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Developing alternative coatings for repair and restoration of pumps for caustic liquor transportation in the aluminum and nickel industry

C.R.C. Lima [a,*], J.A. Batista [a], R. Libardi [a], H.C. Fals [b], R.S. Zamora [b], J.R.S. Ribeiro [c], V.A. Ferraresi [c]

[a] Methodist University of Piracicaba, R. Luis Ometto, Km 24, Sta. Bárbara d'Oeste, SP, Brazil
[b] Oriente University, Santiago de Cuba, Cuba
[c] Federal University of Uberlândia, MG, Brazil

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ABSTRACT

The damage caused by the combination of corrosion and wear processes on the materials that machine elements are produced causes huge losses in several industries such as mineral processing, chemical, petrochemical and power generation. Some devices that operate in harsh environments, such as centrifugal pumps for transportation of caustic liquor used in the industries of production of aluminum, undergo a rapid deterioration of their materials by the coexistence of corrosion and erosion at temperatures around 75 °C. The aim of this work is to study new ways for the corrosive–erosive problems confronted by the aluminum and nickel industries. Several coating materials in powder or wire form applied by GMA welding and HVOF thermal spray techniques are compared in erosion and erosion–corrosion tests. Corrosion tests were performed for comparison. A solution of 1 M NaOH was used as a corrosive medium to get the polarization curves The temperature of the electrolyte was 25 °C. For pure erosion test, the slurry erosive agent was 4 l of water and an erosive particle concentration of 400 g/l. Particles of ferric oxide, HRC = 40–50 and an average diameter of 600 μm, were used as an erosive agent. The impact angle of 90° was tested, with an impact velocity of the abrasive particles of 31 m/s. Tests were performed for each condition at a time of 2 h at intervals of 20 min. The results show that the best performance was that of the mixed stainless steel and cobalt alloys welded coating even though the general resistance to erosive–corrosive wear significantly favors cermets in relation to the other welded deposits.

1. Introduction

Every industry in a globalized age needs to innovate and improve the production processes to gain a better competitive position. Such dynamism is impossible without a high accuracy in forecasting failures and breakages of technological equipment [1,2]. Brazil, for example, currently has a cost for maintenance activities accounting for about 4.4% of GDP compared to a world average of 4.1% [3]. For a GDP of US$ 2223 trillion in 2012 [4], this would represent around US$ 97.8 billion, most of which was spent for the replacement of materials degraded by the actions of corrosion and wear. This reality demonstrates that organizations need to constantly search and apply improvements to the production and maintenance process, as is the standard practice of world class organizations.

One of the world's main complexes for the production of primary aluminum and alumina is located in Brazil. In one phase of the production process that involves the transport of caustic liquor, several maintenance problems have occurred, for example, repairing centrifugal pumps. Recovery of these pumps is performed by coating the damaged parts with E308L or E307L stainless steel applied by welding. The number of existing pumps exceeds 700 units with expectations to double this total in the next years and yet the operating time does not exceed six months. In Cuba, the same situation occurs in several industries such as cement, power generation and mainly nickel. One of the world's main producers of nickel is based in Cuba and faces the same kind of operational problems.

The increasing development of materials science and engineering has been leading to a smarter and much less expensive way to face the industrial design requirements for materials, i.e., the development of coatings or surface modifications of the base material suitable to withstand the increased operational demands [5,6]. Surface modification is a profound change from the technological point of view because until now the idea of a new material supposed to have uniform properties throughout its mass used to be associated with a rise in the cost of the products due to the continuing depletion of the mineral resources [7]. Among the main coating application techniques, welding overlay and thermal spray may be considered the most versatile as well as the most widely used methods for industrial applications [8,9].

This work derives from a combined effort that resulted in an international project aiming to find new ways for the corrosive–erosive problems confronted by the aluminum and nickel industries. The main

* Corresponding author. Tel.: +55 19 3124 1761/1767; fax: +55 19 3455 1361.
E-mail address: crclima@unimep.br (C.R.C. Lima).

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contribution of this project is the evaluation of materials and surface modifications in tribocorrosive environments as an alternative to increase the durability of machine elements. The research also assesses the mechanical properties, microstructural changes and corrosive wear mechanisms that occur as a result of the synergistic effects of the corrosion and wear. Several coating materials in powder or wire form were applied by GMA welding and HVOF thermal spray techniques. The results of the proposed work are perfectly applicable to the petrochemical, mining and processing of minerals, metallurgical and power generation, to cite the most relevant ones.

2. Experimental procedure

2.1. Materials and equipment

The substrates used were AISI 1020 carbon with dimensions varying according to the coating method. The substrate carbon steel hardness is 150 $HV_{0.3}$ with a ferritic–pearlitic structure. Three different wire materials were used for welding overlay: AWS ER 308LSi stainless steel, Stellite 6 and Stellite 21 cobalt alloys. For thermal spraying, three powder materials were used as feedstock: Cr_3C_2–25NiCr (TAFA 1375 V, Praxair, USA), WC–17Co (TAFA 1343 VM, Praxair, USA) and WC–12Co (TAFA 1342 VM, Praxair, USA). The chemical compositions of the materials are presented in Table 1.

