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NiCrSiBC coatings: Effect of dilution on microstructure and high temperature tribological behavior

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ABSTRACT

Protective coatings for high temperature applications have to exhibit good oxidation resistance and microstructure stability. The effective protection of parts with hardfacing techniques depends on the impact of the substrate on the deposited alloy, typically assessed by dilution. This investigation aims to evaluate the effect of dilution on microstructure and high temperature wear of NiCrSiBC coatings processed by plasma transferred arc on a stainless steel substrate. The microstructure was characterized by EDX, XRD, SEM and hardness. High temperature wear behavior was assessed by ball on disc tests with an alumina sphere sliding against the NiCrSiBC coating. Results showed that an increase on dilution suppressed the formation of Cr_5B_3 borides reducing hardness. Wear behavior was ruled by the combined effect of dilution and test temperature. The effect of dilution is two fold, altering the microstructure and oxidation resistance. At low wear temperatures, the microstructure rules the performance and harder coatings exhibited a better resistance. At high temperature, wear depends on the tribolayer formed. The low oxidation resistant Fe rich coatings form more debris during sliding. The more compact tribolayer formed under these conditions covers most of the area of the wear track and accounts for the enhanced performance of high dilution coatings.

1. Introduction

High temperature wear is one of the main factors limiting service life of components in a large number of applications such: power generation, materials processing plants and turbine engines. The demands associated with wear became more severe under high temperature, the loss of mechanical strength and hardness of sliding materials associated with faster oxidation kinetics, require a careful evaluation of each tribosystem [1–3].

A respond to this challenge is to protect components with superior oxidation resistance and stable materials that offer resistance against high temperature wear [4–8]. Among the candidates, boride-containing Ni alloys (the NiCrSiBC alloy system) exhibit a good balance between wear and corrosion resistance in chemically aggressive environments and high temperature working conditions [9–14]. These alloys have been deposited by thermal spray techniques but dense metallurgical coatings can be obtained by arc and laser processes [15].

Although enhanced performance of coated components has been reported, hardfacing techniques impact on the chemical composition of coatings and as a consequence on their performance. The metallurgical bond between coating and substrate causes dilution, that is, the melt pool receives contributions from the substrate and deposited alloy. For each substrate the impact of dilution has to be address to determine the impact on the performance of coatings. The higher the metallurgical complexity of the alloy being deposited the higher the impact of dilution, as it is the case of NiCrSiBC alloys. Relevant contributions on the assessment of the influence of dilution on NiCrSiBC coatings are summarized in Table 1. Literature reports losses in hardness, wear and oxidation resistance at room temperature due to dilution, their magnitude depending on the deposition technique and the chemical composition of the substrate. The range of reported changes in the behavior of the alloy is associated with increasing of Fe content in coatings.

The effect of dilution on the room temperature performance and characteristics of coatings has been widely addressed. However, there are few studies on the impact of dilution on the high temperature wear behavior of coatings. This study aims to

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Table 1
Summary of the main contributions from the literature on the assessment of the impact of dilution of Colmonoy coatings.

Reference	Processing conditions	Observations
I. Hemmati et al. [16]	Colmonoy-69® powder was processed by Laser cladding on low-carbon steel	When Fe content increases the size and volume fraction of Cr borides decreases. Moreover, not only coating, but also chemical composition of Cr borides were changed.
V. Ramasubbu et al. [17]	Colmonoy-6® wire was processed by GTAW on AISI 316L	The volume fraction of Cr carbides does not changed significantly with Fe content increases, hence Cr borides are more sensible to dilution variations than carbides.
C. R. Das et al. [18]	Colmonoy-6® wire was processed by GTAW on AISI 316L	Dilution significantlly deteriorates the wear resistence of coatings at room temperature due to the presence of lower volume fraction of hardness imparting Cr borides.
P. R. Reinaldo et al. [19]	Colmonoy-6® wire was processed by PTA on AISI 1020 and AISI304	Increasing dilution compromises the wear performance due to the dissolution of reinforcing particles
F. Fernandes et al. [20]	Colmonoy-215® powder was processed by PTA on gray cast iron	The increase of dilution proves to be detrimental, since the oxidation resistance of coatings is reduced due to a further increase of iron content in coating processed with high arc current.
S. Chandran et al. [21]	Colmonoy-6® wire was processed by GTAW on AISI 316L	Higher corrosion rate occurs on coatings with higher dilution and lower volumetric fraction of borides. Borides and carbides are cathodic when compared to the Ni matrix.

