Composites: Part B 42 (2011) 473–488

Contents lists available at ScienceDirect

Composites: Part B

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

Prediction split tensile strength and water permeability of high strength concrete containing TiO_2 nanoparticles by artificial neural network and genetic programming

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ARTICLE INFO

Article history:
Received 25 August 2010
Received in revised form 15 October 2010
Accepted 7 December 2010
Available online 13 December 2010

Keywords:
A. Ceramic-matrix composites (CMCs)
B. Strength
C. Computational modeling

ABSTRACT

In the present paper, two models based on artificial neural networks (ANN) and genetic programming (GEP) for predicting split tensile strength and percentage of water absorption of concretes containing TiO_2 nanoparticles have been developed at different ages of curing. For purpose of building these models, training and testing using experimental results for 144 specimens produced with 16 different mixture proportions were conducted. The data used in the multilayer feed forward neural networks models and input variables of genetic programming models are arranged in a format of eight input parameters that cover the cement content (C), nanoparticle content (N), aggregate type (AG), water content (W), the amount of superplasticizer (S), the type of curing medium (CM), Age of curing (AC) and number of testing try (NT). According to these input parameters, in the neural networks and genetic programming models the split tensile strength and percentage of water absorption values of concretes containing TiO_2 nanoparticles were predicted. The training and testing results in the neural network and genetic programming models have shown that every two models have strong potential for predicting the split tensile strength and percentage of water absorption values of concretes containing TiO_2 nanoparticles. It has been found that NN and GEP models will be valid within the ranges of variables. Although neural network have predicted better results, genetic programming is able to predict reasonable values with a simpler method rather than neural network.

1. Introduction

Strength assessment of concrete is a main and probably the most important mechanical property, which is usually measured after a standard curing time. Concrete strength is influenced by lots of factors like concrete ingredients, age, ratio of water to cementitious materials, etc. The pore structure determines the transport properties of cement paste, such as permeability and ion migration. Permeability of cement paste is a fundamental property in view of the durability of concrete: it represents the ease with which water or other fluids can move through concrete, thereby transporting aggressive agents. It is therefore of utmost importance to investigate the quantitative relationships between the pore structure and the permeability. Through experimental studies and then numerical simulations of the pore structure and the permeability of cement-based materials, a better understanding of transport phenomena and associated degradation mechanisms will hopefully be reached [1].

Conventional methods of predicting various properties of concrete are generally based on either water to cement ratio rule or maturity concept of concrete [2]. Over the last two decades, a different modeling method based on neural networks (NNs) has become popular and used by many researchers for a wide range of engineering applications. 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 analogous to the neurons in the brain, which consist of many simple computational elements arranged in several layers [3]. The concrete properties could be calculated using the models built with NNs. It is convenient to use these models for numerical experiments to review the effects of each variable on the mix proportions [4–6]. Besides ANNs, genetic programming (GP) has begun to arise for the explicit formulation of the properties and the performances of concrete recently [7,8]. Genetic programming offers many advantages as compared to classical regression techniques. Regression techniques are often based on predefined functions where regression analyses of these functions are later performed. On the other hand, in the case of GP approach, there is no predefined function to be considered. In this sense, GP can be accepted

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doi:10.1016/j.compositesb.2010.12.004

to be superior to regression techniques and neural networks. GP has proven to be an effective tool to model and obtain explicit formulations of experimental studies including multivariate parameters where there are no existing analytical models [7,8].

The aim of this study is to predict split tensile strength and percentage of water absorption of several types of concrete with and without TiO_2 nanoparticles by ANNs and GP. Totally 144 split tensile strength and 144% of water absorption data from 16 different concrete mixtures were collected, trained and tested by means of different models. The obtained results have been compared by experimental ones to evaluate the software power for predicting the properties of concrete.

2. Experimental procedure

2.1. Materials

Two series of concrete were made in the laboratory. The first was normally vibrated concrete (NVC) series with ordinary river sand as aggregates and the second self-compacting concrete (SCC) series with limestone aggregates. The utilized materials are as below:

Ordinary Portland cement (OPC) conforming to ASTM C150 [9] standard was used as received. The chemical and physical properties of the cement are shown in Table 1. The particle size distribution pattern of the used OPC has been illustrated in Fig. 1.

