iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** VI **Month of publication:** June 2020

DOI: http://doi.org/10.22214/ijraset.2020.6360

Thermal Sprayed Aluminium Coatings: A Review

Sunil Kahar[1], Ashutosh Singh[2], Suraj Dabhekar[3], Urvesh Vala[4], Bhargav Navadiya[5], Kaushik Patoliya[6]
[1, 2, 3]Assistant Professor, [4]DGM – L&T Chiyoda, [5, 6]Undergraduate Student, Department of Metallurgical and Materials Engineering, Faculty of Technology and Engineering, The M.S. Univeristy of Baroda, Vadodara

Abstract: The protection of steel structures from Corrosion, Erosion, Heat and Traction can be achieved by Coating. Thermal spraying method for coating is economically feasible and convenient than other coating methods. Thermal Sprayed Aluminium (TSA) coated components are widely used in industries which provides excellent corrosion prevention properties in various environments and increases lifespan of structures. In this article, we reviewed various techniques such as Arc spray, Wire flame spraying and Powder flame spraying which are efficiently used for TSA coatings and studied impacts and comparison of different techniques on corrosion properties, characterization of coating and applications.
Keywords: Thermal Sprayed Aluminium (TSA), Coating, Arc Spray, Flame Spray, Corrosion, Sealer

I. INTRODUCTION

Thermal Spraying Technique for the protection of metals is well established means of coatings of thickness greater than about 50 μm. A wide range of metals or materials can be sprayed by Thermal Spraying Technique for large variety of industrial applications ranging from heavy engineering working industries to the electronics industries. Thermal spray coatings have been produced for at least 60 years but in the last decade, there are several of virtual revolution occurs in the capability of the technology to produce high performance coatings onto a large variety of materials [1].

The principle of thermal spraying is to melt coating material and molten particles are impacted on the surface of substrate material which will solidify rapidly and built a coat. The bonding mechanism is primarily mechanical, and in some cases metallurgical. Each layer bonds to the previous, making a lamellar structure, unfortunately with some occurrence of inclusions, oxides and pores. Aluminium is quite corrosion resistant metal, at least at neutral pH. This is due to the presence of a very stable oxide on the surface [23]. Fabrication of Aluminium coating on to substrate (mainly steel) using this technique is basically called Thermal Sprayed Aluminium (TSA). TSA coated steel structures are widely used in industries which provides excellent corrosion prevention properties in various environments and increases lifespan of structures.

In today’s Industry, there are development in variety of protective coatings for corrosion resistance and that is why TSA has receiving considerable attention. It becomes an efficient solution for long term corrosion control and protection of steel structures. It provides better shell life and consumes less curing time compared to other techniques in terms of life, protection from high temperature and humid atmospheric conditions [2].

II. LITERATURE STUDY

TSA is classified as “lifetime” coating system since it has been identified with a life in excess of 30 years, with zero service maintenance. TSA is an attractive coating system for the splash zone when life cycle performance, life cycle cost and the possibility of using reduced corrosion allowances are considered [3].

TSA coated structures that are applied for service in different kinds of atmospheres mainly, sea-water, oil-gas pipelines, splash/tidal zones, submerged and buried zones etc. and that are protects steel structure either by acting as a barrier or by providing sacrificial protection. TSA coated parts used in offshore industries that are constantly immersed in seawater are usually protected by cathodic protection (providing sacrificial protection), while parts that are exposed to the marine atmosphere are usually protected by protective coatings (acting as a barrier). In the splash/tidal zone however, the corrosion of structure is controlled by robust coatings and corrosion allowance (in splash zone) as well as cathodic protection (for parts located below mean water level) [4] [5].

Coating material which is more active than steel (i.e. aluminium) provides cathodic protection to the steel and acts as a sacrificial anode. When structure with TSA coating is immersed in seawater for service application, a galvanic coupling is established between aluminium coating (anode) and steel (cathode), and electrons flow from aluminium coating towards the steel substrate with simultaneously dissolution of aluminium coating, as shown in figure 1 schematically[6].

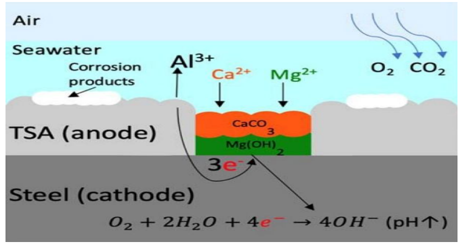


Fig. 1 Cathodic Protection to the steel provided by Al coatings

As per figure, TSA coating (cathode) which is applied on the steel is act as a barrier as well as sacrificial anode to the steel which prevents steel structure from corrosion, erosion, traction etc. and increase lifespan of the structure.

