Study of Slurry Erosion Wear Behavior of SS-304 in a Slurry Pot test Rig under different operating parameters

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Abstract: **Slurry Erosion may be defined as the removal of material from a surface by fast moving solid particles suspended in a fluid. Various salts and mineral particles present in the fluid work as abrasives. Study of slurry erosion is important as it adversely affects the useful life and performance of the equipment handling slurries such as heat exchangers, pumps etc. Hence it is imperative to study the erosion wear characteristics of the materials of such equipment which are subjected to slurry erosion in order to improve their life and efficiency. The main objective of the present study is to find the effect of change in operating parameters on erosion wear of SS-304 sample subjected to sand-water slurry. The main operating parameters which are examined are particle velocity and solid concentration. Experiments are conducted in eight sets with three combinations of particle velocity, solid concentration and particle size. The sample specimens are tested at two solid particle concentrations 10% and 30% with two velocities 4m/s and 5m/s at each concentration. The above experiments are conducted for two particle sizes of 655µm and 362.5µm. Each set consists of particle impact angle varying from 15° to 90° in steps of 15°. Maximum erosion wear is observed at a particular angle for each set of operating parameters. Also, the particle velocity has the predominant effect on erosion wear followed by solid concentration and particle size respectively.**

Keywords: Slurry Erosion, SS304, Operating parameters

1. INTRODUCTION

Slurry Erosion is the loss of material from a surface exposed to a high velocity stream of slurry. Slurries used in practical applications have inherent abrasive solid particles such as impurities and salts which may cause significant damage to the equipment surface. Also, if the turbulence level is high, there may be multiple impacts of erodent particles with the surface and erosion wear is more. Practical situations where slurry erosion is encountered are oil pipelines, nozzles, fluid machineries etc. Use of alloy steels is common in pipeline construction. Slurry erosion wear results in the shortening of life of equipment and impact its efficiency badly which may cause its catastrophic failure. According to one estimate, India loses approximately US $120-150 million due to slurry erosion in hydraulic turbines in dams [1]. Hence it is important to understand the performance of such materials under varying operating parameters which are used to manufacture equipment subjected to slurry erosion.

In past years, there have been many research works focused on investigating the effect of different operating parameters on erosion wear of different materials. Many techniques are used to minimize the effect of erosion wear[2-7]. Some of these are use of new processing methods, use of coatings, use of advanced materials in equipment, surface treatment of equipment etc. But these techniques are of limited scope. It is the operating parameters which should be optimized in order to minimize the erosion wear. These parameters include particle properties such as hardness, size and shape; target material properties such as strength, toughness, hardness and microstructure; slurry properties such as solid concentration; flow characteristics such as particle feed rate, temperature, impact angle and velocity of abrasive particles. There have been many attempts to develop a universal mathematical correlation between different operating parameters and the erosion wear. But the complexity of erosion wear makes it difficult to interrelate the different parameters with erosion wear rate. Also, various types of test rigs have been developed in order to simulate the erosion wear mechanism and rate. In the present study, a pot test rig proposed by Desale et al. [8] has been suitably modified and fabricated to test the erosion wear characteristics of the SS 304 specimen under different operating parameters.

Ss304 is chosen as test material as it has a wide range of applications due to its erosion and corrosion resistant nature. Also, it has excellent formability and weldability. Some of the practical applications of SS304 are heat exchanger tubes, kitchen equipment, components of chemical processing equipment, oil and gas pipelines etc. Stainless steel is also used in brewing industry for making pipelines, valves, storage tanks etc. Components subjected to marine environments also make use of SS304 for their nuts, bolts and screws. Hence, it is important to study the erosion behavior of stainless steel in order to enhance the useful life of the equipment and improve their efficiency. Chemical composition of SS 304 is shown in

Composition	
SS-304	
Element	(Weight %)
Mn	2.00
S	0.030
P	0.045
Mo	-
Cr	7.50-19.50
Si	0.75
Ni	8-12
N	0.10
C	0.030

2. EXPERIMENTAL SETUP

To study the effect of different operating parameters on erosion wear rate, a test rig was designed[9]. The pot used has a capacity of 7 litres and a diameter of 240 mm. Four rectangular baffles of dimension 25mm x 10 mm are provided uniformly along the inside periphery of the pot. The main function of baffles is to prevent the rotational movement of the sand particles near the pot walls and direct them upwards to generate a secondary flow which ultimately helps in achieving a uniformly distributed sand-water slurry.

