Corrosion Behavior of ASME SA-192 Steel Finned Tube by Wire Arc Spray in Temperature Control and High-Salt Environment

M Sangsuriyun¹*, P Surin¹ and K Eidhed²

¹ Department of Advanced Manufacturing Technology, Faculty of Engineering, Pathumwan Institute of Technology, Bangkok, Thailand
² Faculty of Engineering, King Mongkut’s University of Technology North Bangkok, Bangkok, Thailand

*e-mail: montri.sang@npu.ac.th

Abstract. This paper proposes the corrosion behavior of ASME SA-192 steel finned tubes which were spray-coated with TH450 Chrome Nickel amorphous in a salt spray test chamber using 5% sodium chloride solution at a spraying speed of 12 mL/h according to The American Society of Testing and Materials (ASTM) B117 Standard. The salt spray test for 120 hours in the salt spray test in the chamber, the specimens that were exposed to moisture and salt fog in the surrounding air developed thin brown rust dots on the surface. The experimental results concluded that the specimens could withstand the corrosive environment for 5-15 years. The hardness test of coated specimens after the salt spray test for 480 hours showed that hardness and tensile strength of all specimens decreased due to surface damage from salt adsorption which resulted in blackish-brown rust and decreased tensile strength. Though, elongation of the coated specimens increased due to salt adsorption by the specimen surface, resulting in partial corrosion and rusting on the specimen surface. However, both parameters of the specimens exceed the ultimate tensile strength (UTS) standard test. Therefore, the spray coating with Chrome Nickel amorphous can increase the mechanical strength and corrosion resistance.

Keywords: Spray coating, ASME SA-192 steel, Mechanical properties, Cooling of finned tube

1. Introduction
The study of hardness improvement of ASME SA-192 steel finned tube using wire arc spraying process with TH450 Chrome Nickel amorphous, the cooling test showed no difference in the cooling rates between uncoated and coated specimens. The coated specimens will have a higher surface hardness which will increase the tensile stress of all the specimens and pass the Ultimate Tensile Strength (UTS) standard test. Therefore, spray coating a suitable technique for industrial applications that require higher hardness and can reduce maintenance costs. Arc Spraying is a thermal spraying technique that uses the heat released from electric arcing between two electrodes, in which the coating material must be in the form of conductive wire. Two wires are used as electrodes in an electrical circuit. These wires are fed from each side of the spray gun, and the end of each wire touches each other in front of the spray gun. Once electricity is applied through the wires, an electric arcing appears at the wire ends in front of the spray gun. The heat released from arcing increases and the wire ends are continuously heated to the melting point of the wire material. While high-pressure air or gas stream is applied at the wire ends from the back of the spray gun. This air or gas stream must have sufficient pressure to tear the molten wire material off the wire ends into molten aerosols which will then travel into the air or gas stream until these aerosols hit the surface of the specimen and harden and form a coating layer [1-3]. This technique
is a suitable for industrial applications, including the production of new materials and repair work as an alternative to plating which requires higher hardness and corrosion resistance without affecting the toughness of the material [4-5]. A study [6] suggested that spray coating could prevent corrosion caused by salt or chlorine and the coating particles show high density with no crack but a few defects. According to the previous studies, the findings show that the specimen with the highest tensile strength does not always show the highest strength compared to the fatigue test [7].

In this study, we conducted the salt spray corrosion test of the finned tubes that were spray-coated with Chrome Nickel amorphous to simulate the potential exposure of products used in salt environments close to a coast or at sea, the mechanical properties and corrosion of the coated specimens were compared.

2. Experimental Procedure

2.1. Materials and specimen preparation

The materials used in this study were 30 fined tubes made of ASME SA-192 high-carbon coated steel by wire arc spraying process. These finned tubes consist of 0.6-0.18% C, 0.27-0.63% Mn, 0.25% Si, 0.035% P and 0.035% S. The tube has a diameter of 0.38 mm, the wall thickness of 3.2 mm, height and thickness of fin are 16 ± 1 mm and 1 mm, respectively. These specimens in this study were prepared according to the standard finned tube production [7].

2.2. TH450 Chrome Nickel amorphous coated wire and spray parameters

In wire arc spray, chemical properties of the wire used for TH450 Chrome Nickel amorphous coating consist of Cr 30%, Nb 10%, B 4%, Ni 10%, Fe Bal and other substances <50% by weight. Besides, the spray in this research determines the parameters as follows: diameter 1/16” (1.6 mm), air pressure 80-100 psi, voltage 28-32 psi, amperage 100-300 and standoff 4-7” (10-17 cm) [8].

