Prediction of corrosion behaviour of reinforced concrete with manufactured sand using artificial neural network

B Vijaya¹ and S SenthilSelvan²
¹Assistant Professor, Dr.M.G.R Educational and Research Institute, Chennai, India
²Professor, Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, Tamilnadu, India

Abstract. The present study focuses on evaluating the corrosion performance characteristics of steel embedded in concrete, in which Manufactured Sand (M-Sand) is utilized as a fractional and full replacement for natural sand. Corrosion characteristics of steel that is fixed in concrete are analysed by accelerated corrosion test for M40 grade concrete supplanted with 60% manufactured sand for river sand which is found optimum. The modelling of corrosion currents is done using feed forward Artificial Neural Network. The test results exhibits that the durability property of concrete against the effect of corrosion is enhanced, by the partial substitution of 60% M-Sand. Accurate modelling results for corrosion currents was obtained using Artificial Neural Network (ANN). The test results exhibits that ANN structures produced close prediction current values to that of experimental results.

1. Introduction
Corrosion in reinforcement has been described as the primary corrosion mechanism for reinforced concrete buildings, which has a serious impact on structural serviceability and health. Inclusion of steel in concrete structures requires more careful design methodology to prevent processes of corrosion. Akshatha Shetty et al (2012) studied the performance of rebar in accelerated corrosion test. It was concluded that PPC performs better compared to OPC in accelerated rebar corrosion test and it was found that CTD steel showed higher gravimetric loss when compared with MS and TMT steel [1]. AM al-swaidani et al (2015) proposed the incorporation of pozzolan in concrete subjected to corrosion. In this experimental investigation, it was proved that rebar corrosion decelerated with the addition of pozzolan-based cement. It was likewise presumed that utilization of pozzolan at 30% cement substitution builds the administration life of RC structures twice or thrice when compared with control concrete. It was also concluded that pozzolan can be used up to 30% as a partial replacement for OPC and the corrosion resistance property is also enhanced by this partial replacement [2]. Thirumalai Parthiban et al.(2005) concluded that ANN enables the calculation of potential data involved in accelerated corrosion test and the results obtained from ANN analysis were in close agreement with the experimentally obtained potential data [3]. Sanjeev K. Verma et al. (2014) studied that ANN tools used for data processing in the field of durability study, proved to be very efficient when compared with simple regression analysis obtained from the experimental data. Modelling the non-linear behaviour of the corrosion current data in time domain is a difficult process [4]. Devi M (2014) recommended that the inclusion of fibres, fly slag and quarry dust in concrete. It was demonstrated that by including fibres, it offers lower penetrability consequently increases the durability and corrosion obstruction property [5].
Nabeel sheikh and Sheetal sahare (2016), studied the impact of corrosion in reinforced concrete structure. It was concluded that the time consumed for the appearance of first visible crack increases with the increase in concrete cover /diameter ratio for same voltage applied [6]. Mahesh.J et al (2018) studied the corrosion of reinforcement in concrete with M-sand and fly ash. In the experimental investigation 20%, 30% and 40% fly ash replaced concrete samples with the substitution of fine aggregate by manufactured sand concrete are studied. It was concluded that fly ash replaced samples with M-sand showed less corrosion rate when compared with river sand. It was also reported that the M-sand is good as fine aggregate substitution for 30% fly ash replaced concrete samples [7].

2. Experimental Investigation

In order to predict the corrosion resistance, accelerated corrosion test was conducted on concrete specimen to assess the corrosion performance. The Polarization experiment set up is shown in the figure 1.

![Figure 1. Polarization experiment under progress.](image)

![Figure 2. Polarization Graph for M40 grade concrete.](image)

The rebar at the centre acts as the anode and the stainless steel plate placed around the rebar acts as the cathode and are connected to a DC power pack of 5.0 Volt. Figure 2, shows the polarization graph for M40 grade concrete.
From the figure.2, it is clear that the time for depassivation (i.e. the initiation time) for M40 conventional concrete is 11 days, when compared with 60% replaced M-sand concrete it is 14 days. From the graphs it was observed that the initiation time increases for M40 M-sand concrete. The obtained results are modelled using artificial neural network technique.

