

INTEGRATION OF MACHINE LEARNING TECHNIQUES TO PREDICT THE BOND PERFORMANCE OF CFRP/CONCRETE

R.M.H.P. Rajapakse¹, J.C.P.H. Gamage^{1,2}, E.R.K. Chandrathilaka^{1,*}

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa

² Engineering Institute of Technology, Brisbane Campus, Australia, QLD 4000

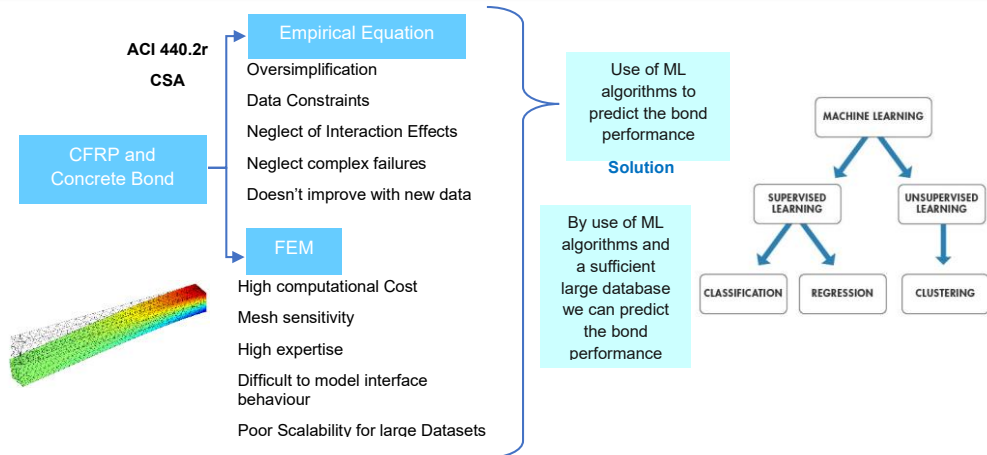
The application of machine learning (ML) techniques to forecast the bond performance of carbon fiber reinforced polymer (CFRP) with concrete is thoroughly examined in this study. The bond behaviours between CFRP and concrete are a critical factor that influences CFRP's performance in structural rehabilitation, retrofitting, and strengthening operations. A solid and durable bond is necessary for the CFRP and the concrete substrate to transfer stress effectively. Enhancing the reinforced member's service life and structural performance is another important function of this bond. Empirical equations obtained through experimental testing and finite element modelling (FEM) techniques have been utilized for years to predict and simulate the response of CFRP-concrete bonds. Although empirical relations offer rapid approximations, they frequently oversimplify the complicated interactions among geometrical parameters, surface preparation methods, and material properties. FEM approaches, on the other hand, can simulate complex behaviours, but they are computationally demanding, time-consuming, expensive to validate experimentally, and frequently constrained by the availability and quality of input data. These limitations emphasize the urgent need for alternative techniques that will result in increased precision and effectiveness. This study uses a large database of more than 800 single-lap shear test results obtained from diverse sources to explore the issue of whether ML models can forecast bond performance. Several ML models were tried and tested, ranging from simple regression techniques to complex ensemble learning models. The models that have been explored are K-Nearest Neighbours (KNN), Support Vector Machines (SVM), Artificial Neural Networks (ANN), Linear Regression, Polynomial Regression, and higher-order ensemble models such as LightGBM, CatBoost, and XGBoost. The results show that ML models are the best in capturing the complex nonlinear patterns of the bond behaviour between CFRP and concrete of all the models that were tested, the XGBoost ensemble model provided the best prediction performance with a final value of coefficient of determination (R^2) equal to 0.9893 and a final value of mean squared error (MSE) equal to 0.8736. The results are comfortably above the accuracy levels offered by conventional empirical methods or finite element simulations. Apart from being able to offer predictive accuracy of a high order, the study applied SHAP analysis (SHapley Additive exPlanations) to elucidate how each input feature supports model prediction. With SHAP analysis, vital information was learned regarding the comparative significance of such variables as CFRP thickness, bond length, surface preparation method, and compressive strength of concrete. Aside from increasing confidence in the model's predictions, interpretability alerts engineers to the factors that are significant to bond strength and improves design and decision-making in practice. Finally, the results reveal the potential of ML to revolutionize structural engineering by predicting CFRP-concrete bond behaviour in a more efficient and interpretable manner. The key step toward data-driven engineering practice, the study opens the way to broader application of ML-based approaches in structural assessment, reinforced design, and retrofitting procedures.

Keywords: CFRP (Carbon Fiber Reinforced Polymer), Single lap shear test, Machine Learning (ML), SHAP, Cross validation, Hyperparameter tuning

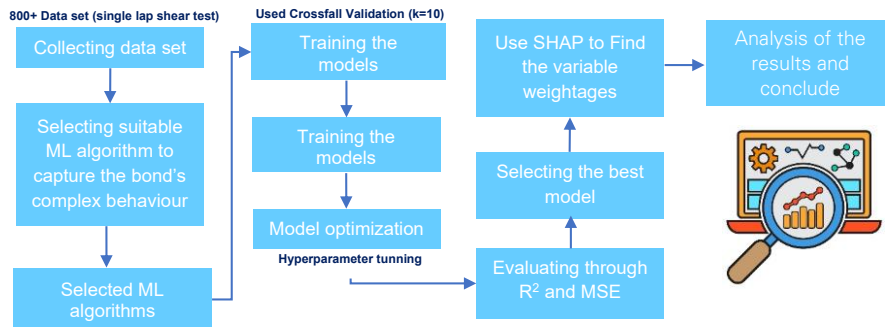
* Correspondence: kanishkach@uom.lk

INTEGRATION OF MACHINE LEARNING TECHNIQUES TO PREDICT THE BOND PERFORMANCE OF CFRP/CONCRETE

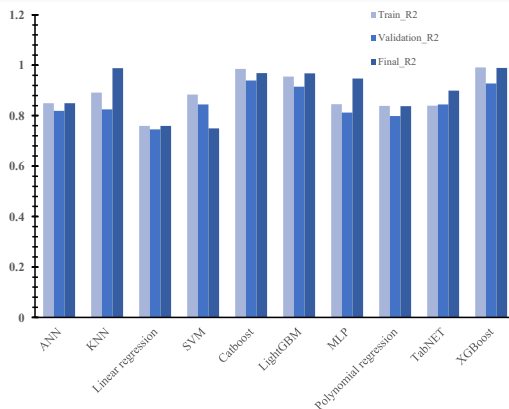
BACKGROUND



METHODOLOGY



RESULTS AND CONCLUSION



Best Algorithm
XGBoost

R^2 - 0.9893

SHAP analysis
Most influencing variables

Bond Width - 3.39
Bond thickness - 2.50

Improvement that can be made further

A large data set with a wide range of variable

Combine ML with existing equations

Improve the data set quality and quantity