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Optimization and Erosion Wear Response of Slurry Pipeline Material with and without Coating

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Abstract

Background / Objectives: In this paper, erosion wear response of slurry pipeline material is optimized by utilizing Taguchi's experimental technique. **Methods / Statistical Analysis**: The investigation of erosion wear due to solid–liquid mixture flow took place with the assistance of a slurry erosion pot tester. The pipe material namely stainless steel SS-317L is utilized to lead the erosion tests. This erosion test is set up to impact the rotational speed, solid concentration and time with multi sized slurry. Fly ash was utilized as the erodent material. **Findings**: In these erosion tests, four experiments were performed. These four tests are performed at four different speeds 600, 850, 1100 & 1350 rpm and the concentration of solid-liquid mixture is 30%, 40%, 50 & 60% with time duration of these experiments are 60, 120, 180 and 240 min. **Improvements / Applications**: For protective coating, High-velocity oxygen-fuel (HVOF) spray process is used for depositing to coating powders Stellite-6 and WC - 12Co - 4Cr on the material namely stainless steel SS-317L. The S/N ratio of with and without HVOF coating of SS-317L varies from 44.88 to 29.77 (Uncoated), 64.43 to 37.09 (Stellite-6) and 80.00 to 49.25 (WC-12Co-4Cr) respectively. Rotational speed was resolved as one of the predominant factor which impacts the erosion wear response of SS-317L.

Keywords: Erosion wear, Fly ash, HVOF sprayed coating (Stellite-6 and WC-12Co-4Cr), Optimization, Rotational Speed, Stainless Steel (SS-317L), Taguchi methodetc.

1. Introduction

Erosion is characterized as the action which removes the target surface material starting with one place and transports it then into the next place. Erosion is identified as one of the major serious problem in the industry nowadays. In petrochemical industry, thermal power plants, oil refineries, aircraft turbines etc. the erosion takes place from a solid surface with the action of solid liquid and gas. In addition to this, the power plants go through the most with the action of erosion wear[1-3]. During to the transportation of fly ash, the unburnt carbons and oxides form a combustion process and strikes with the boiler tube and causes erosion wear and this erosion wear leads to the failure of boiler tube. The setup and replacement cost of damaged tube is too high which is equal to 60% of the total cost. The hard materials present will consequently misshape into the gentler material, which is more powerful. In channeling line transport framework wear is most serious issue looked amid the shipping[4]. In pipeline transport configuration wear assume essential part. Design of slurry transport framework all the erosion wear parameters are consider before planning of framework[5]. At the point when two strong surfaces are connecting with each other wear occur, because of the mechanical activity between two surfaces. This failure of elements due to erosion wear demands the wear resistant and high temperature oxidation protection analysis of various components materials for different applications from engineering as well as economical perspectives. Various parameters of erosion wear which affects erosion wear rate shows different erosion wear rate. Different operational conditions of erosion wear are studied with the help of pilot

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plant test loop. The two great researchers Rohnisch and Vollmer (1970), the first to develop a bench scale test rig to study the various effects of different parameters of erosion wear with a collection of materials from PVC to stainless steels[6]. Several other test rigs were developed over the years later to study the effects of various parameters of erosion wear and this mechanism of erosion wear is also simulated by some researchers on the basis of laboratory scales[7]. Several other investigations were taken place and the investigators suggested that the erosion wear rate can be reduced by using a hard material thin layer of carbides, oxides and nitrides with protective coating on the work-piece[8]. Different techniques of coating can be used to deposit hard material over the material like thermal spray, physical and chemical vapor deposition, laser coating, plasma coating, HVOF coating, electroplating etc. The HVOF spray coating process can deposit coating with high cohesive strength and good mechanical properties[9,10]. Taguchi method was used by most of the investigators proposed by Dr.Genechi Taguchi of Japan to optimize the erosion wear response which gives significant conclusions with minimum experimental tests by reducing the experimentation cost. Over the years, our investigators used WC and Cr coating to control the wear rate of pumping and pipeline materials[11-13]. The great researcher Wheeler and wood had used WC-10Co-4Cr powder coating to control the erosion wear rate in AISI 1020 steel by using erosion jet tester with sand slurry. Studied the effect of WC-9Co-5Cr HVOF coating on Stainless steel AISI-304 used WC-10Co-4Cr to investigate erosion wear on S45C steel by using Disk wear tester and results shows that coating provides a wear resistant. Hong et al. had investigated with Cr2O3-NiCr powder coating on 13CrNi steel by using HVOF coating technique and observed that the micro hardness of base material had improved after depositing powder coating[14,15].

