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Modelling the wear of Cast Iron due to Solid-Liquid Mixture Using Slurry Jet Erosion Tester

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Abstract: Jet erosion is normally used to study the relative erosion behaviour of different material at moderate solid concentration, velocity, and particle size and impact angle. A slurry pot is then fabricated by inserting propeller from the bottom of the cylinder and is rotated at the speed required for uniform distribution. The test specimens are then mounted on test fixture which is fixed and has a provision to move in different angular position to find out the wear for different angles. Erosion of materials is occurs due to the impact of high velocity of slurry which is comes out from the nozzle and impacting on the test specimen. Different experiments were conducted for repeatability test by using parameters such as particle size distribution, solid-liquid concentration, variable angles (from150 to 900) and time variables. The results were obtained for Cast Iron (brittle material) by using above specified parameters. In this project the experimental results are validates by using Adaptive Neuro Fuzzy Inference System (ANFIS) and Regression analysis. It is observed that the erosion wear prediction of cast iron material with Adaptive Neuro-Fuzzy Inference system (ANFIS) using triangular membership function is better than Regression Analysis.

Keywords: Jet Erosion tester, Nozzle, Slurry erosion, Repeatability, Adaptive Neuro-Fuzzy Inference System, Regression.

I. INTRODUCTION

Wear is defined as the progressive volume loss of material from a target surface. It may occur due to corrosion, abrasion or erosion. The wear due to corrosion is caused by chemical reactions, which can be prevented by adopting suitable measures; whereas the wear due to abrasion and/or erosion can only be minimized by controlling the affecting parameters. Erosion wear is a very crucial parameter for selection and design of slurry transportation systems as it affects directly to the economy of hydraulic conveyance of solids.[1] The service life of equipment handling solid-liquid mixtures is limited due to erosion wear and therefore efforts have been made in past few decades to predict the erosion loss of materials.

Erosion wear is a complex phenomenon, which depends on large number of parameters. Erosive wear is the dominant process which can be defined as the removal of material from a solid surface. It is due to mechanical interaction between the surface and the impinging particles in a liquid stream. In Erosion process there is a transfer of kinetic energy to the surface. With the increase in kinetic energy of the particles impacting at the target surface, it leads to increase in the material loss due to erosion.[2-4]It depends on the predominant impact angle of particle impingement with the material surface and it will vary from150 to900.Impact angle depend on both fluid particle and particle –particle interaction. This type of wear can be practically found in slurry pumps, angled pipe bends, turbines, pipes and pipefitting, nozzles, burner's etc.The material loss due to erosion increases with the increase in kinetic energy of the particles impacting at the target surface. [5]

II. SLURRY EROSION

It is defined as that type of wear, or loss of mass, that is experienced by a material exposed to a stream of slurry. This erosion occurs when the material moves at a certain velocity through the slurry or when the slurry moves past the material at a certain velocity. Slurries erode by the action of abrasive particles in the liquid which results in the failure of the surface of material in one or the other mode depending upon the conditions to which the system is exposed. Slurry erosion is a serious problem for the industries, which deals with the liquids having solid particles entrained in them. When such a mixture of liquid and solid particles termed as slurry come in contact with the machine element, the removal of material takes place from the surface making the component redundant from the surface. [6]

III. PARAMETERS AFFECTING ON EROSION WEAR

The prominent parameters and their effect on erosion wear are as under;

Impact angle:
Impact angle is defined as the angle between the target surface and the direction striking velocity of the solid particle. The rate of mass loss due to erosion is a function of impact angle of particles. The variation of erosion wear with the impact angle is different for brittle and ductile materials. The maximum erosion occurs at 20-30 degrees impact angles for ductile materials. Whereas, the maximum erosion wear occurs at 90 degree impact angle in case of brittle materials. [7]

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Velocity of solid particles:
Velocity of solid particle strongly affects the erosion wear. The impact velocity has dominant effect on the material removal rate. As particle velocity increases there is significant in erosion rate. The erosion rate is generally related to the particle velocity using power law relationship in which the power index for velocity varies in the range of 2-4.

Hardness:
Hardness is the characteristic of a solid material expressing its resistance to permanent deformation. Surface hardness as well as hardness of solid particles has profound effect on the erosion wear mechanism. Hardness ratio has been defined as the ratio of hardness of target material to the hardness of solid particles.

