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Prediction of self-healing characteristics of GGBS admixed concrete using Artificial Neural Network

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Prediction of self-healing characteristics of GGBS admixed concrete using Artificial Neural Network

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Abstract: Concrete has become a significant part of our lives; the utilization of concrete is increasing at a high rate. One of the most constituents of concrete is Ordinary Portland Cement (OPC). The manufacturing process of OPC leads to the emission of huge amounts of CO_2. Thus the researchers have started finding alternatives for the replacement of cement. The primary objective of this paper is to investigate the behavior of M40 grade concrete when partially replaced with Ground Granulated Blast Furnace slag (GGBS) at the same time using SAP and study the self-healing behavior of partially replacement concrete. In the self-healing process, the healing agent absorbs the moisture content within the atmosphere to heal the crack. Superabsorbent Polymers (SAPs) are materials that will absorb and retain an oversized volume of water and aqueous solutions. In this investigation, 51 samples of cubes are prepared for compressive strength test and self-healing test, the specimen is pre-cracked on the 28th day for healing purposes. Further, this article aims to predict the self-healing characteristics of the M40 grade of concrete using Neural Networks by incorporating different proportions of GGBS (0%, 40% and 60%) and SAPs. The predicted results obtained from the ANN model were in good agreement with experimental values.
Keywords: Self-Healing, Superabsorbent Polymer, GGBS, ANN

1. Introduction

The consumption and demand for OPC are increasing daily due to increased construction practices throughout the world. The ever increasing production of OPC liberates a massive volume of carbon dioxide gas into the living environment, causing severe pollution and a severe impact on global warming [1]. There is an urgent need to reduce the demand for Portland cement to the maximum extent possible. Ground granulated blast furnace slag (GGBS) is an industrial by-product commonly called slag obtained from the iron and steel industry [2-3]. Proper utilization of GGBS as a supplementary cementitious material in concrete production could bring down the demand for OPC to a greater extent, thereby reducing the emission of Carbon dioxide and other greenhouse gases into the earth's atmosphere [4].

Cracks play a crucial role in determining the limit of the serviceability of concrete. Cracks endanger concrete structures' strength and sturdiness because it will cause more significant damage to the entire structure [5]. The Self-healing property of concrete can be defined as the time taken to cure the micro-cracks on its own [6]. Within the self-healing process, the healing agent absorbs the moisture content present in the atmosphere to heal the crack [7].

The SAP absorbs water and converts it into the gel at the cracking region; simultaneously, the gel volume increases proportionally [8]. This asset is incredibly useful when it involves watering undergrowth over time. The extension in volume tends to clog the water pathways within the concrete mass, consequently improving its water tightness property [9]. The utilization of SAP is proven to be very efficient as a sealant in concrete if a sufficient amount is employed [10]. Several samples were studied in various literatures with different proportions of SAP content. The content of SAP is measured as a proportion of the Partial replacement cement utilized by weight. This research focuses on developing self-healing crack (using SAP) and carbon dioxide emission reduced concrete (by partial replacement of cement with GGBS). The categorizations of the various methods that may be accustomed induce the self-healing property in concrete are as shown in Figure.1

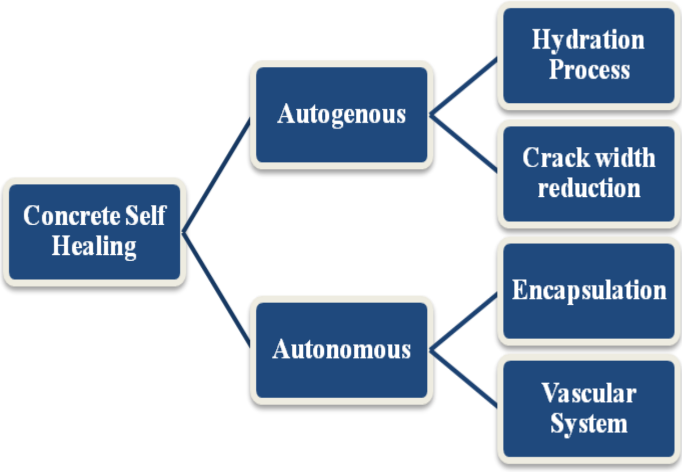

Figure 1. Categorisation of self-healing in concrete.

