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EVALUATION OF PERFORMANCE OF SELF COMPACTING CONCRETE WITH MINERAL ADMIXTURES BY ARTIFICIAL NEURAL NETWORKS

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Abstract- Bentonite a natural pozzolan can reduce the amount of CO_2 produced as an output of cement production. The mechanical properties of cementitious materials used in concrete can be enhanced using bentonite. Durability of structures has become a critical issue in management of reinforced concrete structures. This research work emphasis on analyzing the performance of self-compacting concrete (SCC) using mineral admixtures such as BASF manufactured Super Plasticizer (SP), silica fume and bentonite. Total 16 samples by adding bentonite and silica fume in binder and using 0.8% super plasticizer ultimately have developed SCC. Artificial Neural Network (ANN) model is used for the prediction of mechanical properties of SCC using Levenberg Marquardt (LM) Algorithm having certain inputs/variables and compression strength at 28 and 91 days as output. The ANN model results show overall accuracy of 97%. It was concluded that the bentonite in addition with constant silica fume used in SCC increases the compressive strength of concrete by reduces the chloride ion diffusion, but excess of Bentonite reduces the w/c too much and causes decrease in compressive strength and in workability.

Keywords- Artificial neural network, Bentonite, Self-compacting concrete (SCC), Super Plasticizer (SP)

Introduction

In the late 1990s the use of self-compacting concrete was introduced and studied in Asian countries such as Japan as a material with maximum workability without compromising its compressive strength, so that it can be effortlessly casted, without further effort of compacting, in difficult formwork, congested reinforced structural elements and areas with difficult access. Due to several advantages and structural configuration Self-compacted concrete has gained wide-ranging consumption in many countries [1]. Concrete is one of the most vital element of construction industry. Durability of concrete is the most critical problem for the construction of reinforced concrete structures with protracted service life and to improve construction knowledge due to various economic as well as environmental reasons in recent few years, it is significant to yield well-designed concrete as a construction material with lifelong services. However, production of concrete relies on huge extents of natural sources such as water, sand, gravel particles and cement which are widely used in concrete manufacturing. Also, about 2.99 billion tons of fine as well as coarse materials are used every year for cement manufacturing in the world and, around 2.6% of CO2 emissions are result of cement manufacturing in Industrial sources[2, 3]. The use of mineral admixtures such as fly ash, silica fume or ground granulated blast furnace etc., can effectively reduce the ecological effect as a partly cement replacement. The amount of permeability, pore structure and compressive strength of concrete can be enhanced by the use of admixtures such as fly ash, blast furnace in concrete manufacturing plants, this

is credited to the pozzolanic reaction. [4, 5]. The main criterion of self-compacting technology is achieving a highly plastic conduct while avoiding draining and mixture components segregation. While casting fresh plastic Self-compacting concrete (SCC) the compaction needs are eliminated. This decreases overall cost, increases working environment by saving time and opens the way for the mechanization of the concrete structure. Because of these remarkable advantages, SCC is anticipated to progressively change most of the ordinary concrete currently produced worldwide. Particularly the development and evolution of the self-compacting concrete by considerably contribution of super plasticizer technology. Different from the ordinary Portland cement concrete design, the self-compacting concrete desires the super plasticizers, addition of viscosity increase and pozzolanic admixture additions in bulk amount all together or moderately[6, 7]. The quantifiable constituents of SCC are mostly the same as: water, mineral, chemical admixtures, cement, fine as well as coarse aggregates. The material components contains the main modification in comparative quantities of each of the component constituents[8]. The use of SSC in building industry does not only propose speed due to the lack of constraints on concrete amount to be placed in one shot for proper consolidation, it also makes workability easier without comprising compressive strength of CVC[9]. The resistance to segregation of SCC and its plasticity yields a meticulously compacted material of uniform configuration with great surface appearances. The proper compaction converses greater bond strength and durability. The non-requirement of vibration removes some of the high construction noise which is one of the notable distinguishing feature of CVC[10]. The void filling property of SCC provides an abundant advantage of labor as well as mechanical compactor use reduces for the compaction which enables better attention on accuracy rather than being worried with monitoring the crowd masses handling concrete on site[11]. It is very important for Asian as well as countries beyond Asia to adopt the SCC with several mineral admixtures due to its exceptional attributes and should be adopted worldwide.[12]. Therefore, there is a huge space of data available to be filled concerning unsuitability of SCC as a construction material, with reference to usability of raw materials available locally and production cost with respect to ordinary Portland concrete of comparable strength and toughness features[13].
With certain advances in technology, civil engineers tend to focus on software/models to predict properties of concrete without testing. For this, Artificial Neural network models became the priority these days. An artificial neural network (ANN) is a mathematical model or computational model that is inspired by the structure and/or functional aspects of biological neural networks. It can learn from experiences to develop its performance. Same as human brain, Artificial Neural Network obtains information through learning [14]. ANN consists of three different steps of training, validation and Test. In training step, model is repeated as long as it got the desired output. The errors of the validation step are monitored during the training step [15]. Generally, an ANN model comprises of different layers, Input and Output consists of input and output data. Between these layers, there are one or more hidden layers depending upon the model. It includes neurons and are connected by weights. Each neuron has an activation function to determine the output. There are many kinds of activation functions. Usually, nonlinear activation functions such as sigmoid, step are used [16].
The aim of this study is to construct ANN model as well as to develop environment friendly SCC by utilizing locally available mineral admixtures/waste materials and compare the result obtained from software with experimental results of experimental work. The current research work addresses the alternative to both fundamental alteration on the mix proportions used to keep away from conditions where cement does not accomplish the required compressive strength or by staying away from substantial that is needlessly durable and furthermore for more economic utilization of raw material and less construction disappointments, subsequently decreasing development cost and environmental effects. Thus, prediction of compressive strength and different important parameters of cement has been a functioning space of this research study.

