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Surface Engineering Analysis of D-Gun Sprayed Ni-20Cr Coating in Aggressive Environment

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Abstract: **This paper demonstrates the successful application of Ni-20Cr coatings on 304SS austenitic stainless steel substrates using detonation-gun thermal spray process for corrosion applications. We present preliminary results of fabrication and microstructural characterization of Ni-20Cr coatings. The cyclic hot-corrosion studies were conducted on uncoated as well as D-gun coated substrates in the presence of mixture of 75 wt.%V2O5 +25 wt.% Na2SO4 film at 900 °C for 50 cycles. These coatings were characterized by means of an optical microscope, scanning electron microscope and X-ray diffraction (XRD). Microstructural characterization of as deposited coating indicates the presence of porosity, unmelted and semimelted particles. The extent of degradation of the uncoated as well as D-gun coated substrates was assessed by the thickness loss and depth of internal corrosion attack. It was observed that Ni20Cr-coated substrates showed better corrosion resistance than the uncoated substrates in the presence of molten salt environment as a result of the formation of non porous oxides of chromium and nickel. It was found that Ni20Cr coating offers substantial protection as the bare substrate underwent severe corrosion. The improved protection against corrosion of Ni-20Cr coating can be attributed to the presence of Cr2O3 in the top oxide scale which is homogeneous, intact and having less porous microstructure.**

***Keyword:** Microstructural, Ni20Cr Coating, D-Gun, Hot Corrosion, Oxide Scale*

1. INTRODUCTION

Metal alloys such as NiCr coatings obtained by thermal spraying minimize corrosion in severe working conditions such as at elevated temperatures or in aggressive environments, for example in boiler tubes for power generation or in steam turbine blades [1-8]. These coatings maintain their high corrosion resistance up to 1100º C and can be used to improve the performance life of components working at elevated temperatures. Different studies indicate that chromium oxide is preferentially formed at high temperatures on the coating surface and so prevents oxidation of the whole coating [9-15]. Corrosion is a serious problem in industrial environment and increasing day by day. It occurs at low temperature as well as high temperature according to the environmental condition and present moisture & hazardous elements present in nearby surrounding such as vanadium, sulphur, various salts, fly ash particle, and dust particle. Corrosion mainly depends on the reaction between corrosion species and metal component. As we know corrosion is dangerous for mechanical components such as boiler, turbine, gas pipelines, waste incliners, pumps, mechanical dies and exhaust passage for hot flue gases in any plant [16]. In a surrounding of boiler there is sufficient free oxygen with moisture, high temperature, erodent particle like fly ash etc. present which leads to both erosion and corrosion. No one metal can able to meet or perform all mechanical/desired property at a time. So some modification is required in terms of protection of that metal to use in specific purpose or use in specific condition in any plant/industries. For enhancing the properties of metal either we should apply suitable coating over it or use super alloys instead of normal metal. Super alloys can use for high temperature applications, but they are not fulfil both high temperature strength and high temperature corrosion strength at same time. So to resolve this possible we should apply coatings over the metal components. For protection the metal from wear, corrosion and enhance the life of components we applied coating according to bond strength, metal composition, requirement properties regarding to that particular environmental condition. There are many processes which are used to apply coating over the metal surface such as detonation gun (D-gun), HVOF process, plasma process etc. Thermal spraying is a rapid process, which is a cost effective technique adopted by many industries like as hydraulic machinery, paper processing rolls, costal installations unit and pump components[1,2].Thermal spraying coatings is developed due to rapidly heating of the feedstock material in a hot gaseous medium and projects high velocity towards the desired surface. This is an effective and economical way to produce coatings and apply on the boiler tube of the steam generating plant to overcome the erosion –corrosion problems [2]. D-gun a type of spray coating process which provides, an extremely adhesive strength, low porosity, high dense so it can protect to oxidation at high temperature condition. The coatings properties depend on many factors. In other words we can say there are many parameter which can affect the coatings properties such as properties of the powder, size of particle, distribution of the particle, hardness of the carbide particle, properties of the matrix, coating process which determine the characteristics of coating such as density, micro hardness, density, residual stress and bonding strength[3]. Ni-Cr alloys can be used as coatings to tackling the oxidation environment at elevated temperature condition. These elements oxidises into Cr_2O_3, which leads to make suitable it for elevated temperature [6]. The thermal sprayed NiCr alloy is usually prefers for protection of corrosion of boiler tubes [7].NiCr coating provides greater corrosion resistance as well as oxidation resistance at high temperature condition so it's can prevent the failure of components at high temperature. The formation of Cr_2O_3 into the coating under steam oxidation environment provides safety to the substrate [8]. Therefore, in this study we have synthesize the NiCr corrosion resistant coating using D-Gun process and investigate the structural, hot corrosion behaviour and surface analysis of the as sprayed and oxidized coating. Moreover, the hot corrosion studies could provide an idea regarding the adhesion between the coatings and the substrate steels under thermal shocks.

