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Predicting the compressive strength and slump of high strength concrete using neural network

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Abstract

High Strength Concrete (HSC) is defined as concrete that meets special combination of performance and uniformity requirements that cannot be achieved routinely using conventional constituents and normal mixing, placing, and curing procedures. HSC is a highly complex material, which makes modelling its behavior very difficult task. This paper aimed to show possible applicability of neural networks (NN) to predict the compressive strength and slump of HSC. A NN model is constructed, trained and tested using the available test data of 187 different concrete mix-designs of HSC gathered from the literature. The data used in NN model are arranged in a format of seven input parameters that cover the water to binder ratio, water content, fine aggregate ratio, fly ash content, air entraining agent, superplasticizer and silica fume replacement. The NN model, which performs in Matlab, predicts the compressive strength and slump values of HSC. The mean absolute percentage error was found to be less then 1,956,208% for compressive strength and 5,782,223% for slump values and R^2 values to be about 99.93% for compressive strength and 99.34% for slump values for the test set. The results showed that NNs have strong potential as a feasible tool for predicting compressive strength and slump values.

Keywords: High strength concrete; Neural networks; Compressive strength; Slump

1. Introduction

High strength concretes (HSCs) are used extensively worldwide in construction projects [1,2]. A HSC is defined as concrete that meets special combination of performance and uniformity requirements that cannot be achieved routinely by using conventional constituents and normal mixing, placing, and curing procedures. In Europe, HSC is considered to be a concrete having a high strength at 28 days (typically >60 MPa compressive strength) or a low water-binder ratio (<0.40). In USA, HSC is supposed to be a special mixture, matching specific requirements that cannot be achieved on a routine basis [3]. In Turkey, HSC is considered to be a concrete having compressive strength >40 MPa at 28 days [4]. Several new advanced concretes have been transferred from laboratory research to practical applications and they already occupy a noticeable share of the market. Based on the latest developments in concrete technology, HSC is characterized by a superior level of properties: workability and strength. These advantages could provide large-scale cost savings in many construction projects [5].

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A major difference between conventional concrete and HSC is the use of chemical and mineral admixtures that reduce the water content, thereby reducing porosity within the hydrated cement paste [6]. The reduction in water content to very low value can be achieved by using high dosage of chemical admixtures. However, it is undesirable since the effectiveness of chemical admixtures such as superplasticizer (SP) depends on ambient temperature, cement chemistry, and fineness of aggregate. On the other hand, mineral admixtures act as puzzolanic materials as well as fine fillers resulting in a denser and stronger microstructure of the hardened cement matrix [7]. The mineral admixtures are generally industrial by-products and their usage can provide major economic benefits. Thus, judicial use of SP and mineral admixtures can lead to economical HSC with enhanced durability.

The actual compressive strength of concrete is unknown during the early life of the structure. Also, the concrete market is generally very competitive and it turns out that concrete companies have only restricted budgets to spend in mix-design, although from this fundamental stage comes a great deal of consequences for the site operations and for the structure to be built. Furthermore, in laboratory, to obtain desired concrete strength with suitable workability, technical personnel must try several mix proportions. This time consuming procedure increase the wastage of material and cost of concrete production.

The current empirical equations presented in the codes and standards for estimating compressive strength are based on tests of concrete without supplementary cementitious materials. The validity of these relationships for concrete with supplementary cementitious materials (fly ash, silica fume, superplasticizer, etc.) should be investigated. The more we know about the concrete composition versus strength relationship, the better we can understand the nature of concrete and how to optimize the concrete mixture [8].

Several researchers have looked into the characteristic parameters that affect the compressive strength and slump values of HSC. Some of these parameters include quality of aggregate, strength of cement, water content and water-to-cement ratio. The traditional approach used in modeling the effects of these parameters on the compressive strength and slump of concrete starts with an assumed form of analytical equation and is followed by a regression analysis using experimental data to determine unknown coefficients in the equation [9]. Unfortunately, rational and easy-to-use equations are not yet available in design codes to accurately predict the compressive strength and slump.

Over the last two decades, a different predicting method based on NNs has become popular and has been used by many researchers for a variety of engineering applications [8–16]. NNs are a family of massively parallel architectures that solve difficult problems via the cooperation of highly interconnected but simple computing elements (or artificial neurons). Basically, the processing elements of a neural network are similar to the neuron in the brain, which consists of many simple computational elements arranged in layers [8]. The basic strategy for developing a neural network-based model for material behavior is to train a neural network on the results of a series of experiments using that material. If the experimental results contain the relevant information about the material behavior, then the trained neural network will contain sufficient information about material's behavior to qualify as a material model. Such a trained neural network not only would be able to reproduce the experimental results, but also it would be able to approximate the results in other experiments through its generalization capability [10].

Yeh [8], Kasperkiewics [11], Lai [12] and Lee [13] applied the NN for predicting properties of conventional concrete and high performance concretes. Bai [14] developed neural network models that provide effective predictive capability in respect of the workability of concrete incorporating metakaolin (MK) and fly ash (FA). Ji-Zong [15] developed an automatic knowledge-acquisition system based on neural networks to design concrete mix. Ji-Zong's system consists of three models: the mix-design model, the slump-prediction model, and the strength-prediction model; the first model is the core of the system with the other two models supporting the core. Guang and Zong [16] proposed a method to predict 28-day compressive strength of concrete by using multi-layer feed-forward neural networks. Dias and Pooliyadda [17] used back propagation neural networks to predict the strength and slump of ready mixed concrete and high strength concrete, in which chemical admixtures and/or mineral additives were used.

The aim of this paper is to present a methodology for predicting compressive strength of HSC with suitable workability. For this aim, a computer program was developed in Matlab. Using this program, a NN model with two hidden layers was constructed, trained and tested using the available test data of 187 different concrete mix-designs of HSC gathered from the technical literature. The data used in NN model were arranged in a format of seven input parameters that cover the water-to-binder ratio, water content, fine aggregate ratio, fly ash content, air entraining agent content, superplasticizer content and silica fume replacement. The proposed NN model predicts the compressive strength and slump value of HSCs.

2. Neural Network (NN)

Neural network is a functional abstraction of the biological neural structures of the central nervous