Experimental procedure

Materials

The Portland cement used for experimental work is having a registration code of ISO 9001:2000 meeting the requirements of ASTM 150 [17]. The physical as well as chemical properties of Portland cement are listed in Table 3. The maximum size of coarse aggregate was selected as 19mm (meeting requirement of ASTM C33M) to avoid blocking of SSC. The fine aggregates used in this research having size less than 4.75mm and meeting the requirement of ASTM C33 [18]. The physical properties of coarse as well as fine aggregates are listed in Table 1. BASF manufactured Super plasticizers is used as admixture in concrete and its amount is kept constant which gives us optimum workability at 0.8% use and reducing the excess water requirement of concrete workability. Furthermore, Bentonite is also used to increase the pore structure of cementitious materials, thereby increasing the durability of structure. An excess of bentonite reduces the compressive strength of cement concrete. The chemical properties of Bentonite and Silica fume are listed in Table 3.

Table 1: Physical Properties of Coarse and Fine aggregates

Properties	Coarse Aggregates	Fine Aggregates
Surface Texture	Rough	Smooth
Particle Shape	Angular	Rounded
Specific Gravity	2.58	2.61
Fineness Modulus	6.2	2.4

Mix Proportions

Design mix was done based on Self compacting concrete codes by keeping Silica Fume fix at 5% and 10% and bentonite varies from 2.5 – 20 %. Total of 17 design mixes were made and are given in Table 2.

Preparation of Specimen and Testing

After self-compatibility was controlled by new substantial analyses cements were poured from a point at the highest point of the form and set in moulds without vibration. The compressive strength tests were performed on cube sizes of 100x100x100mm (4x4x4in.) after demoulding the test specimens and curing using tap water.

Concrete Tests

Fresh Concrete

Slump flow, L-Box and V-Funnel tests were performed on fresh concrete to check the filling and passing ability of SCC.

Hardened Concrete

To check the compressive strength of concrete after completion of curing in tap water, compressive strength tests are performed.

