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A Study on Slurry Erosion Wear Behaviour of HVOF Sprayed WC-CO Coating

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***Abstract*— In the present study, slurry erosion wear behaviour of High velocity oxy-fuel (HVOF) sprayed coating has been studied. The HVOF spray process is used for depositing WC-CO powder on the gun metal bronze substrate (pump material). The slurry erosion wear testing was performed using slurry pot erosion tester. The testing is performed at an impact angle in the range of 15-90°. The WC-CO coating shows maximum wear at shallow impact angle and minimum wear at normal impact angle. Further ANN is used to predict the erosion wear of the coating and predicted data is well in agreement with the experimental data.**

***Index Terms* — Gun Bronze, Hvof Coating, Slurry Erosion Wear, Slurry Pot Tester.**

I. INTRODUCTION

THE wear is defined as the progressive volume loss of material from target material. Slurry erosion is result of contact of solid particles present in a liquid and a surface which undergoes loss of mass by the repeated impacts of particles. The slurry erosion is a complex phenomenon and it is not yet fully understood because it depends on many factors, which act simultaneously. Fig.1 shows these factors which include flow field parameters, properties of target material and erodent particle characteristics. Among these parameters, the impingement angle and the target material microstructure plays an important role on the material removal process. The impact angle is angle between the direction of impact velocity of the solid particle and the target surface. It is generally agreed that the rate of mass loss caused by erosion is a function of impact angle of particles [1]. For ductile materials, the maximum erosion usually occurs around 20-30° impact angle (α) on the other hand in case of brittle materials, it occurs at normal (90°) impact angle. The impact velocity has dominant effect on the material removal rate [1, 2, 3]. The erosion rate is generally related to the particle velocity using power law relationship in which the power index for velocity varied in the range of 2-4.

In the present study, The Pump installed at "Dapora Pumping Station" at Village Dapora was dismantled and the impeller of the pump was examined with necked eyes to identify the probable cause of wear and its type Fig.2 From the preliminary examination, it was observed that the impeller and casing of the pump was worm out due to impact of the solid particles. It was observed that the material from edges of the diffuser vanes of the impeller was worn out and deformed due to solid particles loading.

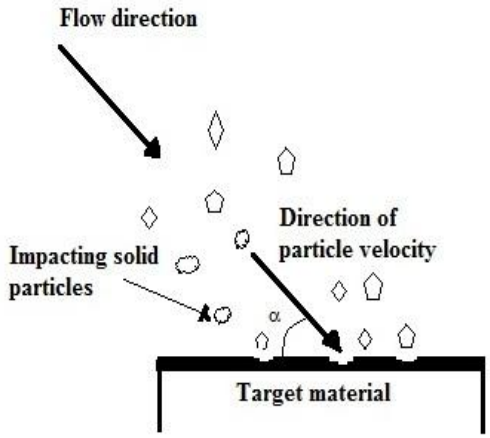

Fig. 1. Erosion wear by solid particles impact.

Fig. 2. Worthington 5 Hp Vertical turbine impeller (Dapora, Jalgaon water supply station)

To enhance the slurry erosion resistance of the bronze impeller, it is coated with the hard facing powder by HVOF technique provides benefit over plasma sprayed coating, the nano coating gives the better erosion resistance than the conventional coating [4]. The Cr_3O_3 and Wc-10Co-Cr coating is done by HVOF process on the Stainless steel substrate and

it has found that Wc-10Co-Cr coating exhibited ductile behaviour and Cr_3O_3 brittle behaviour; he also found that Wc-10Co-Cr coating increases the slurry erosion resistance of steel remarkably [5, 6]. Nowadays, for various industrial applications, high velocity oxy fuel (HVOF) spray is being widely used is due to its ability to produce high quality coating with required hardness and low oxide content due to its high velocity impact inherent in the process. The porosity and hardness are the two important properties for wear and corrosion application [7, 8]. The HVOF spraying leads to high retention of WC in the coating matrix accompanied with lower porosity [9]. The Cr_3C_2-NiCr coating gives the better protection against the high erosion behaviour as it is spraying by HVOF process [10].The two self-alloying powders are mixed and they were applied on the material by HVOF sprayed coating [11].For the high speed slurry erosion wear the test specimens (SUS304 Stainless steel) were coated by NiCrBSi. The experimental results show that the HVOF sprayed NiCrBSi coating exhibits a much slurry erosion resistance than the uncoated SUS304 Stainless steel. The NiCrBSi coating was obtained by the Atmospheric plasma spraying (APS) and HVOF spraying is carried out, the plasma sprayed coating gives the worst sliding wear resistance and HVOF gives best sliding wear resistance [12].

