# Optimization and Erosion Wear Response of HVOF Coated Pipeline Material at Different Impingement Angles

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# Abstract

**Background/Objectives**: Erosion wear characteristic of pipeline material namely stainless steel SS-317L has been investigated with the help of a pot tester under various concentrations and fly ash as erodent was used. **Methods/Statistical** Analysis: In this paper, erosion wear response of slurry pipeline material is optimized by utilizing Taguchi's experimental technique. **Findings**: The phenomenon of erosion wear response is too complex and the behavior has been studied. In this paper, the attempt has been made to expand a methodology to optimize the erosion wear response of pipeline material at various impingement angles 30, 45, 60 and 90 degree with the help of a mixture of slurry with water under various concentrations i.e. 30%, 40%, 50% and 60%. Fly ash and water was used as erodent to prepare the slurry mixture under various concentrations at different rotational were 600, 850, 1100 and 1350 rpm and time period of 60, 120, 180 and 210 min. **Improvements/Applications**: Erosion wear response is investigated with HVOF spayed coatings. It is also observed that the erosion wear response of WC-12Co-4Cr and Stellite-6 coated pipeline material SS-317L increase with the increase in the impingement angle till 30 degree observe maximum value and decreases with the impingement angle 90 degree.

Keywords: Erosion Wear Rate, Fly Ash, HVOF Sprayed Coating (Stellite6 and WC-12Co-4Cr), Impingement Angles, Optimization etc, Rotational Speed, S/N Ratio, Stainless Steel (SS-317L), Taguchi Method

# 1. Introduction

Erosion is defined as the action of deduction of surface material from an object surface due to impact of various erodent particles. The particles floating in the run of solid liquid muddle wear down the wet passage encouraging the overhaul life of apparatus used for slurry transportation system<sup>1</sup>. Erosion wear due to the run of solid liquid slurry mixture depends on the various numbers of organized parameters. The various properties of pipeline materials namely stainless steel and erodent are the parameters which affect the material removal rate. The erosion wear in case of pipeline materials is identified as the major problem in hydraulic transportation systems. In addition to materials properties, the erosion angles, velocity, particles size etc. It is already observed that the erosion wear rate and decreases with change in particles size<sup>2-4</sup>. Also the impact angle plays an important role in observing the relative erosion wear response of pipelines. The materials like cast iron and stainless steels are used as the pipeline materials. Researchers used different pipeline materials and erodent for investigating erosion wear response with and without HVOF coatings. Most of our researchers used Tungsten Carbide (WC) and Chromium (Cr) as HVOF spraying coating material to reduce the surface tribology of pipeline materials as they are the harder materials<sup>5</sup>. Many research papers have been written on the experimental investigation of erosion wear response, most important

