superalloys are known to degrade when exposed to elevated temperatures, like those on petrochemical plants. It is very important to understand the degradation mechanisms such as microstructure coarsening and precipitation, in order to increase service life, through enhanced properties. The Ni alloy used in this study is identified as being corrosion and wear resistant at temperatures up to 600ºC. However, there is no information on long time exposures used to simulate end of life microstructures, so the response of the material to service conditions could be estimated with greater confidence. Coating response after exposure at 1100ºC, for different times, Fig.(5), allow to confirm the presence of a microstructural degradation state, with a peak aging after two hours.

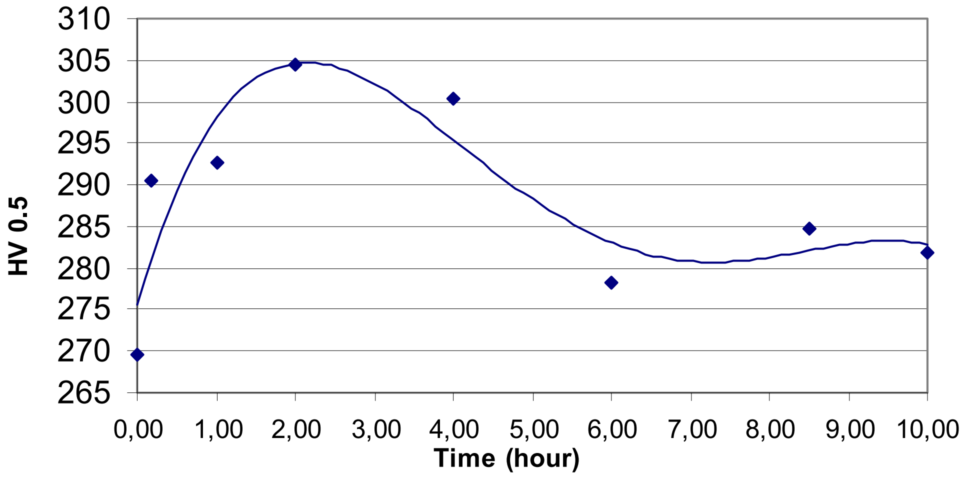


Figure 5. Microhardness measured on the cross-section of as-deposited coatings aged at 1100ºC for different intervals.

The simulation of end-of-life and intermediate microstructures were obtained submitting coated specimens to different temperatures, Fig.(6), for two hours soaking period. A peak hardness was also identified in theses tests, occuring at 1000ºC for both substrate materials.

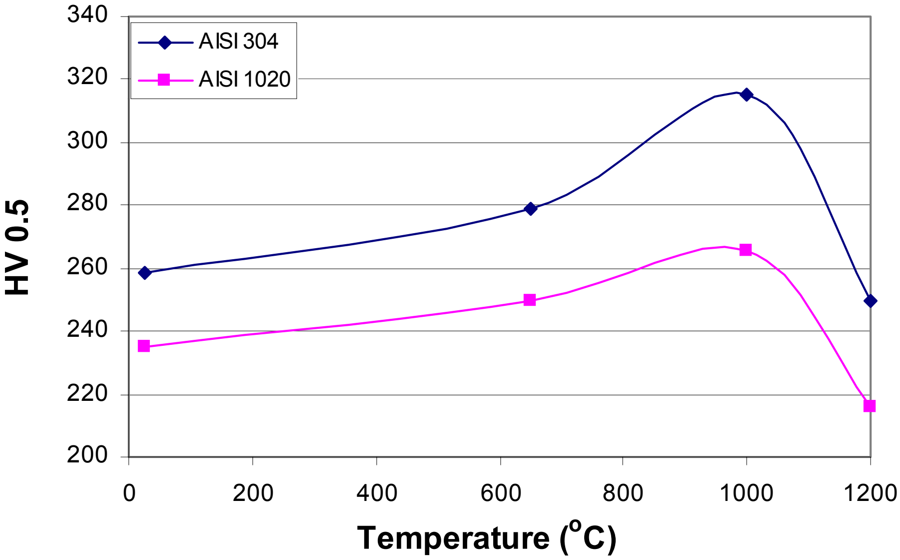


Figure 6. Microhardness measured on specimen aged for 2 h at 650ºC, 1000ºC and 1200ºC for both substrates.

Accelerated aging tests showed that the two sets of coatings exhibited a distinct behavior, with the set deposited on carbon steel presenting a lower peak hardness, but similar hardness decrease after the peak. This can be attributed to a coarser distribution of precipitates, Fig.(7), found on these coatings and to the alloying elements which diffused from the stainless steel substrate. It can be observed, the precipitate morfology similarity between coatings deposited on both substrates. EDS analyses showed that precipitates are richer on Mo and W than the matrix .

