

# **A Review of Enhancement of Corrosion Behaviour of Mild Steel Coated with Metal Particles using Plasma Spray Coating**

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**ABSTRACT:** Plasma Spray Coating (PSC) provides enduring protection in mild steel structure and is widely used in various engineering applications. PSC also strengthens the material surface from corrosion damages caused due to atmospheric conditions and also enhances the life span of the material. However, the mild steel substrate gets corroded easily due to the salt content available in the marine solution and environmental changes, thereby forming a rust layers on the surface. Therefore, to avoid this phenomena, metal with highly corrosion resistance need to be used as a coating material for the steel structures installed in marine applications. In line with the context, the present work focuses to enrich the corrosion resistance property and life span of the mild steel structures with nickel alloy coating with a thickness of 100  $\mu\text{m}$  on the surface through plasma spray technique. Corrosion test like salt spray and hot corrosion was determined as per the ASTM standards. Moreover, the morphological structure was also examined using scanning electron microscopy (SEM). The reported results shown that the employment of Ni alloy coating over mild steel substrate improves the corrosion resistance and its life span even during prolonged expose to marine atmosphere.

**KEYWORDS:** Plasma spray coating; Nickel; Mild steel; Corrosion resistance; Surface morphology

## **I. INTRODUCTION**

Owing to the low cost, better strength and machinability low carbon mild steel named as a versatile engineering material is being used in the hull structures of the mechanized boats. Moreover, the corrosion resistance nature of the applied coatings reduces the erosion as well as increases the life-span of the mild steel material when employed to a marine environment [1-4]. For the past few decades, the phenomenon of corrosion in the sea water has boomed to higher extent due to the offshore exploration of oil and gas. Also in many countries around the globe the desalination plants is highly affected by this corrosion issue, thereby the supply of fresh water was getting diminished, whereas on the other hand the utilization of salt water for purifying into fresh water process was gaining momentum [5-6]. In addition, the heavy metallic structures used in ships, oil platforms, piers, pipelines, etc. over the marine environment are made up of conventionally used mild low carbon and low alloy steels were even exposed to corrosion under unsecured conditions [7-10].

Nickel based alloy containing 60-70 % nickel, 20-29 % copper and negligible amounts of iron, manganese, silicon and carbon named as Monel-400 was one of the mostly used coating material [11]. Monel-400 is well

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Vol. 9, Issue 2, February 2020

known for its better stability and toughness in the corrosive environment, whereas it when exposed to immobile salt water like seawater the pitting corrosion take place [12]. However, a decrement in corrosion was noticed for adding higher amount of nickel content in the alloy. Recently, a few researchers had performed the experimentation and reported the effect of Cu-Ni alloys deployed in natural sea water and chloride solutions beneath dissimilar environments [13]. Higher amount of salinity and humidity in the salt water medium is highly corrosive, resulting in huge degradation and causing breakage over 30% of ships and other marine equipment. Also, it was reported that the total cost of marine corrosion worldwide was estimated to be \$50 - 80 billion every year [14].

Diffusion rate of oxygen from the bulk solution to the steel substrate and the percentage of carbon steel have a less impact in the corrosion rate [15]. The mild steel gets corrodes easily so that the paint was coated above the mild steel and even within 6 to 12 months these paint reacts with seawater and starts corrodes the marine structure. To prevent these corrosion, metal which has highly corrosion resistance in sea water can be used as the coating material in the surface of the structures. Moreover, the hull structure and the engine section available in the small mechanized boat gets corroded easily owing to the salt water and liberation of heat from the engine.

Among the various deposition techniques, plasma spray coating promotes better specific properties over the steel substrate, however for attaining the best outcome from the techniques the influencing parameters in this process should be controlled in a systematic manner [16,17]. The present research emphasises on enriching the corrosion resistance property and age of the mild steel structures using Monel 400 of thickness 100  $\mu\text{m}$  as a coating agent through plasma spray technique.

## MATERIAL AND METHODS

Mild steel plate of 6 mm and Monel 400 powder of 40 $\mu\text{m}$  thickness was used as the base materials as shown in Fig 1a. Initially the cleaning was done with water and then dried in the room temperature for thrice. Later it was immersed with acetone to remove the moisture and impurities existing in the metal. The Monel 400 powder was coated on the mild steel surface of 200mm x 200mm x 6mm with thickness 100 $\mu\text{m}$  (Fig 1b) using the plasma spray coating method from 80 to 100 $^{\circ}\text{C}$ . Specimens were sized using the EDM CNC wire cut machine of model SODICK – AQ537L. Wire made of brass with diameter 0.25 mm was used to cut the samples, whereas for prevention of the thermal effects and cooling of the metal wire distilled water was used. The Current used is 180 – 230 Amps, wire feed is 470mm/min.



