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Experimental Investigation on Hot Dip Aluminized 9Cr-1Mo Steel For Corrosive Properties

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Abstract

Aluminized steel is that the steel which has been hot-dip coated on both sides with aluminium-silicon alloy. This process assures a tight metallurgical bond between the steel sheet and its aluminium coating, producing a material with a unique combination of properties possessed neither by steel not by aluminium alone. Aluminized steel shows a better behavior against corrosion and keeps the properties of the base material steel for temperature lower than 800 °C. Hot-dip aluminizing of 9Cr-1Mo steel is to be done in molten Al-7Si bath at 900°C for dipping time of 60sec. Characterization of the intermetallic layer can be done by using scanning electron microscope with energy dispersive spectroscopy.. In this paper, the high temperature oxidation behavior of a 9Cr-1Mo alloy with hot-dip treatment has been explored. Various tests like Scanning electron microscopy (SEM), Edax and Salt spray corrosion test were conducted.

Keywords: Aluminized steel, hot dip aluminizing, SEM, E dax, Salt spray corrosion test

Introduction

Corrosion of metal costs the world so much of money per year. On an average 40% of steel production goes to replace the corroded parts and products. Erosion is a serious problem in many engineering systems, including steam and jet turbines, pipelines and valves used in slurry transportation matter and fluidized bed combustion systems.The protection of metals or alloys against corrosion and wear can be achieved by development and the use of better corrosion and wear resistant coatings. These corrosion and wear resistant coatings can add value to products by allowing the mechanical properties of the substrate materials to be maintained while protecting them against wear or corrosion. Hot-dip coated with a thin layer of aluminium / silicon alloy containing 5% to 11% silicon to promote better adherence. It is intended principally for heat resisting applications and also for uses where corrosion resistance and heat are involved. Possible end users are mufflers, furnaces, ovens, ranges, heaters, water heaters, fireplaces, and baking pans. Aluminized steel can withstand with almost no change in the base material. But due to silicon content it develops black spot.. In this experimental investigation , the high temperature oxidation behavior of a 9Cr-1Mo alloy with hot-dip treatment has been explored. Various tests like Scanning electron microscopy (SEM), Edax and Salt spray corrosion test were conducted.

Outline of The Paper

In 9Cr-1Mo steel ,chromium is the basic alloying element. Cr is a carbide former and stabilizer in small amounts ,but in larger concentrations it increases the resistance to corrosions and oxidations. Elevated temperature and creep rupture strength increase with increase in molybdenum content. Molybdenum is a carbide stabilizer and It prevents graphitization.9Cr-1Mo ferritic alloy steel is selected for the process of Hot Dip Aluminizing at elevated temperatures of 850-950˚c. Hot-dip aluminizing is an effective and inexpensive coating process to protect steels from oxidation. The main aim is to improve the high temperature oxidation behaviour of 9Cr-1Mo steel by coating it with a layer of aluminium doped with silicon carbide which acts as an oxidizing agent. The coated specimen is subjected to inspection tests such as EDAX (Elemental Dispersive X-ray Analysis), SEM (Scanning Electron Microscopy) and Salt spray corrosion test.

Literature Review

Hot dip aluminizing 9Cr- 1Mo steel

Hot-dip aluminizing is an effective and inexpensive coating process to protect steels from oxidation[1]. The quality of coating depends on the properties of the intermetallics layer forming at the interface. A brittle intermetallic layer may peel off from surface during forming operations, which generally follows aluminizing treatment[2]. Therefore it becomes necessary to study the formation of intermetallics layer under different conditions.. Bouché et al. reported the formation of two intermetallic layers, namely, Fe2Al5 and FeAl3, when solid iron is dipped in liquid aluminum over the temperature range 700°C to 900°C[3]. Shatynski et al. [4] modelled the formation of intermetallic phases from purely diffusional perspective. They found that growth of intermetallics follows parabolic relation. In the case of Cr–Ni stainless steel, Dybkov [5] experimentally proved that the intermetallics follows paralinear (initially linear followed by parabolic) growth kinetics.. Kinetic studies done by Bouayad et al.for medium dipping times (<45 min) showed that the growth of Fe2Al5 layer is diffusion controlled and FeAl3 layer growth is linear with time[6]. Many researchers tried to explain the observed tongue-like morphology of the intermetallic layers and are of the opinion that the anisotropic diffusion is responsible for this growth[7]. Investigation of inter diffusion between low carbon steel and pure Al (99.99%) and Al alloy (Al-5%Si) between temperatures 600°C and 675°C showed that growth rate of -layer (Fe2Al5) is diffusion controlled and it governs overall intermetallic layer growth. Cheng and Wang observed that as the silicon content in the molten bath increases, the thickness of intermetallic layer decreases as well as the interface between intermetallic layer and steel substrate becomes flat. Cheng and Wang investigated the effect of nickel preplating on the formation of intermetallic layer when the mild steel is dipped in pure Al. Li et al. investigated the phase constituents within the intermetallic layer formed during hot-dip aluminizing. Bhat et al.discussed the effect of ZnCl2 + NH4Cl flux on the microstructural formation during dip aluminizing of steel with aluminum.

It is also reported that Si and Cu are the alloying elements in the aluminizing bath which are effective in restraining the growth of intermetallic layer . Addition of Cu has an additional effect that promotes formation of cubic variant for Al7Fe2Si . Cubic variants are better than hexagonal variants because of improved ductility Also, Al-SiCu alloy is one of the filler metals used during dissimilar TIG welding of aluminum alloys to stainless steels . To the best of our knowledge there is no reported investigations on the combined effect of Si and Cu on the intermetallic layer formation during hot-dip aluminizing. In the present work an attempt has been made to study the kinetics of various intermetallic phases formed as a function of time during hot-dip aluminizing of steel with Al-7%Si-2%Cu bath at a dipping temperature of 690°C.

Aluminizing

Aluminizing is a high-temperature chemical vapour deposition (CVD) process whereby aluminium vapors diffuse into the surface of the base metal, forming new metallurgical aluminidealloys.The aluminizing process protects the base material from corrosion in elevated temperatures. Aluminizing is used extensively by industry to protect steel components and structures from heat oxidation and sealing at service temperatures up to 10,000°C, ensuring long-term protection.

There are several techniques that have been used to obtain a layer of aluminium over a steel surface on a commercial scale. These include; electrolytic coating, cladding, pack, gas, spray (metalizing) and hot-dip aluminizing. A brief description of the different aluminizing processes is given below.

Electrolytic Coating

In this process electrolytes comprising either a mixture of fused salts of aluminum chloride or aluminum dipped in ethyl bromide and benzene are used. The substrate is first thoroughly cleaned, degreased and pickled in HCl solution[8]. However, the rate of deposition of an aluminum layer onto the substrate is very slow and an average coating thickness of only 0.01 mm could be obtained in around 30 minutes.

Cladding

Cladding involves cold-rolling of sheets of steel and aluminum which results in the formation of a metallic bond between the two sheets, hence bimetallic strip or sheets are obtained[8]. The thickness of the cladding is usually between 2% and 5% of the total sheet or plate thickness.

since the cladding is usually a softer and lower strength alloy, the presence of the cladding can lower the fatigue strength and abrasion resistance of the product[8] .In the case of thick plate where substantial amounts of material may be removed from one side by machining so that the cladding becomes a larger fraction of the total thickness, the decrease in strength of the product may be substantial[9].

Vacuum Aluminizing

An aluminizing coating is obtained by first vaporizing the pure aluminum or aluminium alloy and then condensing it onto the steel substrate. A vacuum chamber pressure of 10.3 – 10.5 mm of Hg is required and electron beam devices are used to melt the aluminum and raise its temperature up to about 1673K. In addition the substrate must be heated up to 448-643K. This process gives a good coating adherence. The coating thickness in this case is of the order of 0.1 µm[9].

Spray Aluminizing (Metallizing)

An aluminum coating of specific thickness is sprayed onto a pre-cleaned steel surface[8]. The process involves melting and spraying molten metal by a jet of compressed air between 25-60 psi with special metallizers. The bond obtained is of low strength, although the surface adherence can be improved by increasing the surface roughness of the substrate. Annealing to temperatures 1123-1523K for a sufficient amount of time may be done to increase the bond strength.

Gas Aluminizing

During gas-aluminizing, the steel substrate is impregnated with aluminum using a gaseous phase of aluminum chloride[9]. This is carried out in a retort, and the composition of the gas mixture is given as 45% Al, 45% Al_2O_3 and 10% $AlCl_3$. The mixture in the retort is heated to 873K and the substrate is positioned at the opposite end of the retort where it is heated to 1173-1273K. The impregnation of steel with aluminium proceeds according to the following reaction:$AlCl_3\,(g) + Fe(s) \rightarrow FeCl_3\,(s) + Al(s)$.

Pack Aluminizing

The substrate is first cleaned then packed in air-tight retorts with an aluminizing mixture, which consists of aluminum or ferro-aluminum dust/ powder and heated to the aluminizing temperature for up to 30 hrs. This method is expensive and time consuming and is only recommended for articles of intricate shapes.. steel can also be pack-aluminized to improve its high temperature oxidation resistance[8]

Origin of The Investigation

Much of loss caused by the corrosion comes from the corrosion of iron and steel. Steel is the principal construction material for automobiles, appliances, industrial machinery as well as in nuclear industries. The iron in the steel is oxidised to produce rust, which occupies approximately six times the volume of the original material. The corrosion process requires the simultaneous presence of water and oxygen. In the absence of either, corrosion does not occur .so, In order to prevent corrosion, a proper surface protection is required to avoid any failures and extended life cycle of the components. Surface coating is an efficient and economical method to obtain desirable material surfaces properties

Objective

The changes in the physical properties of steel must be prevented by providing a solution to tackle the process corrosion and oxidation when subjected to high temperatures. This can be achieved through surface modification techniques such as Hot Dip Aluminizing which is an effective treatment against oxidation and corrosion of steel.

The objective is to improve the surface hardness of 9Cr 1 Mo steel by surface alloying with aluminium through diffusion. Aluminium coating provides steel with excellent oxidation and corrosion resistance at elevated temperatures up to 1173 K, and also with reasonable scaling resistance. The present study deals with effect of process parameters on the microstructure and micro hardness of aluminized specimens.

In order to identify a suitable aluminizing method, a comparison was made on the relative merits of the different aluminizing methods commonly reported in the literature. Based on this comparison, hot-dip aluminizing was chosen as the method of incorporating the alloying element into the steel samples based on cost effectiveness and rate of productivity of aluminised steels through this process[10]. The results are aimed at achieving improved properties of steel through hot dip aluminising process.

Materials and Methods

2.1 9Cr-1Mo ALLOY STEEL Modified 9Cr-1Mo steel was specified as Grade 91 (Gr.91) in both ASTM and ASME and is finding increasing applications in power generation industries. Grade 91 contains 9 % Chromium and 1 % Molybdenum based on this compositions it is also known as 9Cr-1Mo steel. Grade 91 exhibits high strength up to temperatures in the range of 600 °C. Also the oxidation temperature limits are higher. This allows the power plant designers to engineer components, superheater coils, headers and steam piping, with less thickness. This contributes to a higher thermal fatigue life of almost ten times. This allows them to increase the operating temperature to a higher level, increasing the efficiency of the power plant.9Cr-1Mo alloy is widely used as tubes for heat exchangers, and offers good oxidation and corrosion at higher temperature. To improve oxidation resistance above 600˚c, a surface coating or modification to produce a more corrosion resistant surface layer is commonly used. Steels coated with aluminum apply generally in the electric power plants, petrochemical Industries and other energy conversion systems due to their low cost, good thermal conductivity and oxidation resistance performance. Many research activities have focused on it elsewhere

Properties of 9Cr-1Mo steel

Grade 91 contains 9 % Chromium and 1 % Molybdenum. Chromium improves high temperature strength and increases oxidation resistance. Molybdenum increases the creep resistance. Also present are smaller quantities of Nickel and Manganese which increase the hardenability of the steel.9Cr-1Mo steel is formed by normalizing at 1050 °C, air cooling down to 200 °C. It is then tempered by heating to 760 °C. The temperatures and the cooling rates are very important. This produces the microstructure that results in the high creep strength properties.

Chemical composition of 9Cr-1Mo (Gr.P91) steel

Table 1: Composition ranges for P91 grade steel.

GRADE	C	Mn	Si	P	S	Cr	Mo	Ni
P91 or	0.08-	0.30-	0.20-	0.025	0.01	8.0-9.5	0.80-	0.75

Table 1 shows that in P91 grade steel sulfur has the minimum value and chromium has the maximum value compared with other materials.

Mechanical properties

Table 2: Mechanical Properties of Grade 91 steel.

TENSILE STRENGTH, MPa	YIELD STRENGTH, MPa	ELONGATION, %	HARDNESS, BRINELL HB
585 (min)	415(min)	20(min)	250 (max)

Table 2 shows that various mechanical properties of P91 grade steel are illustrated.

Methodology

A commercial cold rolled ASME SA213 T91 steel sheet was used as experimental materials in this study.

Mechanism of hot dip aluminizing

Hot-dip-aluminizing (HDA) involves essentially a reaction between solid Fe surface and liquid Aluminum. The steel substrate to be aluminized is immersed in a bath of molten aluminum or its alloy. The coating process occurs by wetting, dissolution, inter-diffusion, and then the formation of intermetallics. It must be appreciated that in hot dip aluminizing it is difficult to join the aluminum with steel without the formation of intermetallic layer at the face of the solid because of their limited mutual solubility. A clean surface of the substrate ensures good wetting and authenticates better aluminizing. Aluminum has good affinity with oxygen. The presence of iron oxide in the melt further becomes the problem for hot-dip-aluminizing process.

The intermetallic layer is brittle in nature. This layer grows and dissolves concurrently into the molten aluminum alloy, which is directly associated with the loss of the steel substrate. The growth and the dissolution rates of the intermetallic layer determine thickness of the layer. The rates are closely related with temperature of the molten aluminum alloy and dipping time of the steel. The thickness of the layer also varies depending on chemical composition of the molten alloy and of the steel substrate[11].

Experimental procedure

Rectangular and circular specimens of 9Cr-1Mo steel were cut to the dimensions of 10×10×2mm and Ø25mm respectively by a Wire cutting mechanism.

Figure 1: 9Cr-1Mo steel machined by wire cut mechanism

Aluminium in the form of hollow bars are cut into small pieces by a mechanical saw and are then hammered to obtain flatness. This is mainly done so as to achieve a large volume of aluminum in the melting pot. Aluminium melts easily when its size is reduced and subjected to a furnace at 900-1000 degrees Celsius.

The outer chamber of the furnace is made of Mild Steel sheets and sections finished with powder coating. The furnace has a well-insulated Flap Door with a spy hole for viewing the inner chamber without opening the Door. The Furnace is suitable for Bench mounting

Figure 2: Furnace chamber

The inner chamber of the furnace is made of smooth surface Sillimanite Muffle.The gap between the outer and the inner chamber is insulated with a thick layer of high density Ceramic Fibre Wool Insulation.

The Terminal connections will be provided in a separate chamber at the back side of the furnace for easy maintenance. A safety protection thermal fuse is provided to prevent the heating element from accidental heating. A fume exhaust will be provided at the back side of the furnace.Maximum temperature up to 1000°C and safe recommended working temperature should not exceed 930°C.

Specimens for further hot-dip treatment were hung by stainless steel wires and coated with uniform weld flux. Then specimens were dried and immersed into a molten bath of 950°C aluminum-silicon for 16 seconds. Silicon was added into the aluminum liquid in order to make the surface of the Fe-Al alloy layer smooth and enhance the interfacial bonding strength. Thickness of the external aluminum coating and aluminized layer was approximately of 100μm after hot-dip treatment.

After hot-dip treated, specimens were exposed in a furnace with static air at 950˚C, and then air-cooled to room temperature. A sequential grinding technique was adopted to investigate the distribution of the different phases present in the scale and the alloy substrate. Characterization of the cross-sectional scales was carried out with scanning electron microscopy (SEM).

Figure 3: Sample before coating

Figure 4: Sample after coating

Testing and Analysis

Salt Spray Corrosion Test

The salt spray test is a standardized test method used to check corrosion resistance of coated samples. Coatings provide corrosion resistance to metallic parts made of steel, zamak or brass. Since coatings can provide a high corrosion resistance through the intended life of the part in use, it is necessary to check corrosion resistance by other means. Salt spray test is an accelerated corrosion test that produces a corrosive attack to the coated samples in order to predict its suitability in use as a protective finish. The appearance of corrosion products (oxides) is evaluated after a period of time. Test duration depends on the corrosion resistance of the coating; the more corrosion resistant the coating is, the longer the period in testing without showing signs of corrosion.

ASTM B117 is the oldest and most widely used salt spray cabinet test. The Salt Spray (Fog) Test is often used to evaluate the relative corrosion resistance of coated and uncoated materials exposed to a salt spray or fog at an elevated temperature. Test specimens are placed in an enclosed salt spray chamber and subjected to a continuous indirect spray of salt water (pH- 7) solution. This climate is maintained throughout the duration of the test.

The water used in the salt spray chamber Fig 5 must be compliant with the ASTM D1193 specification. 5% of salt solution is achieved by adding enough sodium chloride to water. When the time the specimens are placed into the chamber, the cabinet should be pre-conditioned to the operating temperature of 35oC and 5% of the salt solution for fogging at the rate of 12ml/hr is required.

The default position for the sample placement is at a 10-30 degree angle from the vertical. Specimens should be placed in the cabinet so as to avoid any dripping of condensation from one specimen to another.Except for the purposes of daily monitoring collection rates, and for the rotation of test specimens, the cabinet should remain closed until the test is complete. Duration of test ranges from 24 hours to 5000 hours usually in increments of 24 hours.

Figure 5: Salt spray test chamber

Salt fog chamber consists of wooden racks having dimensions of 914.4 mm height,914.4 mm deep and 1524 mm wide. Two specimens of each coated and uncoated composition were placed on a wooden rack at a 10° tilt angle. The tap water was mixed with 5% NaCl and pumped from a reservoir through the spray nozzles in the form of fog. The mixed solution was passed with humidified compressed air at nozzles. Then compressed air atomized NaCl solution into a fog at the nozzles.

The test was conducted for 42 hours. The samples were rotated frequently in the test chamber so that all samples were exposed as uniformly as possible to the salt spray mist. The corrosion rate was measured by noting the time period until rusting of the steel is first evident. The weight loss was measured for each sample at intermediate period and the mean weight was calculated.

Scanning Electron Microscope (Sem)

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum, in low vacuum, and (in environmental SEM) in wet conditions.

The most common mode of detection is by secondary electrons emitted by atoms excited by the electron beam. The number of secondary electrons is a function of the angle between the surface and the beam. On a flat surface, the plume of secondary electrons is mostly contained by the sample, but on a tilted surface, the plume is partially exposed and more electrons are emitted. By scanning the sample and detecting the secondary electrons, an image displaying the tilt of the surface is created.

The Scanning Electron Microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. In most applications, data are collected over a selected area of the surface of the sample, and a 2-dimensional image is generated that displays spatial variations in these properties. Areas ranging from approximately 1 cm to 5 microns in width can be imaged in a scanning mode using conventional SEM techniques (magnification ranging from 20X to approximately 30,000X, spatial resolution of 50 to 100 nm). The SEM is also capable of performing analyses of selected point locations on the sample; this approach is especially useful in qualitatively or semi-quantitatively determining chemical compositions (using EDS), crystalline structure, and crystal orientations (using EBSD). The design and function of the SEM is very similar to the EPMA and considerable overlap in capabilities exists between the two instruments.

Figure 6: Scanning Electron Microscope(SEM)

The cross-section and explains the adhesion of the coating to the substrate and determines any crack has been identified between the coating and substrate.The Microscopic analysis was carried out at Sathyabama University, Chennai

Edax Test

Energy-dispersive X-ray spectroscopy (EDS, EDX, or XEDS), sometimes called energy dispersive X-ray analysis (EDXA) or energy dispersive X-ray microanalysis (EDXMA), is an analytical technique used for the elemental analysis or chemical characterization of a sample. It relies on an interaction of some source of X-ray excitation and a sample. Its characterization capabilities are due in large part to the fundamental principle that each element has a unique atomic structure allowing unique set of peaks on its X-ray spectrum.

The emission of characteristic X-rays from a specimen, a high-energy beam of charged particles such as electrons or protons or a beam of X-rays, is focused into the sample being studied. At rest, an atom within the sample contains ground state (or unexcited) electrons in discrete energy levels or electron shells bound to the nucleus. The incident beam may excite an electron in an inner shell, ejecting it from the shell while creating an electron hole where the electron was. An electron from an outer, higher-energy shell then fills the hole, and the difference in energy between the higher energy shell and the lower energy shell may be released in the form of an X- ray.

The number and energy of the X-rays emitted from a specimen can be measured by an energy-dispersive spectrometer. As the energy of the X-rays are characteristic of the difference in energy between the two shells, and of the atomic structure of the element from which they were emitted, this allows the elemental composition of the specimen to be measured.

Figure 7: Edax Tester

Result and Discussion

Salt Spray Corrosion Test.

Figure 8: coated sample in salt spray test

Figure 9: Uncoated sample in salt spray test

Table 3: 9Cr 1Mo Steel *Uncoated sample in salt spray test*

Initial weight (gms)	34 hours (gms)	40 hours (gms)	42 hours (gms)	50 hours (gms)	60 hours (gms)	70 hours (gms)	80 hours (gms)
237.32	237.26 ±0.01	237.11 ± 0.01	-	236.91 ±0.01	-	236.79 ±0.01	-

Table 3 shows the result for 9Cr 1Mo steel uncoated sample in salt spray test.

Table 4: Coated sample in salt spray test

Initial weight (gms)	34 hours (gms)	40 hours (gms)	42 hours (gms)	50 hours (gms)	60 hours (gms)	70 hours (gms)	80 hours (gms)
255.66	-	-	255.60 ±0.01	-	255.52 ±0.01	255.35 ±0.01	255.25 ±0.01

Table 4.shows the result for 9Cr 1Mo steel coated sample in salt spray test.