Various thermal spraying techniques are available on basis of characteristics of feedstock material and heat source used for melting purpose. Generally TSA coatings can be prepared efficiently by two techniques namely Electric Arc (EA) technique and Flame Spray (FS) technique.

A. Electric Arc (EA) Spray Technique

Thermal arc spray aluminium coating is widely used in recent years as a protective coating due to its capability to withstand high temperature and cost effective process.

This technique involves feedstock material (aluminium) in a form of two current carrying wires fed into spray gun at a common arc point and due to the generation of arc between aluminium wires and substrate material (steel), heat is generated which is used to melt the feedstock material. The molten material continuously atomized by compressed air, forming a spray of molten metal with a very high material throughput, as high as 40 kg/h [7].

The equipment setup for TSA coating using arc spray technique contains four major parts described below [8]:

1) Spray gun – to spray molten aluminium on steel substrate
2) Air compressor – to accelerate molten aluminium
3) Blasting pot – for garnet space when blasting preparation is performed
4) Thermal arc spray machine – to melt aluminium by receiving current

This method deposits a consistently atomized coating with high bond strengths and the highest deposition rates of any thermal spray method. However, pre surface treatments are critically important before performing thermal arc spray. The surface must be clean and blasted with compressed air abrasive blasting to give sharp profile to TSA to bond onto steel substrate.

After blasting process, the following conditions must be confirmed before starting TSA coating process [9] :

a) According to ISO 8501-1, degree of substrate surface cleanliness must be at minimum of SA 2.5.
b) Surface roughness must be between 75 to 110 microns, by using a replica tape method. The replica tape is attached on the substrate surface which was blasted and rubbed with a circular ended tool until a circular dark colour appears. Then the replica tape is removed and measured using a dial gauge (ISO 8503-5, 2003).
c) Salt contamination of surface shall not exceed 20 mg/m2 using Elcometer 138 based on ISO 8502-6 (1995).
d) Dust level must be in rating 0 or maximum of rating 1 only by using a cellophane tape according to ISO 8502-3 (2007).

Main purpose of TSA coating is to protect steel from corrosion and to fulfill this purpose, coating process using electric arc spraying should be done correctly. This can be achieved by proper controlling of process parameters and characterization of coating.

Various process parameters of arc spray technique with their possible values/ranges are described below [9]:

TABLE I. Arc Spray Process Parameters

Pressure	4-6 bar
Particle Temperature	Up to 5000ºC
Particle Velocity	100 m/s – 300 m/s
Feed stock form	Ø 1.6 mm -3.2 mm
Max. spray rate	16 kg/hour
Spray distance	15 cm – 25 cm
Power Input	6 – 80 kW
Voltage	30 V
Ampere	200 A

In TSA Coating by arc spray technique, Porosity level can be affected by particle temperature and particle velocity. Increasing in flow rate will increase particle velocity and resulting dense microstructure. With the increase of particle velocity, the size of droplets deposited on substrate will decrease. In a big surface area, small size droplet gives significant presence; during the flight the droplets are oxidized on bigger degree compared to the big size droplet. So there are biggest possibilities of increasing of oxidation [8].
Coating thickness of Arc Sprayed aluminium is affect adhesion strength of TSA coating. As coating thickness increases, adhesion strength increases. The ideal coating thickness could start from 200 microns. Thermal arc spray process would oxidize the TSA coating layer and forms aluminium oxide layer. This oxide layer may help reducing the porosity level of TSA coating and forms dense structures which contribute to the increase in coating hardness [10].
The current density of TSA coating deposited by Arc Spray method is higher than that of the bulk aluminium which could be related to the existence of pores in the thermal spray coating which is indicated by Tafel Polarization reading in 3.5% NaCl solution. The electrolyte is reached to the substrate through interconnected pored and due to galvanic corrosion, current density of aluminium is accelerated. The EIS (Electrochemical Impedance Spectroscopy) measurements indicates that the coatings performance can be improved by increasing the exposure time due to the plugging of defects by corrosion products which obstruct higher penetration of the electrolyte through the porosities. The corrosion products act as barriers to the electrolyte penetration during exposure to seawater. This improvement is due to the pore sealing by corrosion products such as aluminium oxides and aluminium hydroxides during exposure [11].

