Study of the Parameters Affecting Erosion Wear of Ductile Material in Solid-Liquid Mixture

Milind Suryaji Patil, Eknath R. Deore, Ramchandra S. Jahagirdar, Santosh V Patil

Abstract - Erosion wear is recognized as an engineering problem for slurry handling equipments. It plays an important role in design and operation of slurry transportation systems. The present work reports experimental investigations on dependence of erosion wear of Aluminum in sand - water slurry. The aim of present study is to analyze the parametric dependence of erosion wear of Aluminum in sand water suspension. Aluminum has been chosen for target material as representative of ductile material. The effect of various parameters such as impact angle, particle size, velocity and solid concentration on erosion wear of Aluminum has been analyzed. A pot tester is fabricated and special fixtures have been developed to conduct erosion wear tests at various impact angles ranging of from 15° to 90°, in steps of 15°. Experiments have been conducted in the solid concentration (by weight) range of 20 % to 40 % for three narrow - sized particles of 225 µm, 505 µm, and 855 µm in the velocity range of 3.68 m/s to 9.67 m/s. From the data points a correlation were developed which is agreed with the experimental values in an error band of ± 16%

Keywords: Solid-liquid flow; Erosion; Cutting wear; Pot tester

ABBREVIATIONS

A	Surface area of wear piece, *mm^2*
Cv	Solid concentration by volume.
Cw	Weight concentration by volume, Fraction.
d	Particle size, mm.
Ew	Wear rate expressed in terms of loss in wall thickness, mm / year.
N	Function of H_1/H_2
T	Time of run, hrs
V	Velocity of flow, m/s
W	Measured weight loss, g
Wci	Wear, gram of specimen per gram of sand
θ	Angle of impact, degree
ρ	Mass density of wear piece material, g/cc

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I. INTRODUCTION

In the design of slurry transportation system like pipe and pump erosion wear plays an important role. Therefore it is essential to understand the process of erosion. Erosion takes place due to cutting and deformation. Cutting wear is associated with particle velocity parallel to the wear surface where as deformation wear is associated with particle velocity normal to the wear surface. Wear is defined as the progressive volume loss of material from a surface due to abrasion, erosion and corrosion. The volume loss due to corrosion is caused by chemical reactions which can be prevented by adopting suitable measures, whereas abrasion and erosion wear can be minimized by controlling the affecting parameters. Abrasion wear is the loss of material due to passage of hard particles over the surface where as erosion wear is caused by impact of liquid or solid particles on the solid surface. The main cause of the erosion wear is impact. It depends on hard and normally sharp particles for effective wear. [1] Investigators have reported that erosion in slurry pipelines is mainly caused by the cutting action of suspended solid particles as the angle of impact for pipe flow is very small. [2, 3] Experiments were performed by Gandhi et. al. [4] at various solid concentrations, particle sizes and velocities, it shows that the parallel flow wear increases with increase in solid concentration, particle size and velocity. From experimental data Gandhi et. al. also proposed a correlation for parallel flow wear rate as

$$E_w = 2.57 V^{2.56} C_w^{0.83} d^{0.85} \quad (1)$$

Where V is flow velocity ms^{-1}, C_w is solid concentration by weight fraction and d is median diameter of the narrow sized particle, mm. Measured and Predicted results were agreed within uncertainty band of ± 10%. Gupta et. al. [5] from their experimental data has proposed a correlation as

$$E_w = K V^{\alpha} d^{\beta} C_w^{\gamma} \quad (2)$$

where K, α, γ and β are constants whose values depend on the properties of the material of solid particles as well as wear surface. Experimental results and the predicted results were agreed within ± 14% Wellinger determined the erosion as a function of the impact angle for a low carbon steel which is soft and ductile and a hardened high - carbon steel which is brittle. The hard and brittle steel appeared to be more erosion - resistant at low impact angles than the soft steel while at high impact angles the reverse was true. [6] Several studies on erosion wear reported in the literature [3, 5, 7-10] have found the power index for velocity to lie between 2 and 3 for ductile materials. Many researchers [11–14] have also shown that there is a strong dependence of wear on particle size and the power index for particle size varies between 0.6 to 1.2

