Strength Prediction of Concrete with Different Pozzolanic Materials by Fuzzy Logic

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Abstract

This study emphasis on the prediction of variation on compressive strength of concrete by replacing cement with 'flyash' & 'silica fume' .The compressive strength of concrete depends on variants such as Water/Cement ratio, environmental condition, quality etc, which is analysed through MATLAB with assistance of fuzzy logic (FL). In this process flyash & silica fume are replaced with cement at 0%, 15%, 20%, 25%, 30%, and 35% individually, and water/cement ratio of 0.45 & 0.47 for M20 & M30 concrete grade are taken respectively. The experimental Compressive strength of the formed sample at 28 day is determined and compared with the compressive strength values obtained from the fuzzy sets. The relevance of fuzzy logic for prediction of compressive strength of concrete can be obtained.

Keywords: *fuzzy logic, flyash, silica fume, compressive strength*

1. Introduction

Concrete is one of the inevitable ingredients in today's construction industry. It is causing the dominance over other materials because of its materials availability, feasibility & adaptability to the situation. One of the main constituent of concrete is 'cement'. Unfortunately production of which results in emission of CO_2 causing the global warming which is one of the biggest issue for human civilization. Various researches have been going on to find the alternative material for cement. Pozzolanic materials like Flyash, Silica fume, Ground granulated blast furnace slag, Highly reactive metakaoline have been suggested to be used as certain replacement to cement. In this study, flyash and silica fume are used as the replacement to cement.

1.1 Fuzzy Logic

In this rapidly developing phase everything needs to be shortened, for this various technological advancement has been persuaded. Earlier techniques like empirical method based on multiple linear regressions have been used to predict the compressive strength. But, the results obtained from such method are not precise because of complex relation among various factors. As this is time consuming method a new Artificial intelligence

technique such as Fuzzy Interface System & Artificial Neural Network have been adopted.

Dr. Lofti Zadeh et al.(1960) Fuzzy logic relates to the computing process based on the degree of truth differing from the Boolean logic which deals with true or false (1 or 0).

Fuzzy logic system works on the base of the four component- fuzzifier, fuzzy rule base, fuzzy inference, & defuzzifier. The processing of the system is shown in Fig.1

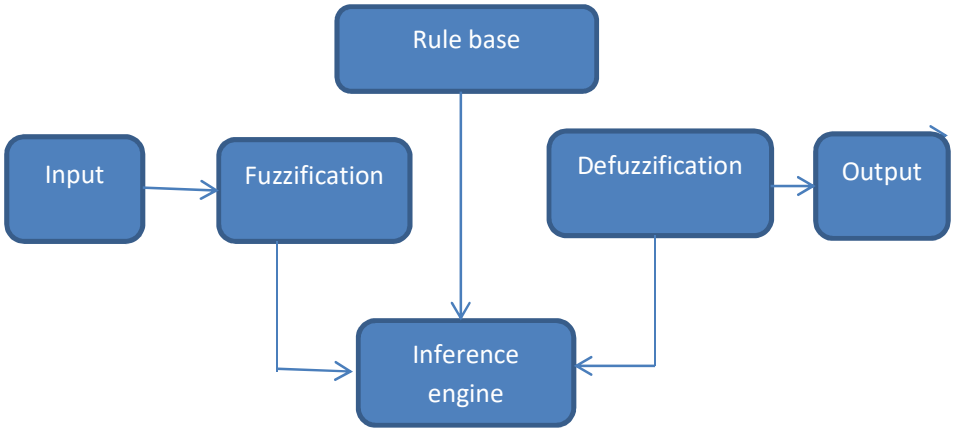

Fig 1. Schematic diagram of fuzzy system

Fuzzifier relates each input data into the number of membership function. The main idea of fuzzy system is to find out the intermediate option instead of the limiting values. Limiting values can be stated as 0 and 1, fuzzy let us use the in-between condition. Fuzzy membership function can take many forms, but practically simple linear function, such as triangular ones is more preferable. In this study we used FL model to assign the triangular membership function for input variables like cement type, environmental condition, w/c &percentage replacements by pozzolanic materials, compressive strength & quality of concrete and output variable of w/c, compressive strength, target compressive strength.

