Study on Strength Prediction of Metakaolin Based Geopolymer Using Artificial Neural Network

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Abstract- *This study deals with behaviour of metakaolin based geopolymer by utilizing ANN tool. Optimization was performed by utilising the MATLAB software .The ANN model was prepared by considering four major parameter viz., alkaline liquid/base material, water/solid ratio , sodium, silicate/sodium hydroxide, and compressive strength. In order to reduce the trial and error process, ANN model was created. Fibre reinforced geopolymer concrete with man-made fibre (polypropylene) can be efficiently replaced by a natural fibre (sisal) having nearly similar properties. Eventually, eco-friendly approach and the outcome can be achieved.*

Keywords- ANN tool, geopolymer concrete,polypropylene fibre, sisal fibre.

I. INTRODUCTION

The worldwide demand for concrete increases consistently in the construction industry and the production of cement for its usage in conventional concrete obviously leads to the increased emission of greenhouse gases on to the environment, contributing to about 5-8% of overall greenhouse gas emission of the world. This proves the need for an eco-friendly alternative for conventional concrete. Geopolymer Concrete serves one such need, as it is cement-free concrete and highly environmental friendly.

Geopolymer plays a vital role in replacement of cement material and considerable restrict the mining of natural resources. Though, the major developments took place in geopolymer , mix design procedure still has a gray area. So. the tedious mix design process can be overcome by machine learning technique. Influence of artificial intelligence in the field leads to economic activities. Eventually, it performs well in less consumption of material, accessed only during data collection. . Machine learning-based classifiers were able to predict the compressive strength with high precision.The strength predictions can potentially guide preliminary mix proportioning of metakaolin-based geopolymers to achieve required strength grade without going through tedious (trial and error) mix formulation. Artificial neural network is a tool, helps in obtaining a robust allegation. The major four parameters are considered to create and train the NN model.

[2]Mukund LahotI, et.al., (2017) This study evaluated the signifi cance of four mix design parameters,namely, Si/Alratio, water/solids ratio, Al/Na ratio and H2O/Na2O ratio.Results showed that Si/Al ratio is the most significant parameter in determining compressive strength of geopolymer followed by Al/Na ratio.SEM facilitated physical reasoning of the statistics results and revealed that Si/Al ratio significantly influences the microstructure of geopolymers.Predictions could classify geopolymers into low, medium and high strength to a reasonable accuracy with high precision .

[9]Thejas C M, et.al., "optimization of mix design of self-compacting concrete using matlab"(2017) This paper Various factors consideredwere fly ash (FA) content, water-binder(W/B) ratio,superplasticizer (SP) content, fine aggregate (S/a) percentage and cement content. The optimal design was tested for tests like passing ability, manufacturing cost, compressive strength and segregation.The different inputs parameters considered are volume of paste and water-cement ratio and fresh properties and compressive strength as output parameters.The volume of paste is taken as 0.39, 0.41 and 0.43 by keeping constant water content as 185 liter. Then water content is varied as 190 liter and 195 liter by keeping volume of paste 0.38 constant.

[14]Abdulrahman Albidah, et.al., (2020) This paper is to study the Three types of mixes were adopted to produce plain and steel fibre-reinforced GPC by controlling both alkaline solids to metakaolin ratio and sodium silicate to sodium hydroxide ratio.The average normalized bond strength of plain GPC mixes was generally lower than that of cement concrete by 11%–27% and 21%–40% for steel and GFRP bars, respectively.The inclusion of steel fibers in GPC improved the bond performance for specimens with steel and GFRP bars by 7%–45% and 33%–114%, respectively. The fiber-reinforced geopolymer showed better bond performance for GFRP rebars as compared to the plain GPC.

[1]Abdulrahman Albidah, et.al., (2020) This paper investigated the effect of mix design parameters (sodium

silicate to sodium hydroxide ratio, alkaline solids to MK ratio, aggregate content, and water to solids ratio) on fresh and hardened properties of local MK-based GPC.Workability was found to improve with the increase in sodium silicate to NaOH (solids) ratio until a certain limit (identified here as 2.5).The compressive strength generally increases with an increase in sodium silicate to NaOH ratio and alkaline solids to MK ratio until a certain limit depending on the molar ratios of the mix.The highest compressive strength was achieved with aggregate content of 73.8% and reduced significantly when it increased to 75.8% and 79.8%.