Using the Taguchi method[16] (DOE), we modified the parameters to a minimum number by using L_{16} array to minimize the number of experiments to maximize the performance. To optimize the design of performance, quality and cost, Taguchi method is the most simple and efficient tool. In this paper, erosion wear response of pipeline material namely Stainless steel (SS-317L) has been analyzed with HVOF sprayed WC-12Co-4Cr and Stellite-6 (S6) coatings. The experiments were carried out at four different speeds 600, 850, 1100 and 1350 rpm with a time period of 75, 120, 180 and 240 min. Fly ash is used as the erodent material with solid-liquid concentrations of 30%, 40%, 50%and 60% by weight. Taguchi method from design of experiments was used to optimize the erosion wear response of slurry pipeline material SS-317L with HVOF sprayed coating process.

2. Materials and Methods

2.1. Testing material

To investigate the erosion wear response in slurry pipeline material, namely stainless steel SS-317L was used. The specimen was adjusted into the slot for this purpose in the flow channel. This specimen was cut down into flat pieces of 75 × 25 × 5 mm each with a drilled hole of 8mm dia at the centre to hold in the specimen as shown in Figure 1. The chemical composition of SS-317L was measured by using Digital micro hardness tester is shown in the Table 1.

Table 1. Chemical composition of SS-317L

Element	Fe	Cr	Mo	Ni	Mn	Si	C	P	S
Content	68%	18-20%	3-4%	11-15%	2%	1%	0.030%	0.045%	0.030%

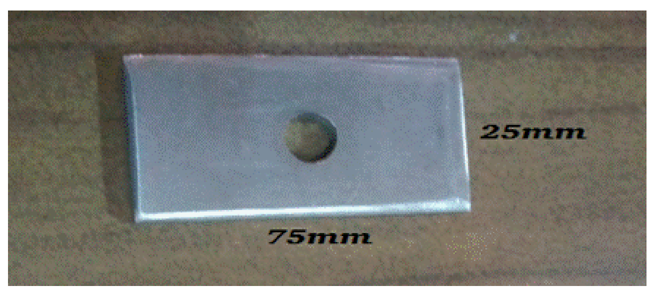

Figure 1. Pictorial View of SS-317L work piece,

2.2 Coating Deposition

In this present study, 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 was grit blasted with Al2O3 grit to improve surface roughness.

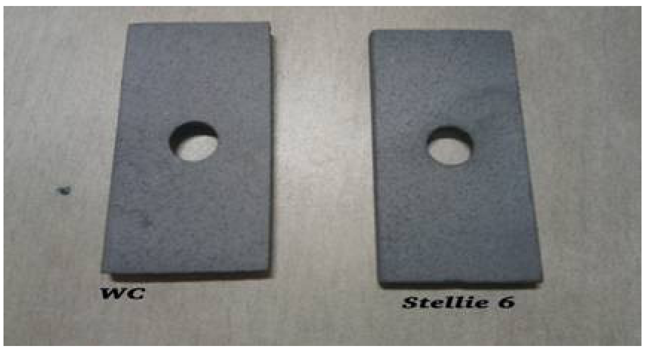

Figure 2. Pictorial view of WC and Stellite-6 HVOF coated SS-317L.

2.2.1 *Parameters of HVOF Coating gun*

HVOF coating panel consists of a coating gun to coat a particular surface and it runs on various parameters shown in Table 2.

Table 2. Parameters of HVOF coating gun

No.	Parameter	Specification
1	Voltage (Input)	AC 220V(Single phase), 50Hz
2	Power (Input)	300 Watt
3	Control	PLC
4	Gas and pressure	0.65 Mpa (Propane)
5	Pressure of Oxygen	1.1 Mpa
6	Pressure of Air	0.8 Mpa
7	Pressure of Nitrogen	1.2 Mpa
8	Pressure of Hydrogen gas	0.3-0.4 Mpa
9	Size of control cabinet	600 × 600 × 1760 mm
10	Weight of control cabinet	130 Kg

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, Distt. Ropar Punjab. Different particles size of fly ash were used for this investigation i.e. <53 µm, 53-106 µm, 106-150 µm, 150-250 µm. 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 to 250 µm and only 7.54% particles are below 53 µm as shown in the Figure 3.

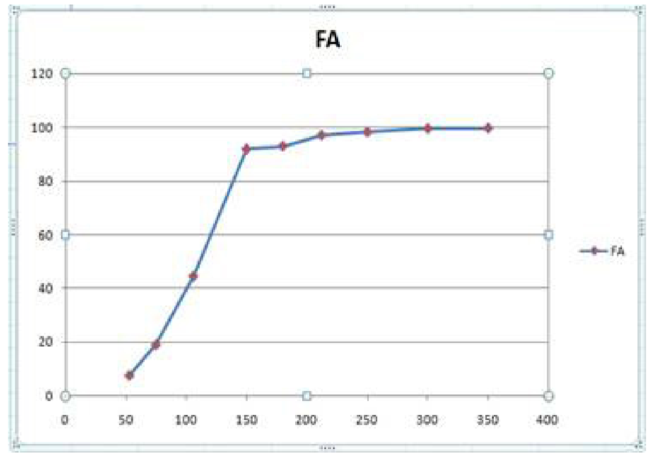

Figure 3. Particle size distribution of Fly ash.

