Construction and Building Materials 180 (2018) 320–333

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

A modified firefly algorithm-artificial neural network expert system for predicting compressive and tensile strength of high-performance concrete

Dac-Khuong Bui [a], Tuan Nguyen [a], Jui-Sheng Chou [b], H. Nguyen-Xuan [c,*], Tuan Duc Ngo [a,*]

[a] Department of Infrastructure Engineering, The University of Melbourne, Melbourne, Australia
[b] Department of Civil and Construction Engineering, National Taiwan University of Science and Technology, 43, Sec. 4, Keelung Rd., Taipei 106, Taiwan
[c] Center for Interdisciplinary Research in Technology, Chi Minh City University of Technology (Hutech), Ho Chi Minh City, Viet Nam

HIGHLIGHTS

- The compressive and tensile strength of high-performance concrete (HPC) is a highly nonlinear function.
- An expert system is proposed to predict the compressive and tensile strength of HPC.
- The expert system is based on artificial neural network and modified firefly algorithm.
- The proposed approach provides an efficient and accurate tool to predict and design HPC.
- The system significantly reduces the amount of laboratory work required.

ARTICLE INFO

Article history:
Received 9 November 2017
Received in revised form 31 March 2018
Accepted 24 May 2018

Keywords:
High-performance concrete
Data mining
Evolutionary optimization
Artificial neural network
Modified firefly algorithm

ABSTRACT

The compressive and tensile strength of high-performance concrete (HPC) is a highly nonlinear function of its constituents. The significance of expert frameworks for predicting the compressive and tensile strength of HPC is greatly distinguished in material technology. This study aims to develop an expert system based on the artificial neural network (ANN) model in association with a modified firefly algorithm (MFA). The ANN model is constructed from experimental data while MFA is used to optimize a set of initial weights and biases of ANN to improve the accuracy of this artificial intelligence technique. The accuracy of the proposed expert system is validated by comparing obtained results with those from the literature. The result indicates that the MFA-ANN hybrid system can obtain a better prediction of the high-performance concrete properties. The MFA-ANN is also much faster at solving problems. Therefore, the proposed approach can provide an efficient and accurate tool to predict and design HPC.

1. Introduction

Nowadays, high-performance concrete (HPC) has many applications in civil engineering, including high-rise buildings, high-speed railways, bridges and extreme loading (e.g., fire, blast, impact) resistance systems [1–12]. HPC has not only high compressive strength but also low permeability, and a high modulus of elasticity. Compared with ordinary concrete, which is composed of three main components including water, fine and coarse aggregates, and cement, HPC is supplemented by an additional cementitious material, for instance, silica fume, nano-silica, blast furnace slag and fly ash to enhance its compressive strength [13–15]. However, the properties of HPC depend on many elements such as mix proportions, material quality and the age of concrete [16].

Therefore, predicting the compressive and tensile strength of HPC is an important task because it can help to schedule operations in the early stages of structural design, thereby reducing experimental requirements. Thus, an accurate method for forecasting the compressive strength of HPC can significantly reduce time and cost. Many researchers have used mechanics-based simulation methods to quantify the strength of concrete [17–22]. Rabczuk et al. modeled the fracture of several reinforced concrete structures by using a three-dimensional mesh-free method [18]. Rabczuk and Belytschko applied particle methods to solve several fracture problems involving reinforced concrete structures and the computational results showed good agreement with experimental data

* Corresponding authors.
E-mail addresses: ngx.hung@hutech.edu.vn (H. Nguyen-Xuan), dtngo@unimelb.edu.au (T.D. Ngo).

https://doi.org/10.1016/j.conbuildmat.2018.05.201
0950-0618/

[20]. Rabczuk et al. proposed a two-dimensional approach to model the fracture of reinforced concrete structures and took into account the interaction between the concrete and the reinforcement [22]. Drzymałaa used a testing method to investigate the effects of high temperatures on the properties of HPC [23]. Zhao et al. performed an experimental study on the shrinkage of HPC containing fly ash and ground granulated blast-furnace slag [24]. In addition, several linear and nonlinear methods were carried out to find the relationship between the key factors, that may influence the compressive strength of HPC such as cement, fly ash, water, superplasticizer and age of testing [16,25].

However, these methods make it difficult to obtain an accurate regression function because the compressive strength of HPC is affected by many factors. Also, the properties of concrete have a highly nonlinear relationship with its constituents, which poses difficulties in calculating the compressive strength of HPC from available data [26]. As a result, the common methods used for conventional concrete are often unsatisfactory for forecasting the compressive strength of HPC.

