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Protection of SAE 213 T-22 Boiler Steel Tube Material with Various Power Coatings using HVOF Spray Technique

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Abstract

Corrosion is an unintentional gradual degradation of metal that occurs because of chemical or electrochemical attach. The corrosive nature of the gaseous environment at high temperature may cause rapid material degradation and result in premature failure of components. Boiler tubes in power plant are subjected to a wide variety of failure due to high temperature corrosion fatigue. For the reduction of corrosion either a material of required mechanical properties is used, which is impossible for a single material to have all these properties or provide the coating to existing material with surface coating methods, which improves the existing properties in economical way and reduce the cost of replacement. In this paper an attempt has been made by conducting the experimental work on SAE213 T-22 boiler steel tubes with different coating powders having composition of WC-10% CO-4% Cr and WC-12% Cr by adopting the High Velocity Oxy Fuel (HVOF) thermal spray technique to protect the boiler tubes from hot corrosion in gaseous environment and do the various calculations to made the comparison between uncoated and coated tube materials, by creating the artificial environment in the lab.

Keywords : *Boiler steel tube, Hot corrosion, Surface coatings, Thermal spraying,*

1. INTRODUCTION

Corrosion is deterioration of material or its properties because of reaction with its environment. Sometimes the deterioration is a weight gain, sometimes it a weight reduction, sometimes the mechanical properties are affected [1]. Corrosion of metals costs the United States over $300 billion per year according to recent estimates-more than the cost of annual floods and fires. Oxidation is a type of corrosion involving the reaction between a metal and air or oxygen at high temperature in the absence of water or an aqueous phase. It is also called dry-corrosion. The rate of oxidation of a metal at high temperature depends onthe nature of the oxide layer that forms on the surface of metal [2]. Material selection, preparation and fabrication are therefore of paramount imortance for the efficient functioning of the system components. Alloys used at high temperature should possess good mechanical properties along with erosion –corrosion resistance. However, it is impossible for a single material to have all these properties, along with ease of manufacturing. Therefore composite system of a base material providing necessary mechanical properties with a protective surface layer, different in structure or chemical composition can be an optimum choice in combining mechanical properties [3]. Boilers and other steam power plant equipments are subjected to a wide variety of failures involving one or more of several mechanisms. Overheating is the main cause of failure in steam generators.

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2. OBJECTIVES

The objective of the proposed research are to develop the coating by HVOF spray process, on boiler tube steels to enhance hot corrosion resistance .As the hot corrosion occurs at rapid rate during initial hours of test and then the rate decreases, hence the studies during initials hours are more important. It is proposed to carry out the cyclic studies in molten salt environment to evaluating hot corrosion behavior.

3. PROBLEM FORMULATION

T–22 steel which are employed for super-heater tubes at National Fertilizer Limited (N.F.L) steam generation Plant, Bathinda, Punjab (India). But, the performance of the material was not found satisfactory. Therefore, the study of behavior of T–22 steel at high temperature became an important aspect. ***The present study is an attempt to evaluate the high temperature corrosion behavior of uncoated and HVOF sprayed WC-10%CO-4%Cr, WC-12%CO coated T-22 boiler steel***. It is planned to study the behavior of T–22 steel material in uncoated as well as coated condition by examining its surface and sub surface by heating it at 900 ^{0}C under cyclic conditions. Different powder coatings will be used as coatings to deal with oxidising environments at high temperatures. The present study will be an attempt to evaluate the high temperature corrosion behavior of uncoated and HVOF sprayed WC-10% Co-4% Cr and WC-12% Co coated T–22 boiler steel. The tests will conducted to be carried out in salt mixture of Na_2SO_4–60% V_2O_5 reported to be most aggressive environment at an elevated temperature of 900 ^{0}C for 50 cycles (each cycle 1 hr heating followed by 20 min cooling in air) in silicon – carbide tube furnace. The temperature of experiments will be kept high than the actual operating temperature as this would also take into consideration the overheating effect in case of boilers. The cyclic conditions will be employed as these conditions constitute more realistic approach

4. PROTECTIVE COATINGS

Surface modifications to improve the corrosion resistance of low cost alloys are an economically attractive alternative to the use of expensive corrosion–resistant alloys. A low grade steel surface modified by a suitable metallic diffusion coating can provide excellent corrosion resistance similar to that obtained with an expensive super alloy.