B. Flame Spray (FS) Technique

There are two types of flame spraying techniques based on form of feedstock material i.e. Wire form, Powder form. Those techniques are described below:

1) *Wire Flame Spraying*: In this technique, Aluminium wire is being melted using flame which uses combustible gas as a heat source and molten particles are accelerated towards the work piece using pressurized air. Acetylene, propane, methyl – acetylene – propadiene (MAPP) gas, and hydrogen, along with oxygen, are commonly used flame spray gases [6] [12]. The control of melt and atomization of metals with various melting points can be achieved by controlling the speed at which wire is fed into flame spray gun. The compressed air also used to control the operating temperatures of the gun and to further atomize the molten spray metal and increase the velocity at which it is sprayed [2]. The main drawback of this procedure is the fact that only specially designed alloys can be fused after spraying. There is also possibility that the base metal properties are negatively modified due to the heat input during fusion of the coating. This point must be taken into consideration before coating of specialty steels by running preliminary tests. By precisely controlling heat input and by the use of automated systems, negative effects on the base metal can usually be overcome [13].
2) *Powder Flame Spraying*: In the Powder Flame spray Process, powdered feedstock is aspirated into the oxyfuel flame, melted, and carried by the flame and air jets to the work piece [14]. Powder flame spraying technique is almost similar to wire flame spraying technique but the only difference is "feedstock" (coating precursor) using here is in powder form instead of wire form before spraying. When aluminium as coating material cannot produce in wire form as per desired criteria easily, powder flame spraying technique is used because it can easily processed into powder form. This flame spray process carried out correctly is called a "cold process" (based on the substrate material which is going to coated) as the substrate temperature can be kept low during processing avoiding damage, metallurgical changes and distortion to the substrate material [24]. This Method has found widespread use around the world for its relative simplicity and cost-effectiveness [7]. Major Characteristics of coating such as Thickness, Microstructure, Porosity, Uniformity and some process parameters like Powder supply rate, Distance between nozzle of flame gun and work piece, Motion of work piece, Step between two parallel passages of work piece and Air over pressure that are influences the corrosion rate of TSA Coatings. “Powder supply” which is one of the process parameters has highest influence on the thickness of coating. With the application of a more quantity of powder a thicker layer can be obtained with same time along with other unchanged parameters. The parameter with the second highest influence is the distance between nozzle of flame gun and work piece. By increasing the distance, coating thickness can be decreasing. The third most important is the step between two parallel passages of the work piece, because the step change directly affects the overlapping layers. By keeping a lower step, a thicker film can be obtained [15]. The only parameter that influences the corrosion rate of TSA coating is the powder supply, while all other parameters have no effect on the corrosion rate. As a rate of powder supply increases, the corrosion rate of the TSA coating is increases. The reason behind increment in corrosion rate is microstructure of the TSA coating which is poor, since the temperature of the gas flame is decreased by increased powder supply, and thus major porosity may occur, that is the reason of increasing corrosion rate of TSA coating. Spraying parameters have a negligible

influence on corrosion potential and polarization resistance [15]. Thus, the main objectives that are Corrosion rate, Wear behaviour, Heat resistance etc. of steel structures exposed to marine environments, splash zones and other corrosive atmospheres can be controlled by controlling process parameters and coating parameters that are mainly thickness of TSA coating, microstructure, uniformity of coating etc.

C. Comparison of Both Methods

A comparison between TSA coatings that are deposited by using Flame Spraying (FS) and Electric Arc (EA) as per some research papers are described below:

1) The oxide layers of coatings that are deposits by using both techniques are different which can be observed by X-ray photoelectron spectroscopy (XPS).This difference also indicate the formation of different aluminium compound. There are different corrosion products that were formed on those coatings after a 4000-hour saline mist test. Bayerite is present in coating by the FS process and boehmite in the coating that was deposited by EA. The coating deposited by EA showed a loss of thickness when subjected to saline mist [16].
2) The coatings deposited by FS onto preheated substrate showed corrosion products adhering strongly to the surface, while the coatings deposited by EA without preheating the substrate showed only weakly adhering corrosion products [16].
3) In case of surfaces with higher roughness and without pre-heated, EA technique must be required to comply with adhesion requirements set by the standards, while in TSA coatings deposited by FS, standard values can be meet only if surface is preheated [17].
4) Based on lab and field tests on TSA that was prepared by using both methods, that the spraying method had smaller influence on the performance of the coating, while the arc-sprayed coatings exhibited better adhesion (arc-sprayed Al: 9.0 ± 1 MPa, flame-sprayed Al: 3.5 ± 0.34 MPa) [18].
5) Coatings that are prepared by FS exhibits a higher level of porosity in comparison to the ones that are prepared by EA [9].
6) Porosity is an inevitable characteristic feature of thermally-sprayed coatings, but its level can be altered by selecting appropriate feedstock material, application method, and spraying parameters. To obtain a less porous coating, oxyfuel flame spraying and small diameter wire (1.6 and 2.3 mm), or low current (100–200 A) arc spraying should be used [19].