2.3.1 *Scanning Electron Microscopy of Fly Ash*

Microscopy scanning electron microscopy (SEM) was performed to study morphological composition of fly ash as shown in Figure 4. SEM micrographs show that the fly ash particles are spherical in shape.

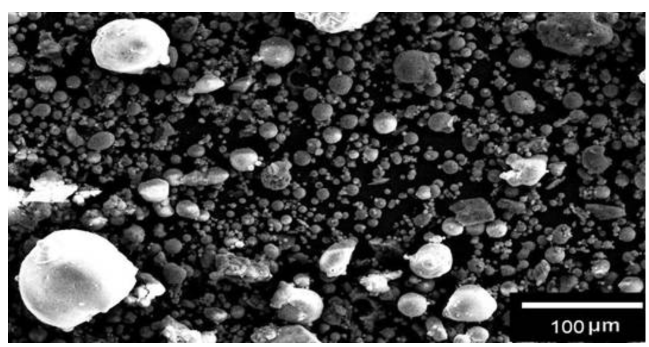

Figure 4. SEM image of Fly Ash.

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 1500RPM. 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 5 shows the view of Slurry pot tester present at Thapar University, Patiala (India).

Figure 5. 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 3. Experimental perimeters

No.	Parameter	Specification
1	Material used	SS-317l
2	Erodent used	Fly ash
3	Particle size	<53, 53-106, 106-150 and 150-250 μm
4	Slurry concentration	30% ,40%, 50% & 60%
5	Speed	600, 850, 1100 and 1350Rpm
6	Time	60, 120, 180 and 240 minutes
7	Coatings	HVOF (Stellite6 and WC-12Co-4Cr)

2.6 Method

By using Taguchi method[14] 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

L_{16} 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.

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 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_{16} orthogonal array was used to conduct experiments which consist of four columns and sixteen rows. Table shows that the impact of speed is higher as compared to concentration and time.

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. Table 4 Shows the L16 orthogonal array with different S/N ratios at different parameters.

Table 4. Experimental plan data L16 and results

Rotational Speed	Concentration (%)	Time (Min.)	Uncoated SS-317L	SNRA uncoated	Stellite-6	SNRA Stellite-6	WC	SNRA WC
600	30	60	0.0057	44.8825	0.0006	64.4370	0.0001	80.0000
600	40	120	0.0064	43.8628	0.0010	60.3999	0.0002	74.4823
600	50	180	0.0126	37.9651	0.0041	47.8081	0.0010	60.2870
600	60	210	0.0209	33.6012	0.0082	41.7290	0.0020	53.9848
850	30	120	0.0080	41.9491	0.0017	55.1641	0.0004	68.2626
850	40	60	0.0076	42.3609	0.0016	56.1375	0.0003	69.3704
850	50	210	0.0246	32.1954	0.0100	39.9740	0.0025	52.1901
850	60	180	0.0179	34.9624	0.0067	43.5045	0.0016	55.8097
1100	30	180	0.0121	38.3443	0.0038	48.4043	0.0009	60.9151
1100	40	210	0.0181	34.8608	0.0068	43.3690	0.0016	55.6701
1100	50	60	0.0105	39.5514	0.0030	50.4143	0.0007	63.0516
1100	60	120	0.0143	36.9176	0.0049	46.2316	0.0012	58.6363
1350	30	210	0.0142	36.9726	0.0048	46.3121	0.0012	58.7202
1350	40	180	0.0237	32.5234	0.0096	40.3772	0.0023	52.6018
1350	50	120	0.0235	32.5971	0.0095	40.4684	0.0023	52.6949
1350	60	60	0.0325	29.7757	0.0140	37.0930	0.0034	49.2594

3.2 S/N Ratio Contour Plots

Contour plots on erosion wear response of HVOF sprayed coated SS-317L is shown in figures respectively. Figure 6 shown 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. The S/N ratio for uncoated SS-317L varies from 44.88 to 29.77. Figure 7 shown 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 Stellite-6 coated SS-317L varies from 64.43 to 37.09. Figure 8 shown 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 WC-12Co-4Cr coated SS-317L varies from 80.00 to 49.25. The Stellite-6 and WC-12Co-4Cr coated SS-317L showed nearly similar erosion wear behavior. S/N ratios of SS-317L with and without coatings varies from 44.88 to 29.77 (Uncoated), 64.43 to 37.09 (Stellite-6) and 80.00 to 49.25 (WC-12Co-4Cr) respectively.

