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Simulation and Prediction of Strength of Geopolymer Concrete by using Artificial Neural Networks

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Abstract— Concrete strength tests are generally calculated at 3 days to one year after discharging the concrete. Waiting period needed to conduct that test can delay the decision modelling construction progression and ignoring that type of test would limit the quality control survey in construction projects. Therefore such kind of determination of strength of the concrete becomes require that the quick and reliable for pre design of construction or quality check of construction. In this paper a try built to develop geopolymer concrete (GPC) of compressive and split tensile strength prediction models with help of Artificial Neural Networks (ANNs). The data analysis and model development were collected at 7-days and 28-days curing period via experiments in the laboratory. The developed models have been also conducted on concrete results taken from the journals. A comparison for the calculated results acquired using the models and it can be accurate that the neural network model with their training function Levenberg-Marquardt (LM) for the prediction of compressive and tensile strength of GPC is the best prediction tool.

Keywords— Geopolymer Concrete (GPC), Artificial Neural Networks (ANNs), Compressive Strength, Split Tensile Strength, Levenberg –Marquardt.

I. INTRODUCTION

Concrete production process is a complicated that includes the action of many processing parameters on the quality control of concrete affecting to workability of the concrete and strength of the concrete etc. These parameters are effective in producing strength quantity of concrete strength.

The requirement for concrete as a building material of construction will increase as the demand for infrastructure development increases especially in countries like India and China. In order to reach this demand the production of OPCshould increase. Although the contribution of emission of greenhouse gases from the OPC production produces around 1.35 billion tons yearly or around 7% of emission of the entire greenhouse gases to the earth's atmosphere.

The utilization of cement may be decreased by using alter possible cementitious materials without compromising the strength of the concrete and durability properties of concrete. Other alternative to make eco-friendly concrete is the evolution of in organic alumina silicate polymer called as Geopolymer synthesized from the by-product materials such as GGBS, fly ash etc. Therefore a try has been built in the presentwork by casting geopolymer concrete mixwith completely replace with OPC.

ANN doesn't require any specific or special equation form it requires sufficient input data and output data. And also it can continuously remodel the new data so that it can user friendly remodel to new data. Modelling with ANN is very easier because however a neural network grabs the mathematical relationships in its collection of inter-connections between its nodes no other mathematical rules or formulae are used or noted within the model.

In this paper, a method to predict 7-days and 28-days compressive and tensile (split tensile) strength of the concrete by using theneural networks. This ANNs model was made to implement the complicate non-linear relationship between the inputs (most of the factors that affect the concrete strength) and the output (concrete strength). The neural networks (NNs) models will give high predicting accuracy.

II. ARTIFICIAL NEURAL NETWORK (ANN)

ANNs are a family of considerably parallel to architectures that are able of learning and statement from examples and experience to develop relevant solutions to the problems even if input data have mistaken and are insufficient. It makes ANNs is a dynamic tool for resolving some of the complex engineering problems. Firstly the processing elements of a neural network (NN) are close to the neurons in the brain which exists of several easy computational elements put in layers.

The essential strategy for progressing a neural network depended on model for behaviour of material is to train a neural network on the results of an array of experiments using that material. When the experimental values contain the suitable information about the material nature (behaviour) then trained ANN will consist sufficient information about material's character (behaviour) to qualify as the material model. The Neural Networks (NNs) having three layers those are input layer, hidden layer and output layer respectively.

Some of the advantages using NNs are given below:

- *Adaptive learning:*The capability to know how to execute tasks based on the given data for training or primary experience.
- *Self-organization:* NN may develop its own presentation or organization of the information it receives mid of the learning time.
- *Real Time Operation:* An ANN calculations can be convey in side by side and distinctive hardware mechanism are been designed and produced which take benefit of this capacity.

III. MATERIALS AND MIX DESIGN

A. *Materials*

*1) Ground Granulated Blast Furnace Slag (GGBS):*It is acquired by cooling molten iron slag from a blast furnace in steam or water to make a glassy granular by-product that is then dried and ground become a fine powder. It contain mainly of silicon di oxide, magnesium oxide, aluminium oxide and calcium oxide. It has similar chemical components as OPC but in dissimilar proportions. For this thesis work GGBS took from SVK ready mix plant in Perecherla was used which was found conforming to IS: 12089.