Fuzzy rule base it relates all the possible links between input and output. It is expressed in if-then format. There are two type of fuzzy rule such as Mamdani, Sugeno. In this study Mamdani-type fuzzy rule was used for linking the output and input variables.

Fuzzy inference considers the entire fuzzy rule base and grasp how to convert a set of given input data to output data. For this process it uses basically two inference operator minimization and product. In this study, product method is used for better performance.

Defuzzifier transforms the fuzzy output from fuzzy inference engine to number. There are various defuzzification methods: centre of gravity (COG; centroid), bisector of area (BOA), mean of maxima (MOM), left most maximum (LM), right most maximum (RM). In this study we have used centre of gravity method which is commonly used.

2. Literature Review

Various reference's have been taken in this research and the main reviews are,

Implementation of fuzzy logic results in successful prediction of 28days compressive strength **[1].** Fuzzy logic can actually predict the compressive strength of high strength concrete with silica fume. The result of fuzzy logic is compared with artificial neural networks (ANNs); employing 3 input variables (binder content, age, and silica fume content) with 24 optimal fuzzy rules which were sufficient for the fuzzy logic model to make satisfactory prediction of compressive strength **[2].** For the high strength concrete, lower water-cement ratio were used along with plasticizer to increase the flow ability. Also, slow early strength gaining by the use of flyash and blast furnace slag was an advantage as it allows more time to place and finish concrete **[3]**

The compressive strength calculation of concrete grade M25 and M30 have been carried out with flyash replacement of 0%, 10%, 20%, 30%, 40%. It is found out that there was decrease in compressive for M25 & M30 concrete with increase in the percentage of flyash **[4].** Found a fuzzy logic approach for estimating the durability of concrete. It was shown that the proposed fuzzy Inference model is rational, clear, reliable, versatile, and flexible, since it can be easily updated with new data or modified to accommodate future findings [5].

The concrete containing high volume of flyash as partial replacement for cement exhibits lower strength than the controlled concrete at the early age **[6].** At the early age of structure we cannot predict the actual compressive strength of concrete **[7]**. Flyash is mainly used as a replacement because of its effect on workability and release of less temperature in fresh concrete. It also increases the durability and long term strength development of hardened concrete **[8]**.

The compressive strength of concrete containing silica fume with various % is observed at 7,14 & 28 days, it is found out that up to 10% replacement of cement the compressive strength of concrete increases but beyond 10% the compressive strength tends to decreases **[9].** The comparative study for the estimation of compressive strength of concrete using neural network and neuro-fuzzy inference model is done. The final result shows that the ANFIS modeling with Gaussian membership function may constitute an efficient tool for prediction of compressive strength of concrete **[10].**

3. Materials Study

Construction materials such as cement, fine aggregate, coarse aggregate, flyash, silica fume & water were used in this study. Lab test was carried out to find the specific gravity of different materials.

3.1 Cement

Cement is a binding material which is used to link all the construction material as a single unit. In this study ordinary Portland cement 53 grade confirming to IS 12269:1987 was used.

3.2 Coarse aggregate

Locally available, machine crushed, hard aggregate was used in the well grade of 20mm. These aggregate used are confirmed through IS 383-1970.

3.3 Fine aggregate

The aggregate used confirm to zone II category. Locally available river sand passing through the sieve of 4.75mm as per IS 383-1970 was used. The physical properties of coarse aggregate and fine aggregate is shown in Table 1,

Table 1: Physical Properties of Coarse Aggregate and Fine Aggregate

Description	Coarse Aggregate	Fine Aggregate
Specific gravity	2.6	2.75
Water absorption	1.57%	2.3%
Surface moisture	Nil	Nil
Fineness modulus	3.1(zone II)	6.4
Bulk density	1450 kg/m^3	1765 kg/m^3

3.4 Flyash

Flyash are the by-product of coal based power plant which enhances the workability, increase ultimate strength, provide better finish to the concrete. Flyash are generally finer than Portland cement and are classified into two Class as F and C depending on its chemical composition. Flyash of class F having specific gravity of 2.2 was used in this study.