A propeller is provided at the bottom of the pot. It provides for uniform and homogeneous distribution of sand particles inside the pot. z

Fig1. Slurry Pot Test Rig

The propeller used is of PTB type as it provides more uniform distribution of solid particles in the slurry. The propeller shaft is supported by bearings and an oil seal is used to prevent any leakage of water. A dc motor of 1.5 hp with variable frequency drive(VFD) is provided to rotate the bottom propeller shaft through a belt-pulley drive. A similar VFD motor is provided at the top to provide rotation to the shaft on which the sample holder is attached. At the bottom of the pot a hole of diameter 20 mm is provided so as to remove the slurry at the after the experiment.

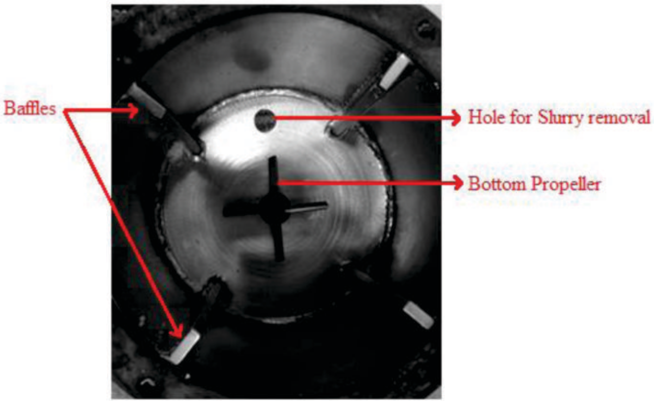

Fig 2. Top View of Slurry Pot

The top shaft consists of a sample holder attached at its end. The sample holder is made of a brass sleeve with two horizontal arms diametrically opposite to each other on which the test fixtures can be attached. This is done to achieve dynamic force balancing and minimize wake interference effect. A groove of the size of sample specimen is made in the test fixture so that the test sample forms a transition fit with the fixture when fixed inside the groove. The sample holder is provided with index plates by which test fixture can be made to orient at different angles from 15° to 90° in steps of 15°, along the direction of peripheral velocity.

Fig 3. Test Fixtures with samples glued inside

The test fixtures are made of high carbon steel and quenched to achieve a hardness of upto 60 RC. As a result, the wear on fixture surface is negligible as compared to wear on specimen. The test specimen is fixed inside the fixture groove so that the top surface of the specimen and the fixture surface are in the same plane. The arm lengths of the sample holder are of 71mm. So, the radius of rotation of sample specimens is 71 mm

3. EXPERIMENTAL PROCEDURE

Before starting the experiments, similar sample specimens were prepared so as to maintain uniformity in every experiment. 96 test specimens of dimensions 30mm x 5mm x 2mm are cut from a SS304 sheet. The cut samples need to be polished on top surface to give it a mirror finish. Polishing of samples is done because the prepared specimens have rough surfaces that need to be finished for accurate results else discrepancies will arise in test results.

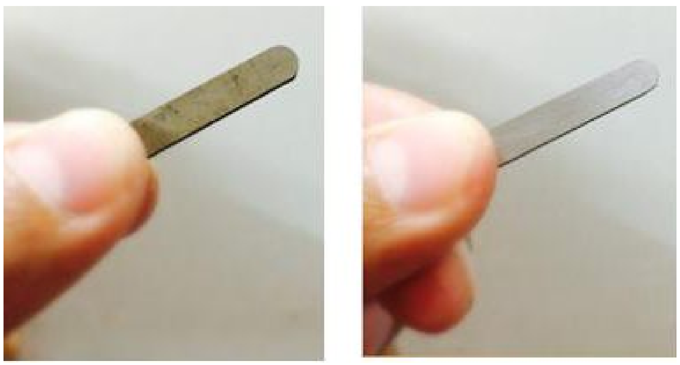

Fig 4. Top Surface of Sample before and after finishing

Emery papers of sizes #600, #1000, #1200, #1500 in increasing order of fineness are used for surface finishing. After finishing, the test specimens are cleansed with acetone. The mass loss of samples after each experiment is measured in grams upto four decimal places. Tests are conducted in six sets. In Set A and set B, effect of particle velocity is observed. Experiments are conducted for two particle velocities 4m/s and 5m/s keeping the particle size and solid concentration fixed at 655 µm and 10% respectively. Similarly in Sets C and D, particle size is varied from 362.5 µm to 655 µm keeping the velocity and concentration fixed at 4m/s and 10% respectively. In sets E and F, concentration is varied from 10% to 30% keeping the velocity and particle size fixed at 5m/s and 655 µm respectively. The average value of the mass loss of samples is used to calculate the erosion wear rate by using standard equations [8].

