

Corrosion behavior of Cr_3C_2 –NiCr vacuum plasma sprayed coatings

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Abstract

The objective of the present work is to determine the influence of the heat treatment on the corrosion resistance of a Cr_3C_2 –NiCr coating of 450 μm thickness, deposited by a vacuum plasma spray process (VPS) on a steel substrate. The post-heat treatment of the as-deposited coating was carried out in Ar at 400 °C and 800 °C, respectively. The coatings were characterized by means of an electron probe micro analyzer (EPMA) with wavelength dispersive X-ray spectrometers (WDS). It was found that no significant changes were produced as a consequence of the heat treatment carried out at 400 °C. Therefore, the corrosion experiments were conducted for the substrate, the as-deposited coating and the post-heat treated coating at 800 °C. Potentiodynamic polarization showed that the annealed coating at 800 °C has a better corrosion resistance than the as-deposited coating. The corrosion current density (I_{corr}) of this coating was approximately 3 and 4 times smaller than that corresponding to the as-deposited coating and steel substrate, respectively. This significant improvement of the corrosion behavior of the post-heat treated coating is mainly due to both the microstructural changes that take place in the coating and the diffusion of Ni into Fe at the coating–substrate interface, which ensures the presence of a metallurgical bond.

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1. Introduction

The increasing concern that has arisen in the last decade in relation to the effects of the traditional coating industry, such as chromium plating, on health, safety and environment, has led to the development of new methods of deposition and coatings, as a plausible alternative. In this regard, thermal spray processing has been one of the leading candidates since such a process could produce competitive coatings from the wear and corrosion resistance point of view [1]. As quoted in the literature, [2] carbides, oxides and cermets, in particular, Ni–Cr-based coatings containing CrC particle dispersions (hard phase), are very attractive due to their excellent oxidation resistance. Thus, such materials are good choices for various applications such as the hardfacing/repairing of turbine blades and shafts. Different

thermal spray deposition techniques have been used to deposit Ni–Cr-based coatings, including high velocity oxy-fuel thermal spraying (HVOF) [3–6], high velocity air fuel thermal spraying (HVOF) [7], atmospheric plasma spray (APS), controlled atmosphere plasma spray (CAPS) [2,7,8] and D-Gun [8]. Thus, the determination of the structure, high high-temperature oxidation resistance, wear-erosion and wear-sliding behavior both at room and high temperature of such coatings has become an important research subject in the past few years. Therefore, the use of thermal spray coatings for the replacement of traditional hard chromium deposits employed in different applications, including pump shafts, guide rollers, cams, extrusion pump screws, roller bearing seats and piston shafts able to perform in aqueous corrosive media, constitutes a very important technological issue. Particularly, the understanding of their degradation mechanisms due to corrosion and corrosion-wear in aqueous environments is of utmost importance in order to extend their service life. Guilemany et al. [9], in a recent investigation, have studied the

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corrosion properties of a Cr_3C_2 -NiCr HVOF thermal spray coating, in three corrosive media (3.4% NaCl, 0.5% H_2SO_4 and alkaline solutions). These authors have indicated that the absence of discontinuities such as pores and cracks plays a fundamental role in preserving the integrity of the coating–substrate system and improves its corrosion resistance, since such defects are the main path followed by the electrolyte to reach the steel substrate. Thus, if the electrolyte reaches a less noble substrate, a galvanic pair is formed which gives rise to substrate corrosion damage, coating depletion and loss of surface properties. Hence, any post post-heat treatment of the thermal spray coatings able to impede or to slow down the aqueous reactive penetration and its contact with the substrate will improve considerably its corrosion resistance. Only recently [10], the potentiodynamic polarization measurement results carried out in 1 N H_2SO_4 for plasma sprayed coatings such as Al_2O_3 , $\text{Al}_2\text{O}_3 + \text{TiO}_2$, $\text{Cr}_2\text{C}_3 + \text{NiCr}$, NiAl, NiCrAl, ZrO_2 and MgZrO_3 coated on a stainless steel substrate have been compared, in order to establish their corrosion performance in such an environment. It has been found that the corrosion resistance of cermets and metallic coatings is lower than that of ceramic coatings.

Thus, given the limited information available in relation to the aqueous corrosion behavior of plasma sprayed Ni–Cr-based coatings, the present study has been conducted with the aim of determining the corrosion resistance of a CrNi9.5 C plasma sprayed coating deposited by VPS on a steel substrate, both in the as-deposited and post-heat treated condition, by means of potentiodynamic polarization tests in a 3.5 wt.% NaCl.

