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Compressive Strength of Concrete

Shreyash Ghatage[1], Rahul Chalke[2], Shrutika Kokane[3], Adil Shaikh[4], Dinesh Dhakkad[5]

[1,2,3,4,5] Department of Computer Science and Engineering (AIML) Saraswati College of Engineering, India

ABSTRACT

Concrete is one of the most widely used construction materials globally, with compressive strength being a crucial parameter determining its structural integrity and durability. Traditional methods of predicting concrete compressive strength often rely on time-consuming and expensive experimental tests. In recent years, machine learning algorithms have emerged as powerful tools for predictive modeling in various fields, including civil engineering. This project aims to develop accurate models for predicting the compressive strength of concrete using boosting machine learning algorithms. Boosting algorithms, such as AdaBoost, Gradient Boosting, and XG Boost, have shown exceptional performance in handling complex datasets and improving prediction accuracy. The proposed methodology involves data collection from diverse sources, including laboratory experiments and field observations, to build a comprehensive dataset with various concrete mix designs and environmental conditions. Feature engineering techniques will be employed to extract relevant features from the dataset, including cement type, water-cement ratio, aggregate properties, curing conditions, and age of concrete. The dataset will be split into training, validation, and testing sets for model training, hyperparameter tuning, and evaluation. Various boosting algorithms will be implemented and optimized to develop robust predictive models. Performance metrics such as mean absolute error, root mean squared error, and coefficient of determination will be used to assess the accuracy and generalization capability of the models. Furthermore, the interpretability of the models will be enhanced through feature importance analysis to identify key factors influencing concrete compressive strength. The developed models will be compared with existing empirical models and traditional statistical methods to evaluate their superiority in terms of prediction accuracy and efficiency. The outcomes of this project are expected to contribute to the advancement of predictive modeling techniques in civil engineering and provide valuable insights for optimizing concrete mix designs and construction practices. Ultimately, accurate prediction of concrete compressive strength can lead to cost savings, enhanced structural performance, and increased sustainability in the construction industry.

Keywords— Concrete, Compressive strength, Predictions, Boosting algorithms.

INTRODUCTION

Concrete is the cornerstone of modern infrastructure, serving as the primary material for constructing buildings, bridges, roads, and various other structures. The compressive strength of concrete, which measures its ability to withstand axial loads, is a critical parameter influencing the performance and durability of these structures. Accurate prediction of concrete compressive strength is essential for ensuring structural safety, optimizing material usage, and minimizing construction costs. Traditionally, the prediction of concrete compressive strength has relied on empirical models derived from experimental tests conducted under specific conditions. However, these approaches often lack accuracy and may not account for the diverse range of factors influencing concrete strength, including variations in materials, environmental conditions, and construction practices. In recent years, machine learning algorithms have emerged as powerful tools for predictive modeling in various fields, offering the potential to overcome the limitations of traditional approaches. Boosting algorithms, in particular, have gained prominence for their ability to effectively handle complex datasets and improve prediction accuracy by combining the strengths of multiple weak learners.

This project aims to leverage the capabilities of boosting machine learning algorithms to develop accurate models for predicting the compressive strength of concrete. By harnessing the wealth of data available from laboratory experiments and field observations, we seek to create robust predictive models capable of capturing the intricate relationships between concrete mix designs, environmental factors, and compressive strength. The proposed methodology involves comprehensive data collection, including information on cement type, water-cement ratio, aggregate properties, curing conditions, and age of concrete. Through rigorous feature engineering and model optimization, we aim to extract meaningful insights from the data and develop predictive models that can generalize well to unseen samples.

Furthermore, the interpretability of the models will be enhanced through feature importance analysis, allowing us to identify the key factors influencing concrete compressive strength. By comparing the performance of our models with existing empirical models and traditional statistical methods, we aim to demonstrate the superiority of machine learning approaches in terms of prediction accuracy and efficiency. The outcomes of this project are expected to have significant implications for the construction industry, facilitating informed decision-making in concrete mix design, structural engineering, and infrastructure development. Ultimately, accurate prediction of concrete compressive strength can contribute to the sustainability, resilience, and safety of built environments, leading to long-term benefits for society.