wear also depends on the other parameters like impact

to a superior accepting the mechanism for erosion wear response. Modeling of the erosion wear process logically follows on from this experimental research. The industrial aim is to develop a system where the components are manufactured from appropriate materials, the materials degraded modes are identified and that model exists to predict the performance of the materials in the industry<sup>6-9</sup>. Various parameters have various impacts on erosion wear response, studied using different investigations. W.Tsai and J.A.C Humphrey (1980) investigated the measurement of erosion wear response in a slurry pot tester. In this experimental work, the investigators calculated erosion wear response for steel alloys with the help of coal as erodent in kerosene. In this investigations, the various observations are discussed which are correlated to fluid mechanism, heat and content of water in the coal. Hector Mel. Clark (1991) investigated the casual impact energy of various particles. In his experimental work, Hector Clark investigates the particles impact by using electro polished copper rod specimens. The particle size were 90, 120, 600 and 750 micrometer and the rotational speed of slurry pot tester were 9.35 and 18.75 m/s with viscosity range of liquid (0.66-60  $\times$ 10<sup>-3</sup> Nsm-2. B. K. Gandhi and S.V Bose (2002) studied achieve of Particle Size Distribution (PSD) of the slurry pot tester. B. K. Gandhi investigated the effect of erosion wear as cast iron was his pipeline material. The effect of different particle size produces a large amount of wear rate. Gnanavelu et al. (2009) investigated the erosion wear response with the help of jet tester method in CFD. In his work, the various impact angles were 90, 105 and 135 degree with velocity of 7 m/s. Desale et al. (2009) studied the effect of various particles size for slurry erosion of aluminum alloy (AA 6063) in a slurry pot tester. He rotates a work-piece under a pot tester at 3 m/s and at different angles in a slurry mixture of 20% concentration. Erosion wear rate was increased with the increase in particle size. Sunil Kumar and Jasbir Ratol (2012) investigated and studied about the erosion wear response of cast iron. The powder used for coating is Al<sub>2</sub>O<sub>3</sub> powder with a D gun spraying. The investigator used various properties to check the wear response of cast iron. Ramesh et al. (2011) investigated erosion wear response of thermal Inconel-718 coatings by using APS process. This coating was sprayed over the mild steel by substrate Air plasma coating technique. Then the testing and comparison of coating was done by using SEM. It was observed that there was increase in hardness and decrease in porosity with the help of increasing the thickness of coating. Singh et al. (2011) investigated the erosion wear effect of plasma sprayed Cr<sub>2</sub>O<sub>3</sub>-3%TiO<sub>2</sub> coatings i.e. is conventional and nano-structured Cr<sub>2</sub>O<sub>3</sub>-3%TiO<sub>2</sub> ceramic coating by using a pin on dry sliding which was a disc type in shape and erosion wear response were investigated by using pot tester and the microstructure was analyzed by using SEM and EDS morphology. Thakur, et al. (2011) investigated the erosion wear response by using a pot tester to eliminate erosion resistance of coating material. The two parameters were used for testing of erosion wear response erodent particle size and concentration of slurry mixture. Y. M. Abd and A. A. Bonel (2013) investigated and studied the impact on slurry erosive wear. He used AISI 5117 Steel end inspect steel at various impact angles and checked the erosion wear response. The silica sand was used as erodent material for the experiments with particle size 250-355 micrometer. SEM images for erodent samples at different stages were present. The result of investigation is obtained that AISI 5117 has better erosion resistance at impact angles. Wang, et al. (2014) investigated and studied the effect of re-melting on microstructure and various solid particles erosion wear characteristics of ZrO2-7wt5 Y2O3 thermal coating geared up by plasma spraying. Quartz and Chromite was the erodent used for the experimental testing. In this investigation, the two metallic bonds are used to coat TiAl alloy. XRD and SEM of erodent and coated material were also used.

In this present work, the erosion wear response of the pipeline material namely Stainless steel SS317L is obtained with and without HVOF Stellite6 and WC-12Co-4Cr coatings at four different impingement angles 30°, 45°, 60° and 90° respectively. The investigational experiments were conducted at different four rotational speeds namely 600, 850, 1100 and 1350 Rpm with time period of 60, 120, 180 and 210 minutes. The solid concentration of erodent material was taken as 30%, 40%, 50% and 60% (by weight). To optimize the process parameter of solid particle erosion wear, Taguchi method is used.

# 2. Materials and Methods

# 2.1 Testing Material

Stainless Steel graded with SS317L is used for this experimental work. SS317L is generally a type of Cr, Ni and Mn stainless steel with related properties as that of grade SS-204/302/202 stainless steel. The hardness of SS-317L is 85. In is one of the dew hardening grade and it have the properties to good corrosion resistance, toughness, hardness and strength. Table 1 shows the chemical composition of pipeline material SS-317L.

The chemical composition of SS-317L was measured by using Digital micro hardness tester is shown in the Table 1.

Element	Chemical composition								
	Fe	Cr	Mo	Ni	Mn	Si	С	Р	S
Content	68%	19%	3%	14%	2%	1%	0.03%	0.45%	0.3%