Fig.1. (a) Monel 400 powder (b) Monel 400 coated Specimen

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Vol. 9, Issue 2, February 2020

## 1. Analysis of Corrosion Behaviour

### Neutral salt spray (NSS) test

Among the various techniques a standardized and popular corrosion test method for inspecting the corrosion resistance of materials and surface coatings can be determined by the salt fog also named as salt spray test. The deposition of rust or oxide layers causing the corrosion is determined after a specified time and the duration of the test depends on the corrosion resistance of the coating. Longer testing period over the coated material determines the corrosion resistant capacity of the materials before prone to oxide formation. This test was carried out using Salt spray testing machine at Chennai Mettlex Lab Private Limited according to ASTM B117.

### 1.2. Hot corrosion test

#### Hot corrosion test

Substrate for the present investigation was selected as the metal disc of diameter 20 mm and thickness 6 mm made of mild steel. Coating layer over the concern mild steel substrate was obtained by the plasma spray process with the application of Monel 400 powder having 40  $\mu\text{m}$  grain size with a thickness of 100  $\mu\text{m}$ . Moreover, an equipment consisting of static constant temperature furnace with a stand tub for placing specimen positioned vertically along with a circular tube for forced cooling of specimens was used for performing furnace cycle test according to the ASTM C 385-58.

### 1.3. Morphological study

Microstructural analysis of the coated specimen was revealed using the COSLAB scanning electron microscope of model SEG100 by viewing it under different magnifications. Positioning and placing of the specimen to the SEM holder was done using a double sided conducting carbon adhesive tapes for prevention of charge formation during exposure to electron beam. Moreover, a thin layer of gold coating is sprayed over the specimen for making the surface conductive and resistance for electron charge gathering.

## II. ANALYSIS OF SPRAY TEST

### 2.1. Effect of salt spray test

Determination of corrosion rate and the oxide formation for the raw and coated Monel 400 specimen of thickness 100  $\mu\text{m}$  were evaluated using the NSS corrosion test. Specimens were kept for an intervened duration of 168 hours and the affecting factors were listed in the table 1. Formation of onset layers like red rust layer ignited over the uncoated specimen in 26 to 30 hours and in 48 to 52 hours for Monel 400 coated specimen respectively. On the other hand, formation of onset of the white rust layer ignited on uncoated specimen in 40 to 44 hours and in 116 to 120 hours for Monel 400 coated specimen respectively and as depicted in table 2 below.

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Vol. 9, Issue 2, February 2020

Table 1 NSS Parameters

Parameters	Requirements	Results
pH Solution	6.5 -7.2	6.88 - 6.94
Air Pressure	12 -18 Psi	13 -15 Pi
Concentration of NaCl	5% ±1	5.2 - 5.3%
Chamber Temperature	35±2 C °	35.2 - 35.8 C °
Collection of Solution/hr	1 - 2ml	1.4 -1.5ml

Table 2 NSS Analysis Result

Specimen	Red Rust Formation in Hours	White Rust Formation in Hours
Uncoated	26 - 30	40- 24
Monel 400	48 - 52	116 - 120

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Vol. 9, Issue 2, February 2020