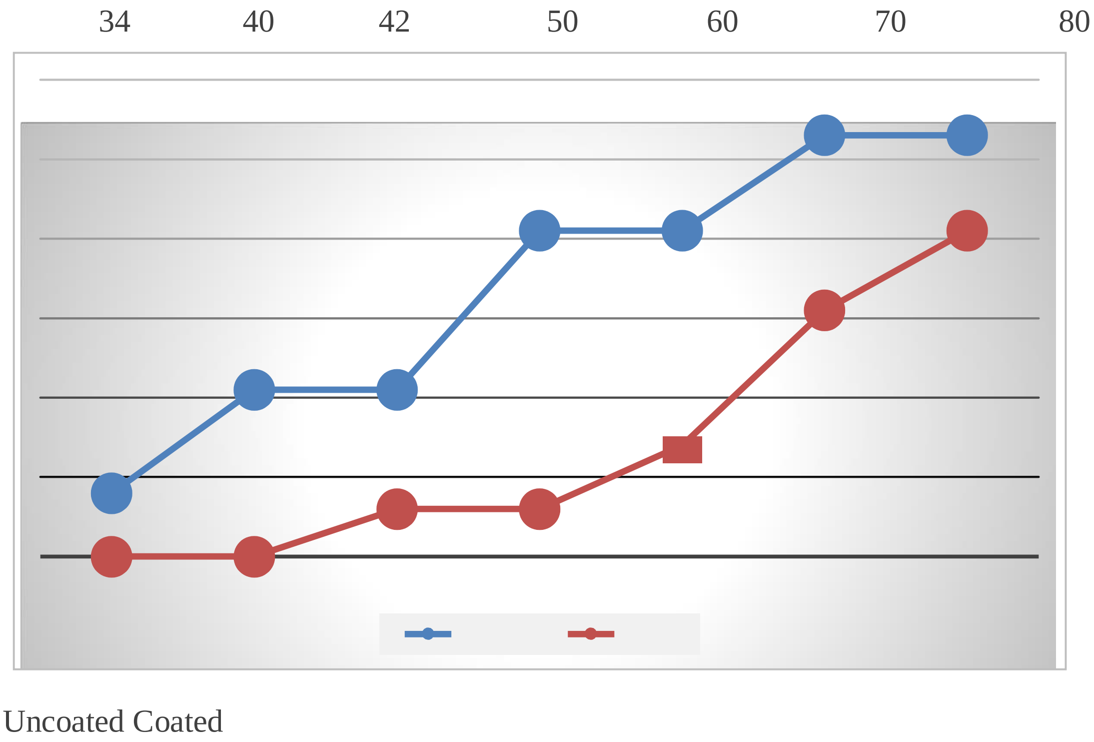

Fig 10 :Comparsion of uncoated and coated sample behaviour in salt spray test

The graph explains the loss of surface of the uncoated and coated sample,for the same time period. The weight loss of the sample increases with the increase in time it is exposed to the salt spray.In the graph the result output for 70 hours exposure time shows an weight loss of 0.53 grams for the uncoated sample whereas for the coated sample the loss of surface weight is 0.31 grams for the same time period of 70 hours. The weight loss on the surface is calculated by subtracting the initial weight of the sample with the weight of sample at 70 hours.

For the uncoated sample the onset of red rust on a sample started at 34 hours. Finally the weight of the specimen is 236.79 grams. It is clearly identified that the weight loss is 0.53 grams.

For the coated sample the onset of red rust on a sample started at 42 hours. Finally the weight of the specimen is 255.25 grams. It is clearly identified that the weight loss is 0.41 grams.

Scanning Electron Microscope(Sem)

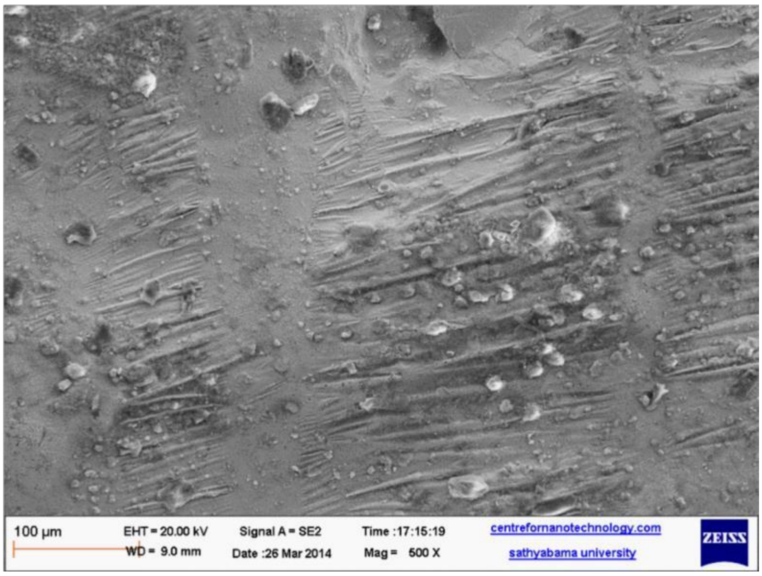

Figure 11: Uncoated 9Cr 1Mo steel

Figure 11 shows that scanning electron microscope photograph with magnification of 500 x. This photo is taken before coating by aluminium.

