Effect of substrate temperature on the resistance to wear for Nitec coatings deposited via thermal flame-spraying technique

Efecto de la temperatura del sustrato sobre la resistencia al desgaste de recubrimientos de Nitec depositados utilizando la técnica de proyección térmica con llama

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Abstract

Results for the deposition of nickel-based coatings on iron substrates using the thermal flame-spraying technique, with surface preparation by sand blasting, are presented. Basically, we studied the influence of the temperature of the substrate on the structural, morphological, and wear resistance properties. The coatings were structurally characterized via X-ray diffraction (XRD), and the surface morphology was characterized through scanning electron microscopy (SEM) and confocal laser microscopy (MLC). The chemical composition was determined by means of X-ray fluorescence (XRF), and wear was evaluated by testing three-body abrasive wear, ball-on-disk and scratch tester. Through XRD results, it was established that the coatings are polycrystalline and have a body-centered cubic (BCC) crystal structure at all deposition temperatures. SEM analysis determined that the surfaces of the films decrease their porosity as the deposit temperature increases, and wear tests showed that the coatings are more resistant to this test than is the substrate.

Keywords

Flame thermal spraying, wear, abrasion, sand blasting, deposition temperature.

Resumen

En este trabajo se presentan los resultados obtenidos en el depósito de recubrimientos a base de níquel sobre sustratos de hierro, con preparación de superficie mediante granallado por arena, utilizando la técnica de proyección térmica por llama. Básicamente, se estudió la influencia que tiene la temperatura de depósito del sustrato sobre las propiedades estructurales, morfológicas y en la resistencia al desgaste. Los recubrimientos fueron caracterizados estructuralmente mediante difracción de rayos X (DRX); la morfología de la superficie se caracterizó mediante microscopía electrónica de barrido (MEB) y microscopia laser confocal (MLC). La composición química se determinó mediante fluorescencia de rayos X (FRX) y la respuesta al desgaste se evaluó mediante pruebas de desgaste abrasivo a tres cuerpos, bola sobre disco y rayado. Los resultados de DRX permitieron establecer que los recubrimientos son policristalinos y tienen una estructura cristalográfica cubica centrada en el cuerpo (BCC) para todas las temperaturas de depósito; el análisis de MEB determino que las superficies de las películas disminuyen su porosidad a medida que la temperatura de depósito aumenta y las pruebas de desgaste mostraron que los recubrimientos son más resistentes a ésta prueba que el sustrato.

Palabras clave

Proyección térmica por llama, desgaste, abrasión, granallado, temperatura de depósito.

1. Introduction

The materials used for equipment in industries such as shipbuilding must have considerably high wear resistance, due to adverse environmental conditions where they perform their function. When these devices have operated for a period of time, they show signs of deterioration, particularly on their surface, which affects their functionality. To prevent this problem, the surface of the components or devices of the equipment are protected with alloy coatings such as (Ni + 5% Fe, B, Si), commercially known as Nitec 10224 [1], which exhibits a low wear rate and is resistant to corrosion. These coatings are made via thermal spraying, a technique that has proved to be efficient and inexpensive for producing coatings with good adhesion to the work surface [2]. Additionally, the coatings produced through this technique are characterized by having a morphology with a lamellar structure, a high density layer, the presence of pores, and good resistance to wear [3]. In addition, these coatings have improved creep, resistance fatigue and wear resistance, which makes them interesting for application in power plant turbines, aircraft engines, and rollers in the paper industry, and many other devices that exhibit wear or damage at extreme high temperatures [4].

Figure 1 shows a diagram of the evolution of the process of thermal flame-spraying. In part (A) an initial powder coating that is manually added to a jet of high pressure air is shown. The development of the method is done by applying thermal fusion (B), and finally air pressure and melt temperature are combined, as shown in (C). The development of the deposition process has resulted in greater adhesion, thus improving the mechanical and electrochemical properties such as wear resistance and resistance to corrosion of the substrate-coating assembly [5].