The slurry is prepared by mixing Indian standard sand with water. Properties of IS sand are shown in Table 2. The sand is sieved between two successive sieves of mesh size 600µm and 710µm to collect mean size of particles 655µm and between sieves of size 300µm and 425µm to collect mean size of particles 362.5µm.

Table 2 : Physical Properties of IS Sand

Solid particle	IS Sand (Quartz)
Colour	Whitish
Chemical formula	SiO2
Particle shape	Sub Angular
Hardness (VHN)	1100
Sp. Gravity (kg/m3)	2652

Fig.5 Sieve Shaker (b) Sieves & sand

10% sand by wt. is taken in the pot and the rest is completely filled with water. The pot is then covered and completely tightened to ensure the slurry does not spill leak. Now, the top shaft is rotated at 538 rpm and 673 rpm in different sets so as to obtain the average peripheral velocity of the samples as 4m/s and 5m/s respectively so that the average peripheral velocity of samples is 5m/s. The bottom propeller shaft is rotated at 400 rpm in a direction opposite to that of the top shaft.

Bree et. al. [10] gave a correlation which is used to compute the erosion wear rate for that average mass loss of two wear sample.

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

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

Where

C_v - Solid concentration by volume in fraction ;

C_W - Solid concentration by weight in fraction ;

ρ_S - Solid particle mass density in kg/m3 ;

E_W - Total erosion wear rate in g/g;

A_{SP} - Surface area of the wear sample subjected to erosion in m2;

T - Time over which mass loss has been measured in sec; VSP - Peripheral velocity of wear specimen in m/s ;

WL -Measured mass loss in kg;

α - Orientation angle of wear specimen in degree.

4. RESULTS AND DISCUSSION

Effect of particle velocity, solid concentration and particle size on erosion wear is observed keeping two parameters fixed at a time. Fig 6 shows the effect of particle velocity on erosion wear of test specimen at different impact angles. The particle size is kept constant at 655μm and the solid concentration is taken as 10% by wt. As the particle velocity is increased from 4m/s to 5m/s, there is a corresponding increment in the erosion wear values at different angles. This increase in erosion wear can be attributed to the increased turbulence levels in the pot due to increased particle velocity. The more the particle velocity, the more is the random motion between the particles. Consequently, the number of collisions between the particles increases and there are more particle impacts on the sample surface which ultimately results in increased erosion of sample.

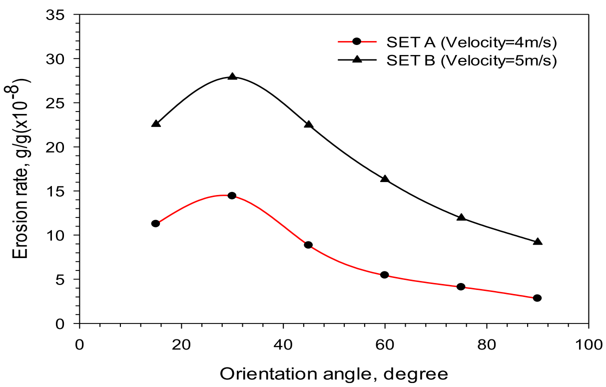

Fig 6. Effect of Particle velocity on erosion wear at different impact angles, Solid concentration=10%, Particle Size=655μm

Impact Angle →	% Change in Erosion wear (Set A & B)					
	15	**30**	**45**	**60**	**75**	**90**
Velocity 4 & 5	**50.102**	**48.320**	**60.695**	**66.624**	**65.625**	**69.281**

Similarly, erosion wear rate increases with increase in particle size keeping the particle velocity and solid particle concentration fixed. But in this case, the increase in wear is marginal as compared to that in particle velocity case. This is evident from the fig.7. As the particle size is increased from 362.5 μm to 655 μm, the wear rate increases for all impact angles. This increase is mainly due to the increase in area of contact between the particle and the sample specimen when the particle size is increased. Increased area of contact between the particle and the sample specimen results in increase in wear. The percentage increase, however, is not of that level as was observed by increase in particle velocity.

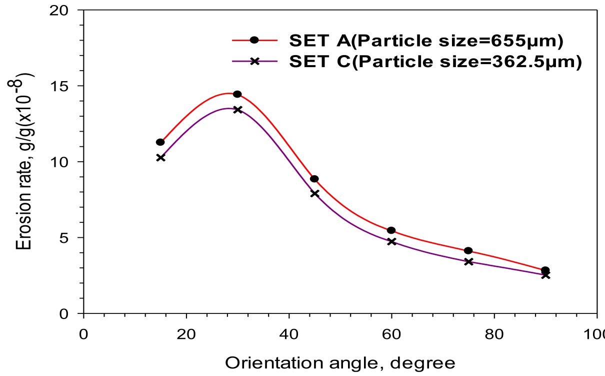

Fig7. Effect of Particle size on erosion wear at different impact angles, Solid concentration=10%, Particle velocity=4m/s