D. Sealer Application (Post Coating Treatment)

On TSA coated steel, corrosion products forms that enhances the barrier properties of coatings by means of blocking cracks and pores on the coating. However during the initial period of application, corrosion products are not present on the coating so that dissolution of aluminium coating is rapid [20].

To increase the lifetime of TSA coatings and prevent the development of discolored areas, suitable Sealant systems can be applied. Sealants are designed to penetrate and fill the surface-connected Porosity, and prevent the penetration of the corrosive substance within the coatings [6].

Organic sealants are comprised of epoxies, phenolics, furans, polymethacrylates, silicones, Polyesters, polyurethanes, and polyvinyl esters. For TSA, aluminium-filled vinyl and silicone have been used [21]. Epoxy based Aliphatic Polyurethane sealer has low odour, has a high gloss, UV stable, exhibiting fast cure time, and excellent stain resistance and chemical resistance protection for the TSA coatings.

Application of sealers must be done within 24 hours if coatings were done at outdoors and in case coatings were done indoors, sealer must be applied within 48 hours. A sealer must have 40 microns thickness [2]. Inadequate sealing and inappropriate TSA thickness can results in blisters and failure of the coatings under certain circumstances [22]. It must be noted that application of sealant will increase the cost of coating process.

E. Applications of TSA

TSA coatings can be used for industrial applications such as seawater, offshore structures, marine applications, hot fluid carrying containers etc. for the purpose of wear resistance, erosion and traction, heat and corrosion resistance. For corrosion control, TSA coatings fall into two groups: anodic and neutral coatings. General for all of the coatings is act as a barrier between corrosive environment and substrate material to protect substrate material. The anodic coating, where aluminium is anodic relative to the steel and act as a sacrificial anode to protect substrate [23].

Hundreds of bridges, tanks, and oil platforms have been thermal sprayed using Zinc or aluminium over the past 100 years. TSA Coating and their alloys are directly sprayed onto the steel bridges, oil and gas pipelines, ship hulls, tanks etc. Some of the photographs of TSA applications are displayed below [2]:

