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MECHANICAL PROPERTIES OF THERMAL ARC SPRAY ALUMINIUM COATING IN ATMOSPHERIC CONDITION

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Graphical abstract

Abstract

Thermal arc spray coating was regard as most preferred method as a protective coating due to its ability to sustain in high temperature, high friction surface, and low cost process. It has been applied by most of industrialist especially in oil and gas field, where current application of the coating used in onshore. This research is a study on mechanical properties of thermal arc spray coating by using aluminium alloy with purity 99.5% as coating material. Two samples with different coating thickness at range of 200 μm – 300 μm and 300 μm – 400 μm were used for this research. Some of tests were prepared to evaluate coating mechanical properties. Surface microstructures were viewed and analysed using scanning electron microscope and energy dispersive x-ray analysis. The hardness was inspected using Vickers Hardness testing. Corrosion rate was established by performing Salt Spray Test. Porosity value was calculated using Image Analyzer. Surface roughness was viewed using Infinitefocus G4 machine. Experimental results were found that coating porosity was raising with enhancing of coating thickness. The increment coating thickness also resulted in reduction of hardness and surface roughness. For corrosion rate purpose, two samples with coating thickness at range of 200 μm – 300 μm and two samples with coating thickness at range 300 μm – 400 μm were prepared. It recorded at Rating 5 – Rating 7 after exposed in salt spray cabinet within 144 hours. As a result, coating thickness at range of 200 μm – 300 μm performs the most efficiency in terms of mechanical properties; less corrosion rate, less porosity and contribute to high hardness and surface roughness.

Keywords: Thermal arc spray coating, aluminium alloy, coating thickness, hardness, porosity

1.0 INTRODUCTION

Protective coating for corrosion prevention was used in past decade. On that time, the coating was successful, but the usage is limited. Just in recent time, industries in oil and gas tend to use thermal spray coating especially thermal arc spray coating as their preventive corrosion for steel structure[1] . The history of thermal spray coating started at 1990s when powder and wires was used for spraying process using oxy-acetylene torches [2]. Then an oil and gas company (Conoco Hutton TLP) applied thermal arc spray aluminium with thickness of 200 microns on offshore structure at North Sea. After eight years, when they make an inspection to the structure, they found the coating is still in good shape. Since that, thermal arc spray usage is slowly expanded until it was developed into great evolution in terms of material , application and equipment [3]. Currently thermal arc spray is identified as the most selected method due to its benefit in terms of production or maintenance consideration.

Thermal arc spray coating can be described as a coating process where melted material released by arc spray gun and sprayed onto a metallic surface. The particles projected by spray gun and form a layer on metal surface [4]. The layer will act as protection for metal surface from corrosion. In thermal arc spray coating, two current carrying wires (in metallic form) are fed into spray gun so that the wires will melt due to arc created. The arc creates a high temperature up to 5000 °C and will melt the wire. Then the molten material sprays onto the substrate using air compressor with high velocity (can achieve until 300 m/s) [5] as shown in Figure 1.

Normally aluminium or aluminium alloy is the most selected compared to other material such as zinc or zinc alloy[6] . This is because aluminium has low density around 2.70 g.cm-3 compared to zinc (7.14 g.cm-3)[7] and has high melting point which is expected in 660.37°C compared to zinc in 419.53 °C. Therefore it does not easily ignite and it can be used near to high temperature environment [8]. Its ability to resist corrosion is one of the important considerations. In theory, aluminium will react immediately if immersed in water. But in reality, when aluminium immersed in water, no reaction is found due to formation of aluminium oxide layer (react with oxygen) onto the surface of metal. The layer will protect underlying aluminium from outside sources such as water or any gasses and lead to the lower tendency to build up pits and blister, and then prevent more corrosion progression[9].

