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A Review on Prediction of Compressive Strength and Slump by Using Different Machine Learning Techniques

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Abstract - Concrete is an extremely advanced material, playing an important role in the construction industry. Thus, selecting and applying the right methodology for predicting its properties such as compressive strength, and slump flow is a crucial task. Hence, the appliance of supervised machine learning (ML) approaches makes it potential to initially predict the targeted result with high accuracy by implementing different machine learning algorithms such as decision Tree (DT), Random Forest (RF), Genetic algorithm (GA), Artificial Neural Network (ANN), Support Vector Machine (SVM), back-propagation neural network (BPNN), sequential feature selection (SFS) to predict the compressive strength and slump flow of the different variety of concrete. Furthermore, the machine learning techniques are used and compared with the assistance of statistical analysis i.e., coefficient correlation (R^2), root-mean square error (RMSE), root absolute error (RAR), mean absolute error (MAE), mean square error (MSE). Development of the algorithms, assembling two ways i.e., ANN with GA, ANN with bagging, GA with backpropagation (hybrid). These algorithms require different input parameters of concrete mix design (i.e., coarse & fine aggregates properties, cement content, water/cement (W/C) ratio, and admixtures type) whereas the output would be the results of statistical analysis of those inputs. The aim of reviewing the research papers is to grasp the most effective algorithm that suits to prospect the slump and compression strength of different types of concrete.

Key Words: **Compressive Strength, Machine Learning, Regression Algorithm, Genetic Algorithm, Artificial Neural Network (ANN), Random Forest, Decision Tree, Support vector machines (SVM)**

1.INTRODUCTION

Concrete is a versatile material that can be simply mixed and cast into effectively any form to satisfy a variety of design requirements. From an associate engineering aspect, strength is the supreme property of any structural concrete design. in the case of concrete mix design and quality control, the uniaxial compressive strength of concrete is considered the foremost crucial property that has proved laborious to determine. The characteristics of the coarse aggregate, fine aggregate, mortar, and type of cement involved playing a significant role to provoke high strength. The gradation of the aggregates determines the workability. Additionally, the other factor for the workability of the concrete is the order in which materials are mixed. To obtain sensible workability, it requires special additives in the concrete, along with a superplasticizer as the water/cement (w/c) ratio in the concrete is lower than normal concrete. The properties of concrete are influenced by the properties of each, and every ingredient added to it.

1.1 Machine Learning

Machine learning (ML) is a highly multidisciplinary field and consists of various methods for obtaining new information [1]. ML is most frequently used for prediction. Predicting the categorical variable values is called classification, whereas predicting the numerical variable values is called regression [2]. Regression is the process of analyzing the relationship between one or more independent variables and a dependent variable [3]. In the recent decade, the ML methods have become more popular as they allow researchers to improve the prediction accuracy of concrete properties [4] and are used for various engineering applications. [5,6]. To increase the accuracy of concrete properties, machine learning methods are significantly used. Different ML predictive Algorithms such as Random Forest, Decision Tree, Support Vector Machine, and Artificial Neural Network are used for predicting given problem. These algorithms can learn the patterns from the data rather than by straightforward programming by humans. The notion of these algorithms is generally based on training, which enables the computer to learn the properties/features that preferably constitute the data set for the given problem and then interprets this information to produce explanations of more available datasets. i.e., if the selected algorithm is trained to transform a benign from a spiteful lesion on imaging and can be applied to other image data and categorize lesions as either benign or malignant, depending on previously "learned" criteria.

2. ANN Model Approach for Prediction

The ANN model is often used either to predict the compressive strength and slump for a given mix or to estimate the various ingredients to attain a targeted compressive strength after 7 and 28 days [9]. artificial intelligence technique based on Random Forest, Support Vector, Convolutional Neural Network (CNN), regression algorithm, Machine learning, and ANN. It offers a mathematical model to indicate the results of a given database [8]. ANN can be divided into 2 main steps: (1) process inputs and outputs of the problem; (2) train the network by modifying the weights and biases of the input [10]. many variants of training algorithms are by experimentation investigated for network optimization. Also, empirical studies investigated different architectural parameters such as the number of hidden neurons, learning rate, activation functions, performance goal, and epochs for the fine standardization of neural networks [7]. Subsequently, the trained network can be applied to predict the result of other sets of input, where data are unknown [8].

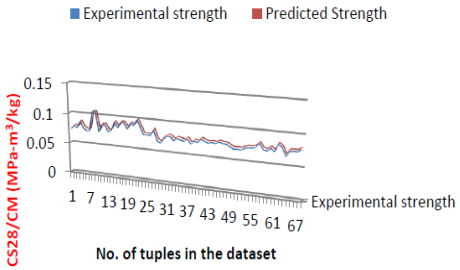

Fig-2: Validation of ANN model using 28 days of compressive strength data [9]

The training method of ANN is the optimization process of the affiliation between neurons in numerous layers [10]. Multifactor authentication (MFA) is employed to optimize the weight and bias vector of ANN and enhance its potency [10]. The performance of Multifactor authentication-Artificial Neural Network (MFA-ANN) is evaluated by exploitation of four performance measures including correlation coefficient R, RMSE, MAE, and MAPE by hypothesis testing [10]. it's deduced that the simplest training algorithm is the 'Levenberg-Marquardt' algorithm which attains over 95% of the average prediction accuracy. seeable of the result of this study, it is inferred that the ANN approach has definite application potential for the prediction of the compressive strength of concrete [7]. The error rates improve by 16.96%–95.67% compared to the fitting curve technique whereas the correlation value R is beyond 0.95 in all cases [10].

