Simulation of Early and Late Compressive Strength of Nano-Silica Concrete

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Abstract: This paper aims to examine the ability of the artificial neural network (ANN) to simulate both early and late compressive strength of nano-silica concrete. Two ANN models were developed to predict both 7-day and 28-day compressive strength of nano-silica concrete. Sex neurons representing OPC content, nano-silica content, w/b ratio, aggregate/cement ratio, dimensions of concrete specimens and 7-day compressive strength were considered in the input layer of the 28-day ANN model. The output layer includes one neuron, which represents the 28-day compressive strength. The first five neurons of the 28-day ANN model were also considered in the input layer of 7-day ANN model. High consistency was found between experimental data and ANN predictions. Both experimental and ANN results confirmed that replacing 1% cement by nano-silica results in the highest increases in early compressive strength, 1.5% nano-silica content gives the highest increases in late compressive strength, and both early and late compressive strength increase with decreasing dimensions of concrete samples. Therefore, the developed ANN models can be used as an alternative approach to predict both early and late strength of nano-silica concrete.

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1. Introduction

Simulation of strength development of concrete has a great positive impact on civil construction industry. This simulation helps to know the appropriate time for formwork removal and gives an idea about project scheduling and reduces the time for completion especially in the large civil construction projects. Concrete gains its desired strength during the first 28 days, but continues to do so over a long period of time after pouring. The 28-day strength of concrete is used as a characteristic compressive strength in all concrete applications. Due to the need to hasten the rate of construction progress, the characteristic compressive strength of concrete may be estimated from early age strength in most of the construction projects. The Egyptian code provides modification factors to estimate the early age strength of concrete based on the characteristic compressive strength. However these modification factors were adopted for specific types of cement namely ordinary Portland cement and rapid hardened Portland cement. Recently, the use of other more advanced materials in construction, such as nano materials, has shown significant improvement in strength development of concrete. Therefore, an alternative method to estimate the 28-days compressive strength of concrete made with such type of materials based upon the early strength data would be of great significance. A significant number of studies have been carried out in this area [1-4].

In the last years, the application of artificial neural networks (ANN) to overcome problems related to construction industry has attracted the attention of many authors. ANN technology has been used to estimate various mechanical characteristics of concrete [5-8]. The most important characteristic of ANN in civil construction-related problems is its capability of learning directly from examples. The other advantages of ANN are their good or nearly good handling of incomplete tasks and dealing with lack of available data. The above-mentioned capabilities make ANN a very promising tool to overcome many civil engineering problems, particularly problems, where data may be complex or in an insufficient amount [9].

2. Research Significance

The main objective of this article is to provide a reliable numerical technique capable of simulating strength development of concrete made with deferent replacement levels of nano-silica. The specific objectives were as follows:

1. To simulate the effect of various factors affecting both early and late compressive strength of nano-silica concrete such as OPC content, nano-silica content, w/b ratio, aggregate/cement ratio and dimensions of concrete specimens using ANN.

2. To determine the reliability of the developed ANN models in simulating strength development of nano-silica concrete.

3. Experimental Data

The experimental data considered thought this research were collected from some previous studies and listed in Table 1 [12-14]. Maximum and minimum values of the collected data are shown in Table 2.

Table 1: Experimental data considered when creating ANN models.

OPC, %	NS, %	W/b ratio	Specimen dimensions (mm)	A/C ratio	Compressive strength, MPa		Reference
					7 day	28 day	
100.00	0.00	0.40	100x100x100	3.65	26.00	35.00	Ali Nazari, 2011
99.50	0.50	0.40	100x100x100	3.65	32.00	43.00	
98.50	1.50	0.40	100x100x100	3.65	29.00	43.00	
9.80	2.00	0.40	100x100x100	3.65	29.00	40.00	
100.00	0.00	0.40	100x100x100	4.00	27.00	36.80	Alireza Najigivi, 2013
99.00	1.00	0.40	100x100x100	4.00	33.10	44.70	
98.50	1.50	0.40	100x100x100	4.00	32.20	50.80	
98.00	2.00	0.40	100x100x100	4.00	31.80	42.50	
100.00	0.00	0.40	150x150x150	3.55	28.00	35.60	Muhammad S. Elfeky, 2013
99.00	1.00	0.40	150x150x150	3.55	29.00	37.70	
98.50	1.50	0.40	150x150x150	3.55	26.70	38.10	
98.00	2.00	0.40	150x150x150	3.55	24.80	38.20	

