Experimental Investigation and Prediction of Fly Ash Efficiency Factor in Concrete with Cost Economic Analysis

Presented by

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(15CEM07/ANJUMAN-24)

Under the Guidance of

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M.E. (CE&M), 2015-2017

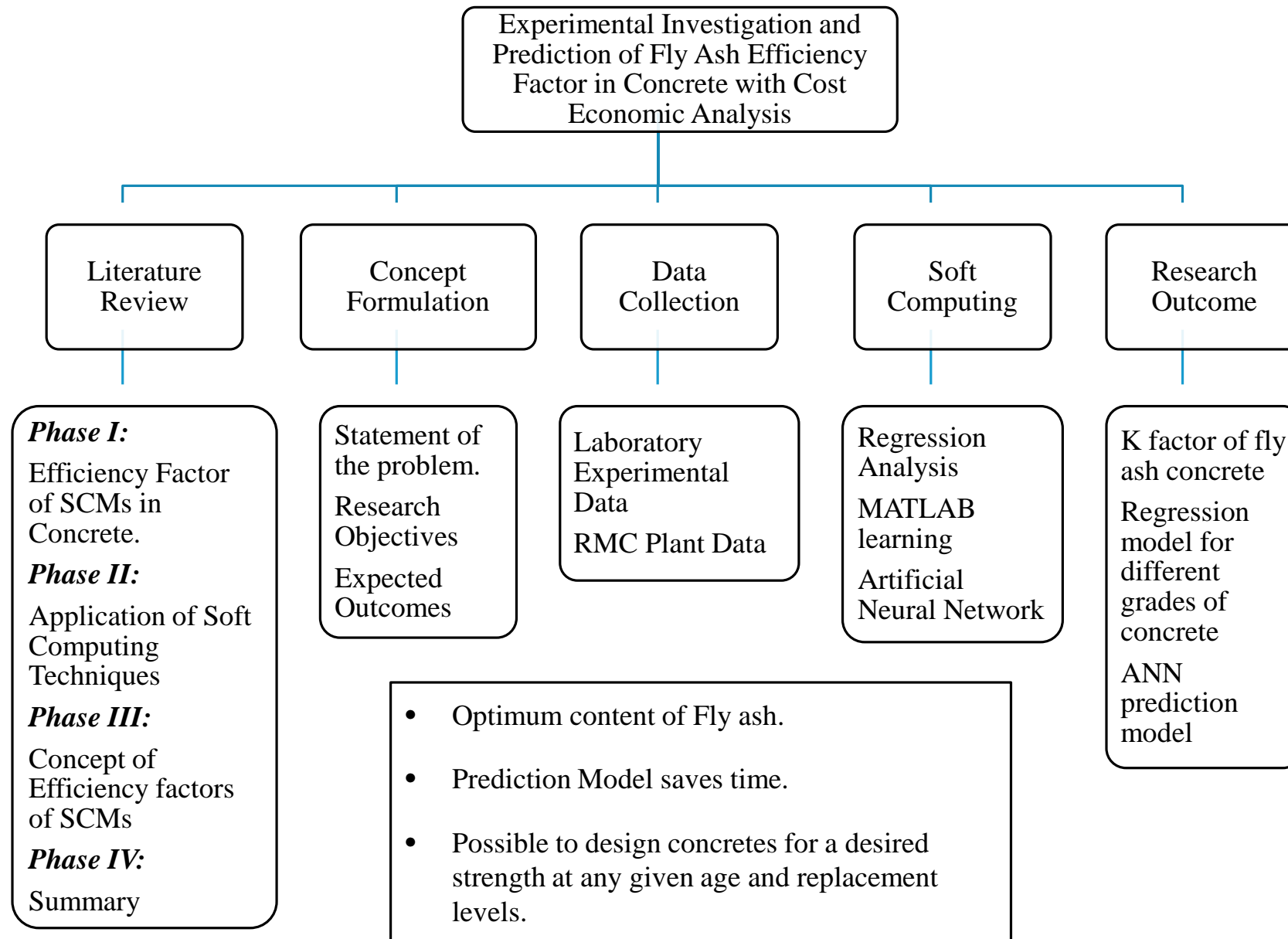# Overview

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Introduction

1. Supplementary cementitious material (SCM) – Fly Ash

2. Quantitative understanding of the efficiency of fly ash as a mineral admixture in concrete is essential for its effective utilization.