Particle size and shape:
Particle size and shape is also one of the prominent parameter, which affect erosion wear. Many investigators have considered solid particle size important to erosion. The erosion wears increases with increase in particle size according to power law relationship. The effect of particle shape on the erosion is not very well established due to difficulties in defining the different shape features. Generally roundness factor is taken into consideration. If roundness factor is one then the particles are perfectly spheres and a lower values show the particle angularity. [8]

Solid concentration:
Concentration is amount of solid particles by weight or by volume in the fluid. As concentration of particle increases more particles strike the surface of impeller which increase the erosion rate, the concentration of slurries can vary from 2% to 50% depending upon the type of slurry. However, at very high concentrations particle interaction increases and this decreases the striking velocity of particle on the surface. [9]

IV. EXPERIMENTAL SET UP

Fig.1 Photograph of jet erosion tester

Description of Jet erosion Tester:

This test rig consist of important part namely as slurry pot. This pot has 7.3 lit capacities similar to one which were developed by Desale, et.al (2005).the function of this pot is to prepare homogeneous mixture of Narmada sand and water for different particle sizes and different concentrations.

To prepare the homogeneous mixtures of different combinations the pot has a stirrer which is to be rotated with the help of 3phase A.C. motor has maximum capacity of 1440 rpm. Rotational speed of a motor is controlled with the help of 3 phase dimmer stat (Transformer).This test rig also contains a centrifugal pump of 0.5Hp capacity made by Kirloskar Pumps. This pump sucks the slurry from slurry pot and supply the high pressure slurry to the converging section of the nozzle having 10 mm diameter where its pressure energy is converted into the velocity of fluid.

There is one control valve also attached to control the mass flow rate of the mixture. It also has a specimen holder (Fixture), which has an arrangement to moves in different angular positions. One tin hopper is also attached to rig which is help to restrict the spreading of mixture into the work environment.

This hopper collects the mixture after impacting on the specimen and drops it back into the slurry pot to recirculate the mixture. There is one acrylic plate which covers the slurry pot and gives support to the hopper or holds the hopper; it has holes on it for the hopper opening to put back the mixture in to the slurry pot. And the main part of the test rig is the frame structure which supports or holds the whole assembly and stirrer motor.

V. PARTICLE SIZE DISTRIBUTION

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.

The particles of IS sand is selected as solid material for the present investigation and its physical properties are given in Table 1. It is not possible to collect identical size particles of the solid material. The particles are, therefore, sieved using successive sieves sizes and the particles collected between two successive sieves are designated by the mean sieve size.

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TABLE 1PHYSICAL PROPERTIES OF ERODENT USED

Solid Particle	Chemical Formula	Colour	Sp. Gravity (Kg/m3)	Hardness VHN	Particle Shape
Quartz (IS Sand)	SiO_2	Whitish	2652	1100	Sub Angular

TABLE II ELEMENTAL COMPOSITION OF TARGET MATERIAL USED

Target Material	Element Composition (Wt. %)					
Cast Iron	C	Si	Mg	Cr	Su	Ph
FG220	3.2-3.8	1.8-2.8	0.85	0.08	0.02	0.03

TABLE III RANGE OF PARAMETERS FOR THE INVESTIGATION ON EROSION BEHAVIOUR OF DUCTILE MATERIAL COPPER IS 191

Target Material	Impact angles	Particle Size (μm)	Solid particle	Solid Concentration % by wt.	Time
Cast Iron FG220	15°,30°,45°,60°,75°,90°	450	Quartz (IS sand)	10%	60 min

VI. REGRESSION

Since multiple regression is used to determine the correlation between a criterion variable and a combination of predictor variables, the statistical multiple regression method is applied. It can be used to analyze data from any of the major quantitative research designs such as causal-comparative, correctional, and experimental. This method is also able to handle interval, ordinal, or categorical data and provide estimates both of the magnitude and statistical significance of the relationships between variables Therefore, multiple regression analysis will be useful to predict the criterion variable of material erosion rate via predictor variables such as Angle, Time, Particle size, and solid concentration. In which experiment 48 test reading are conducted with variable time, concentration, angle, and size. [11]

$$Ea = 0.0000163 \times C^{0.28} \times T^{0.29} \times S^{0.81} \times A^{0.42}$$