Table 2: Mix Design

Sr No.	MIX ID	Cement	Silica Fume	Bentonite	C.A	F. A	water (0.45)	Sp (% of binder)
		kg/m3	kg/m3	kg/m3	kg/m3	kg/m3	kg/m3	kg/m3
1.	Control	500	0	0	629	721.5	225	0.8
2.	SF5B2.5	462.5	25	12.5	629	721.5	225	0.7
3.	SF5B5	450	25	25	629	721.5	225	0.7
4.	SF5B7.5	437.5	25	37.5	629	721.5	225	0.7
5.	SF5B10	425	25	50	629	721.5	225	0.7
6.	SF5B12.5	412.5	25	62.5	629	721.5	225	0.7
7.	SF5B15	400	25	75	629	721.5	225	0.7
8.	SF5B17.5	387.5	25	87.5	629	721.5	225	0.7
9.	SF5B20	375	25	100	629	721.5	225	0.7
10.	SF10B2.5	437.5	50	12.5	629	721.5	225	0.8
11.	SF10B5	425	50	25	629	721.5	225	0.8
12.	SF10B7.5	412.5	50	37.5	629	721.5	225	0.8
13.	SF10B10	400	50	50	629	721.5	225	0.8
14.	SF10B12.5	387.5	50	62.5	629	721.5	225	0.8
15.	SF10B15	375	50	75	629	721.5	225	0.8
16.	SF10B17.5	362.5	50	87.5	629	721.5	225	0.8
17.	SF10B20	350	50	100	629	721.5	225	0.8

Table 3: Physical and Chemical properties of Cementitious material

Physical Properties	Cement	Silica Fume	Bentonite
Specific Gravity	3.063	2.1	1.65
VICAT Initial settling time (min)	150	-	-
VICAT Final settling time (min)	240	-	-
Compressive Strength at 28^{th} day (MPa)	17.2	-	-
Le-Chatelier Expansion (mm)	1.66		-
Chemical Properties %			
SiO_2	19.15	80	70.10
$AI2O_3$	4.80	1.12	12.18
Fe_2O3_3	3.20	1.4	5.12
CaO	60.90	0.5	3.51
MgO	2.01	0.4	3.14
Na_2O_3	0.32	0.6	5.02
K_2O	0.80	0.50	0.54
TiO_2	-	-	0.14
MnO	-	-	0.06

Research Methodology

Self-compacting Concrete was developed according to mix design by hit and trail method and after developing, fresh properties were determined. Figure 1 is attached below. In evaluating hardened properties of SCC, total of 9 cube samples were used for each age. The samples were prepared and cured a day after at 23 ± 2°C using mineral admixtures as mentioned before. The samples were used to measure the compressive strength after 28 and 91 days, figure 2 is attached below. The compressive strength of each sample is measured using UTM with a capacity of 200KN with a loading rate of 0.3MPa/s. An artificial neural networks study was carried out to predict the compressive strength of SCC. Several inputs and outputs of conducted experiments are defined. The compressive strength of SCC is evaluated using ANN Testing network comparing predicted values and actual values.

Figure 1: Evaluating Fresh properties of developed SCC.

Figure 2: Compression Strength Test

Experimental Results

Fresh Properties

Slump Flow Test

Slump flow test is used to check the workability of concrete and is considered 1st workability test. Slump flow values fall in the range given by EFNARC i.e., 650 mm – 800 mm. Results are shown in fig. 3.