II. EXPERIMENTAL PROGRAM

A. *Experimental setup*

The slurry pot test rig was developed by Desale et al. (2005) [15] has been used in the present study. Fig.3 shows the schematic diagram of the pot tester with dimensional details. The AISI SS304L cylindrical pot of diameter of 240 mm and height of 155 mm is used to fabricate the slurry pot tester. Four baffles of size 10 mm x 25 mm x 155 mm are provided at wall of cylindrical pot at equal distance to break the vortex motion produced due to rotation of the propeller. At the bottom of the pot, a drain hole of 20 mm diameter is provided to drain the solid-liquid mixture after the experiment**.** A 12 mm thick transparent acrylic sheet is provided to cover the pot which allowed visual observations. The shaft is held in position by bearings assembly placed at a distance over the cover of the cylindrical pot. The shaft is coupled to the shaft of AC motor with Love jaw coupling as shown in Fig. 3, a hole of 11 mm diameter with oil-seal is provided at the bottom of the pot to insert a shaft for rotating the propeller. A PBT-4 propeller is mounted on this shaft for kept slurry in suspension at a distance of 24 mm above the bottom and is rotated by a 0.66 kW DC motor. A shaft is also inserted from the top of the tank through the transparent sheet to rotate the wear specimens at desired speeds by a separate 1.2 kW, 2 Amp AC motor. At lower end of the shaft, a brass sleeve of 30 mm length and 25 mm diameter is provided with provision for fixing two horizontal arms to hold two test fixtures at diametrically opposite ends.

B. *Properties of materials used*

In the present study, Worthington 5 Hp Vertical turbine impeller made of the gun metal bronze is used as a substrate material. The WC-Co powder is used for HVOF coating on the substrate. The erosion wear experiments were conducted using the solid-liquid mixture of Quartz (IS Sand) with tap water.

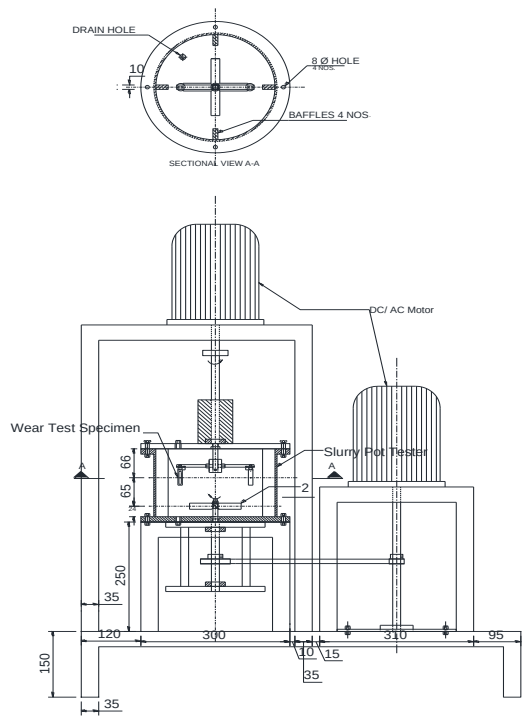

Fig. 3. Schematic diagram of Slurry pot tester.

1) Target material properties

In the present study, Worthington 5 Hp Vertical turbine impeller made of the gun metal bronze is used as a substrate material. As discussed above, the impeller is brought from the "Dapora Pumping Station" and it is observed that, the edges of diffuser vanes of the impeller was worn out and deformed, due to solid particle loading see Fig.2 The vanes of the impeller were cutting and the specimens were prepared from that material with the help of water jet cutting. The chemical composition of the material has been determined by using the optical emission spectrometer. The elemental composition of the target material is given in TABLE I.

TABLE I
ELEMENTAL COMPOSITION OF THE TARGET MATERIAL

Target Material	Elemental composition (wt. %)							
	Cu	Sn	Pb	Zn	Al	Ni	Sb	Fe
Bronze IS 318	85.50	5.25	4.26	4.25	0.003	0.43	0.15	0.10

2) Particle size distribution

Naturally the particles are present in the different size ranges so the distribution of the particle size is essential. The distribution of the particle size is obtained by the dry sieve analysis method. In this analysis the sample of the solid particle is taken and sieving is done with the different sets of the sieves. The Quartz (IS Sand) is used for the present work, its physical properties are given in Table II, it is not possible to collect the identical size particles of the solid material so they are sieved by the successive sieves are designed by the mean sieve size [14]. In the present study, the Grade III quartz is used. The mean particle size is 256 μm which is retained between the two sieves of 300 μm and 212 μm sizes.

