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Estimating unconfined compressive strength of cockle shell–cement–sand mixtures using soft computing methodologies

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ABSTRACT

The accuracy of soft computing techniques was used in this research to estimate the unconfined compressive strength according to series of unconfined compressive tests for multiple mixtures of cockle shell, cement and sand under different curing periods. We developed a process for simulating the unconfined compressive strength through two techniques of soft computing, the support vector regression (SVR) and the adaptive neuro-fuzzy inference (ANFIS). The developed SVR and ANFIS networks have one neuron (UCS) in the output layer and four neurons in the input layer. The inputs were percentage of cockle shell, cement and sand content in the mixtures, and age (in days). First, the ANFIS network was used to select the most effective parameters on the UCS. The linear, polynomial, and radial basis functions were employed as the SVR's kernel function. The simulation results proved the performance of proposed optimizers. Additionally, the results of SVR and ANFIS were compared through the Pearson correlation coefficient and the root-mean-square error. The findings show that the predictive accuracy and capability of generalization can be an improved by the ANFIS approach in comparison to the SVR estimation. The simulation results confirmed the effectiveness of the proposed optimization strategies.

1. Introduction

Currently, most of the materials used in concrete production are natural aggregates that are mainly excavated from mines, river beds or dredged from the sea shelf. Lately, several research works proposed to replace the natural aggregates in concrete with by-products and waste materials [1–5]. These innovative materials would help decreasing the environmental impacts due to over-exploitation of natural aggregates. Motamedi et al. [6], for instance, examined the effect of Pulverized Fuel Ash content on the Unconfined Compressive Strength (UCS) of the sand–cement mixture. Their results indicated that optimum PFA content can increase the UCS of the mixtures up to 40%. More recently, incorporation of ecological measures in construction has limited the use of conventional materials. Motamedi et al. [7] stated that the majority of conventional substances, which are used in production of the structural concrete, do not consider ecological imbalances that can occur to the environment.

In this regards, it is important to utilize eco-friendly, innovative waste and by-products for producing concrete and mortars. Huge volumes of Seashell-By-Products (SBP) are produced annually [8]. Authorities either burn or bury the majority of these wastes [9]. Environmental concern motivates the authorities to develop novel waste-utilization programs. Most of the studies conducted on utilization of Seashell By-Products (SBP) agree on the positive effect of this material on the final quality of the produced concrete [10,11].

The previous studies [12–14] investigated the main composition of SBPs and claimed that the Calcium Carbonate ($CaCO_3$) is the main component of these materials, having more than 90% of the total weight. Based on the majority of these studies, $CaCO_3$ is an economic alternative for replacement of sand and cement in concrete, or mortar production compared to other types of additives.

Falade [12] used the genus Viviparous (a type of freshwater snail) to produce cement mixtures. The results showed that both

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the tensile and the compressive strength of specimens decreased upon increase in the freshwater snail content. In a similar work, Yoon et al. [13] suggested that by replacing the sand with the ground oyster during production of the concrete and mortar mixtures, the unconfined compressive strength is decreased. In another work, Ballester et al. [14] reported that the inner components of mortar combined with the mussel shells produced interweaved structure and lowered void ratio, leading to higher compaction and bending resistivity. The grounded particles of mussel shell are slim needle shaped, contrasting the circular shape of the sand particles. Mosher et al. [15] reported that compared to the limestone powder, the ground SBPs (i.e. cockle shells and mussel shells) achieve higher compressive strength because they contain Aragonite (a form of $CaCO_3$) and Calcite (the most stable polymorph of $CaCO_3$).

The effect of ground SBPs as a replacement material to produce concrete or mortar has been widely studied. For instance, Lertwattanaruk et al. [16] utilized the cockle shell to increase the compressive strength of cement–sand mixtures. Their results proved that, in general, higher replacement ratio of cement by the cockle shell decreases the compressive strength in comparison to the mixtures, whereby the cement content is higher. Dissimilar to the workability and plasticity, the compressive strength is not of key significance for rendering and plastering utilizations [17]. Thus, applications that require lower strength material can use mortars and concrete materials composed of the SPBs. The previous studies have focused on the utilization of cockle shell as a SBP for the concrete or mortar production. Therefore, this article aimed to investigate the effect of cockle shell content on the Unconfined Compressive Strength (UCS) of the cement–sand mixtures.

