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PREDICTION OF RESIDUAL STRENGTH OF RECYCLED AGGREGATE CONCRETE BY USING ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING TECHNIQUES

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Abstract: The sustainability of construction and its impact on the environment are becoming increasingly important to researchers and policymakers. As an eco-friendly option, recycled aggregate concrete (RAC) is gaining popularity. This study investigates the mechanical properties of RAC under outrageous circumstances, especially after openness to high temperatures. Key findings regarding the residual strength of RAC were synthesized through a comprehensive literature review. Inventive cross breed AI models were then evolved to foresee compressive strength, flexural strength, versatility modulus, and elasticity of RAC post-high temperature openness. With R2 values ranging from 0.91 to 0.96, these models performed well and provided professionals in the industry with equations that were simple to use. In addition to advancing sustainable construction, this work provides useful tools for everyday use.

Keywords: recycled aggregate concrete; machine learning model; mechanical properties; high temperature; regression; M5p; ridge; lasso

1. Introduction

Concrete's thermomechanical properties deteriorate as a result of physicochemical changes at higher temperatures that are influenced by aggregate type, cement matrix, and their interaction. At first, strength misfortune is minor at low temperatures yet becomes huge up to 600°C, where microcracking and total dissolving happen. Substantial's protection from high temperatures is its capacity to keep up with load-bearing capabilities under such circumstances. This resistance can be influenced, potentially leading to explosive spalling, by factors such as heating rate, maximum temperature, moisture content, calcium silicate hydrates, $Ca(OH)_2$ content, cement matrix, and aggregate type. The warm crisscross between growing totals and contracting concrete network prompts bond breaking at the interfacial change zone. When creating heat-resistant concrete, it is essential to take into account the aggregates because they make up 60–80 percent of the concrete's volume and have a significant impact on its behavior at high temperatures [1]. Reused total cement (RAC), with higher water retention, porosity, and more interfacial zones, acts uniquely in contrast to ordinary cement. Perceived as primary cement by the European Norm (EN 12620) and utilized in structures around the world, RAC is a supportable other option. However, more research is required into its high-temperature performance. The focus of this study is on RAC made solely from recycled aggregates in varying proportions. Advanced machine learning models have replaced statistical methods for predicting concrete properties based on material proportions. A hybrid model that used genetic algorithms and adaptive network-based fuzzy inference to predict compressive strength was created by Yuan et al. High accuracy and practical applicability were demonstrated by this genetically optimized model, which has the potential to replace conventional regression models. Support vector machine regression was used by Mozumder et al. to predict the uniaxial compressive strength of fiber-reinforced polymer-confined concrete, outperforming both existing empirical models and artificial neural networks. This suggests that this method is a reliable alternative for predicting the performance of concrete [2].

For estimating concrete compressive strength, Feng et al. proposed an adaptive boosting method for combining multiple weak learners into a strong learner. To verify the model's generalizability, they used 1030 sets of data on compressive strengths, aggregates, cement, water, additives, and curing times, in addition to 103 samples. Decision trees were identified as the best weak learners within the boosting framework, and as a result, their approach outperformed existing methods like artificial neural networks and support vector machines. Bingol et al. used artificial neural networks to model the compressive strength of lightweight concrete containing pumice aggregate at high temperatures, taking into account factors like temperature, the ratio of pumice to aggregate, and the amount of time that had to pass before heating [3]. The rising utilization of reused total cement (RAC) highlights the requirement for easy-to-use expectation techniques for its mechanical properties under different circumstances, particularly high temperatures. In order to accurately assess the mechanical characteristics of RAC following fire exposure, this study aims to provide engineers and researchers with a versatile instrument. There are no such predictive models in the literature, and machine learning applications in this context have been largely ignored. The linearity of the dataset is the first step in this investigation's quest for an ideal solution. The M5p decision tree method and a variety of linear regressions are used to create an interpretable and accurate model for predicting RAC's residual compressive strength, flexural strength, elasticity modulus, and splitting tensile strength in the event that linear models are insufficient. Utilizing metrics, cross-validation, uncertainty, and sensitivity analyses, these models are rigorously evaluated to determine the variables' importance and reliability [4-5].

2. Organization

2.1. Handling Unnecessary Data

Engineering issues with unbalanced data are common, especially when dealing with continuous numerical variables, which are more manageable than categorical variables. Oversampling minority groups or undersampling majority groups are common solutions. Due to the continuous nature of the target variable, defining minority groups in regression problems is difficult, and establishing target values for new data points adds complexity. This is addressed in three steps by the SMOTER procedure:

1. utilizing a relevance function to locate minority data [6-7].

2. interpolating new examples into a coherent whole.

3. calculating the new examples' target variables.

