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To study the Erosion Behavior of H.V.O.F. Coating of 16Cr5Ni at the Different Velocity of Slurry

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ABSTRACT

This paper describes erosion characteristics of high velocity oxy fuel (H.V.O.F.) along with commonly used steels 16Cr5Ni in Turbine and studied the comparison the effect of erosion at Different Velocities of the slurry on Cr_2O_3 and CrC-NiCr coating on steel. The four different ranges of velocity is taken *i.e.* 35 m/s, 50 m/s, 60 m/s and 70 m/s. at normal impact angle and comparison regarding the erosion resistance was determined from the mass loss results. Higher erosion takes place at medium range of velocity i.e. at 50 m/s. Based on this experimental study coating was considered acceptable for the processes employed.

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1. INTRODUCTION

Erosion is a serious problem in a number of Indian hydropower stations especially those located in Himalayan region [1]-[2]. This causes a loss of the order of US$ 120–150 million in a year for these hydro power stations due to drop in efficiency, forced outages, and repair. Attempts are being made to reduce the damage caused by silt erosion either by reducing the particle velocity, controlling their size and concentration, or by using HVOF cermet coatings and surface hardening by plasma nit riding [8]-[3]. HVOF cermets coatings of hard carbide phase tungsten carbide (WC) embedded in ductile matrix; typically coating system consisting of WC–Co, WC–Co–Cr, WC–Ni–Cr and FeCrAlY–Cr3C2 are being used in different industries. The most satisfactory results have been obtained with the powder having carbide content of >80% [4]. It has been reported that detonation as well as HVOF sprayed coatings and boronising provide remarkable improvements compared to plasma nitriding at these velocities [3]-[12]. However, contradicting results regarding plasma nitriding have been reported and depending upon their degree of success, plasma nitriding as well as HVOF coatings are being exploited commercially to overcome the power loss arising due to excessive erosion of hydro turbines [8]-[13].

Stainless steels are widely used in hydroelectric power plants due to their good corrosion properties and acceptable resistance to solid particle erosion, since many components are in contact with aqueous solutions containing hard particles that impact against the surface causing significant material loss (slurry erosion condition). The magnitude of the damage caused is a consequence of the amount, type and size of solid particles in the flow, together with the mechanical properties of the surfaces, physical-chemical properties of the water and operating conditions [16]-[17]. Slurry erosion problems are particularly important during rainy seasons due to the increase in the number of solid particles impacting the surfaces, especially in systems where an exhaustive filtration process is not possible. This is the case of the Francis turbines installed in a hydroelectric power plant in north western Colombia, where intense erosive wear has led to changes in surface texture and loss of adjustment between the liners and the spiral case.

1.1. HVOF Spraying and Plasma Nitriding

In recent years, HVOF spraying has been considered an asset to the family of thermal spray processes especially for materials with melting point below 3000 K. It has proven successful, since it shows advantages in density and bond strength making it attractive for many wear and corrosion resistance applications [4]-[5]. Its high coating quality results from the use of a hot combustion-driven high-speed gas jet for thermal spraying. These coatings have environmental advantages compared to chemically/electrochemically formed coatings. Tungsten carbide powders are widely used in the HVOF spraying system [6]-[7]. These are used to produce dense, high hardness and excellent wear resistance coatings generally to combat the erosion and corrosion occurring in hydro power plants and pumps. In applications where abrasive or erosive wear resistance is of primary importance, WC–Co with and without nickel or chrome is used. WC–Co–Cr powders are preferred when high corrosion resistance is needed. The abrasive and erosive wear resistance also depends upon oxides, pores, and the phase transformation occurring during spraying [9]-[11]. High-velocity oxy fuel sprayed coatings are commonly applied by HP/HVOF JP-5000, DS-100, and Met jet II, OSU, Diamond jet and Praxair 2000 HVAF systems. These systems are based on liquid as well as gaseous fuel and oxygen/air. Using the HP/HVOF system, the performance of 10 different types of WC-based cermet coatings with Co or Ni as binder has been evaluated under both dry particle and slurry erosion conditions at 90 and 20◦ impingement angles [10]. It is reported that coating microstructure, hardness and composition were the major determinants in erosive wear. The matrix corrosion also influences the erosive wear. However, similar coatings with 12% Co and 17% Coas binder applied by HP/HVOF do not show significant difference in ASTM G-65 abrasion test results [11]. The microstructures, porosity and phase composition of WC 17% Co coatings when applied by this system using 100mm spray barrel instead of 200mm spray barrel, do not make much difference. The difference in their abrasion was reported only at 8%. The porosity variation was reported between 0.120 and 0.90% the powders used were agglomerated and sintered (TAFA 1343V and Amperit 526.074).

