A novel method to predict pozzolanic nature of concrete with sintered clay using soft computing techniques

R Archana Reddy, A Sivakrishna, R Gobinath and D Ramesh Babu
S R Engineering College, Warangal, India
E-mail: archanareddy.srec@gmail.com

Abstract: This research focuses on studying the effect of different pozzolanic materials (Metakaolin, fly ash, silica ash, micro clay, ordinary clay and their combinations) on strength of concrete cured for a period of time - 56 days. This work primarily deals with the compressive strength and split tensile strength of concrete. First four mixes were made by adding 1-2% of pozzolanic materials in concrete. Next five mixes were made by increasing the percentage of clay and lime as a substitute of cement in concrete. A comparative study is done between experimental data and predicted data. Bountiful research works were done using soft computing tools to predict the strength characteristics of concrete, in this work we had employed Levenberg-Marquardt and Bayesian Regularization approach to predict. ANN is employed to measure the outcome performance of admixtures added while varying the curing period. Best fit models were arrived using back propagation method of ANN, $R^2$ values were obtained in the range of 0.91 showing the effectiveness of the study. It is suggested that this proposed algorithm can be employed to predict the strength characteristics of concrete.

Keywords: ANN, Bayesian regularization, concrete strength, pozzolanic nature

1. INTRODUCTION

Pozzolans are silicate-based materials that react with the hydrated lime generated by hydrating cement to make further building materials. Pozzolans are silicate-based materials that react with the hydrated lime generated by hydrating cement to make further building materials. Hydrated lime accounts for up to twenty-fifth of the hydrous cement, and lime doesn't contribute to the concrete’s strength or durability. Pozzolans mix with the lime to provide further Ca.SO3i.H2O, the material accountable for holding concrete along. By consuming a higher amount of lime, the strength of the concrete is enhanced. Substituting the amount of cement with pozzolans preserves the combination proportions. Pozzolans replace cement by increasing the material consistent with proportion. By consuming the excess lime, the strength of the concrete and density is increased. Efflorescence is decreases and the propensity for alkali-silica reaction (reaction with glass) is decreased or even virtually eliminated. (kulaasuriya et al., 2014). Pozzolans replace cement pound for pound. Depending upon the particle
size, chemical composition, and dosage, different pozzolans will affect the concrete strength differently and at different times during curing [4]. Addition rice husk ash and micro clay to concrete also improve the strength and mechanical properties. The percentage of the material enhances the impermeability of the high performance of concrete [22]. The workability of the concrete increases with the percentage of replacement of cement by clay increase. The Compressive strength of cement mortar specimen has increased after incorporating clay, compression strength reached a maximum at 10%, as it can be concluded that for replacement of cement to raw clay is efficiency [21]. The impact of clay particles in concrete enhances the strength of the concrete. Cement is replaced by 5%, 10%, 15%, and 20% of raw clay [13]. Replacement of cement with lime improved the long term build up strength as compared to cement use alone. This is also considerable for energy savings and cost reductions [9]. Artificially intelligent systems have shown their capability in solving real-life problems; particularly in non-linear tasks. Such tasks are often assigned to an artificial neural network (ANN) model to arbitrate as they mimic the structure and function of a biological brain; albeit at a basic level. Testing through an ANN model to predict and classify the compressive strength of different concrete mixes into low, moderate or high strength [26]. The study reported in this paper employed the use of pozzolanic materials (metakaolin, fly ash, silica ash, micro clay, ordinary clay, and their combinations) in concrete which focuses on strength of the concrete cured for a period of time - 56 days. The comparative study is done on both experimental and predicted data of different combinations.

2. MATERIALS AND METHODS

2.1 Flyash. Fly ash is a coal combustion product that is composed of the particulates. Depending upon the source and composition of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amount of silicon dioxide (SiO\textsubscript{2}) (both amorphous and crystalline), aluminium oxide (Al\textsubscript{2}O\textsubscript{3}) and calcium oxide (CaO), the main mineral compounds in coal-bearing rock strata.

2.2 Metakaolin. Metakaolin is the anhydrous calcined form of the clay mineral kaolinite. Minerals that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles.

