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Concrete Strength Prediction Using Machine Learning Algorithms: Survey

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ABSTRACT
Concrete quality is determined by its compressive strength, which is considered the most important factor in civil engineering. Compressive strength is influenced by input variables like water content, concrete age, temperature, humidity, and the type of concrete being used. Identifying the strength of concrete can be very challenging and time-consuming, since it involves a lot of inputs and laboratory work. Therefore, AI models have been introduced to overcome these challenges as another approach to predicting concrete's compressive strength and other properties. Machine learning and deep learning techniques include artificial neural networks, random forests, and LSTMs. There has been a survey of various works and method systems, along with an analysis of the factors. Each article's results and principal issues are discussed and analyzed in this paper.
Keywords: *Compressive strength, ensemble technique, machine learning, artificial neural network, fuzzy logic, random forest, HPC, lightweight concrete.*

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I. INTRODUCTION

Concrete is primarily composed of sand, cement, and aggregate. A concrete's strength depends on a number of variables, including the specific compressive strengths of its constituent components (cement, sand, and aggregates), the caulking procedures, the water-cement ratio, and the amount of air entrainment mixture. An evaluation of concrete mixture effectiveness is based on its compressive strength. Concrete's ability to endure loads that impact its size can be determined primarily by this feature. By evaluating specific mixes, it is possible to determine whether they are appropriate for a particular project. Concrete is capable of resisting compression loads. As a result of its remarkable ability to withstand compressive loads, concrete is an ideal material for building arches, columns, dams, foundations, and tunnel linings. In order to measure the material's compressive strength, cylindrical specimens of fresh concrete are used. After that, it is tested for compression at various ages. It is also possible for the stated strength to vary according to the size and form of the product. Other tests are also conducted to gather comprehensive data on strength growth competency. Even alien elements have been known to occasionally enter the mixture, weakening it. Therefore, removing the irrelevant components and paying attention to the important ones is a crucial first step in reaching the necessary strength. A thorough inspection also ensures that there are no changes that could weaken the concrete.

The development of artificial intelligence in numerous civil engineering approaches during the past ten years has been crucial. Artificial intelligence is frequently employed in many sectors for classification and regression since it has shown to be a flexible tool for learning complex patterns. In recent years, machine learning and deep learning have gained popularity as methods of assessing concrete strength because these methods are simpler, faster, and more effective than previous methods.

In computer science, neural networks are at the forefront of technology. In essence, they are programmable algorithms that imitate a few brain functions. As a result, they gain the capacity for self-training, the capacity to formalize unclassified knowledge, and—most significantly—the capacity to generate predictions based on accessible historical data. Many business applications, like forecasting and market research, are increasingly using neural networks. The key industries where neural networks have been used include business analytics, trading, corporate planning, and product maintenance. All types of traders may use neural networks profitably, therefore if you're a trader and you haven't already learned about them, you should. Machine learning algorithms can produce more accurate results than statistical models, according to these studies.

To lower the system learning error, a significant amount of trial data is needed, however choosing the right input variable might be challenging. Other methods, like random forest, are also fairly simple to construct because the default hyper parameters they utilize frequently yield a reasonable forecast result. Depending on the input variables, the model's prediction accuracy varies. There aren't too many of the hyper parameters, and understanding them is rather simple. Overfitting, one of the main issues in machine learning, can be solved by employing this ML approach. The significance of input parameters can be demonstrated by deep learning algorithms that use variables that impact concrete properties to predict its compressive strength.

II. Literature Review

[1]Dr. Ashraf Shaqadan1

According to the study, random forest algorithms are the most efficient way to predict the compressive strength of mix concrete since laboratory analysis can be time consuming and expensive. This study used 90 experimental samples to determine whether adding silica affected compressive strength. By analyzing the percentage of silica and other variables, it shows great performance and capability in predicting cement compressive strength.

Curing time and milling time have a greater impact than silica percentage, according to the study. R language and rattle package are used in conjunction with other statistical analysis methods in the application procedure. The data is imported as a .csv file with a partitioning of 70/15/15. As regressors (m=4), cement and silica percentages, milling time, and the age of the sample are used. A total of 1000 trees will be used. A neural network model and a linear regression model are then compared with the model. Based on the results of this study, random forest is intuitive, effective, and capable of predicting regression issues with experimental inputs.