Fig.2. Monel 400 Coated specimen for NSS

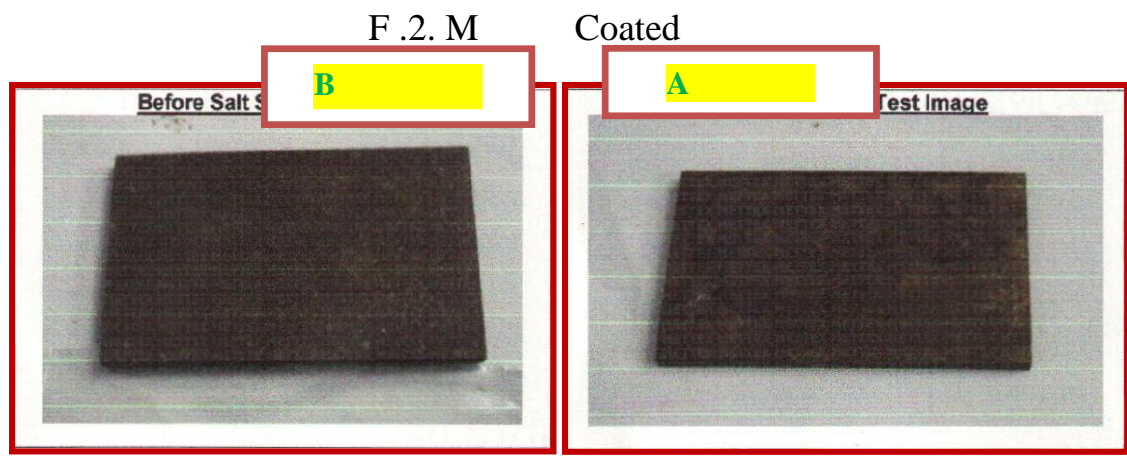
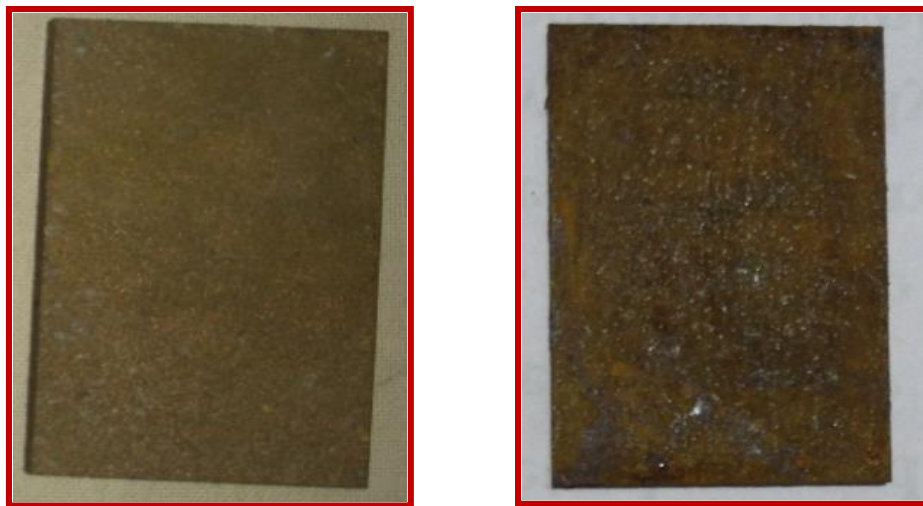


Fig.3. Optical Image of Salt Spray Test

Monel 400 coated specimen having a dimension of size 50 mm x 30 mm x 2 mm displaying the corroded layer before and after NSS were represented in figure 2. However, the images captured for the same specimens through optical microscope before and after NSS test highlighting the visibility of white rust formation was delivered in figure 3. Hence, by viewing the figure 2,3 and table 2 it results in an evident proof for the Monel 400 coated specimen exposing better corrosion resistance than other raw mild steel structures. Higher thickness of specimen, the corrosion slowly declines from raw to the coated specimen. Henceforth, due to the superior properties of the Monel 400 coating it is being suggested for implementation over the surface of mild steel substrates.

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Vol. 9, Issue 2, February 2020

Effect of hot corrosion study



Fig.4. After Hot Corrosion (a) Mild Steel (b) Monel 400 Coated Material

Specimen when reaches the elevated temperature at 500°C the hot corrosion test was investigated, whereas the removal of the coated layer had started only after 48 hours (2 days) and finished at 168 hours (7 days). It was noticed that the initial weight of the parent specimen was 14.4 gm, meanwhile when it crossed 48 hours the weight was reduced to 13.82 gm and reached 168 hours the weight was further dropped to 11.34 gm as shown in table 3. Similarly, the initial weight of the coated specimen was 14.6 gm and after 48 hours the weight was reduced to 14.32 gm and at 168 hours the mass was again dropped to 14.08 gm as depicted in table

3. Since there is a drop in both the specimen but when compare with each other the coated specimen has lowest rate of loss in weight. So we can use this coated specimen for the marine structures which can with stand from thermal energy liberated from the engine or atmosphere. From fig 4 (a) it is obvious that the materials on the surface gets corroded due to the thermal shock and fig 4 (b) shows that it is not corroded as much or comparable to the conventional specimen.