Table 2
Nominal chemical composition of NiCrSiBC powder and AISI 304 stainless steel substrate (wt%).

	C	Si	Mn	P	S	Cr	B	Ni	Fe
NiCrSiBC	0.7	2-4.5	–	–	–	14–15	3.1–3.5	Bal.	4
AISI 304	0.08–0.1	0.75	2	0.04	0.03	18-20	–	8–10	Bal.

Obs: Nominal chemical composition as informed by suppliers.

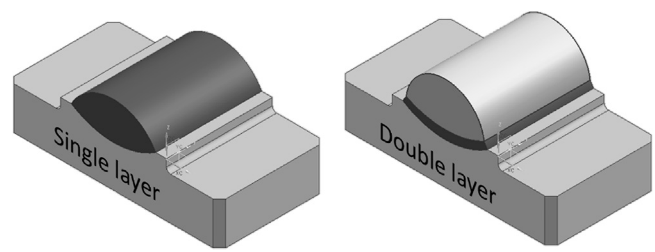

Fig. 1. Schematic representation of single and double layer coatings.

Table 3
PTA deposition parameter.

Torch stand off	Powder feed rate	Plasma gas flow	Carrier gas flow	Shield gas flow	Travel speed	Deposition current
(mm)	(g min^{-1})	(L min^{-1})	(L min^{-1})	(L min^{-1})	(mm min^{-1})	(A)
10	17	2	0.8	15	60	180

contribute to this discussion with the evaluation of the effect of dilution on high temperature wear behavior of NiCrSiBC coatings processed by plasma transferred arc (PTA) on stainless steel AISI 304 substrate.

2. Experimental details

2.1. Coatings deposition

The atomized NiCrSiBC alloy (Colmonoy 6®) grain size in the range 50–50 μm was processed by plasma transferred arc (PTA) on AISI 304 stainless steel substrate ($60 \times 100 \times 12.7$ mm^3). The Ni alloy and substrate chemical compositions are presented in Table 2. Single and double layer coatings (Fig. 1) were deposited with the processing parameters shown in Table 3.

2.2. Coatings characterization

The amount of dilution was calculated based on the iron content in the coating, powder and substrate according to Eq. (1). Iron is a representative element to assess dilution, the increase in Fe content shifts the original alloy system causing changes in NiCrSiBC coating microstructure and properties [16,17].

$$\text{Dilution}(\%) = \frac{Fe_{coating} - Fe_{powder}}{Fe_{substrate} - Fe_{powder}} \quad (1)$$

Semi-quantitative chemical composition analysis were carried out by Energy Dispersive X-ray Fluorescence on the top surface of coatings after machining and polishing. X-ray diffraction analysis using Cu Kα radiation (λ=0.15406) in continuous scan mode with speed of 1° min^{-1} and sampling of 0.02° was also carried out on the top surface of coatings

Samples for Scanning Electron Microscopy (SEM) analysis and hardness measurements were prepared by standard metallographic procedures with grinding on silicon carbide papers and polishing down to alumina 1 μm. Energy Dispersive Spectroscopy (EDS) analysis under 20 kV was used to assess chemical composition spot analysis and mapping and 5 kV to tribolayer. Vickers hardness was measured under a load of 10 N.

2.3. Sliding wear tests

Sliding wear tests were performed on a ball on disk high temperature tribometer following ASTM G99 recommendations. A counter body of an inert material (as opposed to a counter body of the same material as the coating) was selected to mitigate its impact on the characterization of the effect of chemical composition of coatings on the wear behavior. The set-up used to evaluate the effect of dilution on wear mechanism consists of an alumina ball (Ø 6 mm) that slides against a disc of the NiCrSiBC

Table 4 summarizes the wear test conditions. Previous work and preliminary tests contributed to choose the test parameters. A three step procedure was carried out to: