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Residual stresses and corrosion performance of plasma sprayed zinc-based alloy coating on mild steel substrate

M.H. Mathabatha [a], A.P.I. Popoola [a], O.P. Oladijo [b,*]

[a] Department of Chemical, Metallurgical and Materials Engineering, Tshwane University of Technology, Pretoria, South Africa
[b] Department of Chemical, Materials and Metallurgical Engineering, Botswana International University of Science and Technology, Palapye, Botswana

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ABSTRACT

Plasma spraying technique stands out among the various processes for enhancing the surface characteristics of engineering materials. Many authors have conducted research on different types of deposition technologies in relation to the corrosion performance of different coatings. However, not all aspects of these processes are fully understood. This study focused on the residual stresses and corrosion behaviour of plasma sprayed zinc-based alloy coatings on mild steel substrate. Characterization of coated surfaces was done using optical microscopy, X-ray diffraction, and scanning electron microscopy to observe the morphology, phases, grain sizes and probable defects. The residual stresses were measured by X-ray diffraction $\sin^2\Psi$ techniques using Cu-Kα radiation. The corrosion and micro hardness properties were investigated using Auto lab potentiostat (PGSTAT30) linear potentiodynamic polarization and Emco Dura Scan tester. The experimental results revealed an improvement in the corrosion and micro hardness properties of the coated samples as compared to the substrate. The residual stresses of the as-sprayed coatings show compressive stresses. The magnitudes of the stresses in the as-sprayed condition were low, with slight variation due to the effect of cooling and difference in powder compositions. Overall, zinc-base coatings have significant positive effects on the corrosion performance, mechanical properties and residual stresses of the substrate.

1. Introduction

Outstanding technologies and analytical methods are being developed in many engineering fields mainly to improve the surface properties of metallic materials used in industries [1]. Eminent productivity and efficacy spanning the entire spectrum of manufacturing and engineering industries have ensured that most modern day components are prone to day by day increasing harsh environments in regular operations [1]. All vital engineering components of the machines are exposed to additional speedy degradation as the parts fail to resist the aggressive operating conditions and this has an impact on the industry's economy to a very high extent [1].

Considerable efforts to improve the hardness, corrosion and wear resistance of mild steel have been widely researched by numerous authors [1–8]. It was reported that zinc has enhance the longevity and performance of steel, because its coatings provide an effective and economical way of protecting steel against corrosion hence the wide acceptability [2]. It is anodic to steel as it protects the base metal against aggressive environments [3–7]. This is usually achieved by adding a layer of zinc through galvanizing which offers two benefits; zinc has good resistance to chemical corrosion and it corrodes preferentially to the steel in the presence of an electrolyte [6]. Zinc is applied with greater ease and at lower cost than other metallic coatings such as chromium and nickel [6]. Owing to the limitations of corrosion protection offered by pure zinc metal, the possibility of alloying zinc with a combination of different metals has been explored by various researchers [2–9].

The properties of materials can be improved by alloying metallic powder on the material of interest [5]. Alloys such as Zn-Co, Zn-Fe and Zn-Ni have gained a wide range of applications in both manufacturing and marine industries as better substitutes for ordinary zinc coating [3,5,6]. The deposition of zinc and zinc alloy coatings on steel is one of the most important processing techniques used to protect steel components exposed to corrosive environments [4,7]. Zn-Al alloy possesses the advantage of both Al and Zn, making it a good coating material for corrosion protection [3,4,5]. Aluminium is potentially a vital material for tribological applications because of its low density and high thermal conductivity. However, aluminium and its alloys exhibit poor resistance to seizure and galling [8]. Aluminium and its alloys have been used as matrix for a variety of reinforcements such as continuous boron, Al_2O_3, SiC and graphite fibers [8]. The corrosion resistance of aluminium and its alloys can be attributed to the natural protective oxide layer (passive film) that forms on their surface [8]. Thus protective oxide film is subject to localized breakdown, allowing pitting and crevice corrosion of the underlying substrate [8].

* Corresponding author.
E-mail address: seyiphilip@gmail.com (O.P. Oladijo).

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Popoola et al. [5] reported an increase in the microhardness value of Zn-Al coating on mild steel substrate compared to the as-received sample and Zn coated specimens when using electroplating technique. The increase in hardness of the Zn-Al coated specimen was attributed to the presence of the Al as a reinforcement additive [3]. The surface morphology also indicated that the Al distribution within the steel matrix resulted in a good surface finish and its high affinity for oxygen resulted in the formation of Al_2O_3 oxide film on the surface which led to good resistance to corrosion attack and finer microstructure [3].

Coating technologies have advanced within the last decades, and it is now possible to deposit films with variety of properties [10]. Thermally sprayed coatings often have superior properties, lower application costs and less environmental issues in comparison to other industrially used coatings [12]. Plasma spray is one of the most widely used surface techniques due to its great versatility and its application to a wide spectrum of materials [10]. The behaviour of the coated surface is controlled by geometry of contact, the material characteristics and finally the operational parameters [10]. A plasma sprayed coating is built up and the microstructure is formed, when individual, fully or partially molten particles, travelling at a particular velocity, flatten, adhere and solidify on impact with the substrate [11].