TABLE II
PHYSICAL PROPERTIES OF ERODENT

Solid particle	Chemical Formula	Colour	Sp. Gravity (Kg/m^3)	Hardness (VHN)	Particle Shape
Quartz (IS Sand)	SiO_2	Whitish	2652	1100	Blocky

3) HVOF Coating

In this present work, the WC-Co powder is used for HVOF sprayed coating on the specimens having size 30mm x 5mm x 2 mm at optimum HVOF operating parameters. The WC-Co powder particle size was in the range of 10-45 μm. The WC-Co coated specimens are presented in Fig.4.

Fig. 4. WC-CO coating by HVOF process on erosion wear test specimens.

C. *Range of parameters*

The HVOF sprayed WC-Co coating was performed on the substrate material at optimum operating parameters. In order to investigate the erosion behaviour of the coating solid-liquid mixture was prepared by mixing 256 μm size Quartz (IS Sand) with tap water. The range of the parameters for the testing is listed in the TABLE III. The experiments were performed for 10 % by wt. solid concentration at 4.5 m/s velocity at different impact angles 15-90^0.

TABLE III
RANGE OF PARAMETERS FOR THE INVESTIGATION OF EROSION BEHAVIOUR OF WC-CO COATED GUN METAL BRONZE USING SLURRY POT TESTER.

Target Material	Impact Angle	Particle size	Solid concentration (% by wt.)	Velocity	Slurry type
Bronze IS 318	15,30,45, 60,75, 90^0	256 μm	10%	4.5 m/s	Quartz with tap water

D. *Experimental procedure and data analysis*

The WC-Co coated test specimens are finally polished with #2000 emery papers before conducting any wear test to keep identical initial condition for each experiment. The wear specimens are cleaned with tap water, rinsed in acetone and dried with hot air blower before and after each test. The mass of the wear specimen is measured before and after experiment using an electronic balance (Make: Merck, Model No. SI234DE) having least count of 0.1 mg. To prepare the solid-liquid mixture, a predetermined mass of solid particles was poured first in the pot and then it was closed by tightening the acrylic cover. The known quantity of water was then poured through the hole at the top of the cover to completely fill the pot. The propeller shaft is rotated in down-pumping mode at the desired suspension speed to achieve nearly uniform distribution of solid particles in water. The speed of each shaft is measured by using a non-contact type tachometer. The assembly of the test fixture was mounted on upper shaft, which is to be rotated at desired test speed [15]. The average mass loss is calculated and given in Table IV and further used to evaluate the erosion rate according to the relationship proposed by Bree et al. [1982] which is given as below,

$$Ew = \frac{W_L}{\rho_S \times A_{SP} \times Cv \times V_{SP} \times T \times Sin\alpha} \quad (1)$$

$$Cv = \frac{Cw}{\rho_S - (\rho_S - 1) \times Cw} \quad (2)$$

Where; E_w is erosion rate in g/g, W_L is average mass loss in g, ρ_s is solid particle density Kg/m^3, Asp is area of test specimen in m^2, C_v is the solids volumetric concentration, V_{sp} is the velocity of test specimen m/s, T is Experimental time in min, α is impact angle in degree and C_w is solids concentration by weight.

TABLE IV
ACTUAL VALUES OF INPUT AND OUTPUT VARIABLES

INPUT [Angle]	OUTPUT [Experimental Average Mass Loss]
15	0.0065
30	0.0075
45	0.00815
60	0.0094
75	0.008
90	0.00794

TABLE V
NORMALIZED VALUES OF INPUT AND OUTPUT VARIABLES

INPUT [Angle]	OUTPUT [Experimental Average Mass Loss]
0.1	0.1
0.26	0.3758
0.42	0.5517
0.58	0.9
0.74	0.5137
0.9	0.5

III. ANALYSIS USING ANN

The wear process is considered as a non-linear problem with respect to its variables, either materials or operating conditions. The ANN is the technique which involves the database training to predict the input-output relation. In the present study three layer neural network having input layer with one input node, the hidden layer with 15 neurons, and the output layer with the one output node is used and given in Fig. 5. The software package NEURALNET for neural computing using the back propagation algorithm is used to predict the average mass loss under various test conditions [16, 17]. The accuracy of the prediction depends on the how well the network has to been trained. The number of neurons in the hidden layer is intentionally chosen to start with the five neurons and hidden neurons are added to the hidden layer incrementally.

