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Modelling of compressive strength of geopolymer paste, mortar and concrete by optimized support vector machine

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Abstract

To date, many artificial intelligence-based techniques have been conducted to predict compressive strength of concrete specimens. However, modified models by metaheuristic optimization algorithms to present approaches with higher performance may be of special interest. In this work, support vector machine (SVM) is utilized to predict compressive strength of geopolymers, cement-free eco-friendly construction materials. Parameters of SVM are sometimes hard to be found especially in the case of complex models. Therefore, task of finding these parameters was followed by five different well-known optimization algorithms including genetic algorithm (GA), particle swarm optimization algorithm (PSOA), ant colony optimization algorithm (ACOA), artificial bee colony optimization algorithm (ABCOA) and imperialist competitive algorithm (ICOA). Results of these five hybrid models were compared by a model using just SVM, and other traditional artificial intelligence techniques namely artificial neural networks (ANNs) and adaptive neuro-fuzzy interfacial systems (ANFIS). A total number of 1347 data were collected from the literature for modelling. It was suggested that hybrid models can be appropriately used for modelling of compressive strength of geopolymer paste, mortar and concrete specimens. By evaluating the proposed models through their coefficient of determination and errors, it was concluded that ICOA and GA are more suitable to optimize parameters of SVM for predicting compressive strength of the considered geopolymers. Additionally, ANN model was remained as one of the simplest approaches which can be used with reasonable accuracy for the problem of this paper.

Keywords: Geopolymer; Support vector machine; Particle swarm optimization; Ant colony algorithm; Bee colony algorithm

1. Introduction

Properties of concrete for specific applications depend on a wide variety of factors from mix design to the type of applied loads. Definitely, the main aspect of using concrete specimens is the mix design. Ranges in constituent materials and mixture proportions of concrete make the selection procedure hard. Additionally, it is not warranted that the selected mix design procedure is the best among the considered mixtures. Optimization by artificial intelligence (AI) tools may be one of the appropriate methods for mix design of concrete specimens. Application of metaheuristic algorithms such as genetic algorithm (GA) [1–6] and particle swarm optimization algorithm (PSOA) [7–12] to evaluate different properties of concrete mixtures has been reported widely in the literature.

Yuan et al. [1] successfully predicted the compressive strength of concrete by using a hybrid GA-artificial neural networks (ANNs) model, where GA was applied to optimize the weights and thresholds of back-propagation algorithm. In the Tsai's proposed weighted operation structures (WOS) [2], GA was used to determine selection of functions and proper weights by programming three kinds of concrete-typed specimen strengths including concrete compressive strength, deep beam shear strength, and squat wall shear strength. Lim et al. [3] used GA to optimize mix design of concrete. Several concrete mixtures were examined experimentally and were divided into high and normal strength specimens. The relation between compressive strength (and slump) and input parameters including water to binder ratio, water content, fine

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aggregate ratio, fly ash replacement ratio, silica fume replacement ratio, air-entraining agent content, and superplasticizer content was achieved by genetic programming (GP). The results indicated that GA is capable to optimize the mix design for the considered concrete specimens in both normal and high strength ranges. Lee et al. [4] used GA to perform the discrete optimization of reinforced concrete plane frames subject to combinations of gravity and lateral loads. Camp et al. [5] employed GA for discrete optimization of reinforced concrete frames to minimize the material and construction costs of the elements subject to serviceability and strength requirements which are described by the American Concrete Institute (ACI) code. Cheng et al. [6] utilized GA to optimize the input parameters of their proposed evolutionary support vector machine (SVM) model consisting of 1030 different concrete mixtures.