The aim of the present study is to analyze the parametric dependence of erosion wear of Aluminum in sand - water suspension. Aluminum has been chosen for target material as a representative of ductile materials. Aluminum has been selected as it is expected to give higher wear and thereby resulting in higher accuracy during measurements. The effect of various parameters namely impact angle, particle size, velocity and solid concentration on erosion wear of Aluminum has been analyzed. This has been achieved by conducting experiments in a pot tester to generate the data at an accelerated rate. Silica sand has been chosen as the solid material for the preparation of slurry because of its high abrasivity and low attrition rate

II. EXPERIMENTAL SETUP

A pot tester of 6.6 liter capacity similar to one used by Desale et. al. (2001) has been fabricated and used in the present study. Fig. 2.1 gives the schematic diagram of the pot tester with dimensional details. Slurry is kept in suspension by a propeller rotated through a steel shaft having a diameter of 12 mm. The propeller is attached to the shaft at its bottom. A brass sleeve of 84 mm length and inner diameter 12 mm is provided with the provision of fixing four horizontal arms to hold two test fixtures at diametrically opposite ends. The cylindrical Aluminium pot has diameter of 245 mm and height of 150 mm. Four U-shaped baffles are provided at wall of cylindrical pot at equal distance to break the vortex motion produced due to rotation of the propeller. A 12 mm thick transparent acrylic sheet is provided to cover the pot which allowed visual observations. The shaft is held in position by two bearings placed at a distance over the cover of the cylindrical pot. The shaft is coupled to the chuck of a drilling machine.

Fig 2.1 6.6 Litre Capacity Pot Tester

A. *Test Fixture*

Special test fixtures have been designed and fabricated to fix Aluminium wear test pieces. A slot is provided at the center of the test fixture to fix the wear test piece inside it leaving around 2 mm surface at all sides. Provision has also been made to orient the wear test pieces at desired angle of impact with the suspension of solid-liquid mixture in the pot. The impact angle can be varied between 0° to 90°, in the steps of 15°. The fixtures are made of high chromium high carbon steel and heat treated properly to achieve a hardness of approximately 65 (Rockwell Scale - C).

Each test fixture is fabricated to have a 2 mm deep groove of size 40 mm X 5 mm. A notch having thickness of 1 mm and width of 2.5 mm is provided in each fixture to fix the wear test pieces at the desired impact angle with the help of slotted angular plate. The slotted angular plate is attached with the upper flat arm. A fixture was held between the upper and lower flat arms with the help of screws. The arrangement showed allowed the flexibility of fixing the fixtures at any angle in the range of 0° to 90° (in steps of 15°) to the tangential direction of rotation. Provision was made to fix only two fixtures at 180° apart to minimize the wake interference effect. The inside details of the pot tester is shown photographically in Fig 2.2.

Fig. 2.2 Inside Details of Pot Tester

B. *Test Specimen*

Aluminium being a ductile material has been chosen as the wear test piece material for the present study. The specific gravity of Aluminium is 2.7g/cc. The size of the wear piece used was 40 mm x 4 mm of thickness 2 mm (surface are 157 mm^2) to fit in the slot of the fixture. Each wear test piece was fixed in the test fixture groove with the help of glue. The wear pieces were polished using 1000 number emery paper and cloth before conducting the experiment to ensure identical initial conditions for each set of data.

C. *Particle Size*

Measurement of particle size distribution is essential to establish the variation in the particles in the solid sample and the percentage of particles present in different size ranges. For the coarser particles, sieve analysis can be used to determine the particle size distribution. This distribution has been obtained by dry sieve analysis method. A representative sample of the solid particle is taken and sieving is done with a set of sieves. Special care is taken to ensure that the sample is properly dried. The sample retained on each sieve is collected and its percentage is calculated following the standard procedure.