A Sigmoid function is used in this study to identify minority parts and determine the relevance of data points. Interpolating between minority data points chosen at random and assigned a weight variable between 0 and 1 creates new data points. This guarantees that the synthesized data remain within the original data's range. Averaging the target values of the two source points, which are weighted according to their distance from the synthesized point, yields the new points' target value [8-10].

2.2. Predictive Models

2.2.1. Model Tree

Regression trees have one drawback in that each leaf node only assigns a constant prediction value, which can result in oversimplification or very large tree structures. Model trees create a model at each leaf to extend this strategy and make it more understandable than other approaches like artificial neural networks. The M5p calculation is a vigorous model tree procedure, which includes three primary advances: tree development, pruning, and smoothing. Divide-and-conquer is used in tree construction to create subspaces with the lowest standard deviation, which measures error. Pruning eliminates overfitting by merging leaves with errors below a predetermined threshold into upper-level nodes to generalize predictions. Smoothing reduces the possibility of sharp discontinuities between adjacent nodes caused by pruning. According to Quinlan, smoothing improves accuracy [11-14].

3. Impression of Accepted Algorithm

Models for predicting the compressive, flexural, modulus of elasticity, and splitting tensile strengths of recycled aggregate concrete (RCA) are presented in this article. The models are meant to be easy to use for scientists, engineers, and practitioners. For compressive strength, sample sizes are 403, 65, 323, and 85, respectively, for flexural strength, splitting tensile strength, and modulus of elasticity. To guarantee vigor, the SMOTER method tends to information irregularity, trailed by over-testing if necessary. The method begins with mechanical property prediction models based on linear regression. Model creation is unnecessary if linear models are accurate. If this is not the case, a practical regressive equation-based rule-based decision tree-based hybrid model of model trees and linear regression is proposed. The performance is compared to that of support vector machine (SVM) and neural network (NN) models. The rectified linear unit activation function and three hidden layers containing 128, 64, and 32 neurons make up the NN model. The R2 and MSE metrics are used to assess each model.

4. Results and Conversation

4.1. Presentation of the Models

4.1.1. Comparative Residual Compressive Strength

The performance metrics for models that predicted the relative residual compressive strength of recycled aggregate concrete after being exposed to high temperatures are presented in Table 1. 175 synthesized samples were added to the original 403 samples to correct for data imbalance. R2 values of 0.75, 0.76, and 0.76 were obtained by the Lasso, linear, and ridge regression models, respectively, indicating that these models were unable to accurately represent the complexity of the problem. The proposed hybrid models, on the other hand, demonstrated significant performance enhancements. The M5p-Lasso model increased R2 by 12 percent to 0.84. Even better were the M5p-linear and M5p-ridge models, which had R2 values of 0.91 and 0.90, respectively. This half and half models outflanked both the brain organization (NN) and support vector machine (SVM) models in exactness. The metrics of the NN model were higher than those of the M5p-Lasso model, but it did not match the performance of the M5p-ridge and M5p-linear models. The SVM model performed slightly better than the linear models.

Table 1. Performance metrics of the developed models for the prediction of relative residual compressive strength.

Model	***R*2**	**MSE**
M5p-Lasso	0.85	96.21
M5p-linear	0.92	58.12
M5p-ridge	0.93	58.65
Lasso	0.77	148.19
Linear	0.78	146.95
Ridge	0.78	146.98
NN	0.89	87.55
SVM	0.79	142.52

Moreover, the M5p-direct model shows a somewhat preferred exhibition over the M5p-edge model, with a typical R2 of 0.84 and 0.83, individually. Importantly, the results show that M5p-linear and M5p-ridge's cross-validation accuracy is significantly higher than that of M5p-Lasso. This could be because of a superior speculation of these two models.

4.1.2. Comparative Residual Flexural Strength

The results of the models used to predict the relative residual flexural strength of recycled aggregate concrete that has been exposed to high temperatures are shown in Table 2. To address information irregularity, 34 incorporated examples were added to the 65 gathered examples. The outcomes show that non-crossover models can anticipate the objective with adequate precision, discrediting the requirement for half and half models. More specifically, the R2 values of 0.91, 0.93, and 0.94 for the Lasso, linear, and ridge regression models were all very high. This proposes that the issue of foreseeing the relative leftover flexural qualities of intensity uncovered reused total substantial displays huge linearity. Table 2 also contains the five-fold cross-validation outcomes. The M5p-Lasso, M5p-linear, and M5p-ridge models have, on average, validation R2 values of 0.88, 0.89, and 0.88, respectively. These outcomes demonstrate brilliant execution across every one of the three models, with unimportant contrasts in their exactness.

Table 2. Performance metrics of the model developed for the prediction of relative residual flexural strength.