2) Fly Ash (FA): The majority of fly ash used in a by-product from the burning of pulverized coal to produce electricity at power stations. A higher percentage of silica (SiO_2) and or the sum of alumina (Al_2O_3), silica (SiO_2)and iron (Fe_2O_3) are needed to ensure that sufficient potential reactive glassy constituent is present in FA. For this thesis work fly ash conforming to IS: 3812 was obtained from the local dealers in Vijayawada.

3) Alkaline Liquids: A mixture of alkaline hydroxide solution and alkaline silicate solution were selected as the alkaline solutions. Sodium (Na) based solutions were preferred because they were inexpensive than potassium (K) basedsolutions.

*4) Aggregates:*Local coarse aggregates in surface dry condition of size conforming to 20 mm and 12 mm sizes were used. River sand was used as fine aggregates (Sand) in saturated surface dry condition. All the aggregates used were conforming to IS: 383-1970 specifications.

*5) Water:*Water is an essential component in concrete. It is chemically reacts with the cement to produce hydration as a result of which C-S-H gel is formed thereby giving the desired properties to the concrete. This mixing water has an impact on the concrete slump value. The water to binder ratio is the one of major deciding factors which affect the strength of the concrete and the durability properties of the concrete. Besides it quantity, the quality of the mixing water also has valuable effects on workability and the setting time of the mix initially as well as the durability of the mix on a longer run.

*6) Super Plasticizers (SP):*These are water reducers which are capable of decreasing the amount of water by about 30%. Still it is to be noticed that efficiency of the superplasticizer may be obtained only when it is mixed to a concrete mix that has an initial slump of 20mm to 30mm. Adding of superplasticizer to stiff type concrete mix decreases its water reducing efficiency. Based on the content of the concrete a dosage of SP took 1-3 percent by its weight of binding material is advisable. In this paper, a superplasticizer used namely as CONPLAST SP-430 was used for getting concrete as workable at low w/b ratio.

B. Mix Design

1) Mix Design of Geopolymer Concrete (GPC)

In the mix design of geo-polymer concrete (GPC) fine and coarse aggregates combinely taken as 75% of total mixture by the total mass. This value is same to that used in OPC concrete, in that it can be take the scale of 75% - 80% of the total mixture by the mass. From the previous survey it is noted that the mean density of binding materials based on geo polymer concrete is same to that of OPC 2400kg/m^3. By knowing the concrete density the entire mass of cementitious materials and alkaline solution can be achieved. By assuming the ratio of alkaline liquids to cementitious materials as 0.35 the mass of GGBS and Fly ash and mass of alkaline solution were determined. To calculate the mass of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions the ratio of Na_2SiO_3 solution to NaOH solution was fixed as 2.5. Extra water used to obtain workable concrete. The mix design for GPC is given below in Table I.

TABLE I

MIX PROPORTIONS

Materials	**Cementitious Materials**	**Fine Aggregate**	**Coarse Aggregate**	**Sodium Hydroxide**	**Sodium Silicate**
Quantity of materials in kg/m3	533	504	1176	53	134

2) Preparation of Geopolymer Concrete

To make 8 M concentration of NaOH solution, 320 grams of NaOH pellets was soften in distilled water and make it to 1 litre. The NaOH liquid produced is combined with Na_2SiO_3 solution 1 day before mixing to the concrete mixture to get the proper alkaline solution. The solid materials of the GPC mixture i.e. GGBS, Fly ash, fine aggregate and coarse aggregates were mixed as dry in the miller for about 3 to 4 min. After proper mixing alkaline liquid was combined to the dry mix and wet mixing was done for 3 to 4 min. Finally add extra water to obtain workable GPC mix.

IV. EXPERIMENTAL DETAILS

The test samples for compressive strength was made on cubes cast in cast iron moulds having a size of 150 x 150 x 150 mm. For every mix proportion 6 no. of cubes were casted and tested at the age of 7-days and 28-days. The test samples for split tensile strength test was made on cast in cast iron cylinders having a size of 150 mm dia and 300 mm height. For every mix proportion 6 numbers of cylinders were casted and tested at age of 7-days and 28-days.