Table 1. Chemical composition of SS-317L

# 2.2 HVOF thermal spray system

HVOF coating or spraying is defined as the technique or method of coating in which melted or heated material sprayed on the surface of the work-piece material with the help of plasma or arc gun. The HVOF thermal coating system is too different as compared to other thermal spray coating systems. It consists of number of components and this process produces very high spray velocity. Figure 2 shows the pictorial view of HVOF coating Panel present at Harsha Welding Industry, Panchkulla (India). WC-12Co-4Cr and Stellite-6 (S6) coating powders were studied to investigate the erosion wear response of slurry pipeline material to resist erosion. These coating powders were deposited with the help of thermal sprayed coating process called HVOF process. HVOF coating or spraying is defined as the technique or method of coating in which melted or heated material sprayed on the surface of the work-piece material with the help of plasma or arc gun. The HVOF thermal coating system is too different as compared to other thermal spray coating systems. It consists of number of components and this process produces very high spray velocity. Figure 2 shows the pictorial view of HVOF coating Panel present at Harsha Welding Industry, Panchkulla (India).WC-12Co-4Cr and Stellite-6 (S6) were deposited on specimens SS-317L samples with the help of HVOF thermal sprayed coating process. The specimens were cooled during and after the spraying with the help of compressed air jet and to obtain good coating adhesion the specimen were grit blasted with Al2O3 grit to improve surface roughness. (Figure 1).



Figure 1. HVOF control panel.

# 2.3 Erodent

The erodent material used to investigate the erosion wear response of slurry pipeline material Stainless steel grade SS-317L was fly ash. The samples of fly ash were collected from National Fertilizers Limited, Nangal, District, Ropar, Punjab. Different particles size of fly ash were used for this investigation i.e.  $<53 \mu$ m,  $53-106 \mu$ m,  $106-150 \mu$ m,  $150-250 \mu$ m. The particles size distribution of fly ash was determined by using Sieve and Shaker analysis. From the particle size distribution of fly ash, it is observed that 98.16% particles are in the range of  $<53 \mu$ m as shown in the Figure 2.



Figure 2. Particle size distribution of fly ash.

# 2.4 Slurry Pot Tester

Slurry pot tester is a very simple and low priced trouble free test rig which provides the rapid erosion wear response of the materials. It consists of a cylindrical pot which is used to pour the prepared slurry mixture and this pot is adjusted in this way that we can move it up and down direction with the help of fixtures and a testing sample which is fastened to the rotating shaft. The rotating speed of vertically placed shaft can be changed according to different parameters to calculate the weight loss of materials. The shaft is placed vertically inside the tester and it is rotated with the help of electric motor which is placed at the top of the pot tester enclosed from sides. The maximum speed of rotating shaft for a particular test is 1500 rpm. The slurry pot tester was generally developed for testing of wear resistance materials for various industrial applications. Moreover, this tester is suitable for the materials like steels and rubbers. Figure 3 shows the view of Slurry pot tester present at Thapar University, Patiala, India. (Figure 3).



Figure 3. Pictorial view of slurry pot tester.

# 2.5 Experimental parameters

To optimize the erosion wear response of pipeline material with and without coating, the following are the various experimental parameters shown in the Table 3. (Table 2).

Table 2.	Experimental	perimeters
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S. No.	Experimental Parameters				
	Parameter	Specification			
1	Material used	SS-317l			
2	Erodent used	Fly ash			
3	Particle size	<53, 53-106, 106-150 and 150-250 μm			

C No	Experimental Parameters					
5. INO.	Parameter	Specification				
4	Slurry concentration	30%, 40%, 50% and 60%				
5	Speed	600, 850, 1100 and 1350 rpm				
6	Time	60, 120, 180 and 210 minutes				
7	Coatings	HVOF (Stellite6 and WC- 12Co-4Cr)				
8	Impingement angle	30°, 45°, 60° and 90°				

# 2.6 Method

By using Taguchi method<sup>10</sup> from design of experiments, it has been observed that the S/N ratio is required to get erosion wear response of pipeline material. S/N ratio is defined as the ratio of "signal" to "noise" where "signal" is the mean value of the output data and "noise" is the square deviation for the output data.

i.e. S/N ratio = Mean/Square deviation

The S/N ratio is used to measure the erosion wear response of pipeline materials with the help of various parameters through ANOVA.

S/N ratio for erosion wear is calculated by using equation as given below:

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\sum yi^2\right]$$

#### 2.6.1 Statistical Analysis

L16 array was used as the process parameter for output values and S/N ratio. MINTLAB 16 software package was used measure the characteristics through the ANOVA from design of experiments.