5. THERMAL SPRAYING

Thermal spraying is a process of depositing a superior material layer over a base metal or substrate either to improve the surface characteristics like corrosion resistance, wear resistance, surface fatigue or to get the desired dimension, size, surface appearance etc. Thermal spray coating processes are not only capable of applying coatings with excellent wear resistant properties, but also the range of materials capable of being sprayed so wide that applications for thermally sprayed wear resistant coatings are unlimited [5].The thermal spray processes that have been used to deposit the coatings for the protection against the high-temperature corrosion are enlisted summarized below:

- Flame spraying with a powder or wire
- Electric arc wire spraying
- Plasma spraying
- Spray and fuseoHigh Velocity Oxy-fuel (HVOF) spraying
- Detonation Gun spraying

6. HIGH VELOCITY OXY-FUEL (HVOF) SPRAYING COATING PROCESS

HVOF process belongs to the family of thermal spraying technologies. HVOF process is based on a combination of thermal and kinetic energy transfer is that the melting and accelerationof powdered particles, to deposit the desired coating. In the HVOF process, powder/ wire material is melted and propelled at high velocity, with the use of oxygen and fuel gas mixtures, towards a surface as shown in (fig.1).

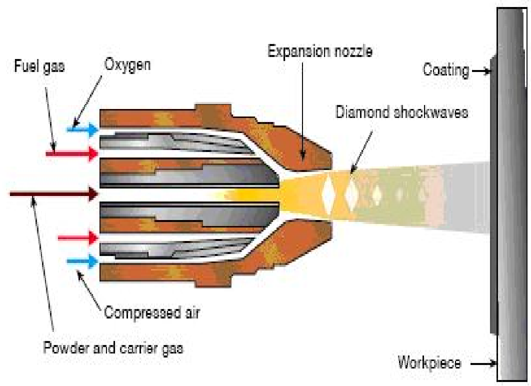

Fig.1: HVOF Thermal Spray Coating on Substrate

7. ADVANTAGES OF HVOF COATING PROCESS

HVOF Spraying is able to make denser and less oxidized coating compared with other methods, such as plasma spraying. Furthermore, this spraying system enables metals and alloys with high melting point up to 2300 ^{0}C to be deposited on the target surface. HVOF Process has many advantages over other spraying processes like high density, low porosity, high hardness, high bond strength, thick coating, fine finishing capability, low oxide content, more uniform and efficient particle heating, low surface oxidation, much shorter exposure time in flight of particles.

8. EXPERIMENTAL TECHNIQUES

The specimens of the steel sample were cut with dimensions of approximately 20 mm õ 15 mm õ 5 mm as per ASTM standards. The specimens were polished by using 180, 220, 400, 600 and 1000 grade SiC emery papers and subsequently grit blasted with alumina powder (Al_2O_3) before spraying of coating by HVOF process.

The surface analysier microscope analysis of substrate was conducted for the surface study. The selected coatings used are in the form of powders, the coating powders selected for coating are WC-10%Cr-4%Co and WC-12%Co. The reason behind the selection of coating are large literature survey and it was found that the selected coating powders were best in use and give very good results in case of hot corrosion protection, but still are not use on SAE213 T-22 boiler steel material. Materials are often exposed to environments that are both corrosive and erosive. In the process industry, in offshore piping and production systems flowing corrosive media often contain solid particles. This leads to a reduction of the life time of certain components and high maintenance costs. Protection of the metallic components by ceramic–metallic (cermets) coatings or hard oxide coatings is an effective method to reduce wear and corrosion. Commercially available WC-10%Co-4%Cr and WC-12%Co in the powder form, made by H. C. Starck of Germany, was used as the coating material in this study. The coating powder was made available by M/S Metalizing Equipment Co. Pvt. Ltd., Jodhpur, Rajasthan (India).

9. EXPERIMENTAL SETUP AND PROCEDURE

The high temperature hot corrosion study was conducted in laboratory using silicon carbide tube furnace at temperature 900 ^{0}C. Firstly, the furnace was calibrated using Platinum – Rhodium thermocouple and a temperature indicator with a variation of ± 5 ^{0}C. Heating zone in the tube was found out for 900 ^{0}C with the help of thermocouple. The uncoated steel specimens are mirror polished using alumina paste on a wheel cloth before study. After polishing, the samples were washed properly and dried in hot air to remove the moisture. The dimensions of the specimens were noted down with the help of Mitutoyo (Japan) made digital vernier caliper, to calculate the surface area. Al_2O_3 boats were used to place the samples in furnace for corrosion studies. The boats were pre-heated at a constant temperature of 1250 ^{0}C for 8–10 hrs. It is done to assure that their weight will remain constant during the high temperature corrosion study. For conducting the experiment, each sample was kept in the boat and the weight of boat and sample was measured. Then, the boat with sample was inserted into the heating zone in the furnace at 900 ^{0}C . The holding time in the furnace is 1 hr and after that the boat with sample was taken out and cooled in ambient air for 20 min. Then the weight of the boat with sample was measured with the help of electronic weight balance meter made of Citizen (Type–300–9321/N, Switzerland with least count 1mg) . This constituted one cycle of the study. The study was carried out for 50 such cycles. The spelled scale in the boat is also taken into consideration for weight change measurement.