D. *Specific Gravity*

Specific gravity is an important property of solid material. It is useful in estimation of settling characteristics of the slurry. The density of solid particles was determined using standard Pycnometer method. The specific gravity of sand used in the present work is measured as 2.68 gm/cc

E. *Range of Parameters*

The present study has been carried out to evaluate erosion wear of Aluminium in the mixture of sand-water. The wear tests have been carried out with the three equi-

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sized sand particles of 225 µm, 505 µm, and 855 µm. These are the mean size of particles obtained between two successive sieves of -150 µm, + 300 µm, -300 µm, + 710, and -710 µm, + 1000 µm. The ranges of parameters investigated are given in the table 2.1. The experiments for equi-sized particles of 225µm and 855 µm, were conducted at six impact angles between 15° to 90° at 3.68 m/s velocity using 20% weight concentration slurry. For the medium particle size (505 µm) slurry, the experiments have been carried out at six impact angles ranging from 15° to 90^0 for 20% solid concentration (by weight) and 3.68 m/s velocity. This slurry was also used analyze the effect of solid concentration and velocity in erosion wear. For this purpose, tests were conducted at five impact angles in the range of 15° to 75° at 3.68 m/s velocity for two more solid concentration (by weight) of 30 % & 40 %. The velocity effect has been studied by conducting experiments at 20 % solid concentration (by weight) at 30° & 45° impact angles for the velocities of 5.46 m/s, 6.91 m /s and 9.67 m/s respectively .

Table 2.1 Range of Parmeters

Sr. No	Impact Angle (Degree)	Mean Particle Size (µm)	Solid Concentration % by weight	Velocity m /sec
1	15 to 90 (6 angles)	225	20	3.68
2	15 to 90 (6 angles)	505	20	3.68
3	15 to 90 (6 angles)	855	20	3.68
4	15 to 75 (5 angles)	505	30 to 40	3..68
5	30 and 45	505	20	5.46, 6.91, 9.67

III. RESULTS AND DISCUSSION

A. Effect of Impact Angle

One of the most important characteristics of erosion is the variation of erosion rate with impingement angle. Determining the effect of the impingement angle on erosion is the most sensitive way of studying the mechanism of erosion. The erosion wear of Aluminum wear test pieces measured at 3.68 m/s velocity for sand-water mixture of 20% concentration (by weight) Fig 3.1 shows erosion rate at different impact angles for three narrow size particles of 225 µm, 505 µm, and 855 µm. It is seen that the erosion rate for 225 µm, size particle is 16.33 mm/year at 15^0 impact angle which increases with increase in impact angle reaching to a maximum of 28.41 mm/year at 45° impact angle and then decreases to 12.91 mm/year for further increase in the impact angle to 90°. Similar behavior is seen for other two particle sizes. The erosion rate in mm/year for 505 µm and 855 µm size particles at 15°, 30°, 45°, 60°and 75° impact angles are 29.44, 53.21, 88.34, 51.14, 32.54 and 128.12, 136.90, 161.6, 122.65, 113.14 respectively. It is seen from fig. 3.1 that the erosion wear for all the three particle sizes increases with increase in impact angle till 45° attaining a maximum rate and decreases with further increase in impact angle at 90°.

The increase in weight loss is gradual from 0° to 45° and then decreases up to 90°. The rate of increase from 0° to 45° being more than the rate of decrease from 45° to 90°.

B. Effect of Particle Size

It is seen that the erosion rate increases with increase in particle size at all impact angles (Fig. 3.2). To further investigate the dependence of erosion rate on particle size, the variation of erosion rate with particle size is presented in Fig. 3.2 for six impact angles of 15°, 30°, 45°, 75°, 60° and 90°.