LITERATURE REVIEW

“Predicting the 28 Days Compressive Strength of Concrete Using Artificial Neural Network” (2021) by Faezehossadat Khademi and Sayed Mohammadmehdi Jamal says Predicting the compressive strength of concrete has always been a difficulty since the concrete is sensitive to its mixture components, methods of mixing, compaction, curing condition, etc. Scientists have proposed different methods for predicting the compressive strength of concrete. [1]

“Prediction of Compression Strength of Concrete by Using Artificial Neural Network” (2018) by D.A. Sonawane and R.M. Jadhav says Concrete cubes strength determination tests are usually performed at three days to one year after pouring the concrete. The waiting period required to perform such test may delay the construction progress, decision making and neglecting such test would limit the quality control checks in large construction projects. Therefore, it becomes necessary that the rapid and reliable prediction of concrete strength is essential for pre-design or quality control of construction. [2]

“Using the Artificial Neural Networks for Predicting Compressive Strength of Normally Concretes” (2020) by Dr. Ibrahim Farouq Varouqa. In this study Artificial Neural Networks (ANNs) models were developed for predicting the compressive strength, at the age of 28 days, of normally concretes. The experimental results used to construct the models were gathered from laboratory of Isra University - Amman in 2019. Total of 15 experimental design used for modeling ANN models. 80% in the training set, and 10% in the testing set, and 10% in the validation set. To construct the model, three input parameters were used to achieve one output parameter, referred to as the compressive strength of normally concrete. The results obtained in both, the training and testing phases strongly show the potential use of ANN to predict 28 days' compressive strength of normally concretes with average accuracy 90% and correlation coefficient 95%. [3]

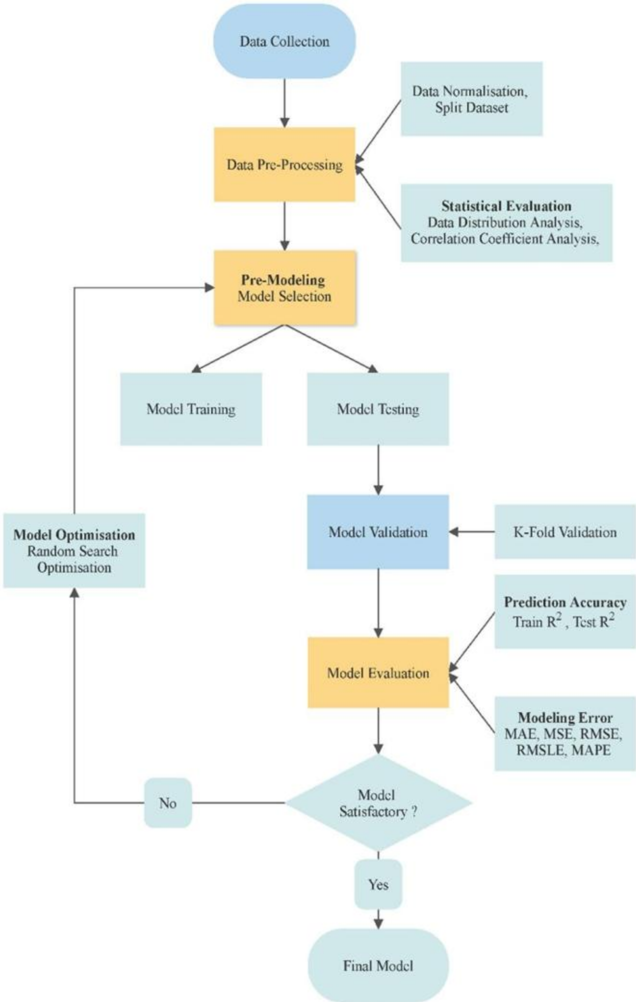
“Prediction of Compressive Strength of Concrete using Artificial Neural Network” (2018) Wankhade M W and Kambekar says A R Concrete cube strength determination tests are usually performed at three days to one year after pouring the concrete. The waiting period required to perform such test may delay the construction progress, decision making and neglecting such test would limit the quality control checks in large construction projects. Therefore it becomes necessary that the rapid and reliable prediction of concrete strength is essential for pre-design or quality control of construction. The early prediction of concrete strength is essential for estimating the desirable time for concrete form removal, project scheduling, quality control and estimating delay if any. Artificial Neural Network (ANN) is used to predict the compressive strength of concrete. Standard back propagation and Jordan– Elman algorithms are used to train the networks. Networks are trained and tested at various learning rate and momentum factor and after many trials these were kept constant for this study. Performance of networks were checked with statistical error criteria of correlation coefficient, root mean squared error and mean absolute error. It is observed that artificial neural networks can predict compressive strength of concrete with 91 to 98 % accuracy. [4]

