# Indirect Estimation of the Tensile Strength of Plastic-Infused Concrete using Gradient Boosting

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**Abstract**

This paper applies gradient boosting (GB), a machine learning (ML) methodology for modeling the tensile strength (TS) of concrete made with waste plastic. Firstly, for development of GB models, the database including 235 data records was obtained from the existing studies. Following that, several GB models were developed by using the combination of different hyperparameters and their performance was validated through several statistical metrics. The optimum model achieved $R^2$ values of 0.9 and 0.89 for the training and testing datasets, respectively. The root mean square error (RMSE) was noted as 0.29 MPa for training and only marginally higher at 0.32 MPa in testing meanwhile mean absolute error (MAE) was found 0.25 MPa in training and 0.27 MPa in testing. These results demonstrate the capability of GB modeling in predicting TS of concrete.

**Keywords:** Gradient boosting; Waste plastic concrete; Tensile strength

## 1. Introduction

The incorporation of waste plastic (WP) into concrete mixtures is gaining popularity as a sustainable method for lowering the amount of pollution in the environment and improving the concrete properties [1]. WP in concrete not only reduces the disposal issues of WP but also enhances the mechanical properties of the concrete [2], [3]. Accurate prediction of the TS of such modified concrete is crucial for its practical application in construction. Conventional methods for determining concrete strength are often laborious and expensive [4], [5]. In this context, ML techniques, particularly GB, offer a promising alternative by providing efficient and reliable predictions [6].

Gradient Boosting (GB) is an ensemble method that constructs models in sequence to rectify the inaccuracies of preceding models, hence enhancing predictive precision. This study aims to develop a GB model to predict the TS of concrete containing WP using a dataset collected from the literature. The model's accuracy was evaluated using $R^2$, RMSE, and MAE metrics, providing insights into its efficacy for this application [7].

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## 2. Materials and Methods

### *2.1. Data Collection*

A dataset comprising 235 data points was compiled from various research studies that investigated the TS of concrete containing WP [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23]. The data points included various features such as the amount of plastic, concrete mix proportions, curing time, and measured TS.

### *2.2. Data preprocessing*

During the data preprocessing phase, missing values were substituted with the corresponding feature to maintain data integrity. Subsequently, normalization and feature scaling were performed to bring all variables to a comparable range. Finally, the database was split into training and testing subsets using a 70:30 ratio to assist model training and performance evaluation. The statistical summary and distribution of data are presented in **Table 1** and **Figure. 1**, which show the random distribution of entries in the entire domain.

**Table 1:** Statistics for developed database.

| Inputs | Plastic | Cement | Gravel | Water | Age | Sand | TS. |
|---|---|---|---|---|---|---|---|
| **SD** | 153.50 | 68.30 | 214.20 | 34.60 | 9.60 | 132.40 | 0.90 |
| **Range** | 637.00 | 255.00 | 1059.20 | 135.30 | 21.00 | 823.60 | 4.70 |
| **Skewness** | 1.50 | 0.30 | -0.70 | -0.20 | -0.90 | -0.80 | 0.30 |
| **Mean** | 113.10 | 407.00 | 849.50 | 194.70 | 21.70 | 678.10 | 2.80 |

