The Influence of Spray Distance of Thermal Sprayed Aluminum (TSA) on its Corrosion Resistance and Bond Strength

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Abstract. This study investigates the ideal spray distance to result in a high quality aluminum coating on 316L stainless steel substrates. Thermal spray process is used using Aluminum as the coating material, well-known as TSA (Thermal Sprayed Aluminum). To get high coating quality must do the coating using proper parameters, one of them is the spraying distance. In this investigation is want to observe the influence of the spray distance on corrosion resistance and its bond strength. The spray distance variants 10, 20, and 30cm. To evaluate the corrosion resistance and the bond strength of thermal sprayed aluminum, the researchers apply a salt spray and mechanical pull-off test. The result shows that the spray distance of 20cm produce the strongest corrosion resistance and the highest bond strength, 12.5 MPa.

Keywords : Corrosion resistance; Electric arc spraying; 316L stainless steel substrates; Aluminum; Bond strength

1. Introduction

Stainless steel substrates are, abundantly, used in such industries as oil and gas, chemical, and automotive because they have excellent corrosion resistance, good ductility, high mechanical strength at room temperature, and are relatively low cost [1]. Despite high corrosion resistance, in environments containing aggressive ions such as Cl-ions, this steel may still risk local corrosion [2]. Enhancing the corrosion resistance and life time of these steel, one can coat them with paints or metals such as Al, Ni, Cr, and Mo [3].

To coat stainless steel substrates, the researchers applied a thermal spray method. The method was used to improve the properties of the stainless steel against abrasive environment, corrosive environment and application in high temperature. The procedure of thermal spray includes, first, spraying molten metal particles on the surface of the object and, secondly, quenching which causes solidification. This coating technique will provide protection from the negative effects of chemicals, atmosphere, brine, and high-temperature environments [3,4].

Among several thermal spray techniques is electric arc spraying. This technique is applied to this investigation and involves two wires as the melted coating materials and then sprayed on the surface of the object. Unlike other thermal spray techniques that commonly utilize heat from combustion gases to melt coating materials, electric arc spraying exploits the thermal energy of the arc generated by a contact
between two electrically-charged metal wires [3,4]. Of the many measures classified as electric arc spraying, Thermal Spray Aluminum (TSA) is the one applied to this study. The advantages of TSA are relatively low cost, simple, having no curing time, having an operating temperature up to 538°C, providing sacrificial anodes, and protecting objects for around 30 years in corrosive environments. This technique is widely used to such high corrosive environments as platforms, tanks, and risers in the oil and gas industry [5,6].

The research gap is obtained from Performance and Microstructure Analysis of 99.5% Aluminium Coating by Thermal Arc Spray Technique [5]. There, Muhamad Hafiz Abd Malek, Nor Hayati Saad, Sunjadi Kiyai Abas, N.R. Nik Roselina, and Noriyati Mohd Shah investigate the aluminum bond strength, its ductility, hardness, as well as porosity and find that overall performance of the aluminum coating is generally good. Nevertheless, they do not base those four features on the spray distance, as this research does, in exploring the aluminum coating best performance. In addition, lecturers and researchers interested in this investigation as well as experts at PT Thermic Coating Industries also contribute to determining the topic of this research.

This study explores the ideal spray distance to yield the best aluminum coating on stainless steel substrates. To find out the quality of the coating, this study involves a salt spray and mechanical pull-off test. Before undergoing those two tests, the surface of the sample is cleaned with thinner, heated to 80-90°C, and Al₂O₃-blasted.

2. Experimental method

2.1 Materials

The research materials are comprised of stainless steel substrates, aluminum wires, thinner solution, and aluminum oxide abrasives. The type of stainless steel substrates in this research is 316L (SS 316L) with dimensions of 150x70x5 mm. The table below gives information about the chemical composition of 316L stainless steel substrates.

| Elements | C  | Si  | Mn  | P  | S  | Ni  | Cr  | Mo  | Ni  |
|----------|----|-----|-----|----|----|-----|-----|-----|-----|
| (%)wt    | 0.025 | 0.6 | 0.9 | 0.035 | 0.001 | 10.1 | 16.7 | 2.04 | 0.03 |

Aluminum wires were involved in the process of electric arc spraying. These wires contain 99.5% Al and are 1.6 mm in diameter. Thinner and C # 24 aluminum oxide abrasives were, respectively, used in the process of cleaning and blasting.

2.2 Method

In this sub-chapter, the researchers explain the stages of investigation including the surface preparation, coating, the corrosion resistance test, and the bond strength test.

First, the surface preparation began with cleaning surface contaminants such as dust, oil, and rust with thinner. The surface then underwent a preheating process at a temperature by 80°C-90°C, controlled with an infrared digital thermometer. Subsequently, the surface was blasted in a blasting cabinet with a spray distance of 10-15 cm and a 4-5 bar air pressure to obtain an Sa 3 clean level in accordance with ISO 8501-1. After the blasting process was conducted, the sample should enter the coating process. Samples must not be left in an open room for more than 4 hours, otherwise the sample must be re-blasted.

Next, the surface of stainless steel substrates was coated with aluminum. This process was carried out through electric arc spraying. To deal with electric arc spraying, the researchers used an OSU hesller, its consuming two 1.6 mm-diametered wires of metallized aluminum. The process required a voltage of 27-29 V and a current of 150-200 A, and was taking place under atmospheric condition inside a closed container to reduce noise and dust pollution. The thickness of the coating layer on each sample is 90-100 μm while the spray distance parameters are 10, 20, and 30 cm. Before do the coating, all preparation
must be in proper results, the cleanliness and the surface roughness. In the process, electric arc spraying exploits the thermal energy of the arc generated by a contact between two electrically-charged metal wires. The melted Aluminum wires are sprayed by compressed air and help the Aluminum bonded to the substrate (SS 316L). The coating results are done and without finishing process represent to the actual application in Oil & Gas platform.