3.5 Silica Fume

Silica fume are the by-product of silicon and ferrosilicon alloy. These are very fine particles whose size is less than 1 micron which is very much smaller than cement particle. It is mostly used along with flyash or individually in condition where more durable concrete is required. The used silica fume had specific gravity of 2.63.

4. Analytical Study

The analytical study is carried through MATLAB software with the assistance of fuzzy logic designer. This is done to obtain the compressive strength of concrete from the fuzzy interface system. The data for input have been taken from literature and the corresponding output is obtained.

4.1 Data Sets and Model Construction

In this study 3-layers of set was formed, the output from 1st layer is taken as input in second layer and 2nd layer output is respectively taken as input to the 3rd layer. In the 1st layer input of cement type (OPC53 & OPC43) and environmental condition like mild, moderate, severe, very severe, extreme were assigned. Similarly, in 2nd layer w/c (0.35-0.55) and flyash, silica fume with different variations (0%-60%) were given as input. Flyash and silica fume variation are used individually in 2nd layer. In 3rd layer compressive strength and quality of concrete (low, medium, high) were assigned as input. Finally the output of compressive strength and target compressive strength is obtained. Each layers input and output functions are shown in table 2.

Table 2. Input and Output Variable for Each Layer

Layers	Input	Output
1st	cement type & environmental condition	w/c
2nd	w/c & (flyash, silica fume)%	compressive strength
3rd	compressive strength & quality of concrete	target compressive strength

After defining each input and output variable the membership function is defined individually. The rules for the system are provided as,

IF w/c is 0.4 AND silica fume % is 30 THEN compressive strength is M50

IF w/c is 0.4 AND flyash % is 35 THEN compressive strength is M45

Similarly, various numbers of rules have been provided to the system. Depending on the rules provided the surface graph for each layer was obtained. The surface graph shows the corresponding values of the output referred to input. The surface plot and the rules for each system can be seen in Fig 2.