Artificial Neural Networks are generally employed to solve complex engineering problems to predict when there is no connection between the input and output variables. Nowadays, it has been used extensively in the field of construction materials to forecasting the critical parameters such as cement content [11], concrete mix design [12], shrinkage of concrete [13], compressive strength characteristics [14], workability of concrete [15] etc., with more accuracy. Furthermore, the ANN framework was developed in MATLAB (2016) with the application of the Lavenberg Marquardt (LM) algorithm to forecast the self-healing properties of GGBS based concrete from compressive strength results.

2. Materials and Methods

2.1. Materials

Commercially available OPC of grade 53 with specific gravity 3.16 and GGBS were used as the binder materials for the concrete preparation. The crushed granite stone of 20 mm size with specific gravity 2.62 was used as the coarse aggregate. Manufacturing sand of specific gravity 2.58 was used as the fine aggregate. Ordinary portable water is used in this investigation for both mixing and curing purposes. Sodium polyacrylate [CH2-CH (COONa)] was employed as the SAPs in the study. It has the potential to suck up the maximum amount as 200 to 300 times its mass in water. Sodium polyacrylate is Anionicpolyelectrolytes with harmfully exciting carboxylic groups within the main chain, and it is shown in Figure 2.

Figure 2. Super Absorbent Polymer.

2.2 Methods

The mix design for M40 grade of concrete was carried as per the guidelines of Indian standard codebooks - IS10262: 2019 [16] & IS456: 2000 [17]. The various quantities of materials required per 1 m^3 are listed in Table 1. Similarly, the quantity of materials required to replace 40% and 60% of cement with GGBS were given in Table 2.

Table 1. Details of Material quantities for M40 grade concrete.

Materials	Quantity
Cement	425.73kg/m^3
Water	153.264 lit
Fine aggregate	734.247kg/m^3
Coarse aggregate	1158.19kg/m^3

Table 2. Material quantity for concrete with GGBS.

Materials	Quantity	
	40% Replacement.	40% Replacement.
Cement	255.438kg/m^3	170.292kg/m^3
Water	153.264lit	153.264lit
Fine aggregate	734.247kg/m^3	734.247kg/m^3
Course aggregate	1158.19kg/m^3	1158.19kg/m^3
GGBS	170.292kg/m^3	255.438kg/m^3

The weight batching method was adopted to calculate the quantity of materials required for one cube of 150×150×150mm with 0%, 40%, and 60% of concrete replacement with GGBS are listed in Table 3. In total, nine mix proportions were arrived to calculate the self-healing characterizes of the GGBS based concrete by varying the proportions of GGBS and SAPs. The arrived mix proportions details for the present experimental study were stated in Table 4.

Table 3. Quantity of materials required for one cube.

Sample ID	Cement (Kg)	FA[d] (Kg)	CA[e] (Kg)	Water (Lit)	GGBS (Kg)	SAP (kg)
P[a]100G[b]0S[c]0	1.43	2.47	3.90	0.51	0	0
P100G0S0.5	1.42	2.47	3.90	0.51	0	0.007
P100G0S1	1.41	2.47	3.90	0.51	0	0.014
P60G40S0	0.85	2.47	3.90	0.51	0.57	0
P60G40S0.5	0.84	2.47	3.90	0.51	0.57	0.007
P60G40S1	0.84	2.47	3.90	0.51	0.57	0.014
P40G60S0	0.57	2.47	3.90	0.51	0.85	0
P40G60S0.5	0.56	2.47	3.90	0.51	0.85	0.007
P40G60S1	0.56	2.47	3.90	0.51	0.85	0.014

[a]Portland Cement, [b]Ground granulated blast furnace slag [c]Superabsorbent polymer [d]Coarse Aggregate, [e]Fine Aggregate.