[2] Sushmitha, Akash , Jalok, Ravikumar, Arjun V

Concrete's compressive strength is considered to be one of its most important mechanical properties, since it indicates its quality. In this study, artificial neural networks are used with MATLAB software to predict concrete's compressive strength. This paper focused on building a MATLAB model and validating it. Models have input layers with 10 nodes, hidden layers with 20 nodes, and output layers with one node. 1195 mixtures were obtained. 70% of that is for training, 15% for testing, and 15% for validation.

The community works entirely on bugs and has been fixed accordingly. Community generalization is measured using validation information and stops while improvement stops. They use the Levenberg-Marquardt algorithm to train the ann version. It is commonly used to solve nonlinear least-squares methods. The graph shows that we chose 20 hidden neurons to limit the implicit squared error and maximize the regression to show the maximized regression. The best validation performance of the model was found at the 12th epoch (0.7382). In this epoch, the nonlinear sigmoidal characteristic changed to the fitted characteristic as a switch function.

The results show that the developed ANN version perfectly learned the relationship between the input and output parameters. The fact that the correlation coefficient is nearly equal to 1 proves the accuracy of the neural community model. A common error of 0.693 N/mm2 was found. This version is therefore designed to be time- and cost-effective and is ideally suited for specific blending plans for blending development and dosing.

[3]Liu Pengcheng, Wu Xianguo, Cheng Hongyu* and Zheng

A study on high performance concrete demonstrates that machine learning models, such as artificial neural networks, support vector machines, ensemble algorithms, and decision trees, are more efficient because they reduce learning errors.By increasing the importance of influencing errors, the random forest algorithm optimizes the number of input variables and then predicts compressive strength by using regression.

Concrete samples were tested for mix proportion and 28-day compressive strength. The techniques used are bootstrap resampling method and then random forest algorithm where feature selection is performed using MSE and regression and prediction using CART algorithm and then result is evaluated using root mean square error. Model comparison is made and recorded in aspect with feature selection and without and BP neural network with feature selection and without.

As a result of the feature selection of variable importance measurement, the prediction accuracy of the model can be improved, and the RF method can get more accurate and stable prediction results than the BP neural network model, further expanding its application prospects.

[4] MehdiNikoo, Farshid TorabianMoghadam, and Aukasz Sadowski

Model samples of cylindrical concrete parts are constructed using 173 experimental data patterns with different characteristics. An ANN model was used to calculate the compressive strength of concrete based on the inputs of water-cement ratio, maximum sand size, amount of gavel, and coefficient of soft. Study results reveal that ANNs are more flexible, capable, and accurate in predicting concrete's compressive strength than traditional methods.

In order to calculate the strength of the concrete, the study uses a database of cylinder samples with a 15 cm diameter and a 30 cm height, along with information on the amount of sand, water-cement ratio, and silt in kilograms. 139 patterns are used in total for training, 17 are used for cross validation, and 17 are used for network testing. Each sample of concrete receives 25 blows from a hydraulic jack. The paper begins by using mix designs to calculate strength, followed by the selection of multi-layer, feed forward, radial basis function, and time lag recurrent networks, and finally the need for compressive strength. Following the identification of the best weights using GA, the compressive strength is measured using MLR, or multiple linear regression. preceded by the performance evaluation of the EANN model among all models taken into consideration.
The study focuses on finding out if the comparison is made qualitatively or quantitatively. Utilizing the correlation coefficient, mean square error, and coefficient of determination. The values achieved were 0.910, 0.935, and 0.899 for the correlation coefficient in the training, testing and validation test respectively. It is hence proven that EANN is superior as per accuracy, correctness and flexibility and the slope of the straight line is observed to be 0.9061, 0.9043, 0.9039. As these results prove the reliability of the proposed model.

[5] Kabiru O. Akande1, Taoreed O. Owolabi2, Ssennoga Twaha1 Sunday O. Olatunji

The study describes the compressive strength as a very important for performance of the concrete and determination of its mix proportion. It is noticed that the conventional method is extremely complicated and time exhausting hence ANN is proposed. While it was discovered that the ANN is unstable because its optimization objective contains local minima. As a result, they have compared the performance of the stable algorithm support vector machine in this study.

The research used a total of 425 data points. The data set is first decoupled from the original data, and then random shuffling is used to divide the data into training and testing groups in an 8:2 ratio. Next, data randomization is carried out, and the MATLAB environment is used for the programming portion. The training of ANN and SVM models are then performed using a training data set and validating it with testing the data. ANN uses a feedforward network algorithm to set up the model. SV regression was used by using varying parameters to obtain optimum output.