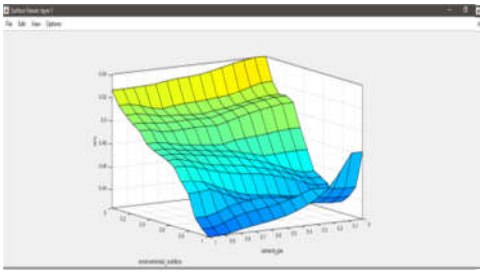

Fig 2a) Surface for 1st layer

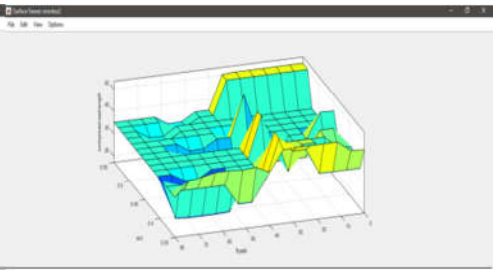

Fig 2b) Surface for flyash 2nd layer

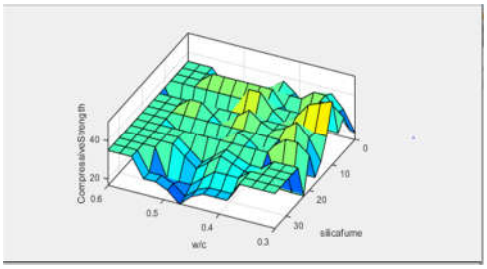

Fig 2c) Surface for silica fume 2nd layer

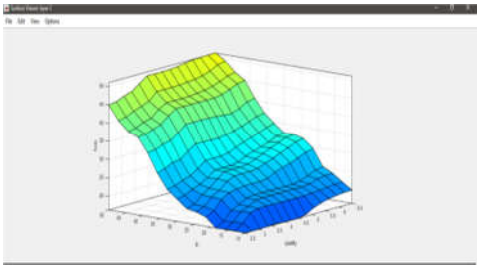

Fig 2d) Surface for 3rd layer

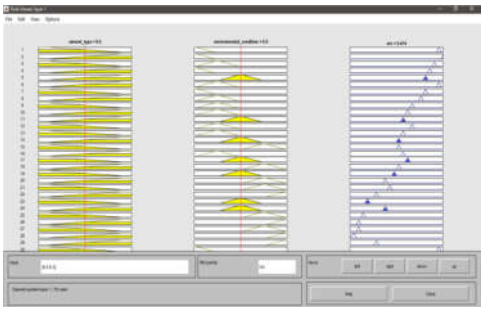

Fig 2e) Rules for layer 1

Fig 2f) Rules for layer 2 flyash

Fig 2g) Rules for layer 2 silica fume

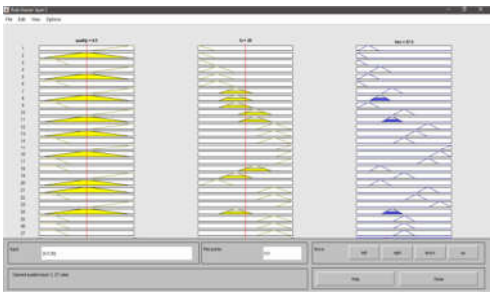

Fig 2h) Rules for layer 3

Depending upon the fuzzy rule provided in fuzzy interface the respective output was obtained. The compressive strength and target compressive strength obtained from fuzzy logic are listed in the table 3

Table 3: 28 Days Compressive Strength Obtained from Fuzzy Logic

Compressive Strength of Concrete (Mpa)					Target Compressive Strength (Mpa)			
Replacement	Flyash Grade		Silica fume Grade		Flyash Grade		Silica fume Grade	
(%)	M20	M30	M20	M30	M20	M30	M20	M30
0	23	38.3	26.1	32.8	25.8	38.3	27.5	29.6
15	25.5	36.1	31.1	37.8	27.5	34.6	28.2	37.6
20	25.5	36.1	26.1	32.8	27.5	34.6	27.5	29.6
25	20.5	26.2	25.6	30	23.8	27.5	27.5	27.5
30	20.5	26.2	20.6	25	23.8	27.5	23.9	23.9
35	16.9	25.8	17.5	22.2	22.5	27.5	22.5	22.5

5. Experimental Study

In this process standard cubes (150mm*150mm*150mm) have been casted for each variation in two numbers. The cube is then tested for its load carrying capacity while put on compression. The test was carried on universal testing machine to find out the load carrying capacity and the corresponding compressive strength is obtained.

Fig 3. Compressive strength testing

The standard target compressive strength needed to be found out for the comparison with the target compressive strength obtained from fuzzy logic. The standard target compressive strength was obtained as below:

Standard target compressive strength (Fck) = fck+ 1.6*S where,

fck= characteristics compressive strength at 28days

S= assumed standard deviation in N/mm2 (as per Table 1 of IS 10262-2009)

After casting of specimen, continuous curing in controlled environmental condition for 28 days was carried out. The testing of the specimen was done after 28 days and its respective compressive strength was obtained as in table 4.

Table 4: 28 Days Compressive Strength Obtained Experimentally

Compressive strength of concrete (MPa)					**Standard Target Compressive Strength (MPa)**	
Replacement (%)	Flyash		Silica fume			
	M20	M30	M20	M30	M20	M30
0	24.5	36.2	27.8	36	26.6	38.25
15	27.1	38.2	32.3	39.4	26.6	38.25
20	24.12	35.13	27.9	34.82	26.6	38.25
25	21.01	29.49	24.2	32.68	26.6	38.25
30	19.49	28.67	18.1	28.2	26.6	38.25
35	14.2	27.9	14.8	25.6	26.6	38.25

Here we can visualize that the maximum utilization of pozzolanic material is in between 0-15%, as the maximum compressive strength value is obtained at 15% replacement. With further increase in % replacement the compressive strength tends to decrease afterwards.