Table 3 Hot Corrosion Result

Specimen	0 hours	48 hours	96 hours	168hours
Uncoated MS	14.4	13.82	13.26	11.34
Monel 400 Coated MS	14.6	14.32	14.21	14.08

Effect of morphological analysis

Microstructural analysis of the paint coated and Monel 400 coated specimen was inspected via COSLAB scanning electron microscope of model SEG100 at different locations and magnifications. Figure 5a explains about the inter-laminar bonding feature of the parent metal was less owing to the poor adhesion factor for the paint coated specimen. Meanwhile, the binding nature of the specimen was good owed to its smooth surface, semi-liquid behavior and pores are found to be very less in the paint coated specimen. Techniques like bond coating and over

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Vol. 9, Issue 2, February 2020

coating also lost its performance over the paint coated specimen due to its negative impacts over the metal surface. On the other hand, figure 5b describes an excellent inter-laminar bonding nature of the parent metal with the monel 400 coating done using the plasma spray coating technology. It was also noticed that better binding nature between the parent and coated particles was seen due to the particle size and solid powder state along with less porous nature. Hence, because of the superb features like binding with coated specimen over the base metal under both bond coat and over coat, Monel 400 coating can be deployed for mechanized boat hull structures in the salt water mediums.

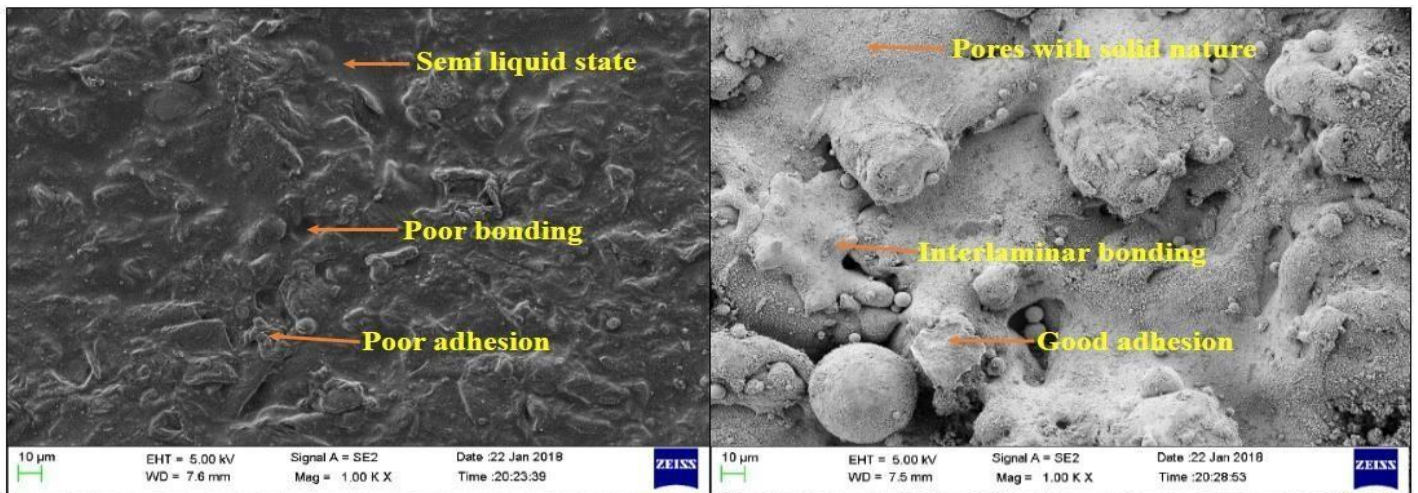
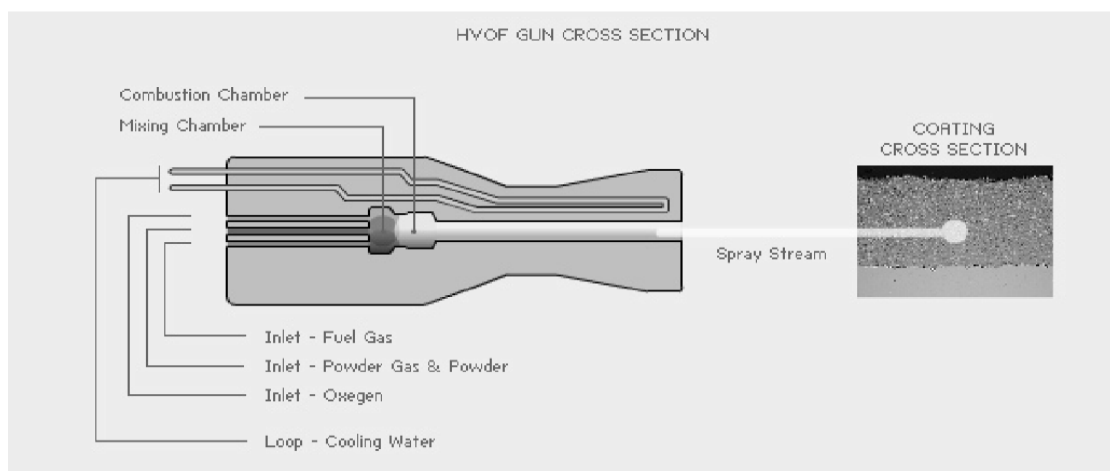