Coefficient of correlation, mean squared error, and absolute error are used to measure performance. Performance is indicated by a low absolute error value. Both SVM and ANN are given the best parameters. The most significant influence on SVM performance comes from the kernel option parameter. It was observed that SVM remained stable during all the experiments hence shows better performance and therefore a viable alternative to ANN.

[6] Dr. B. Vidivelli, A.Jayaranjini

The compressive strength of concrete is predicted by the study using an ANN-based model. Twelve different proportions of the concrete mix were used with 71 specimens. The ten input parameters used to organize the data for the multilayer feed forward neural network models are cement, fly ash, silica fume, age of the specimen, coarse aggregate, water, metakoalin, and superplasticizer. These parameters predict that concrete containing industrial byproducts will have a compressive strength.

For each of the five mixes, there are 71 concrete cubes and cylinders in the test specimen. To achieve a uniform color, all of the ingredients are thoroughly mixed in a dry state machine. Water is thoughtfully incorporated into the mixture. Two distinct artificial neural networks, dubbed ANN-I and ANN-II, are created as part of the analysis process. One hidden layer is chosen for ANN-I and two hidden layers are chosen for ANN-II. In each hidden layer, 10 neurons are chosen based on the hidden layer's minimum absolute percentage error, and the output results in the network prediction. Iterations are used to determine the experimental results for both models' momentum rate, learning rate, and error after learning cycle.

Both models' training uses 71 data from the results of experiments. The following methods are used to obtain coefficients: root mean square, mean square error, mean absolute percentage error, and r square. Both models predict the compressive strength, but it can be seen that the ANN-II model's results are more in line with the experimental findings. Compressive strength is observed to have high accuracy with ANN.

[7]Suescum-Morales, D.; Salas-Morera, L.; Jiménez, J.R.; García-Hernández, L.

It is rumored that it is very challenging to predict the compressive strength of recycled concrete. The dosage of the constituents also affects this aggregate. The study recommends using an artificial neural network to forecast the compressive strength after 28 days. There are 11 inputs in the neuron layer, and Levenberg-

Marquardt (LM) and Bayesian Regularization (BR) were used as training methods. From the 15 studies completed, a database of 177 mixes was chosen. The study's primary goal is to evaluate the method's effectiveness in situations where the data are heterogeneous and noisy.

Different machine learning techniques are sorted down in a tabular form from the different researches taking into consideration the samples that have been adapted and their different types of input concrete parameters. The machine learning techniques used include ANN, multiple linear regression, GEP, fuzzy logic, and others. The datasets used for training, validating, and testing the model in this study are divided by 70%, 15%, and 15%, respectively. The mean absolute error, mean absolute percentage error, root mean square error, and correlation coefficient are the four options used to delimit the errors.

The outcomes are then contrasted with those of linear regression, support vector machine, and Gaussian process regression. Additionally, some alternatives are taken into account to further determine the effects of the parameters, including combining the cement amount, ignoring the amount of superplasticizer the input, fitness modulus, and disregarding the maximum particle sizes. The results hence verify that model predicts strength of the concrete with good amount of accuracy therefore saving time and laboratory testing.

[8]Duan, Z.H., Kou, S.C., and Poon, C.S. (2013)

The study involves the use of ANNs to forecast the compressive strength of concrete made with recycled aggregate. The researcher's collection of 146 datasets from 16 sources is used in the model. There are 14 parameters, such as the coefficient of various concrete specimens, saturated surface dry density, and recycled coarse aggregate. MATLAB is the programming environment that will be used.

The ANN model employs a back propagation network, with one output layer neuron and 14 input layer neurons. The results of the back propagation are measured by r square, MSE and MAPE. Comparisons are made between the performance of the training and testing sets. The majority of compressive strength values are matched to the target strength, but some data will not fit as well, and this could be due to a variety of factors, including the type of cement, various RA characteristics, and errors in the experimental data.

The findings demonstrated that the maximum aggregate size, water absorption rates, and SSD density accurately predict the compressive strength of RAC and reflect the characteristics of recycled aggregate. However, if more parameters are taken into account, ANN model performance can still be enhanced.

[9]Firas Abed. Turkey, Salmia Bt. Beddu, Ali Najah Ahmed, Suhair Al-Hubboubi

In the study, compressive strength of four different kinds of lightweight concrete is predicted. The Artificial Neural Network (ANN), Convolutional Neural Network (CNN), Long Short Term Memory (LSTM), Decision Tree (DT), Random Forest (RF), Support Vector Regressor (SVR), and Linear Regression (LR) are seven machine learning algorithms that are used in the prediction process. Furthermore, six metrics are employed for their evaluation.