A. *Casting and Curing of Samples*

The test samples were casted in cast iron steel moulds. The mould samples were applied with grease oil in all inside surfaces for easy removal of samples after demoulding. The materials used for making concrete are weighed with accurate proportions. Mixing was done up to the level a uniform workable concrete was achieved. The mixed concrete was poured in the moulds with 3-layers of equal heights which were then compacted at every filling to get a well-balanced concrete without any segregation. After 24 hours the samples were demoulded and kept in the normal atmospheric condition. It can be justified that no curing is required for a GPC as compared to an OPC concrete because of the fact that OPC concrete is an organic one and the strength of which results as reason of the formation of hydration process resulting in C-S-H gel formation. Whereas GPC is an in-organic mixture containing Si-Al bonds there by no hydration takes place to achieve strength.

B. *Testing of Specimens*

1) Compressive Strength Test

All the casted cubes were tested under dry condition. For every mix proportion 3 cubes were test conducted at age of 7-days and 28-days. Compression testing instrument of 2000 kN capacity as per code IS: 516- 1959 was used. The tests were done by the application of stress at a uniform rate after placing the specimen properly and at the centre in the testing machine in Fig. 1. Load was applied uniformly with the use of hydraulic pumps until dial gauge reading just get reverses its direction of sign. The reversing of needle displays the failure load of sample. The dial gauge reading is kept as the failure load which is ultimate load of sample. From which the compressive strength of a particular mix can determined by dividing the ultimate load by the area of cube.

$$f_{ck} = \frac{Ultimate\ Load}{Cube\ Area}$$

Where,

f_{ck} = Characteristic Compressive Strength of cube in MPa.

Fig. 1 Compression testing machine

2) Split Tensile Strength Test

This is an indirect test method to calculate the split tensile strength of the concrete of test specimen of cylinders. Split tensile strength was conducted at the age of 7-days and 28-days for the cylinder specimen placed horizontally in Fig. 2. Applied the load uniformlyusing compression testing instrument of 2000 kN capacity as per code IS: 516-1959. The split tensile strength of specimen were calculated from the following relationship.

$$F_t = \frac{2P}{\pi DL}$$

Where,
F_t - Split tensile strength of concrete in MPa.
P - Failure load in kN.
D - Cylinder diameter.
L - Cylinder length.

Fig. 2 Split tensile test

V. RESULTS AND DISCUSSIONS

A. *Experiment vs Simulated Results*

In this, we consider nearly 142 samples of different percentage of material and different molarity of alkaline solutions but here we compare the some of the experiment results with respected simulated and predicted results by Artificial Neural Networks (ANNs) as below. Material used in this were GGBS, Silica fume, Fly ash, Metakaolin and Rice husk ash.

1) *Compressive Strength*

Comparison of experiment results with simulated results for Compressive strength at 7-days and 28-days in Table II.

TABLE II

COMPARISON FOR COMPRESSIVE STRENGTH @ 7 AND 28 DAYS

Mix. no	No. of Days	Compressive Strength N/mm^2		%age of Error
		Experiment Results	Simulated Results	
M 96	7	48.95	59.3	-21.14
	28	56.73	66.36	-16.97
M 97	7	66.5	69.07	-3.86
	28	71.47	72.47	-1.39
M 98	7	24.3	24	1.23
	28	31.4	32.51	-3.53
M 99	7	41.5	37.31	10.09
	28	50.7	45.89	9.48
M 100	7	49.6	48.85	1.51
	28	58.1	57.05	1.8
M 101	7	54.1	59.3	-9.61
	28	64.5	66.36	-2.88
M 102	7	69	69.07	-0.1
	28	76.4	72.47	5.14
M 103	7	27.6	24	13.04
	28	31.4	32.51	-3.53
M 104	7	45.3	37.31	17.63
	28	56.1	45.89	18.19
M 105	7	54.5	48.85	10.36
	28	64.2	57.05	11.13

The above results are some of the results of compressive strength samples under ambient curing. The variation of compressive strength at the age of 7-days and 28-days with optimum percentage of fly ash, GGBS etc. given above. It was observed that from above table increased with the percentage of GGBS, compressive strength of concrete also increased. Also observed that increased with fly ash percentage, compressive strength of concrete was decreased. And also observed that from above results while increasing the molarity of the alkaline solutions, compressive strength of concrete was increased and vice-versa.

