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Some Studies on D-Gun Sprayed ASTM SAE213 T22 Steel for High Temperature Applications

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Abstract **- Detonation gun spray coatings are known for their high density, high bond strength and better wear/corrosion resistance. In this study, detonation gun spray technique was used to deposit WC-12Co and Cr_3C_2-25NiCr coating on boiler steel ASTM SAE213 T22 steel. The specimens with and without coating were subjected to cyclic oxidation at 500oC for 50 cycles in air environment to ascertain usefulness of the coating at the said temperature. The weight change technique was used to establish the kinetics of oxidation/corrosion. X-ray diffraction (XRD) and FE-SEM/EDS techniques were used to analyze the exposed samples. The behavior of the uncoated and coated samples supported by various characterization techniques in detail have been reported in the present study.**

Keywords: **Boiler Steel, D-gun Thermal Spray, High Temperature Corrosion**

I. Introduction

The scaling of metals that takes place at elevated temperature under dry conditions is known as high temperature corrosion. High temperature corrosion is most often called oxidation [1]. High temperature is considered to be at 500^0 and above [2]. Power station boilers and the other parts of coal fired plants are subjected to frequent degradation by erosion corrosion problems relevant to reliability and economics of these installations. The environment of the furnaces is characterized by high temperature conditions together with aggressive atmospheres, leading to corrosive deposits adhered to the walls and to erosion processes due to ash particles. During the last few years, this problem has been the focus of several research groups, which have generated the knowledge for the improvement of usually used materials and for the development of new structural materials and coating capable of withstanding these aggressive conditions [3]. In a wide variety of applications, materials have to operate under severe conditions such as erosion, corrosion and oxidation at high temperature. Surface modification is necessary to protect them against the indicated types of degradation [4]. The continuing development of modern energy generation systems requires materials capable of withstanding increasing temperatures, mechanical loads and chemical degradation [5]. Only composite materials are able to meet such a demanding spectrum of requirements, the base material provides the necessary mechanical strength and coating provides a way of extending the limits of use of material at the upper end of their performance capabilities by allowing the mechanical properties of the substrate material to be maintained while protecting them against wear, erosion or corrosion [4]. Protective means to counteract the problem of high temperature degradation is to coat the base material with a protective layer different in structural and/ or chemical composition and supplied by a surface treatment can be optimum choice in combining material properties [6]. Thermal spray coating provides a vital role in protecting turbine against high temperature oxidation and hot corrosion at elevated temperature [7]. D-gun spraying is one of the most promising thermal spray techniques and it was originally developed and patented by Union carbide (now praxair) in 1955. D-gun spraying is characterized by spraying of particles that are accelerated by detonation wave and impact on the substrate at high velocity [8]. Depending upon the ratio of combustion gases the temperature of the hot gases can go up to 4000^0c and the velocity of the shock wave can reach 3500m/s [9]. The coatings are produced with very high bond strength and generally porosity lower than 2% with thickness ranging from 50 to 500µm [10].

The objective of this work is to investigate the possibility of use of WC-12Co and Cr_3C_2-25NiCr coatings for the steam generating plants. An attempt has been made to deposit WC-12Co and Cr_3C_2-25NiCr coatings on a boiler steel substrate by detonation-gun spray process. The cyclic oxidation of the coatings has been studied at 500^0c. Moreover, the high-temperature boiler studies could provide an idea regarding the adhesion between the coatings and the substrate steels under thermal shocks [11].

II. Experimentation

A. Substrate Material

ASTM-SAE 213-T22 (T22) boiler steel has been chosen as substrate material in the current study. This steel is being used in boiler superheater at Guru Nanak Dev Thermal Plant, Bathinda. The substrate is selected to study oxidation behavior in the boiler working conditions. To reduce the oxidation losses surface coating was done by Detonation-gun thermal spray coating process. Specimens each measuring 20 mm × 15 mm × 5 mm approximately were cut from the fresh steel. After grit blasting with Al_2O_3 (Grit size 40) deposition of the WC-12Co and Cr_3C_2-25NiCr coating was done by D-gun spraying.

Table I Chemical composition of ASTM-SAE 213-T22 steel (in %age)

C	0.15
Mn	0.3-0.6
P	0.03 max
S	0.03 max
Si	0.5 max
Cr	1.9 – 2.6
Mo	0.87 – 1.13
Fe	94.66

B. Development of coatings

A commercially available WC-12Co and Cr_3C_2-25NiCr powders having particle size 30-50µm size (M/S H.C.Starc company, Germany) were deposited on substrate by D-gun process at SVX Powder M Surface Engineering Pvt. Ltd, New Delhi (India). Samples were grit-blasted before the D-gun spraying. All the process parameters, including the spray distance (165mm) were kept constant throughout the coating process. The coating was deposited on all six surfaces of the specimen.

Table II Thermal Spray parameters employed for D-gun coating.