[13]Andres Espinoza, et.al., (2020) This paper is to study the PPF were incorporated into the geopolymer-based mortar matrix in different proportions like 0.5, and 1wt.%
The use of natural zeolite in the preparation geopolymers mortars through alkaline activation with NaOH, Ca(OH)2 and Na2SiO3,and with river sand as a fine aggregate.The best mix design among the ones used: NaOH (10 M), Na2SiO3/NaOH ¼ 3, Ca(OH)2 ¼ 1.5 wt.% and PPF ¼ 0.5 wt.%PPF can improve the compressive strength of the samples which have been cured for seven days. The optimum mix design showed a compressive strength of 4.63 Mpa..

[5]Amir Bahador Moradikhou, (2020) Mechanical and physical properties of GPC reinforced with different fiber types (Polypropylene or PP, 2-part PP, 4-part polyolefin) and volume content (0.15,0.2 and 0.25%) is investigated. In the PP fiber reinforced GPC composites, the flexural strength increases from 0.15 to 0.2% fiber content, and slightly decreases from 0.2 to 0.25%Due to the crack-bridging mechanism of the fibers, the fiber reinforced GPC composites displayed significant improvement in tensile and flexural strength over unreinforced GPC

[10]Jingming Cai, et.al., (2020) This paper is to study the The heat evolution and compressive behavior of KOH activated geopolymer materials The 28-day compressive strength for all geopolymers increased with the increase of alkali concentration and slag replacement ratio cured under ambient temperature. The fly ash-based geopolymer showed single exothermic heat peak and low chemical activity in ambient curing condition, while the cumulative released heat and chemical activity for metakaolin-based geopolymer was much higher than fly ash-based geopolymer.

[6]Tao Bai, et.al., (2020) This paper is to study Mechanical properties of metakaolin-based geopolymer (MGP) reinforced with glass fiber using laboratory testing methods.The optimum period of vibration operation was demonstrated to be 25 minutes. The Glass fiber used in this work was pretreated using ZrO2 in the factory to generate a protective film on the fiber surfaceThe relative large length of fiber led to the worse dispersion of fiber in MGP. Thus, the fiber length is not recommended to exceed 9 mm. . The optimized composition of fiber length and mass dosage were found to be 6 mm and 3 ‰, respectively.

[7]K.V. Sabarish, et.al., (2019) This paper is to study the The real contribution of the fiber is to increase the hardness of the concrete under any type of loading. The percentage of fiber is 1.5% is added in the concrete. The 1.5% of the fiber is chosen based on the beam dimensions and aspect ratio of the sisal fiber. The durability property of sisal fiber is more as compared to other natural fiber is one of the main reason for choosing sisal fiber in concret. Sisal fiber is recommended to the alternate method for economic and environmental aspects.

II. MATERIAL

A. Metakaolin

Metakaolin is the calcinated form of kaolin. Kaolin is a china clay.By pre-processing the kaolin at 1058 F. meta-kaolin is formed.Due to the dehydroxylation process. During the process, kaolin modify its chemical composition especially detach its bond between hydroxyl and turns into a new compound. Metakaolin has slightly vary properties than kaolin.

Table (1): Metakaolin properties

Material	SiO2	Al203	K2O	LOI
Metakaolin	52%	46%	0.03%	0.09%

B. Sisal Fiber

Sisal is a member of the agave family; Agavae Sisalana is the commercially grown species. The plants grow for 7 to 12 years and then produce a flower stalk 4 to 6 meters tall. The life of sisal plant is usually 15-18 years. Sisal is generally harvested once a year but if the soil and the climate permits it can harvested three times in two years.The World production is about 3000,000 tones. Brazil being the largest producer followed by China, Mexico,Tanzania, Kenya and Madagascar.

Table (2): Sisal fiber properties

Material	Cellulose	Hemi-cellulose	Lignin	Ash
Sisal fiber	55-65	10-20	10-20	0.7-1.5

C. Polypropylene Fibre

Polypropylene fiber also known as polypropene or PP, is a synthetic fiber, transformed from 85% propylene and used in a variety of applications. The fiber is thermoplastic, resilient, light weight and resistant to mildew and many different chemicals. The chemical resistance is generally excellent and tensile strength is 3.5 to 5.5. It has relative density as 0.91.

D. Alkaline Solution

Alkaline solution plays a vital role in polymerisation process.Typical,alkaline solution contains sodium silicate and sodium hydroxide. It creates a base environment where robust polymerisation can be achieved.

III. EXPERIMENTAL INVESTIGATION

A. Overview

The Experimental program involves casting of cubes at different mixes and collecting relevant data regarding strength especially compressive strength.By processing the data, preparing of Artificial Neural Network model performed.Validating the model prediction with the experimental compressive test.Then,3 beams were casted of which one is conventional and other two is hybrid fibre reinforced. Flexural test were conducted on beams and results were concluded.