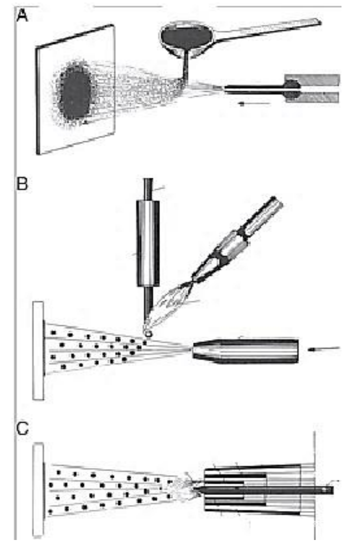

Figure 1. Evolution of the thermal spray from (A) to Siegmann Stephan, B-process of air pressure and thermal fusion and integration c- steps A and B. [6].

As a background to coatings made with thermal projection, nickel-based alloy on 1045 steel and Ni-Cr-Si-B on bronze in an argon atmosphere are important, with excellent results in resistance to corrosion and wear [1],[7],[8]. In this paper, the results of the study of the influence of the substrate temperature (gray cast iron) on the wear resistance of Nitec 10224 coatings [9], deposited via the thermal flame-spraying technique, are presented.

Experimental details

The deposition of nickel-based (Nitec) coatings was performed using the thermal flame-spraying technique at high temperatures employing a Superjet Eutalloy [9] system [10]. Coatings were deposited with oxygen and acetylene at pressures of 37 and 9 psi, respectively, at a distance of 1 m on gray cast iron substrates, varying the temperature between 573 and 773 K in steps of one hundred degrees. To monitor the temperature of the substrate, a digital thermometer with a K-type thermocouple with a range of 223 to 1473 K was used.

The chemical composition of the substrate was determined via X-ray fluorescence. The results are shown in Table 1.

Table 1. Results of the X-ray fluorescence of the substrate.

E	Fe	C	Si	Mn	Cr	S	Cu	P	Ni	Sn	Mo
%	92,71	3,49	2,66	0,38	0,22	0,19	0,12	0,09	0,06	0,05	0,03

The morphology of the coatings was determined using a QUANTA 200 scanning electron microscope operating at 30 kV. The images were taken with secondary and backscattered electrons. The patterns of X-ray diffraction (XRD) were determined using an X-pert Pro Panalytical computer, with k line of copper (1,540998Å), working at 45 kV and 40 mA. The sweep rate was 20 to 120°, in continuous mode with step size 0.02°.

The scuffing test was performed according to the ASTM G65-04 2013 standard. DSRW wear assays were made according the G-65 paragraph B standard with the following procedure: First the samples were cleaned with alcohol, and then they were dried with hot air; the initial mass of the sample was measured with 4-digit precision, and five measurements were taken for each specimen and the average was calculated; the sand used for the assay was kept in a room with an electric heater to extract moisture. Post-test, the samples were reweighed, in order to evaluate the average of the mass removed. Pin-on-disk tests were performed with a CERT micro tribometer with a pellet-shaped indenter, which is steel reinforced to 65RC hardness, with a rotating turret, where the specimen is mounted and the rotation speed (rpm) [11] is programmed. This test is an abrasion test, basically for two bodies. The test had a duration of 30 minutes with load of 400g.

The adhesion-cohesion test was measured using the scratch test [12]. using an Xpress equipment CSM Revetest scratch tester, with a Rockwell C diamond indenter. The scratch tests were made at 5, 10, 15 and 25N of pressure, a velocity of 4mm / min, and 2 mm in total creep.

The chemical composition of the specimens and the coating was determined with a Philips brand MagiXPro fluorescence spectrometer and a PW-2440 computer with a rhodium tube. This equipment has a sensitivity of 200 ppm (0.02%) for the detection of heavy metals. The roughness values Ra and RSA were obtained from measurements made with a Zeiss LSM 700 Power laser confocal microscope, maximum reference resolution of 250 nm, providing images with a maximum magnification of 20X.