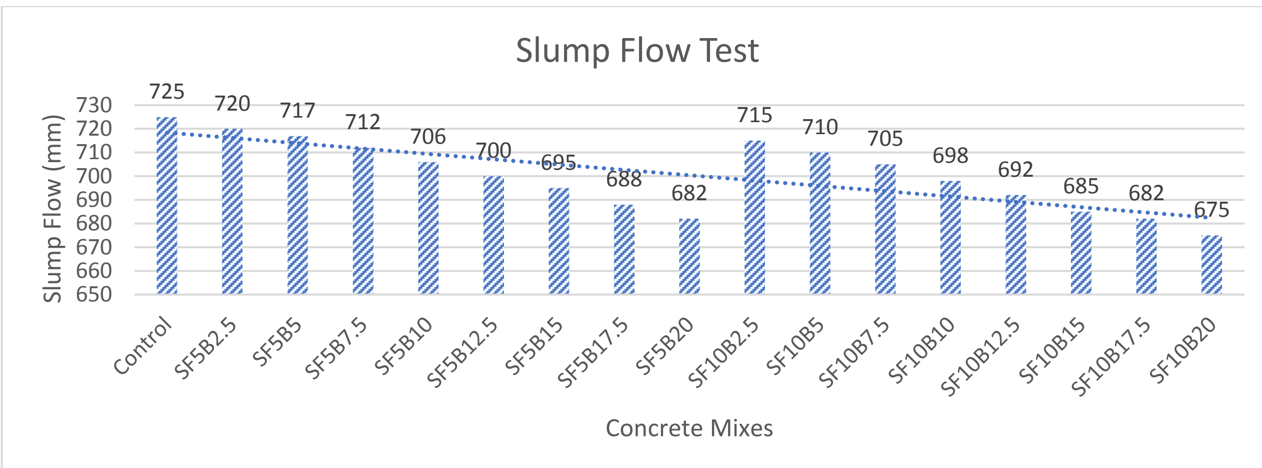

Figure 3: Slump Flow Test Results

V – Funnel Test

V-funnel test is considered a second workability test performed on fresh concrete to check the flow ability of SCC. Results obtained after experimentation fall in the range given by EFNARC i.e., 6-12 sec. Results are shown in Fig. 4.

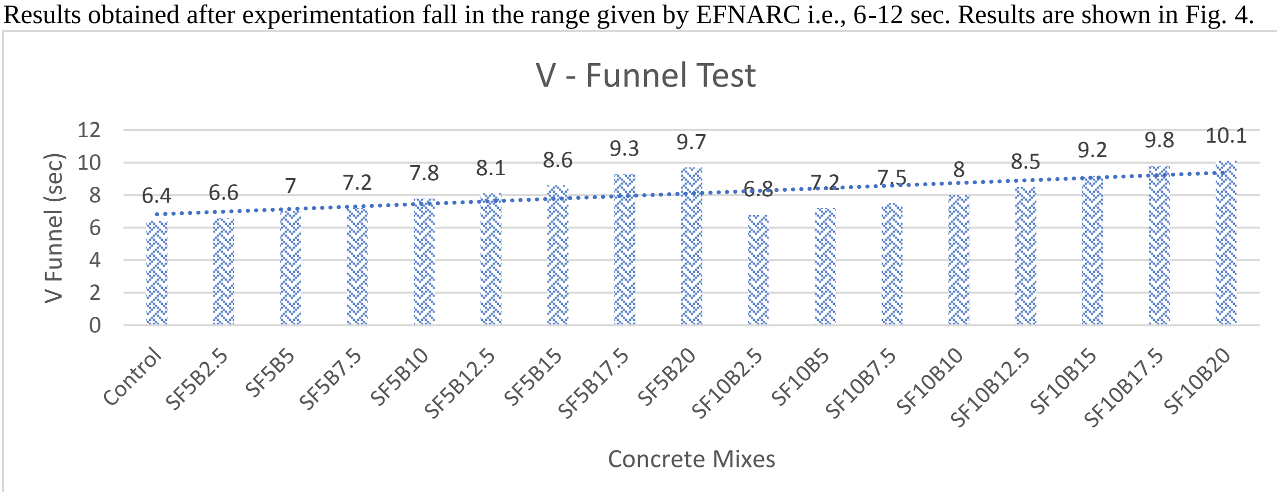

Figure 4: V-Funnel Test Results

L – Box Test

L-Box test is used to check the passing ability and blockage ratio (h2/h1) of SCC and considered as a third workability test. Blockage ratio obtained from L-Box test lies within acceptable range given by EFNARC i.e., 0.8-1.0. Results are shown in Fig. 5.