2.3 Clay. Clay is a finely-grained natural rock or soil material that combines one or more clay minerals with possible traces of quartz (SiO\textsubscript{2}), metal more oxides (Al\textsubscript{2}O\textsubscript{3}, MgO etc.) and organic matter. Geological clay deposits are mostly composed of phyllosilicate minerals containing variable amounts of water trapped in the mineral structure. Clays are plastic due to particle size and geometry as well as water content, and become hard, brittle and non-plastic upon drying or firing.

2.4 Model development through artificial neural networks. Artificial neural networks (ANN) or connectionist systems are computing systems vaguely inspired by the biological neural networks that constitute animal brains. Different layers may perform different kinds of transformations on their inputs. Signals travel from the first layer (the input layer), to the last layer (the output layer), possibly after traversing the layers multiple times.

2.5 Levenberg-marquardt algorithm. In mathematics and computing, the Levenberg–Marquardt algorithm (LMA or just LM), also known as the damped least-squares (DLS) method, is used to solve non-linear least squares problems. The LMA interpolates between the Gauss–Newton
algorithm (GNA) and the method of gradient descent.

2.6 Bayesian regularization. Bayesian regularization is more robust than standard back-propagation nets and can reduce or eliminate the need for lengthy cross-validation. Bayesian regularization is a mathematical process that converts a nonlinear regression into a "well-posed" statistical problem in the manner of a ridge regression. The advantage of Bayesians is that the models are robust and the validation process, which scales as $O(N^2)$ in normal regression methods, such as back propagation, is unnecessary. These networks provide solutions to a number of problems that arise in QSAR modeling, such as choice of model, robustness of model, choice of validation set, size of validation effort, and optimization of network architecture. They are difficult to over train, since evidence procedures provide an objective Bayesian criterion for stopping training.

3. RESULTS AND ANALYSIS

The M30 mix design was used in this study. The ratio of proportions for Class M-30 is 1:1.74:2.71, i.e. cement, fine aggregates and coarse aggregates respectively. The pozzolans quantity used was given as a percentage to the total weight of cement used in every mix. First four mixes were made by adding 1-2% of pozzolanic materials in concrete. Next five mixes were prepared for each with clay and lime content of 5%, 10%, 15%, 20% and 25% of the total weight of the cement. The total weight of the cement.

3.1 Moulding and casting. As it will be seen, the mechanical strength tests are carried out on specimens that are cylinders. Cylindrical specimens shall have a length equal to twice the diameter. The cast concrete specimens were then marked and dated. After 24 hours the specimens were removed from the moulds and immediately submerged in clean fresh water for curing. After 7, 14, 21, 28 and 56 days the specimens were tested using the cube crushing test and tensile test.

3.2 Compressive strength test. Compressive strength test indicates the compressive strength of cement concrete specimens. It is the most common test conducted on hardened concrete as it is an easy test to perform and also most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength. The test was carried out on cylindrical specimens shall have a length equal to twice the diameter at the concrete laboratory according to IS: 516 - 1959. After 7, 14, 21, 28 and 56 days of curing, the cubes were taken out of the curing tank, dried and tested using a compression machine.

Calculation, The compressive strength is given by, $F_c = \frac{P}{A}$

$F_c$ = compressive strength, $P$= crushing load, $A$= surface area of cylinder.

3.2.1 Prediction procedure. The compressive strength of the concrete is predicted for different combinations. The strength that is calculated for various hardening times at 7, 14, 28 and 56 days is given in Figure 2. The regression values for the training data set is found for Levenberg-Marquardt Algorithm is $R^2 = 0.98539$, and for Bayesian, Regularization Algorithm has resulted in a value of 0.91303. For the development of a predictive model, 70% of the data employed for training the model. The very optimal network resulting the best configuration suggests that the model predictions precisely match with the experimental results. With this confidence, the model is validated for the 15% validated data set and 15% testing data set. It was discovered that the validation of regression for L.M is found
to be 0.95146. When the model is checked for the testing data set and found that values for L.M and B.R are 0.90297 and 0.86601, respectively. Once the data of the model is checked entirely, the regression coefficient for the entire data was found to be for L.M is 0.92007 and for B.R is 0.91804 as shown in Figure 3 and Figure 4. Variation of Mean square Error (MSE) against different epochs for the validation of the performance of compressive strength of the concrete using the L.M and B.R approaches, resulting in epoch 4 at 7.9212 and epoch 70 at 0.079386 respectively (See Figure 5 and Figure 6). Based on these results, it can be concluded that L.M algorithm provides the best results. Comparison between compressive strength of predicted and actual experimental values is shown in Figure 7