B. Geo-Polymerisation

It is the phenomena of dessolving the alumino--silicate in the base solution. It attains the good bonding structure which escalate the physical and chemical properties of the element.The process of geo-polymerization is carried out in the manner as the following mentioned below.

- Dissolution
- Speciation equilibrium
- Gelation
- Re-Organisation

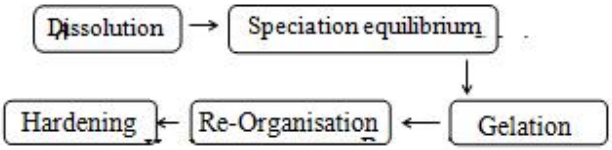

Fig.1 Flowchart of Geo-polymerisation

C. Mix design

Metakaolin based GPC contains metakaolin, coarse aggregate, fine aggregate and alkaline liquid. Metakaolin of properties specific gravity is 2.5 and bulk modulus is 300 kg/m³. Natural river sand conforming to zone-II of IS383:2016. Coarse aggregate at size 20mm was taken.8M of alkaline solution was prepared before the day of casting. Cube specimen size of 100mm*100mm*100mm was casted .AL/MK ranges from 0.35-0.45, $Na_2 SiO_3$/NaOH ranges from 2.1-2.5. By varying this parameter different mix was prepared 76% of aggregate was kept constant for all mixes. In the cases of beam,fibres are

Table(3):Mix proportion and quantity of material

Mix No	Metakaolin Kg/m³	solidium silicate Kg/m³	NaOH Kg/m³	Fine Aggregate Kg/m³	Coarse Agrregete Kg/m³	water/solid	Workability	Oven Curing	Hour
1	426.6667	106.6667	42.66667	547.2	1276.8	0.18701	high	333K	3
2	426.666.	104.0808	45.25253	547.2	1276.8	0.189045	high	333K	3
3	411.4286	110.1881	48.40836	547.2	1276.8	0.211763	high	333K	3
4	411.4286	114.7013	49.87013	547.2	1276.8	0.212433	high	333K	3
5	426.6667	99.55556	49.77778	547.2	1276.8	0.191036	high	333K	3
6	417.3913	103.916	54.69265	547.2	1276.8	0.206162	high	333K	3
7	411.4286	103.7959	58.77551	547.2	1276.8	0.216515	high	333K	3
8	417.3913	107.4446	51.1641	547.2	1276.8	0.204569	high	333K	3
9	405.6030	113.7401	51.62612	547.2	1276.8	0.22157	high	333K	3
10	400	123.6667	53.33333	547.2	1276.8	0.230687	high	333K	3
11	417.3913	103.916	54.69265	547.2	1276.8	0.206162	high	333K	3
12	402.7972	100.0526	64.14918	547.2	1276.8	0.231567	high	333K	3
13	408.5166	107.6717	59.81763	547.2	1276.8	0.221303	high	333K	3

added based on the metakaolin quantity. Sisal fibre and Polyproylene fibre are at 0.6% and 0.4% respectively.Two point bending test comducted on the beam specimen. Beams are casted as per the below detailing.

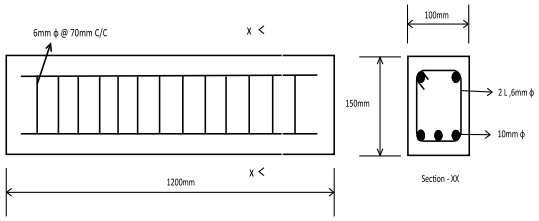

Fig.2 Dimension of beam

As no mix design code avails for geopolymer concrete, the mix proportion study done by RANGAN was taken as a key procedure. Spreadsheet is prepared for design mix calculation. Steel moulds are lubricated before the casting process. After batching of dry material, alkaline solution which was prepared a day before the casting is poured and mixing was performed for 4 minutes. Then it was poured into

the mould and compaction was performed. After a day, the specimen was placed in the oven for 3 hours at 60˚C.

In the case of beam, batching of dry material along with the fibre content was done. Akaline liquid prepared for the mix was poured into it and mixing process was done for 4 minutes. M eanwhile, the steel mould for beam was lubricated and reinforcement cage was placed at 20mm cover. After mixing, the mixture was poured. Vibrator was used to compact the mixture. In order to avoid honeycomb and pores in specimen.