#### 2.7 Erosion Wear Rate

Erosion wear is defined as the ratio of mass of eroded material per unit mass of slurry used to be balanced in the swept volume, was determined by using Equation 2 given by<sup>11</sup>.

$$E = \frac{W \times 10^3}{\rho C v A V T \sin \alpha}$$

Where,  $\alpha$  is the impingement angle (°), is the mass density of slurry (kg/m<sup>3</sup>), A is the surface area of the eroded piece (m<sup>2</sup>), Cv is the solid concentration by volume (fractions), E is the erosion wear rate (g/g of solids), T is the time duration (min), V *is* the velocity of the center of the eroded piece (m s–1), W is the average weight loss of the two eroded pieces in time T (g).

The erosion wear rate of the uncoated and coated stainless steel is shown in Figures 3 and 4. From the curve, it is observed that the erosion wear rate of Stellite-6 coated SS-317L is slightly higher than that of the WC-12Co-4Cr coated SS-317L steel at various impact angles. The WC-12Co-4Cr coated stainless steel performs better as compared to Satellite-6 coating during solid particle erosion. On the other hand it reveals that the HVOF coatings gave the higher mass loss as compared to that of the uncoated steels. All the uncoated and coated SS-317L has shown relatively higher erosion rate in the early investigations. The variation in erosion wear rate was more during the uncoated SS-317L investigation period and thereafter variation reduces, because of HVOF coated surfaces. In general, the WC-12Co-4Cr coated Stainless steel SS-317L under investigation shown low mass loss as compared to Stellite-6 coated.

# 3. Results and Discussion

#### 3.1 Experimental Plan

The erosion wear response of stainless steel SS-317L with HVOF sprayed Stellite-6 and WC-12Co-4Cr coatings with various independent factors like Speed, slurry concentration, impingement angle and time period of experiment is given in the table. MINTLAB-16 software package was used to obtain the S/N ratio to get erosion wear response. The difference of S/N ratio values obtained with the help of MINTLAB-16 showed the strongest impact of parameter. Higher difference in S/N ratio value showed the greater impact of parameter. The effect of speed is considered as the impact parameter over concentration and time. The erosion wear response of SS-317L with HVOF sprayed coatings is calculated at various parameters in terms of loss in weight. L<sub>16</sub> orthogonal array was used to conduct experiments which consist of four columns and sixteen rows. Table 3 shows that the experimental data of HVOF coated SS-317L. (Table 3).

Б		Experimental data table							
Exp. No.	Speed (rpm)	Concentration (%)	Time (Min.)	WC wear @60	WC S/N ratio	S6 Wear @60	S6 SN ratio		
1	600	30	60	0.00072	60.7242	0.00019	74.42493		
2	600	40	120	0.0012	57.0774	0.00067	63.4785		
3	600	50	180	0.00492	45.8146	0.00439	47.15071		
4	600	60	210	0.00984	39.9653	0.00931	40.62101		
5	850	30	120	0.00204	52.995	0.00151	56.42046		
6	850	40	60	0.00192	53.4733	0.00139	57.1397		
7	850	50	210	0.012	38.2728	0.01147	38.80873		
8	850	60	180	0.00804	41.6815	0.00751	42.4872		
9	1100	30	180	0.00456	46.4479	0.00403	47.8939		
10	1100	40	210	0.00816	41.5559	0.00763	42.34951		
11	1100	50	60	0.0036	48.4043	0.00307	50.25723		
12	1100	60	120	0.00588	44.3219	0.00535	45.43292		
13	1350	30	210	0.00576	44.4951	0.00523	45.62997		
14	1350	40	180	0.01152	38.6214	0.01099	39.18005		
15	1350	50	120	0.0114	38.7108	0.01087	39.27541		
16	1350	60	60	0.0168	35.391	0.01627	35.77225		

 Table 3. Experimental plan data L16 and results

# 3.2 Effect of Slurry Concentration

Higher the concentration of solid-liquid mixture (Slurry) with rotational speed, higher is the mass loss. The uncoated SS-317L shows a high mass loss as compare to coated SS-317L. The erosion wear rate with mass loss is reduced with the help of coating by increasing thickness of material to reduce mass loss.