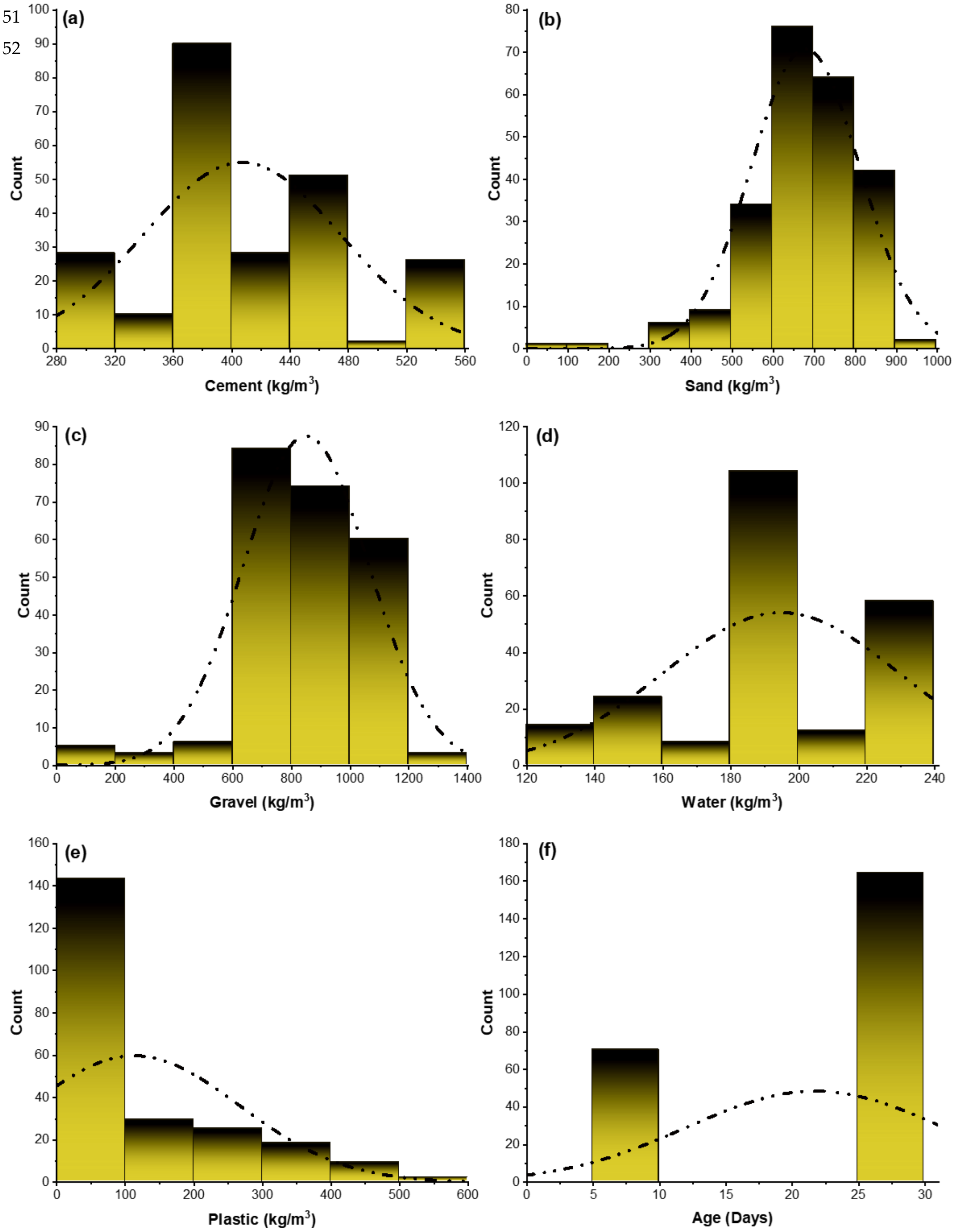


**Figure 1:** Database distribution plots.

*2.3. Model development*

The Gradient Boosting model was implemented in Python using the XGBoost library. In this approach, decision trees are generated sequentially, and each new tree aims to reduce the errors made by the previous trees. To achieve the best predictive performance, the main hyperparameters; learning rate, maximum tree depth, and the number of trees were carefully tuned using a grid search method.

### *2.4. Model Evaluation*

The efficacy of the GB model was measured using $R^2$, RMSE, and MAE. These measures provide a thorough evaluation of the model's accurateness and error distribution. The $R^2$ value indicates how good the GB model's predictions fit the actual data points. RMSE and MAE measure the average magnitude of prediction errors.

## 3. Results and discussions

The GB model showed excellent predictive ability, achieving $R^2$ values of 0.90 for training and 0.89 for testing, as seen in **Figure. 2 (a)** and **Table 2**. Similarly, the low RMSE values of 0.29 MPa (training) and 0.32 MPa (testing) suggest that the model's predictions are very close to the actual tensile strength values. Additionally, the error distribution in **Figure. 2 (b)** shows that most prediction errors are under 0.4 MPa, confirming the model's reliability and accuracy.