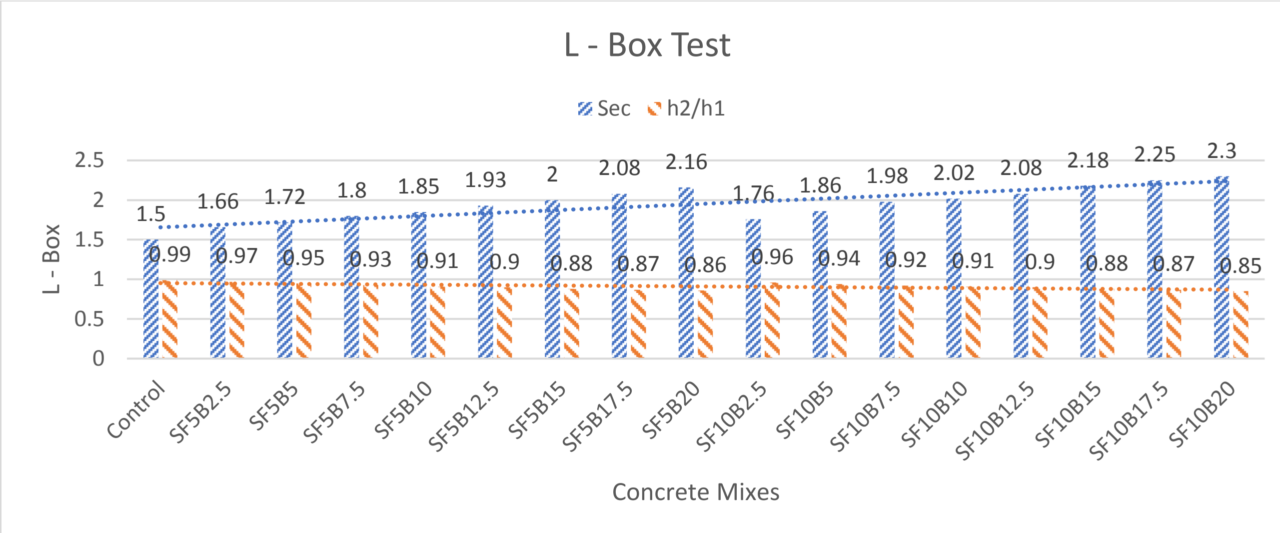

Figure 5: L-Box Test Results

Hardened Properties

Compressive Strength

Compressive strength test was performed fulfilling the requirements of ASTM C39 [19] on hardened concrete after 28 and 91 days and their results are shown in Figure 6. It is noted that the value of compressive strength is maximum for sample #08 because by increasing the value of bentonite the amount of W/C decreases and workability increases ultimately decreeing the value of compressive strength. Results shows that the 0.8% super plasticizer and 17.5% use of bentonite having constant 10% silica fume gives us maximum compressive strength values of 27.0 and 27.3 MPa for 28 days and 91 days, respectively.

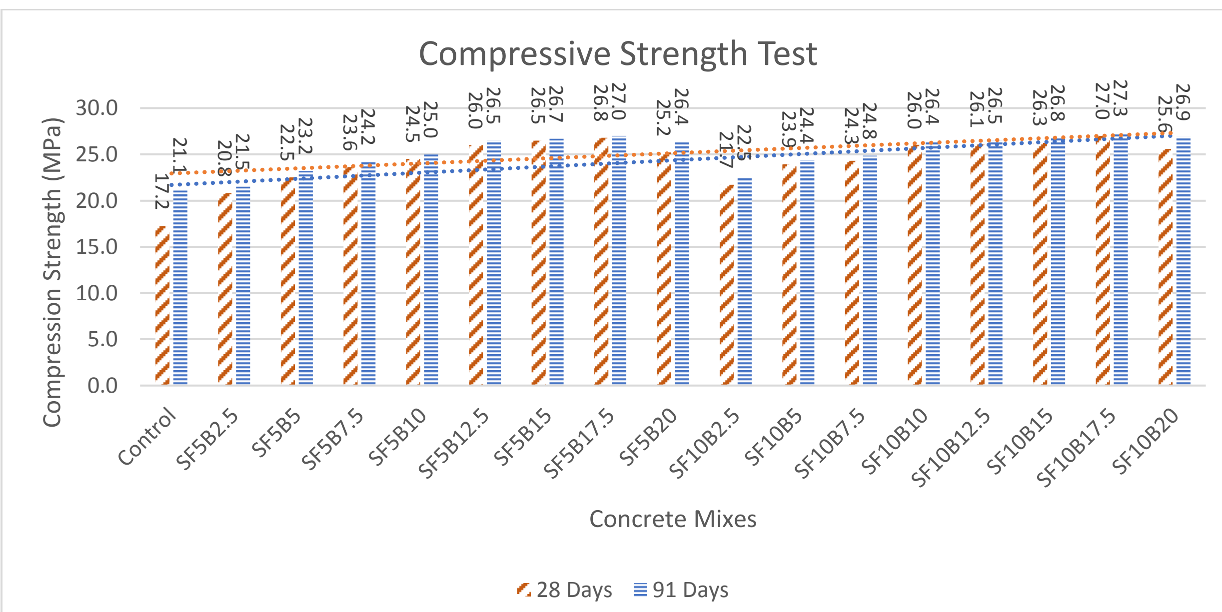

Figure 6: Compressive strength test results for mixes at different ages using mineral admixtures.