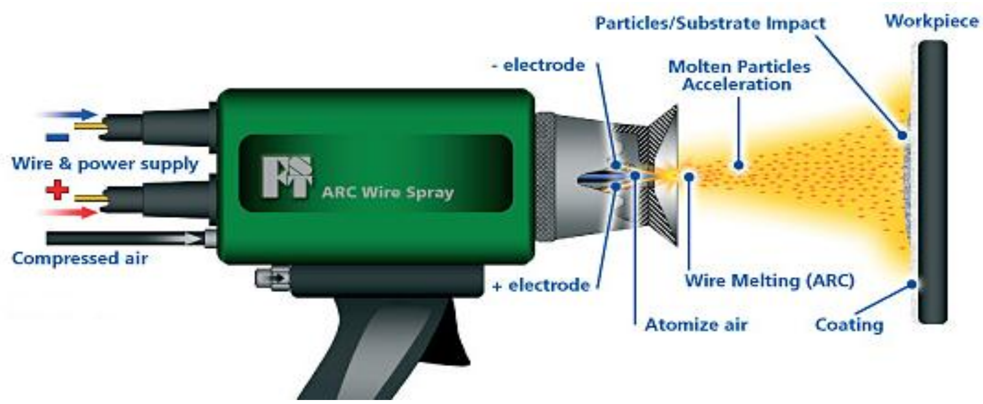

Figure 1 Block diagram of the processes of the system

2.0 EXPERIMENTAL

Two pieces of mild steel plates with dimension of width 7cm x length 15 cm x 5mm thickness were coated in different thickness range of 200 μm-300 μm and 300 μm – 400 μm. Coating was sprayed on mild steel plate using thermal arc spray method using aluminium alloy at 99.5% purity. The material was fed into spray gun in wire form at 1.6 mm diameter and 200A current was supplied into the spray gun so that arc can be created between two fed wires. The coating was sprayed onto the substrate at distance of 15 cm-25 cm using air compressor at 4-6 bar.

Then mechanical properties of thermal arc spray aluminium coating were investigated. Surface microstructures of the coating were viewed for both coating thickness using scanning electron microscope (SEM) and energy dispersive x-ray (EDX). Both samples were zoomed at 200x magnification. Coating porosity was measured by applying image analyzer. Five areas were identified on the coating and average porosity value was calculated. One area covered at 0.307 mm2.

The coating surface roughness was inspected using Infinitefocus G4 machine. The area covered for the analysis at 1.2 cm width x 1.2 cm length. The symbol of surface roughness exist in the analysis was represented as Ra (average surface roughness). Vickers hardness testing was conducted to evaluate coating hardness. Five trials were performed for both coating thickness and the average value was produced to represent hardness value.

Corrosion rate evaluation was performed in salt spray cabinet to inspect how well thermal arc spray coating can withstand under corrosive environment. 4 samples were prepared where 2 samples with coating thickness at range of 200 μm – 300 μm and 2 samples with coating thickness at range of 300 μm – 400 μm were used in the cabinet. The coating surface must be free from contamination material such as grease, dirt, and oil before it is placed inside the cabinet. The process was conducted at temperature of 35°C, pH of salt solution at 6.8, fog rate at 1.3 mL/hr per 80 cm2 and was exposed within 144 hours.

3.0 RESULTS AND DISCUSSION

Table 1 Mechanical Properties of Aluminium 99.5% Coating at atmospheric condition

Coating Thickness , µm	Average Hardness (HV)	Average Porosity (%)	Surface Roughness of Coating (µm)
200-300	49.6	9.89	24.29
300-400	45.6	16.00	15.73