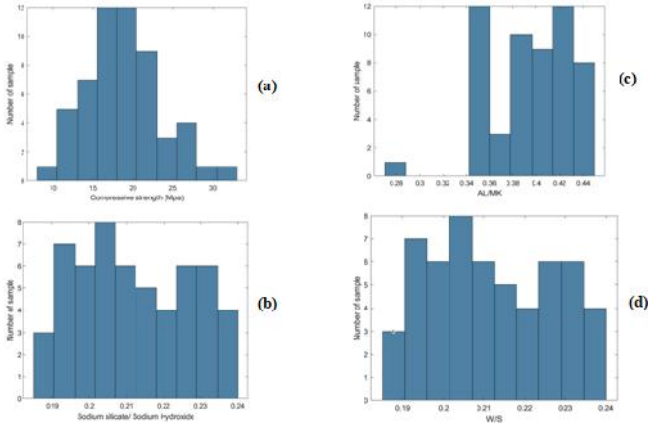

Fig.3 Histogram of a)compressive strength b)Alkaline liquid/Metakaolin ratio c)Sodium silicate/Sodium hydroxide ratio d)water/solid

D. Artificial Neural Network

It is an adaptive inter-connecting system that earns by inter-connecting nodes.It consist of more than one layers. Algorithm involves series of mathematical operation that calculates the some of the inputs at each node. Each neuron in a layer has an adjustable bias for its input.NN operates by adjusting all of its bias. MATLAB R2019b is a software version used to create a ANN model.MATLAB is a programming and numeric computing platform used by engineers and scientists to analyse data .develop algorithms .and create models.MATLAB is a high performance language for technical computing. It integrated computation .visualization and facile to use in the situation where the problem can be expressed in mathematical form and solution are arrived in same form. To approach the precise value, hidden layer has be favourable to the training data. Training data are prepared from the experimental tests as well as data from literatures. From the collected data , Ann model can beprepared by training the 75% of data and validating the 25%of data. This is an effect way to achieve precise result.Matlab script was written to train the ANN model. Training the model and getting the error rate .Plotting the the graph between training set and validation set.From the graph, suitable hidden layer is identified. After suitable hidden layer,model was trained again with newly modified hidden layer to reduce error.

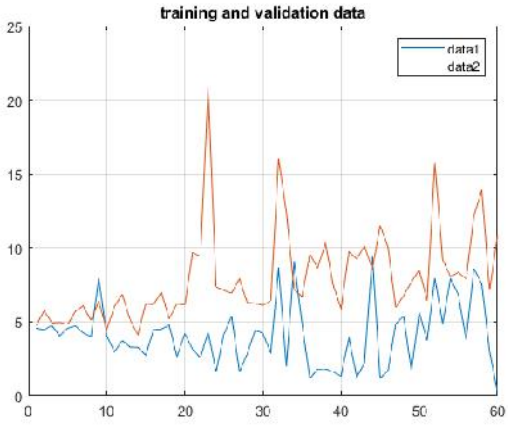

Fig.4 Graph of trainingand validation set

E. Simulation of ANN model

Simulation is the essential portion of the model. After training process, some data sets was provided with the three parameter viz., Na_sSiO_3/NaOH , Alkaline liquid/Metakaolin, Water/Solid. Compressive strength of the sets were provided after processing a given parameters. These output comes with an error of ±4.1706 .To ensure the results, validation performed by experimental test conducted by preparing concrete as per the input parameters. It was tested in Universal Testing Machine. The results were compared and represented in the graph . It depicts a minimum error nearly similar to ANNmodel.Thus, ANN model is trustable and performs well in prediction of compressive strength.

IV. RESULTS AND DISCUSSION

A. Data collection for ANN model

Samples prepared for the purpose of collecting data to train ANN model was tested by Universal Testing Machine. Results obtained from experimental testing was fed to ANN model. Obtained results are shown in table(4)

Table(4):Sample and its compressive strength

Mix no	Na_2SiO_3/ NaOH	AL/ MK	W/S	Compressive Strength N/mm²
10	2.5	0.35	0.188	15.97
2	2.3	0.35	0.189	19.25
3	2.4	0.4	0.212	22.25
4	2.3	0.4	0.212	25.5
5	2	0.35	0.191	17.35
6	1.9	0.38	0.206	19.43
7	1.8	0.4	0.217	13.64
8	2.1	0.38	0.205	16.43
9	2.3	0.42	0.222	17.04
10	2.3	0.44	0.231	19.76
11	1.9	0.38	0.206	12.98
12	1.7	0.43	0.232	15.5
13	1.8	0.41	0.221	16.43