Parties Size ↓	Impact Angle →	% Change in Erosion wear (Set A & C)					
		15	**30**	**45**	**60**	**75**	**90**
655 & 362.5		**8.762**	**6.875**	**10.576**	**13.057**	**17.045**	**10.638**

This trend continues, when the solid particle concentration is increased keeping particle velocity and particle size constant. Erosion of the sample increases when the solid particle concentration is increased from 10% to 30%. This increase in wear can be due to increased number of inter-particle collisions as the particle density increases due to increased particle concentration.

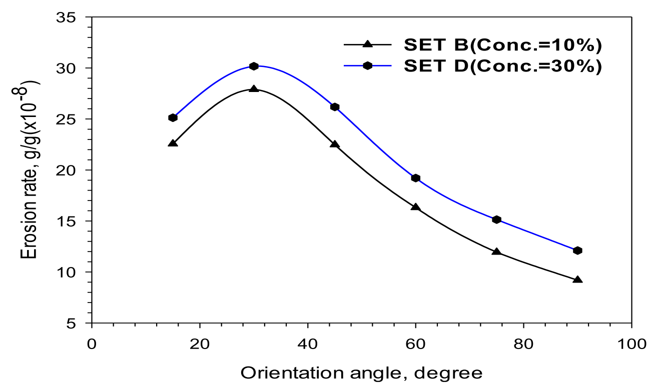

Fig.8 Effect of solid concentration on erosion wear at different impact angles, Particle velocity=5m/s, Particle size= 655 μm

Con. ↓	Impact Angle →	% Change in Erosion wear (Set A & C)					
		15	**30**	**45**	**60**	**75**	**90**
10% & 30%		**10.181**	**7.535**	**14.141**	**15.079**	**21.09**	**24.01**

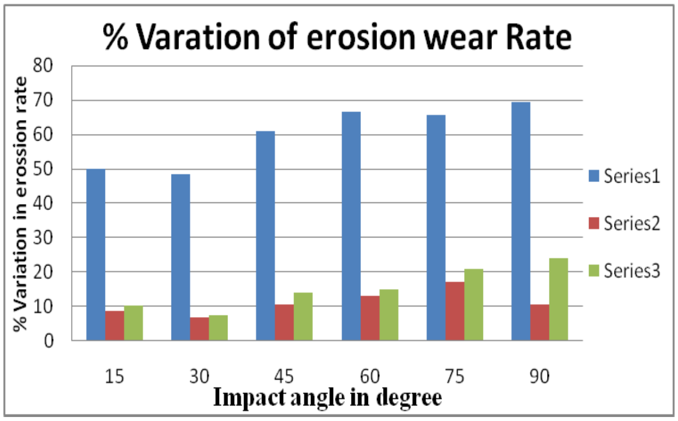

Fig 9: % Variation in erosion wear rate for different parameters

Fig.9 shows three series 1,2 and 3 namely for velocity, particle size and solid particle concentration respectively. Series 1 shows the effect of velocity on erosion wear rate for Set A and Set B. Series 2 shows the effect of particle size on erosion wear rate for Set A and Set C. Series 3 shows the effect of solid particle concentration on erosion wear rate for Set B and Set D. From the three series, it can be concluded that the particle velocity has the predominant effect on erosion wear rate followed by solid particle concentration and particle size respectively.

5. SURFACE ROUGHNESS ANALYSIS

Fig.10 & Fig.11 show the change in the average roughness values of the test specimens before and after experiments. For set A, the average surface roughness value before and after experiment shows a considerable increase in its value.

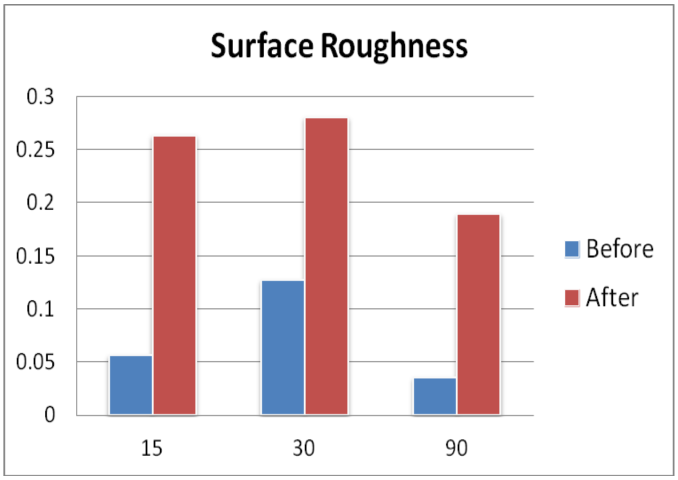

Fig 10: Average surface roughness of Set A before and after experiments .