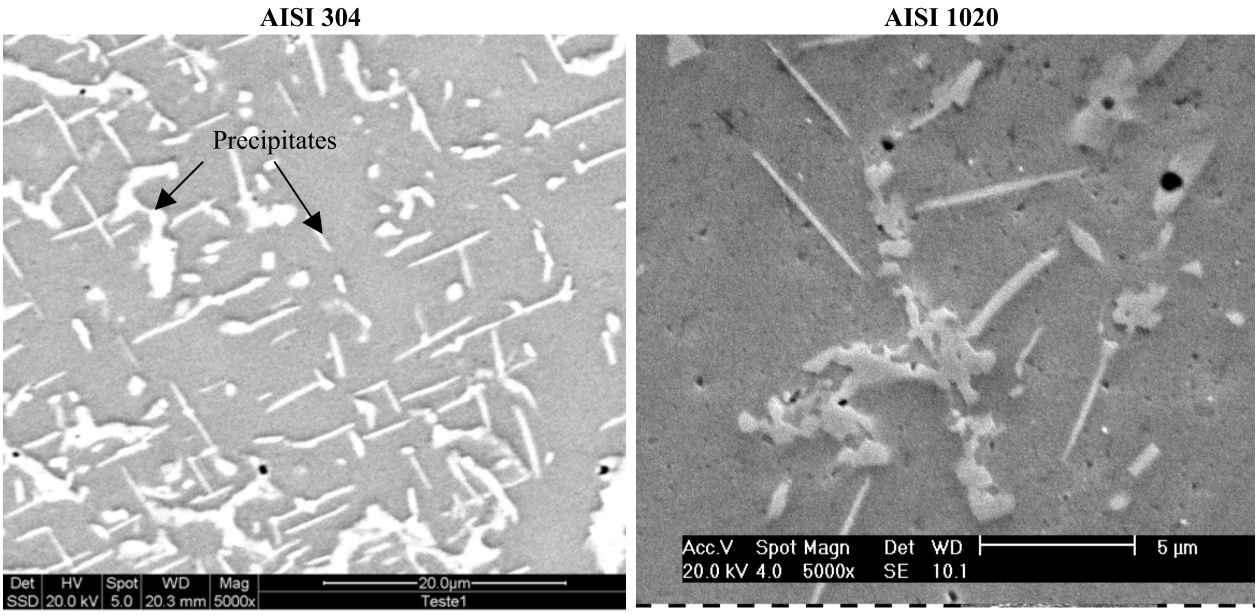


Figure 7. Microstructctures after aging for 2 h at 1000ºC for both substrates, magnified 5000x.

Further temperature exposure, up tp 1200°C, reveals significant microstructure degradation as coarsening occurs on the coatings strutures, Fig.(8).

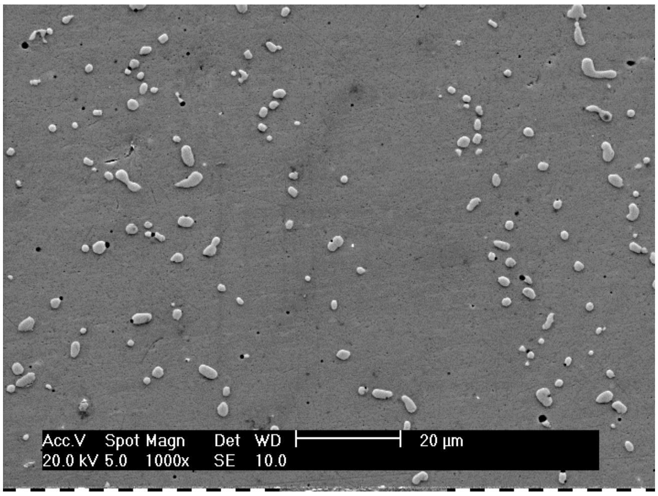


Figure 8. Microstructcture after aging for 2 h at 1200ºC, magnified 1000x.

According to Archard wear equation, Eq.(2), one can predict surface wear performance as microstructural damages are accumulated.

$$Q = K \times \frac{W}{H} \qquad (2)$$

where:
Q – volume wear permit
W – applied load
H – surface hardness
K – wear coefficient

Thus, for coatings evaluated in this work, one should expect a variation on the wear surface behavior on long life applications. As deterioration mechanisms undergoing in the material are understood, a significant and rapid decrease on expected wear resistance of components can be predict, and consequently, the end of life of the component (Hutchings, 1992). Maintenance operations can then have an optimized schedule.

4. Conclusions

- PTA process produces coatings with excellent characteristics, very similar to the powder ones;
- It is expected a deterioration of coatings after exposure for long times service at temperatures about 600ºC;
- Precipitation and coarsening are responsible for microstructure changes and, as a consequence, coating degradation.

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6. References

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