Table 2: Maximum and minimum values of the collected data

Item	Maximum	Minimum
Nano-silica content %, by mass of OPC	2	0
Aggregate / cement ratio	4	3.55
7-day compressive strength, MPa	33.1	24.8
28-day compressive strength, MPa	50.8	35
Dimension of concrete specimens, mm	150x150x150	100x100x100

Table 3: Actual Input and Output data for 7-day ANN model

Input					Output
OPC, %	NS, %	A/C ratio	W/b ratio	dimensions	7 day strength
1.0000	0.0000	0.0365	0.0040	0.1000	0.2600
0.9900	0.0100	0.0365	0.0040	0.1000	0.3200
0.9850	0.0150	0.0365	0.0040	0.1000	0.2900
0.9800	0.0200	0.0365	0.0040	0.1000	0.2900
1.0000	0.0000	0.0400	0.0040	0.1000	0.2700
0.9900	0.0100	0.0400	0.0040	0.1000	0.3310
0.9850	0.0150	0.0400	0.0040	0.1000	0.3220
0.9800	0.0200	0.0400	0.0040	0.1000	0.3180
1.0000	0.0000	0.0355	0.0040	0.1500	0.2800
0.9900	0.0100	0.0355	0.0040	0.1500	0.2900
0.9850	0.0150	0.0355	0.0040	0.1500	0.2670
0.9800	0.0200	0.0355	0.0040	0.1500	0.2480

4. Application of artificial neural network

Two back-propagation neural networks (BPNN) were developed to predict both 7-day compressive strength and 28-day compressive strength of nano-silica concrete. Sex neurons representing OPC content, nano-silica content, w/b ratio, aggregate/cement ratio, dimensions of concrete specimens and 7-day compressive strength were considered in the input layer of the 28-day ANN model. The output layer includes one neuron, which represents the 28-day compressive strength. The first five neurons of the 28-day model were also considered in the input layer of 7-day ANN model The output layer of the 7-day ANN model includes one neuron, which represents the value of the corresponding 7-day compressive strength of nano-silica concrete. a three-layer ANN was selected for the present application. A scaling range between 0 and 1 with the logistic sigmoid activation function were found to be the best settings for the present application. So it is necessary to perform data processing. Data processing for input and output is described as Eq. (1).

Error! Not a valid link. (1)

Where P_n is input value for training of learning, P_{acutal} is actual input data, P_{max} is the maximum value of a set of input data. In data processing for the two ANN models, P_{max} equals 1260 for both input and output values. Tables 3 and 4 list the actual data adopted to build the two ANN models.

Back propagation (BP) algorithm was employed for the ANN training in which a Tansig function was used as the nonlinear transfer function and the sum of the mean squared error (SMSE) in the output layer as the convergence criteria.

Table 4: Actual Input and Output data for 28-day ANN model

Input						Output
OPC, %	NS, %	A/C ratio	W/b ratio	dimensions	7-day strength	28-day strength
1.0000	0.0000	0.0365	0.0040	0.1000	0.260	0.350
0.9900	0.0100	0.0365	0.0040	0.1000	0.320	0.430
0.9850	0.0150	0.0365	0.0040	0.1000	0.290	0.430
0.9800	0.0200	0.0365	0.0040	0.1000	0.290	0.400
1.0000	0.0000	0.0400	0.0040	0.1000	0.270	0.368
0.9900	0.0100	0.0400	0.0040	0.1000	0.331	0.447
0.9850	0.0150	0.0400	0.0040	0.1000	0.322	0.508
0.9800	0.0200	0.0400	0.0040	0.1000	0.318	0.425
1.0000	0.0000	0.0355	0.0040	0.1500	0.280	0.356
0.9900	0.0100	0.0355	0.0040	0.1500	0.290	0.377
0.9850	0.0150	0.0355	0.0040	0.1500	0.267	0.381
0.9800	0.0200	0.0355	0.0040	0.1500	0.248	0.382