Prediction of Experimental Results using Artificial Neural Network (ANN)

In this investigation total 7 input variables such as Cement, Silica fume, Bentonite, coarse and fine aggregates, water/cement ratio and superplasticizer are used. The compressive strength at 28 and 91 days were the output. Number of hidden neurons are set as 10. MATLAB was used for modelling. The structure of the ANN model is shown in Figure 7.

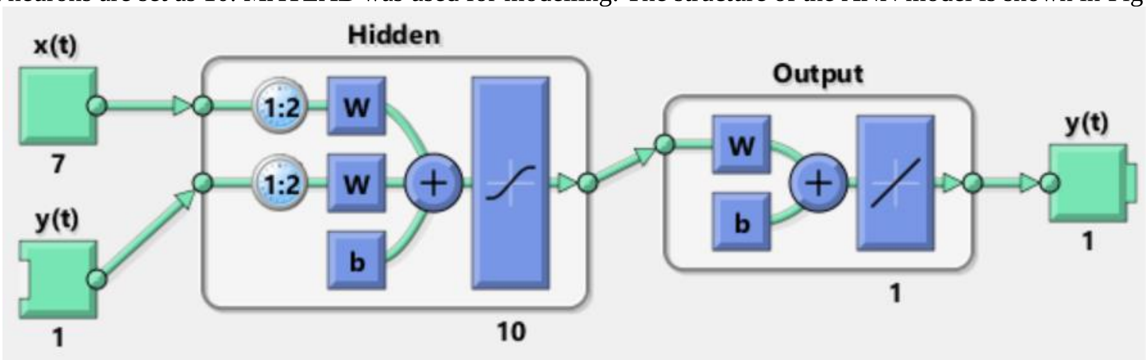

Figure 7: Structure of ANN Model

ANN model is based on back propagation technique using Levenberg-Marquardt Algorithm. The data set is divided into three categories such as training, validation, and testing with percentages 70, 20 and 20, respectively. The results of 28 days strength and 91 days strength by ANN modelling are shown in Figure 8 and 9. Graphs shows that ANN model was developed for 28 days and 91 days compression strength with an overall accuracy of 93% respectively proving LM algorithm to be a good learning algorithm for this research study despite limited data.