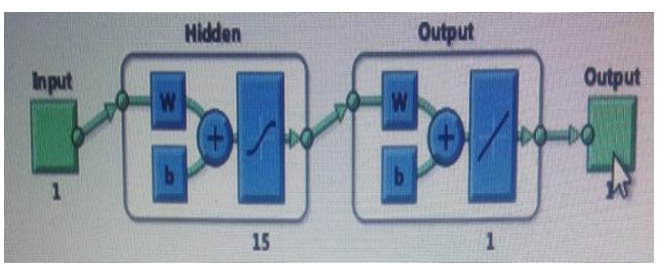

Fig. 5. Neural Network

The addition of the hidden neurons continuous until there is no significant progress in network performance. The input data is converted into the normalized form which is given TABLE V, in order to get data in between range of 0.1 to 0.9 using given equation,

$$0.1 + 0.8\frac{(x - x_{\min})}{(x_{\max} - x_{\min})} \quad (3)$$

TABLE VI
EXPERIMENTAL AND ANN PREDICTED AVERAGE MASS LOSS

Experimental Average Mass loss	Ann Predicted Average Mass Loss	% Error
0.0065	0.006555	0.7633
0.0075	0.007518	0.239
0.00815	0.008217	0.815
0.0094	0.00968	2.89
0.008	0.008126	1.55
0.00794	0.008772	9.484

The data sets used were 70% training, 15% validation and 15% testing. In the present study the algorithm used for the neural network technique is Bayesian Regularization. The percentage error between experimental average mass loss and ANN predicted average mass loss is given in TABLE VI and the percentage error of erosion rate is shown in TABLE VII.

TABLE VII
EXPERIMENTAL AND ANN PREDICTED EROSION WEAR RATE

Experimental erosion wear rate	ANN predicted erosion wear rate	Error (%)
5.02×10^{-8}	5.06×10^{-8}	0.790
3.002×10^{-8}	3.009×10^{-8}	0.232
2.306×10^{-8}	2.325×10^{-8}	0.860
2.172×10^{-8}	2.327×10^{-8}	2.90
1.65×10^{-8}	1.683×10^{-8}	1.96
1.591×10^{-8}	1.755×10^{-8}	9.34

IV. RESULTS AND DISCUSSION

The average mass loss from the WC-Co coated test specimen at different impact angles is given in Table IV and further used to calculate the erosion rate in g/g.

The erosion rate data of WC-Co coating at different impact angle is given in Table IV and graphically presented in Fig. 8. It is observed that the WC-Co coating shows maximum erosion at 15° impact angle. The erosion rate continuously decreases from 15° impact angle up to normal impact (90°) angle.

In order to authenticate the working of the ANN software and its ability to predict slurry erosion wear, a set of six experiments at different impact angles with same other process parameters is used. Accordingly, the erosion rate was predicted using ANN and given in Table VII and further graphically presented in Fig.6. The predicted erosion rate using ANN is well in agreement with the experimental data. The experimental and predicted erosion rate data are graphically presented in Fig.7 with ±5 % error. It is observed that the error in the predicted data is within 10%.

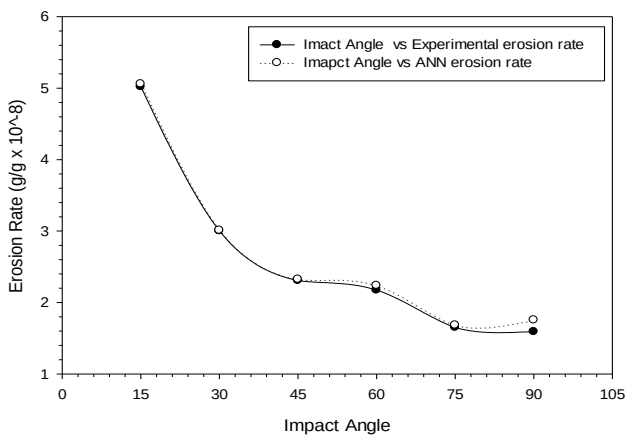

Fig. 6. Experimental and ANN erosion rate at different Impact angles

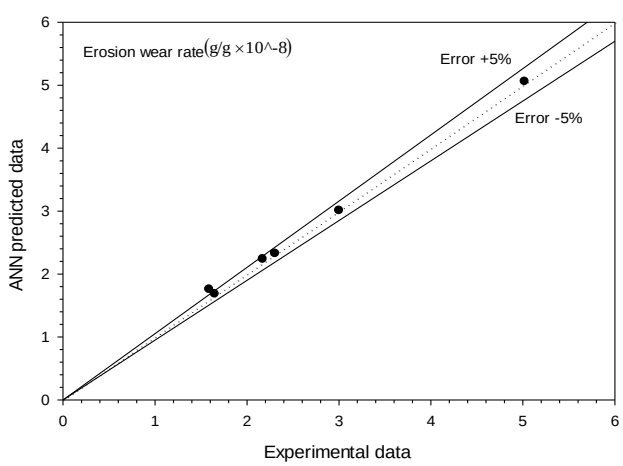

Fig. 7. Experimental vs. ANN Predicted Erosion rate

V. CONCLUSION

In this paper, the focus is to evaluate the slurry erosion behaviour of HVOF sprayed coating on substrate material gun metal bronze. From the experimental result of coated samples after erosion the following conclusions can be drawn:

1. The WC-Co coating shows maximum 5.02 x 10^{-8} g/g erosion rate at 15° impact angle and decreases continuously up to normal impact (90°) angle.
2. The predicted erosion wear data is well in agreement with the experimental data.
3. It is observed that the procedure gives an error of ± 5% in the estimation of erosion wear for a given material.

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REFERENCES

[1] H.M.Clark. (1993).Specimen diameter, impact velocity, erosion rate and particle density in the slurry pot erosion tester. *wear* .162-164 pp. 669-678.

[2] Milind Suryaji Patil, Eknath R. Deore, Ramchndra S. Jahagirdar, Santosh V Patil (2011). Study of the parameters affecting erosion wear of ductile material in solid liquid mixture", *Proceeding of the world Congress on Engineering*.

[3] Randall S. Lynn, Kein K Wong, H.M Clerk (1991). On the particle size effect on the slurry erosion. *Wear*, 149 pp. 75-71.

[4] Lalit Thakur, Navneet Arora (2013). A comparative study on slurry and dry erosion behaviour of HVOF sprayed WC–CoCr coatings. *Wear* 303 pp. 405–411.

[5] Deepak Kumar Goyal, Harpreet Singh, Harmesh Kumar, Varinder Sahni, (2012). Slurry erosion behaviour of HVOF sprayed WC–10Co–4Cr and Al2O3+13TiO2 coatings on a turbine steel. *Wear* 289 pp. 46–57.

[6] Deepak Kumar Goyal, Harpreet Singh, Harmesh Kumar, Varinder Sahni (2012). Slurry Erosive Wear Evaluation of HVOF-Spray Cr2O3 Coating on Some Turbine Steels. 838 Vol. 21(5) September.

[7] K. Murugan, A. Ragupathy, V. Balsubramanian, K. Sridhar, (2014). Optimization HVOF process parameters to attain minimum porosity and maximum hardness in WC-10CO-4Cr coatings. *Surface & coatings Technology* 247 pp. 90-102.

[8] Kanchan Kumari, K. Anand, Michelangelo Bellacci, Massimo Giannozzi, (2010). Effect of microstructure on abrasive behaviour of thermally sprayed WC-10Co-4Cr coatings. *Wear* 268 pp. 1309-1319.

[9] M.R. Ramesh, S. Prakash, S.K. Nath, Pawan Kumar Sapra, B. Venkataraman (2010). Solid particle erosion of HVOF sprayed WC-Co/NiCrFeSiB. *Wear* 269 pp. 197-205.

[10] Rakesh Bhatia, Hazoor Singh, Buta Sungh sidhu (2012). Characterization of 80% Cr_3c_2-20% (Ni-Cr) Coating and erosion Behaviour. *AJEAT 2*.

[11] Andrei Surzhenkov, Veldek Mikli, (2015). Wear Resistance self-fluxing alloy based TIC-NIMO and CR_2C_3-NI Hardmetal particles reinforced composite coatings.

[12] J.M. Miguel, J.M. Guilemany, S. Vizcaino (2003). Tribological study of NiCrBSi coating obtained by different processes. *Tribology International* 36 pp. 181-187.

[13] G.R. Desale, B.K. Gandhi, S.C. Jain (2005). Effect of physical properties of solid particle on erosion wear of ductile material. *World Tribology Washington D.C.*

[14] B.K. Gandhi, S.V. Borse, (2002). Effect of particle size and size distribution on estimating erosion wears of cast iron in sand-water slurries. *Indian Journal of Engineering & Material Sciences* Vol.9, pp. 480-486.

[15] G.R. Desale, B.K. Gandhi, S.C. Jain, (2008). Slurry erosion of ductile materials under normal impact condition. *Wear* 264 pp. 322-330.

[16] Zubin Mishra **(**2015). Parametric Optimization of Slurry Erosion in Pipeline Materials Using Fuzzy Logic and Artificial Neural Networks. pp. 1-56.

[17] Pravat Ranjan Pati and Alok satapathy (2013). Prediction and simulation of erosion wear response of Linz-Donawitz (LD) slag filled epoxy composite using ANN. vol. 1, pp. 40-45.