Compressive strength prediction of ordinary concrete, fly ash concrete, and slag concrete by novel techniques and presenting their optimal mixtures

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ABSTRACT

In this study, four concrete types, including ordinary Portland cement concrete, fly ash concrete, slag concrete, and slag-fly ash concrete, are taken into account in order to estimate their compressive strength by two novel machine learning methods (genetic algorithm and soccer league competition algorithm), and four types of regressions (linear, 2nd order polynomial, exponential, and logarithmic). Subsequently, the precision of prediction models are compared based on performance indicators, and the most accurate models are applied in the optimization problem modeling. Drawing on results, the most precise model to estimate the compressive strength of ordinary Portland cement concrete is the genetic algorithm, and the soccer league competition is the most accurate model to estimate the strength of other concrete types. Afterward, a model is developed so as to design mixture proportions of 40MPa concretes. Fly ash concrete, slag-fly ash concrete, and slag concrete reduce the unit cost by 35.2%, 29.9%, and 23.1%, respectively, compared with ordinary Portland cement concrete. Fly ash concrete, slag-fly ash concrete, slag concrete, and ordinary Portland cement concrete require 217.25 kg, 150.47 kg, 102 kg, and 414.64 kg cement to be manufactured. Furthermore, the slag concrete can reduce the amount of cement in the mixture proportion by 75.4%, and it is the most eco-friendly concrete.

KEYWORDS

Compressive strength prediction, Mixture design optimization, Machine learning, Regression, Metaheuristic algorithms

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1. Introduction

Cement, aggregate, and water are fundamental concrete ingredients. Approximately 6.1 million tons of concrete are produced annually. 1.5-ton materials and roughly 4000 MJ energy are consumed to produce each ton cement. Therefore, cement has been considered a harmful material to the environment. Moreover, the weights of other concrete ingredients in the mixture proportion considerably affect several concrete features such as strength, durability, environmental pollution, and cost. Hence, finding the optimal mixture proportion of concrete has been a significant concern [1].

The optimal mixture proportioning of concrete is generally obtained by the experimental test method. Nonetheless, huge amounts of landfills are generated, raw materials are consumed, various emissions are produced, a considerable amount of energy is consumed, and it takes a long time to find an appropriate mixture proportion. Furthermore, the optimal mixture proportion may not be obtained by the experimental test method because it only considers a finite number of specimens [2].

Various computational techniques are employed to design the optimal mixture ingredient. Machine learning approaches are employed to predict concrete's vital features, and optimization techniques are applied to optimize the mentioned features [3].

In this investigation, a new prediction method called "soccer league competition programming (SLC" is developed to estimate concrete's compressive strength. Subsequently, the optimal mixture proportion of four different concretes containing fly ash concrete (FA), ordinary Portland cement concrete (OC), slag concrete (BFGS), and concrete containing fly ash and slag simultaneously (FAS) are designed.

2. Methodology

In this study, a new prediction technique (SLC) is developed, and it is compared with the conventional prediction methods, including genetic programming (GA), linear regression (LR), 2nd polynomial regression (PR), exponential regression (ER), and logarithmic regression (LOR). These regressions are selected due to the capability of regression to generate the equation of target based on model's features. The SLC is inspired by the soccer league competition that is a robust metaheuristic algorithm. This algorithm is originated by the real-life soccer league competition among various teams and players in order to win titles and become super star players [4]. This optimization algorithm is converted a prediction method based the details and procedures provided by Naseri et al [1]. The precision of machine learning methods is compared based on the determination coefficient (R^2), mean absolute error (MAE), and root mean square error (MSE) [5], indicated in Eqs.(1) to (3), respectively.

$$R^2 = \left(\frac{\sum_{i=1}^{n} (\mathrm{EXP}_i - \overline{\mathrm{EXP}_i}) \times (PRE_i - \overline{PRE_i})}{\sqrt{\sum_{i=1}^{n} (\mathrm{EXP}_i - \overline{\mathrm{EXP}_i})^2 \times \sum_{i=1}^{n} (PRE_i - \overline{PRE_i})^2}} \right)^2 \quad (1)$$

$$MAE = \frac{\sum_{i=1}^{n} \left| EXP_i - PRE_i \right|}{n} \quad (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (EXP_i - PRE_i)^2}{n}} \quad (3)$$

Where, EXP_i, $\overline{EXP_i}$, PRE_i, $\overline{PRE_i}$, and n are the results of experimental data, the average of results of experimental data, predicted data, the average of predicted data, and the number of samples in the order given.

