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Predicting the ingredients of self compacting concrete using artificial neural network

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Abstract Self compacting concrete (SCC) is a highly flowable type of concrete that spreads into form without the need of mechanical vibration. This paper presents a comparative study between two methodologies which have been applied on two different data sets of SCC mixtures, which were gathered from the literature, using artificial neural network (ANN). The two methodologies aim to get the best prediction accuracy for the SCC ingredients using the 28-day compressive strength and slump flow diameters as inputs of the ANN. In the first methodology, the ANN model is constructed as a multi input – multi output neural network with the six ingredients as outputs. In the second methodology, the ANN model is constructed as a multi input – single output neural network where the six ingredient outputs are predicted separately from six different neural networks of multi input – single output type. Also, the influence of the mixes homogeneity on the prediction accuracy is investigated through the second data set. The results demonstrate the superiority of the second methodology in terms of accuracy of the predicted outputs. Moreover, the uniformity of the training data assures the accuracy of the predicted ingredients.

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1. Introduction

SCC is a type of concrete which has the ability to get compacted under its own weight without the need to get vibrated, and without the occurrence of bleeding or segregation [1]. It could be used with areas with restricted features as well as the places with heavily reinforcement in order to ensure the filling in a proper way. Its first innovation took

place in the University of Tokyo in the last of 1986th by the team of professor Okamura, with the aim of improving the construction quality as well as overcoming the defects made by the workmanship [2]. As opposed to the traditional concretes, the SCC has more mineral fillers as well as bigger quantities of high range water reducer admixtures. On the other hand, it has a smaller maximum size for the coarse aggregate [3]. There are various pozzolanic materials which could be used in order to make SCC such as silica fume, granulated blast furnace slag, metakaolin and fly ash. Their influence on the SCC has been investigated by many researchers [4–7]. Fly ash was considered the most suitable as opposed to the other pozzolanic materials considering the quality control [8]. Other advantages could be gained by using the SCC such as reducing the construction time and the noise caused by casting [9].

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ANN was inspired by understanding the structure of the biological neurons in the human brain and knowing how it works [10]. Recently there was a wide interest by researchers of the ANN, which is approach for nonlinearly modeling, due to its ability to approximate or predict the nonlinear mapping (or linear) between the inputs and outputs of any complicated problem with an acceptable error. The approximation is done using a learning algorithm with the help of a training data set. The training data set is used in the form of pairs of training data pairs of inputs and outputs. The ANN could be used in the situations when there is information which is imprecise or not complete. The high capability of the ANN approximation makes it a suitable tool when the relationship between the inputs and outputs is not clear.

There are numerous researchers that have used the ANN in the discipline of civil engineering. Researchers have used the ANNs in predicting the properties of the following types of concretes: normal, high performance and self-compacting [11–13]. ANNs have been used also in detecting the damage of the structure [14], identifying the structure system [15], modeling the behavior of materials [16], monitoring the ground water [17], optimizing the structure [18], and making a model for the mixtures of flowable concrete in the constructions built underwater [19]. ANNs are extended to other applications in the civil engineering such as predicting the concrete compressive strength due to long-term sulfate attack [20], evaluating the chloride diffusivity in high performance concrete [21], and detecting the permeability of the asphalt concrete [22].

Recently, the SCC is widely used in the construction market. But, there is no accurate or standard design method for detecting its ingredients. So, to the best of the authors' knowledge and based on the previous studies, there are sufficient works that cover the prediction of SCC properties using ANNs. But the prediction of SCC ingredients as an output based on its hardened and fresh properties has not been covered well. So, this study aimed to use the ANN for predicting the ingredients of the SCC using the 28-day compressive strength and slump flow values. The artificial neural network is constructed, trained and tested using MATLAB R2013a Runtime Environment.

2. Artificial neural network

ANN could be considered as a network comprises several processors which are called units or neurons. The units are connected by channels for communication which are called connections. Each one of them carries numerical data which could be referred to as weights. The operations of the units are applied to the data received via the connections. It could be said that ANN has the capability of learning from the examples of input and output data pairs and making some generalization in order to deal with data not included in the initial inputs to generate the corresponding outputs. Some another data could be used with the aim of testing [23]. There are three main steps should be considered in order to build an effective neural network: choosing suitable architecture of the network, training the constructed network using sufficient training data set and testing the trained neural network to measure its accuracy via a different testing data set. The architecture of the network depends mainly on the number of hidden layers between the input and the output layers, the number of hidden

layers, the number of neurons in each layer and the type of activation function responsible for the effectiveness of the constructed neural network [10].

There are different types of neural networks such as Hopfield, Kohonen and back propagation network which has been used in this study [16,24]. Neural network with back propagation type has a structure consists of several layers: input layer, one or more hidden layers and output layer. The layer of inputs comprises units which represent the factors with possible influences on the outputs of the network but they don't have activities related to the computation processes. In the learning process using the back-propagation learning algorithm of ANN model, the errors of neurons outputs are getting propagated backward to the neurons of the hidden layer and then to the neurons of the input layer. These error signals are used to update the weights and biases of the ANN model using the generalized delta learning rule which is via the gradient descent of the error. The convergence depends mainly on several items such as the number of neurons in the hidden layer, the value of the learning rate parameter and the amount of the training data set. The optimization of choosing suitable architecture of the network could be achieved using trial and error method.

3. Database

The comprehensiveness of the data used for training is very vital to build an effective network, which will lead to a better learning for the network about all aspects of the relationship between inputs and outputs. Two different data sets have been used in this study, data set 1 which consists of 59 SCC mixes collected from different technical papers [25–47], as listed in Table 1. The data set 2 represents a homogenous sample of SCC mixes and contains 10 mixes taken from one technical paper [31] and is listed in Table 2.

4. Methodology

The parameters used in this study were the 28-day compressive strength and slump value as inputs. In both data sets, data set 1 and data set 2, the inputs were fixed in the process of training and testing in all methodologies and stages. There were two methodologies have been adopted for the outputs. The first methodology used a multi input – multi output neural network labeled as ANN-I to predict -at the same time and from the same network- the six ingredients outputs: cement, fly ash, water/binder (W/B), fine aggregate (FA), coarse aggregation (CA) and superplasticizer (SP). The architecture of the ANN-I network is shown in Fig. 1. Only the data set 1 is applied to the ANN-I network. The second methodology used a multi input – single output neural network labeled as ANN-II to predict one output of the six ingredients at a time. Thus, ANN-II network uses six times with different weights and biases to predict the six ingredient outputs. The architecture of the ANN-I network is shown in Fig. 2. The data set 1 and data set 2 are applied to the ANN-II network. All data sets are used in the training and testing processes for ANN-I and ANN-II network. The training process is done using the Levenberg – Marquardt backpropagation algorithm from matlab toolbox with its default settings. The run-time environment is MATLAB R2013a.

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