These samples are casted and cured in an oven at 60˚ C for 3 hours after a day from casting. And ambient cured for 28 days. Then, it was produced for compressive testing and its results were collected. Test resukts were utilised to train the Neural Network. Results of the samples under compression are shown in the graph. Fig.5

Fig.5 Picture of few samples for data collection

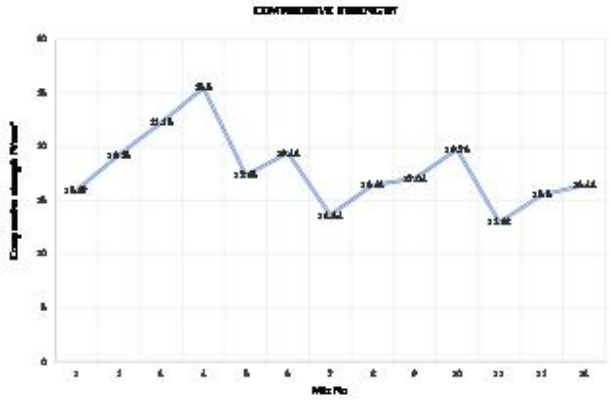

Fig.6 Graph represents compressive strength of samples

B. ANN Model's Prediction

Simulation was performed in ANN Model. Three sets of data was given as input and simulated the model. It predicted the values according to the input parameter. The error found to be ±4.1706 or below.

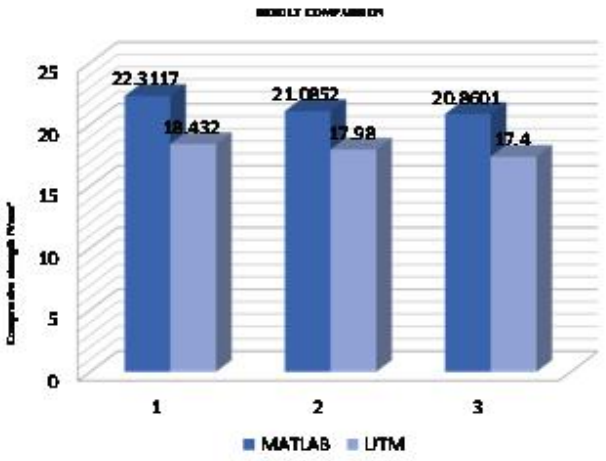

Fig.7 Comparition between Matlab and UTM results

C. Flexural behaviour of fibre reinforced beam

Beam was casted as per the detailing provided in Fig.4. It was cured for 28 days. Three beam were casted in which one was conventional and another two was fibre reinforced. Sisal and polypropylene fibre were added at percentage of 0.6 and 0.4 respectively. Percentage taken related to Metakaolin content. Formula used to calculate fibre,

Fibre content = percentage * mass of metakaolin

Flexural strength of three specimen were noted and tabulated which was shown in table(5).

Table(5):Strength of beam

MIX	COMPRESSIVE STRENGTH N/mm²	FLEXURAL SRENGTH N/mm²
GPC	25.5	3.1
GPC(SF-0.6%:PP-0.4%)-1	27.2	3.5
GPC(SF-0.6%:PP-0.4%)-2	26.98	3.4

Eventually flexural strength increase, when fibre content is about SF and PP as 0.6% and 0.4% respectively. GPC was casted without any fibre. It showed a good flexural property. Two GPC(SP-O.6%:PP-0.4%) beam were casted to get a clarity in results. As fibre were added, it preformed well,

in the post cracking duration. Fibre acted as a extra bonding to the specimen.

V. CONCLUSION

In this study,strength prediction of metakaolin based geoplymer concrete and its behaviour when fibre embedded were learnt. Based on the study following conclusion have been made,

1) Prediction of compressive strength of metakaolin based geopolymer with an error of ±4.1706 N/mm²was achieved.
2) The inclusion of fibers in GPC improved the flexural performance for specimens with sisal fibre and polypropylene fibre by 0.6% and –0.4%, respectively.
3) Sodium silicate to Sodium hydroxide ratio ranges from 2.3-2.5 showed better results in compressive strength.
4) Alkaline liquid to Metakaolin ratio 0.4 provided better results than other ratio.

VI. FUTURE SCOPE

- The work can be further proceed effectively with more specimen of various AL/MK, Na2SiO3/NaOH, W/S conditions. Thus even much precise conclusions over our result can be produced.
- Conducting various test viz., durability and updating the ANN model leads to effective usage.

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