Many Artificial intelligence (AI) techniques have been proposed to solve the aforementioned problem. Chou and Pham introduced ensemble models to forecast the compressive strength of HPC [27]. This ensemble model was created by combining many individual AI techniques. Prasad et al. used an artificial neural network (ANN) model for predicting the compressive strength of self-compacting concrete and HPC [28]. Naderpour et al. predicted the compressive strength of recycled aggregate concrete by using ANN [29]. Ali et al. predicted the compressive strength of ordinary concrete and HPC by using the M5P model tree algorithm [30]. These AI techniques disregard any physical interaction between the input and output variables. In addition, the input parameters of the predictive data should be within the range of input parameters of the trained data, which is a shortcoming of these AI models [31]. These are all promising approaches but they are highly dependent on the initial parameters, which is a strong constraint that inhibits their performance.

Therefore, these AI techniques need to be combined with optimization algorithms and hybrid models [32]. Some authors have proposed these models to solve issues in many fields or areas. Nazari and Sanjayan optimized the parameters of a support vector machine to estimate the geopolymer, mortar and concrete compressive strengths [33]. In their research, five meta heuristic algorithms including the ant colony optimization algorithm, genetic algorithm, imperialist competitive algorithm, artificial bee colony optimization algorithm and particle swarm optimization algorithm, were used to optimize the parameters of the support vector machine (SVM). In another study, Marek applied Bayesian inference to a neural network for forecasting the compressive strength of HPC [34].

Among many optimization algorithms, the firefly algorithm is an efficient optimization tool, which was used to optimize machine learning models in many areas of research. Chou et al. used firefly algorithm-based least square support vector regression to solve many civil engineering prediction problems [35]. Ibrahim and Khatib optimized the random forests technique using the firefly algorithm and applied this model to forecast hourly global solar radiation [36]. However, using the firefly algorithm for enhancing the capability of artificial neural networks (ANN) has not received much attention, especially in civil engineering.

Therefore, this research seeks to apply the modified firefly algorithm (MFA) to optimize the weights and biases of ANN for effectively predicting the compressive strength of HPC. Specifically, the firefly algorithm has been modified for high dimensional optimization and combined with two smart components such as chaotic map and Lévy flights. Moreover, the parameters of ANN are updated, memorized and optimized by MFA during the training process, so the computing time is remarkably reduced. This study also aims to validate the expert system by employing the k-fold cross-validation algorithm. Meanwhile, the performance of MFA-ANN will be compared with that of other techniques employed in similar work by hypothesis testing.

The remaining structure of the paper is divided into five sections. The next section presents a literature review on the current research related to prediction of the compressive and tensile strength of HPC by using machine learning technique. Section 3 describes the research methodology and performance evaluation methods. Section 4 outlines the properties that affected the compressive and tensile strength of high-performance concrete and two experimental datasets used in this study. Section 5 subsequently presents data preprocessing, model application, prediction of results of the MFA-ANN, and compares performance of the model with other methods based on the analytical results. The final section will summarize the research and provide concluding remarks.

2. Literature review

Forecasting the mechanical properties of concrete such as compressive strength is an important task in civil engineering because it requires many input parameters from various design practices [37,38]. An efficient and reliable model for estimating the compressive strength in the early stages of a project can certainly shorten project duration [37]. In recent years, many studies using various approaches for estimating the compressive strength of concrete have been reported [39–42].

Erdal [43] used two-level and hybrid ensembles of decision trees for predicting the compressive strength of HPC. In this study, the author proposed three different ensemble approaches including single ensembles of decision trees, a two-level ensemble approach and a hybrid ensemble approach. The obtained results demonstrate that the proposed ensemble models could significantly improve the prediction accuracy of the compressive strength of HPC. Another study was conducted by Yuvaraj et al. [44], who examined the applicability of support vector regression (SVR) to forecast the fracture characteristics of high strength and ultra-high strength concrete beams. The authors confirmed that SVR could obtain similar results with those from experiments.

Back in 1998, Yeh demonstrated the possibilities of using artificial neural networks (ANN) for predicting the compressive strength of HPC [26]. The author concluded that ANN obtained more accurate results than a model based on regression analysis, and ANN could be used as numerical experiments to review the effects of each ingredient in the concrete mix. In addition, Sobhani et al. compared adaptive network-based fuzzy inference systems and ANN models in terms of predicting the compressive strength of no-slump concrete [42]. This study indicated that ANN was more feasible in predicting the 28-day compressive strength of no-slump concrete than the traditional regression models.

However, the performance of ANN depends on the choice of initial weights and biases [45]. To this effect, many optimization algorithms were used to enhance the capability of ANN. Lee et al. proposed the harmony search algorithm to determine the near-global optimal initial weights in the training phase of ANN model [45]. Alavi and Gandomi proposed simulated annealing methods for determining the optimal initial weights of ANN [46]. Chang et al. used genetic algorithms to find the optimal set of initial weights to enhance the accuracy of ANN [47]. Liu et al. implemented the ensemble method to improve the accuracy of the ANN model [48].

The aforementioned studies agree that hybrid models achieve high-performance in solving prediction issues of many areas.