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A Review on Concrete Strength Prediction Models Based on Machine Learning Algorithms

Er. Tushant Seth[1], and Dr Sandeep Singla[2]

[1]M.Tech. Scholar, Department of Civil Engineering, RIMT University, Mandi Gobindgarh, Punjab, India
[2]Professor & Head, Department of Civil Engineering, RIMT University, Mandi Gobindgarh, Punjab, India

Correspondence should be addressed to Er. Tushant Seth; tushantseth143@gmail.com

ABSTRACT- In the present time, machine learning algorithms are used for design concreate strength prediction models due to numerous advantages over the manual methods such as cost and time effective and more effectively predict the strength based on the historical information. Therefore, the main aim of this paper, is to study and analyse the various machine learning algorithms are used to design concrete strength prediction model. In the literature, last five years paper is taken under consideration. Based on literature survey, open research gaps are defined which helps the other authors to contribute their research in this area.

KEYWORDS- Concrete Strength Prediction, Machine Learning Algorithms,

I. INTRODUCTION

In modern construction, concrete has mostly displaced other materials due to its shown stability in exhibiting tremendous strength. There are a variety of cement composition elements that have been utilised in place of the traditional concrete components of cement, fine aggregate, coarse aggregate, and water [1]. These materials include blast furnace slag, fly ash, and chemical combinations like superplasticizer. Since Portland cement comprises the most costly part of a concrete mix, reducing its proportions via the use of other cement composition materials has financial advantages as well. However, adding chemicals to concrete is common since it improves the material's workability, longevity, and strength. To simulate the concrete's compressive strength now includes these additional factors brought about by the additional ingredients in the concrete's mix. Predicting the behaviour of concrete using conventional modelling techniques, however, is more challenging. Testing the concrete's strength is typically done between 7 and 28 days after it has been poured. Due to the minimum wait time of 28 days between each test, the next phase of construction may be delayed. To avoid limiting quality control on a big and complex building scale, testing must be prioritised. As a result, even at the conceptualization stage, it is crucial to have a rapid and accurate method of predicting the concrete's compressive strength for the sake of quality control. When the concrete's strength isn't sufficiently strong for the job's requirements, if altering the mixture's proportions can be done right once, it may save time and money on the job. Predicting concrete strength early on helps with scheduling, quality assurance, and forecasting how long it will take to open the formwork. Due to the nonlinear nature of the connection between constituents and concrete's personality, modelling using a purely quantitative method quickly becomes intractable. In order to estimate compressive strength, the current standard code provides an empirical calculation based on testing concrete without any extra cement mix material. It is crucial to optimise a concrete mixture by having a firm grasp of the connection between the concrete's ingredients and its final strength. Large volumes of study have been conducted via costly and time-consuming experimental experiments. So, it's important to develop a new modelling system that can accurately estimate the concrete's compressive strength without resorting to costly and time-consuming experiments. In recent years, machine learning (ML) techniques have surpassed more traditional approaches to regression and classification issues [2].

The main contribution of this research is to study and analysed the concrete strength prediction models based on the machine learning algorithms. To achieve this goal, recent literature survey is conducted by study the various research papers are published in this area. From the analysis, we found that the researchers are used numerous machine learning models such as artificial neural network, support vector machine, long-short term memory (LSTM), decision tree *etc*. Further, they have done the hybridization of the machine learning algorithms with nature-inspired algorithms such as genetic algorithm and simulated annealing to enhance its performance. In the last, we have defined the open research gaps.

The remaining paper is defined into 4 sections. Section 2 shows the related work is conducted on concrete strength prediction models are based on the machine learning algorithms. Section 3 shows the open research gaps. Finally, conclusion is drawn in section 4.

II. RELATED WORK

In this section, we have studied and analysed the existing machine learning algorithms are employed for concrete strength prediction.

