Influence of ReinforcementParticles in MMC Coatings Made by Flame Thermal Spray Technology

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Abstract

Surface coatings by thermal spraying technique are extensively used in various industrial fields where the wear and corrosion resistance is paramount. However, mechanical performances are not always satisfactory because of high porosity, cracks and weaker adhesion. NiCrSiB is a Nickel based alloy universally recognized for its superior mechanical properties, attributed to the presence of hard-dispersed carbides and borides, which is dependent on the deposition technique. This work is devoted to the discovery by experimental study of the morphology, microstructure and mechanical properties of thick NiCrBSi coatings synthesized onto a mild steel substrate S235JR prepared beforehand using an oxyacetylene flame spraying torch (SuperJetEutalloy, Castolin Eutectic). Composites materials will aim to combine the resilience of metals with high wear resistance specific of ceramics. In order to study the addition effects of a reinforcing ceramic phase on the microstructure and mechanical properties of the metal alloy, NiCrBSi coatings reinforced with tungsten carbide were also made. The resulting layers were analysed to study the evolution of the microstructure, the tungsten carbide dispersion in the nickel matrix, using characterization methods: optical microscopy, scanning electron microscopy coupled with EDS technique and X-ray diffraction analysis. Roughness measurements of the substrates and as-sprayed samples were made using roughness measuring system TIME TR200. Microhardness tests were carried out using microdurometer LECO M-400-A operating with a Vickers indenter with a square base and the load being 3N. Furthermore, the addition effect of the reinforcing particles on the microstructure and the mechanical performances of the layers were investigated.The results show that the microstructure contain some inhomogeneities such us porosity, microcracks for the composite coating and oxides. The XRD analysis revealed that the phases present in the coatings are different from the initial powders. In addition, the presence of WC hard particles makes the hardness of the composite coating much higher than that of the metallic alloy.

Keywords: Coating; Thermal spray; Wear resistance; Adhesion; NiCrBSi; Composite; Characterization

1. Introduction

Nowadays, NiCrBSi coatings are among the most widely used coatings in a variety industrial applications, to protect materials against wear, corrosion and oxidation at high temperature conditions up to 800 °C [1,2]. For example, they are applied to components such as gas turbines, roller, piston rods, wearing plates, tools, extruders, plungers, rolls for rolling mills, agricultural and mining machineries served in hostile condition [3,4], and in many studies, they are used as a replacements for environmentally harmful hard chromium coatings to the environment [5]. The presence of the chromium element is responsible for corrosion oxidation resistance, while boron and silicon is decreasing the alloy's melting point, which limits the rate of unmelted particles. The presence of carbon allows creating carbides responsible to increase coating hardness and wear resistance. The composition of self-fluxing NiCrBSi alloy also allows its fusion after deposition step by a laser or flame re-melting process[6-8] to increase its functional properties, including the homogenization of the microstructure and decreasing the porosity level. Metallic coatings such as NiCrBSi are a less expensive alternative to other materials, such as cermet powders, which are extremely expensive. Indeed, properties of ceramic and cermet coatings are reduced at high temperatures; while metallic alloys retain good mechanical properties in hot environments and are thus preferred for high temperature applications. However, because of environmental conditions that may be more critical in some applications, innovative materials known as Metal Matrix Composites (MMC) are used. They provide, in many cases better performance wear thanks to the combination of performances conferred by metal matrix and those conferred by reinforcing phase.This work is devoted to implement the morphology, the microstructure evolution of two coatings: NiCrBSi alloy and NiCrBSi alloy with a mixture of 60% by weight of WC, deposited onto mild steel substrates S235JR beforehand prepared using Oxyacetylene flame spraying process. Our contribution will have an interesting economic impact aiming at improving the wear resistance of mechanical parts damaged in service. The microstructure and chemical composition of the manufactured layers were characterized using optical microscopy, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and X-ray diffraction (XRD). Roughness measurements of the substrates and as-sprayed samples were made using roughness measuring system. This work was also extended to study the coating effect on the microhardness. Detailed characterization (in terms of microstructure, interface, chemical composition, microhardness) of the coatings (both surface and cross section) was carried out.

2. Experimentalprocedure

2.1 Materials and deposition technique

Two commercially powders used as feedstock material were identified from Castolin Eutectic Company. The first powder is Ni-based alloy powder, designated Borotec 10009, with spherical morphology, hardness of 58 HRC and nominal chemical composition: Cr 14,8%, B 3,1%, Si 4,3%, Fe 3,7%, C 0,75%, and Ni balance. A second powder consisting of a mixture of NiCrBSi matrix with 60%-wt. of WC designated Eutalloy 10112 with a non-spherical angular morphology and hardness of 63 HRC. This latest has nominal chemical composition: WC 60%, Cr 7,3%, B 3,3%, Si 4,5%, Fe 6,3%, C 0,25% max, and Ni balance. Mild steel S235JR was used as substrate and the nominal chemical composition is: C 0.17% max., S 0.045% max., Mn 1.40% max., P 0.045% max., N 0.009% max. and Fe balance. Before the coating process, specimens are manufactured from mild steel S235JR bars that were cut and then machined into discs with 50mm in diameter and 10mm in thickness.