Fig.5. (a) SEM of Paint Coated Structure (b) SEM of Monel 400 Coated Structure

### JOURNAL PAPER

Asa Singh et al (2017)



Schematic diagram of HVOF spraying process

Hot corrosion is a serious problem in various high temperature applications. The thermal spray coatings provides possible solution to counter the problem of hot corrosion in high temperature environment and enhances the

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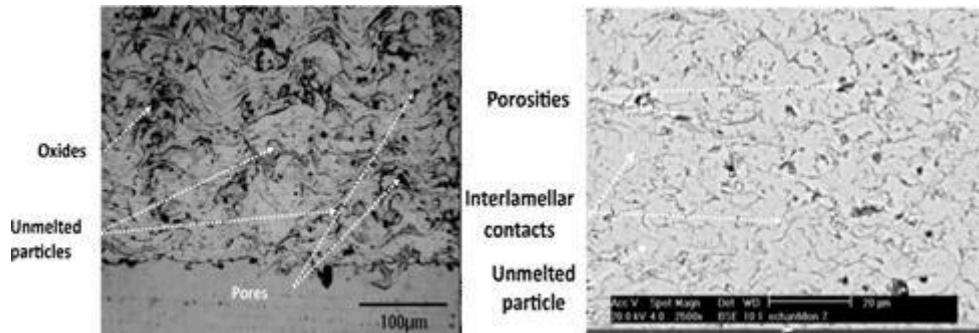
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Vol. 9, Issue 2, February 2020

life of equipment. Thermal spraying is an effective and low cost method to apply thick coatings to change surface properties of the component. Thermal spraying, a group of coating processes in which finely divided metallic or non-metallic materials are deposited in a molten or semi molten condition to form a coating. The coating material may be in the form of powder, ceramic-rod, wire, or molten materials. In this review, the performance of Thermal spray Nickel-Chrome coatings by different investigators has been presented.

P. Fauchais et al (2012)



Coatings have historically been developed to provide protection against corrosion and erosion that is to protect the material from chemical and physical interaction with its environment. Corrosion and wear problems are still of great relevance in a wide range of industrial applications and products as they result in the degradation and eventual failure of components and systems both in the processing and manufacturing industries and in the service life of many components. Various technologies can be used to deposit the appropriate surface protection that can resist under specific conditions. They are usually distinguished by coating thickness: deposition of thin films (below 10 to 20  $\mu\text{m}$  according to authors) and deposition of thick films. The latter, mostly produced at atmospheric pressure have a thickness over 30  $\mu\text{m}$ , up to several millimeters and are used when the functional performance and life of component depend on the protective layer thickness. Both coating technology can also be divided into two distinct categories: "wet" and "dry" coating methods, the crucial difference being the medium in which the deposited material is processed. The former group mainly involves electroplating, electroless plating and hot-dip galvanizing while the second includes, among others methods, vapor deposition, thermal spray techniques, brazing, or weld overlays. This chapter deals with coatings deposited by thermal spraying. It is defined by Hermanek (2001) as follows, "Thermal spraying comprises a group of coating processes in which finely divided metallic or non-metallic materials are deposited in a molten or semi-molten condition to form a coating". The processes comprise: direct current (d.c.) arcs or radio frequency (r.f.) discharges-generated plasmas, plasma transferred arcs (PTA), wire arcs, flames, high velocity oxy-fuel flames (HVOF), high velocity air-fuel flames (HVAF), detonation guns (D-gun). Another spray technology has emerged recently; it is called cold gas-dynamic spray technology, or Cold Spray (CS). It is not really a thermal spray technology as the high energy gas flow is produced by a compressed relatively cold gas ( $T < 800^\circ\text{C}$ ) expanding in a nozzle and will not be included in this presentation.