3. Fraction of potland cement that can be replaced by a SCM at an unchanged strength.

4. Efficiency of Fly ash – Bolomey's empirical equation

5. MLR and ANN

6. Cost economic analysis

Process Flow Chart

Experimental Investigation and Prediction of Fly Ash Efficiency Factor in Concrete with Cost Economic Analysis

Literature Review	Concept Formulation	Data Collection	Soft Computing	Research Outcome
Phase I: Efficiency Factor of SCMs in Concrete. **Phase II:** Application of Soft Computing Techniques **Phase III:** Concept of Efficiency factors of SCMs **Phase IV:** Summary	Statement of the problem. Research Objectives Expected Outcomes	Laboratory Experimental Data RMC Plant Data	Regression Analysis MATLAB learning Artificial Neural Network	K factor of fly ash concrete Regression model for different grades of concrete ANN prediction model

- Optimum content of Fly ash.

- Prediction Model saves time.

- Possible to design concretes for a desired strength at any given age and replacement levels.

Objective of the study

1. To save the resources used in concrete like cement and aggregates.

2. To produce durable and economical concrete mix design.

3. To investigate the effects of various replacement levels of fly ash on compressive strength and workability of concrete.

4. To predict the Efficiency factor of fly ash at different levels of replacements using ANN and MLR.

5. To develop efficiency factor model which, could be helpful in the design of fly ash concretes at different age, at different level of replacement, and different water-binder ratio with greater confidence.

6. Efficiency factor model can be used as a tool for a more efficient proportioning of blended concrete.

Motivation of the study

1. These days' fly ash are used for enhancement of concrete properties.

2. Use of fly ash is gaining importance due to its vital characteristics.

3. Fly ash and other SCMs help in developing high performance concrete (Babu and Rao, 1993).

4. This study aims at determining **efficiency factor (k)** for fly ash.

5. The efficiency factor helps in **economic mix design** of supplementary cementitious materials.

Scope of the study

1. When **k=1**, CHR almost equal to PR

2. When **k>1**, it indicates the SCM used is more efficient than cement, as hydration process is fast compared to OPC. In such a case saving of cement is possible resulting economic mix design of concrete.

3. When **k<1**, it indicates the SCM used is less efficient than cement as hydration process is slow compared to OPC. In such a case more quantity of SCM should be used to achieve required target strength.

4. The efficiency of SCMs with regard to compressive strength and workability in concrete was investigated using MLR and ANN approach.

*CHR = cement hydration rate, PR = pozzolanic reaction

Efficiency Factor

1. Supplementary cementitious materials (SCMs), such as fly ash, pozzolan or blast furnace slag, are widely used to produce blended portland cements.

2. They lead to a significant reduction in CO_2 emission in the production phase.

3. A practical and generally accepted approach to evaluate the contribution of SCMs to the strength of the hardened concrete is through the concept of the SCMs efficiency factor (i.e. $k-$value concept).

Smith (1967) determined 'k' based on the relation between concrete compressive strength and the water cement ratio (w/c) and obtained the efficiency of fly ash using…

$$w/c_o = w/(c + kF)$$

Where, '**k**' is the efficiency factor, c_o is the cement content of normal concrete, C is the cement content of the equivalent binder, and F is the fly ash content in a concrete of equal strength.

Literature Review

Author	Journal	Year	Findings
Ho and Lewis	Cement and Concrete Research, ScienceDirect	1985	Efficiency of fly ash to concrete strength is strongly dependent on the w/c, type of cement and fly ash and age of concrete
Gopalan and Haque		1989	
Fraay etal.		1989	
Bijen and Van Selst		1993	
Babu and Rao		1993	
Babu and Rao		1996	
Sata et al.	Computers and Concrete, Techno-Press	2010	Used modified Bolomey's law with linear relationship for the analysis of compressive strength.