Subsequently, the equation of different concrete's compressive strength is used in concrete mixture proportioning optimization. A deterministic optimization approach is utilized to solve optimization problems. The aim of the optimization problem is to minimize the concrete unit cost, reduce the cement content in concretes' mixture ingredient, and design the concrete mixture design with required compressive strength.

Afterward, the optimal mixture designs are compared according to concretes' essential criteria.

3. Results and Discussions

The SLC is modeled, and it is employed to predict the compressive strength of FA, OC, BFGS, and FAS. The accuracy of SLC is compared with GA, LR, PR, and LOR based on R^2, and the results are illustrated in Fig. 1. Similarly, the precision of prediction algorithms are compared based on MAE, and the outcomes are presented in Fig. 2. The machine learning methods' performance is analyzed according to RMSE, and the accuracy comparison is demonstrated in Fig. 3.

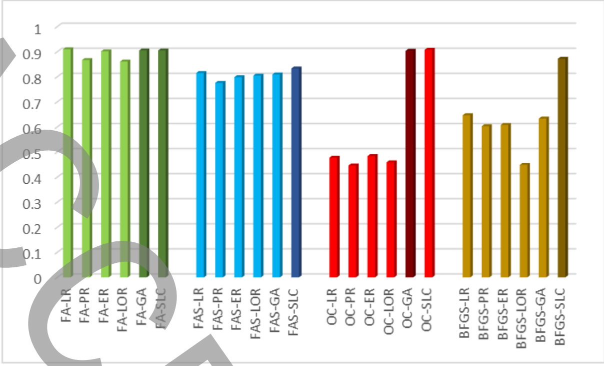

Fig. 1. Machine learning methods' precision based on R^2 for different concrete types

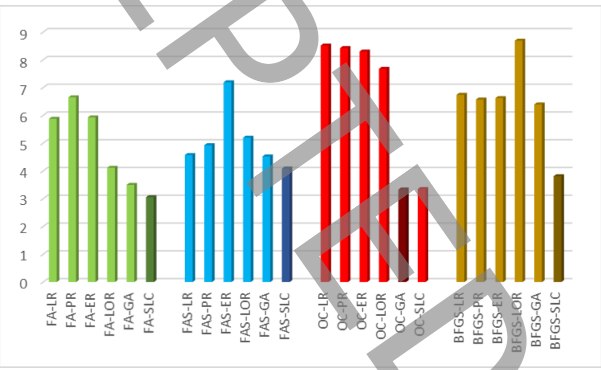

Fig. 2. Machine learning methods' precision based on MAE for different concrete types

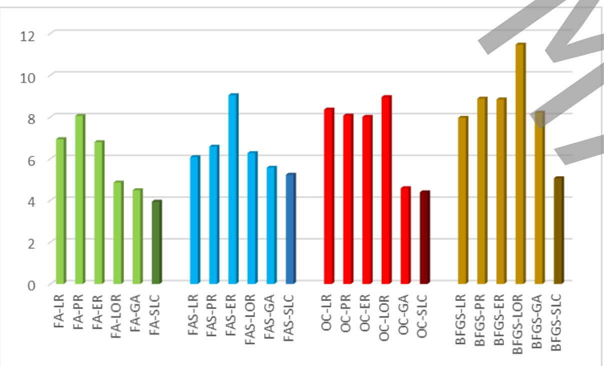

Fig. 3. Machine learning methods' precision based on RMSE for different concrete types

As can be seen from Fig. 1, Fig. 2, and Fig. 3, the introduced algorithm noticeably outperform LR, PR, and LOR based on R^2, MAE, and RMSE in all concrete types.

The mixture designs of different concrete types with 40 MPa strength are optimized, and the optimal mixture design of concretes and their corresponding unit cost are presented in Table 1.

Table 1. Optimal mixture proportions (kg/m^3) and their corresponding cost

Material	FA	BFGS	FAS	OC
Cement	217.25	102	150.47	414.64
Slag	0	302.12	90.07	0
Fly ash	200	0	1193	0
Water	161.39	195.01	172.74	101.59
Superplasticizer	4.18	6.21	6.15	12.17
Coarse aggregate	1098	859.96	1074.65	1125
Fine aggregate	746.39	859.94	703.46	895.63
Cost (USD)	82.32	97.76	89.13	127.13

4. Conclusions

SLC provides the highest accuracy compared with powerful regression models. FA is the cheapest concrete, followed by FAS, BFGS, and OC. Moreover, FA, FAS, and BFGC can reduce the cement consumption by 35.2%, 29.9%, and 23.1% compared with OC.

5. References

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