Table 1. Chemical composition (wt%) of NiCrBSi and NiCrBSi-WC powders.

Powder	Ni	Cr	B	Si	Fe	C	WC
NiCrBSi	Balance	14,8	3,1	4,3	3,7	0,75	_
NiCrBSi-WC	Balance	7,3	3,3	4,5	6,3	0,25 max	60

2.2 Microstructural analysis

After the coating process, coated and other basic steel samples are cut, hot-mounted with resin to allow easier handling of the samples and ensure the flatness of the surface during polishing. Then, they were ground with SiC abrasive paper and finally polished with diamond suspension to obtain a specular surface condition, using automatic polisher from STRUERS to ensure good reproducibility. Thereafter, samples were placed in an ultrasonic bath and cleaned with demineralized water and dried with compressed air. Finally, they were chemically etched using Murakami etchant for composite coatings and Nital etchant for both substrate and Ni-based coatings, making the microstructure observation easier. These samples were characterized (both on surface and cross-section) by 3D optical microscope (KH-8700, Hirox) and Scanning Electron Microscope (SUB020, Hitachi). By means of SEM, the basic elements of studied layers namely Ni, Cr, Si, C, W and Fe were detected. However, due to the detection sensitivity limit, the weight percentage of boron element B cannot be determined, although its presence can be confirmed. Chemical composition of coatings was analyzed by Energy-Dispersive X-ray spectroscopy (EDS). A detailed analysis of phases and their composition was made by X-ray diffraction technique (XRD) using a diffractometer (D5000, Siemens). Operating voltage and current were 40 kV and 100 mA respectively. To determine peak positions of the various phases in the range of $20° < 2\theta < 80°$, data were collected with a scan step of 2° and measurement time of 10s per step.

2.3 Microhardness

Microhardness measurements are made by means of Vickers microhardness tester (M-400-A, LECO) under a load of 300 gf, on metallographic sections, perpendicular to the deposit surface and also on cross-sections, knowing that the hardness varies depending on the sections directions owing to the characteristic anisotropy of thermal spray coatings microstructure. The residence time is 7 µm in the case of steel, 5 to 6 µm for Nickel matrix and about 4 µm for the NiCrBSi-WC composite. An average hardness was calculated from 20 indentations for each sample. The calculation formula of microhardness is as follows:

$$HV = \frac{2F \sin\left(\frac{136°}{2}\right)}{g.d^2} = 0{,}189 \times \frac{F}{d^2}$$

where HV : vickers hardness, F : applied force (N), d : diagonals indentation average (mm), g : gravity (m/s^{-2}) 9,80665

3. Results and discussion

In this section, coatings characteristics in terms of microstructure, chemical composition, present phases, microhardness and the effect of WC particles will be presented.

3.1 Microstructural characterization of coatings

As-sprayed coatings were etched with etchants to reveal the microstructure and making the precipitates observation easier.

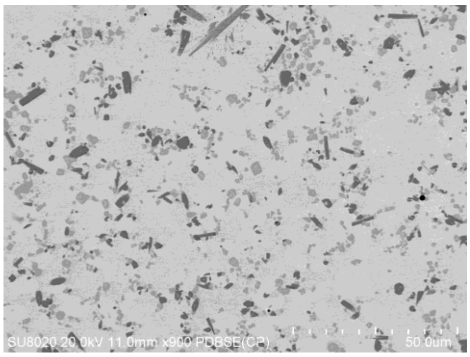

Fig. 1. Microstructure of NiCrBSi coating deposited by flame thermal spraying.

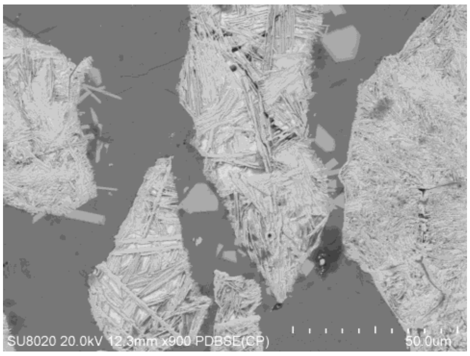

Fig. 2. Microstructure of NiCrBSi-WC coating deposited by flame thermal spraying process.

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