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Hot Corrosion Behaviour of NiCr Coating deposited by different Thermal Spray Techniques in various Aggressive Environments

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Abstract: At presently, metal alloys based coatings have been used to increase hardness and to improve the wear and corrosion resistance of structural materials. Hot corrosion is found as a severe problem in various powers producing system such as thermal power plants, hydro power plants, gas power plants and various industries like oil refineries, aircraft, paper and pulp industries, automobiles and industrial waste incineration. For prevention and repairing the components a huge amount of money and time will wastage, which directly affect the economic loss. No one metal can fulfil all mechanical property or requirement at a time. To prevent the component from hot corrosion nanostructured coating and conventional coating are attractive options but nanostructured coating given to preference over conventional, due to its properties such as high hardness, very low porosity, highly dense, wear resistance and able to withstand at high temperature. In the present review report, the current situation of fighting hot corrosion and the high temperature erosion to the boiler surface has been discussed. Various types of coatings can be used according to requirement and environmental conditions, but in this literature review we focused only NiCr based coating deposited on different boiler steel by using various thermal spray techniques. The performance of the NiCr metal alloys coatings in aggressive environment has been reported. This article may help to understand the hot corrosion behaviour of NiCr coatings to resist the failure of boiler.
Keywords: Hot corrosion, NiCr coating, Thermal spray process, Boiler steel.

I. INTRODUCTION

Corrosion and wear resistant protective coatings are being used on structural alloys in energy conversion systems to protect the surface of their components from wear and hot corrosion [1]. The requirement of energy is increasing day by day in the country so supply should be fulfilled by the power plants or energy production systems. Energy production systems either increase the production or increase the efficiency to cover the requirement of energy which is increasing day by day in the country but due to hot corrosion their efficiency as well as service life of working component decreases. The main cause of decreasing the performance is hot corrosion in the boiler tube in power plant.

Corrosion leads to premature failure of the working component, the boiler tube got corroded due to the impurities like Na, K, S present in the coal so they have limited life due to corrosion and for maintain huge amount will wastage in terms of direct and indirect cost[1,2].

Corrosion related problem can't be vanished completely, but corrosion related cost can be subtraction by more than an estimated 30% through the development and use of corrosion prevention technologies [2]. For effective protection against corrosion-erosion coating can play an important role, thermal spray coating can be produced by various techniques. Coating offer great corrosion resistance and wear protection [3].

NiCr coating can be used in hot corrosion for boiler tubes in power plant. It has been discovered that the Cr content provide corrosion resistance to the coating [4].

NiCr coating can also be used to deal with oxidation environments at high temperature. This alloy element oxidised to Cr_2O_3 which make it suitable to use up to 1200°C [5,6]. Applications of NiCr coating are found in large areas like automobiles, aerospace, petrochemical, etc. and high strength NiCr alloy are generally used in the aero-engine applications where reduction of weight is one of the essential condition [7, 8]. In this paper we compare the hot corrosion behaviour of NiCr coating deposited on different substrate by various thermal spray processes with different environmental condition such as actual boiler, stimulated boiler circumstances or molten salt environment.

II. HOT CORROSION

Hot corrosion is dangerous for mechanical component under working in severe atmospheric condition. Main cause of hot corrosion & erosion is due to impact of pollutants, hazardous element such as fly ash particle, dust, S, Cl and unburned carbon particles are in those areas where temperature is above 600º C [9].

Almost more than 50% of the total production cost wastage as a maintenance cost for replacing and maintain the broken tubes in power plant [10]. The thermal sprayed 50/50 NiCr are generally preferred for prevention from corrosion to the boiler tubes in power generation applications [11]. NiCr alloys are widely preferred to provide corrosion resistance at high temperature, oxidation of Cr element forms a slowly growing and protective continuous layer [12].

Corrosion protection is mandatory because huge amount of money wastage to protect the base metal from hot corrosion [13]. Corrosion protection can be done by many techniques but nanostructured coating deposited by thermal spray process is widely used. Coating play important role and behave like barrier to base metal for its prevention. NiCr coating provides great resistance to hot corrosion in aggressive environment.

According to Binary diagram of Ni-Cr [14], Cr is soluble in Ni up to 47 wt. % at the eutectic temperature and it drops to almost 30 wt. % when it decreases to room temperature. So Cr is the main element which can form oxide scale, so its solubility in the matrix play vital role to the corrosion resistance alloys [14]. Oxidation resistance of NiCr alloy is responsible for the formation of a highly adherent protective scale, so that the diffusion rate of oxygen decreases [12]. This oxide scale contrived mixture of Ni & Cr in Ni-Cr alloy (NiO, Cr_2O_3, $NiCr_2O_4$) [12]. It is well known fact that by increasing the level of Cr in NiCr alloys, oxidation/corrosion resistance of Ni-Cr alloy increases [15,16].

III. THERMAL SPRAY TECHNIQUES USED FOR COATINGS

Ni based alloys having various useful properties such a wear, corrosion resistance, erosion, low porosity. They all occurs due to high amount of Cr, widely used for coating material. They also offer great corrosion /oxidation resistance [17, 18]. Thermal spray techniques are very useful, that's why they used to deposit alloy powders on substrate material. These coatings are provided to protection the material from hot corrosion because these coatings make Cr_2O_3 when exposed in high temperature zone and Cr_2O_3 thermodynamically stable up to high temperature limit because of its high melting point and dense coating structure, so they prevent its base material from hot corrosion [19-21]. In thermal spraying process a consumable material used which is melted by heating application into droplets or molten droplets, to impact over the substrate to form a continuous coating. There are many thermal process which are used to develop the coatings and selecting one is depends on the requirement and application of substrate [22]. Some of the important thermal spray processes are detonation Gun (D gun), high velocity oxy fuel (HVOF), high velocity arc spray (HVAS), high velocity air fuel (HVAF), plasma spray process, cold spray and wire arc spray.

A. High Velocity Oxy Fuel (HVOF) Process

HVOF is the one of the important thermal spray process, in which kinetic energy of coating material is increased by high velocity gas by burning of combustion product. The coating materials/feed-stock powder travels with the supersonic speed. In HVOF spraying a partial melting is sufficient to achieve high quality coating and the reason behind this the particle velocity impact on the substrate is higher in HVOF spraying [23]. Due to high velocity and high impact of thermal sprayed powder, the coating gets higher bond strength, less porosity, highly adherent and highly dense [24,25]. In HVOF, oxygen is mixed in the combustion chamber with fuel of a spray gun and feed stock material is inject into the chamber by a carrier gas stream so particles are rapidly heated and accelerated towards substrate, which attains velocity 450-1200 ms^{-1} [26]. Generally HVOF spray process includes two fuels gas (Hydrogen, Methane, Propane, Natural gas) and liquid (Kerosene etc.) and oxygen is used for combustion [27].

B. Plasma Spraying Process

In this process the feedstock material either form of powder or wire which is heated to molten /semi molten state and propelled on the substrate surface using the kinetic energy to form a hot gas stream [22]. Plasma jet temperature reaches to more than 15000º C which causes high degree particle melting. It is generally used for material having high melting point such as ceramic coating, cermets and high melting point alloys thus it possess very high hardness and wear properties for substrate. A gas using argon, but occasionally including He, H_2,N_2 is allowed to flow between a tungsten cathode and water cooled copper anode and arc is generated between two electrodes[22]. The arc ionizes the gas and creating high pressure gas plasma, and powder is heated and accelerated by the high temperature plasma gas stream towards the substrate [28]. Deposition density of material is high, high bond strength so it can be used for corrosion and wear resistant coatings.

C. Cold Spray Process

In this process gas temperature is below the melting temperature of the material so that the particle in the jet cannot be melting [29]. In cold spray process gas such as air, nitrogen or helium is used to carry powder particle which accelerated through nozzle. The carrier gas gets supersonic velocity after passing through nozzle and propels the particle at high velocity by momentum transfer principle [30]. These particles after striking the substrate surface plastically deformed and formed desired coating [31]. Metals, polymers, composite material powder can be deposited using cold spray process.

D. Detonation Gun (D-gun)

In recent years D-Gun spraying has been widely used to deposit coatings. D-gun and HVOF are generally selected to get highly dense, hard and wear resistant coatings [32]. Lakhwinder et.al [33] reports that, predefined quantity of the combustion mixture fed through a tubular shaped barrel with oxygen and acetylene, nitrogen is also provided to prevent the back firing. The gas mixture in the chamber is ignited by a spark plug, due to combustion of gas mixture high pressure shock waves (detonation wave) generates.In D-Gun process, spraying of the particles accelerated by the detonation wave unlike other thermal spray process and impact on the substrate surface with a high velocity of 800-1200 ms^{-1}. These particlesthen come out from the barrel and impact to the component. The high kinetic energy of hot particles on impact on substrate results as a very dense and strong coating. The thickness of coating depends on various parameters such as the ratio of combustion gases, powder particle size, flow rate of carrier gas and distance between the substrate and barrel end. It is the one of the promising thermal spray process which provides excellent adhesive strength, low porosity and dense coating [34].

Table1. Comparison of NiCr coating by various thermal spray process:

S.N.	Base material	Coating material	Coating technique	Environment	Temperature	Reference
1.	T 22 boiler steel	Ni-20Cr	HVOF	Super heater zone of boiler	700±10º C	Niraj Bala et.al. [23]
	T22 boiler steel	Ni-20Cr	Cold spray	Super heater zone of boiler	700±10º C	Nirajbala et.al. [23]
2.	Mild steel	Ni-30Cr	HVAS	Salty environment with/without So_3	650º C	OuXue-Mei et.al. [34]
3.	T22 boiler steel	Ni-20Cr	Cold spray	Super heating zone of boiler	740±10º C	Manoj kumar et.al. [35]
	SA 516 steel	Ni-20Cr	Cold spray	Super heating zone of boiler	740±10º C	Manoj kumar et.al. [35]
4.	ASME P92 Boiler steel	Ni-50Cr	HVOF	TGAexposure+ Hot furnace	700º C	B.Song, Z. Pala[38]
5.	Stainless steel	Ni-20CrC Nano	HVAF Spray	Stimulated boiler circum- stances -	750º C	T. Kai et.al. [39]

IV. DISSCUSION

Bala et.al. found that micro hardness of Ni-20Cr coating under HVOF technique in the range of 175-351 Hv, having average value of 267Hv for the coating where as in cold spray process the micro hardness lies in the range of 207-319 HV, with the average value of the coating is 247 Hv [23]. Some researchers also reports that micro hardness value of NiCr coating using HVOF technique is more than the cold spray technique. Bala et al. reports that in her XRD analysis of Ni-20Cr coating deposited by HVOF technique NiO, Ni phase were present but in Cold Spray technique only Ni phase was present. Value of porosity of Ni-20Cr through HVOF was found 1.65-1.68% and through cold spray value was 1.59-1.63%. Both HVOF and Cold spray techniques confirmed better result to decrease to hot corrosion but if we say in terms of corrosion rate of T22 boiler steel decreased by 82% in case of HVOF whereas 56% in cold spray technique. It concluded that the HVOF have better hot corrosion resistance than the cold spray process [23]. Ouxue-Mei et al. describes that the study of hot corrosion rates of Ni-30Cr coating produced by High Velocity Arc Spray (HVAS) technique and simulated in different environment such as with/without salt and with/without SO_3. In first condition (i.e. with/without SO_3) author found that corrosion rate is very-very low in this condition. NiCr coating has almost same oxidation in presence or absence of SO_3, so we concluded NiCr coating not affected in presence or absence of SO_3 environment [34]. In second condition (i.e. present of Salt + with/without SO_3) author found different oxidation rate for both sample of NiCr coating due to present of salty (K_2SO_4+Na_2SO4) environment. So it has concluded the corrosion rate of NiCr coating sample is more aggrasive in presence of SO_3 than without SO_3 when both samples were exposed to molten salt environment [34].

Manoj et al. reports that NiCr inhibits corrosion while investigating the behaviour of Ni-20Cr coating deposited by cold spray process on T22 boiler steel & SA 516 Grade 70 steels, evaluated under the real boiler environmental condition and investigate samples for 15 cycles at the temperature of 750º C, each cycle having 100 hours heating exposure followed by 1hour cooling. These above material generally used for boiler tubes in India [35]. There type of powder were taken, powder (p_1 : Ni 74 µm, p_2: 67 nm, p_3: 60 nm) and mixed in ratio of 72%,8%, 20% respectively so overall composition (wt%) should be Ni: 80% , Cr:20% [36]. Thermal spray techniques are very useful, that’s why they used to deposit alloy powders on substrate material. These coatings are provided to protection the material from hot corrosion because these coatings make Cr_2O_3 when exposed in high temperature zone and Cr_2O_3 thermodynamically stable up to high temperature limit because of its high melting point and dense coating structure, so they prevent its base material from hot corrosion [19-21]. Kai et.al explains the corrosion behaviour and variation in micro hardness of the coated stainless steel substrate [39]. Coating thickness achieved by the HVAF was 200-250 µm. NiCrC coating which is deposited by high velocity air fuel (HVAF) spray process increases the micro hardness of substrate due to the high density and cohesive strength of the coating. The micro hardness value varies from edge of the coatings, so when compared to the stainless steel (bare substrate) it has found that NiCr coated substrate possesses more hardness and low porosity. Due to this NiCr coating provide better corrosion resistance than the bare substrate. Corrosion can be prevented by surface modifications (applying suitable coating over it), right selection of materials, uses of inhibitors and by decreasing the amount of pollutants in the nearby surroundings. With the outcome of various researches it has been concluded that any NiCr can be easily coated on substrate by HVOF, HVAF and D-Gun processes.

V. CONCLUSION

A. Hot corrosion resistance of HVOF coating was better than the cold spray process for the same NiCr coating.
B. Overall NiCr coating have good corrosion resistance in various aggressive environment.
C. Ni-20Cr coating deposited by HVOF process shows better corrosion resistance than the bare steel substrate.
D. It has been also observed that dense coating provides high micro hardness as compared to substrate material.

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