Author	Journal	Year	Findings
Sobhani etal.	Construction and Building Materials, Elsevier	2004	Researchers used Neural network model for predicting various properties of concrete and concluded that neural network showing good correlation in case of complex or an insufficient data.
Ince	Engineering Fracture Mechanics, Elsevier	2006	
Topc and Saridemir	Computational Materials Science, Elsevier	2007	
Pala and O Zbay	Construction and Building Materials, Elsevier	2008	
Adhikary and Mutsuyoshi	Construction and Building Materials, Elsevier	2010	

Author	Journal	Year	Findings
Thomas	CRC Press	2013	Remarkable contribution towards sustainable development of the cement and concrete industry can be achieved by utilization of SCMs.
Lollini etal.	Construction and Building Materials, Elsevier	2016	Developed practical and generally accepted approach to evaluate the contribution of SCMs through the concept of efficiency factor.

Materials

1. **Cement:** Ordinary Portland cement 43 grade confirming to IS:8112-1989; Specific gravity is 3.15.

2. **Fly ash:** Ashtech (India), Class F Fly Ash.

3. **Fine Aggregate:** Locally available crushed sand, confirming to Zone-II used as fine aggregate, sourced from a quarry in Turbe, Mumbai, India.

4. **Coarse Aggregate:** Locally available coarse aggregates of size 10mm and 20mm, sourced from a quarry in Turbe, Mumbai, India.

5. **Water:** Potable water confirming to IS 456-2000 is used

6. **Admixture:** Polycarboxylic ether (Sikaviscocrete5210NS).

Methodology- Bolomey's Law

1. The Bolomey's empirical expression frequently used to predict the strength of concrete.

2. Efficiency factors found from this strength equation are used to describe the effect of the SCMs replacement.

3. Efficiency factors are generally used to describe the impact of SCMs replacements on the compressive strength of Concrete mixes.

4. The Bolomey's strength equation is:

$$S=A[c/w]+B$$

S is compressive strength in MPa,

c is cement content in kg /m^3,

w is water content in kg/m^3.

A and B are constants

Multi-linear Regressions (MLR)

1. Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data.

2. One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable.

3. MLR attempts to model the relationship between two or more independent variables and dependent variables by fitting a linear regression equation to observed data.

4. If it is assumed that the dependent variable y is affected by m independent variables x_1, x_2,…., x_m and a linear equation is selected for the relation among them, the regression equation of y can be written as:

$$y = a + b_1 x_1 + b_2 x_2 + \cdots + b_m x_m$$

Artificial Neural Network (ANN)

1. Biologically inspired networks.

2. Ability to learn from empirical data information.

3. Ability to imitate the brain's activity to make decisions and draw conclusions when presented with complex and noisy information.

4. A neural network model's degree of success in predicting the efficiency factor largely depends on the availability of a large variety of pre-existing experimental data.

5. The experimental data, however, showed the ability of learning the network in all aspects of the relationship between the concrete mixture variables.

Architecture of selected network

- **4 Neurons** Input, **10 Neurons** hidden layers and **1 Neuron** Output.
- **70%** Training, **30%** Testing.
- **Levenberg-Marquardt** optimization through **MATLAB**

Data Sets

Mix	No. of Trials	% Replacement of fly ash
M40	217	
M35	217	
M30	217	20-35% (*0.5 variation)
M25	217	
M20	217	
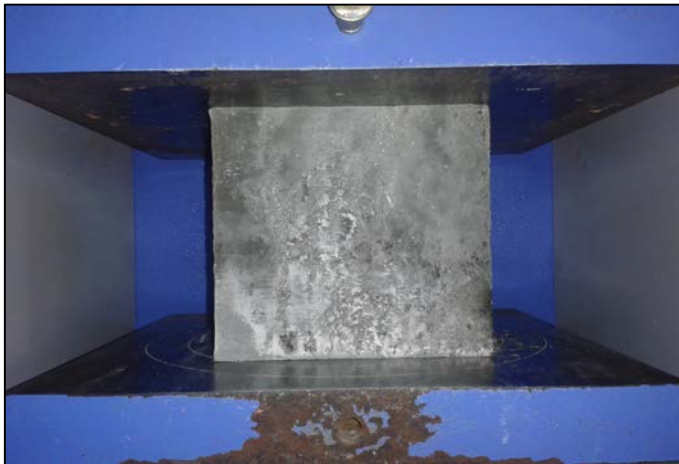
Results and Discussions

1. Variation in strength at different replacement level of fly ash

2. Variation in efficiency factor at different replacement levels

3. MLR Models for different grades of concrete

4. MLR: Actual VS Predicted Efficiency Factor

5. ANN: Actual VS Predicted Efficiency Factor

6. Comparison of MLR and ANN results with respect to k-value

7. Cost economic analysis

Variation in strength at different replacement level of fly ash
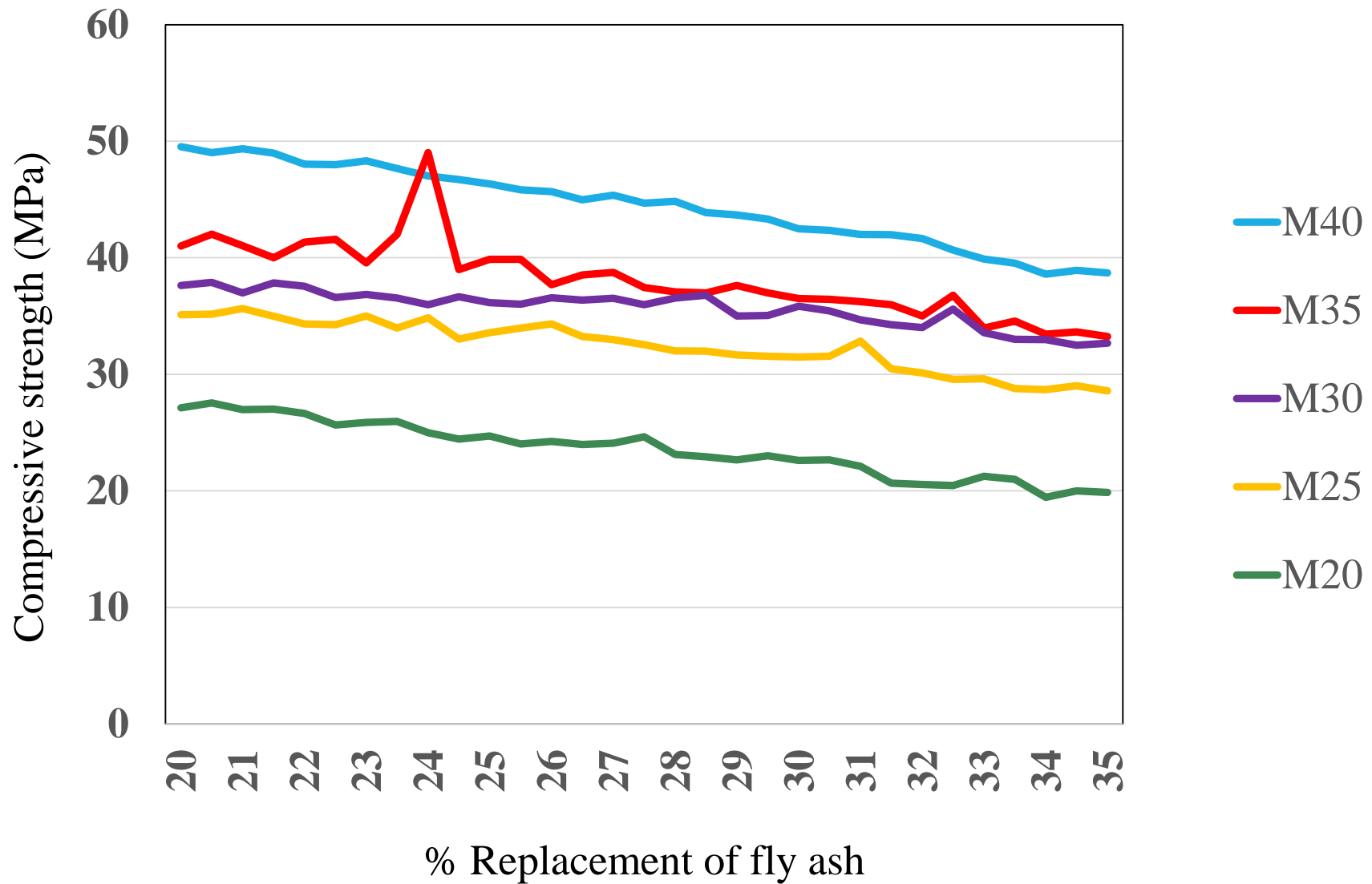
Variation in efficiency factor at different replacement levels