Where, Ea- Erosion rate of selected material, C—Solid concentration in percentage, T- Time in minute, S- Particle size in micron and A- Angle in degree. New empirical model Eq. (1) is developed for prediction of material erosion rate using Angle, Concentration, Time, particle size. It is observed that the proposed equation establishes relation among input variables and response variable. The average deviation observed in measured value and regression predicted value is 5.50 % at confidence level of 94.5%. This regression prediction model compares with ANFIS prediction model values to verify the accuracy of prediction models.

VII. ADAPTIVE NEURO FUZZY INFERENCE SYSTEM

Adaptive Neuro Fuzzy Inference System (ANFIS) is a fuzzy inference system implemented in the frame work of adaptive networks. Using a given input/output data set, the ANFIS method constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using a back propagation gradient descent and a least-squares type of method. This allows fuzzy systems to learn from the data they are modelling. FIS structure is a network-type structure, which maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs. ANFIS applies two techniques in updating parameters. Forpremise parameters that define membership functions, ANFIS employs gradient descent to fine-tune them. For consequent parameters that define the coefficients of each output equations, ANFIS uses the least-squares method to identify them. This approach is thus called hybrid learning method since it combines the gradient descent method and the least-squares method.

ANFIS modelling process starts by obtaining a data set (input–output data pairs) and dividing it intotraining and testing data sets. The training data set is used to find the initial premise parameters for themembership functions by equally spacing each of the membership functions. A threshold value for the error between the actual and desired output is determined. The consequent parameters are found using the least-squares method. Then an error for each data pair is found. If this error is larger than the threshold value, update the premise parameters using the gradient decent method. The process is terminated when the error becomes less than the threshold value. Then the testing data set is used to compare the model with actual system. A lower threshold value is used if the model does not represent the system Jang (1993).
The adaptive network in the proposed fuzzy inference system was feed forward type. The membership function was Sugeno type triangular shape membership function.

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There are three input membership function for each input and 27 learning rules. The learning weight was set to 1 with linear input / output values and for the defuzzification that is to produce crisp output of the consequent part weighted average scheme was used. For simplicity, we assume the fuzzy inference system under consideration has two inputs X and Y and one output Z. For the first order Sugeno fuzzy model a typical rule with two fuzzy if-then rules can be expressed as:

Rule 1: If (X is A1) and (Y is B1) then (Z1 = p1X + q1Y + r1),
Rule 2: If (X is A2) and (Y is B2) then (Z2 = p2X + q2Y + r2),

Where, X and Y are the inputs, Ai and Bi are the fuzzy sets, Zi (i = 1,2) are the output within the fuzzy region specified by the fuzzy rules, pi, qi and ri are the design parameters that are determined during the training process.[12]

VIII. RESULTS AND DISCUSSION

In this experiment we can conduct 48 readings. The fuzzy inference system was trained up to 100 epochs. The experiment was conducted using Sugeno type fuzzy inference system with 27 rule, triangular membership function of each input parameter, hybrid of least square–gradient descent learning algorithm and linear output.

The analysis of experimental data was conducted on Mat Lab 7.6.0 workstation. The first four columns were treated as input and the last column as output data forthe Fuzzy inference system (FIS).

In which two tables are shown in below. First table shows the experimental readings validates with regression analysis and second table shows the experimental readings validates with Adaptive Neuro Fuzzy Inference System.

TABLE 1 IT SHOWS THE EXPERIMENTAL READINGS VALIDATES WITH REGRESSION ANALYSIS. AND IN BETWEEN ERROR IS SHOWN IN PERCENTAGE.