Table 1. Material contents

| S no | Cement | C.a | F.a | Water | Fly Ash | Metakaolin | Micro Clay | Silica Ash | Clay | Lime |
|------|--------|-----|-----|-------|---------|-------------|------------|------------|------|------|
| 1    | 4.41   | 11.959 | 7.686 | 2     | 0.262   | 0.262       | 0.525      | 0          | 0    | 0    |
| 2    | 4.41   | 11.959 | 7.686 | 2     | 0.262   | 0           | 0.525      | 0.262      | 0    | 0    |
| 3    | 4.41   | 11.959 | 7.686 | 2     | 0.262   | 0.262       | 0.262      | 0.262      | 0    | 0    |
| 4    | 4.41   | 11.959 | 7.686 | 2     | 0.262   | 0.262       | 0.525      | 0.262      | 0    | 0    |
| 5    | 4.19   | 11.959 | 7.686 | 2     | 0       | 0           | 0          | 0          | 0.12 | 0.12 |
| 6    | 3.969  | 11.959 | 7.686 | 2     | 0       | 0           | 0          | 0          | 0.23 | 0.23 |
| 7    | 3.75   | 11.959 | 7.686 | 2     | 0       | 0           | 0          | 0          | 0.34 | 0.34 |
| 8    | 3.52   | 11.959 | 7.686 | 2     | 0       | 0           | 0          | 0          | 0.44 | 0.44 |
| 9    | 3.3    | 11.959 | 7.686 | 2     | 0       | 0           | 0          | 0          | 0.55 | 0.55 |

Figure 1. Compressive strength for all the samples for the 7, 14, 21, 28 and 56 curation days
Figure 2. Scatter plots showing the performance of compressive strength through model prediction (L.M Algorithm) against the experimental values for the training, validation, testing and overall data.

Figure 3. Scatter plots showing the performance of compressive strength through model prediction (B.R. Algorithm) against the experimental values for the training, validation, testing and overall data.
Figure 4. MSE against different Epochs for the validation of the performance of compressive strength of the concrete for the L.M approach

Figure 5. MSE against different Epochs for the validation of the performance of compressive strength of the concrete for the B. R approach

Figure 6. Performance of compressive strength by model against the actual experimental values
3.3 Split tensile strength test.

3.3.1 Experimental procedure. The tensile strength of concrete with pozzolans is obtained by the direct uniaxial tensile test. The Splitting tensile test is used because it is much simpler and less expensive as compared to other sophisticated methods used in the developed countries. The splitting tensile test, also known as the split-cylinder test, is an indirect method to measure the tensile strength in concrete and therefore signifying the relative tensile strength of the concrete with pozzolans. This test is performed in accordance to IS: 5816-1970.

The cylindrical specimen of diameter 101.6mm and height 200mm were used to determine the split tensile strength. Three cylindrical specimens were tested for each percentage of replacement of pozzolans in concrete.

Calculation: Assuming concrete behaves like an elastic body, a uniform lateral tensile stress of \( f_t \) acting along the vertical plane caused failure of the specimen, which was calculated from the formula below as,

\[
f_t = \frac{2P}{\pi DL}
\]

\( f_t \) = split tensile strength, \( P \)=Applied loading at failure, \( L \)=Length of cylinder, \( D \)=Diameter of cylinder