3. Preprocessing of data
In this study, the corrosion performance of steel fixed in concrete is investigated. The process involved in the ANN simulation is shown in Figure 3. In ANN process the time interval is fed as input data and the corrosion current is the output data [8]. The training and testing process involved is shown in figure 4.

![Network Diagram](image)

**Figure 3.** The process used in the ANN model.

For this analysis, 1 hidden layer with 10 neurons is used. For the training process about 75% of the data are randomly selected and the remaining data are selected for testing process. MATLAB is the software developed for the training and testing of data.

![Graphs](image)

**Figure 4.** Training and testing data for ANN model.  
**Figure 5.** Experimental and predicted train data.
Figure 4. shows the correlation between time index and corrosion current obtained from ANN analysis. From the Figure 4, it is clear that there exists a good correlation between the trained and tested data of corrosion current and both the data forms a similar curve pattern with the best fit.

Figure 5 explains the relationship between the predicted and experimental train data. From the figure 5 it is clear that the predicted values of corrosion currents for different time index were nearly same as that of experimental values. The fitting between the experimental values and predicted values are considerably high and hence the predictions made correlated well with the experimentally observed behaviour. In this process Levenberg-Marquardt algorithm of back propagation is used [8]. The results of r Train, r Test, MAPE and RMSE are tabulated in Table 1. The results of training and validation, neural network training process and the training and testing performance for M40 grade concrete is shown in figure 6, 7 and 8 respectively.

Table 1. Results of error analysis parameters showing the performances of ANN.

| SI.No | Concrete Grade       | r Train | r Test | MAPE Train | MAPE Test | RMSE Train (x10^-4) | RMSE Test (x10^-4) |
|-------|----------------------|---------|--------|------------|-----------|---------------------|-------------------|
| 1     | M40 (Conventional)   | 0.9520  | 0.9190 | 0.6880     | 0.6920    | 8.67                | 8.79              |
| 2     | M40 (M-sand 60% )    | 0.9250  | 0.9160 | 0.6120     | 0.6450    | 6.12                | 6.34              |

From the Table 1 it is clear that the error analysis results of ANN obtained for M40 M-sand concrete showed less error values when compared with M40 conventional concrete.

The equation for training and testing is given below.

\[ Y = X + (3.71 \times 10^{-5}) , R^2 = 0.9990 \] for ANN Training

\[ Y = X - 0.000279 \] , \( R^2 = 0.9988 \) for ANN Testing

![Figure 6. Results of training and validation for M40 grade concrete.](image)

Figure 6 depicts how the minimum error was obtained during the training process with respect to the testing and validation. The best validation performance was reached at the 4 epochs. The results of validation shows that the mean squared error of training and testing function converges at the 4 epoch.
From the Figure 7, the data obtained from the training and testing in the ANN models are very similar to the experimental results. The results show that there exists a good linear fit between the experimental and the ANN output for the training, testing and validation and the R values are nearly equal to 1.

4. Conclusion
This study concludes that the initiation time of corrosion activity decreases with the inclusion of M-sand in concrete and the durability property against the effect of corrosion is enhanced considerably with the addition of M-sand. Depending on the damage occurrence time, it has been observed that the most affirmative results were observed for 60% substitution of M-sand in concrete. In addition, the RMSE, MAPE and $R^2$ statistical values are calculated and compared with the experimental results and ANN model results, showed lower error rate and the accuracy of these models were evaluated. The ANN predictions that were made based on the training and testing pattern were observed to correlate well with the experimentally predicted behaviour. The current required for corrosion are analysed using the ANN modelling. ANN modelling depicted successfully the nonlinear deviation curve for the predicted corrosion currents with respect to time for M40 grade concrete. The obtained results of the training and testing phase shows that the ANN models are capable of generating a good correlation between the input and the output data with best prediction results. From the experimental results obtained it is proved that ANN analysis correlated well with the experimental investigation on the corrosion behaviour. To sum up, it is concluded that ANN proves to be an efficient tool for modelling of corrosion currents.

5. References
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