Table 4. Details of the number of samples with mix proportions.

Sample ID	No. of cubes	% of OPC	% of GGBS	% of SAP
P100G0S0	3	100%	-	-
P100G0S0.5	7	100%	-	0.5%
P100G0S1	7	100%	-	1%
P60G40S0	3	60%	40%	-
P60G40S0.5	7	60%	40%	0.5%
P60G40S1	7	60%	40%	1%
P40G60S0	3	40%	60%	-
P40G60S0.5	7	40%	60%	0.5%
P40G60S1	7	40%	60%	1%

2.3 Prediction of Self-healing properties of GGBS based concrete using Neural Networks

ANN is the combination of a numerical and mathematical model interlinked, similar to the series of neurons present in the human brain. It is generally classified under the branch of deep learning technique, which mimics the structure of the human biological brain and ANN comprises five essential parts: input data, target data, sum function, activation function, and weights of the neurons presented in equation 1[18].

$$\mathrm{T} = \mathrm{F}\left(B + \sum_{\mathrm{k}=0}^{\mathrm{n}} \mathrm{X_k W}_k\right) \quad (1)$$

Where, 'T' represents the output values, 'B' is bias, 'F' denotes the activation function, 'n' represents the number of neurons exists in the ANN framework, 'X_k' indicates the input data of the k^{th} neuron and 'W_k' denotes the weight of the k^{th} neuron.

ANN constitutes three types of layers: the input layer, hidden layers, and the output layer. In this study, a Multi-Layer Perception ANN framework was developed in MATLAB (2016) using Lavenberg Marquardt Algorithm to predict the self-healing characteristics of the M40 grade of concrete varied with different percentages of GGBS (0%, 40% and 60%) and SAP content (0%, 0.5% and 1%) as shown in Figure 3.

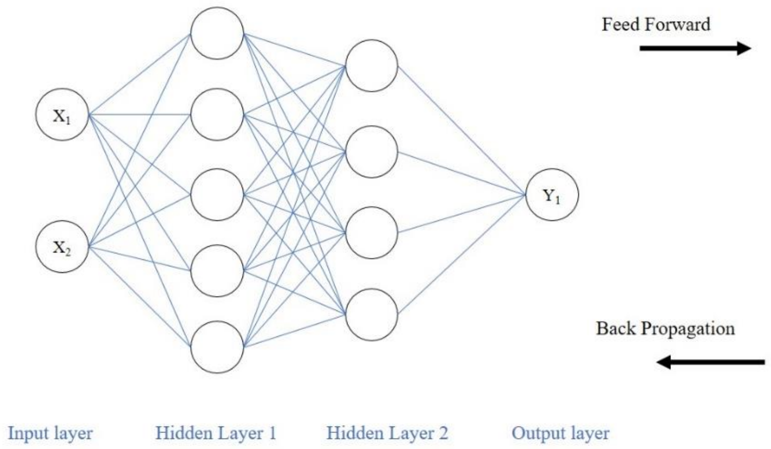

Figure 3. Selected ANN model for the prediction of Pozzolanic strength properties.

The input layer comprises two independent variables: the percentage of GGBS replacement (X_1) and the percentage of SAPs (X_2). The output layer selected for the present ANN study yields the self-sealing properties of GGBS based concrete in terms of compressive strength (Y_1) at different ages and curing conditions. The optimization of the output results acquired from the ANN model can be carried out using the Mean Square Error (MSE) function, which is expressed in equation 2 [16].

$$\mathrm{MSE} = \frac{1}{2}\sum_{k=1}^{n}(\overline{y_k} - y_k)^2 \quad (2)$$

Where, 'n' is the number of values, $\bar{y}$ is the experimental data, and y is the predicted data.