6. Comparison of Analytical and Experimental Results

Analytical and experimental work has been conducted and their corresponding output was obtained. The obtained output was compared to find the relevance of fuzzy system practically.

6.1 Comparison of Compressive Strength

Following trend line illustrates the comparison of fuzzy logic (FL) compressive strength with experimentally obtained compressive strength.

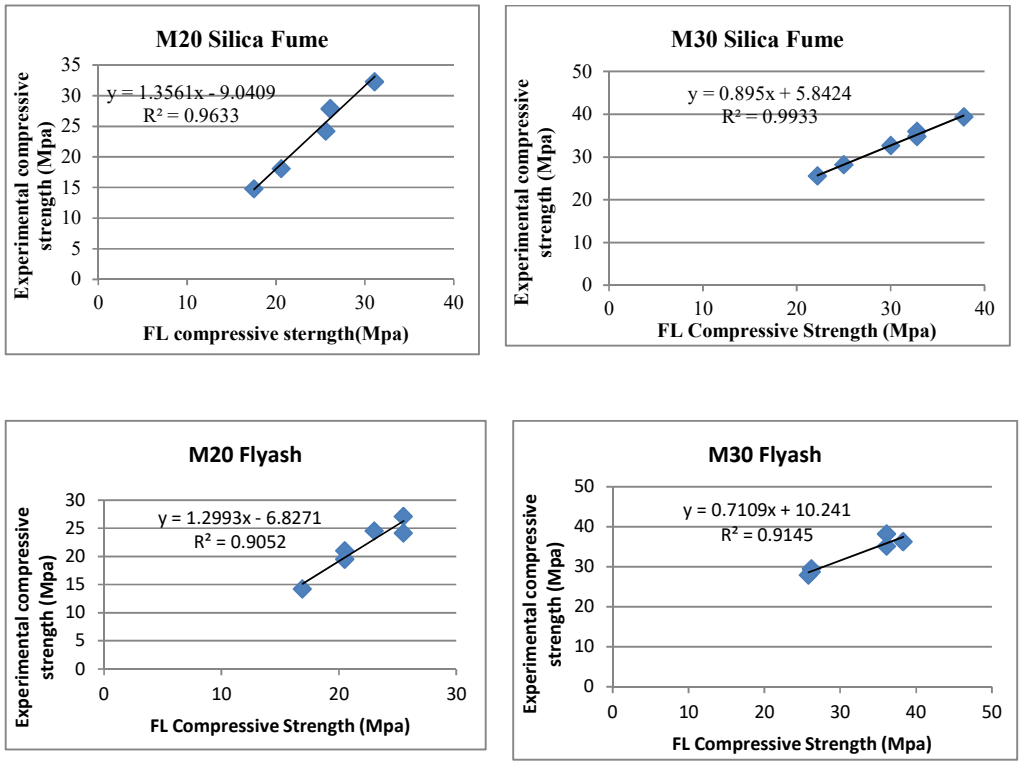

Fig 4. Comparison of experimental and fuzzy compressive strength

While comparing this characteristics compressive strength obtained from fuzzy system with the strength obtained experimentally, we found out that it has a correlation coefficient above 0.9. The maximum correlation coefficient is of 0.99 is obtained in M30 grade concrete model with silica fume as its constituents. The difference between predicted and experimentally obtained strength goes on increasing with the increase of percentage replacement.

6.2 Comparison of Target Compressive Strength

Here we compared standard target compressive strength with target compressive strength from fuzzy logic (FL).