5. Results and Discussion

5.1. 7-day compressive strength ANN model

Table 5 show the results of compressive strength obtained from both ANN and compressive strength test for the different hardened OPC concrete made with various nano-silica contents (0, 1, 1.5, and 2%, by mass of OPC), different aggregate/cement ratios (4, 3.55, and 3.65), various dimensions of concrete samples, and constant w/b ratio (0.4). It is generally apparent from the results obtained from both ANN model and experimental data that the value of 7-day compressive strength increased with increasing the nano-slilca content up to 1% by mass of OPC. Also, it is obvious from Table 5 and Fig. 1 that, considering constant dimensions of concrete specimens (10x10x10 cm), the values of 7-day compressive strength obtained from both ANN and experimental data increased with increasing aggregate/cement ratio. The increases in 7-day compressive strength of concrete mixtures made with aggregate/cement ratio of 4.0 reach about 3.8, 3.4, 11, and 9.7%, when 0, 1, 1.5, and 2% nano-silica replacement levels were adopted, respectively, compared with the corresponding values of concrete mixtures made with aggregate/cement ratio of 3.65.

Table 5: Results of 7-day compressive strength model

OPC, (%)	NS, (%)	A/C Ratio	w/b ratio	Specimen dimensions, (cm)	7-day Compressive strength, (MPa)	
					Exp. data	ANN
100	0	3.65	0.4	10x10x10	26.00	26.00
99	1	3.65	0.4	10x10x10	32.00	32.00
98.5	1.5	3.65	0.4	10x10x10	29.00	29.04
98	2	3.65	0.4	10x10x10	29.00	28.36
100	0	4	0.4	10x10x10	27.00	27.00
99	1	4	0.4	10x10x10	33.10	33.06
98.5	1.5	4	0.4	10x10x10	32.20	32.20
98	2	4	0.4	10x10x10	31.80	31.84
100	0	3.55	0.4	15x15x15	28.00	28.00
99	1	3.55	0.4	15x15x15	29.00	29.00
98.5	1.5	3.55	0.4	15x15x15	26.70	26.70
98	2	3.55	0.4	15x15x15	24.80	24.83

Replacing 1% cement by nano-silica results in the highest significant gain in 7-day compressive strength. The increases in 7-day compressive strength of 1% nano-silica mixtures reach about 23%, 23% and 4.0% when considering aggregate/cement ratios of 3.65, 4.0, and 3.55 respectively, compared to the corresponding values of 0% nano-silica mixtures.

In addition, it is generally clear from the results obtained experimentally and those predicted by ANN models that the early compressive strength of all nano-silica concrete increased with decreasing the dimensions of concrete specimens. The increase in the 7-day compressive strength of concrete samples of dimensions 10x10x10 cm and aggregate/cement ratio of 3.65 reaches about 10, 8.6, and 14% when 1, 1.5, and 2% nano-silica replacement levels were considered, respectively, compared with the corresponding values of concrete samples of dimensions 15x15x15 cm.

5.2. 28-day compressive strength ANN model

Table 6 show the results obtained from both ANN and compressive strength test for the different hardened OPC concrete made with various nano-silica contents (0, 1, 1.5, and 2%, by mass of OPC), different aggregate/cement ratios (4, 3.55, and 3.65), various dimensions of concrete samples, and constant w/b ratio (0.4). It is generally apparent from the results obtained experimentally and those predicted by ANN models that the value of 28-day compressive strength increased with increasing the nano-slilca content up to 1.5% by mass of OPC.