2. MATERIAL AND METHODS

2.1. Selection of Substrate Material

Steel 16Cr5Ni steel which is used as material for Hydro power plants in some plants in northern part of India has been used as a substrate in the study. The specimens with approximate dimensions of 40 mm × 40 mm × 5 mm were cut from the turbine material for erosion studies. Samples were grinded with SiC papers down to 180 grit and Shot–blasted with SiO2 before being HVOF sprayed to develop better adhesion between the substrate and the coating. Stainless steels commonly used for turbines and hydraulic accessories were used, namely 13Cr5Ni steel, whose nominal chemical compositions are shown in Table 1. Also, two commercial powders, Cr2O3 and CrC + NiCr were deposited onto 13 Cr4Ni steel by High Velocity oxy fuel (HVOF) processes, respectively spraying was carried out using a HIPOJET 2100 equipment), which utilize the supersonic jet generated by the combustion of liquid petroleum gas (LPG) and oxygen mixture. LPG fuel gas is cheap and readily available as compared to other fuels used for HVOF spraying. The spraying parameters employed during HVOF deposition are listed in Table 2. All the process parameters, including the spray distance were kept constant throughout the coating process.

Table 1. Nominal chemical composition of the substrate materials (wt %)

Materials	C	Mn	Si	Cr	Ni	P	S
	0.06	1.0	0.80	15-17	4-6	0 .036	0.025

2.2. Apparatus Required

2.2.1. Measurement of Coating Thickness

The coating thickness was measured during spraying with a Minitest-2000 Thin Film Thickness Gauge (precision ± 1 µm), to obtain coating of uniform thickness. For verification of thickness of deposited coating, the as sprayed specimen was cut across the cross-section with a diamond cutter. 2 X-Ray Diffraction (XRD) analysis. The XRD analysis was performed on the coated and uncoated specimens to identify the various phases present on their surfaces.

2.2.2. Porosity Measurement

Porosity of the coatings was measured with an image analyser using Zeiss Axiovert 200 MAT inverted optical microscope, fitted with imaging software Zeiss Axiovision Release 4.1, (Germany) software, which was developed based on ASTM B276. The magnification was chosen such that the coating microstructure image covers the screen and allows the resolution of the voids that contributes notably to the total porosity area percentage The analysis using image processing software determines the pore area size in the view field by converting the pore areas (grey-level areas) into a background color such as red while the rest of the microstructure remains in its original color. The area of one feature is numerically related to the total area of the picture, as the program counts the number of one color type pixels (red) and sets that as a ratio of the total number of pixels in the picture (total area).

2.2.3. Measurement of Surface Roughness

The surface roughness (Ra) values of the plasma sprayed as coated specimens were measured using Surface Roughness Tester (Mitutoyo SJ-201, Japan). Each reported value of surface roughness (Ra) is the mean of five observations taken at different locations. The centre line average (CLA) method was used to obtain the Ra values.

2.2.4. Scanning Electron Microscopy (SEM)/EDAX

SEM was used to identify the change in Microstructures of coated & uncoated eroded samples and also used to study the cross-section of specimens. SEM was used to identify the change in microstructures of coated & uncoated eroded samples and also used to study the cross-section of as coated mounted specimens. EDAX was used to find the percentage of $Cr2O3$ and CrC-NiCr after the erosion test on coating.

Table 2. Spray parameters employed for HVOF spray process

Air-flow rate	700 l/min
Spray distance	200 mm
Powder feed rate	30g/min
Fuel pressure	588 kPa
Oxygen pressure	900 kPa
Air pressure	590 K
Oxygen flow rate	280 l/min
Fuel (LPG) flow rate	70 l/min

These parameters are within the range that is generally adopted for applying an HVOF coating [6–7].

2.2.5. Slurry Erosion Tests

The slurry erosion testing is conducted out in a modified test rig which is known as JET IMPACT TEST RIG in which the specimens were subjected to the erosion conditions which are very much similar to those of the hydro power plant. The mean impact velocity of the slurry was 35 m/s, 50m/s and 60m/s and the erosion resistance was determined from the mass loss results. Mass losses were measured every 40 min by using measuring balance which is having a accuracy a scale with 0.01 mg resolution. The total duration of each test was 160 min, and after that period both the sample and the slurry were replaced.

2.2.6. Analysis of Worn Surfaces

The worn surface were analyzed in stereoscopic and scanning electron microscopes in order to identify the wear mechanism and relate them to the mass loss results.

3. RESULTS AND DISCUSSION

3.1. Microstructure of 16 Cr5Ni Steel

The microstructure of this steel is composed of austenitic-martensitic steel with delta ferrite about 20 to 25 stable austenite Chromium carbides. Microstructure of ASTM 16Cr5Ni steel, after coating Cr2O3 and Microstructure of 16Cr5Ni steel after coating with CrC-NiCr as shown in Figure 1 and Figure 2.

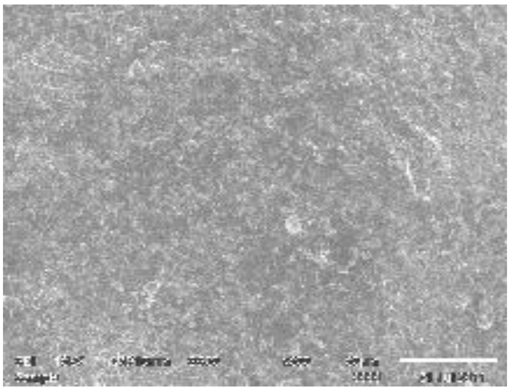

Figure 1. Microstructure of ASTM 16Cr5Ni steel, after coating Cr2O3

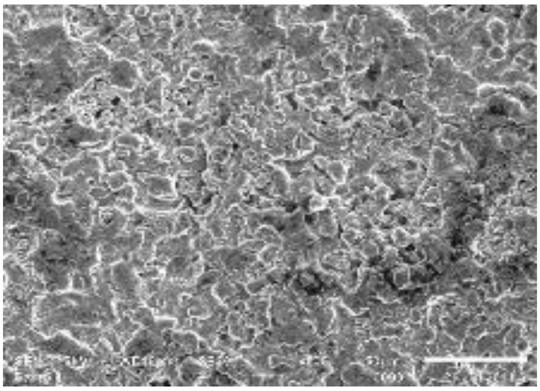

Figure 2. Microstructure of 16Cr5Ni steel after coating with CrC-NiCr

3.2. Cr2O3 Coating

The thickness of coating is measured 190µm. The coating layer is composed by soft, nickel-rich matrix (181HV average hardness) containing elongated chromium oxide particles (1140HV, 25gf, 15 s). The measured average volume fractions of Cr2O3 particles and pores were 14.25% and 10.12%, respectively. The wear-resistant Cr2O3 coating is composed of hard, Cr particles (1120 HV average hardness) and softer Ni-Cr regions (639HV average hardness), together with a number of unmelted particles and pores. The volume fraction of pores was estimated to 17% by digital image processing of SEM images. This porosity amount is acceptable for HVOF coatings**.** This average value is in agreement with literature for the HVOF process [24] and it is an indication of acceptable quality of the coating.

3.3. CrC-NiCr coating

The thickness of the coating was measured circa average 170-190 µm. The microstructure of the wear-resistant coating CrC-NiCr (690 HV300 g, 15 s) is a distribution of chromium carbides in a high carbon steel matrix. The measured volume fraction of chromium carbides and porosity were 12% and 15%, respectively.

3.4. Examination of Worn Surfaces

The typical aspect of the worn surfaces as seen in stereographic microscope is shown in Figure 3 and 4. Detailed analysis of the worn surfaces revealed wear marks typical of erosion at grazing incidence, with micro-cutting and microploughing as the main wear mechanisms observed at the surface of all the stainless steels tested and the Cr2O3 coating (Figure 4), being these marks more evident and evenly distributed in the stainless steel samples. The SEM image on micrographs tells us about the surface morphology of the various samples. The 16Cr5Ni steel has shown platelet mechanism which is being operational zed in erosion. The formation of crater and lips can be viewed. These are formed due direct impact and can be removed by impact of slurry.fig shows splat by splat lamellar structure formation in both the coatings with the presence of partially melted region of the nano particles in Cr2O3 coatings. On the other hand, the worn surfaces of the CrC-NICr coatings showed a differential response as a function of the phases present in the microstructure, as shown in Figure 3-4. Chromium and oxides in Cr2O3 and Cr/Co areas in CrC-NiCr coatings contributed to increase the wear resistance due to their high hardness and Young modulus. As the testing time increased the hard phases were gradually exposed to the erosive particles and the main wear mechanism changed from micro cutting of matrix to spalling of hard phases. Evidences of brittle fracture were observed in the CrC-NiCr coating. Nevertheless, the analysis of the coatings before the slurry erosion tests reveals that similar cracks are formed as a consequence of the thermal spray process employed due to the high cooling speeds and the thermal coefficient mismatch between Cr/Co particles and Ni-Cr regions (Figure 3-4). Unmelted particles and droplets can also be observed before the surface is submitted to the slurry wear tests, but these features are removed during the tests due to their low adherence to the substrate. A significant increase in micro-hardness was observed in the stainless steels surfaces after the slurry erosion tests, probably as a consequence of both martens tic transformation of retained austenite and work hardening effect.

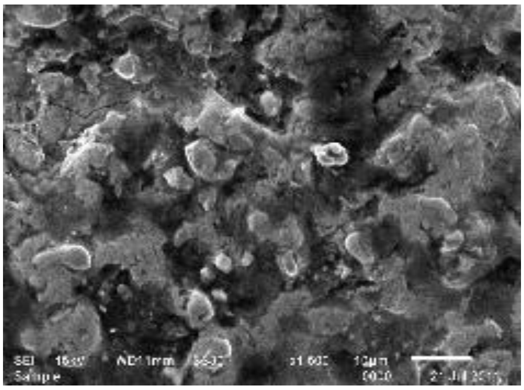

Figure 3. Specimen after conducting 2hrs erosion testing coated with CrC-NiCr

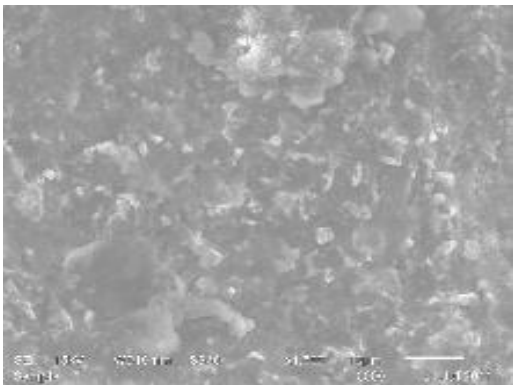

Figure 4. Specimen after conducting 2Hr erosion testing coated with Cr2O3

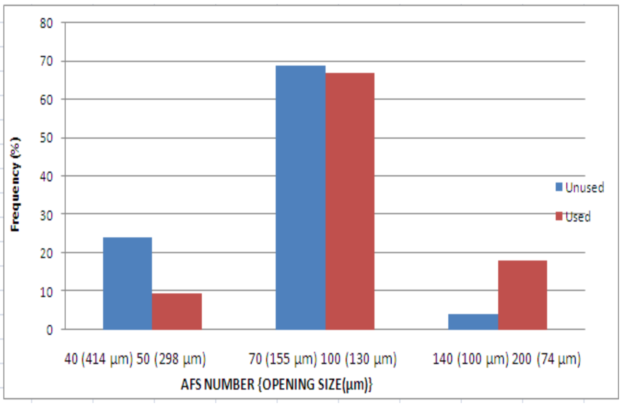

Figure 5. Grain size distribution before and after the test in micrometers

3.5. Degradation of Abrasive Particles

The typical morphology of abrasive particles before the tests and the change in size distribution as a consequence of the erosive process are after presented in Figure 5. Note that after the tests the distribution is shifted to smaller grain sizes, which reveals fragmentation of the particles and subsequent loss of their ability to erode the surface of the samples.

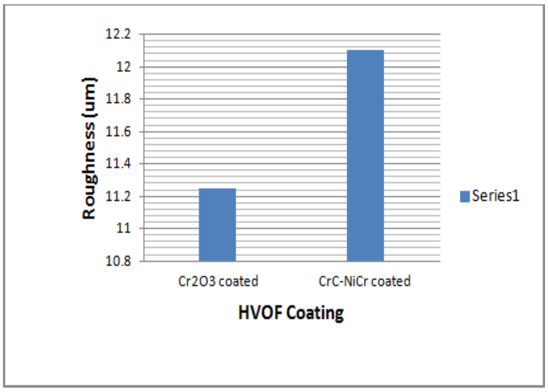

Figure 5. Roughness of coating surface 16Cr5Ni

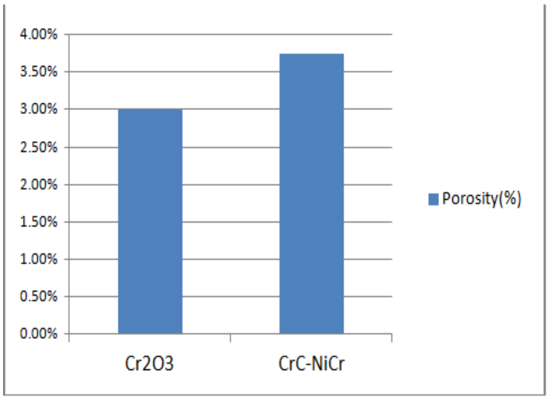

Figure 6. Porosity of coating surface 16Cr5Ni

Table 3. Roughness of coating surface 16Cr5Ni

Sr. NO	Coating on 16Cr5Ni	Surface Roughness
1	Cr2O3	11.25 um
2	CrC-NiCr	12.1 um

Table 4. Porosity of coating surface 16Cr5Ni

Sr. NO	Coating on 16Cr5Ni	Porosity (%)
1	Cr2O3 o	3.00%
2	CrC-NiCr	3.75%

3.6. Mass Loss

The mass loss of all the samples in the slurry erosion tests is shown in Figure 8-10 The reported values were calculated from the measured cumulative mass losses and and velocity. The Cr2O3 coating showed the best erosion résistance in all the velocity ranges, while the CrC-NiCr steel reported the higher mass losses of the tested materials with coating. It is worth noticing that the uncoated stainless steels presented small difference volume losses during the first stages to last stage of the tests . Nevertheless, after 120 min testing the 16Cr5Ni steel samples undoubtedly showed better erosion resistance, probably due to the differences in microstructure such as the presence of hard chromium carbides precipitated at grain boundaries. The one another important thing to be noted down that as the velocity ranges increases the amount of erosion also increase up to the 50 m/s after going higher range of velocity the erosion is not linear with respect to other Three velocities. This may be due to that as the velocities are increasing the kinetic energy of the particle also increases as a result of which the particles are rebounded back and they interrupt the path of incoming particles. The maximum erosion will takes place at 50 m/s. The result shows that coatings save the substrate material from erosion successfully [25].

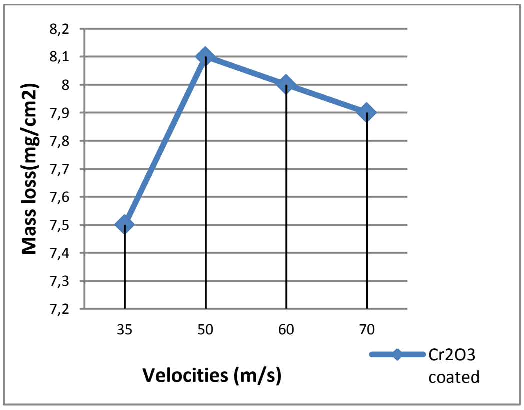

Figure 8. Mass loss in mg/cm^2

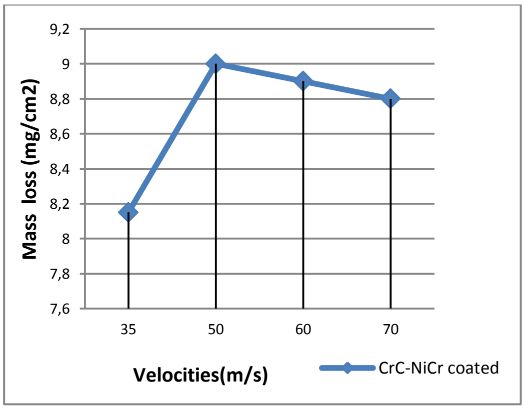

Figure 9. Mass loss in mg/cm^2

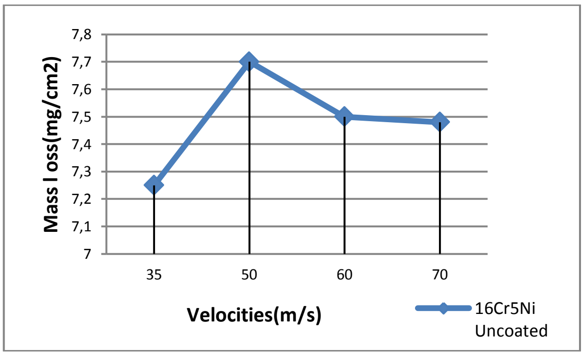

Figure 10. Mass loss in mg/cm^2

4. DISCUSSION ON THE EROSION BEHAVIOR Cr2O3 AND CrC-NiCr BASED COMPOSITE COATING

The results from this study indicate that, the poor performance observed from In case of CrC-NiCr coatng as comparison of Cr2O3 coating CrC-NiCr coatng attributed to the high degree of porosity/presence of voids and micro-cracks within the coating. It is likely that the coatings contain numerous networks of continuous voids, pores and cracks that extend from the coating surface through to the substrate. Such findings are in agreement with previously studies.

5. CONCLUSION

The results of the present study on the Cr2O3 and CrC-NiCr HVOF sprayed coatings can be summarized as follows:

(1) Coatings exhibit high hardness with a high volume fraction of carbides being preserved during the HVOF spraying process.

(2) Hardness and wear resistance of the Cr2O3coatings were better than those of the CrC-NiCr coatings. Compared to HVOF sprayed CrC-NiCr coatings, Cr2O3 coatings exhibit a low porosity.

(3) The Cr2O3 coating applied by HVOF process onto 16Cr5Ni stainless steel reported the best slurry erosion resistance of the studied materials, having properties of hard, wear-resistant particles.

(4) HVOF coated Slurry erosion tests shows that higher erosion takes place at 50m/s. the coated surfaces showed higher erosion resistance than the uncoated stainless steels, with the lower volume losses measured for the Cr2O3 deposit conditions. Even the cracks are formed as a consequence of the thermal spray process employed 16Cr–5Ni steels. However, they able the resistance to abrasive and erosive wear as their micro hardness values are below those of the erodent (<1100).

(5) Both Cr2O3 and CrC-NICR coatings contributed to increase the wear resistance due to their high hardness and Young modulus.

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