Construction and Building Materials 119 (2016) 277–287

Contents lists available at ScienceDirect

Construction and Building Materials

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

Prediction and modeling of mechanical properties in fiber reinforced self-compacting concrete using particle swarm optimization algorithm and artificial neural network

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HIGHLIGHTS

- Mechanical behavior of fiber reinforced SCC investigated.
- The rheological, and durability properties were tested and compared.
- The PSOA and ANN were used to predict mechanical properties of fiber reinforced SCC.

ARTICLE INFO

Article history:
Received 11 May 2015
Received in revised form 4 February 2016
Accepted 3 May 2016
Available online 18 May 2016

Keywords:
Fiber
Self compacting concrete
Artificial neural network
Particle swarm optimization algorithm

ABSTRACT

Intelligence system is a field of computer science that designs and studies efficient computational methods for solving problem. The purpose of present study is to investigate the effects of fibers on the performance of self compacting concrete (SCC). In this experiment study, 9 concrete mixtures containing two types of fibers (polyphenylene sulfide: 0.1, 0.2, 0.3 and 0.4% by volume and steel: 0.1, 0.2, 0.3 and 0.4% by volume) and unreinforced samples have been tested and compared. Fresh, mechanical and durability properties and ultrasonic pulse velocity of all SCC mixtures were evaluated. Then this experimental data was used to train the feed forward artificial neural network type. Finally the trained ANN (artificial neural network) and PSOA (particle swarm optimization algorithm) are used to generate a polynomial model for predicting SCC properties. The obtained results showed that the mechanical properties can be significantly improved by fiber reinforcement and workability of the SCC decreases with increasing fiber content. Moreover, steel fibers have better performance with relation to mechanical properties than polyphenylene sulfide fibers. In addition, PSOA integrated with the ANN is a flexible and accurate method in prediction of mechanical properties of fiber reinforced SCC properties.

1. Introduction

Self-Compacting Concrete (SCC) was first introduced to improve workability, stability and durability of concrete matrixes in Japan [1]. SCC is a highly flow able homogenous concrete which can eliminate several common problem in ordinary concretes such as permeability, segregation, bleeding, etc by means of its compaction under its own weight [2–3].

The behavior fiber reinforced concrete has been widely investigated by a number of researchers. El-Dieb [4–5] investigated the durability, rheological and mechanical properties of high strength steel fiber-reinforced SCC. Soutsos et al. [6] studied the flexural behaviors of fiber-reinforced SCC made with synthetic and steel fibers. Cattaneo et al. [7] presented an experimental study of the flexural performances of pre-stressed, composite and reinforced beams. Eren and Celik [8] explored the effect of silica fume and fibers on the performances of high strength fiber-reinforced concrete. They found that the fiber aspect ratio and fiber content has a significant effect on the compressive strength of the concrete. Moreover, they have shown that use fiber in concrete can increase the tensile, flexural, abrasion and impact resistance and can control the crack in concrete structures. Botson et al. [9] performed several tests in order to explore the effect of fiber in enhancing the shear resistance of steel fiber reinforcement beam. They reported that the presence of fibers will result in a reduction in crack spacing

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http://dx.doi.org/10.1016/j.conbuildmat.2016.05.034
0950-0618/

and widths. In additional the post peak strength increases significantly with an increase in fiber content. Parra-Montesinos et al. [10] studied the behavior of high-performance concrete beams reinforced with discrete fibers. They concluded that fibers inclusion limiting the propagation of splitting cracks at the interface between concrete and steel which leads to an improvement in the post-cracking ductility. Choi et al. [11] performed an investigation on the effects of polypropylene macro fiber surface area on the bond characteristics of the fiber. They found that changing the cross-sectional shape of fiber leads to a significant increase in surface area and better interlocking property of concrete.

The use of ultrasonic pulse velocity test as one of the nondestructive methods has recently become more popular for estimation of mechanical properties of concrete due to short length and low cost of the experiment. The ultrasonic pulse velocity of SCC is influenced by a number of parameters such as type of fiber, water–cement ratio, type of cement, aggregate used in mixture, concrete age, distance length, fiber content and curing time [12–14]. Malhotra and Carino [15] have investigated the velocity of wave propagation in concrete samples with different gravel amounts and water–cement ratio. They introduced a pattern for the estimation of concrete quality based on ultrasonic pulse velocity. Nik and Omran [16] investigated the effect of concrete age, nanosilica and fiber content on the ultrasonic pulse velocity of fiber reinforcement SCC. They found that the ultrasonic pulse velocity increases rapidly at an early age and the rate of increase in pore ultrasonic pulse velocity gets flatten later. Moreover, they report that nanosilica fiber inclusion increases the velocity of wave propagation in SCC specimens. Ulucan et al. [17] explored the effect of fly ash and silica fume on the ultrasonic pulse velocity of SCC. They reported that the ultrasonic pulse velocity decreased with increasing fly ash content.