Table 1 show the pattern of hardness, surface roughness and porosity of coating was exposed in atmospheric condition. It was noticed that surface roughness (sometimes called surface profile) and coating hardness show a decreasing value in increasing of coating thickness. The enhancement of coating thickness resulting in rising of coating porosity. Hardness porosity, and surface roughness of coating thickness at 200 µm - 300 µm were recorded at 49.6 HV, 9.89% and 24.29 µm respectively. While for the coating thickness at 300 µm - 400 µm, the hardness and surface roughness of coating was dropped until at 8% and 35% level, while porosity are increasing at 62% levels. Porosity area was shown at red arrow and presented in Figure 2 and Figure 3. From a previous research, rising the coating thickness will drop mechanical strength of a material by increasing porosity[10]. Expanding the porosity will lower coating hardness[11]. Porosity can happen because some of coating particle still wet when it sprayed onto surface metal during coating process and will cause trapped air. It is very impossible for the trapped air or gas to escape since the coating particle having short cooling time, expecting just 10^{-7}s to 10^{-6} s only and resulting the gas confined in the coating. Increasing in coating thickness will reduce surface roughness, hence reducing coating surface friction.

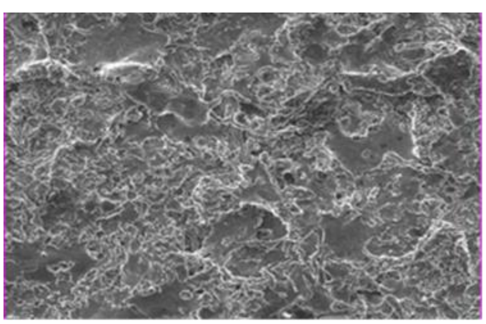

Figure 1 SEM image of coating thickness range of 200 µm – 300 µm

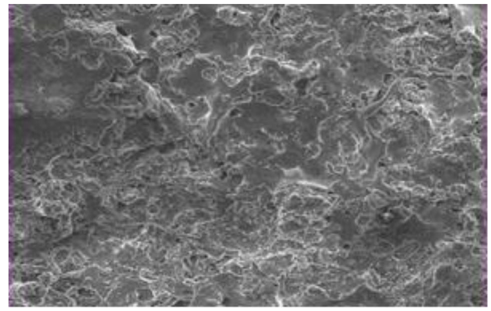

Figure 2 SEM image of coating thickness range of 300 µm – 400 µm

Table 2 EDX analysis of thickness of 200-300µm

Element	Weight %	Atomic%
C	13.65	23.87
O	18.18	23.87
Al	66.62	51.87
Fe	0.49	0.18
Ag	1.07	0.21

Table 3 EDX analysis of thickness of 300-400µm

Element	Weight %	Atomic%
C	11.56	20.21
O	22.36	29.35
Al	64.11	49.89
Fe	0.93	0.35
Ag	1.04	0.20

From EDX analysis shown in Table 2 and Table 3, carbon content was found in high number around 11%-13%. The possibility of carbon content is increased because of thermal arc spraying process. Higher exit temperature at spray gun (overcome aluminium alloy melting point) was confined of surrounding air including carbon dioxide. When it was sprayed together with coating material, it falls on metal surface and trapped inside coating layer. The decreasing of carbon content of increasing in thickness mostly because of coating process for all was done in close area, conducted at same place and in continuous process. During the spraying, coating process was started at thickness range of 200 µm – 300 µm followed by 300 µm – 400 µm.

There is high possibility most of carbon content inside room was trapped on coating during first process and it slowly decreases once coating process is continuous. So coating hardness changes directly with the carbon content and there is a significant increment in hardness with expanding carbon content.

In corrosion rate evaluation, 2 samples with coating thickness of 200 µm – 300 µm and 2 samples with coating thickness of 300 µm – 400 µm (dimension 7.5cm length and 3.5 cm width) were prepared and tested in salt spray test. The result of salt spray test was shown in Table 4. Results of salt spray test was evaluated using ASTM D610-08. Condition of sample before salt spray test and after complete the experiment was revealed in Figure 3 and Figure 4.