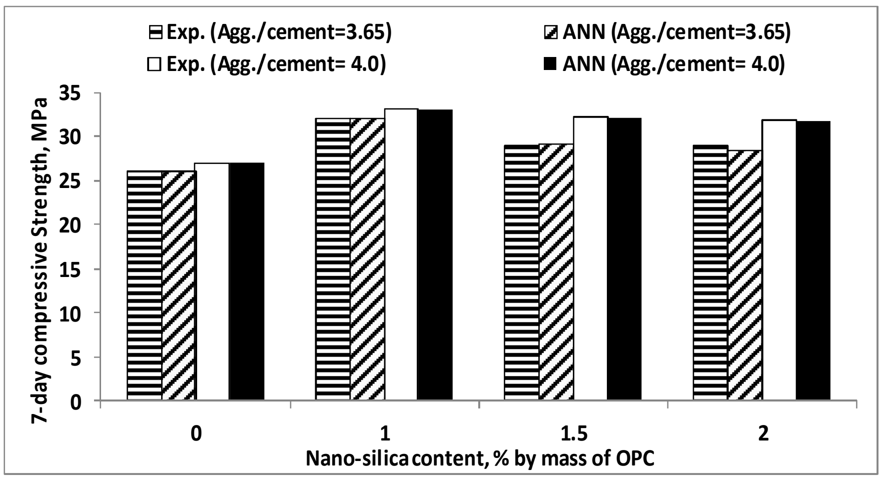

Fig. 1: Effect of Agg./cement ratio on 7-day compressive strength of nano-silica concrete.

Table 6: Results of 28-day compressive strength model

OPC, (%)	NS, (%)	Aggregate / Cement Ratio, (%)	w/b ratio	Specimen dimensions (cm)	7-day Compressive strength, (MPa)		
					7-day	28-day	
					Exp. data	Exp. data	ANN
100	0	3.65	0.4	10x10x10	26	35.00	35.23
99	1	3.65	0.4	10x10x10	32	43.00	43.00
98.5	1.5	3.65	0.4	10x10x10	29	43.00	43.00
98	2	3.65	0.4	10x10x10	29	40.00	38.00
100	0	4	0.4	10x10x10	27	36.80	35.90
99	1	4	0.4	10x10x10	33.1	44.70	44.70
98.5	1.5	4	0.4	10x10x10	32.2	50.8	50.80
98	2	4	0.4	10x10x10	31.8	42.5	42.50
100	0	3.55	0.4	15x15x15	28	35.6	35.60
99	1	3.55	0.4	15x15x15	29	37.7	37.70
98.5	1.5	3.55	0.4	15x15x15	26.7	38.1	38.10
98	2	3.55	0.4	15x15x15	24.8	38.2	37.40

Also, it is obvious from Table 6 and Fig. 2 that, considering constant dimensions of concrete specimens (10x10x10 cm), the values of 28-day compressive strength obtained from both ANN and experimental data increased with increasing aggregate/cement ratio. As seen from ANN predictions, the increases in 28-day compressive strength of concrete mixtures made with aggregate/cement ratio of 4.0 reach about 2, 4, 18, and 12%, when 0, 1, 1.5, and 2% nano-silica replacement levels were considered, respectively, compared with the corresponding values of concrete mixtures made with aggregate/cement ratio of 3.65. While, it is obvious from experimental results that the increases in 28-day compressive strength of concrete mixtures made with aggregate/cement ratio of 4.0 reach about 5, 4, 18, and 15%, when 0, 1, 1.5, and 2% nano-silica replacement levels were considered, respectively, compared with the corresponding values of concrete mixtures made with aggregate/cement ratio of 3.65.