Three different material combinations were tested in a set-up using the method of Gas Metal Arc Welding (GMAW) dual wire in parallel. In this set-up, two similar or different wires can be fed to the weld pool at the same time from two separate wire-feeders. Three weld beads were obtained for each combination and the sample collection for characterization, wear and corrosion tests was performed as shown in Fig. 1. Because of the roughness characteristic of the resulting welding beads, all the extracted samples were machined and polished to obtain a more regular and homogeneous surface for further tests and improved comparison. The welded beads were around 1.6 mm thick. The samples from the welding deposits were machined to a final thickness of 0.8 mm and then polished to a final roughness of 0.02 μm.

The welding equipment used was a Lincoln 455 Multiprocess (Lincoln Electric, USA). The shielded gas was a mixture of 95% Ar and 5% O_2. Table 2 shows the operational parameters for the deposition welding of the beads.

For the thermal sprayed samples, High Velocity Oxygen Fuel (HVOF) was the chosen method for the application of the three selected materials. The equipment used was a HP-HVOF JP-5000 (Praxair-TAFA, USA). Table 3 shows the spraying parameters as well as the powder size for each material. Just before spraying, the substrates were degreased with acetone and grit blasted with white corundum at 5.6 bar, 45° blasting incidence angle and using a blasting distance of 250 mm. The grit-blasted substrates had a mean roughness (Ra) of 5 μm. Thermally sprayed samples were tested in the as sprayed roughness condition in order to test the coating without the requirement of further machining or polishing, that takes time and has a high processing cost. Only one sample was polished for comparison.

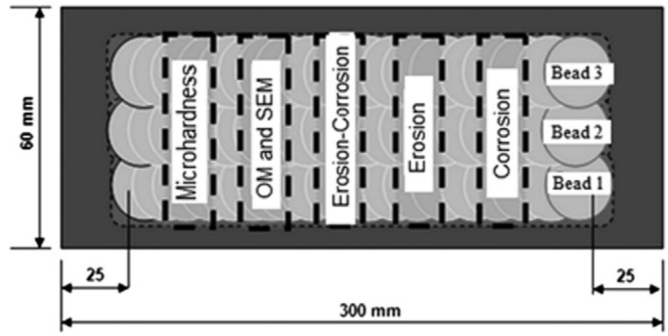

Fig. 1. Scheme details of welded deposits and sample collection.

2.2. Microstructural characterization and mechanical properties

Samples' characterization included cross-sectional Optical Microscopy (Olympus BX60M, USA) and Scanning Electron Microscopy (JEOL–JXA 840) images, as well as phase analysis by Energy Dispersive Spectroscopy-EDS (Quantum, Kevex). X-ray diffraction was performed on Shimadzu equipment (Cu, λ = 1.54 nm). The surface roughness of the obtained coatings was measured using a Mitutoyo TIMESURF TR-200 V1.4 (Mitutoyo, USA). Vickers microhardness of the coatings was measured with 1000 HVS equipment with an indentation load of 500 g ($HV_{0.5}$). Values quoted for both microhardness and roughness are an average of 20 measurements for each coating.

2.3. Corrosion tests–polarization curves

The polarization curves for the different materials tested were obtained in a potentiostat AUTOLAB connected to an interface and GPES professional package, which allows the choice of the electrochemical technique to use, graphical options and determination of the main parameters of the test (corrosion potential, sting passivation current, corrosion rate, etc.). A solution of 1 M NaOH was used as corrosive medium (pH = 14). The temperature of the electrolyte was 25 °C. For the measurements, a platinum counter electrode and a reference electrode of Ag/AgCl was employed to a scanning speed of 1.66 mV/s from −800 to 900 mV with respect to the potential for corrosion.

2.4. Erosion and erosion–corrosion tests

Erosion tests were performed in the mass testing machine. Fig. 2 shows the details of the experimental setup. The welded and HVOF sprayed samples for testing were obtained from deposits and zones of interest in the form of prismatic bodies of 10 × 8 × 4 mm. The prismatic bodies had just one side coated and exposed (10 × 8 mm) to the slurry in the tests. All the welded samples of the different alloys were polished with sand paper to 1200 mesh. The surface roughness of the coatings was measured before (Ra = 0.02 μm for all samples prior to testing erosion) and after being eroded over a period of 2 h. For a pure erosion test, the slurry erosive agent was: 4 l of water and an erosive particle

Table 1
Chemical composition of the substrate and coating materials.

Material		wt.%											
		C_{tot}	W	Co	Cr	Mo	P	Ni	Si	Mn	Al	Fe	S
Substrate	AISI 1020	0.2					0.05		0.35	0.6		Bal.	0.05
	ER308LSi	0.03			19.4	0.3		9.9	0.8	0.9		Bal.	
Welding	Stellite 6	1.1		Bal.	28.0				0,3	0.5			
	Stellite 21	0.25		Bal.	28.0	5.0		3.0	0.3	0.5			
	Cr_3C_2–25NiCr	11.0	–	–	Bal.	–	–	19.0	–	–	0.002	–	–
HVOF	WC–17Co	5.3	Bal.	17.0	–	–	–	–	–	–	–	–	–
	WC–12Co	4.0	Bal.	11.0	–	–	–	–	–	–	–	–	–