This study used new soft computing techniques to warrant accurate UCS estimation for cockle shell–cement–sand mixture. The basic idea underlying the soft computing methodologies is to collect input/output data pairs, and use these data to learn the proposed network. The adaptive neuro-fuzzy inference system (ANFIS) or the neuro-fuzzy network are used to predict [24–27], model [18–23], and control [28–32] several engineering systems. The ANFIS combines the knowledge representation of fuzzy logic with the learning power of ANNs. Researchers use the improved version of ANNs, called the Support Vector Machines (SVMs), to forecast environment-related problems [33,34]. Specifically, the SVR algorithms developed for the regression problems are applied to a large variety of regression problems, because they not only consider the error approximation, but also the model generalization. These are based on a structural risk minimization principle and the statistical learning theory [35–37].

This study first used the ANFIS network for variable selection. The most influential parameters that are important for the UCS estimation were selected [38–41]. An advanced approach was employed that considers the variable selection problem as an optimization procedure via the genetic algorithms [42]. Proper explanatory variables (input) were selected to reduce the error between the model predictions (output) and the true values. Thus, the ANFIS was employed for searching the most influential input parameters (cockle shell (%), cement (%), sand and age in days) on the UCS (output parameter).

Moreover, this study used the SVR and the ANFIS schemes to estimate the UCS based on the input parameters. The SVR schemes applied polynomial function (SVR with polynomial kernel), the radial basis function (SVR with RBF kernel), and the linear function (SVR with linear kernel) to assess the UCS based on a series of unconfined compressive tests for several mixtures of cockle shell, cement sand and age (in days). The main purpose of this study was to examine the performances of ANFIS and SVR for estimation of UCS for cockle shell–cement–sand mixture.

2. Material and methods

2.1. Materials

2.1.1. Cockle shell

In this study, the cockle shell was collected from the Carey Island, Malaysia. Furthermore, the material was grounded until it turned into fine powder. Table 1 summarizes the physical properties of cockle shell. The physical properties of the ground cockle shell were examined based on the following standards; specific gravity in accordance with the ASTM C 118 [43], the strength index complied with the ASTM C311 [44], the particle size distribution through a laser particle size analyzer. Table 2 summarizes the chemical composition of the cockle shell based on the ASTM D 5381 [45], performed through the X-ray fluorescence spectrometry (XRF). Table 2 presents the chemical composition of the cockle shell based on the evaluation results. Fig. 1 depicts the color and texture of the cockle shell that was used in this study, and Fig. 2 illustrates the particle size distribution.

2.1.2. Cement

Cement is a man-made material, which is formed of Portland clinker and an average of 5% gypsum [46]. The cement is classified into five groups (*I–V*); in practice, the Portland cement classes I and II are consumed in construction [47]. The Portland cements Type I was used in this study. Table 2 summarizes the cement's chemical composition based on the ASTM D 5381 [45] performed through the XRF. The physical properties of cement, assessed in accordance with the ASTM C 150 [47] are summarized in Table 1, and Fig. 2 illustrates the particle size distribution.

2.1.3. Sand

Sand was a major material in this research; it was important to classify the sand type used in this research. In this study, the sand was categorized as poorly-graded sand (SP) according to the ASTM D 2487 [48]. The sand was collected from Selangor, Malaysia. Table 2 summarizes the chemical composition of the cement based

Table 1
Physical properties of cockle shell and cement used in this study.

Physical index	Cockle shell	Cement
Color	Pinkish light-Brown	Grey
Odor	Fishy smell	Odorless
Moisture content (%)	0.13	0.06
Specific gravity	2.74	3.04
Strength index – 7 days (%)	61.87	100
Loss in ignition (LOI) (%)	41.87	1.69
Water requirement (%)	98	100
Strength index – 28 days (%)	56.12	100

Table 2
Chemical composition for cement, cockle shell and sand used in this study.

Chemical component	Cement (%)	Cockle shell (%)	Sand (%)
Silica (SiO_2)	20.65	1.37	87.32
Aluminia (Al_2O_3)	5.87	0.14	5.24
Iron oxide (Fe_2O_3)	2.52	0.04	0.78
$SiO_2 + Al_2O_3 + Fe_2O_3$	29.04	1.55	93.34
Calcium oxide (CaO)	63.55	51.37	2.81
Sulphur trioxide (SO_3)	1.62	0.24	0.07
Magnesium oxide (MgO)	2.79	0.18	1.31
Potassium oxide (K_2O)	0.63	0.08	0.98
Sodium oxide (Na_2O)	0.85	0.46	0.41
Calcium carbonate ($CaCO_3$)	–	96.15	–
Titanium dioxide (TiO_2)	0.48	0.05	0.23