2. MATERIALS AND METHODS

2.1 Development and characterization of coatings

In the present investigation specimens with dimensions of approximately 20×15×5 mm^3 were cut from the as-received 304SS steel sheets. Commercially available Ni20Cr alloy powder was deposited on 304 SS sample by using Detonation Gun thermal spraying process (220-250 µm thickness). The coating was deposited at SVX Powder M surface Engineering, Greater Noida, India. Chemical composition of AISI 304 SS substrate is shown in table1 and D-Gun parameters used during application of Ni-20Cr coating on AISI 304 SS substrate are shown in table 2.

Table1: Chemical composition of the substrate:

Steel	C	Mn	Cr	Ni	N	P	Si	Fe
AISI 304SS	0.08	2	18-20	8-12	.10	.045	.75	Bal

Table2: Technical details of parameters during application of Ni-20Cr coating

Substrate	AISI 304 SS
Film thickness	220-250 µm
C2H2 Pressure (MPa)	0.14
N Pressure (MPa)	0.4
O Pressure (MPa)	0.2
Air Pressure (MPa)	0.4
Firing rate	1-10 Hz
Consumption rate of water	15-25 lit/min

*2.2 **Molten Salt Corrosion study***

The specimens were mirror polished by cloth wheel polishing machine and cleaned with acetone. After cleaning, both coated as well as bare substrates were heated to about 250 ^{0}C for removal of other contaminants and good adhesion of salt layer. Then a salt of 75 wt.%V_2O_5 +25 wt.% Na_2SO_4 is mixed thoroughly in distilled water. A uniform layer of 75 wt.%V_2O_5 +25 wt.% Na_2SO_4 is deposited with the help of camel hair brush. The hot corrosion study of bare and coated specimen was done in aggressive molten salt environment (75 wt.%V_2O_5 +25 wt.% Na_2SO_4) for 50 cycles under cyclic conditions at a temperature about 900^o C. Each cycle of study is followed by 1 hour heating in the furnace and then cooling of these specimens in air for half an hour. These entire salt-coated specimens were loaded to alumina boats and kept in oven for 3-4 hour at temperature about 100 ^{0}C to ensure proper drying and adhesion of salts. Then both bare and coated specimens kept in furnace at 900 ^{0}C for hot corrosion study. The hot corrosion studies of coated as well as bare specimen were performed. For cross sectional analysis, the coated substrates which were exposed to molten salt environment were cut vertically using EDM wire cut and then properly mounted for polishing. Surface finishing of the samples was done by using 220,400, and 600 grit size emery papers followed by alumina cloth polishing. After exposure for 50 hours, the morphology of the oxidized samples was analyzed by using optical microscope and field emission scanning electron microscope (FE-SEM).

3. RESULTS AND DISCUSSION

3.1 XRD Analysis

It is evident from the spectra that there is no extra peak has been observed and no any extra phase was detected in this study. The XRD pattern of Ni-20Cr as-sprayed coating depicted in figure 1b shows that the most prominent peaks of the own coating composition (Ni–20Cr). The major peaks were present at 44.1413^o, 51.4198^o, 75.6758^o and 92.0591^o. The XRD diffraction spectrum shows polycrystalline structure of Ni-20Cr coating. The XRD pattern was taken in the presence of thin film geometry in powder XRD setup where the beta nickel filter was used to remove the Kα2 emission peak of the X-Ray generator.

Peak List

Pos.[°2Th.]	Height [cts]	FWHMLeft[°2Th.]	d-spacing [Å]	Rel. Int. [%]
44.1413	2020.97	0.1378	2.05173	100.00
51.4198	702.72	0.1378	1.77711	34.77
75.6758	220.46	0.1181	1.25676	10.91
92.0591	147.31	0.1968	1.07120	7.29
97.5373	47.47	0.1771	1.02511	2.35

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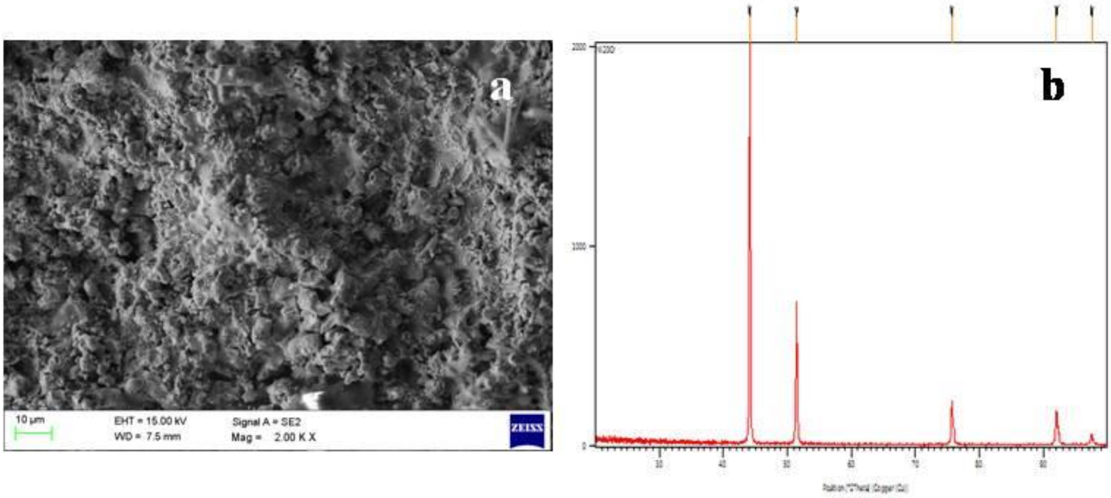

Figure1. (a) SEM image showing surface morphology of as sprayed Ni-20Cr coating (b) XRD analysis of as sprayed Ni-20Cr coating

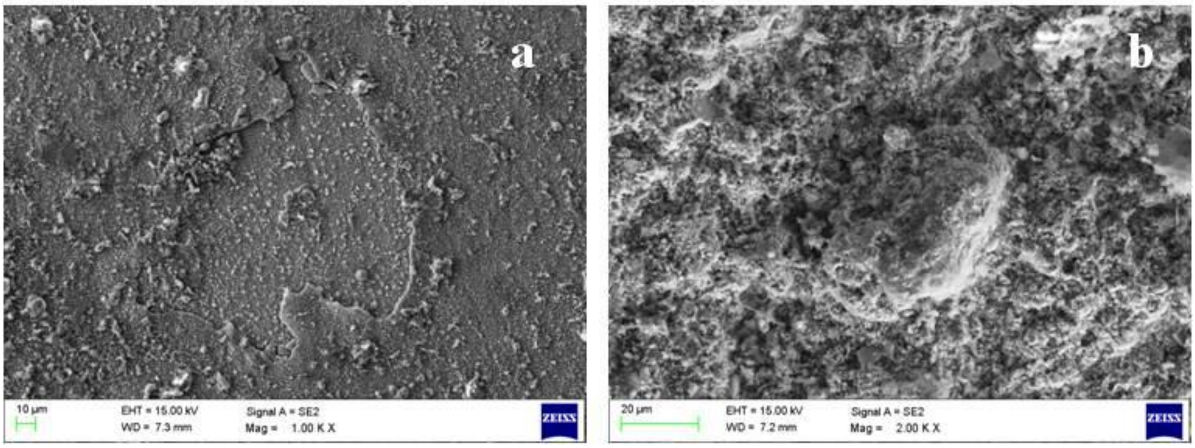

Figure2. (a) SEM image showing surface scale morphology for AISI 304SS subjected to cyclic oxidation in molten salt environment at 900 °C for 50 cycles (a) in uncoated condition, and (b) with D-gun sprayed Ni-20Cr coating.

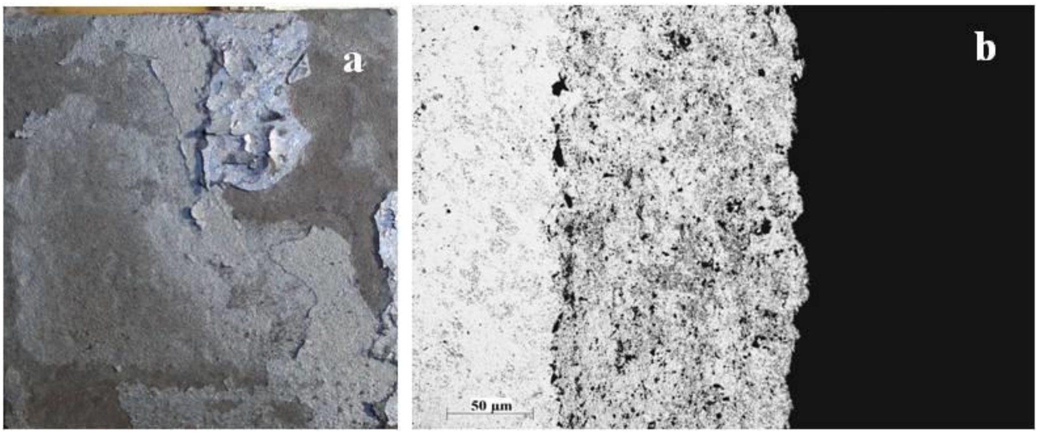

Figure3. (a) Optical image showing surface scale morphology for AISI 304SS subjected to cyclic oxidation in molten salt environment at 900 °C for 50 cycles, (b) Optical image showing oxide scale morphology across the cross-section of D-gun sprayed Ni-20Cr coated substrate subjected to cyclic oxidation in molten salt environment at 900 °C for 50 cycles.

3.2 SEM analysis

The surface morphology of as deposited (figure 1a) were analyzed using Field Emission Scanning Electron Microscope (FESEM). It is evident from Fig. 1a that the as sprayed coating contains porosity, unmelted and semimelted particles. The porosity can clearly be seen as dark areas. The deposited films were almost uniform, homogenous and crack free as depicted in the figure 1a. The SEM micrograph of uncoated and coated substrates after subjected to cyclic oxidation in molten salt

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environment at 900 °C for 50 cycles is shown in figure (2a and 2b). SEM image for bare sample showed the formation of large granular iron oxides which is fragile. Furthermore, big cracks were too observed which is due to the iron oxide scale which has low thermal coefficient of expansion. It can be seen that oxide layer formed was of porous nature which was unable to stop the diffusion of corrosion species which further increases the oxidation of the specimen. Optical image (Figure 3a) showing surface scale morphology for AISI 304SS subjected to cyclic oxidation in molten salt environment at 900 °C for 50 cycles. Optical image (Figure 3b) showing oxide scale morphology across the cross-section of D-gun sprayed Ni-20Cr coated substrate subjected to cyclic oxidation in molten salt environment at 900 °C for 50 cycles. The porosity can clearly be seen as dark areas. D-Gun sprayed Ni-20Cr coating on 304SS exhibits a uniform splat like microstructure, with splats oriented parallel to the substrate surface. The coating/oxide scale was intact with the surface of substrate which provides a necessary protection against corrosive species.

3.3 Thickness Loss Measurements

The thickness loss of uncoated and coated substrates subjected to cyclic oxidation in molten salt environment at 900 °C measured using digital vernier caliper and was found to be 1.672 mm and 0.034 mm respectively. The metal loss in milli-inches per year for both uncoated and coated substrates are given in Figure 4.The degradation rate in terms of milli-inches per year has reduced after the deposition of the Ni-20Cr coating. The lower thickness loss rate in case of coated substrate exposed to the molten salt environment at 900º C might be attributed to the compact structure of its oxide scale.

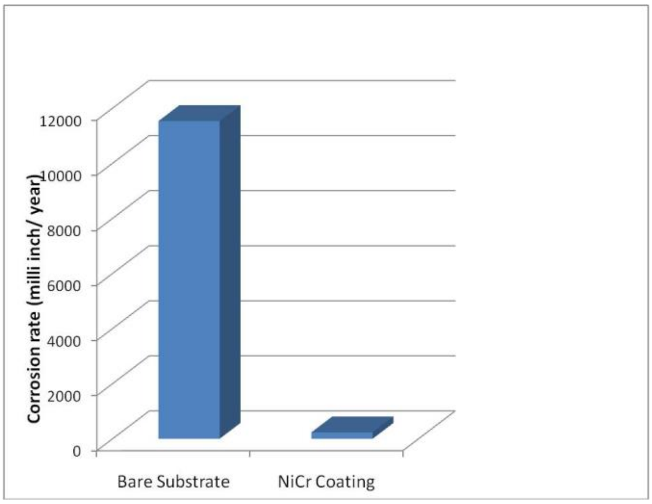

Figure 4. Corrosion rate in milli-inches per year for uncoated and coated substrates subjected to cyclic oxidation in molten salt environment at 900 °C.

4. CONCLUSION

Bare AISI 304SS substrate suffered widespread oxidation attack in the molten salt environment, with the scale sharp deeply into the substrate. Poorer resistance of bare substrate is attributed to the formation of cracks and freely bounded oxide scale. D-Gun sprayed Ni-20Cr coating was found useful in providing necessary hot corrosion resistance to bare substrate in the aggressive environment. The improved hot corrosion resistance of Ni-20Cr coating is attributed to the presence of chromium and nickel oxide in the top oxide scale and impenetrable microstructure. FESEM results confirm that the deposited films were almost uniform, homogenous and crack free.

REFERENCE

[1] T. Sundararajan, S. Kuroda, and F. Abe, Steam Oxidation Resistance of Two-Layered Ni-Cr and Al APS Coating for USC Boiler Applications, Corros. Sci., 2005, 47, pp 1129-1147
[2] Bala N, Singh H, Prakash S. high temperature oxidation studies of cold sprayed Ni-20Cr and Ni-50Cr coatings on SAE 213-T22 boiler steel. Appl. Surf. Sci. 2009, 255, pp 6862-6869.
[3] Shi-Hong Zhang, tong-yulcho,Jae-Hong Yoon, Fang w,Ki-O song, Ming-Xi Li, Yun-KonJoo, Lee Cg. Characterization of microstructure and surface properties of hybrid coatings of WC-CoCr prepared by laser heat treatment and HVOF. Mater, charact. 2008,59, pp1412-1418.
[4] D.Y. Kim, M.S. Han, in: C.C. Berndt (Ed), Thermal Spray: Practical Solutions for Engineering Problems, ASM International, Ohio,1996, pp.123-128.
[5] B.Q.Wang, in: T.S.Sudarshan, et al.(Eds.), surface modifications technologies XI, The Institute of Materials, Paris, 1997, pp. 458-467.
[6] H.S. Sidhu, B.S. Sidhu, S. Prakash, and S. Prakash, Mechanical and Microstructural Properties of HVOF Sprayed WC-Co and Cr3C2-NiCr Coatings on the Boiler Tube Steels Using LPG as the Fuel Gas, J. Mater. Process. Technol., 2006, 171, pp 77-82
[7] Aguero A, Muelas R, Gonzalez V. HVOF coatings for steam oxidation protection. Mater Corros 2008;59: pp393-401.
[8] Viswanathan R, Coleman K, Rao U. Materials for ultrasupercritical coal-fired power plant boilers. Int J Pressure Vessels Piping 2006,83, pp 778–83.
[9] T.N. Rhys-Jones, “Thermally sprayed coating systems for surface protection and clearance control applications in aero engines,” Surf. Coat. Technol. 43/44, 1990, pp. 402-415.
[10] R.V. Hillery, Coatings for performance retention, J. Vac. Sci. Technol. A4, vol. 6, 1986, pp. 2624-2628.
[11] T.S. Sidhu, S. Prakash, and R.D. Agrawal, Hot corrosion studies of HVOF sprayed Cr3C2–NiCr and Ni–20Cr coatings on nickel-based superalloy at 900 °C. Surf. Coat. Technol. 201 (2006) 792-800.
[12] Rakesh Goyal, Buta Singh Sidhu and J.S. Grewal, Surface engineering and detonation gun spray coating, International Journal of Engineering Studies, Vol. 2 (3), 2010, pp. 351-357.

[13] Vikas Chawla, Buta Singh Sidhu, D. Puri and S. Prakash, Performance of plasma sprayed nanostructured and conventional Coatings, Journal of the Australian Ceramic Society, Vol. 44 (2), 2008, pp. 56-62.

[14] N. Bala, H. Singh, and S. Prakash, High Temperature Oxidation Studies of Cold Sprayed Ni-20Cr and Ni-50Cr Coatings on SAE 213-T22 Boiler Steel, Appl. Surf. Sci., 2009, 255, pp 6862-6869

[15] S. Srikanth, B. Ravikumar, S.K. Das, K. Gopalakrishna, K. Nandakumar, and P. Vijayan, Analysis of Failures in Boiler Tubes Due to Fireside Corrosion in a Waste Heat Recovery Boiler, Eng. Fail. Anal., 2003, 10, pp 59-66

[16] R.A. Mahesh, R. Jayaganthan, and S. Prakash, Evaluation of Hot Corrosion Behaviour of HVOF Sprayed NiCrAl Coating on Superalloys at 900º C, Mater. Chem. Phys., 2008, 111, pp 524-533