# 3.3 Effect of Rotational Speed

The spindle of pot tester increases the removal rate with increase in rotational speed. When the speed of spindle is more than 1350 rpm, the material removal rate is high with maximum slurry concentration.

# 3.4 Effect of Time Duration

The loss of mass of a material increases continuously with increase in time duration of investigation with higher speed and slurry concentration. The mass loss at 210 min. is higher as compared to 60, 120, 180 min. respectively.

#### 3.5 Contour Plots

Contour plots on erosion wear response of HVOF sprayed coated SS-317L is shown in figures respectively. Figures 3 and 4 showed the contour plot of erosion wear response vs. S/N ratio, speed plot showed that at low speed weight loss is minimum for higher S/N ratio erosion but increase in speed showed the clear increase in erosion wear with the same S/N ratio and in S/N ratio vs. speed plot, for the low value of speed concentration shows the maximum S/N ratio. With the increase in speed and concentration, the S/N ratio value is fully less with final circumstances. Figure 4 showed S/N ratio vs. speed plot, lower values of speed, concentration and time showed the maximum signal to noise ratio as we proceed towards higher speed, concentration and time minimum signal to noise ratios values were obtained. The S/N ratio for WC-12Co-4Cr coated SS-317L varies from 60.72 to 35.39. Figure 5 showed the S/N ratio vs. speed, concentration and time plot. With lower speed, concentration and time maximum values of sound to noise ratio was obtained and higher values of speed, concentration and time showed minimum signal to noise ratios. The S/N ratio for Stellite-6 coated SS-317L varies from 74.42 to 35.77. (Figures 4 and 5).







Figure 5. Main effect plot for S/N ratio (WC-12Co-4Cr coated SS317L).

# 3.6 Variation of Curves

It is very hard to attain the preferred impact angle of solid mixture relative to the eroding surface in a slurry pot tester and it is generally difficult to optimize the erosion wear response. From the investigation, it is observed that the erosion wear increases with the increase in particle size at all the impingement angles but the ratio of increase is not constant at different impingement angles. It is investigated that the rate of increase of the wear with the increase in particle size increases with the increase in impingement angle and decreases continuously up to 90°.

In order to compare the erosion wear response of SS-317L coated with WC-12Co-4Cr and Stellite-6. Figure 6 shows the variation of erosion wear with different impingement angles. In this Figure 3 the two curves shows nearly similar individuality. (Figure 6).

The value of erosion wear ratio for the same particle size and solid concentration further decreases, particularly in the range of 30° to 60° impingement angle with decrease in the speed. This is due to decrease in relative impact energy of the particles at lower speed, which is responsible for further fall in the contribution of deformation wear. It is also seen that at high speed and high solid concentration for large size particles the data points are very close at 45° impingement angle. For these particles, erosion wear on particle diameter is same at all the impingement angles. However, for the case of small particle size slurry, it is observed that more deviations in the value of the wear ratio compared to the larger particles, more so at 30° and 45° orientation angles shown in the figure 7. This could be as a result of the lower relative impacting energy of these particles due to smaller mass. (Figure 7).



**Figure 6.** Variation of erosion wears of WC-12Co-4Cr and Stellite-6 with different impingement angles.



**Figure 7.** Variation of erosion wear ratio with impingement angle.

# 4. Conclusion

To optimize the erosion wear response of pipeline material SS-317L at various parameters like impingement angles, rotational speed, slurry concentration, time duration etc. Taguchi method from design of experiments with L16 array was used for investigation with and without HVOF coating (Stellite-6 and WC-12Co-4Cr) powders. Following are the various conclusions drawn on the bases of present investigation of erosion wear response:

- The uncoated stainless steel SS-317L have shown high mass loss as compared to the HVOF coatings.
- The WC-12Co-4Cr coating performs better than Stellite-6 coating during solid particle erosion for various impact angles. The WC-12Co-4Cr coating also shows fine, uniform and layered microstructure.
- Stainless steel SS-317L and WC-12Co-4Cr coating indicate ductile mechanism whereas Stelliet-6 shows the brittle mechanism of erosion.
- The erosion wear rate increases with the increase in speed and particle size but decrease with increase in solid concentration.

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