3 Results and Discussion

3.1 Slump Cone Test

A slump cone test is carried out to determine the workability of concrete. Generally, three types of slump may occur during the slump test, namely true slump, shear slump and collapse slump. Out of these three, GGBS based concrete, which yields the true slump, was considered for the use. Based on test results, it can be concluded that the maximum of 1% SAP can be added in concrete for more than 1%; the result obtained is zero slump, which in turn makes this concrete invalid to use.

3.2 Ultrasonic Pulse Velocity Test (UPV)

UPV test is generally conducted to check the quality of concrete by determining the velocity of an Ultrasonic pulse passing through a concrete cube Specimen. Higher Velocity indicates good quality of concrete, which is free from cracks and voids between the aggregates. Lower Velocity indicates that it has low quality of Concrete and cracks and Voids in cube samples. In all Cube Specimens, Pulse velocity Passes above 3.0 km/sec, as listed in Table 5. According to the UPV test, If Pulse velocity shows above 3.0 km/sec, it means that it is good concrete. Figure 4 depicts the test set up used for the UPV test.

Table 5. UPV Test Results for test specimens.

Sample ID	Pulse Velocity, Km/sec
P100G0S0	3.4
P100G0S0.5	3.5
P100G0S1	3.5
P60G40S0	3.4
P60G40S0.5	3.5
P60G40S1	3.6
P40G60S0	3.3
P40G60S0.5	3.4
P40G60S1	3.4

Figure 4. The test set up for Ultrasonic Pulse Velocity Test (UPV).

3.3 Compressive strength test

The compressive strength of M40 grade of concrete with different proportions of GGBS and SAPs were tested according to IS 516:1959 guidelines. The compressive strength was obtained by testing the cube samples of size 150×150×150 mm in the Compression Testing Machine, as shown in Figure 5.

Figure 5. The test set up in CTM.

The compressive strength results of the cube samples with 40% and 60% replacement of cement with GGBS are as show in table 6. From the above test results, it was observed that the replacement of cement with GGBS up to 40% increases the strength to 4%. The graphical representation of the effect of the addition of various proportions of GGBS based concrete on the compressive strength is shown in Figure 6.

Table 6. Compressive Strength of Cube Samples with GGBS content.

Sample ID	Compressive Strength (MPa)	
	7 days.	28 days.
P100G0S0	27.73	44.31
P60G40S0	28.43	46.12
P40G60S0	25.21	39.16

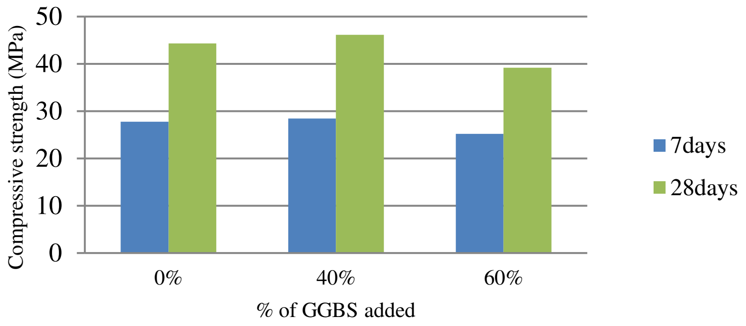

Figure 6. Graphical representation of compressive strength with various GGBS content.

The effect of compressive strength results on the addition of different percentages of SAP are as shown in Table 7. For 40% GGBS based concrete samples, the addition of 0.5% of SAP decreases the compressive strength by 0.9%, whereas 1% inclusion of SAP enhanced the compressive strength by 4%. In 60% GGBS based concrete samples, the addition of 0.5% and 1% SAP increases the compressive strength of cube samples by 10% and 13%, respectively. The graphical representation of the concrete samples' compressive strength with various percentages of SAPs is depicted in Figure 7.

Table 7. Compressive Strength of SAP Concrete.