2. Results and discussion

Table 2 shows the results for the chemical composition of the coating, which show a high content of Ni and a chemical balance of Si and Fe, which are the main components of Nitec powder [9].

Table 2. Results of X-Ray fluorescence analysis of the coatings deposited on the substrate.

Element	Ni	Si	Fe	Na	Al	Cl	S	K	Cr
%	95,88	1,99	0,98	0,58	0,42	0,09	0,07	0,06	0,04

Figure 2 shows the pattern of X-ray diffraction (XRD) of the Nitec coatings, varying the substrate temperature. XRD patterns do not show the detection of large differentials among the crystallographic structure of the Nitec coatings, indicating that the substrate temperature does not affect the crystallographic structure of Nitec. The XRD pattern corresponds to a polycrystalline material with highlight planes belonging to Ni, with a BCC crystal structure with lattice parameters of 3.5238 Å. Similar results for the behavior of the crystal structure according to the substrate temperature have been reported in the literature: Siamak Pilban Jahromi and collaborators [13] and Saw Kim and collaborators [14]. Furthermore, using the Williamson-Hall equation, the crystallite sizes were determined: 24.60 (T = 573K), 23.45 (T = 673 K) and 24.18nm (T = 773 K), and also the micro tensions, obtaining percentages of 0.003 in all coatings. It is important to note that because of the average thickness of the coatings (~ 300 microns), planes of the substrate do not appear in the XRD pattern.

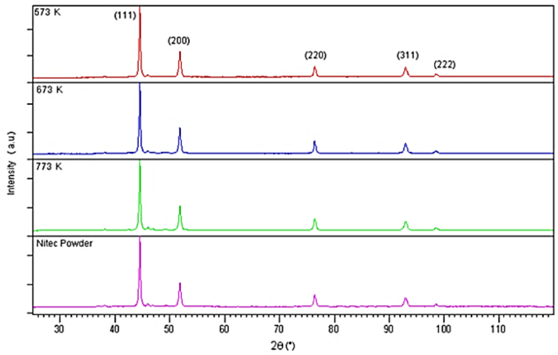

Figure 2. Patterns of X-ray diffraction for coatings deposited at different temperatures.

Figure 3 shows an SEM micrograph with a magnification of 1000x, where the microstructure of the Nitec powder can be observed. Basically, the powder is made up of spheroidal particles.

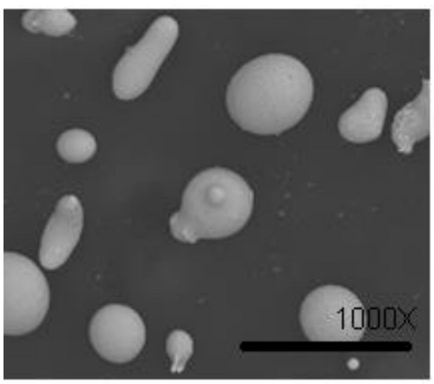

Figure 3. Microstructure of Nitec powders.

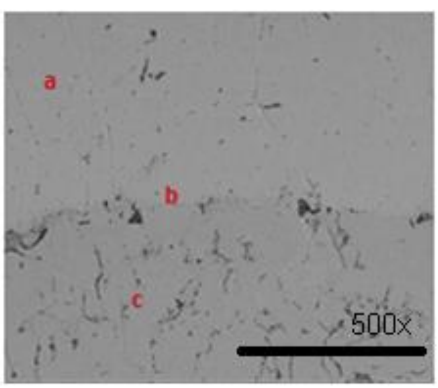

Figure 4. Cross section of the substrate, with Nitec coating deposited at 573 K.

Figure 4 shows an SEM micrograph of the cross section of the coating deposited on the substrate. In the micrograph, three distinct areas can be observed: area I- is formed by Nitec powder particles superimposed on one another and molted homogeneously, with the presence of pores [15]; II- area b is the coating-substrate interface, where Nitec material adheres to the substrate surface, most likely through the action of mechanical forces, and III- is the cast iron substrate. In the latter area, Nitec diffusion can be observed on the substrate, due to the energy acquired by the particles of the material to be projected onto its surface.