“Prediction of Compressive Strength of Concrete Using Artificial Neural Network and Genetic Programming” (2020) Palika Chopra, Rajendra Kumar Sharma and Maneek Kumar. In this study An effort has been made to develop concrete compressive strength prediction models with the help of two emerging data mining techniques, namely, Artificial Neural Networks (ANNs) and Genetic Programming (GP). The data for analysis and model development was collected at 28-, 56-, and 91-day curing periods through experiments conducted in the laboratory under standard controlled conditions. The developed models have also been tested on the in situ concrete data taken from literature. A comparison of the prediction results obtained using both the models is presented and it can be inferred that the ANN model with the training function Levenberg-Marquardt (LM) for the prediction of concrete compressive strength is the best prediction tool. [5]

PROPOSED SYSTEM

Our major project represents a pioneering effort to seamlessly blend the capabilities of Artificial Intelligence (AI) with the intricacies of concrete technology, fundamentally redefining the arena of concrete compressive strength prediction and enhancement. This comprehensive system commences with meticulous data collection and centralization of diverse datasets, including concrete mix compositions, curing conditions, and associated compressive strength measurements, forming the bedrock of our AI-driven approach. Data preprocessing and feature engineering then follow, ensuring data quality and identifying key factors influencing concrete strength. The core of the system lies in the development of a machine learning model, diligently trained on the preprocessed dataset, serving as the intellectual engine of real-time predictions. The system provides a user-friendly software tool for instant concrete strength estimates, underpinned by interpretability and visualization features for transparency. Furthermore, ethical and sustainability principles are woven into the system, promoting responsible construction practices and resource optimization. Collaboration, knowledge sharing, and ongoing maintenance cement its role in reshaping construction practices. In sum, this project embodies a transformative leap, enhancing efficiency, cost-effectiveness, quality control, and sustainability, ultimately ensuring the safety and durability of constructed structures.

ARCHITECTURE



Model structure. For the most part, we utilised the Python programming language on Google's Colab plat- form to analyse the data and create the models. An open-source, low-code machine learning library 'PyCaret' was used in research[63]. Figure 3 illustrates the step-by-step procedure for training, optimising, and validating the BML models in predicting the concrete compressive strength. Seven key processes are involved in the develop- ment of the optimised BML model, and each stage is described in detail below, with brief explanations:

- Data Collection – This entails collecting data from the laboratory and compiling it appropriately.
- Data Pre-Processing – To correctly identify and arrange the acquired data, it is necessary to sort out the missing values and then normalise the dataset in preparation for model building.
- Model Selection—For prediction and evaluation in this research, BML algorithms, i.e., LBGM, CATB, GBR, ADAB, and XGB, were utilised.
- Hyper-parameter Optimisation – The RS approach was employed in each of the five proposed BML algorithms, and the results are compared to the original models.
- Model Validation—Validation and testing of the models were performed using the k-fold cross-validation approach, which randomly splits the dataset and minimises overfitting.\
- Model Evaluation – All the models are compared, and the best performing algorithms are selected based on evaluation metrics, i.e., R^2, RMSE, MAE, MSE, RMSLE, MAPE.

CONCLUSION

Comparing all 5 BML models, the GBR model has outperformed the LBGM, CATB, ADAB, and XGB models. The GBR model optimised with RS algorithms achieved the highest prediction accuracy of 0.96 and the least prediction errors, with an MAE of 2.73, an RMSE of 3.40, and an RMSLE of 0.03. Notably, the RS algorithms optimisation technique improved the model prediction accuracy and reduced the modelling errors in all 5 BML models.

Simultaneously, the evaluation of 14 commonly used ML models also suggests that the BML models have superior prediction accuracy and minimum prediction errors. These studies conclude that the optimised BML models, i.e., the GBR model are the best choice to predict the compressive strength of concrete, mainly for HPC and concrete with high volume GGBS replacements. For future research, a comparison study between ANN models with BML models or hyperparameter tuning with different optimisation algorithms, i.e., Grid Search, can be evaluated and compared with the proposed BML model's performance.

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