Sample ID	Compressive Strength (MPa)	
	7 days	28 days
P100G0S0.5	28.21	44.56
P100G0S1	30.91	46.21
P60G40S0.5	30.23	45.72
P60G40S1	32.51	48.10
P40G60S0.5	25.86	40.23
P40G60S1	27.62	41.41

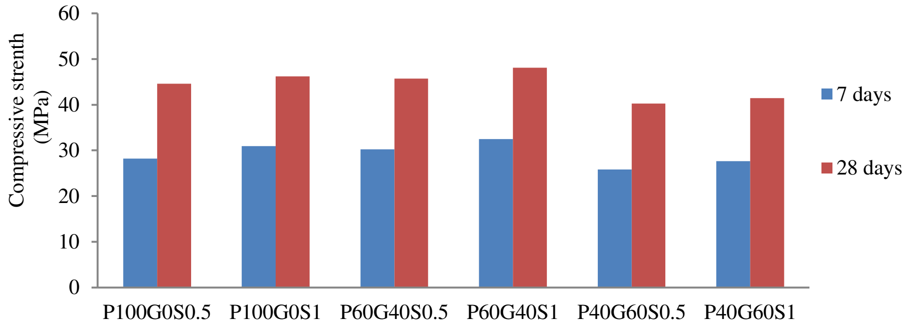

Figure 7. Graphical representation of compressive strength with various proportions of SAPs.

3.4 Applied Pre-crack in sample cubes

To determine the self-healing properties of GGBS based concrete in the presence of SAP, the compressive load was applied in the CTM until the occurrence of first visible crack (Refer Figure 8). The concrete cube samples were cured in water and room conditions, as shown in Figure 9 & 10.

Figure 8. Application of compressive load up to first visible crack.

Figure 9. Cracked cubes in room temperature.

Figure 10. Cracked cubes placed in water.

Further, observations were made on the cracks' visibility after 28 days from the cubes cured at room temperature and water.

Figure 11. Cracks visibility before and after curing in water for 28 days.

Figure 12. Cracks visibility before and after curing in a room atmosphere for 28 days.

From the above figures 11 & 12, it can be concluded that self-healing occurs in both specimens, but the progress of self-healing occurring at a faster rate in contact with water than the room temperature curing.

3.5 Reloading

The compressive load is applied again on the pre-cracked concrete samples to obtain the strength results after 28 days of curing in water and room temperature. The compressive strength details of the pre-cracked samples under two different curing conditions were listed in Table 8.

Table 8. Compressive Strength of samples after Curing 28 days.

Sample ID	Compressive Strength (MPa)	
	Room temperature curing	Water curing
P100G0S0.5	20.16	25.90
P100G0S1	19.54	30.22
P60G40S0.5	18.88	28.12
P60G40S1	20.16	29.33
P40G60S0.5	17.92	23.59
P40G60S1	18.65	24.99

The experimental results showed that the cube samples placed in water attain nearly 60% of its original strength, whereas the cube samples placed in the room temperature yield low strength values.

From this study, it can be concluded that the samples kept in water curing were healing expeditiously, as the superabsorbent particles present in the cracking portion absorbs the surrounding water and forms a gel a structure which then starts to swell in the crack region. As a result of this action, the cracks start to heal faster for the samples placed in the water curing condition. The healing rate is comparatively low for the samples kept at room temperature, as it takes more time for absorbing water in the atmosphere.

3.6 Predicted self-healing properties of GGBS based concrete from ANN model

The experimental, predicted and the ratio of the experiment to predicted compressive strength results obtained from the self-healing characteristics of M40 grade of concrete incorporated with different proportions of GGBS and SAPs were mentioned in Table 9. From Table 9, it can be stated that the results obtained from the experimental and ANN model were comparable. Figure 13 & 14 depicts the variation of the experimental and predicted compressive strength results obtained from the concrete samples at 7 and 28 days, respectively.

Table 9. Experimental and Predicted compressive strength results.