Fig. 2 TSA application in offshore structures

Fig. 3 River Bridge structures coated with TSA

Fig. 4 Oil Refinery Pipelines coating using TSA

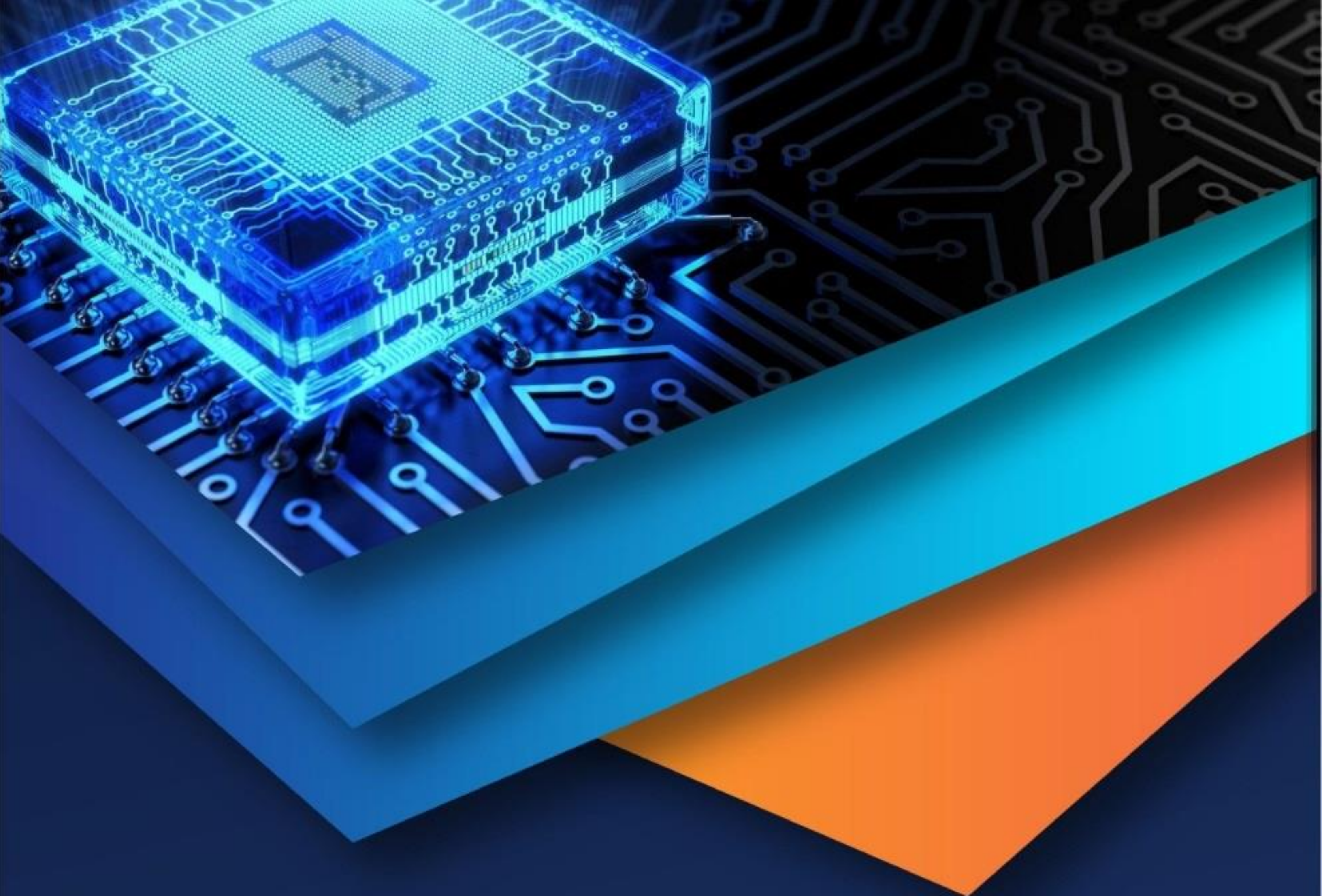
The TSA Coatings should provide a minimum of 20 to 30 years reliable service. Thus saving a significant amount on repair, labour and materials. TSA coatings are most cost effective in terms of purity and quality of the product and corrosion related issues in-terms of monitoring and controlling the situations leading to lower shell life, and damage to the environment [2].

III. SUMMARY

Thermal spraying method for coating is economically feasible and convenient than other coating methods. A wide range of metals or materials can be sprayed by Thermal Spraying Technique for large variety of industrial applications. For TSA coatings, aluminium can protect steel by acting as a barrier and by acting as a sacrificial anode. For aluminium, Arc Spray method and Flame Spray method are efficiently used which can provide resistance to corrosion, erosion, heat, traction etc. Improvements in such properties are totally depends on process parameters and coating characteristics. So, controlling process parameters to exhibit proper TSA coating is most important. In terms of adhesion of coatings, porosities, coating performance and densification of coatings, Electric Arc spraying techniques is better to use while in terms of cost comparison, portability, equipment maintenance and deposition efficiency, Flame spraying technique is advantageous. Therefore, both methods are perfect for its own specific applications. Application of sealers after coating is must require and must be done within 24 hours when coatings are done at outdoors and 48 hours for indoor. For TSA, aluminium-filled vinyl and silicone have been used.