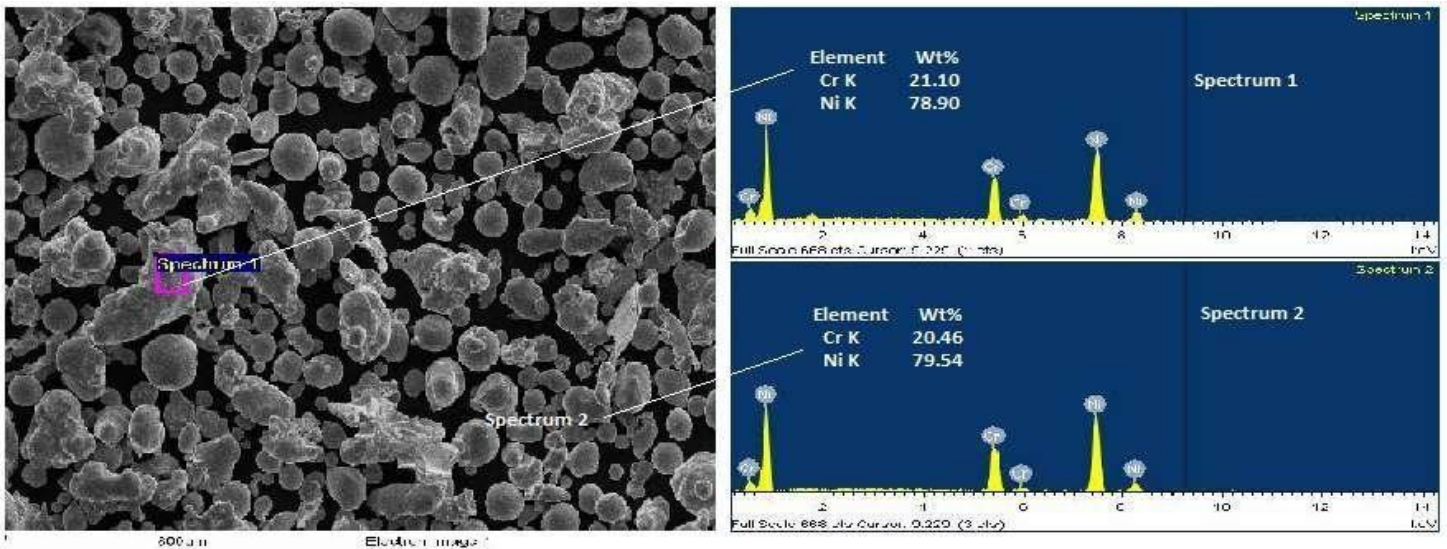
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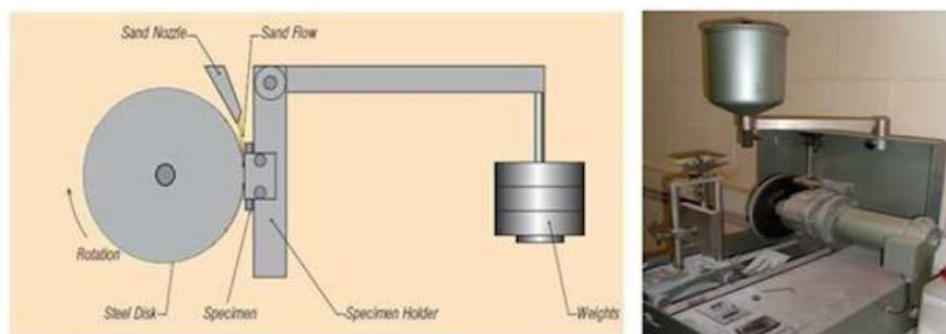
Vol. 9, Issue 2, February 2020

Arunish Mangla et al (2017)