Tsai [7] used centre-unified particle swarm optimization (CUPSO) approach to optimize the strength in concrete cylinders, reinforced-concrete deep beams and reinforced-concrete squat walls, which had been predicted by hybrid multilayer perceptron (HMLP) networks. Gilan et al. [8] developed a hybrid support vector regression (SVR)–PSOA model to predict the compressive strength and rapid chloride penetration test results of concrete specimens, where PSOA was exploited to optimize the hyper-parameters for SVR. Jayaram et al. [9] used PSOA for design of high volume fly ash concrete mixes including cement content, fly ash content, and water content to maximize the 28-day compressive strength of concrete specimens. Cheng et al. [10] proposed an optimization method based on PSOA to determine thermophysical properties of phase change material (PCM)-concrete bricks. Fonna et al. [11] proposed inverse analysis by minimizing the cost function using PSOA for detecting the corrosion of reinforcing steel in concrete from a relatively small number of potential data measured on the concrete surface. Ahmadi-Nedushan and Varaee proposed [12] a hybrid multi-stage dynamic penalty-PSOA algorithm to solve the constrained cost optimization problem of one-way concrete slabs.

Although GA and PSO have shown their performance in optimization of engineering problems dealing with concrete specimens and structures, developing other algorithms more, to obtain higher performance, may be of interest. Ant colony optimization algorithm (ACOA), artificial bee colony optimization algorithm (ABCOA) and imperialist competitive optimization algorithm (ICOA), computational method used to solve optimization problems, may be considered as competitive methods by GA and PSOA.

The ant system was introduced by Dorigo et al. [13] and is a relatively new iterative search algorithm for science and engineering problems. It has been inspired by real ant colonies, where in a systematic collaboration ants look for the shortest path they efficiently find from their nest to a food source [14]. Through ACOA, an indirect form of memory of the performance of previously generated solutions is uniquely exploited [14,15]. Some applications of ACOA in civil engineering problems can be found in Refs. [14,16–18].

ABCOA belongs to the class of stochastic swarm optimization methods inspired by the foraging habits of bees in nature. The artificial bee colony is partially alike to the colonies in nature; however, some differences exist. In ABCOA, configuration of the collective intelligence of the social insect colonies is done by contribution of the communication systems between individual insects. ABCOA's basic idea is to create a colony of artificial bees called a multiagent system, which is capable of successfully solving difficult combinatorial optimization problems [19]. Some civil engineering problems have been solved efficiently by using ABCOA [19,20].

ICOA does not require the gradient of the function in its optimization process in spite of most of the methods in the area of evolutionary computation. ICOA begins by generating a set of candidate random solutions in the search space of the optimization problem where the generated random points, called the initial countries, are the complement of chromosomes in GA and particles in PSO. On the basis of the power of each country which is determined by cost function, some of the best initial countries become Imperialists and control the other countries which are now called colonies. Therefore, the initial Empires are formed [21]. Assimilation and revolution are the two main operators of ICOA where assimilation encourage the colonies of each empire to get closer to the imperialist state in the space of socio-political characteristics and revolution breeds sudden random changes in the position of some of the countries in the search space. Therefore, a colony may access to a better position by the chance of controlling the entire empire during assimilation and revolution [22]. Imperialistic competition takes place between all the empires to get possession of colonies of the other empires. Algorithm continues by assimilation, revolution, and competition until obtaining the best performance results [21,22].

Metaheuristic optimization algorithms not only are used as optimization tool for civil engineering problems, but they are employed to optimize parameters of artificial intelligence (AI) techniques [2,6,8,10–12]. To date, many AI techniques such as artificial neural networks (ANNs) and adaptive neuro-fuzzy interfacial systems (ANFIS) have been used for predicting the effect of mix design of concrete specimens on properties of hardened mixtures. Therefore, developing of newer AI methods such as support vector machine (SVM) may be of interest. SVM has been applied successfully to some civil engineering problems including mix design of concrete specimens [23–27]. However, there are limited works on hybrid SVM approaches, where parameters of this AI technique are optimized by metaheuristic algorithms. Some of these limited works in relation to civil engineering problems are achievable in Refs. [6,28].

In the present paper, hybrid and simple SVM models are used to predict compressive strength of geopolymer paste, mortar and concrete containing various mixture proportions. Geopolymers (alkali-activated binders) are produced by alkali activation of an aluminosilicate source such as fly ash, slag or metakaolin. These eco-friendly cement-free construction materials with lower greenhouse gases emissions [29–32] are considered as the most probable constituent materials for ordinary Portland cement (OPC). Some evidence of their applications in construction can be found in some bridges