3.3.2 Prediction procedure. The split tensile strength of the concrete is predicted for different combinations. The strength that is calculated for various hardening times at 7, 14, 28 and 56 days is given in Figure 8. The regression values for the training data set is found for Levenberg-Marquardt Algorithm is \( R^2 \)=0.96183, and for Bayesian, Regularization Algorithm has resulted in a value of 0.94949. For the development of a predictive model, 70% of the data employed for training the model. The very optimal network resulting the best configuration suggests that the model predictions precisely match with the experimental results. With this confidence, the model is validated for the 15% validated data set and 15% testing data set. It was discovered that the validation of regression for L.M is found to be 0.99445. When the model is checked for the testing data set and found that values for L.M and B.R are 0.93529 and 0.88856, respectively. Once the data of the model is checked entirely, the regression coefficient for the entire data was found to be for L.M is 0.92235 and for B.R is 0.90712 as shown in Figure 9 and Figure 10. Variation of Mean square Error (MSE) against different epochs for the validation of performance of compressive strength of the concrete using the L.M and B.R approaches, resulting in epoch 2 at 0.010666 and epoch 70 at 0.053077 respectively (See Figure 11 and Figure 12 ). Based on these results, it can be concluded that L.M algorithm provides the best results. Comparison between compressive strength of predicted and actual experimental values is shown in Figure 13.
Figure 7. Split tensile strength for all the samples for the 7, 14, 21, 28 and 56 curation days

Figure 8. Scatter plots showing the performance of split tensile strength through model prediction (L.M Algorithm) against the experimental values for the training, validation, testing and overall data.
Figure 9. Scatter plots showing the performance of split tensile strength through model prediction (B.R. Algorithm) against the experimental values for the training, validation, testing and overall data

Figure 10. MSE against different Epochs for the validation of the performance of split tensile strength of the concrete for the L.M approach
Figure 11. MSE against different Epochs for the validation of the performance of split tensile strength of the concrete for the B. R approach

Figure 12. Performance of split tensile strength by model against the actual experimental values.

4. CONCLUSION

Based on the investigation of the comparative study of experimental data and predicted date the use of an equal amount of pozzolans increases the strength of the concrete. By a gradual increase of clay and lime by replacing the cement decreases the strength of concrete. During the comparative study, variations have observed between experimental values and predicted values.
REFERENCES

[1] Alex, J., Dhanalakshmi, J., and Ambedkar, B. (2016). Experimental investigation on rice husk ash as cement replacement on concrete production. Construction and Building Materials, 127, 353–362.

[2] Bodian, S., Faye, M., Sene, N. A., Sambou, V., Limam, O., and Thiam, A. (2018). Thermomechanical behavior of unfired bricks and fired bricks made from a mixture of clay soil and laterite. Journal of Building Engineering, 18, 172–179.

[3] Cheng, Y., Wang, S., Li, J., Huang, X., Li, C., and Wu, J. (2018). Engineering and mineralogical properties of stabilized expansive soil compositing lime and natural pozzolans. Construction and Building Materials, 187, 1031–1038.

[4] Dinakar, P., Pradosh, K. S., and Sriram, G. (2013). Effect of Metakaolin Content on the Properties of High Strength Concrete, International Journal of Concrete Structures and Materials, 7(3), 215-223.

[5] Fan, Y., Zhang, S., Wang, Q., and Shah, S. P. (2015). Effects of nano-kaolinite clay on the freeze–thaw resistance of concrete. Cement and Concrete Composites, 62, 1–12.

[6] Firdous, R., Stephan, D., and Djobo, J. N. Y. (2018). Natural pozzolan based geopolymers: A review on mechanical, microstructural and durability characteristics. Construction and Building Materials, 190, 1251–1263.

[7] Gaston Espinoza-Hijazin; Álvaro Paul and Mauricio Lopez, Ph.D. e. a. .., 2012. Concrete Containing Natural Pozzolans : new challenges for internal curing. journal of materials in civil engineering, 24(8), pp. 981-988.

[8] Grist, E. R., Paine, K. A., Heath, A., Norman, J., and Pinder, H. (2015). Structural and durability properties of hydraulic lime–pozzolan concretes. Cement and Concrete Composites, 62, 212–223.

[9] Gulbe, L., Vitina, I., and Setina, J. (2017). The Influence of Cement on Properties of Lime Mortars. Procedia Engineering, 172, 325–332.

[10] Hefni, Y., Zaher, Y. A. E., and Wahab, M. A. (2018). Influence of activation of fly ash on the mechanical properties of concrete. Construction and Building Materials, 172, 728–734.

[11] Helson, O., Beaucour, A.-L., Eslami, J., Noumowe, A., and Gotteland, P. (2017). Physical and mechanical properties of soilcement mixtures: Soil clay content and formulation parameters. Construction and Building Materials, 131, 775–783.