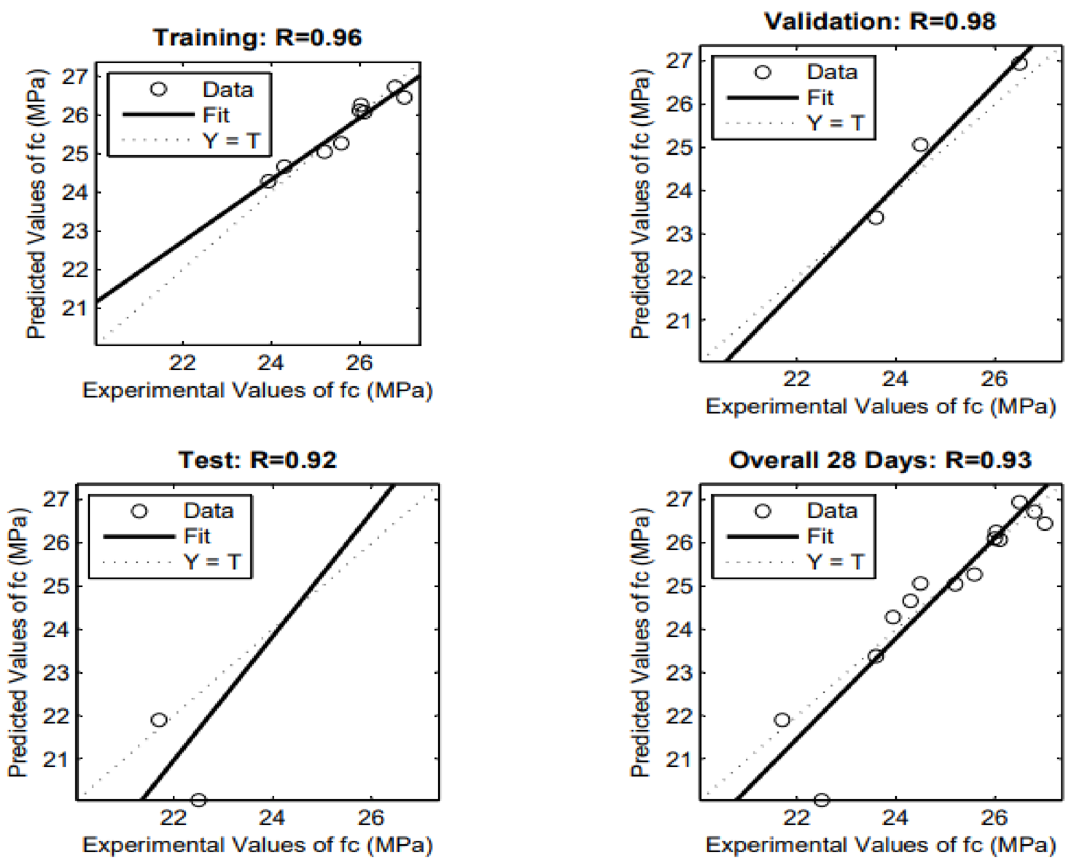

Figure 8: Artificial Neural Network ANN) Modelling on MATLAB for experimental and predicted compression strength at 28 days.

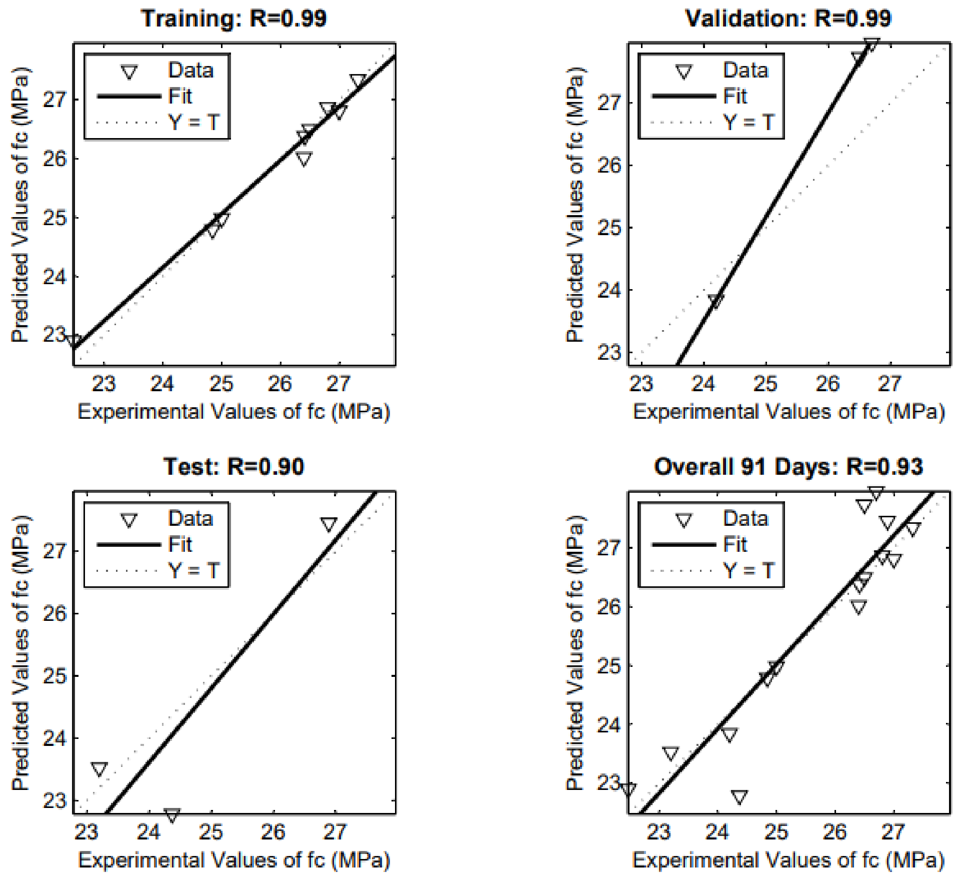

Figure 9: Artificial Neural Network ANN) Modelling on MATLAB for experimental and predicted compression strength at 91 days.