Data is gathered, normalized (preprocessed), and divided into two groups (80% and 20%) for training and validation. Hyper parameter optimization is then carried out as performance can be influential by these parameters. The optimal value is then determined using the seven models, and model performance is assessed using the mean square logarithm error, mean absolute error, root mean square error, relative square error, root mean logarithm square error, and r2 coefficient of determination.

The various types of concrete are then compared using all seven models, and it is found that recycled concrete of the Leca, Porcelanite, and RFA types has the highest accuracy because the predicted values are most closely related to the values actually obtained for these types of concrete. It has been demonstrated that for the leca, RBA, and porcelanite types, the LR model outperforms other models in terms of compressive strength. CNN, however, does a better job of predicting RFA type.

[10]Liang Chen

The study describes using a substitute artificial neural network to predict the compressive strength of concrete. Data on high performance concrete that takes different types of concrete into account in mix designs is gathered from the literature repository. Innovative equilibrium optimization and particle swarm optimization are used during algorithm training and testing.

The data collection consists of three mix designs and different mixtures of fly ash, silica fume and superplasticizer. The flexible study for division of dataset into 70% and 30% for training and validation is considered. The model that is suggested is a feed-forward back propagation neural network with multiple hidden layers, and to produce an accurate model with little complexity, two new algorithms, novel equilibrium and particle swarm optimization algorithms, are used. For the hybrid model evaluation process, statistical metrics are used. They are the coefficient of determination (R2), mean absolute error (MAE), variance account factor (VAF), root means square error (RMSE), and object values.

After calculating values, a comparison is performed for the six hybrid models. The study results in overcoming the difficulties of HPC concrete as they are more complex due to fly ash, silica fume, and superplasticizer. The two models enhance the accuracy and decrease its complexity.

Table 1: Summary of survey of compressive strength prediction system

AUTHOR	REF.	ML TECHNIQUES	CONCRETE TYPE	SAMPLES	CONCLUSION
Dr. Ashraf Shaqadan1	[1]	Random Forest	mix concrete	1000 experimental sample	Good for prediction of regression issues
Sushmitha, Akash , Jalok, Ravikumar, Arjun V	[2]	ANN	Mix concrete	1195	Model tends to save time and cost
Liu Pengcheng, Wu Xianguo, Cheng Hongyu* and Zheng	[3]	Random Forest And BP neural network	HPC	56 sets of samples	RF model is proven to be more accurate
MehdiNikoo, Farshid TorabianMoghadam, and Aukasz Sadowski	[4]	EANN and ANN	Cylindrical concrete parts	173 experimental samples	EANN performs efficiently
Kabiru O. Akande1, Taoreed O. Owolabi2, Ssennoga Twaha1 Sunday O. Olatunji	[5]	ANN and SVM	Mix concrete	425 samples	SVM remained stable
Dr. B. Vidivelli, A.Jayaranjini	[6]	ANN-I and ANN-II	12 different concrete mixes	71	ANN-II with two hidden layer is closer.
Suescum-Morales, D.; Salas-Morera, L.; Jiménez, J.R.; García-Hernández, L.	[7]	Various ML techniques like ANN, SVM, fuzzy logic	Recycled aggregate concrete	177	ML algorithms have better techniques than laboratory testing
Duan, Z.H., Kou, S.C., and Poon, C.S.	[8]	ANN	Recycled aggregate concrete	146	ANN performs well but can be better if more parameters of concrete are considered
Firas Abed. Turkey, Salmia Bt. Beddu, Ali Najah Ahmed, Suhair Al-Hubboubi	[9]	Various ML algorithms are compared	Recycled aggregate concrete, lightweight concrete	25 for each concrete type	LR is better in compressive strength prediction
Liang Chen	[10]	Comparison between six hybrid models	HPC	3 mix designs and different mixtures	Overcome difficulties of HPC

III. CONCLUSION

For the prediction of compressive strength, a number of methods and techniques are put forth, demonstrating the machine learning and deep learning algorithms that are frequentAs development models and evaluation metrics for comparison and accuracy generation, the researchers used random forest, fuzzy logic, support vector machine, artificial neural network, and convolution neural networks. The types of concrete and how their parameters affect model performance, such as whether the concrete is high performance, regular, or recycled, have also been considered by the researchers. The regular lab testing methods, which demand a lot of effort and planning, are found to be less effective and useful than these machine and deep learning algorithms. With the advancement of technology, these methods have been shown to be significantly more advantageous than conventional processes in terms of cost and time savings.

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