Optimizations of Process Parameter for Erosion Wear Using Sustainable Machine Learning Approach

Kaushal Kumar1*, Monika Khatkar1, Kriti Sharma2, Ruchika Bhakhar1, Prashant Chaudhary3, N. Sateesh4, G. Ramesh4, Soosan Chhabra5 and K. Maithili6
1School of Engineering and Technology, K.R. Mangalam University Gurugram-122103, Haryana, India
2School of Engineering and Technology, Sushant University, Gurugram-122003, Haryana, India
3Division of Research & Innovation, Uttaranchal University, Dehradun, India, India
4Department of Civil Engineering, GRIET, Bachupally, Hyderabad, Telangana
5Lovely Professional University, Phagwara Punjab, 144001, India
6KG Reddy College of Engineering & Technology, Moinabad, Hyderabad, Telangana

Abstract. Aim of current study is to utilize different sustainable artificial intelligence (AI) tools to check the influence of test factors on erosion wear. Bottom ash is taken as erodent at different solid concentration while brass is considered as base material. The parameters involved are rotational speed (N), solid concentration (CW), and testing time duration (T). According to experimental results and analysis based on different AI tools, it is abundantly found that erosion wear have a significant dependency on parameters such as N, CW, T and the order of maximum erosion was found as N > CW > T. The rate of rotation speed (N) has been identified as the factor that has the greatest impact on the degree to which erosion wear occur. 3D analysis has been conducted for the maximum and minimum erosion wear condition. In order to verify the accuracy, four distinct methods are utilized; nonetheless, the accuracy of the regression analysis has been found more promising when compared to that of the Ridge, lasso and neural network methodologies.

Keywords: Erosion wear; AI; Brass; Accuracy; Regression analysis; Sustainability.

1 INTRODUCTION

When two solid surfaces come into contact with each other, wear occurs as a result of the mechanical deeds that occur between them; this type of wear is referred to as "erosion" wear [1]. Erosion is also the term used to describe the deformation of material (softer from harder one) through mechanical action. Erosion is a serious worry for the equipment used to handle slurry since it can cause leakage and sudden failure of the equipment without any previous

* Corresponding author: kaushal.kumar@krmangalam.edu.in

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notice, both of which can result in costly repairs as well as a loss of production time. The rate of erosion and wear in wetted parts (pipes or pumps, for example) might have an impact on the entire life of the component [2]. As a result, a significant amount of high-quality research is required in order to achieve a fundamental approach to this complex failure mode through the implementation of novel methods in order to reduce the consequences of erosion.

Pipelines are the main infrastructure for the transportation of slurry due to heaving properties like less maintenance and are better for the environment [3]. On the other hand, erosion impact pipelines due to two different mechanisms, including cutting and deformation [4]. During the span of the prior ten years, a number of different laboratory scale tests and setups have been established to study the erosion mechanism [5,6]. According to the findings of some researchers, the process of slurry erosion is determined by a wide variety of characteristics of the erodent (the slurry) as well as the materials that are being eroded, such as the target material's shape, size, velocity, hardness, density, and impact angle, as well as the concentration and viscosity of the slurry [3,7]. Researchers have observed that the concentration of solid material in the slurry has an effect on the rate of erosion [9–11].

Many research projects have been carried out in preparation for the development of a slurry transportation system[12-16]. However, the planning and operation of such pipelines is not yet entirely finished. Because of this, significant testing has been necessary in order to acquire experimental data. This is because an immense number of parameters are involved in the planning and selection of pipeline material [17-19]. Because of its excellent mechanical qualities and resistance to wear, researchers regarded brass to be an acceptable material for pipe construction [20-22]. A substantial amount of research was done on the erosion wear behavior of many slurry pipe line materials; however, there is currently no well-established study accessible for the material brass as a pipeline material with the appropriate design of experimentation (DOE) [23-26].

The primary purpose of this study is to offer specific information regarding the erosion and wear behavior of the material brass under a variety of different parametric conditions using an appropriate design of experimentation (DOE) with higher accuracy.

2 EXPERIMENTAL INVESTIGATION

2.1 Materials
The eroded material that was was used as bottom ash, which was collected from the Rajiv Gandhi thermal power plant at Khedar, Hisar (Haryana). Ash is collected from the bottom of the combustion chamber of the hopper. For the purpose of measuring scanning electron microscopy (SEM) of bottom ash, an Energy Dispersive X-ray spectroscope (Model: JEOL, 6510LV) is utilized. Figure 1 displays the scanning electron micrograph of a sample of bottom ash (a). As a result of the presence of unburned carbon, the particles that make up bottom ash have a rougher texture, an asymmetrical shape, shows darker grey colour, and an uneven surface roughness. In order to investigate the size of the particles that are eroded, a procedure known as particle size distribution (PSD) was carried out with the use of a sieve shaker that had standardized sieves. As indicated in Figure 1, approximately 62.50% of the erodent's particles are coarser than 150 mm, while only 7.40% of the particles are finer than 53 mm (b). Slurry was made out of the mixture of water and bottom ash that was used. For the purpose of determining the erodent material's chemical composition, a Master
Spectrometer is utilized. The erodent contains SiO$_2$ and Al$_2$O$_3$ in majority, however CaO, CuO, MgO shows the presences but in small extent as shown in Figure 1(b).