TiO_2 nanoparticles with average particle size of 15 nm and 45 m^2/g Blaine fineness producing from Suzhou Fuer Import & Export Trade Co., Ltd. was used as received. The properties of TiO_2 nanoparticles are shown in Table 2. Scanning electron micrographs (SEM) and powder X-ray diffraction (XRD) diagrams of TiO_2 nanoparticles are shown in Figs. 2 and 3.

Locally available natural sand with particles smaller than 0.5 mm and fineness modulus of 2.25 and specific gravity of 2.58 g/cm^3 was used as fine aggregate for NVC series concrete. Crushed basalt stored in the laboratory with maximum size of 15 mm and specific gravity of 2.96 g/cm^3 was used as coarse aggregate in NVC series concrete.

Crushed limestone aggregates were used to produce self-compacting concretes, with gravel 4/12 and two types of sand: one coarse 0/4, for fine aggregates and the other fine 0/2, with a very high fines content (particle size < 0.063 mm) of 19.2%, the main function of which was to provide a greater volume of fine materials to improve the stability of the fresh concrete. A polycarboxylate with a polyethylene condensate defoamed based admixture (Glenium C303 SCC) was used. Table 3 shows some of the physical and chemical properties of polycarboxylate admixture used in this study.

Table 2
The properties of nano-TiO_2.

Diameter (nm)	Surface volume ratio (m^2/g)	Density (g/cm^3)	Purity (%)
15 ± 3	155 ± 12	<0.13	>99.9

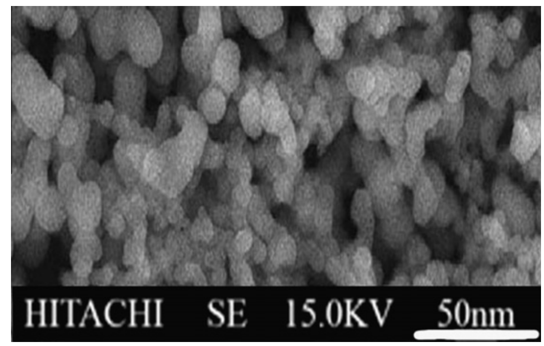

Fig. 2. SEM micrograph of TiO_2 nanoparticles.

2.2. Mixture proportions

Totally six series of mixtures were prepared and tested experimentally. C0 series mixtures were prepared as control specimens. The control mixtures were made of natural aggregates, cement and water. C0 series mixtures were cured in water (W) and saturated limewater (LW) and designated as C0–W and C0–LW series, respectively. N series were prepared with different contents of TiO_2

Table 1
Chemical and physical properties of Portland cement (wt.%).

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss on ignition
Cement	21.89	5.3	3.34	53.27	6.45	3.67	0.18	0.98	3.21

Specific gravity: 1.7 g/cm^3.

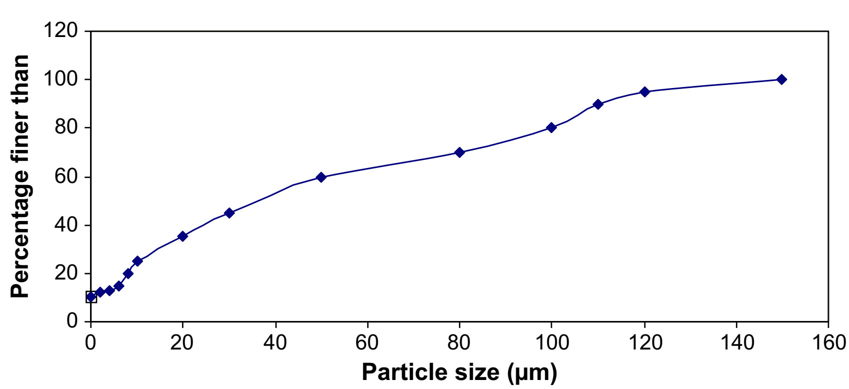

Fig. 1. Particles distribution pattern of ordinary Portland cement.