2.3. Wire arc spray coating

Before spray coating, rust stains on all 30 specimens must be removed by sandblasting and then wiped clean. After that the specimens were spray-coated with ASME SA-192 high-steel carbon using TH450 Chrome Nickel amorphous by wire arc spraying process using Thermion Auto Arc AVD 3350, AHB-20A/D, air compressor at 20 HP, 15 kW, air 6 bar, 37.5 voltage and 19.6 A. All specimens were spray-coated, which default values of spraying as the following parameters: air compressor, 20 HP/15 KW, model AH 20A 8 bar, voltage 37.5 V, electric current flowing through a conductor 19.6 A and temperature 926.67°C or 1,700°F.

2.4. Corrosion test

Corrosion testing procedure of the coated specimens with TH450 Chrome Nickel amorphous using Salt Spray Tester TU380 is as follows: all 30 specimens were placed in the chamber which was designed and controlled according to ASTM B117 standard. The corrosion test was performed at 38°C by using 5% NaCl at a flow rate of 12 mL/h. The salt fog accumulated in both volumetric cylinders for at least 80 mm³, in which the first cylinder was kept near the salt spray nozzle and another cylinder was placed farthest from the sprayer. Visual inspection of specimens was then performed and compared with the microscopic examination results at 100 μm magnification on the 24, 120, 240, 360 and 480 hours [9].

2.5. Micro- and macrostructural analysis

The micro- and macrostructural analysis of all seven specimens was performed using an inverted microscope model Zeiss Vert A1 in order to investigate the corrosion caused by the salt spray test.

2.6. Hardness test using Micro Vickers Hardness Tester

After the salt fog was sprayed on the surface coated specimen with TH450 Chrome Nickel amorphous in the Salt Spray Tester TU380 chamber and left for 480 hours, the hardness test of all seven specimens was performed with the design parameters as [7]. Before the hardness test, the specimen surface was polished using 180 - 1200 grit sandpaper and then finished using felt cloth and 0.3 – 0.1 μm alumina
powder. The specimens were then etched with a mixture of nitric acid and alcohol (10:90) to expose the microstructure of the specimens. After these pretreatment steps, the hardness test of all specimens was performed with 0.98 kg compression load using Micro Vickers Hardness Tester model HV-1000. The results were expressed as HV$_{0.5}$.

2.7. Tensile strength test
The tensile test of specimens was performed at Disp of 0.500 mm/min, 1.00 kN/s or 10 MPa/s load and 0.0500 mm/s extension speed in triplicate per treatment to compare between the specimens with and without salt spray test. Then the specimens are tested for tensile strength in order to compare with the standard ultimate tensile strength (UTS) that is higher than 350 MPa [10].

3. Results

3.1. Salt spray corrosion test of coated specimens with Chrome Nickel amorphous

3.2. Compare the hardness of the ASME SA-192 steel finned tubes using Nickel Chromium amorphous coating with salt spray testing.

The corrosion test using Salt Spray Tester TU380, the rusting or oxidation reaction $\text{Fe} + \text{H}_2\text{O} + \text{O}_2 = \text{Fe}_2\text{O}_3\text{H}_2\text{O}$ [11] occurred on the surface coated specimen with Chrome Nickel amorphous on the first day or within 24 hours as shown in figure 1 (a). On 480 hours, the visual inspection of coated specimens showed that there were blackish-brown rust layers all over the specimen surface and the microscopic examination at 100 μm magnification showed that there was only 10% of Chrome Nickel amorphous coating layer left on the specimen surface as shown in figure 1 (b). The corrosion appeared as wells and rust layers. In conclusion, the results showed that after the coated specimens with Chrome Nickel amorphous was sprayed with salt fog in Salt Spray Tester in the chamber for 120 hours, corrosion occurred did not severally affect the strength and specimens. So, the specimens can withstand corrosion in normal environments for 5-15 years [12]. However, when continuing the test, the rusting of the specimen in the chamber on 480 hours caused by the oxidation due to moisture and salt in the surrounding air, which would affect the safety.

3.3. Compare the hardness of the ASME SA-192 steel finned tubes using Nickel Chromium amorphous coating with salt spray testing.

Figure 2 (a) shows the test points for hardness test using Micro Vickers Hardness Tester comparing the hardness after the salt spray test (NiC-S) of coated specimens with Chrome Nickel amorphous. As shown in figure 2 (b), the hardness at point 1-3 and point 8-10 were similar and were in the range of 400-650HV because these areas were coated with Chrome Nickel amorphous and all seven specimens were spray-coated simultaneously. However, the heat-affected zone (HAZ) was observed between the coating layer, and the tuned point of the specimen was affected by the heat resulting in higher hardness compared to the heat-affected zone, and hardness at point 1-7 of all specimens decreased to 131-155HV$_{0.5}$.
Figure 2. The hardness of specimens that are coated with TH450 Chrome Nickel amorphous, without salt spray test (NiC) and with salt spray test (NiC-S) using Salt Spray Tester TU380.