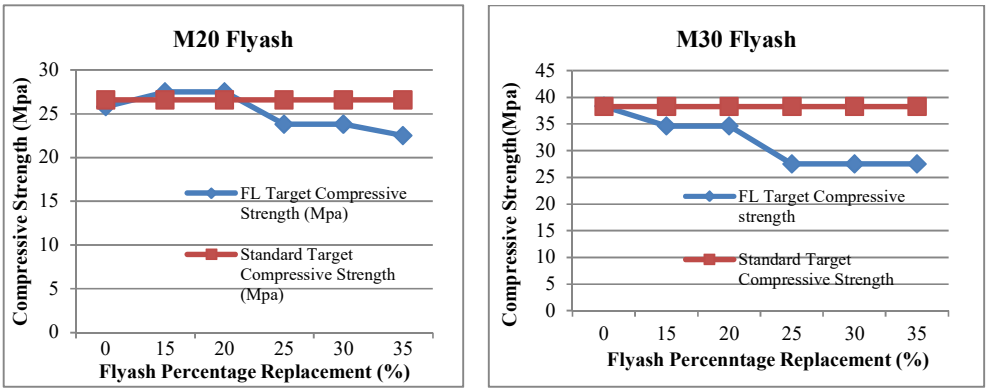

Fig 5. Comparison of standard and fuzzy target compressive strength

In M20 concrete with flyash replacement it is found that the fuzzy logic target compressive strength is found to be higher than that of standard target compressive strength upto 20% replacement, on further increase in flyash the fuzzy logic target compressive strength decreases. While in M30 concrete with flyash replacement its visible that fuzzy logic target compressive strength continuously decreases without meeting the standard target compressive strength.

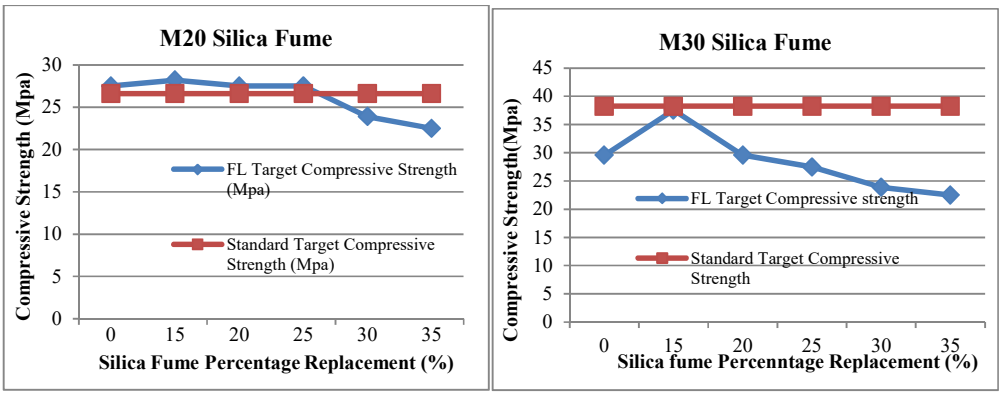

Fig 6. Comparison of standard and fuzzy target compressive strength

In M20 concrete with silica fume replacement, it is found that the fuzzy logic target compressive strength is found to be higher than that of standard target compressive strength up to 25% replacement, on further increase in silica fume the fuzzy logic target compressive strength decreases. While in M30 concrete with silica fume replacement it is visualised that fuzzy logic target compressive strength meets the standard target compressive strength with 15% replacement of silica fume, beyond that it goes on decreasing.

7. Conclusion

Here, the fuzzy logic based model was used to estimate the compressive strength of concrete containing flyash and silica fume. Experimentally, compressive strength of concrete increases with replacement of cement by pozzolanic materials like flyash and silica fume up to 15%. On further increasing the pozzolanic material content the compressive strength of concrete goes on decreasing. Thus using pozzolanic material as a

replacement to some extent is a good choice. The target strength can also be achieved and even in some cases it exceeds the standard value with the certain percentage replacement of pozzolanic materials with cement. In this research it is visible that performance of silica fume is better than flyash. On comparison a good linear relationship between fuzzy and experimental compressive strength was obtained. As concrete is very much complex material for prediction of exact strength each time in site, experimenting each time is more time consuming, it also increase a waste of materials which directly effects the design cost. Hence, it can conclude that fuzzy approach can be an efficient method in determining the compressive strength of concrete.

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