Swarm intelligence models are computational models inspired by animal social behavior. Several swarm intelligence models exist in literature such as ant colony optimization (ACO), particle swarm optimization (PSO), artificial bee colony, bacterial foraging, cat swarm optimization, artificial immune system and glowworm swarm optimization. However as far as swarm intelligence applications in supply-chain management (SCM) are considered only ACO and PSO are prevalent in literature. Artificial neural networks are created as information processing tool that are inspired by biological neurons systems. As in nature, the network function is determined largely by the connections between elements. A neural network can be trained to perform a particular function by adjusting the values of the connections (weights) between the elements. Nowadays, the application of ANN and PSOA in the engineering world are well known to engineering sciences [18–25]. Tavakoli et al. [26] investigated the possibility of ANN for prediction the mechanical properties and energy absorption capability in fiber reinforced self-compacting concrete. They indicated that the ANN results are in very good agreement with experimental data. Kutanaei and Choobbasti [27] explored the capability of PSOA for modeling mechanical properties of fiber reinforcement cement sand.

In this study the performance of fiber reinforced SCC has been investigated. For this purpose the fresh, mechanical and durability properties and ultrasonic pulse velocity of fiber SCC mixtures were evaluated. Finally the PSOA integrated with the ANN is used to generate a polynomial model for prediction of mechanical properties of SCC.

2. Materials and mix plan

2.1. Materials

The gravel used in the present study was crushed gravel with a specific gravity of 2.61 a maximum size 12.5 mm and lies in grading curve of standard ASTM. Moreover, the sand used was natural river type with a specific gravity of 2.61 and was selected from Sieve No. 4.75 mm. The gradation curves for coarse and fine aggregates in accordance with ASTM C33 standard limits are presented in Fig. 1. In this study a superplasticizer (SP) upon ether carboxylic was used for improving the workability of SCC in all mix plans with the concentration of 7 kg/m^3 (its trade name is GELENIUM-110P) and the specific gravity of 1.1 g/cm^3 (at 20 °C). Two types of reinforcing fibers of steel and polyphenylene sulfide were used. The properties of the fibers are shown in Table 1 and Fig. 2. The cement used was commercially available Portland type II with the specific gravity of 3.12 which produced by Mazandaran cement companies in Iran. The chemical and physical properties are presented in Table 2 and 3. Limestone powder was used to make the SCC. The chemical properties of limestone are presented in Table 2.

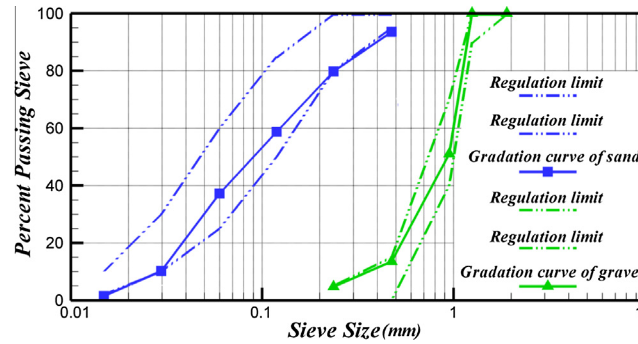

Fig. 1. Grading curve for fine and coarse aggregates used in the experiment.

Table 1
Properties of glass, steel and PPS fibers.

Type	Length (mm)	Diameter (mm)	Aspect ratio l/d	Elastic modulus (Gpa)	Density (g/cm^3)
St	40	0.7	57	160	7.8
PPS	50	0.8	62	35	0.9

2.2. Mix plan

Total of 9 mixtures were used for the experimental study. Mix plans included two types of fibers (polyphenylene sulfide: 0.1, 0.2, 0.3 and 0.4 vol.% and steel: 0.1, 0.2, 0.3 and 0.4 vol.%). Table 4 shows the concrete mix compositions for the samples. Ninety tests were performed to investigation the effect of fiber on the mechanical, durability and rheological properties of SCC. L-Box and slump flow tests were performed to assess the rheological and physical properties of fresh SCC. Furthermore, mechanical properties of harden concrete were assessed by compressive, splitting tensile, fracture energy and flexural strength tests. Water absorption and resistance to chloride ion penetration tests were conducted to determine the effect of fibers on the durability properties of SCC. Mechanical and durability properties of the hardened concrete were assessed at the age of 28 days. In addition, the non-destructive test techniques (ultrasonic pulse velocity test) are performed.

Each mixing design included three 100 × 100 × 100 mm cubic specimens for ultrasonic pulse velocity, water absorption and compressive strength test, three 300 × 150 mm cylindrical specimens for splitting tensile test, three 500 × 100 × 100 mm beam specimens for flexural strength test, three 100 × 200 mm cylindrical mold for chloride ion penetration test and finally three 100 × 100 × 840 mm beam specimens with an initial notch-depth equal to 50 mm for fracture energy test. Three identical samples were created for each test and their average value was considered. There were a total of 189 specimens for 9 mix design protocols. Once the mixing process was completed, the specimens were placed into molds and covered with cling film to prevent water loss and kept under laboratory condition for 24 h. They were then removed from the molds and kept in a water tank at 22 ± 2 °C until testing.

2.3. Test methods

In order to determine passing ability and filling property of fresh fiber reinforced SCC, L-box, V-funnel and slump flow tests were performed. Compressive and splitting tensile strength test were conducted according to the standard B. S1881:Part116 and ASTM C496, respectively. According to ASTM C597 and ASTM C293, ultrasonic pulse velocity and flexural strength values of specimens were determined, respectively. Moreover, chloride ion penetration test and water absorption test was performed according to the standard ASTM C1202-12 and ASTM C642-06, respectively.