2) *Split Tensile Strength*

Comparison of Experiment results with simulated results for Split Tensile Strength at 7-days and 28-days in Table III.

TABLE III

COMPARISON FOR SPLIT TENSILE STRENGTH @ 7 AND 28 DAYS

Mix. no	No. of Days	Compressive Strength N/mm^2		%age of Error
		Experiment Results	Simulated Results	
M 31	7	2.77	2.73	1.44
	28	4.36	4.24	2.75
M 32	7	2.48	2.73	-10.08
	28	3.96	4.24	-7.07
M 33	7	2.55	2.78	-9.01
	28	3.07	3.68	-19.86
M 34	7	3.02	2.78	7.94
	28	3.47	3.68	-6.05
M 35	7	3.15	2.78	11.74
	28	3.81	3.68	3.41
M 36	7	2.8	2.73	2.49
	28	4.15	4.24	-2.61
M 37	7	3.59	2.73	23.95
	28	4.91	4.24	13.64
M 38	7	3.73	2.73	26.8
	28	4.43	4.24	4.28
M 39	7	3.52	2.78	21.02
	28	3.62	3.68	-1.65
M 40	7	3.02	2.78	7.94
	28	4.03	3.68	8.68

The above results are some of the results of split tensile strength samples under ambient curing. The variation of split tensile strength at the age of 7 and 28 days with optimum percentage of fly ash, GGBS etc. given above. It was observed that from above results while increasing the molarity of the alkaline solutions, split tensile strength of concrete was increased and vice-versa.

B. *Predicted results vs Experiment results*

Here considered a sample replaced with 50% of GGBS and 50% of Fly ash of 8 M. In this, compare the predicted results using ANN with respected experiment results in Table IV.

TABLE IV

COMPARISON FOR COMPRESSIVE AND SPLIT TENSILE STRENGTH @ 7 AND 28 DAYS

No. of Days	Compressive Strength (N/mm^2)		%age Of Error	Tensile Strength (N/mm^2)		%age Of Error
	ANN	Experiment		ANN	Experiment	
7	43.57	43.72	-0.03	4.19	3.96	5.49
28	60.43	63.58	-5.21	5.37	4.53	15.64

The above results are compressive and split tensile strength under ambient curing. The variation of compressive and split tensile strength at the age of 7-days and 28-days with optimum percentage of fly ash and GGBS were given above. It observed that percentage of error was less for 7-days strength compare to the 28-days strength.

VI. CONCLUSIONS

In the actual context of sustainable development the usage of solid wastes in concrete has become an attractive way to reduce the environmental impact of both the huge amount of solid wastes produced and the over use of virgin materials as well. In this present study of producing geopolymer concrete it was targeted to decrease the environmental effect of cement used in the production of concrete and as well as early determination of strength.

In summary of all the above investigations some of the conclusions are made from the results indicate the followings.

- From the experimental work, it was observed that increasing the GGBS usage is found to increase the strength of Geopolymer concrete.
- In constructing early calculation of compressive strength value is very important. Normally calculation of compressive and split tensile strength takes 28-days but using the proposed ANN model the compressive and split tensile strength value can be predicted in shorter time.
- This study shows the practicality of using the ANNs in building the model for predicting the compressive and split tensile strength of concrete using the materials. The data were took from reputed journals and thesis.
- ANN cannot be used for simulate the strength of geopolymer concrete for 7-days because the results show huge variations compared to the experimental values.
- ANN can used for simulate the strength of GPC for 28 days because the results show lower variation compared to experiment values.
- The model is used successfully for predicting the 28 day strength of concrete The test of the model by un used data within the range of input parameter shows that the absolute maximum error for model was about 35% and 70% of the output results has absolute errors less than 15%.
- The cost of geopolymer design mix is cheaper than conventional concrete.

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