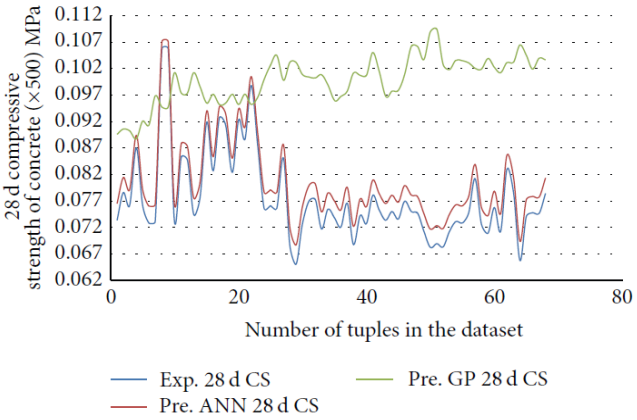

Fig-1: Validation of the proposed model of 28 days compressive strength of concrete with in-situ dataset [7]

Table -1: Range of values in various parameters [8]

Water Cement ratio	0.42 - 0.55
Cement content	350 - 475@ 25 kg/m3
Water content	180 - 230@ 10 kg/m3
Workability	Medium and HIgh
Curing age in days	28, 56, 91

3. Genetic Algorithm Approach for Prediction

The genetic algorithm (GA) exemplifies the biological process, and therefore the solution is highlighted in the form of chromosomes. computational models of evolutionary processes like selection, crossover, and mutation as stochastic search techniques for locating global minimum for complex non-linear issues having numerous sub-optimal solutions. GA is employed for evolving the optimal set of initial weights and biases for the training of the neural network [12]. Genetic programming (GP) is a technique that makes genetic evaluation-based models and adopts the properties of regression and neural techniques. The GP technique works on the Darwinian reproduction principle simplified in a computer-based solution. a version was proposed based on the evolutionary population algorithm named Genetic expression Programming (GEP). The GEP process has been executed by exploiting the GeneXproTools 5.0 computer tool [11]. statistical indicators are wont to evaluate the fitness criteria. Finally, the reproduction process has started for everyone, and assessment is completed by the fitness function as the result of Relative Root Mean sq. Error (RRMSE)% yielded by Random Forest Regression (RFR) and SVM models were considerably lesser than 10% i.e., 5.157% and 7.932%, respectively [11]. SVM regression

models are typically utilized for the analysis between input and outputs due to their efficient capability of determining non-linear regression problems and satisfying the mentioned criteria of statistical indicators presented. SVM kernel-functions reminiscent of radial basis, linear, sigmoid, or polynomial are wont to determine support vectors along with the function space [11, 12]. a fixed mapping procedure converts the SVM based mostly regression data to an n-dimension functional space. SVM regression is exclusive as a result of its use insensitively to compute the linear regression function for the new hyper-dimensional space simultaneously decreasing model complexity [11]. Random Forest Regression (RFR) is a reliable and effective approach for the estimation of fc of Sugarcane bagasse Ash (SCBA) concrete followed by SVM and GEP [11]. The prophetical power of the trained ANN once presented with examples not enclosed in the neural network training. To facilitate training and testing of the neural networks, the collected data were randomized and split into training, validation, and test datasets. The validation dataset is indirectly used during the training of ANN to observe the over-fitting of the neural network and to act as a guide to stop the training of the neural network when the validation error begins to rise. The statistical performance metrics show that GA alone cannot effectively train an ANN. this is often proved by a high training RMSE, MAPE, statistics of 9.4308 mm and 4.895% severally statistics of 0.6322. moreover, negative values of statistics E, 1.5108 and 4.6479 and high values of NMBR, 9.815% and 18.6721% during validation and testing respectively indicate that training of Artificial Neural Network by Genetic algorithm alone leads to unacceptable performance [12].

The increasing order of the influence of input variables followed the trend: CC (55.73%) > W/C (17.15%) > CA (16.38%) > SCBA% (6.38%) > fa (3.76%). Boosting and bagging are based on distinct ensemble learning techniques respectively for the classification of trees. A more powerful prediction technique known as RFR is based on a modified bagging mechanism. RFR changes the method regression trees are created once employing a bootstrap sample. RFR resolves the matter of overfitting and provides superior performance compared with NN and SVM [11].