Figure 5 show the surface morphology of the Nitec coatings deposited on cast-iron substrates at temperatures of a)573, b) 673, and c)773 K, respectively. Through the program ImageJ -Test, percentages of porosity in the coatings were determined. Obtained outcomes allowed establishing that the percentage of porosity decreased as a function of increasing substrate temperature, which was 14.82% in coatings deposited at a substrate temperature of 573 K, decreased to 11.42% (573 K), and finally decreased to 6.40% in coatings deposited at 773 K. Furthermore, because of the decrease in porosity it can be observed that the morphology of the coating becomes more uniform when the substrate temperature increases.

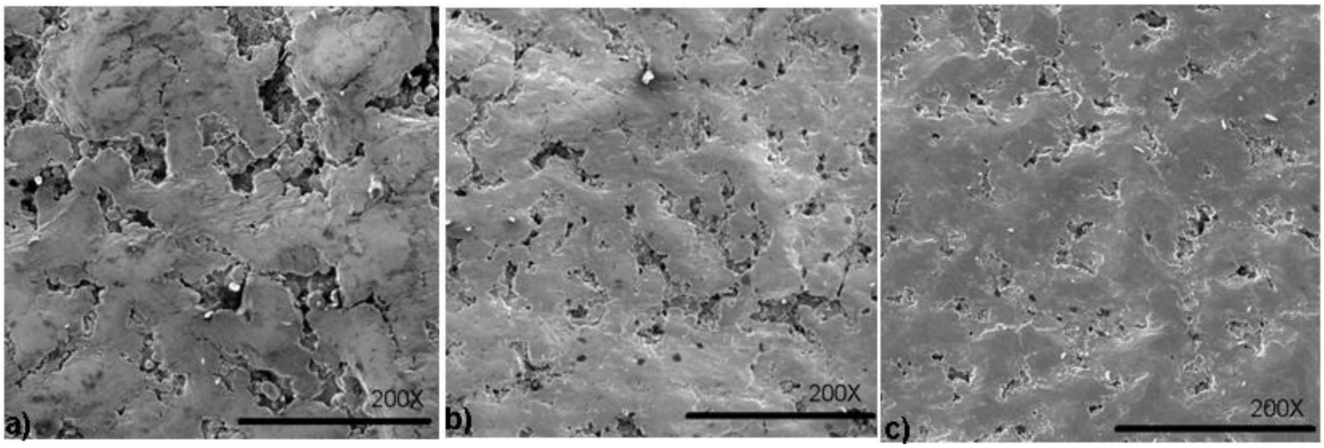

Figure 5. Surface morphology Nitec powder at a)573 K, b)673 K and c)773 K.

Figure 6 shows the average values of the average roughness (Ra) as a function of the substrate temperature. The figure shows that the change between the roughness values of the coatings varies on the order of 0.5μm with increasing temperature from 573 K to 673 K and shows decreases of 0.3 microns with respect to roughness the lower the temperature, when the maximum temperature is reached. These outcomes indicate that the coatings have very similar average roughness values on the order of 1.4 ± 0.5 microns. In comparison, the substrate surface is less rough.

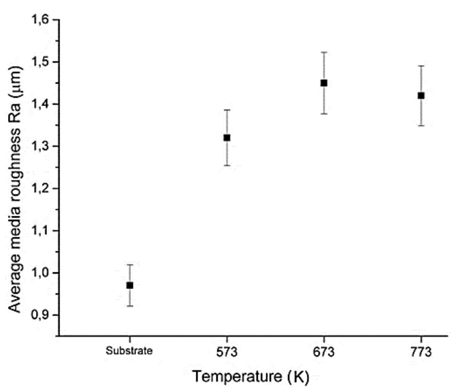

Figure 6. Average roughness of Nitec coatings as a function the temperature of substrate.