The control of residual stresses is an important study in coating technology. Residual stresses are stresses that remain after deformation after all external forces have been removed. One of the present authors [13–15] has investigated the origin of residual stresses in coatings. It was reported that both material and deposition process control residual stress [13]. Residual stresses play a fundamental function in materials as they can either boost or degrade performance [13]. The residual stress can be determined when the total strain and inherent strain of the material or coating is known. The residual stress in thermal spray coatings can be measured by destructive or non-destructive techniques. This work employs the use of nondestructive X-ray techniques for this study. These stresses can also be compressive or tensile depending on the direction of the forces [13–15].

In this study, plasma spraying technique was used to deposit Zn-Al powders on mild steel to enhance the surface properties such as hardness and corrosion resistance. Characterization of coated surfaces was done using optical microscopy, X-ray diffraction, and scanning electron microscopy. The residual stresses were measured by X-ray diffraction while the corrosion and micro hardness properties were investigated using Auto lab potentiostat (PGSTAT30) linear potentiodynamic polarization and Emco Dura Scan tester.

2. Materials and methods

2.1. Plasma spraying process

The powders used for this work were mixed in the following ratios: Zn-Al (25/75), Zn-Al (50/50) and Zn-Al (75/25) for a period of 6 h using Turbular Shaker T2F. The equipment used for coating was a 9MC plasma control unit (Sulzer Metco) with argon/nitrogen and helium as inert gases. It consist of a hoop powder feed unit (9MP) and a robot that controls the position and angle of the spray gun at a speed of 400 mm/s. The substrate was grit blasted using coarse alumina grit prior to deposition to increase adhesion of the coating to the substrate as well as proper cleaning. The powder was fed into a hopper and a mild steel bar was clamped/placed tightly on a stand inside the plasma spray booth. The spray gun deposits the powder of interest on the surface of the substrate until the required coating thickness of 200 μm is achieved. The temperature was measured using a hand held device infrared thermometer (Lutron electronic, model Tm-958, −30 to 300 °C) and the coating thickness was measured with a Venire caliper. During the spraying, the gun was stopped frequently to avoid overheating the substrate. Additional spraying parameters are listed in Table 1.

Table 1
Spraying parameters.

Plasma spray parameters	
Hydrogen	0.00011 bar
Argon	0.00175 bar
Powder feed rate	32 g/min
Coating thickness	200 μm
Temperature	300–3000 °C
Stand-of-distance	10 mm

2.2. Coating characterization

For microstructural analysis, a coating of about 200 μm thickness was deposited on a substrate of 100 × 100 mm dimension. The specimen were cut and the cross-sectional part of the coating were prepared by cold mounting resin, followed by grinding using sequentially finer grades of SiC abrasive paper: 120, 320, 400, 600, 800, and 1200 μm. They were then polished with a cloth sequentially using fine diamond paste: 6, 3 and 1 μm. The cross sectional micrographs were investigated and observed by scanning electron microscopy (SEM) in conjunction with energy dispersive electroscopy (EDS). The phases present in the coating layers were identified with X-ray diffractioner with Cu-Kα radiation at 40 kV and 20 mA. Micro hardness measurements were conducted on the coated samples using a Vickers indenter with a load of 300 g and a dwell time of 10 s. The reported hardness is the average of five indentation measurements. Porosity measurements were done using point-counting method on SEM images at 5000× magnification.

2.3. Electrochemical tests

Electrochemical measurements were carried out using linear potentiodynamic polarization technique on the as-received and coated samples with the aid of Auto lab potentiostat (PGSTAT30) to study their corrosion behaviour. The electrochemical cell consisted of working electrode, a silver/silver chloride 3 M KCl electrode as the reference electrode (SCE), and a graphite rod as counter electrode. The corrosion potential (Ecorr), polarization resistance (Rp) and corrosion rate were determined by scanning the specimens from a potential of −1.5 to 1.5 V. Experiments were carried out at ambient temperature using 1 M H_2SO_4 and 3.65% NaCl solution. The solution was prepared from analytical grade reagents and distilled water.

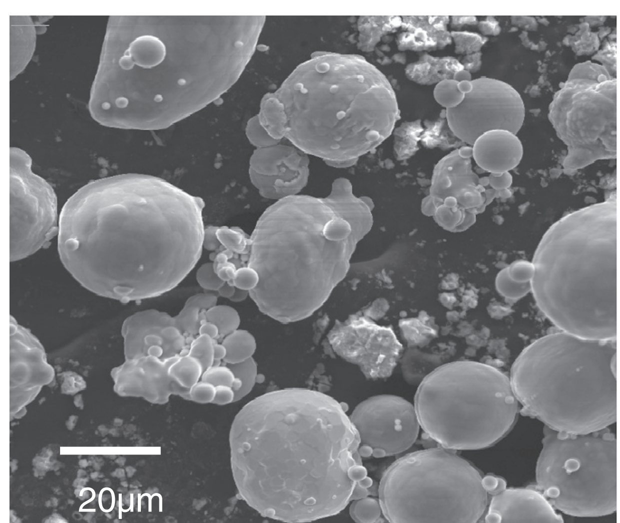

Fig. 1. SEM micrographs of starting material: Zn-Al powder.

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