10. RESULTS & DISCUSSION

Hot Corrosion Studies in Molten Salt Environment

Thermo Gravimetric Study

The corrosion kinetics for uncoated substrate T–22 steel and WC-10%CO-4%Cr, WC-12%CO coated T–22 steel in molten salt

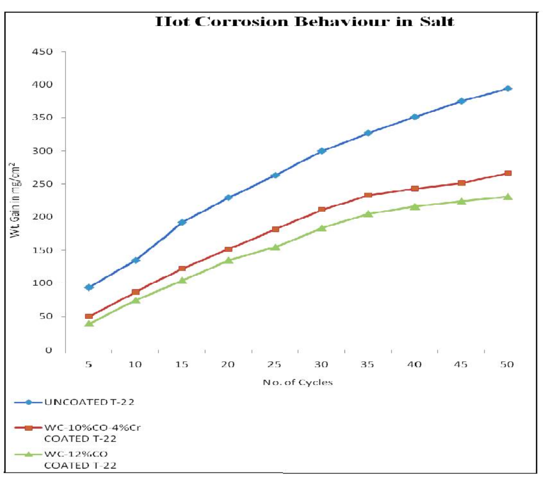

Fig. 2: Weight gain / area Vs. number of cycles plot for WC-12%CO, WC-10% CO, 4%Cr coated and uncoated T –22 steels exposed to Na_2SO_4 – 60% V_2O_5 at 900 ^{0}C for 50 cycles.

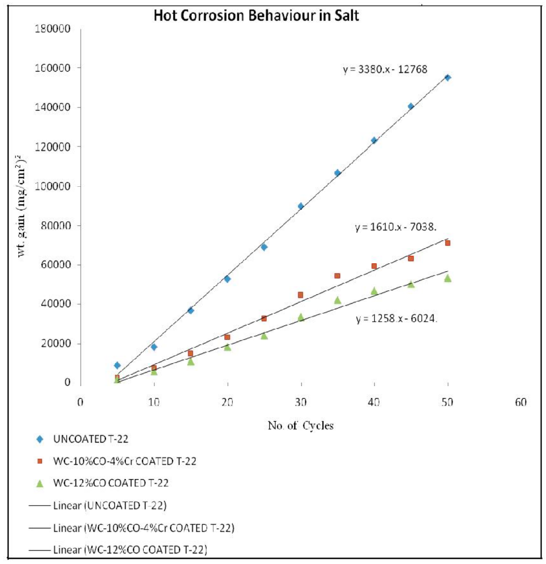

Fig.3: (Weight gain / area)^2 Vs. number of cycles plot for WC-12%CO, WC-10%CO-4%Cr coated and uncoated T –22 steels exposed to molten salt(Na_2SO_4–60% V_2O_5) at 900 ^{0}C for 50 cycles

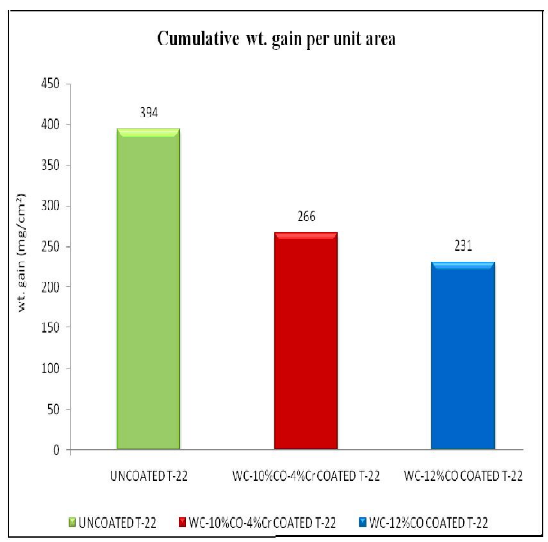

Fig. 4: Bar chart shows the cumulative weight gain per unit area for uncoated, WC-10%CO-4%Cr coated and WC-12%CO coated T –22 steel substrate exposed to molten salt (Na_2SO_4 – 60% V_2O_5) at 900^{0}C