REFERENCES

[1] Thorpe, M.L. (1993), Advanced Materials & Processes (ISSN 0882-7958), vol. 143, No. 5, pp. 50-56, 59-61.
[2] Tailor, Satish. (2016). Thermal Spray Aluminum (TSA) Coating. 10.13140/RG.2.2.11347.99363.
[3] Tiong, D. K.-K., & Pit, H., Experiences on "Thermal spray aluminum (TSA)" coating on offshore structures. NACE International (2004).
[4] Ce, N., & Paul, S. (2016), Thermally Sprayed Aluminum Coatings for the Protection of Subsea Risers and Pipelines Carrying Hot Fluids, Coatings, 6(4), 58.
[5] Det Norske Veritas. Recommended Practice DNVGL-RP-0416 Corrosion Protection for Wind Turbines; DET NORSK VERITAS: Oslo, Norway, 2016.
[6] Syrek-Gerstenkorn, B., Paul, S., & Davenport, A. J. (2020), Sacrificial Thermally Sprayed Aluminium Coatings for Marine Environments: A Review, Coatings, 10(3), 267.
[7] Herman, H., & Sampath, S. (1996), Thermal spray coatings, Metallurgical and Ceramic Protective Coatings, pp. 261–289.
[8] Malek, M.H.A., Saad, N.H., Abas, S.K. and Shah, N.B.M. (2014) 'Critical process and performance parameters of thermal arc spray coating', Int. J. Materials Engineering Innovation, Vol. 5, No. 1, pp.12–27.
[9] Malek, M. H. A., Saad, N. H., Abas, S. K., & Shah, N. M. (2013). Thermal Arc Spray Overview. IOP Conference Series: Materials Science and Engineering, 46, 012028.
[10] Malek, M. H. A., Saad, N. H., Abas, S. K., Roselina, N. R. N., & Shah, N. M. (2013). Performance and Microstructure Analysis of 99.5% Aluminium Coating by Thermal Arc Spray Technique. Procedia Engineering, 68, pp. 558–565.
[11] Abedi Esfahani, E., Salimijazi, H., Golozar, M. A., Mostaghimi, J., & Pershin, L. (2012), Study of Corrosion Behavior of Arc Sprayed Aluminum Coating on Mild Steel, Journal of Thermal Spray Technology, 21(6), pp. 1195–1202.
[12] Amin, S.; Panchal, H. A review on thermal spray coating processes. Int. J. Curr. Trends Eng. Res. 2016, 2, pp. 556–563.
[13] Heath, G. R., Heimgartner, P., Irons, G., Miller, R. D., & Gustafsson, S. (1997), An Assessment of Thermal Spray Coating Technologies for High Temperature Corrosion Protection, Materials Science Forum, 251-254, pp. 809–816.
[14] R.C. Tucker, Jr., Thermal Spray Coatings, Surf. Eng., Vol.5, ASM Handbook, ASM International (1994), pp. 497–509.
[15] Glogović, Z., Alar, V., Kožuh, Z., Stojanović, I., & Kralj, S. (2011). Corrosion properties of thermal sprayed aluminium (TSA) coatings deposited by powder flame spraying. Materialwissenschaft Und Werkstofftechnik, 42(3), pp. 224–228.
[16] Pombo, R.R.M.H.; Paredes, R.S.C.;Wido, S.H.; Calixto, A. Comparison of aluminum coatings deposited by flame spray and by electric arc spray, Surface & Coatings Technology 202 (2007), pp. 172–179.
[17] Paredes, R. S. C., Amico, S. C., & d' Oliveira, A. S. C. M. (2006), The effect of roughness and pre-heating of the substrate on the morphology of aluminium coatings deposited by thermal spraying, Surface and Coatings Technology, 200(9), pp. 3049–3055.
[18] Gartland, P.O.; Eggen, T.G. Cathodic and anodic properties of thermally sprayed Al and Zn-based coatings in seawater Paper No. 367, NACE International: Houston, TX, USA, 1990.
[19] American Welding Society Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminium and Zinc and their Alloys and Composites; AWS C2.18: Florida, FL, USA, 1993.
[20] Lee, H.S.; Singh, J.K.; Park, J.H., Pore blocking characteristics of corrosion products formed on Aluminium coating produced by arc thermal metal spray process in 3.5 wt.% NaCl solution, Construction and Building Materials 113 (2016), pp. 905–916.
[21] Fauchais, P.; Vardelle, A. Thermal sprayed coatings used against corrosion and corrosive wear. In Advanced Spray Applications; Jazi, H.S., Ed.; IntechOpen: London, UK, 2012; pp. 3–39. ISBN 978-953-51-0349-3.
[22] Thomason, W.H.; Olsen, S.; Haugen, T.; Fischer, K. Deterioration of Thermal Sprayed Aluminum Coatings on Hot Risers Due to Thermal Cycling; Paper No. 04021. pp. 1–16.
[23] https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/248984
[24] https://www.gordonengland.co.uk/cps.htm



10.22214/IJRASET

INDEX COPERNICUS

45.98

IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY