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PREPARATION AND PROPERTIES OF HVOF COATED B_4C +NiCr STEEL FOR HYDRO TURBINE APPLICATIONS

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***Abstract**— Higher micro hardness, adhesion and erosion resistance of materials used for hydro turbine applications is required to achieve a longer service life of equipments. In this paper,* **B_4C +NiCr** *composite coatings were prepared on 18Cr8Ni stainless steel with HVOF process to improve hardness, adhesion strength and erosion resistance of coated substrate. The effect of process parameters impingement angle, impact velocity impingement angle and sand discharge on slurry erosion characteristics of composite coated substrate was investigated. The microstructure of coating was analyzed by using scanning electron microscope and energy dispersive spectroscopy. The incorporation of hard* **B_4C and NiCr** *particles results in refined structure and increased hardness, adhesion and erosion resistance.*

***Keywords**— hardness, adhesion, erosion resistance, composite coating, HVOF*

I. INTRODUCTION

The components of hydro-power plants should possess outstanding mechanical and erosion/corrosion resistance along with low density and weld ability. **[1-2].** Mass failure of failure of equipment takes place due to continuous exposure to erosive envirenment which leads to replacement of items which costs more than 50% the manufacturing cost **[3-4].** Working life of equipments reduces due to all these factors resulting in intermittent power generation and higher financial losses **[5-6]**. This harmful effect of erosive particles can be efficiently reduced by coating the surface which reduces the adverse effects of erosive particulates with increased the service life of the components used in the erosive environment **[7].** Numerous coating processes have been developed to improve various required surface properties; for example, thermal spraying techniques have withdrawn significant consideration and are used to deposit a variety of powders on various substrate materials **[8-12].** Various types of thermal spraying coating techniques such as cold gas spray, flame spray, plasma spray, high-velocity air–fuel spray and high-velocity oxy-fuel spray have been used to improve the surface properties of substrate materials. Among these, high-velocity oxy-fuel (HVOF) spraying is the most commonly used thermal spraying processes due to its capability in depositing hard elemental powders of nitrides and carbides on different components materials and, to produce homogeneous dense adherent coatings with increased toughness, hardness and wear resistance. **[13-16]**. Wear performance of the coatings largely depends process parameters such as pH value, impact velocity, Impingement angle and shape, size and flow rate of erodent, and coating thickness as well as the binding ability of coatings, etc., **[17-19]**. Tan et al. **[20]** investigated HVOF-sprayed aluminium bronze coatings and found that brittle mode of erosion increases to reach a maximum value at 90°. However ductile mode happened at much lower angle of impingement. Mathapati et al. **[21]** and Anand and Conrad **[22]** studied the dependency of wear rate impingement angle. In addition, Singh et al. **[23]** investigated the HVOF-sprayed ceramic coatings for slurry erosion analysis.

It can be concluded that material performance changes with erodent properties, different process parameters and with required properties of target material properties. The effect of parameters related to operating conditions, erodent and target material turn out to be more complex and greatly influences erosion properties of coatings. Therefore, influence of these parameters should be taken into consideration. In this paper, B_4C +NiCr coatings are deposited on 18Cr8Ni stainless steel substrates by using HVOF spraying technique.

II. EXPERIMENTAL DETAILS

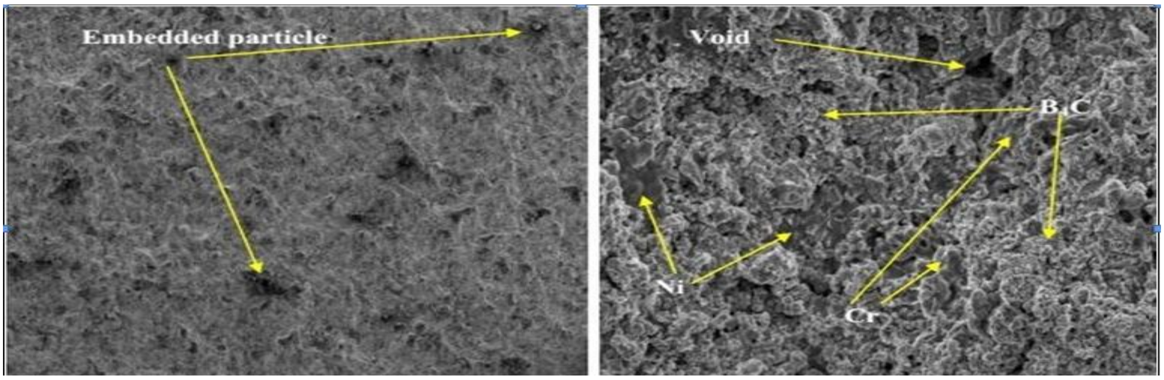
In the present research work 18Cr8Ni stainless steel was used as the substrate material. B_4C +NiCr was selected for high velocity oxy-fuel (HVOF) thermal spray coating powders. The size of specimens selected was 24×24×6mm. Grinding of samples with SiC papers and sand blasting was done prior to coating. A mixture of B_4C & NiCr coating powders were prepared in which the percentage of NiCr is 25% and acts as a binder in the HVOF coating process. Ni and Cr are mixed in the ratio of 2:1. The ratio of B_4C to NiCr 4:1 was used. The HVOF thermal spray system is employed to develop the coatings. The combustion pressure of 0.65 ± 0.7 MPa , oxygen flow rate of 950 l min^{-1} at 10 bar pressure, carrier gas flow rate of (nitrogen) of 13 l min^{-1} at 6 bar pressure, and fuel flow rate (LPG) of 0.45 l min^{-1} at 6 bar pressure was used during deposition process. The spraying distance of 400 mm and angle of 60° with a feed rate of 60 ± 2 g/min were maintained. The structure of the coated surfaces and elemental analysis are investigated by using scanning electron microscope (SEM) equipped with energy-dispersive spectroscopy (EDS). Thickness of HVOF coatings on 18Cr8Ni stainless steel was measured by "Posi Tector 6000" coating thickness gauge. Micro hardness of TiB_2+NiCr and B_4C+NiCr thermal coatings were measured by INNOVA TEST NEXSUS

4303 micro Vickers hardness tester at a load of 300gf for a time period of 10 seconds. Scratch tester Ducom TR-101 was used to characterize the coatings for parameters like scratch resistance, critical load, adhesion and nature of damage under high stress. Water jet erosion test rig was used for erosive wear studies. Ultrasonic cleaned in an acetone bath were dried before and after each test. The weight of samples was measured with the help of microbalance (Make: Contech. Instruments Ltd, precision ± 0.1 mg). The samples were fitted in the sample holder with a provision of measuring erosion from 15° to 90° in 15° interval. 4 mm diameter nozzle with 50 mm standoff distance between sample surface and tip of the nozzle was used for all impingement angles. The average mass loss for three eroded samples was considered.

III. RESULTS AND DISCUSSION

A. SEM Analysis

After High Velocity Oxy-Fuel (HVOF) coating work, B_4C+NiCr coated samples were examined under JEOL JSM-IT 100 Scanning Electron Microscope (SEM). SEM analysis of B_4C+NiCr coated samples is shown in Fig. 1. Nickel (Ni) and Chromium (Cr) embedded with Boron Carbide (B_4C) were observed on the coated surface and simultaneously some embedded particles with some voids on the surface were also been found during microstructure characterization of coated samples surface.



(a) **(b)**

Figure 1: SEM Analysis of B_4C+NiCr Coating

B. Coating Thickness Measurement

Five readings were taken randomly on one coated sample of B_4C+NiCr coated samples by Posi Tector 6000 and the results are shown in Table I.

TABLE I: COATING THICKNESS MEASUREMENTS

S. No.	B_4C+NiCr Coating
1	170µm
2	180µm
3	168µm
4	190µm
5	202µm
Average	182µm

Thickness variation for B_4C+NiCr coating, thickness varied between 168µm to 202µm with average thick of 182µm.

C. Micro Hardness Test Analysis

Five readings were taken randomly on one coated sample of each 18Cr8Ni stainless steel, and B_4C+NiCr coated samples on INNOVA TEST NEXSUS 4303 micro Vickers hardness tester under a fixed load of 300gf for a fixed time period of 10 seconds. Average micro hardness was calculated and the results obtained during Vickers micro hardness test for all three types of samples are shown in Table II.

TABLE II: MICRO VICKERS HARDNESS TEST RESULTS

S. No.	18Cr8Ni Steel	B_4C+NiCr Coating
1	233HV	1326HV
2	245HV	1305HV
3	240HV	1295HV
4	242HV	1314HV
5	235HV	1330HV
Average	239HV	1314HV

Table II clearly shows that there is an increase in the micro hardness of the steel sample when hard coatings are deposited on its surface by HVOF thermal spray coating technique. It was found that B_4C+NiCr coated sample have highest average micro hardness (1330HV) as compared to 18Cr8Ni stainless steel (239HV) which is mainly due to very high micro hardness of boron carbide (B_4C) in nature. Variations in the micro hardness of 18Cr8Ni steel is due to manufacturing defects and variations in micro hardness of both the coatings is mainly due to the formation of voids and various compounds on the steel surface.

D. Scratch Test Analysis

Three readings were taken randomly on coated sample of each B_4C+NiCr coated square samples of size 24mm **X** 24mm by Ducom TR-101 scratch tester at a load of 300gf and at a scratch speed of 0.5mm/sec. Results obtained from the scratch test on B_4C+NiCr coated samples are shown in Table III.

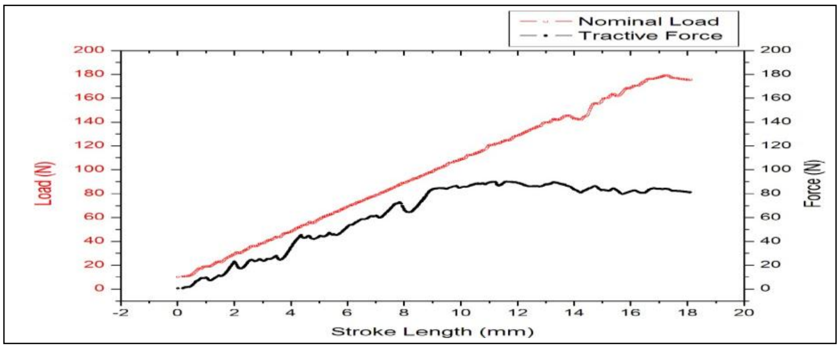
TABLE III: SCRATCH TEST RESULTS

S. No.	B_4C+NiCr Coating	
	Critical Nominal Load	Maximum Tractive Force
1	128.2N	89.2N
2	127.2N	88.4N
3	127.6N	88.8N
Average	127.7N	88.8N

It is found that for B_4C+NiCr coating maximum tractive force (89.2N) found to occur at a critical nominal load of 128.2N. It was found that B_4C+NiCr coating have better average scratch resistance (127.7N) which is mainly attributed to higher micro hardness of Boron Carbide (B_4C).

Variation of tractive force with stroke length and nominal load for B_4C+NiCr coated sample is shown in Figure 5.1. Red lines indicate the nominal load and black lines indicate tractive force. Fig. 2 shows that tractive force increases as nominal load increases with stroke length from no load condition to a critical nominal load of 128.2N where tractive force becomes maximum (89.2N) and after that it decreases and then remains almost constant for all values of nominal loads.

Figure 2: Scratch Test Results of B_4C+NiCr Coating



E. **COATING PERFORMANCE**

Slurry erosion test on samples of 18Cr8Ni steel and B_4C+NiCr coatings was conducted to test the coatings behaviour and improvement in the slurry erosion resistance of 18Cr8Ni stainless steel after the application of hard coatings under various working conditions. Mass loss results for all the prepared samples are discussed in this section and the effects of various parameters on slurry erosion rate are compared to each other.

5.2.1 Slurry Erosion Test Results for 18Cr8Ni Steel and B_4C+NiCr Coated 18Cr8Ni Steel

Mass loss results of slurry erosion test for 18Cr8Ni stainless steel and B_4C+NiCr Coated 18Cr8Ni stainless steel obtained from the experiment are shown in the Table IV

TABLE IV: MASS LOSS RESULTS FOR 18Cr8Ni STAINLESS STEEL

S. No.	Input Parameters			18Cr8Ni SS Mass Loss (g/min)	B_4C+NiCr Coated 18Cr8Ni SS Mass Loss (g/min)
	Impact Velocity (m/s)	Impingement Angle (°)	Sand Discharge (g/min)		
1	10	30	160	0.0011	0.0004
2	10	45	200	0.0011	0.0005
3	10	60	240	0.0015	0.0006
4	10	75	280	0.0018	0.0007

From the results it is found that for 18Cr8Ni stainless steel maximum erosion rate occurs at impact velocity of 10m/s, impingement angle of 75° and sand discharge of 280g/min and erosion rate is minimum at impact velocity of 10m/s, impact angle of 45° and sand discharge of 160 g/min. For B_4C +NiCr coated samples maximum erosion rate occurs at impact velocity of 10m/s, impingement angle of 75° and sand discharge of 280g/min and Minimum erosion rate occurs at impact velocity of 10m/s, impingement angle of 30° and sand discharge of 160g/min.

IV. CONCLUSIONS

- Thickness variation for B_4C+NiCr coating, thickness varied between 168µm to 202µm with average thick of 182µm
- B_4C+NiCr coated sample was found to have better Vickers micro-hardness. as compared 18Cr8Ni stainless showed least Vickers micro hardness. Micro hardness of 18Cr8Ni stainless steel was found to increase by 354% when coated by B_4C+NiCr hard powders.
- B_4C+NiCr coated sample showed better average scratch resistance.
- Rate of erosion decreases substantially due to hard coating of B_4C+NiCr on 18Cr8Ni stainless steel.
- For TiB_2+NiCr coated samples maximum erosion rate occurs at impact velocity of 10m/s, impingement angle of 75° and sand discharge of 280g/min and Minimum erosion rate occurs at impact velocity of 10m/s, impingement angle of 30° and sand discharge of 160g/min.

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