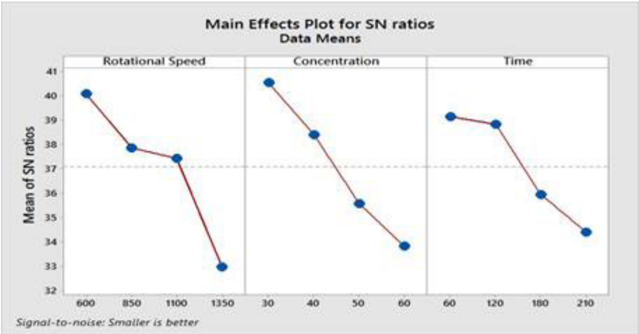

Figure 6. Main effect plot for S/N ratio (uncoated SS317L).

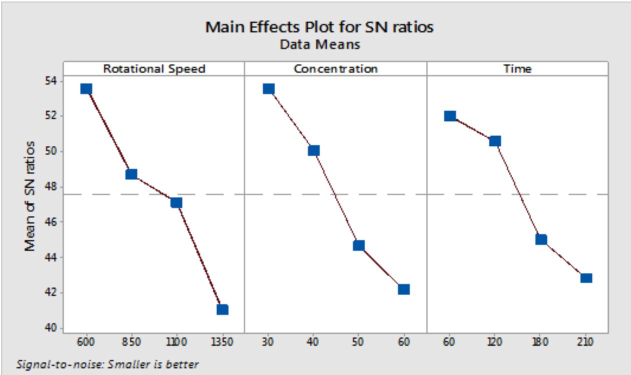

Figure 7. Main effect plot for S/N ratio (Stellite-6 coated SS317L).

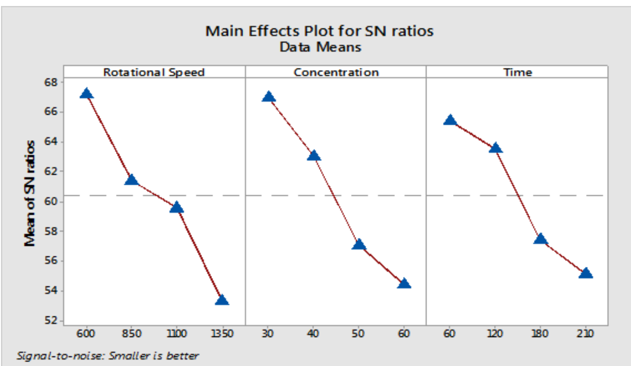

Figure 8. Main effect plot for S/N ratio (WC-12Co-4Cr coated SS317L).

3.3 Response Tables

The characteristics of S/N ratio help in generating the values of "rank" and "delta". Table is summarized as the response table for different S/N ratios for erosion wear response. It was observed that the rank of time is lower that of speed and concentration. The rotational speed shows the value of delta to be 7.11, 12.53 and 13.87. Hence, the minimum erosion wear occurred at rotational speed at N = 600rpm, concentration Cw = 30% and Time T = 60min. and the maximum erosion wear occurred at rotational speed at N = 1350rpm, concentration Cw=60% and Time T = 240min as shown in Table 5-7 respectively.

Table 5. Response table for Signal-to-noise ratios (Uncoated) -Smaller is better

Rotational			
Level	Speed	Concentration	Time
1	40.08	40.54	39.14
2	37.87	38.4	38.83
3	37.42	35.58	35.95
4	32.97	33.81	34.41
DELTA	7.11	6.72	4.74
RANK	1	2	3

Table 6. Response table for Signal-to-noise ratios (Stellite-6) -Smaller is better

ROTATIONAL			
Level	Speed	Concentration	Time
1	53.59	53.58	52.02
2	48.70	50.07	50.57
3	47.10	44.67	45.02
4	41.06	42.14	42.85
DELTA	12.53	11.44	9.17
RANK	1	2	3

Table 7. Response table for Signal-to-noise ratios (WC-12Co-4Cr) -Smaller is better

ROTATIONAL			
Level	Speed	Concentration	Time
1	67.19	66.97	65.42
2	61.41	63.03	63.52
3	59.57	57.06	57.40
4	53.32	54.42	55.14
DELTA	13.87	12.55	10.28
RANK	1	2	3

4. Conclusion

To optimize the parameters of erosion wear response like rotational speed, concentration of slurry mixture, time interval 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:

- Find minimum erosion wear at 600 rpm, Cw=30%, T=60min, Particle Size <53.
- Important sequence of parameters is: Time > RPM > Concentration > Particle Size.
- Resistance of coating is two times better than that of uncoated SS-317L.
- This study is beneficial to pipeline applications because HVOF sprayed WC-12Co-4Cr and Stellie-6 coatings were found useful to enhance the erosion wear resistance of SS-317L because of its higher hardness.

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