Oxygen Flow rate	2800 SLPH
C_2H_2	600 SLPH
N_2	2400 SLPH
Spray distance	165mm
Frequency of shots	3

*SLPH: Standard Liters per Hour

C. Characterization of as-sprayed coatings

The visual inspection of as-sprayed coatings was done. The Surface Roughness of the as sprayed coated samples was measured with the help of surface roughness tester (Surftest, SJ-210,Mitutoyo) . In each coated specimen on four fields on the surface were used to obtain the value of surface roughness (µm). Metallurgical microscope (Letiz India pvt. Ltd.) was used to measure the porosity of the as-sprayed coatings. Three fields on the surface of each coated specimens were used to obtain the value of porosity. FE-SEM/EDAX (JSM-6610LV and FEI, Quanta 200F) analysis was done to characterize the surface morphology of the coating.

D. Oxidation Studies

Oxidation studies were performed for 50 cycles under the cyclic conditions. Each cycle consisted of 1 hour heating at 500^0c in a silicon carbide tube furnace followed by 20 minutes of cooling at room temperature. This cyclic study provides the most severe conditions for testing. A cyclic study of 50 cycles had been performed as the study of 50 cycles is considered to be adequate for attaining the steady state oxidation for the material [12]. The studies were performed for uncoated as well as coated specimens for the purpose of comparison. The specimens were polished on cloth. The mass change measurements were taken at the end of each cycle with the help of an electronic balance having a sensitivity of 0.002 g. The mass change technique was used to formulate the kinetics of corrosion. Visual observations were also made after the end of each cycle with regards to color, adherence/ spallation tendency and other physical aspect of the oxide scale/coatings. After the oxidation studies, the corroded samples were analyzed by FE-SEM/EDS analysis.

III. Results

A. Visual Observation and Coating Thickness

The D-gun sprayed WC-12Co was dark grey in color and Cr_3C_2-Nicr light grey in color. The thickness of the coating was found by coating thickness tester at SVX Powder M Surface Engineering Pvt. Ltd, New Delhi (India). The thickness of the coating was found to be 200-250 µm.

B. Surface Roughness and Porosity

The surface roughness was measured with the help of surface roughness tester (Mitutoyo).The surface roughness of the as-sprayed WC-12Co was 5.97 µm and surface roughness of the as-sprayed Cr_3C_2-25NiCr was 5.43**µm**. The porosity measured with metallurgical microscope of WC-12Co and Cr_3C_2-25NiCr as sprayed specimens was found to be 0.40% and 0.52% respectively.

C. SEM/EDS analysis of As-sprayed Coatings

The FE-SEM micrograph of as-sprayed WC-12Co coating is shown in Fig. 2a. The microstructure consists of irregular sized particles. There is also a presence of some superficial voids in the microstructure. The EDS analysis of the coating at two different points 1 and 2 indicated that the coating has a nearly uniform composition. As expected, W has been found to be the main constituent. The FE-SEM micrograph of as-sprayed Cr_3C_2-25NiCr shows . The FE-SEM micrograph of as-sprayed Cr_3C_2-25NiCr shows elemental composition at some points as depicted in Fig 2b. There is also a presence of some superficial voids in the microstructure.

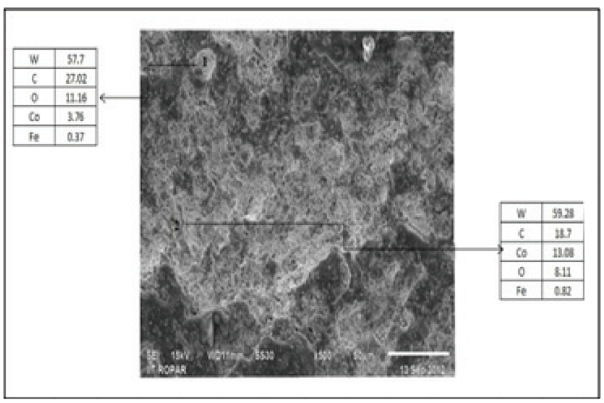

Fig. 2a FE-SEM/EDS analysis of D-gun sprayed WC-12Co T22 steel.

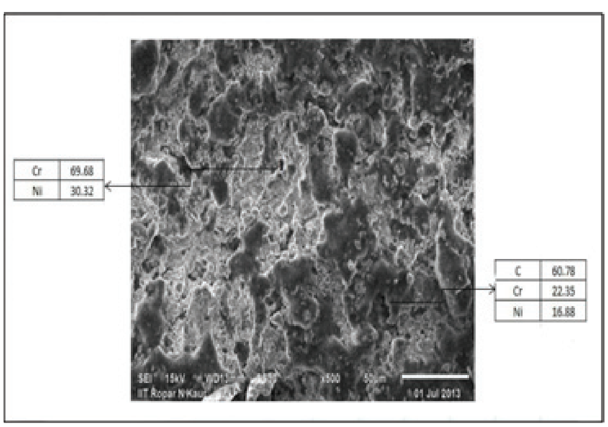

Fig.2b FE-SEM/EDS analysis of D-dun sprayed Cr3C2-25NiCr coated T22 steel

D. High Temperature Oxidation Behavior

In the case of oxidation study of bare steel at 5000c the color of specimen turned dark black at the end of 1st cycle. There is continuous variation of weight throughout of cycles. The weight reduced significantly during the cyclic studies. During the high temperature oxidation testing of WC-12Co coated steel at 5000C the color of the specimen turned black after the 1st cycle. At the end of 24th cycle the color of the specimen changed to greenish tone and remained so thereafter. The weight increased in initial 11 cycles, thereafter weight loss was recorded upto 18th cycle. However after that negligible variations in weight change were observed and it remained almost constant.