![Image of erodent particles]

**Fig.1.** (a) Chemical Composition and (b) Particle size distribution (c) Chemical Composition of FA Sample

Brass is used as the basis material, and it is cut into flat pieces with dimensions of 75.10 mm by 25.10 mm by 5.02 mm. These pieces facilitated with a hole drilled in the center of them having a diameter of 5.20 millimetres so that they may be kept in the rotating spindle of the tester. Figure 2 depicts the substrate of the base material along with its geometry and chemical composition. For the purpose of determining the base material's chemical composition, a Master Spectrometer is utilised. The base material contains 63 % copper, 33 % zinc, 2 % tin, and 2 % each of lead, iron, manganese, nickel, aluminium, and silicon, in that order. With the assistance of a micro Vickers hardness tester (Model MVH1, India), we were able to determine that the base material possesses a vicker’s hardness of 228 Hv. The micro hardness tests are performed around three times, and the average value is taken as hardness of the base material. Prior to testing, the roughened surfaces of the brass substrates was providing smoothness by grinding them using emery sheets (grade 100).
2.2 Methods

Experiments have been carried out at three distinct rotational speeds (N = 500, 700, and 900 rpm) at a solid concentration (Cw) range of 30–50% (by weight) for a time duration (T) of 90, 120, and 150 minutes in order to study the erosion wear. The purpose of these experiments is to determine how the wear takes place and what the actual factor responsible for it was. The trials are carried out on a bench-scale device known as an erosion wear pot tester (1.8 L, manufactured by Ducom in India), as described in reference [11]. The synchronised motor, spindle, specimen holder, jack, and pot are all components of the testing device. The specimen is held securely in place by the holder that is attached to the spindle. Adjusting the position of the pot requires the use of a screw jack. The tester's pot has a larger cup on the bottom with a smaller cylindrical cup positioned on top of it. Slurry is poured into the larger cup. The rate of erosion and wear can be expressed as a mass loss in grammes per square metre. For the purpose of determining how much mass has been lost, an electronic weighing equipment with a minimum count of 1 104 g is utilized.

Table 1: General presentation of factors with their levels

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>rpm</td>
<td>500</td>
<td>700</td>
<td>900</td>
</tr>
<tr>
<td>Cw</td>
<td>% by weight</td>
<td>30</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>T</td>
<td>min</td>
<td>90</td>
<td>120</td>
<td>150</td>
</tr>
</tbody>
</table>

Artificial intelligence is an important tool to solve the complexity of the system. In this research four different artificial tools has been used to check the influence of process parameter on the erosion wear characteristics of brass. Four different algorithms has been used to check the accuracy of model and the influence on the process parameters. Four algorithms named as Linear Regression (LR), Neural Network (NN), Lesso (L), Ridge (R). The variables are categorized in two different category named as dependent and independent. Variables like rotational speed, solid concentration and time duration are considered as the independent variable, while the erosion wear has been considered as dependent variable. The independent variables have been taken for three levels while the range and factors are showing in Table 1. In order to measure the erosion wear, pot tester
has been used for each and every sample of brass with different set of independent variables. Python 3.16 has been used to check the accuracy of the different used algorithms in this study. The system configuration for the analysis is Acer Predator Helios 300PH 315-53-72E9 Laptop Intel Core i7-10750H (10th Gen) NVIDIA GeForce RTX 2060 16 GB 1 TB HDD+256 GB SSD Windows 10. Also most influencing parameter which is responsible for maximum wear on the base material has been investigated.

3 RESULT AND DISCUSSION

Correlation and confusion metrics are two different statistical measures used to assess the performance and relationship between variables in data analysis. Correlation is a statistical technique that measures the strength and direction of the relationship between two continuous variables. Correlation is useful in determining whether two variables are related and in what direction they are related. In this study we used Pearson correlation method to get the correlation of features. Pearson correlation also known as Pearson's r or simply r, is a statistical measure that assesses the linear relationship between two continuous variables. The coefficient ranges from -1 to 1, where -1 indicates a perfect negative correlation, 0 indicates no correlation, and 1 indicates a perfect positive correlation. So, the relationship between two variables was examined by the Pearson correlation coefficient, the formula is:

\[ r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}} \]

where:
- \( n \) is the number of observations
- \( x \) and \( y \) are the two variables being analysed.
- \( \Sigma xy \) is the sum of the product of \( x \) and \( y \)
- \( \Sigma x \) and \( \Sigma y \) are the sum of \( x \) and \( y \), respectively.
- \( \Sigma x^2 \) and \( \Sigma y^2 \) are the sum of the squared values of \( x \) and \( y \), respectively.

