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CHARACTERISATION OF AS-SPRAYED INCONEL-625 COATING DEPOSITED BY HIGH VELOCITY OXY-FUEL (HVOF) PROCESS ON BOILER STEEL.

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Abstract- Among the various thermal spraying techniques, high-velocity oxy-fuel (HVOF) thermal spraying is a technique that can be applied to deposit erosion-corrosion resistant coatings, since it produces higher density, high bond strength, and negligible porosity than many of the other thermal spraying methods. In this present investigation, Inconel 625 powder was deposited on T22 boiler steel by HVOF thermal spray process. The coatings were examined using X-Ray diffraction (XRD), Scanning electron microscope (SEM) and energy-dispersive spectroscopy (EDS). The SEM/EDS analysis of as-sprayed IN 625 coatings exhibited cloudy morphology with a well adherent interface with the substrate. The EDS analysis of the coating showed richness in Ni, Cr and Fe with good amount of oxygen. The XRD analysis revealed the formation of Ni as major phases and the results are endorsed by SEM/EDS. Surface roughness and micro-hardness of the coating was also measured.
Keywords: HVOF, IN 625, X-Ray Diffraction (XRD), Scanning Electron Microscope (SEM)

1. INTRODUCTION

Alloys working at high temperature should have good mechanical properties along with erosion-corrosion resistance. However, it is not possible for a single material to own all these properties, along with easiness of manufacturing. Moreover, due to high cost of super-alloys, surface coating techniques have recently attracted the concern of researchers worldwide. Therefore, a composite system using a substrate material providing the essential mechanical strength with a protective surface layer that is different in structure and chemical composition can be an optimal choice in combining material properties [1]. Among the various coating techniques, high-velocity oxy-fuel (HVOF) process is reported to be a versatile technology and has been accepted by many industries owing to its flexibility, cost-effectiveness, and the superior quality of coating produced, since it alters the surface without changing the bulk material properties [2]. Coatings formed by HVOF spray have comparatively lower porosity, higher hardness, superior bond strength, and less decarburization than many of the other thermal spraying methods such as plasma spraying [3]. It was learned from the literature that Inconel 625 is a widely used engineering material due to its better resistance to hot corrosion, high temperature strength and weldability [4]. Because of its high cost, they are normally used in the form of coatings on low cost substrates such as steels [5].

Al-Fadhli et. al. [6] studied the erosion-corrosion characteristics of HVOF sprayed Inconnel 625 powder coating over different metallic surfaces and the coating resulted in outstanding erosion–corrosion resistance and not much influenced by material of substrate. Zhang et al. [7] investigated Inconel 625 coatings on Ni-based super-alloy produced by HVOF process. The coatings were done by a liquid-fuelled and gas fuelled guns. The coating by liquid fuel gun produced 10-20 times lower current density than the coating by gas fuelled gun. The improvement in corrosion resistance was due to reduced extent of melting and high speed of the liquid fuelled gun which diminished the interconnected porosity and low oxidation. Boudi et al. [8] studied the influence of HVOF sprayed Inconel 625 coatings on mild steel and stainless steel samples and carried out electrochemical test in 0.1N H_2SO_4 + 0.05N NaCl solution. It was established that the coating was of layered structure and segregated, with the presence of a slightly darker contrast phase assumed to be oxide.

There is a few published literature on the characterization of HVOF sprayed IN 625 coatings on T-22 boiler steel. It is important to know that characterization of the coatings are necessary for understanding behavior of thermal spray coatings as well as to formulate guidelines for improving coating performance in aggressive environments. In the present investigation, an attempt has been made to characterize the HVOF sprayed IN 625 coatings on T-22 boiler steel for high temperature applications. The microstructures and phase formulation of HVOF sprayed IN 625 coatings were characterized using X-Ray diffraction (XRD), Scanning electron microscope (SEM) and energy-dispersive spectroscopy (EDS). The influence of IN 625 coatings on surface roughness and micro-hardness was also examined.

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2. EXPERIMENTAL PROCEDURE

2.1. Development Of Coatings

2.1.1. Substrate Material

T22 boiler steel were used as substrate material in the present study. The actual chemical composition of these steels were analyzed with the help Optical Emission Spectrometer of Foundry Master make. The nominal and actual compositions of these steels are reported in Table No. 1. The specimens, each measuring 20 mm X 15 mm X 5 mm approximately, were cut from the boiler tube, polished with SiC papers down to 180 grit and afterward grit blasted with alumina powders (20 grit) prior to development of the coatings by HVOF process.

2.1.2 Coating Formulation

The IN 625 powder was coated on the steel specimens using a commercially available HIPOJET-2100 HVOF-spray apparatus. The coating was deposited at Metallizing Equipment Co. Pvt. Ltd. (Jodhpur, India), using oxygen and liquid petroleum gas (LPG) as input gases. Nitrogen gas was used as carrier gas. The employed coating parameters are reported in Table 2. All the process parameters were kept constant throughout the coating process.

Table 2. Process parameters adopted for HVOF coating

Oxygen flow rate	270 SLPM
Fuel (LPG) flow rate	55-60 SLPM
Air-flow rate	650 SLPM
Powder feed rate	40 g/min
Fuel pressure	7 Kg/cm^2
Oxygen pressure	10 Kg/cm^2
Air pressure	5.5 Kg/cm^2

2.2. Characterization of as-sprayed coating

X-ray diffraction (XRD) analysis was performed on both feedstock powders as well as HVOF coated specimens to identify the various present phases. X-ray diffraction (XRD) analysis was carried out at IIT Ropar using Instrument of PAN Alytical, Model X'Pert PROMPD made in Neitherland using CuKα radiation. The specimens were scanned with 2θ range of 20^o to 100^o, step size (^{o}2Th.) of 0.008 and scan step time (s) of 10.16. The diffractometer interfaced with XRD software provided the 'd' values directly on the diffraction pattern, which were further used for identification of various phases with the help of inorganic ASTM X-ray diffraction data cards. Surface morphologies of the feedstock powders and coated specimens were examined with the help of Scanning Electron Microscope (SEM) of JEOL Japan make having model JSM-6610LV equipped with EDS facility having model number 51-ADD0013 at IIT Ropar. The surface roughness (R_a) values of the IN 625 coating were taken with surface roughness tester, Mitutoyo make at NITTTR Chandigarh. The microhardness of the coating surface was also measured with a load of 1Kgf for 15 sec. by taking average of five values using the Vickers Hardness Tester, FIE make at CITCO Chandigarh.

Table 1: Chemical Composition (wt %) of substrate used in study.

Type of steel grade	Chemical Composition								
		C	Mn	Si	S	P	Cr	Mo	Fe
T-22	Nominal	0.15	0.3-0.6	0.5	0.03	0.03	1.9-2.6	0.87-1.13	Bal.
	Actual	0.148	0.506	0.265	0.01	0.02	2.31	1.02	95.6

3. RESULTS

3.1. SEM/EDS ANALYSIS

Scanning electron microscopy image of IN 625 powder has been shown in Fig. 1. The image revealed a spherical morphology of the particles. The surface morphology of HVOF-sprayed IN 625 coated T22 boiler steel has been shown in Fig. 2 . The as-sprayed coating is found to have a cloudy morphology consisting of irregular shaped splats. The splats have uneven shapes and sizes, which are interconnected. Some superficial voids can also be seen in the microstructure. The EDS analysis of the coating surface indicates the presence of mainly Ni, Cr and Fe elements in the coating compositions which is nearly the same to feedstock powder composition. There is a presence of small amount of O also, which indicates that some localized oxides may have also been formed in the structure.

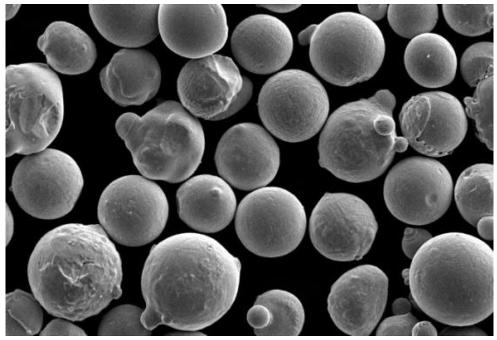

Fig. 1 - SEM morphology of IN 625 coating powder.

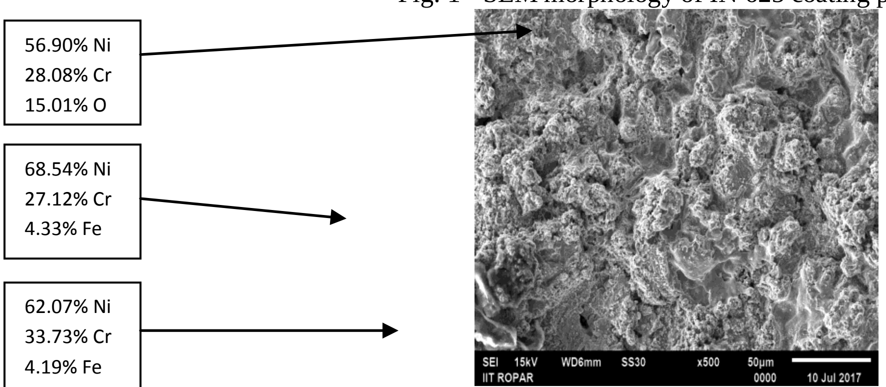

Fig. 2 - Surface morphology and EDS analysis for HVOF sprayed IN 625 coated T22 steel.

3.2. XRD Analysis

The XRD diffractogram of the HVOF sprayed IN 625 coating is shown in Fig. 3. The analysis results in the formation of Ni and NiO as major phase whereas Cr_2O_3 as secondary phase.

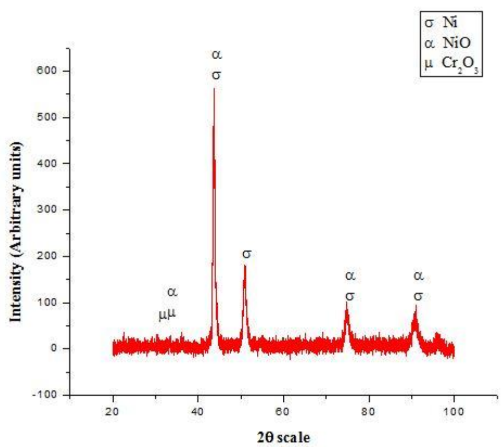

Fig. 3 - XRD diffractogram for HVOF sprayed IN 625 coated T22 steel.

3.3. Surface Roughness And Micro - hardness Analysis

The average microhardness of the substrate steels has been measured to be 192 Vickers hardness (Hv). The average microhardness values of IN 625 coating in as-sprayed condition has been observed to be 320 Vickers hardness (Hv). The average value of apparent surface roughness (R_a) of the as-sprayed coating has been found to be 7.40 µm.

4. DISCUSSION

The Inconnel 625 powder was successfully deposited on T22 boiler steel substrate by the HVOF process at the given process parameters. The X-ray diffractogram for the IN 625 coating authenticated the presence of high amounts of Ni as the principal phase and Cr as the minor phase, which is expected from the basic composition of the powder. The XRD results are in good agreement with those reported earlier by Edris et al. [9]. The XRD results are further supported by EDS analysis, which shows the dominance of Ni and Cr in the coating composition. A similar phase was observed by Zhang et. al. [7] on HVOF sprayed IN 625 on mild steel. The presence of NiO and Cr_2O_3 phases are reported to be protective oxides [10-12]. The existence of Cr_2O_3 phase in the coated steels offers a guard to the substrate metal against any diffusion of oxidizing/corroding species. In addition, the chromium oxide phase is thermodynamically stable [13] up to very high temperatures because of its high melting point and it makes dense, continuous, and adherent layers that grow relatively slowly. The scale of this type provides a solid diffusion barrier that hinders interaction of oxygen of the underlying coating. Moreover, the coating was formed without any diffusion of basic elements from the base steel, which is a desired feature of any good quality coating/substrate system. The coating, by and large, is found to have a continuous contact with the substrate steel.

The microhardness values of the coatings are measured to be greater than those of the substrate steels. A higher microhardness value may be attributted to the high kinetic energy attained by the powder particles, which ensures good cohesion, and a denser and more homogeneous structure, as recommended by Verdon et al. [14] and Hawthorne et al. [15].

The SEM images revealed cloudy morphology having irregular shaped splats. A similar morphology was reported by Kaushal et. al. [2] in case of HVOF sprayed Ni-20Cr coating on ASTM A213 347H boiler steel. Microstructural characteristics with fine splat size, good adhesion, low porosity and oxides, and lack of cracks results in the improvement of erosion resistance as suggested by Hearley et al. [16] and Wang and Lee [17]. The porosity may start the microcracking, leading to the removal of the coating.

5. CONCLUSIONS

1. The HVOF spraying process was used successfully to deposit IN 625 on T22 steel with the given process parameters.
2. The as-sprayed coating was found to have a cloudy morphology with a well adherent interface with the substrate. The EDS analysis of the coating surface indicates the presence of mainly Ni, Cr and Fe elements with small amount of O in the coating compositions.
3. The X-ray diffractogram for the IN 625 coating revealed the presence of high amounts of Ni as the principal phase and Cr as the minor phase, which is expected from the basic composition of the powder.
4. The microhardness measurement showed that the coatings have higher hardness values when compared with the substrate steel. A higher microhardness value may be attributed to the high kinetic energy attained by the powder particles, which ensures good cohesion, and a denser and more homogeneous structure.
5. NiO and Cr_2O_3 phases formed in the coated steel are reported as protective oxides and provide a shield to the substrate against oxidizing-corroding species and may be used for high temperature applications.

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