The corrosion resistance of the layers was then examined through a salt spray test according to ASTM B117-16 standard. In this process, the surface of the object was first scratched with a knife diagonally to form an X. Afterwards, the samples were placed in a salt spray cabinet at 30° against the vertical line. This test spent 96 hours to finish. Next, an ASTM D 1654-standardized visual observation was conducted to evaluate whether any layer was peeled after the scratched area was scraped for the second time.

To test their coating layer’s bond strength, the samples underwent a mechanical pull-off test. Before this evaluation took place, the surfaces of both samples and dolly were cleaned. the dolly surface then coarsened with a sandpaper. The surface of sample was attached to the dolly using Araldite glue. The dolly position was kept and designed so it unable to move until the glue was completely dry. The curing time was 24 hours. In operation, the pull-off test device utilized a perpendicular force to pull the dolly until it detached from the samples’ surface or reached its maximum limit, 22 MPa by using a tool for rotating the screw inside the device. Below is the picture of the device and the process of mechanical pull-off test.

![Mechanical pull-off test](image)

3. Results and discussion

3.1 Visual Observation

Figure 2 shows the results of visual observation of coatings at spray distances of 10, 20, and 30 cm. On this image, particulate aluminum obviously spread over the entire surface of each sample. The white gloss layers also do not exhibit any particular traits. In addition, the appearance of the coating layers does not indicate any sticking failures. As well as that, no layer peels occur in all samples. These points imply that the spray distance has no effect on the layers’ view.
Figure 2. The visual observation of aluminum coatings at spray distances of: (a) 10 cm, (b) 20 cm, and (c) 30 cm.

3.2 Corrosion Resistance Test
The next stage was the corrosion resistance test. The aluminum layers were tested through a salt spray test. Before undergoing the salt spray test, as shown on Figure 3, the aluminum coatings looked shiny and clean while after passing this test, as shown on Figure 4, its color changed wholly at all spray distances. The color entire change indicates a response to destructive environments and protection capability.

Figure 3. The pre-salt spray test samples.
This observation indicates that as long as the aluminum coatings are attached entirely to the samples’ surface and have no sticking failures, they will keep protecting the surface from aggressive ion attacks in the corrosive environment. The aluminum layers act as a barrier between the coated objects and destructive surroundings. As well as that, the coatings also served as a sacrificial anode and cathodic protector [8].

Among all the spray distances, 20cm yields the best corrosion resistance. On the contrary, the corrosion resistance is relatively low at further spray distance, 30cm, as the porosity becomes higher. This high porosity is triggered by the pace of the bigger particulates which faster leads to the surface of the object that, then, drives air trapped when quenching. So happens at closer spray distance. This distance brings about microcracks which, in turn, produces porosity within the layer [11,12]. All these imply that aluminum coatings can provide long-term protection which is much better than painting [9]. The same results are shown in research conducted by Oladijo (2016) and Wang (2016).

3.3 Bond Strength Test
The bond strength of the aluminum coatings on the stainless steel substrates’ surface determines the resistance power of the object in question. This aluminum-coated object tends to be durable when the coating retains on the surface as it keeps the object against all destructive factors. The bond strength value of each sample is shown on the graph below.

Figure 5 shows that the bond strength of the coating layers at a spray distance of 20cm, 12.5 MPa, is greater than that at 10 and 30cm. That of 20cm has proved to have the best interlocking strength because
at this distance, particulate aluminum penetrate well on the stainless steel surfaces coarsened through the blasting process. Meanwhile, the bond strength of those at 10cm is not as good as that at 20cm due to its closeness. This nearness leads to overheating and internal stress in the aluminum coating layers [10]. Like the layers’ bond strength at 10cm spray distance, that at 30cm also has a lower adhesive force than that at 20cm. The reason is that at this spray distance, the larger particulates accelerate to the surface of the object so that they do not penetrate properly. Because of this poor penetration, the interlocking between the coating layers and the surfaces of the substrates becomes weak. This investigation results are not different from those obtained by Gedzevicius dan M Hafiz Abd Malek, that the best spray distance for thermal spray methods, particularly, electric arc is 15-25cm [13].

4. Conclusion
The aluminum spray distance of 10 cm are not optimum enough because the heat of the electric arc spraying can lead to overheating and make the internal stress to the coating results, it can lead to lower bond strength (9 MPa) and lower corrosion resistance due to in this distance can bring microcracks inside the layer and then produce porosity or coating failure within the layer. If the distance are further can results the interlocking mechanism and the corrosion resistance become weak due to the larger particulates accurate to the surface due to its kinetic force and causing poor penetration and leading the high porosity to the coating results. In fact, All the spray distance does not indicate any coating failure and all the surface are covered with Aluminum which the coating also served as a sacrificial anode and cathodic protector, so this implied that the spray distance 10 cm, 20 cm, and 30 cm are may be used. Based on this investigation above, to get high quality of the coating, the 20cm spray distance yields the strongest corrosion resistance and the highest bond strength, 12.5 MPa, among others.

Acknowledgment
This research is fully funded by PITTA UI year 2018 under the contract number of 2520/UN2.R3.1/HKP.05.00/2018 and, in terms of research equipment, supported by Thermic Coating Industries and Gunanusa Utama Fabricators, Inc.

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