Conclusion

The following findings of our investigations are as:

1. It is concluded that the SCC can be developed using fixed amount of Super Plasticizer (0.8%) and using control quantity of bentonite and silica fume.
2. In examining fresh properties of SCC, it is demonstrated that Slump flow, L-Box and V-Funnel decreasing by addition of Bentonite but well within the range of EFNARC.
3. The presence of excessive amount of bentonite causes decrease in workability.
4. Compressive Strength of SCC Mixes increased up to addition of 17.5% Bentonite, however, strength loss was observed beyond 17.5% addition of Bentonite.
5. Based on compressive strength development tendency, some further research is needed to find out the optimum amount of bentonite for developing optimum strength SCC changing other parameters.
6. ANN model shows overall accuracy of 93% despite limited data proving LM algorithm to be a good learning algorithm for this research study. Therefore, to predict the compressive strength of concrete with high reliability, instead of using costly experimental investigation, ANN model can be replaced.

References

1. Su, N., K.-C. Hsu, and H.-W. Chai, *A simple mix design method for self-compacting concrete.* Cement and concrete research, 2001. **31**(12): p. 1799-1807.
2. Bilim, C., et al., *Predicting the compressive strength of ground granulated blast furnace slag concrete using artificial neural network.* Advances in Engineering Software, 2009. **40**(5): p. 334-340.
3. Bui, D.-K., et al., *A modified firefly algorithm-artificial neural network expert system for predicting compressive and tensile strength of high-performance concrete.* Construction and Building Materials, 2018. **180**: p. 320-333.
4. Dehn, F., K. Holschemacher, and D. Weiße, *Self-compacting concrete (SCC) time development of the material properties and the bond behaviour.* Selbstverdichtendem Beton, 2000. **5**: p. 115-124.
5. Dinakar, P., M.K. Reddy, and M. Sharma, *Behaviour of self compacting concrete using Portland pozzolana cement with different levels of fly ash.* Materials & Design, 2013. **46**: p. 609-616.
6. Khayat, K.H., J. Assaad, and J. Daczko, *Comparison of field-oriented test methods to assess dynamic stability of self-consolidating concrete.* Materials Journal, 2004. **101**(2): p. 168-176.
7. OUCHI, M., et al., *A Quantitative Evaluation Method for the Effect of Superplaticizer.* Transactions of the Japan Concrete Institute, 2001. **22**: p. 15-20.
8. Kapoor, Y., C. Munn, and K. Charif. *Self-Compacting Concrete-An Economic Approach*. in *7th International Conference on Concrete in Hot & Aggressive Environments, Manama, Kingdom of Bahrain*. 2003.
9. Ramsburg, P., et al. *Durability of Self-Consolidating Concrete in Precast Application*. in *Proceedings, Third International Symposium on High Performance Concrete, PCI National Bridge Conference, Orlando, FL*. 2003.
10. Zhu, W. and P.J. Bartos, *Permeation properties of self-compacting concrete.* Cement and Concrete Research, 2003. **33**(6): p. 921-926.
11. Persson, B., *Chloride migration coefficient of self-compacting concrete.* Materials and Structures, 2004. **37**(2): p. 82-91.
12. Goodier, C.I., *Development of self-compacting concrete.* Proceedings of the Institution of Civil Engineers-Structures and Buildings, 2003. **156**(4): p. 405-414.
13. EFNARC, S., *Guidelines for self-compacting concrete.* London, UK: Association House, 2002. **32**: p. 34.
14. Nikoo, M., et al. (2015). "Prediction of concrete compressive strength by evolutionary artificial neural networks." Advances in Materials Science and Engineering 2015.
15. Khademi, F. and S. M. Jamal (2016). "Predicting the 28 days compressive strength of concrete using artificial neural network." i-manager's Journal on Civil Engineering 6(2).
16. Bilim, C., et al. (2009). "Predicting the compressive strength of ground granulated blast furnace slag concrete using artificial neural network." Advances in Engineering Software 40(5): 334-340.
17. ASTM C150 / C150M - 20 *"Standard Specification for Portland Cement"*
18. ASTM C33 / C33M - 18 *"Standard Specification for Concrete Aggregates"*
19. ASTM C39 / C39M - 21 *"Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens"*