[12] Huang, H., Gao, X., Wang, H., and Ye, H. (2017). Influence of rice husk ash on strength and permeability of ultra-high performance concrete. Construction and Building Materials, 149, 621–628

[13] Kaleeswari.G, Dr.Dhanalakshmi.G ,and, Manikandan.N (2016).Clay as a Partial Replacement of Cementitious Material in Cement International Journal of Advanced Research in Biology Engineering Science and Technology (IJARBEST), 2(3), 91-96

[14] Khan, R., Jabbar, A., Ahmad, I., Khan, W., Khan, A. N., and Mirza, J. (2012). Reduction in environmental problems using rice-husk ash in concrete. Construction and Building Materials, 30, 360–365.

[15] Khashman, A., and Akpinar, P. (2017). Non-Destructive Prediction of Concrete Compressive Strength Using Neural Networks, Procedia Computer Science, 108, 2358–2362

[16] Kulasuriya, C., Vimonsatit, V., Dias, W., and Silva, P. D. (2014). Design and development of Alkali Pozzolan Cement (APC). Construction and Building Materials, 68, 426–433.

[17] Marthong, C., and Agrawal, T. P.(2012). Effect of Fly Ash Additive on Concrete Properties, International Journal of Engineering Research and Applications, 2(4), 1986-1991.

[18] Naderpour, H., Rafiean, A. H., and Fakharian, P. (2018). Compressive strength prediction of environmentally friendly concrete using artificial neural networks. Journal of Building Engineering, 16, 213–219.

[19] Nassif, H. H., Najm, H., and Suksawang, N. (2005). Effect of pozzolanic materials and curing
methods on the elastic modulus of HPC. Cement and Concrete Composites, 27(6), 661–670

[20] Norvell, J. K., Stewart, J. G., Juenger, M. C., & Fowler, D. W. (2007). Influence of Clays and Clay-Sized Particles on Concrete Performance. Journal of Materials in Civil Engineering, 19(12), 1053–1059.

[21] Otoko, G. R. and Ephraim M. E. (2014) USE OF BUILDING CLAY IN CONCRETE International Journal of Engineering and Technology Research 2(2), 1 – 8.

[22] Olutoge, F. A., & Adesina, P. A. (2019). Effects of rice husk ash prepared from charcoal-powered incinerator on the strength and durability properties of concrete.

[23] Poornima.E., Meenakshi.N, Gopalsamy.P, and Yasararafath.N.(2017). An experimental investigation of concrete of partial replacement of cement by using metakaolin. International research journal of engineering and technology (irjet), 4(6), 2286-2289.

[24] Patil .B.B., and P. D. Kumbhar. (2012) Strength and Durability Properties of High Performance Concrete incorporating High Reactivity Metakaolin. International Journal of Modern Engineering Research (IJMER), 2(3), 1099-1104

[25] Dr.Rajamanaya. V.S., and kulakarni. N. K. (2015). STRENGTH PROPERTIES OF META KAOLIN & FLY ASH PLANE CEMENT CONCRETE International Research Journal of Engineering and Technology (IRJET), 2(9), 115-119

[26] Sarıdemir, M. (2009). Predicting the compressive strength of mortars containing metakaolin by artificial neural networks and fuzzy logic. Advances in Engineering Software, 40(9), 920–927

[27] Sitpalan, A., Ananda, E.M.S., Aashik .A.R., Preththiha, V., Rajitha, V.K.M., and Suventhiran, S.(2018). Feasibility of Natural Clay Additives in Cement Mortar, Journal of Pure and Applied Physics, 6(1), 1-7.

[28] Srinivasu, K., KrishnaSai, M. L. N., and VenkataSairam, k. N. (2014). A Review on Use of Metakaolin in Cement Mortar and Concrete. International Journal of Innovative Research in Science, Engineering and Technology, 3(7), 14697-14701.

[29] Twubahimana. j. d. and mbereyaho. L. (2013). Impact of clay particles on concrete compressive strength, International Research Journal on Engineering, 1(2), pp. 049-056, International Research Journal on Engineering Vol. 1(2), pp. 049-056, December, 2013 Available online at http://www.apexjournal.org ©2013 Apex Journal International