BKA et al. [3],The purpose of this research was to employ Artificial Neural Networks (ANNs), which have shown to be effective in predicting the mechanical characteristics of concrete, to investigate the compressive strength of recycled aggregate concrete. The Levenberg-Marquardt

(LM) algorithm is used to build three distinct ANN models, each of which is trained and tested using 1030 datasets extracted from the relevant literature. The models each feature either one hidden layer with 50 neurons, two hidden layers with (50 x 10) neurons, or two hidden layers (modified activation function) with (60 x 3). The ANN models were trained using the 8 input parameters, including such cement, fly ash, blast furnace slag, water, coarse aggregate, superplasticizer, fine aggregate, and age. The precision of a prediction may be improved by increasing the number of hidden layers, increasing the number of neurons, or switching to a different kind of algorithm. The anticipated compressive strength of recycled aggregates demonstrates that the mechanical characteristics of recycled aggregates are significantly influenced by the admixture compositions, including binders, water-cement ratio, and blast furnace-fly ash ratio. The findings demonstrate that the proposed ANN-based model can forecast the recycled aggregate concrete's compressive strength with a high degree of accuracy. Further applications of the proposed ANN-based model include determining the optimum mix of waste and other elements to achieve a range of desired concrete compressive strengths.

Naderpur et al. [4],The purpose of this research was to create a neural network in order to objectively assess the durability of recycled aggregate concrete using a set of well-defined criteria. When using the selected network for these purposes, they get regression values of 0.903, 0.89, and 0.829, respectively. Epoch 5 had the highest validation performance. They found that the model's MSE was 0.004447, therefore they can confidently say that the ANN technique can reliably estimate RAC compressive strength with a high degree of precision. It is determined that the compressive strength of RAC can be predicted with high accuracy using the ANN technique. The compressive strength of RAC is significantly affected by its water absorption and water-to-total material ratio, each of which contributes around 20%. It is also important to note that the final qualities of recycled aggregates are typically affected by the maximum size of aggregates, water absorption values, and saturated surface dry (SSD) specific densities.

Chen et al. [5],One of the most common methods used to repair deteriorated reinforced concrete flexure structures nowadays is externally joining fibre reinforced polymer (FRP) plates or sheets. However, due to the unpredictability of the essential FRP-concrete interfacial (FCI) bond strength, the capacity of strengthened structures cannot be accurately determined. Several empirical theories have been offered to this problem after extensive experimental research were conducted. These models were shown to be generally deficient in generalisation capacity as a result of using small experiment samples. Accordingly, this research applied an ensemble learning approach called "gradient boosted regression trees" (GBRT) to create a prediction model for FCI bond strength prediction using data from a large database of 520 previously tested samples. The model's accuracy and speed have been extensively compared to both widely-used machine learning methods and representative empirical models. Using feature importance analysis, they've defended the validity of this model. Based on the findings, the model presented here is the most accurate and viable method currently available for estimating FCI bond strength in the real world.

Salami et al. [6],The purpose of this research was to examine the accuracy of predicting the compressive strength of ternary-blend concrete utilising characteristics from the datasets employing least square support vector machine (LSSVM), genetic programming (GP), and Coupled simulated annealing (CSA). The 1030 datasets were collected from a research project archived at the UCI Machine Learning Repository (http://archive.ics.uci.edu/ml/). With the goal of improving prediction accuracy for, we built and evaluated two machine learning models that were driven by data. For verification, they compared their findings to those of other research and used statistical tools to determine how well our suggested models predicted the compressive strength. The results of the predictive performance of the models obtained and discussed indicate that the LSSVM-CSA model with smaller deviation (AARD and ARD), lower error (RMSE), and higher R2 values is superior to the other proposed model in predicting the response variable (concrete compressive strength). This study validates, in comparison to prior research, that the LSSVM's predictive ability for ternary-blend compressive strength was significantly enhanced by optimising the model's hyperparameters using CSA. Most of the input factors were found to have substantial correlations with the outcome variables in the sensitivity analysis. Superplasticizer, concrete, water, and curing time were the input factors that controlled the output. Future researchers would benefit greatly from knowing these regulating inputs so that they may more efficiently arrange their experimental effort. When compared to correlations from previous research, the LSSVM-CSA model in particular demonstrated greater resilience and appropriate prediction error.

Ahmad et al. [7],In order to predict the compressive strength of fly ash-based geopolymer concrete, this research used supervised machine learning techniques, including a bagging regressor (BR), a decision tree (DT), and an Ada-Boost regressor (AR). The accuracy of the model was calculated using R2, MAE, MSE, and RME as metrics. Using the k-fold cross-validation method, they were able to further verify the model's performance. With an R2 of 0.97, the bagging model outperformed the DT and AR model in terms of accuracy of prediction. Better model performance was indicated by smaller mean absolute error (MAE), mean standard error (MSE), and root mean square error (RMSE) values and larger R2 values. As a follow-up, a sensitivity analysis was performed to see how much influence each variable had on the final outcome forecast. Time and money may be saved in the field of civil engineering if machine learning methods were used to forecast the mechanical characteristics of concrete.

Barkhordari et al. [8],Concrete is widely used in the construction sector and is a widely used material for constructing a variety of different kinds of buildings. The emission of various gases during cement manufacture and usage has a substantial influence on the environment. Fly ash concrete (FAC) is essential for fixing this problem. However, cementitious composites come with a wide range of qualities, and it's important to be aware of these differences in order to ensure everyone's safety. However, machine learning techniques are often used algorithms for predicting the mechanical features of concrete. The purpose of this research is to find the best method for estimating the compressive strength of FAC and lowering the high variance of the forecasting analytics by comparing different ensemble deep neural network models, such as the simple averaging, super learner algorithm, integrated stacking, weighted averaging, and separate stacking ensemble models. The maximum accuracy (97.6%) was achieved by independent stacking using the random forest meta-learner, which also yielded the highest coefficient of determination as well as the smallest mean square error & variance.

Ahmed et al. [9],Recent developments in the forecasting of concrete's mechanical characteristics have focused on the use of supervised learning systems. Using data from 207 experiments, this research proposes random forest (RF), AdaBoost, and decision tree (DT) models for estimating concrete's compressive strength when heated to high temperatures. Inputs employed in the creation of the models were cement content, fine and coarse aggregates, water, nano silica, silica fume, super plasticizer, fly ash, and temperature. Statistical metrics such as the root mean squared error-observations standard deviation ratio (RSR), coefficient of determination (R2), mean absolute percentage error, and relative root mean square error are used to compare the accuracy of the AdaBoost, RF, and DT models. In order to prove that the aforementioned supervised learning methods for modelling are appropriate for predicting the compressive strength of concrete at high temperature, researchers compare the applications of the aforementioned approach to each other and to the artificial neural network and adaptive neuro-fuzzy inference system models described in the literature. During both the training and testing stages, the AdaBoost model showed a high degree of agreement between experimental and predicted values (R2 > 0.9, RSR 0.5). The sensitivity analysis also showed that the cement percentage in the mixture was the most influential factor.

Sarmad Dashti Latif [10],The compressive strength of concrete is a crucial design factor. With precise measurements of concrete's compressive strength, one can cut down on both time and money spent. The environmental impacts have little effect on the durability of concrete. Severe weather and increases in humidity rates have a significant impact on the manufacture of concrete compressive strength. Using the long short-term memory (LSTM) deep learning technique and the support vector machine (SVM) algorithm, a model for predicting concrete compressive strength has been constructed in this study. The dataset used in this research was collected from a number of previously published publications (SVM). Cement, fly ash, blast furnace slag, water, coarse & fine aggregate, superplasticizer, age of specimens, and superplasticizer are all input variables in the model. Mean absolute error (MAE), coefficient of determination (R2), and root mean squared error (RMSE) were employed as statistical indicators to show how effective the suggested models were. Results reveal that LSTM performs better than SVM, with MAE=1.861, RMSE=2.36, and R2=0.98 vs R2=0.78, MAE=6.152, and RMSE=7.93. This study's findings provide support for the validity of the suggested LSTM model for measuring high-performance concrete (HPC) compressive strength.