Mix ID	Compressive Strength (MPa)					
	At 7 days			At 28 days		
	Exp	Pred	Exp/Pred	Exp	Pred	Exp/Pred
P100G0S0	27.73	28.23	0.98	44.31	45.25	0.98
P60G40S0	28.43	30.2	0.94	46.12	48.46	0.95
P40G60S0	25.21	26.42	0.95	39.16	42.12	0.93
P100G0S0.5	28.21	27.45	1.03	44.56	43.74	1.02
P100G0S1	30.91	29.98	1.03	46.21	48.07	0.96
P60G40S0.5	30.23	32.01	0.94	45.72	47.23	0.97
P60G40S1	32.51	33.17	0.98	48.1	48.98	0.98
P40G60S0.5	25.86	26.73	0.97	40.23	42.65	0.94
P40G60S1	27.62	25.87	1.07	41.41	39.76	1.04

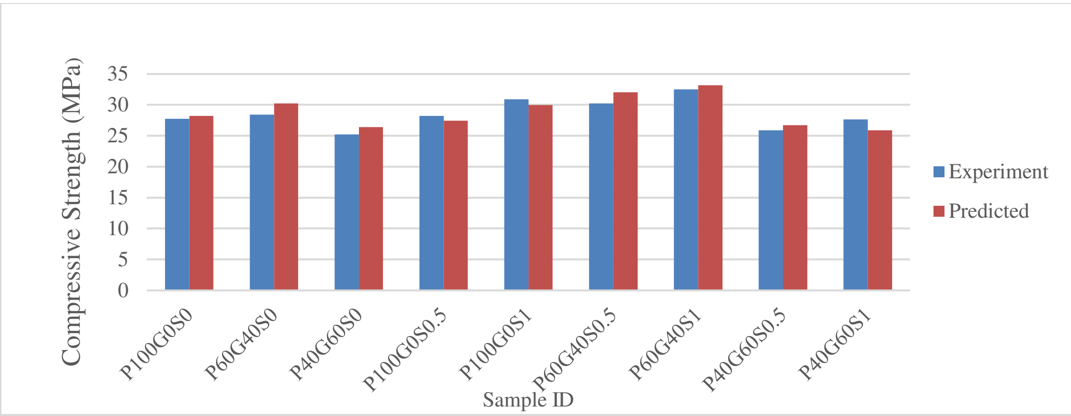

Figure 13. Comparison of Predicted and Experimental 7 day compressive strength.

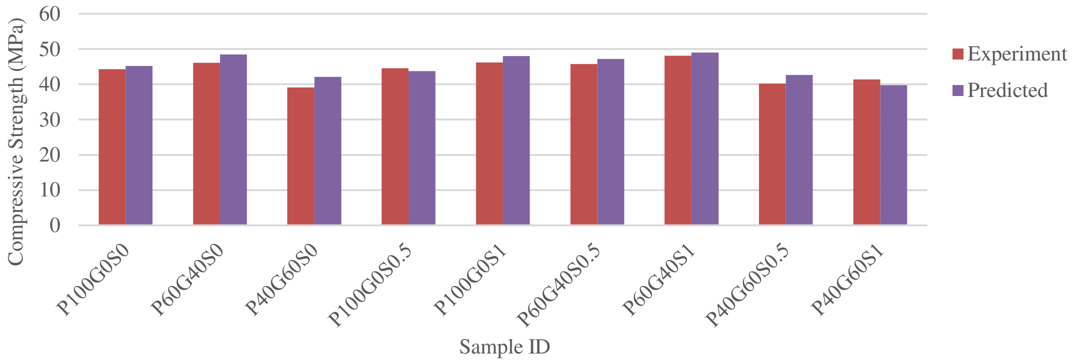

Figure 14. Comparison of Predicted and Experimental 28 day compressive strength.

4 Conclusion

The conclusions obtained from the experimental and predictive studies are mentioned below,

- All the mix proportions considered in this study satisfies the requirement of obtaining the characteristics strength of 40 MPa.
- The application of SAP as a successful self-healing agent in GGBS based concrete has been verified visually and it also improves the strength of the concrete.
- The developed ANN framework was turned out to be an effective tool for predicting the self-healing properties of M40 grade of concrete incorporated with different percentages of GGBS and SAPs because the predicted values are similar to the experimental results.