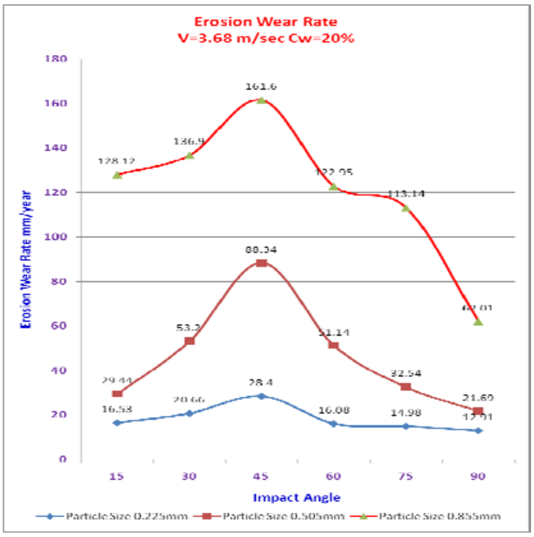

Fig 3.1 Effect of Impact Angle on Erosion Wear Rate in mm/year

It is seen that the erosion rate increases linearly with increase in particle size at all the six impact angles. It is seen that the rate of increase in erosion with increase in particle size is maximum at 90° impact angle. Lin and Saho (1991) also reported variation in dependence of erosion rate on particle size at different impact angles. They concluded that erosion rate increases with increase in particle size. The increase in erosion wear with particle size has also been reported in the literature (Elkholy 1983) and he is reported, the value of power index for particle sized to be 0.0616.

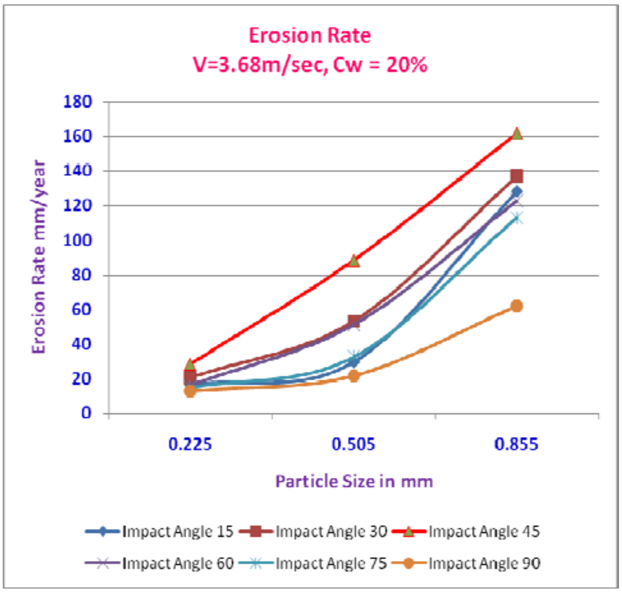

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Fig 3.2 Effect of Particle Size on Erosion Wear Rate in mm/year

C. Effect of Solid Concentration

The erosion wear of Aluminum in sand-water mixture has also been measured at few selected impact angles for 30% and 40% weight concentration at 3.68 m/s velocity for medium narrow size particles of 505 µm. The comparison of erosion wear data at six impact angles of 15°, 30°, 45°, 60°, 75° and 90° for 505 µm size particles at 20% weight concentration and 30 % and 40 % weight concentrations Fig 3.3 shows that the erosion rate has increased with increase in solid concentration. It is seen from Fig 3.3 that the increase in erosion rate with solid concentration is non-linear and show a diminishing rate of increase in erosion rate with increasing solid concentration.