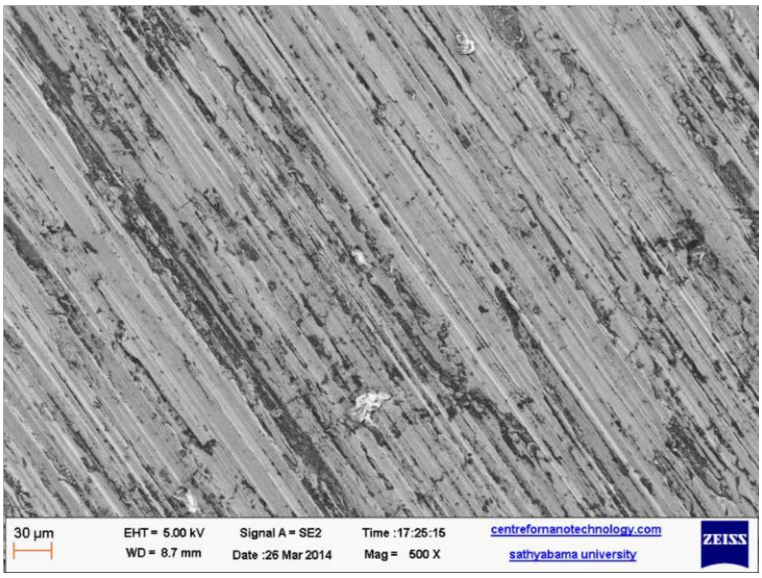

Figure 12: coated 9Cr 1Mo steel

Figure 12 shows that scanning electron microscope photograph with magnification of 500 x . This photo is taken after coating by aluminium. At this magnification it shows the formation of aluminium as coating on the sample and confirms that the coating is densely packed which is achevied perfectly by the process of hot dip aluminizing.

The result clearly shows that only aluminium diffuses into the steel substrate without the dissolution of iron and forms the intermetallic compound between the steel substrate and melt.Initial stages of dipping the intermeatallic layer forms are Fe2Al5 and FeAl3.

Edax Test

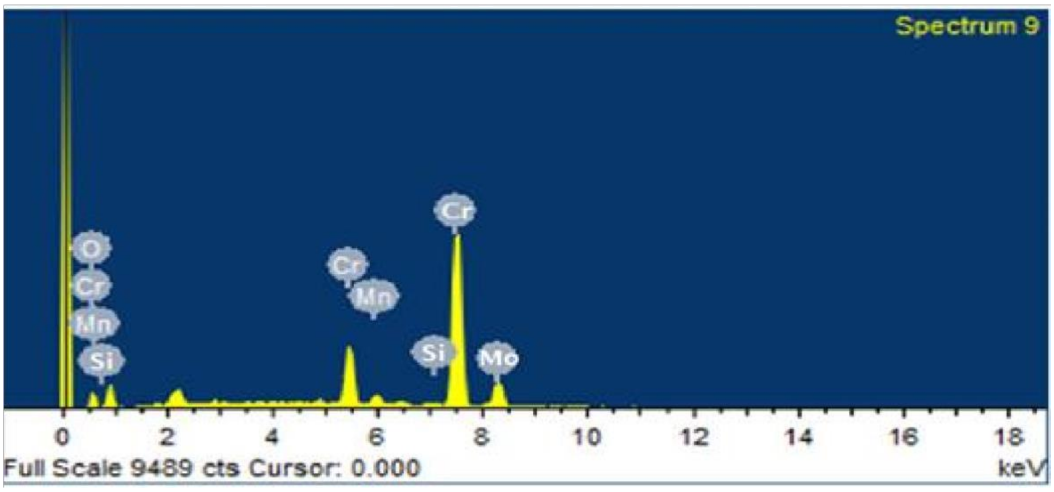

Figure 13: Plain 9cr 1mo steel

From this figure 13 It is understood that the uncoated steel has the composition as silicon, manganese, chromium.