4. Min – Max Normalization Techniques

In this study, the Shapiro–Wilk normality test results demonstrated that the datasets weren't unremarkably distributed. the most productive techniques for the determination of the fc and S values are the decimal scaling and min-max normalization methods, respectively. Therefore, as the variation ranges of the impact variables influencing the concrete properties varied substantially, it was necessary to preprocess the raw data for the estimation of the concrete properties. Seven different ml methods, such as DT, RF, SVM, Partial Least Square (PLS), ANN, bagging, and federated learning (FL) have experimented for the prediction of the Compressive Strength (fc) and Slump (S) values. consistent with the statistical analysis results of correlation coefficient R, RMSE, and MAEs, concluded that fl is the best regression technique for the maximum aggregate size. The similarity between the actual and expected values is high for the compressive strength. A minimal distinction between the actual and predicted slump values represents that the slump values are additional sensitive to the experimental error, simultaneously uncontrollable effect variables, and variation intervals of the effect variables. the flexibility of the computational structure of the FL approximated the results instead of providing the precise results. In particular, the uncertainties in the problem-solving and decision-making processes will be processed by the appliance of the fl. Thus, complicated problems can be solved, creating the FL additional functional than any other ml method [13].

In experimental designs, wherever the number of simultaneously uncontrollable effect variables is high, it's crucial to scale back the number of the experiments to save costs and time. Therefore, the predicted values about to the actual values need to be obtained with the minimum number of the experiments [13].

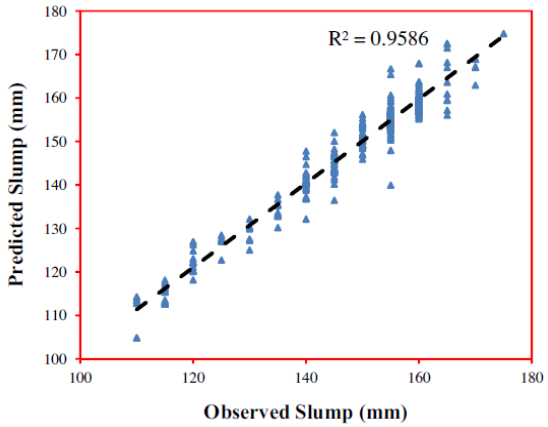

Fig-3: Observed Slump value [13]

5. Six Population-Based Hybrid Algorithms Approach for Prediction

six population-based hybrid algorithms were accustomed to training the multilayer perceptron (MLP) to enhance the classification accuracy, within the stability assessment. a complex drawback of slope stability against failure is intended in Optum G2 software. Considering four key factors of shear strength of clayey soil, slope angle, the ratio of foundation distance from the slope to the foundation length, and therefore the applied surcharge, the stability or failure of the proposed slope are

anticipated. The provided data are used to develop the MLP combined with biogeography-based optimization (BBO), ant colony optimization (ACO), GA, evolutionary strategy (ES), particle swarm optimization (PSO), and probability-based incremental learning (PBIL). The results showed that the MLP trained with the BBO algorithm achieved the simplest accuracy of classification due to the obtained AUROC=0.995 and CR=92.4%. Following this, the GA-MLP and PBIL-MLP emerged because the second and third accurate models with the respective area beneath the Receiver operational Characteristics (AUROCs) of 0.960 and 0.948 and catholic Relief Service (CRs) of 84.3% and 79.3%. Additionally, three methods of ES-MLP, PSO-MLP, and ACO-MLP performed satisfactorily with respective AUROCs of 0.879, 0.878, and 0.798 and CRs of 65.7, 71.3, and 60.7%. As is seen, the outcomes proved that employing soft computing approaches along with considering four conditioning factors (i.e., shear strength of clayey soil, slope angle, the ratio of foundation distance from the slope to the foundation length, and therefore the applied surcharge) provides appropriate results for stability analysis of soil slopes. The authors believe that it's potential to attain even a lot of accurate prophetical models through numerous ways; like optimizing the slope stability conditioning factors and applying the used algorithms to other robust predictive tools like adaptative neuron fuzzy interface system (ANFIS). It can be a decent subject for future studies [14].

6. Conclusion

Concrete is an extremely advanced material, playing a crucial role in the construction industry. Thus, selecting and applying the correct methodology for predicting its properties such as compressive strength, and slump flow is a crucial task. such as the prediction of various types of concrete slump flow and compressive strength suffers from abnormal attributes and the variance in the ingredients both of which could influence prediction accuracy and precision. This review concluded that for the prediction of compressive strength the simplest fitting algorithm is Levenberg-Marquardt' algorithm which attains over 95% of the average prediction accuracy. This review concluded that seven different ml techniques, such as DT, RF, SVM, PLS, ANN, bagging, and fl experimented for the prediction of the fc and S values. according to the statistical analysis results of R, RMSE, and MAEs, concluded that FL is the best regression method for the maximum aggregate size.

A GA is considerably used with ANN, Back-proportion, and bagging method verified that the alone GA leads to unacceptable performance. For recycled concrete slump prediction geometric semantic genetic programming (GSGP) has higher accuracy and dependability than conventional methods The random forest algorithm has higher prediction accuracy on additional discrete data. SVM regression models are typically utilized for the analysis between input and outputs due to their efficient capability of finding non-linear regression problems and results can be found for each ingredient of concrete individually. Multi-Factor Authentication (MFA) has been proven reliable for optimizing the weight and bias vector of ANN, whereas the correlation value R is above 0.95.

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