Microstructure and properties of arc sprayed Zn-Al alloy coatings

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Abstract. In this study, zinc-aluminum alloy coatings were deposited on low carbon steel substrates by arc thermal spraying with different current and spraying distances. Optical microscope (OM) was used to characterize the deposited coatings. From the experiment, it is found that the samples that use different electric currents and spraying distances result in the different microstructure of the coating surfaces and different mechanical properties. The sample that uses higher current tends to have a higher hardness than the sample with a lower electric current at the same spraying distance.

1. Introduction

Corrosion is the chemical or electrochemical reaction of metals which are in contact with the environment such as in the gaseous media or in water, or in other chemical solutions [1]. Corrosion protection can be done in many ways, such as hot-dip galvanizing [2-3], electrodeposition [4-5], thermal spray process [6-7]. There are many materials used for spray coating, including pure metals, alloys, plastics, and ceramics. Raw materials selection depends on the desired features and applications.

Thermal sprayed Zn-Al alloy coating has been applied to prevent corrosion of steel using cathodic protection [8]. Zn-Al alloy coating is generally superior than Zn or Al coatings in term of corrosion resistance in humidity or in moderately aggressive solution such as in chloride solution [9]. A salt spray test of arc-sprayed Al and Zn/15Al coatings was done by Gulec et al [10]. It is reported that Al and Zn/15Al coatings perform better corrosion resistance than that of Zn coatings. Tailor et al [11] reported that arc-sprayed Zn-Al coatings also has better mechanical properties when compared to those of Zn coating. It was also found that Zn-Al coating has better corrosion resistance than pure Zn coating in salt fog as well as in microbial environment.

Arc spraying is one of the thermal spray techniques where two metal wires fed independently into the spray gun to form the coating. Auto-feeding was used to direct the wires and electric arc occurs in order to provide heat to melt the wires. Compressed air or gases are used to propel the molten droplets to deposit on the substrate. [12].
Arc spraying is an economical way to produce coatings with high spray rates and efficiency suitable for spraying on a large area. On-site coating can be done to provide resistance to atmospheric corrosion [11,13].

In this research, zinc-aluminum alloy coating was deposited on low carbon steel by arc spraying process. In order to find an optimum processing parameter, current and spraying distance were varied. The microstructure and hardness of the coatings were analyzed to understand the effects of spraying parameters. The optimum processing parameter is to be suggested.

2. Experimental methods

2.1. Materials and methods
In this research, Zn/15Al feedstock wire with a diameter of 1.6 mm was selected as the raw materials. The Zn/15Al was arc-sprayed and coated on a low carbon steel substrate with a dimension of 30mm x 70mm x 3 mm. Before spraying, substrates were grit blasted with alumina (Al₂O₃ of 24 mesh size) to provide a profile on the substrate. The processing parameters of arc spraying are listed in Table 1. Three samples were prepared for each coating condition.

| Spray parameter                      | Value       |
|--------------------------------------|-------------|
| Current (A)                          | 100, 150, 200, 250 |
| Arc load (V)                         | 30          |
| Spraying distance (mm)               | 100, 150, 200 |
| Wire feed rate (g/s)                 | 1.8-4.5     |

2.2. Coatings Characterization
The microstructure of the coatings was investigated by optical microscope (OM). The specimens were cross-sectioned and prepared following a standard sample preparation method: grinding using SiC papers and polishing using diamond suspension until a mirror surface finish. Surface Roughness Tester was used to measure the surface roughness of the coated specimens. Ra value of each coated sample was measured form 5 different locations. The thickness of the coating was averaged from 20 measurements. The hardness of the coatings was measured by a SMV-1000 Vickers microhardness tester, following ASTM E384 under a load of 300 g, dwelled time of 15s. At least 15 hardness measurements were taken on the cross-section of coated samples. Image J software was also used to analyze the porosity content.

3. Results and discussion

3.1. Coating microstructures and properties
Figure 1 shows the cross-section of Zn-Al alloys coatings by arc spraying. The thickness of the coating surface every samples is in a range of 500 to 1000 µm. It was observed that the sample that uses less spraying distance to have smaller size of splat layer than the sample with a more spraying distance at the same current. Similar observation was reported by Djerourou et al [14].
Figure 1. Optical micrographs of Zn-Al coating is sprayed with different current and spraying distance at 100x magnification (a) 100 A, 100 mm, (b) 100 A, 150 mm, (c) 100 A, 200 mm, (d) 150 A, 100 mm, (e) 150 A, 150 mm, (f) 150 A, 200 mm, (g) 200 A, 100 mm, (h) 200 A, 150 mm, (i) 200 A, 200 mm; (j) 250 A, 100 mm, (k) 250 A, 150 mm, and (l) 250 A, 200 mm.

The surface roughness of the substrate and Zn-Al coating were measured as $Ra = 10.47 \mu m$ and $Ra = 8.79 \mu m$, respectively. It can be seen that the surface roughness of the coating is less than that of substrate. This is similar to Tailor et al. [11] who confirmed that the surface roughness of the substrate and Zn-Al coating were in the same range as reported in this research. The microhardness of the as-sprayed specimens were also measured. From the figure 2, it can be seen that the sample that is sprayed with current 250 A at spraying distance 100 mm has the highest hardness (45.18 $\pm$ 1.95 HV), while the sample that is sprayed with current 100 A at spraying distance 200 mm has the lowest hardness (34.86 $\pm$ 3.50 HV). It was observed that the sample that uses higher current tends to have a higher hardness than the sample with a lower electric current at the same spraying distance. The sample that uses shorter spraying distance has a higher hardness than the sample with a longer spraying distance at the same electric current. Increasing spraying distance has been known to cause more porosity fraction in the coating, which reduces the hardness [14]. This observation is confirmed by almost all samples in this.
experiment. However, some results indicated that hardness increased with more porosity fraction (100 A, 100 mm) and decreased with lower porosity (150 A – 200 A, 200 mm). There might be other contributing factors to the hardness that needs further investigation.

Figure 2. The average hardness of various coating samples.

Figure 3. The average %porosity of various coating samples.

4. Conclusion

Arc-sprayed Zn-Al coatings were deposited on to low carbon steel substrates. It is found that the hardness of the coating depends on many factors such as spraying current and spraying distance leading to various coating porosity. Higher spraying current and shorter spraying distance tend to yield the highest hardness. The results shows that the sample sprayed with current 250 A at spraying distance 100 mm has the highest hardness, suggesting an optimum condition for this study.

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