Material deterioration is a major issue in various high temperature applications. So it is important to understand the mechanism of hot corrosion in metals/alloys at high temperatures and to provide the protective coating for their economic, reliable and safe operation. Nickel based coatings are commonly used for the enhancement of resistance against the hot corrosion. These coatings can be developed by using different thermal spray techniques. The present investigation is an attempt to compare the resistance offered against hot corrosion by Nickel based coating sprayed by two different thermal spray techniques. Coating powder containing 80%Ni20%Cr was deposited on SA-213 (T22) using two thermal spray techniques, HVOF and Plasma spray. Hot corrosion studies were performed in Na<sub>2</sub>SO<sub>4</sub>-60%V<sub>2</sub>O<sub>5</sub> environment at 900°C under cyclic conditions on bare and coated specimens. Thermo-Gravimetric, Scanning Electron Microscope SEM/EDS and X-ray diffraction tests were performed to examine the hot corrosion behavior. It was found that both thermal spray techniques used in the present study were successful in controlling the hot corrosion of 80Ni20Cr coated specimens. Mass gain in HOVF sprayed coated specimen was minimum, followed by Plasma coating and bare metal. From the results of various analysis techniques used, it may be suggested that the HVOF sprayed coating provided the better resistance to hot corrosion than plasma sprayed coating in the given environment

R. Rachidi et al (2017)



NiCrBSi is a Ni-based alloy universally recognized for its superior mechanical properties, attributed to the

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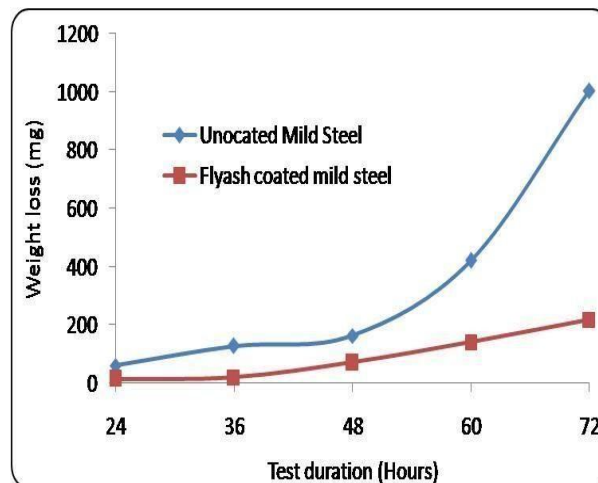
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Vol. 9, Issue 2, February 2020

presence of hard -dispersed carbides and borides, which is dependent on the deposition technique. Moreover, Metal Matrix Composites (MMC) materials will aim to combine the resilience of metals with high wear resistance specific of ceramics which made them innovative for a large wide of wear resistance applications. In this paper, thick NiCrBSi and NiCrBSi-WC coatings are made onto S235JR mild steel substrates using an oxyacetylene flame- spraying torch (Super Jet Eutalloy, Castolin Eutectic). Two different wear tests: sand/wheel wear test in dry conditions and the pin-on-disc wear test in continuous motion are used to investigate addition effects of WC reinforcing ceramic phase on the microstructure and wear resistance of the coatings layers. The results show that the presence of ceramic phase affects the wear resistance of the coating. For both wear tests, the metallic alloy coating has an improved wear resistance than the reinforced ones. WC reinforcement does not play the protective role of the matrix against wear but improve the hardness. Wear mechanism is mainly controlled by the scratching and by the pull out of WC particles because of their faceted shape.

Vivek Singh et al (2015)



This paper focuses on development and corrosion behaviour of thermally sprayed flyash coatings on mild steel substrate. Plasma spray coating technique was employed to deposit flyash on mild steel. Developed flyash coated mild steel specimens were subjected to SEM studies, Bond strength test and salt spray test. Salt spray test was carried out on both uncoated and flyash coated samples as per ASTM B117 standard test method.

Microstructure studies reveal uniform and dense deposition of flyash with good interface. Salt spray test results shows a significant improvement in flyash coated mild steel compared with uncoated mild steel.