environment Na_2SO_4–60% V_2O_5 at 900 ^{0}C have been studied for 50 cycles. The overall weight gain for 50 cycles for uncoated T–22 steel was 3678 mg and WC-10%CO-4%Cr coated was 2649mg and WC-12%CO coated was 2240mg. The weight gain per unit area data have been plotted for number of cycles as shown in (Fig. 2). Efforts were made to formulate the kinetics of corrosion. The WC-12%CO coated T–22 steel have gained less weight as compared to uncoated T–22 and WC-10%CO-4%Cr coated T–22 steel. Thus WC-12%CO coated T–22 steel had shown good corrosion resistance in molten salt environment. The cumulative weight gain per unit area for uncoated and coated T–22 steel is as shown in (Fig. 4). The weight gain square (i.e. mg^2 / cm^4) data are also plotted as function of number of cycles as shown in (Fig. 3). Both uncoated and coated steels follow parabolic law. The parabolic rate constant K_p was calculated from the slope of linear regression fitted line(massgain/area)^2 versus number of cycles. The formula used for evaluating the value of parabolic rate constant K_p for uncoated and coated with WC-10%CO-4%Cr and WC-12%CO powder T-22 boiler steel is shown below. The value of parabolic rate constant K_p for uncoated T–22 boiler steel was calculated to be 9.39 x 10^{-13} g^2 cm^{-4} s^{-1} and for WC-10%CO-4%Cr coated T-22 steel was 4.47 x 10^{-13} g^2 cm^{-4} s^{-1} and for WC-12%CO coated T–22 boiler steel was calculated to be 3.49 x 10^{-13} g^2 cm^{-4} s^{-1} and all these calculated values are shown in Table 1.The parabolic rate constant K_p value clearly shows that WC-12%CO coated T–22 steel was more protective against hot corrosion as compared to uncoated T–22 boiler steel and WC-10%CO-4%Cr coated T-22 boiler steel. Formula used for evaluating the value of parabolic rate constant K_p for uncoated and coated T-22 boiler steel.

$$Kp = \frac{A}{0.36} * 10^{-10}\ g^2cm^{-4}s^{-1}$$

Here

A=Slope of straight Line Y=AX+C

Table 1. Kp value of uncoated and coated substrate T-22 steel subjected to hot corrosion, exposed to molten salt (Na_2SO_4–60% V_2O_5) at 900 ^{0}C for 50 cycles

Substrate	Parabolic Rate Constant Kp (x 10^{-13} $g^2cm^{-4}s^{-1}$)
Uncoated T-22 Steel	9.39
WC-10%CO-4%Cr coated T-22	4.47
WC-12%CO coated T-22	3.49

11. CONCLUSIONS AND FUTURE SCOPE

CONCLUSIONS

The conclusions from the present study have been enumerated below:

1. The base T–22 boiler steel have undergone intense spelling and peeling of scale and enormous weight gain in aggressive environment of Na_2SO_4 – 60% V_2O_5 at 900 ^{0}C after 50 cycles
2. The WC-12%CO coated T–22 have gained less weight than WC-10%CO-4%Cr coated and uncoated T–22 in molten salt environment, then by proved to be corrosion resistant one.
3. The parabolic rate constant K_p was obtained from the slope of linear regression fitted line. The value of K_p for uncoated T–22 was 9.39 x 10^{-13} g^2 cm^{-4} $s^{-1}$and WC-10%CO-4%Cr was 4.47 x 10^{-13} g^2 cm^{-4} s^{-1} and WC-12%CO coated T –22 was calculated to be 3.49 x 10^{-13} g^2 cm^{-4} s^{-1}. The value clearly shows that WC-12%CO coated T-22 was more protective against hot corrosion as compared to uncoated T–22 and WC-10%CO-4%Cr coated T-22.

4. The higher corrosion rate was observed during the initial hours of study, which might be attributed to the rapid reaction of metal or coating directly with the salt.
5. Rate of corrosion was observed to be high during initial hours of study, which may be attributed to the rapid reaction of metal or coating directly with the salt, resulting in acidic oxide dissolution and non–protective reprecipitation.
6. The coating has protected the substrate for 35-40 cycles, but could not sustain up to 50 cycles. This may be due to difference in thermal expansion coefficient of the substrate and the coating.

12. FUTURE SCOPE

1. Studies can be made to evaluate other types of coating for providing resistance to hot corrosion for T-22 boiler steel.
2. Behavior of the T-22 boiler steel may be evaluated in the actual industrial environment of a boiler.
3. The behavior of the coatings can be studied for different lengths of time so that progressive development and mechanism of the scale can be studied.
4. The adhesive strength for the coating can be determined.
5. Cost effectiveness analysis may be done for coating.
6. High temperature erosion behavior may also be investigated.

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