Figure 7 shows the results of the abrasion test to three bodies, according to ASTM standard G65-04. The results indicate a direct relationship between the COF and the morphology of the coating, since the surfaces that exhibit greater porosity have higher coefficients of friction. These results can be explained considering that the most porous surfaces have a higher mechanical grip on the surface.

In order to determine the mechanism of wear that occurs in the abrasion test, the Fang methodology [7] was used, in which it is considered that there is an adhesive wear and shear forces. Figure 7 shows graphs of the displacement volume in mm^3 versus temperature in K. The results show that the volume of wear is greater for the coatings than for the substrate. This indicates that for the coatings, the wear mechanisms proposed by Fang are determining the volume of material removed. Furthermore, these results show that increasing the substrate temperature up to 773 K results in a larger volume of material removed. This is related to the morphology, because materials with lower porosity and lower friction coefficient exhibit a higher degree of wear of the adhesive type.

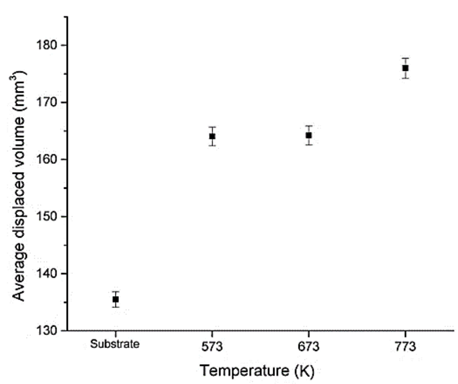

Figure 7. Averages of wear vs. temperature in mm^3 for the Nitec coatings.

In order to establish the behavior of the average value of the coefficient of friction (COF) of the coating depending on substrate temperature, pin-on-disk measurements were made over a period of 30 minutes (Figure 8). The plotted average values establish that the friction coefficient decreases with an increase in the deposition temperature. Furthermore, the results show that the coatings have a lower COF than the substrate. These results suggest that the coating, which consists mainly of nickel, has a high degree of ductility.

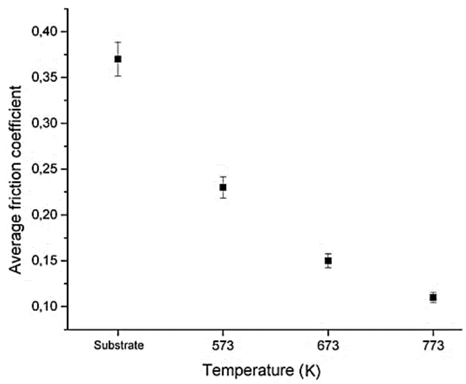

Figure 8. Averages of the friction coefficiont for the substrate, 573, 673, and 773K, respectivly, for the pin-on disk test.

Figure 9 shows the projected areas of the cones in square micrometers (mu.m.sup.2) 10224 Nitec coating deposited on cast iron, for the applied load of 10 N in the adhesion. Data were obtained for coatings deposited at 573, 673 and 773 K respectively.

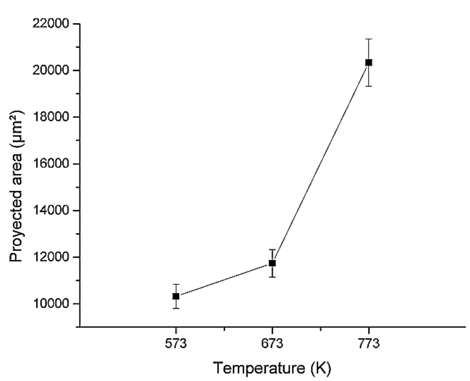

Figure 9. Projected areas of Nitec coating after adhesión test, as a function of substrate temperature.

Conclusions

The results obtained in this study allowed establishing that the substrate temperature determines the morphology of the coating and that the morphology is related to the tribological performance of the Nitec coatings.

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