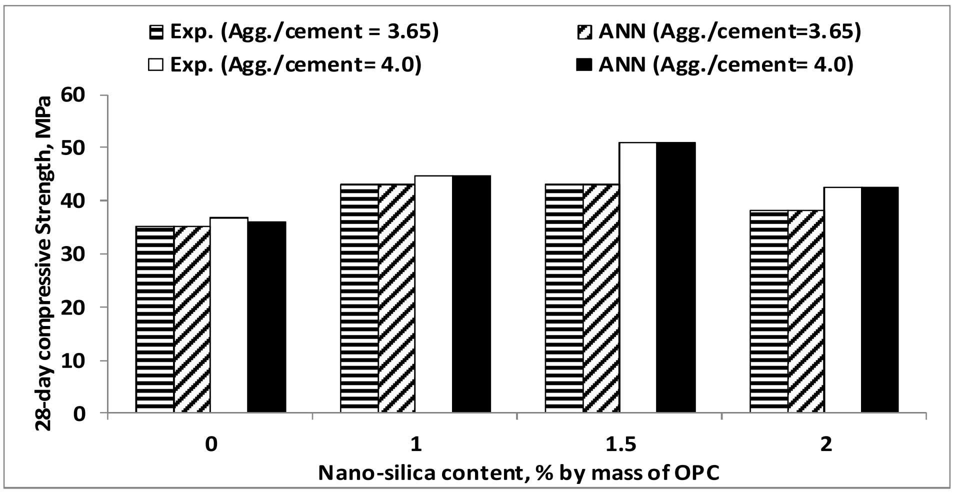

Fig.2: Effect of Agg./cement ratio on 28-day compressive strength of nano-silica concrete.

Replacing 1.5% cement by nano-silica results in the highest significant gain in 28-day compressive strength. The increases in 28-day compressive strength of 1.5% nano-silica mixtures reach about 23%, 38% and 7% when considering aggregate/cement ratios of 3.65, 4.0, and 3.55 respectively, compared with the corresponding values of 0% nano-silica mixtures.

Generally, it is clear from the research results that the developed ANN models gives very close estimates of strength of nano-silica concretes, where, comparison between results obtained experimentally and ANN models predictions has proven that there was a high correlation between early and late compressive strength obtained from compressive strength test and those predicted by ANN models. Therefore, the developed ANN models can be used to simulate the strength development of nano-silica concrete.

6. Conclusions

The main conclusions of this study can be summarized as follows:

1. The research results obtained from both ANN model and experimental program demonstrate that 7-day compressive strength of nano-silica concrete increased with increasing the nano-silica content up to 1% by mass of OPC.
2. Experimental result and ANN predictions confirmed that 28-day compressive strength of nano-silica concrete increased with increasing the nano-silica content up to 1.5% by mass of OPC.
3. The values of both 7-day compressive strength and 28-day compressive strength obtained from both ANN and experimental data increased with increasing aggregate/cement ratio.
4. Research results confirmed that replacing 1% cement by nano-silica results in the highest increases in early compressive strength, where, the increases in 7-day compressive strength of 1% nano-silica mixtures reach about 23%, 23% and 4% when considering aggregate/cement ratios of 3.65, 4.0, and 3.55 respectively, compared to the corresponding values of 0% nano-silica mixtures.
5. Replacing 1.5% cement by nano-silica results in the highest increases in late compressive strength, where these increases reach about 23%, 38% and 7.0% when considering aggregate/cement ratios of 3.65, 4.0, and 3.55 respectively, compared to the corresponding values of 0% nano-silica mixtures.

6. Both experimental data and ANN predictions confirmed that both early and late compressive strength of all nano-silica concrete increased with decreasing the dimensions of concrete specimens.

7. Comparison between results obtained experimentally and ANN models predictions has proven that there was a high correlation between early and late compressive strengths obtained from compressive strength test and those predicted by ANN models, where, the prediction ANN model gives very close estimates of strength of nano-silica concretes. Therefore, the developed ANN models can be used to simulate the strength development of nano-silica concrete.

8. Research results indicated that the methodology described using Backpropagation Artificial Network is a useful, powerful tool to identifying correlations between output and inputs.

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