Table No: 5 Elemental composition of materials present in uncoated part

Element	Weight%	Atomic%
Cr	62.54	50.25
O	4.77	3.33
Si	9.25	6.26
Mn	8.21	5.84
Mo	15.23	34.32
Totals	100.00	100.00

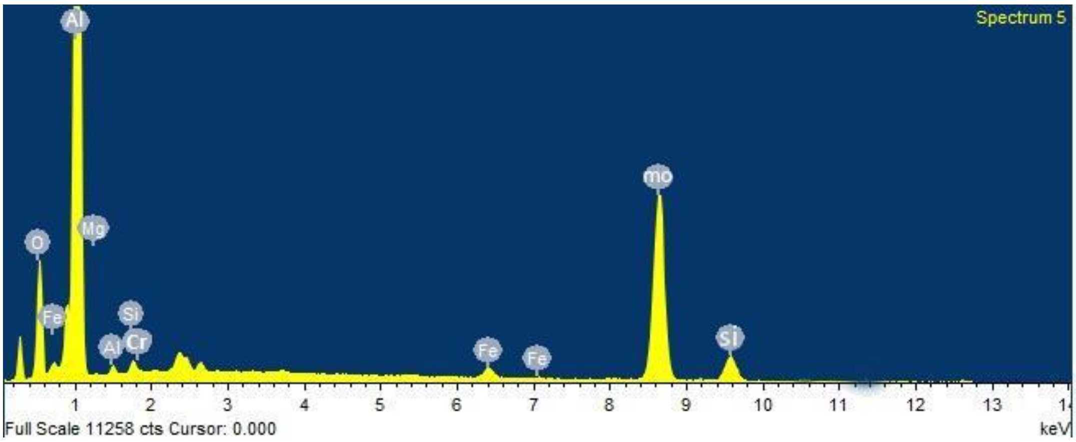

Fig 14: Aluminum coated 9cr 1mo steel

From this figure 14 It is understood that the coated steel has the composition as silicon,manganese chromium, oxide, aluminium, iron.The Edax test identifies the composition of element present in the coated samples

Table No: 6 Elemental composition of materials present in coated part

Element	Weight%	Atomic%
Cr	0.42	0.62
O	4.12	5.84
Al	60.22	60.78
Si	0.49	0.64
Mg	4.70	5.98
Mo	29.65	25.58
Fe	0.40	0.56
Totals	100.00	100.00

Summary and Conclusion

Summary

There are variety of aluminum-coating processes, including hot dipping, thermal spray, pack cementation, slurry, cladding, electroplating, etc. On the basis of cost and feasibility in industrial processes, hot-dip aluminizing process, as a surface treatment of alloys, is used. The performance and phase constitution of the Fe-Al alloying layer depend on the composition of raw materials, temperature, time history and other processing In this investigation, the high temperature oxidation behaviour of a 9Cr-1Mo alloy with hot-dip treatment was explored.

9Cr-1Mo ferritic alloy steel is selected for the process of Hot Dip Aluminizing at elevated temperatures of 850-950˚c. Hot-dip aluminizing is an effective and inexpensive coating process to protect steels from oxidation. The main aim is to improve the high temperature oxidation behaviour of 9Cr-1Mo steel by coating it with a layer of aluminium doped with silicon carbide which acts as an oxidizing agent.

Hot-dip-aluminizing (HDA) involves essentially a reaction between solid Fe at steel surface and liquid Aluminum. The steel substrate to be aluminized is immersed in a bath of molten aluminum or its alloy. The coating process occurs by wetting, dissolution, inter-diffusion, and then the formation of intermetallic. It must be appreciated that in hot dip aluminizing it is difficult to join the aluminum with steel without the formation of intermetallic layer at the face of the solid because of their limited mutual solubility. A clean surface of the substrate ensures good wetting and authenticates better aluminizing. Aluminum has good affinity with oxygen. The presence of iron oxide in the melt further becomes the problem for hot-dip-aluminizing process.

Characterization of the intermetallic layer can be done by using scanning electron microscope with energy dispersive spectroscopy. Intermetallic phases can be identified in the reaction layer.

Conclusion

9Cr-1Mo alloy steel is hot-dip aluminized using Al-7Si bath at 900˚ C for dipping time of 16sec.Characterization of the intermetallic layer is studied by scanning electron method and the coated thickness is reported as 1.66µm.Salt spray test is done on the aluminium coated alloy as well on plain alloy and the results show that the coated alloy is more corrosion resistant.Presence of silicon in the aluminium melt produces a significantly thinner and plain intermetallic phase that is less brittle compared to a thicker and ragged intermetallic layer formed between steel coat with pure aluminuim.Aluminizing as a surface treatment step may be recommended for applications such as heating elements,exhaust systems and in corrosive oxidizing enviroments but not for applications that may require the material to undergo plastic deformation or formingHence, it can be concluded that the addition of silicon with aluminum coated 9Cr 1Mo steel coatings can be used in order to resist corrosion.

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