2. Experimental methods

Square samples of 2 cm^2 were machined from a 4 mm thick AISI 1010 steel sheet and subsequently degreased with acetone. Prior to the deposition process, the samples were grid blasted with Al_2O_3 (grade 24) in order to obtain an average surface roughness of $5\ \mu\text{m}$. A 1376T PRAXAIR commercial powder of CrNi9.5 C was sprayed employing a VPS system (Medicoat AG, Switzerland) onto the plain low carbon steel coupons to obtain coatings of approximately $450\ \mu\text{m}$ in thickness according to the operational parameters shown in Table 1. The XRD microstructural characterization of the coatings has been reported elsewhere [11], and has pointed out the presence of Cr_3C_2 and Cr_7C_3 in a matrix of NiCr. The presence of Cr_7C_3 is due to the partial decomposition of the initial Cr_3C_2 . Also, Cr_2O_3 was detected indicating that oxidation of both molten particles and possibly some carbide particles occurred to a small extent during the spraying process, as a consequence to the

Table 1

Plasma spray parameters used in this study

Spraying parameters	Value
Dynamic pressure (mbar)	60
Voltage (V)	53.6
Argon flow rate (l/min)	48
Current (A)	800
Stand-off distance (mm)	375

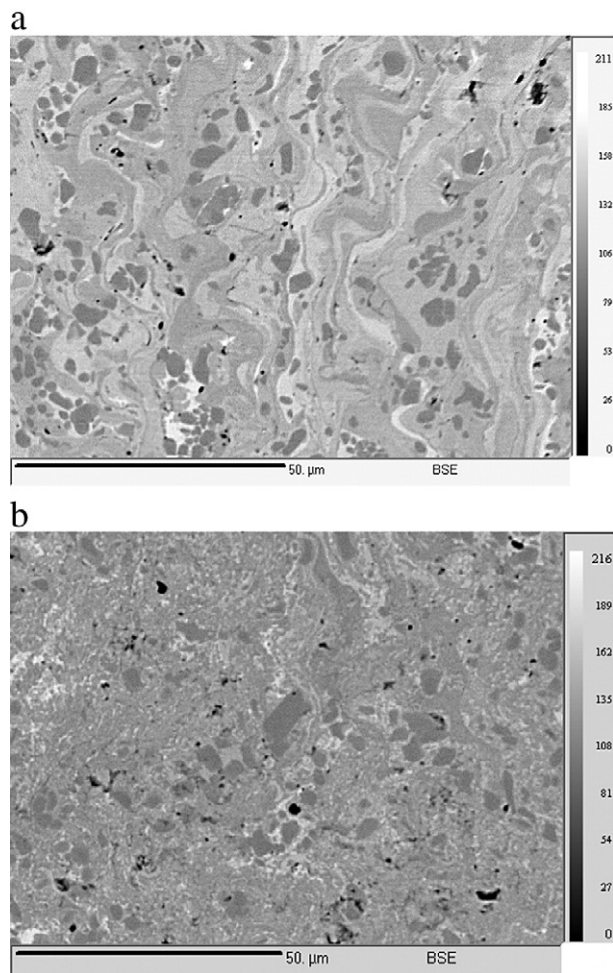


Fig. 1. Microscopic images (back-scattered electrons) of the Cr_3C_2 -NiCr coating after post-heat treatment at: (a) $400\ ^\circ\text{C}$ and (b) $800\ ^\circ\text{C}$.

reaction of Cr with oxygen, which comes from the reactor atmosphere.

Part of the samples were subsequently annealed at $400\ ^\circ\text{C}$ and $800\ ^\circ\text{C}$, in an Ar atmosphere for 2 h, followed by furnace cooling to room temperature. Coated samples prior and after heat treatment were prepared metallographically down to $9\ \mu\text{m}$ diamond paste in order to evaluate the hardness of the coating, employing a microhardness tester (Struers), applying a load of 300 g during 15 s.

The porosity of the coating was determined by means of electrochemical measurements following the method proposed by Urgen et al. [12]. Both, the as-deposited and post-heat treated coatings were characterized with a Cameca SX100 electron probe micro analyzer (EPMA). All samples were embedded into an epoxy resin, polished (up to $1/4\ \mu\text{m}$) and carbon coated by means of a Bal-Tec SCD005 sputter coater. Back scattered electron (BSE) images were obtained at 20 kV, 10 nA. Low and high magnification images were taken in various parts of the samples in order to have a representative picture. Cr, Ni, and Fe X-ray mappings and profiles were carried out at 20 kV and 40 nA. When both $\text{K}\alpha$ and $\text{L}\alpha$ X-ray mappings were conducted, the conditions were 20 kV and 200 nA.

The electrochemical study was carried out using the coated samples prior and after heat treatment, which were prepared

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