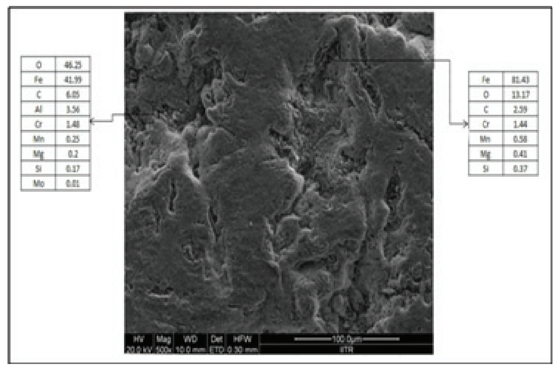

Fig.2c FE-SEM/EDS analysis of uncoated T22 steel after cyclic oxidation.

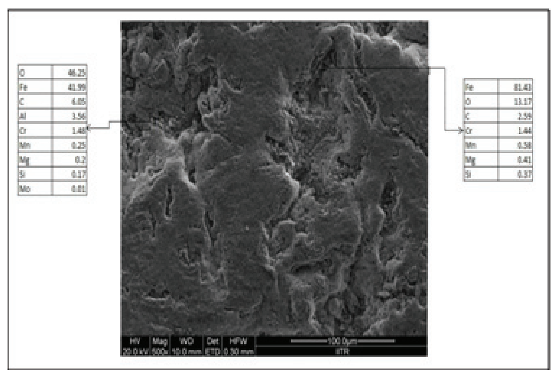

Fig. 2d FE-SEM/EDS analysis of D-gun sprayed WC-12Co T22 steel after cyclic oxidation at 5000c.

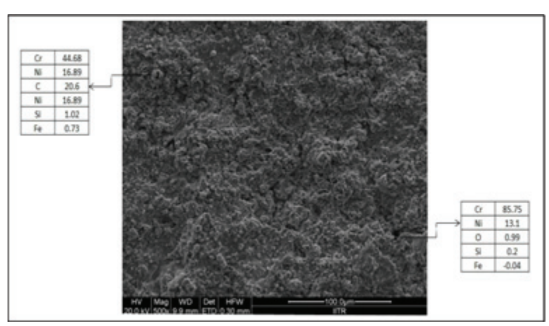

Fig.2e FE-SEM/EDS analysis of D-dun sprayed Cr3C2-25NiCr T22 steel after cyclic oxidation at 5000c.

The D-gun spray process provides the possibility of the deposition of WC-12Co and Cr_3C_2-25Nicr coatings on the T22 steel. Detonation-gun sprayed WC-12Co and Cr_3C_2-25Nicr coatings on T22 steel exhibits a dense adherent and uniform microstructure with little porosity. A coating of about 200-250 µm was obtained. As depicted in Fig. 2a and Fig. 2b, most of the deformed particles seem to be interlocked each other in the both coatings. The coatings possess some voids and oxide inclusions that are typical characteristics of the D-gun sprayed coating. It is learnt that the coatings should have minimum possible porosities because high values can do harm to the persistent erosion-corrosion resistance of thermal spray coatings. The porosity of the D-Gun coatings has been found to be low with an average value of 0.6% which seems to be acceptable from the point of view of oxidation protection. The weight change graph indicate that the performance of Cr_3C_2-25NiCr is better as weight change become almost uniform after the initial weight loss. This may be because of formation of protective oxides as indicated from SEM/EDS analysis. The surface EDS analysis of the Cr_3C_2-25Nicr coating after exposure to environment revealed high amount of Cr in the oxide scales, thereby indicating the formation of a Cr_2O_3 rich scale.

V. Conclusion

The D-gun process provides the possibility of developing WC-12Co coatings on the T22 steel. The coating has shown uniform adherent and dense structure. The value of surface roughness in case of D-gun sprayed Cr_3C_2-25Nicr was found to be better (5.43µm) than D-gun sprayed WC-12Co coated substrate (5.97µm). The value of porosity in case of D-gun sprayed WC-C0 coated substrate was found to be better (0.4%) than D-gun sprayed Cr_3C_2-25Nicr coated substrate (0.52%). The D-gun sprayed Cr_3C_2-25Nicr coated substrate was found to be more successful than bare steel and WC-12Co coated steel in reducing the oxidation rate of the T22 boiler steel, although the diffusion of Fe from the substrate to the coating was observed.

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