For NiC-S method, after the salt spray test in Salt Spray Tester TH380, the hardness at the coated points significantly decreased. The average hardness at point 1-10 was in the range of 150-190 HV as shown in figure 2 (b) which was consistent with the microscopic examination results showing saline adsorption and blackish-brown rust on specimen surface on 24 hours which increased continually until 480 hours. Corrosion appeared as rust layers covering a wide area of the specimen surface and resulted in decreased in hardness.

3.3. Compare the tensile properties of the ASME SA-192 steel finned tubes using TH450 Nickel Chromium amorphous coating with and without salt spray testing using Salt Spray Tester TU380

Figure 3. Comparison of the tensile strength of the coated specimens with TH450 Chrome Nickel amorphous without (NiC) and with salt spray test (NiC-S) using Salt Spray Tester TU380.

The comparison of the tensile strength of the coated specimens with Chrome Nickel amorphous, the specimens without salt spray as shown in figure 3 (a) showed high tensile strength and exceed the UTS standard test, while the coated specimens with Chrome Nickel amorphous and sprayed with salt fog in the Salt Spray Tester TU380 (NiC-S) showed a decrease in tensile strength as shown in figure 3 (b). The accelerated rusting using sodium chloride solution with NiC-S method showed that there were two types of rust, reddish-brown and blackish-brown rush dots and cracks and crack propagation in the blackish-brown corrosion holes were also found. A study [12] suggested that as tensile strength decreased, elongation of specimen increased compared to that of uncoated specimens because Chrome Nickel amorphous coating layer was only partially damaged by rust. The experimental found that all specimens showed high tensile strength and exceed the UTS standard test.
4. Conclusions and Recommendations

- In this study, the salt spray test of ASME SA-192 steel finned tubes that are coated with TH450 Chrome Nickel amorphous was studied using Salt Spray Tester TU380. The results showed that arc spray coating with TH450 Chrome Nickel amorphous could increase the corrosion resistance against salt spray. The corrosion was not severe and did not affect the strength of specimens. This coating technique can extend the useful life of specimens by 5-15 years in normal environment according to ASTM B117 standard. The coating can be done many times, resulting in reduced maintenance costs. And this method should be used in other materials.

- The hardness of the specimens sprayed with salt fog using the Salt Spray Tester TU380 decreased after 480 hours of testing. Besides, the specimens showed a decrease in tensile strength. However, coating with Chrome Nickel amorphous could protect the specimen surface and result in partial damage and higher elongation compared to uncoated specimens. The results also showed that all specimens showed high tensile strength and exceeded the UTS standard test.

References

[1] Kelkar M, and Heberlein J 2002 Wire-arc spray modeling. J. Plasma chemistry and plasma processing. 22 1-25
[2] Ducos M and Durand J P 2001 Thermal coatings in Europe: a business perspective. J. Thermal Spray Technology. 10 407
[3] Hutchings I and Shipway P 1992 Tribology: friction and wear of engineering materials vol 2nd, ed Butterworth-Heinemann 13 187
[4] Zahrani E M and Alfantazi A M 2012 Molten salt induced corrosion of Inconel 625 superalloy in PbSO4–PbO4–PbCl2–Fe2O3–ZnO environment. J. Corrosion Science. 65 340-359
[5] Rigney R W, Grubowski A, McCaw R and Scandell K 2001 Component repair and chrome plating replacement with new thermal spray in the united states navy: successes and the future. Materials Characterization, February-March.
[6] Qin E, Yin S, Ji H, Huang Q, Liu Z and Wu S 2017 Hot corrosion behavior of arc-sprayed highly dense NiCr-based coatings in chloride salt deposit. J. Thermal Spray Technology. 26 787-797
[7] Sangsuriyun M, Surin P and Eidhed K 2006 Optimization of high-frequency resistance welding process using mechanical property of finned tube SA-192 steel. J. Engineering and Applied Sciences. 15 607-612
[8] Basumatyari J, Wang H, Watson S,Powrie H E G 2005 The corrosion of nickel-aluminium bronze in seawater [in A Century of Tafel’s Equation: A Commemorative Issue of Corrosion Science] J. Corrosion Science. 47 3336-3367
[9] Wan Y, Macha E N and Kelly R G 2012 Modification of ASTM B117 salt spray corrosion test and its correlation to field measurements of silver corrosion. J. Science and Engineering. 68 036001-1-036001-10
[10] ASTM D and others 1995 Standard test method for tensile properties of thin plastic sheeting. J. American Society for Testing and Materials. ed West Conshohocken 194-202
[11] Hua Y, Barker R and Neville A 2015 Understanding the influence of SO2 and O2 on the corrosion of carbon steel in water-saturated supercritical CO2. J. Corrosion. 71 667-683
[12] Van Boven G, Chen W, Rogge R and Sutherby R 2007 The Effect of Residual Stress on Pitting and Stress Corrosion Cracking of High Pressure Natural Gas Pipelines. J. Acta mater. 55 29-43