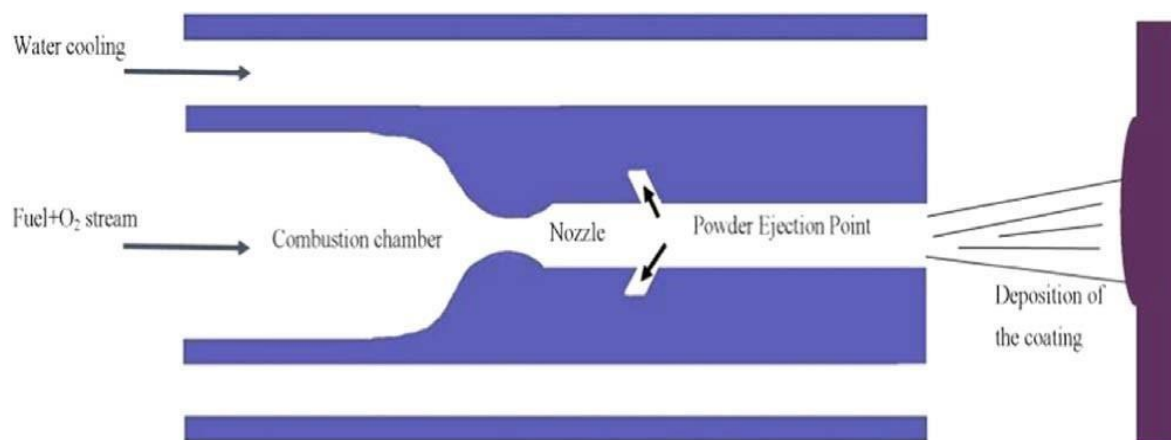
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Vol. 9, Issue 2, February 2020

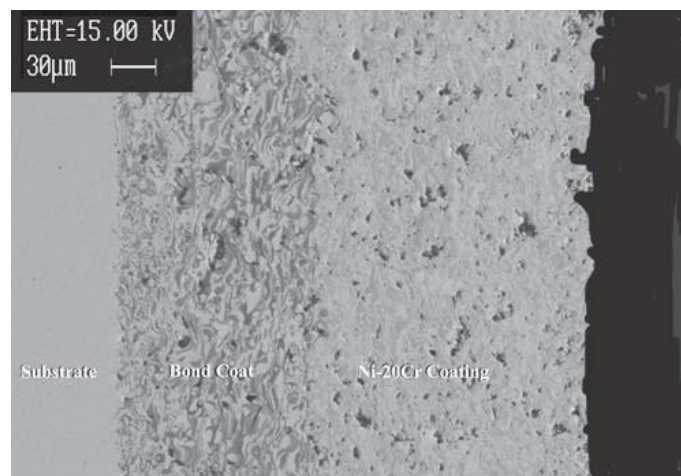
Vibhu Sharma et al (2019)



F CrosssectionoftheHVOFnozzle.

The increase in rate of erosion due to the excessive silt concentration in river water of the Himalayan region is adversely affecting the availability of most demanded hydropower in India. Many researchers investigated several methods to minimize the rate of erosion wear on hydro turbine blades, runners, pumps, guide vanes, seats, etc. However, some of them are successful, some are not. The problem of slit erosion is encountered during the high flow monsoon period. Various techniques have been developed to rally suitable coating like chemical vapour deposition technique, thermal spray coating, an electroplating technique, etc. Therefore, in this paper, an attempt has been made to provide an overview of suitable micro and nanocomposite coating with the application of thermal spray high-velocity oxygen fuel deposition process to minimize the problem of erosion due to silt in hydropower plants.

Buta Singh Sidhu et al (2005)



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Vol. 9, Issue 2, February 2020

Coal gasification systems operate upto 1093° Can data pressure of up to 10 MPa, depending on the specific process and the product. In addition to hydrogen and carbon-containing gaseous species, there are many undesirable species including sulphides, sulphites, sulphates, ammonia, cyanides, volatilized oils, phenols, and aggressive trace elements such as potassium, sodium, vanadium, and lead (Ref 1). The corrosive nature of this gaseous environment may cause rapid material degradation and result in premature failure of components (Ref 2, 3).

Surface degradation of metal containment walls and heat exchanger tubing by a combined erosion- corrosion (E-C) mechanism have been experienced in some boilers, particularly fluidized bed combustors (Ref 4). It was observed primarily that E-C occurred as a single phenomenon that integrated both chemical and mechanical behavior of the base metal and the boiler gas particles. It was further predicted that the loss of sound metal is related to the rate of oxidation.

### III. CONCLUSIONS

Based on the investigations done, it was noticed that the corrosion resistant obtained using salt spray test and hot corrosion test evidently illustrates only small amount of weight loss when coated with Monel 400 powder of 100 µm thickness in mild steel structures. Mechanized boat mild steel coated with Monel 400 powder with increase in coating thickness gives better mechanical behaviour and corrosion resistance than the conventional raw mild steel structures. SEM reveals the coated material has better bonding feature and the coated material can be utilized for mechanized boat hull structure in marine applications thereby reducing corrosion, painting cost, increases mechanical behaviour, wealth of fisherman and its lifespan.

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