The Pearson correlation method assumes that both variables are normally distributed and have a linear relationship. Confusion metrics, on the other hand, are used in the field of machine learning to evaluate the performance of a classification model. A confusion matrix is a table that summarizes the performance of a binary classification algorithm. The matrix contains four terms: true positives (TP), false positives (FP), true negatives (TN), and false negatives (FN). These metrics are used to evaluate the accuracy, precision, recall, and F1 score of a classification model. The confusion matrix with respect to varying parameters has been showing in Fig. 3. Here relationship between N and \( E_w \), value 0.89 shows high dependency on each other, means both are highly correlated and we cannot ignore any one of them. Relationship value of T and \( E_w \) is 0.26 means erosion loss is lesser dependency on these features. By checking the confusion metric, \( E_w \) is less dependent on T as compared to other features, but ignoring this feature can be harmful as T might impact the overall performance of process. Now the data is ready to process with machine learning and artificial Neural Network techniques.
3.1 Visual analysis of eroded parts

Scanning electron microscopy (SEM) and three-dimensional surface mapping were both utilised in this study to investigate the surface morphology of eroded brass specimens. The actual eroded image along with the three-dimensional surface plot of brass specimen is presented in Figure 5 at the following conditions: \( N = 500 \) rpm, \( C_w = 30\% \), and \( T = 90 \) minutes. Figure 6 displays the eroded image together with the 3D surface map of the brass specimen at the conditions of \( C_w = 50\% \), \( T = 120 \) minutes, and \( N = 900 \) rpm. The removal of the more delicate components of the composition is represented by the dark phase of the topography. From the combination of different varying parameters minimum and maximum erosion wear condition are to be used for the 3D analysis. Condition 1 or Figure 5 shows the case of minimum erosion wear while condition 2 or Figure 6 shows maximum erosion wear. It has been discovered that surface wear brought on by micro pores and cutting is the factor that is most responsible for the loss of material. According to the findings of the aforementioned researchers [17–20], the most common
types of erosion wear mechanisms in pipelines are cutting and fracture.

Fig. 5. 3d analysis of eroded part at N=500 rpm, Cw =30% and T=90 min

Fig. 6. 3d analysis of eroded part at N=900 rpm, Cw =50% and T=120 min

3.2 Accuracy of model

In order to check the accuracy of the algorithms applied for the experimental results, an comparative analysis has been conducted among the different algorithms like Linear regression (LR), Ridge (R), Lesso (L) and Neural network (NN). All the algorithms shows good agreements with the findings from the experimental result and Minimum accuracy was found as 89% while maximum accuracy was considered as 93%. LR has maximum accuracy while Ridge has minimum accuracy. The order of accuracy is LR>L>NN> R and having the values 93>92>90>89% respectively. The models shows that more accuracy was also needed may be during the experimentation or may be due to some other factors responsible for the erosion wear. But it is clear that all three varying parameters are responsible for erosion wear and no one can be eliminate and any of the above mentioned algorithms could be used for further investigations. Researchers also reported different type of approaches by using the artificial intelligence in erosion wear measuring technique, risk evaluation factors and pipeline failure [21,23,25, 27-32].
4 CONCLUSION

Experiments have been carried out in order to determine the impact that N, C_w, and T have on the eroding and wearing of brass material. Based on experimental results the AI algorithms have been checked in terms of accuracy. According to the findings of the existing research:

- Maximum erosion wear was observed at N=900 rpm, C_w =50% and T=120 min. While minimum erosion wear was observed at N=500 rpm, C_w =30% and T=90 min
- The erosion wear rate (E_w) goes up when the rotational speed (N), the solid concentration (C_w), and the time period (T) are increased. In contrast to C_w and T, however, N is regarded as the element with the greatest pronunciability.
- The 3D analysis provides additional support for the testing by demonstrating that rotational speed (N) is the most significant factor when compared to C_w and T. This was clearly seen to be in the case of maximum and minimum erosion wear.
- AI tools reported that all the parameters have close relationship with each other in order to increase the wear rate. So During optimization of process parameters or design of experimentation none can eliminate.

Linear regression has been found as most accurate algorithm as compared to ridge, lesso and neural network. However lesso considered as good agreements with the accuracy of Linear regression model

References