5 References

[1] Mehta A and Siddique R 2018 Sustainable geopolymer concrete using ground granulated blast furnace slag and rice husk ash: Strength and permeability properties *J. Clean. Prod.* **205** 49–57

[2] Magesh M, Jawahar S, Dhanesh E and Vasugi V 2019 Influence of bottom ash as fine aggregate in GGBFS geopolymer concrete *InternationalJournalof Innovative Technology and Exploring Engineering* **8(6)** 919-924

[3] Nishant Mishra and Vasugi V 2014 Experimental assessment of properties of ternary blended concrete using GGBS and ceramic powder *The Indian Concrete Journal* **89**(7) 74-80

[4] Sai Krishna Teja T, Sai Pradeep P and Vasugi V 2015 Influence of curing conditions on strength development of geopolymer concrete *International Journal of Applied Engineering Research* **10 (5)** 589-605

[5] Rodríguez C R, Figueiredo S C, Deprez M, Snoeck D, Schlangen E and Šavija B 2019 Numerical investigation of crack self-sealing in cement-based composites with superabsorbent polymers *Cem. Concr. Compos* **104** (Article no:103395)

[6] Li G, Liu S, Niu M, Liu Q, Yang X and Deng M 2020 Effect of granulated blast furnace slag on the self-healing capability of mortar incorporating crystalline admixture *Constr. Build. Mater* **239** 117818

[7] Mignon A, De Belie N, Dubruel P and Van Vlierberghe S 2018 Superabsorbent polymers: A review on the characteristics and applications of synthetic, polysaccharide-based, semi-

synthetic and "smart" derivatives *Eur. Polym. J* **117** 165–178
[8] Li D, Chen B, Chen X, Fu B, Wei H and Xiang X 2020 Synergetic effect of superabsorbent polymer (SAP) and crystalline admixture (CA) on mortar macro-crack healing *Constr. Build. Mater.* **247** 118521
[9] Park B and Choi Y C 2018 Self-healing capability of cementitious materials with crystalline admixtures and super absorbent polymers (SAPs) *Constr. Build. Mater.* **189** 1054–1066
[10] Chandra Sekhara Reddy T and Ravitheja A 2019 Macro mechanical properties of self healing concrete with crystalline admixture under different environments *Ain Shams Eng. J.* **10 (1)** 23– 32.
[11] Oh J W, Lee I W, Kim J T and Lee G W 1999 Application of neural networks for proportioning of concrete mixes *ACI Mater. J.* **96**(1) 61–67
[12] Ji T, Lin T and Lin X 2006 A concrete mix proportion design algorithm based on artificial neural networks *Cem. Concr. Res.* **36(7)** 1399–1408
[13] Bal L and Buyle-Bodin F 2013 Artificial neural network for predicting drying shrinkage of concrete *Constr. Build. Mater* **38** 248–254
[14] Bilim C, Atiş C D, Tanyildizi H and Karahan O 2009 Predicting the compressive strength of ground granulated blast furnace slag concrete using artificial neural network *Adv. Eng. Softw.* **40(5)** 334–340
[15] Hammoudi A, Moussaceb K, Belebchouche C and Dahmoune F 2019 Comparison of artificial neural network (ANN) and response surface methodology (RSM) prediction in compressive strength of recycled concrete aggregates *Constr. Build. Mater.* **209** 425-436
[16] BIS:10262, 2009 Indian Standard Guidelines for concrete mix design proportioning *Bur. Indian Stand. New Delhi* p. New Delhi, India.
[17] IS 456, 2000 Concrete, Plain and Reinforced *Bur. Indian Stand. Dehli*
[18] Nazari A and Pacheco Torgal F 2013 Predicting compressive strength of different geopolymers by artificial neural networks *Ceram. Int.* **39(3)** 2247–2257