	Input Parameter				Predicted Erosion		
Sr	Concentration	Time	Size	Angle	Erosion		Error
1	10	60	450	15	0.045	0.045	0.53
2	10	60	450	30	0.057	0.060	5.06
3	10	60	450	45	0.067	0.071	5.98
4	10	60	450	60	0.08	0.080	0.16
5	10	60	450	75	0.095	0.088	7.37
6	10	60	450	90	0.104	0.095	8.65
7	10	90	450	15	0.06	0.050	16.08
8	10	90	450	30	0.072	0.067	6.44
9	10	90	450	45	0.085	0.080	6.04
10	10	90	450	60	0.095	0.090	5.13
11	10	90	450	75	0.105	0.099	5.73
12	10	90	450	90	0.112	0.107	4.59
13	10	60	655	15	0.068	0.061	10.78
14	10	60	655	30	0.08	0.081	1.46
15	10	60	655	45	0.092	0.096	4.61
16	10	60	655	60	0.11	0.109	1.27
17	10	60	655	75	0.129	0.119	7.54
18	10	60	655	90	0.14	0.129	8.03
19	10	90	655	15	0.07	0.068	2.52
20	10	90	655	30	0.082	0.091	11.34
21	10	90	655	45	0.1	0.108	8.25
22	10	90	655	60	0.12	0.122	1.79
23	10	90	655	75	0.14	0.134	4.17
24	10	90	655	90	0.15	0.145	3.44
25	30	60	450	15	0.065	0.061	6.33
26	30	60	450	30	0.08	0.081	1.82
27	30	60	450	45	0.097	0.097	0.43
28	30	60	450	60	0.11	0.109	0.92
29	30	60	450	75	0.13	0.120	7.93
30	30	60	450	90	0.14	0.129	7.7
31	30	90	450	15	0.07	0.068	2.17
32	30	90	450	30	0.088	0.092	4.12

33	30	90	450	45	0.1	0.109	8.63
34	30	90	450	60	0.12	0.123	2.15
35	30	90	450	75	0.138	0.135	2.44
36	30	90	450	90	0.15	0.145	3.1
37	30	60	655	15	0.09	0.083	8.31
38	30	60	655	30	0.11	0.110	0.37
39	30	60	655	45	0.127	0.131	3.07
40	30	60	655	60	0.14	0.148	5.51
41	30	60	655	75	0.179	0.162	9.37
42	30	60	655	90	0.19	0.175	7.82
43	30	90	655	15	0.11	0.093	15.62
44	30	90	655	30	0.13	0.124	4.48
45	30	90	655	45	0.142	0.147	3.69
46	30	90	655	60	0.17	0.166	2.27
47	30	90	655	75	0.2	0.182	8.76
48	30	90	655	90	0.22	0.197	10.46
Average							**5.5089**

TABLE 2 IT SHOWS THE EXPERIMENTAL READINGS VALIDATES WITH ADAPTIVE NEURO FUZZY INFERENCE SYSTEM (ANFIS) AND IN BETWEEN ERROR SHOWN IN PERCENTAGE.

	Input Parameter				Predicted Erosion		
Sr	Concentration	Time	Size	Angle	Erosion		Error
No	%	Min	µm	Degree	Experimental	ANFIS	%
1	10	60	450	75	0.095	0.0921	3.05
2	10	90	450	45	0.085	0.0847	0.35
3	10	60	655	90	0.14	0.149	6.43
4	10	90	655	30	0.082	0.0862	5.12
5	30	60	450	15	0.065	0.0637	2
6	30	90	450	60	0.12	0.118	1.67
7	30	60	655	90	0.19	0.207	8.95
8	30	90	655	60	0.17	0.167	1.76
Average							**3.6662**

IX. CONCLUSIONS

Arrangements in the Jet Erosion Tester have been made to evaluate the effect of impact angle, concentration, velocity, particle size etc. on erosion wear. This design of jet erosion tester is intend to conduct wear tests at moderate solid concentrations and actual flow of velocities to simulate the wear conditions for pipeline, bend, pump etc. and may provide more realistic results. Finally, the contributions of jet erosion wear is find out in the form of weight loss for the series of different impact angles such as 150,300,450,600,750,900at 10% solid concentration of sand for 60 minutes for Brittle materials.

For different angular positions, it is observe that the weight loss is increases as the angle is increases from 15° to 900 the maximum weight loss is occur at 900 angle of impact and it increases as angle is increases from 150 to 900respectively. By completing the validation with ANFIS and Regression analysis. It is observed that the erosion wear of cast iron materialby ANFIS with triangular membership function is 96.34%, with the error of 3.66% and by using Regression analysis is 94.5%, with the error of 5.50%.

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