Table 4 Salt spray test result

Coating Thickness , µm Before test	Coating Thickness , µm After test	Sample Markings		Product yield / mmol	Ratio of Lewis acid to Brönsted acid [b]
			48 hours	96 hours	144 hours
280	252	Sample 1	Rating 6	Rating 6	Rating 5
280	255	Sample 2	Rating 6	Rating 5	Rating 5
320	309	Sample 3	Rating 7	Rating 7	Rating 7
320	314	Sample 4	Rating 7	Rating 7	Rating 7

Table 4 shows salt spray test result based on rust rating. 3 interval times were done during the test at 48 hours, 96 hours and 144 hours. Coating thickness range of 200 µm – 300 µm shows a decreasing in rust rating number (decreasing means produce high percentage of surface rusted) from Rating 6 to Rating 5 (1% - 3% of surface rusted). Coating thickness range of 300 µm – 400 µm show a constant rusting grade at Rating 7 (0.1% - 0.3% surface rusted) and produce less percentage of surface rust compared to coating thickness range of 200 µm – 300 µm. The results produced also supported by image was captured as shown in Figure 3. Comparison picture after complete of 144 hours reveal more rust was appeared on sample with coating thickness range of 200 µm – 300 µm compared to sample with coating thickness range of 300 µm – 400 µm. As a result, we can conclude that increasing of coating thickness will reduce corrosion resistance.

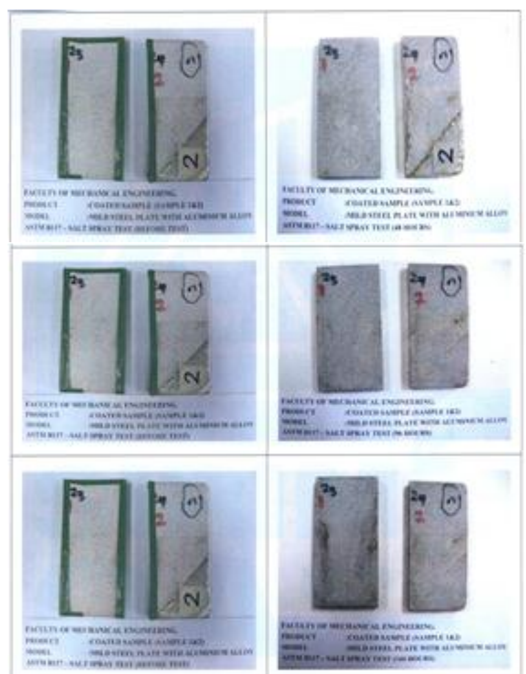

Figure 3 Sample 1 and sample 2 condition after 144 hours of salt spray test

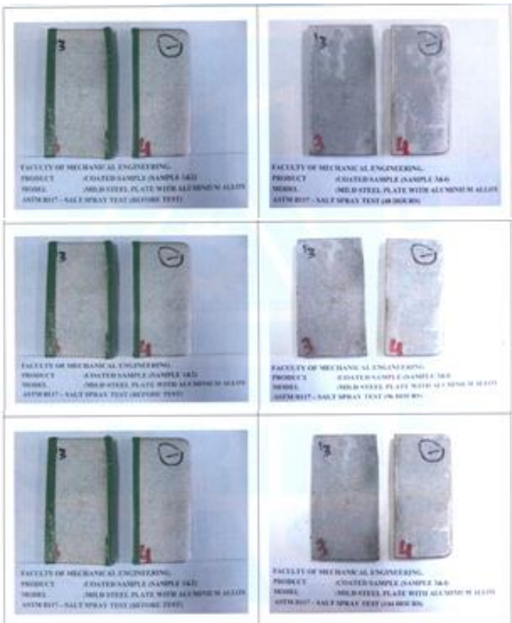

Figure 4 Sample 3 and Sample 4 condition after 144 hours of salt spray test

4.0 CONCLUSION

The finding shows that enhancing coating thickness may reduce coating hardness, coating surface roughness, corrosion rate and increase coating porosity. It was also found that enhancing coating thickness is likely to reduce carbon content if the coating process is continuous and conducted in same place. It will reflect on coating hardness; showing less hardness in increasing of coating thickness.

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