Sharafati et al. [11],For the benefit of both design and sustainability, the ability to estimate concrete's compressive strength is crucial. Multiple novel hybrid adaptive neuro-fuzzy inference system (ANFIS) evolutionary models are explored in this study to predict the foamed concrete compressive strength. These models include ANFIS-particle swarm optimization (PSO), ANFIS-differential evolution (DE), ANFIS-ant colony, and ANFIS-genetic algorithm. The cement content (C), water-to-binder ratio (W), oven dry density (O), and foamed volume (F) of the concrete are all utilised as inputs. Predictive models are developed with the use of a data collection gleaned from publicly available experimental studies. The mean performance (MP), the average of numerous statistical error indicators, is used to compare the effectiveness of different suggested predictive models. Univariate (C, O, W, and F), bivariate (C-O, C-W, C-F, O-W, O-F, and W-F), trivariate (C-O-W, C-W-F, O-W-F), and four-variate (C-O-W-F) combinations of input variables are generated for each model in maximising each predictive model and its input variables. Based on the findings, the ANFIS-DE- (O) (MP = 0.96), ANFIS-PSO- (C-O) (MP = 0.88), ANFIS-DE (O-W-F) (MP = 0.94), and ANFIS-PSO- (C-O-W-F) (MP = 0.89) models performed the best in making predictions across the various combinations of variables tested. The most accurate prediction of compressive strength (at an MP value of 0.96) was achieved by ANFIS-PSO- (C-O).

Rajakarunakaran et al. [12],A major drawback of Self-Compacting Concrete (SCC) is the difficulty in accessing its hidden internal components. Repeatedly mixing concrete is a costly and time-consuming problem. It is possible that the construction industry is now experiencing stress over assessing suitable mixture components and their impact on the mechanical behaviour of SCC due to a lack of expertise in mixture design. The goal of this study is to develop regression models based on machine learning to estimate SCC compressive strength. This was accomplished using data collected from 99 SCC samples in a laboratory setting. Multiple input and output parameters characterise SCC's machine-learning regression model. The real strengths were compared using Python machine learning. Many different types of regression models are used for making predictions in machine learning, including linear regression, Ridge regression, Lasso regression, multi-layer perceptron regression, random forest regression, and decision tree regression. Model precision may be evaluated using RMSE, MSE, MAE, and R2. Findings suggest that the Random Forest model may accurately predict the compression strength of self-compressing concrete. The compressive strength of concrete may be reliably predicted using the RF model.

III. OPEN RESEARCH GAPS

In this section, we have defined the open research gaps are determined from the existing study and analysis.

- In the literature, the researchers are used the single machine learning algorithms for predict the concrete strength. However, its performance varies if the appropriate attributes are not given to the models.

Therefore, the hybridization of the machine learning algorithms is done in which various attributes are taken under consideration for enhance the performance of the concrete strength model.

- In the literature, nature inspired algorithms (NIA) are used with machine learning algorithms. NIA algorithms are used for find the optimal weight or bias values of the machine learning algorithms. In the literature, GA, PSO, SA are successfully used in the concrete strength prediction models. However, these algorithms have numerous challenges such as low exploration rate, convergence rate, and numerous parameter tuning required. Therefore, need to explore recent NIA algorithms which overcome these limitations.

IV. CONCLUSION

Machine learning algorithms are gained popularity in the concrete strength prediction models because its monitor its conditions based on the historical information. Therefore, in this paper, we have studied and analysed the various machine learning algorithms are used for concrete strength prediction models. We found that neural network, LSTM, SVM, and DT algorithms are maximum used in these models. Further, some of the authors used the genetic and simulated annealing algorithm to enhance the machine learning models. Moreover, from the analysis, we defined the open research gaps and found out the standard dataset and its attributes which impacts the concrete strength.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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