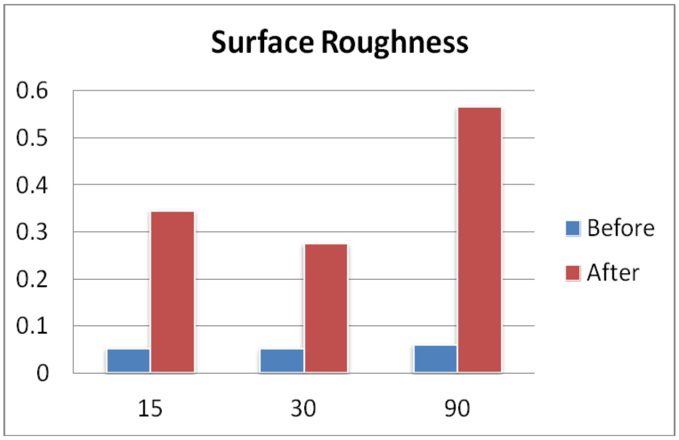

Fig11: Average Surface roughness of Set B before and after experiments.

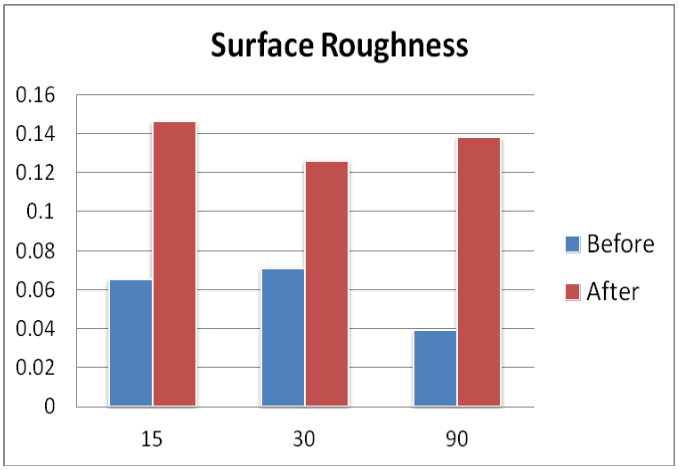

Fig12: Average Surface roughness of Set C before and after experiments

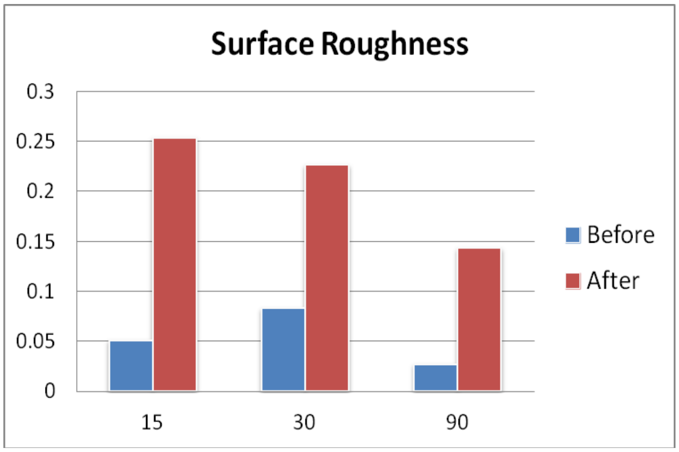

Fig13: Average Surface roughness of Set D before and after experiments

Similar increments in the roughness values of the test specimens for all four sets are observed but with different magnitudes. This indicates the level of surface erosion wear caused during the experiments.

CONCLUSIONS

The effect of particle velocity, particle size and solid concentration are sequentially investigated in this study. From experimental results and data, the following conclusions can be made:

- The erosion wear rate of a material depends predominantly on the particle velocity. As the particle velocity is increased keeping other parameters constant, the erosion of the material almost doubled i.e. it material witnesses a 100% increment in the erosion rate.

- As the solid concentration is increased keeping other parameters constant, erosion wear increases but here the increment is very small as compared to that of the previous case. Here, the erosion rate increases by about 10-12% which is very small as compared to the 100% increment in the previous case.

- Finally, when the particle size is increased keeping the particle velocity and solid concentration constant, the erosion rate increases marginally by about 7 to 8 %.

Hence, it can be concluded that the erosion wear rate of a material is affected by particle velocity the most, followed by solid particle concentration and particle size.

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