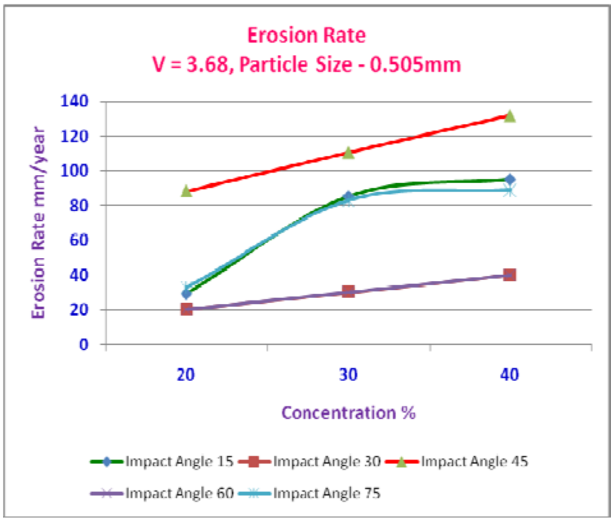

Fig 3.3 Effect of Concentration on Erosion Wear Rate in mm/year

D. Effect of Velocity

It has been reported by many investigators (Elkholy, 1983; Lin and Saho, 1991) that erosion rate depends largely on flow velocity. To investigate the effect of velocity on erosion wear of Aluminum, the weight loss of wear pieces has also been measured at two selected impact angles of 30° and 45°for three additional velocities of 5.46, 6.91 and 9.67 m/s for medium size particle of 505 µm at 20% weight concentration of sand-water mixture as shown in Fig 3.4. The duration of test was reduced at higher velocity to minimize the effect of attribution and rounding-off of particles. At higher velocities, the weight loss in the reduced duration was significant and measurable with the available electronic weighing machine (least count = 0.1 mg.). These data also have been presented graphically in Fig. 3.4.

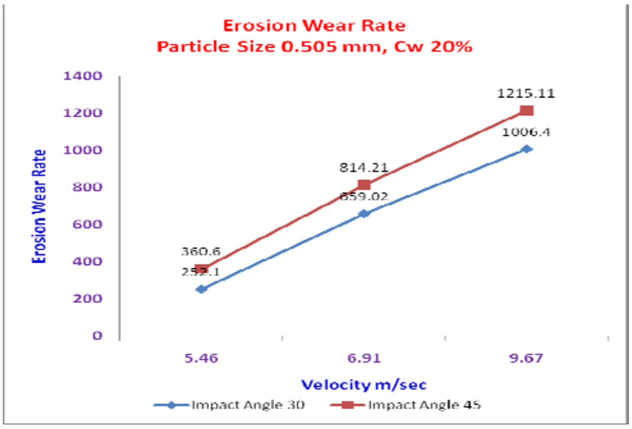

Fig 3.4 Effect of Velocity on Erosion Wear Rate in mm/year

IV. DEVELOPMENT OF CORRELATION

Based on the data points as obtained during the experimentation with regression analysis a correlation were developed with an R^2 value of 0.91. Correlation has an error band of $\pm$ 16%

$$Ew = 0.075\theta^{0.12}Cw^{1.09}V^{3.55}d^{1.37}$$

Where

θ = Impact Angle in Degree

Cw = Concentration by weight in %

V = Velocity in m/sec

D = Particle Size in mm

Fig 4.1 represents the predicted vs experimental data relation ship

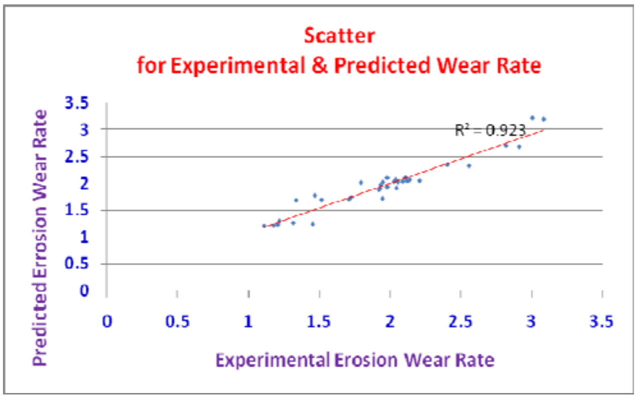

Fig 4.1 Scatter for Experimental & Predicted Erosion Wear Rate in mm/year

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V CONCLUSION

Based on the present experimental investigations in the pot tester for erosion wear of Aluminum using narrow sized sand-water slurry, the following conclusions can be drawn.

1. The erosion wear of Aluminum increases with increase in impact angle attaining a maximum at 45° and then reduces at 90°.
2. Erosion wear of Aluminum increases linearly with increase in particle size. The rate of increase at low impact angles are lower compared to that at higher impact angles.
3. Increase in solid concentration (by weight) increases the erosion wear. The increase in erosion wear at higher solid concentration is not very significant which depict diminishing rate of increase in erosion wear with increasing solid concentration.
4. Velocity has dominant effect on erosion wear. At higher velocities, the weight loss in the reduced duration was significant.

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