Model	***R*2**	**MSE**
Lasso	0.95	109.65
Linear	0.97	86.88

Ridge	0.99	86.68

4.1.3. Comparative Residual Elasticity Modulus

To address imbalanced information, 137 combined examples were added to the 327 gathered information tests. With R2 values of 0.74, 0.76, and 0.75 for M5p-Lasso, M5p-linear, and M5p-ridge, respectively, non-hybrid models provided suboptimal accuracy. As a result, hybrid models were created. With an R2 value of 0.9, the M5p-linear model was the most accurate of these, while the M5p-Lasso and M5p-ridge models performed sub-optimally with R2 values around 0.85. This pattern was also confirmed by the Mean Squared Error (MSE), with M5p-linear performing best. For the brain organization (NN) and support vector machine (SVM) models, an unobtrusive change in execution was noticed contrasted with the general leftover compressive strength models. The SVM model accomplished a R2 esteem equivalent to that of the direct model however was outstandingly lower than the half breed models, like the lingering compressive strength models. On the other hand, the NN model displayed lower execution contrasted with each of the three half breed models, varying from the situation with lingering compressive strength models where the NN's presentation outperformed that of the M5p-Tether model.

4.1.4. Comparative Residual Splitting Tensile Strength

To manage imbalanced information, 42 orchestrated examples were added to 116 gathered information tests. Based on the R2 value, all three models predict the relative residual splitting tensile strength of recycled aggregate concrete with excellent accuracy, capturing over 95% of the complexity of the problem. This is a mark of outrageous linearity of the issue.

4.2. Doubt Analysis

The M5p-linear model gives the best results for relative residual compressive strength, as was anticipated, with a 95% confidence interval of 15.24 to 14.60. A linear model with a 95% uncertainty bandwidth of 17.99 has the lowest uncertainty for the relative residual flexural strength. Also, the M5p-linear model has the lowest uncertainty for the relative residual elasticity modulus, with a 95 percent uncertainty bandwidth of 14.31 and a 95 percent range of 13.71 to 14.92. In comparison to the linear and Lasso models, the uncertainty result for the relative residual splitting tensile strength produced by the ridge model is superior. In general, the proposed models give an elevated degree of conviction in foreseeing the boundaries under study.

4.3. Compassion Analysis

Maximum temperature is the most crucial parameter for the compressive strength prediction model, with the R2 value decreasing the most. On the other hand, exposure time and cement content have a negligible impact on the model's accuracy, resulting in a reduction of 5% and 0% in the F/C and W/C, respectively. The RCA proportions, on the other hand, are somewhat relevant to the model because they all contributed to an accuracy decrease of 50% to 40%. The importance order of the variables for flexural strength is slightly different. Noncontributing factors for the flexural strength prescient model are openness time, equivalent to compressive strength, and RCA extent. Any remaining boundaries are essential for the model and overlooking any of them prompts in excess of a 90% decrease in the exactness of the model. The only nonimportant variable in the elasticity modulus predictive model is the exposure time. The factors arranged by significance are F/C, W/C, max temperature, concrete substance, and RCA extent. The awareness examination for parting rigidity prompted fascinating perceptions. Max temperature was the only variable whose accuracy decreased when replaced with its average. For the remaining variables, there was almost no change in accuracy. This can be made sense of by the way that these factors catch a similar change of the objective variable. Since another variable can capture the same variance of the target variable, changing only one of them does not affect the model's accuracy.s

5. Conclusions

This study intended to foster prescient models for assessing the overall leftover mechanical properties of reused total cement after openness to raised temperatures, including compressive strength, flexural strength, flexibility modulus, and ductile parting strength. At first, linear models were used, which performed well for splitting tensile strength and flexural strength but not well enough for compressive strength or elasticity modulus. Hence, mixture models consolidating M5p and straight models were proposed to improve exactness and relevance. Compared to traditional machine learning methods like neural networks (NN) and support vector machines (SVM), the hybrid approach has a number of advantages, especially the ability to provide transparent and comprehensible results through rule-based frameworks. For real-world applications, such as assessing the structural integrity and functionality of buildings following fires, this transparency is essential. Each model was subjected to an uncertainty analysis, and 95% confidence intervals were established to show that the proposed models were more accurate and reliable than alternatives. In addition, sensitivity analysis revealed that exposure time had little effect on mechanical property prediction, while maximum temperature had the greatest influence. In addition, while the proportion of recycled concrete aggregate (RCA) played a smaller role in predicting flexural strength and splitting tensile strength, it had a significant impact on predicting compressive strength and elasticity modulus. Engineers can effectively assess structural performance and stability based on mixture design and post-fire environmental conditions with this nuanced understanding. In conclusion, the developed models offer useful resources for evaluating the mechanical properties of RCA structures following fires. By utilizing these models, designers can direct far reaching underlying examinations to guarantee the flexibility and wellbeing of reused total cement in different situations.

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