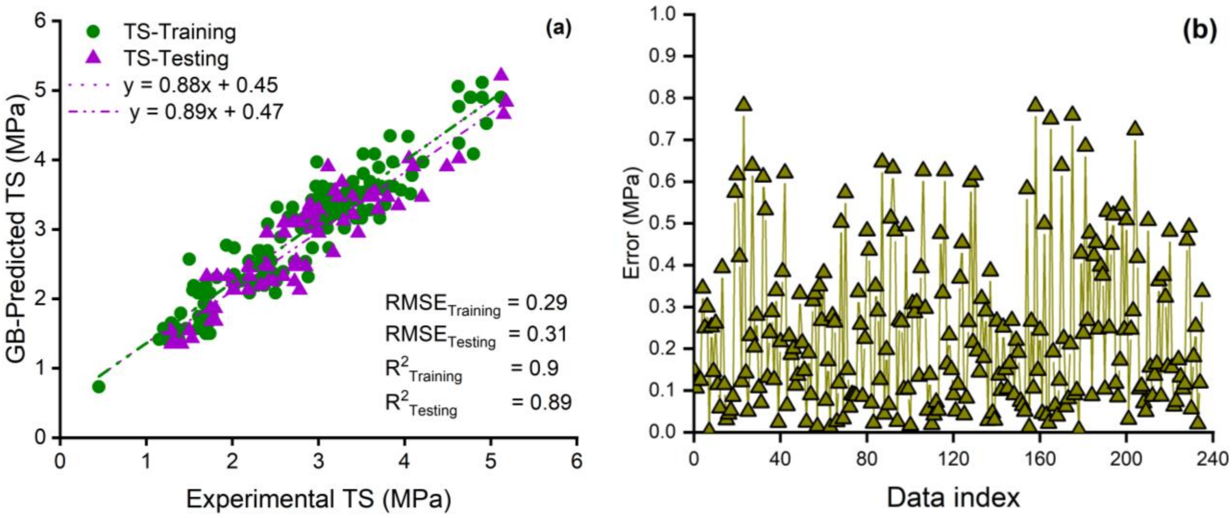


**Figure 2:** GB performance evaluation plots (a) regression plot and (b) absolute error plot.

**Table 2:** Statistical performance metrics outcomes for the GB model.

| Phase | RMSE | $R^2$ | MAE |
|---|---|---|---|
| GB-Training | 0.291 | 0.901 | 0.227 |
| GB-Testing | 0.317 | 0.891 | 0.254 |

These results clearly demonstrate the effectiveness of GB in predicting the TS of concrete containing WP. According to the literature [24], an $R^2$ value above 0.8 indicates good predictive accuracy, which is achieved in this case. Likewise, the low RMSE and MAE values further confirm that the model's predictions are precise and reliable. The model's high accuracy is due to its capacity to learn how the input features interact to influence the target which is tensile strength in this case. Moreover, using GB in this context aligns with the broader trend of employing advanced ML techniques in civil engineering to enhance material mix design and properties prediction. The findings support the feasibility of incorporating WP in concrete, contributing to sustainable construction practices.

## 4. Conclusions

This study demonstrates the effectiveness of Gradient Boosting in predicting the tensile strength of concrete incorporating waste plastic. The model demonstrated strong predictive performance, attaining $R^2$ values of 0.88 (training) and 0.89 (testing), along with low RMSE values of 0.29 MPa (training) and 0.32 MPa (testing), indicating reliable predictive results. These results suggest that GB can be a valuable addition to the toolkit for designing and evaluating sustainable concrete materials. Future work could explore the application of other ML techniques and expand the dataset to further improve prediction accuracy and generalizability.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| WP | Waste plastic |
| MAE | Mean absolute error |
| ML | Machine learning |
| TS | Tensile strength |
| GB | Gradient boosting |
| RMSE | Root means squared error |

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