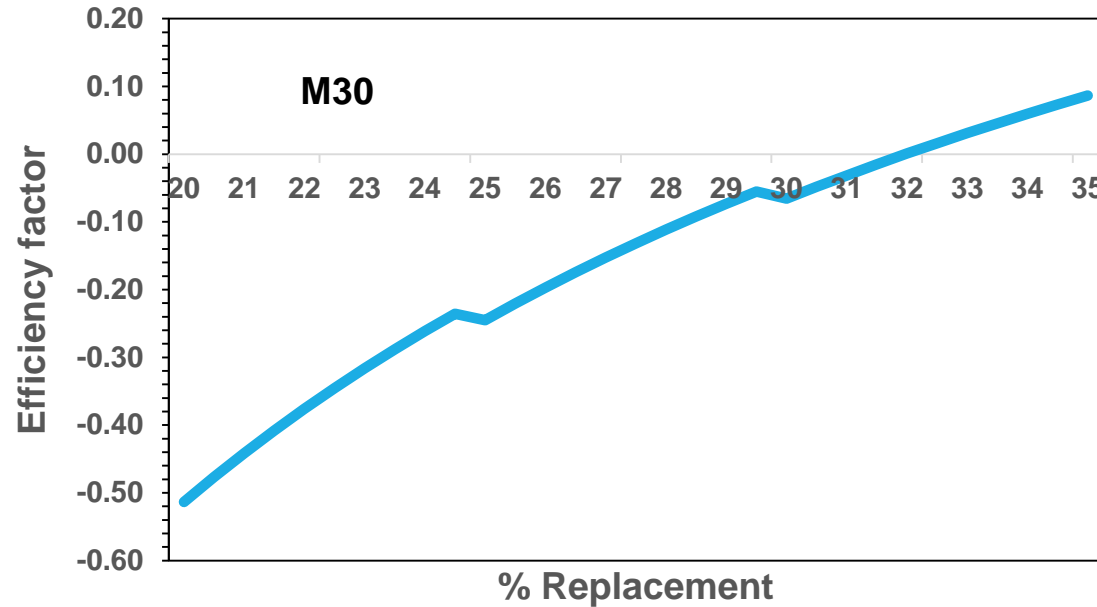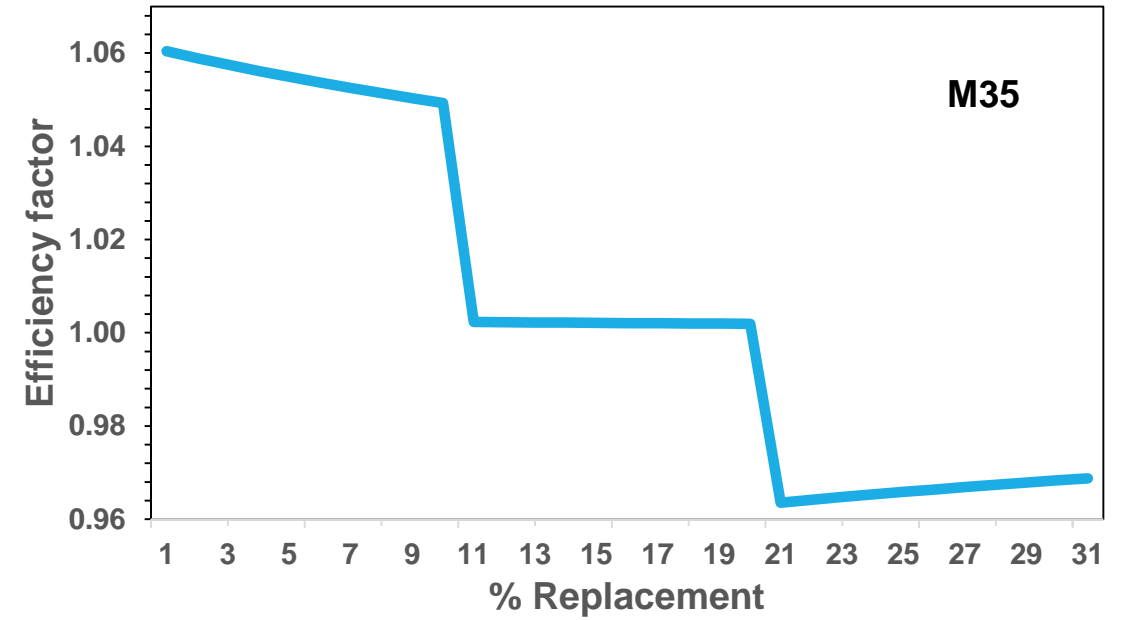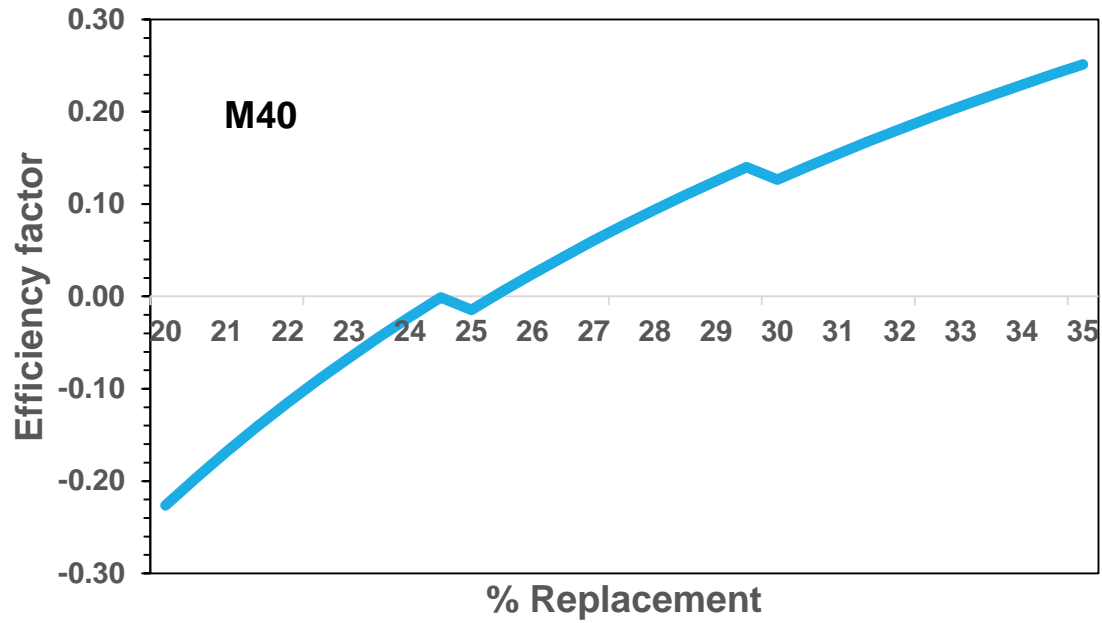
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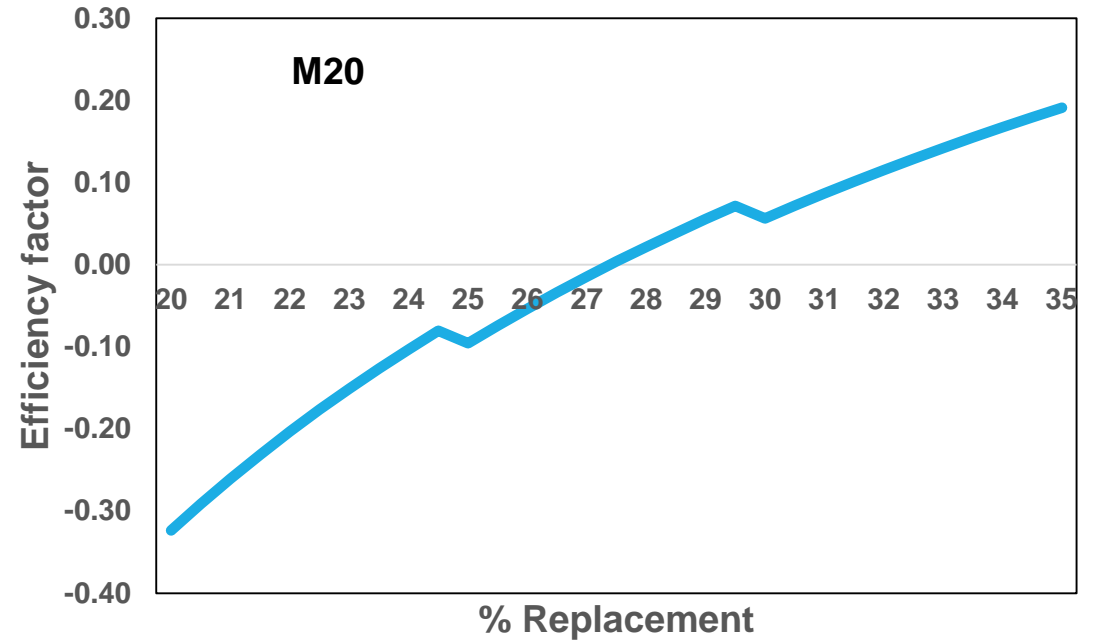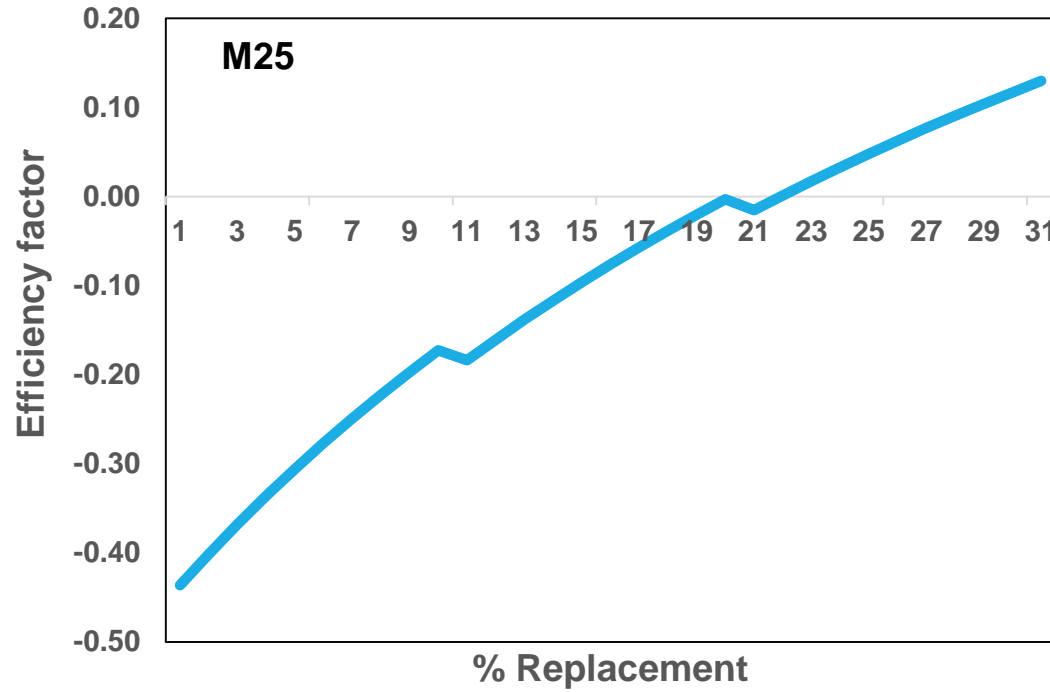
MLR Models for different grades of concrete

$$k_{m40} = -85.636 \times OPC + 3.824 \times FA + 116.560 \times ADM + 8.243 \times W/C + 62.560$$

$$k_{m35} = 10.673 \times OPC - 0.214 \times FA - 11.656 \times ADM + 5.435 \times W/C - 9.512$$

$$k_{m30} = -201.244 \times OPC + 8.730 \times FA + 284.110 \times ADM + 8.795 \times W/C + 145.314$$

$$k_{m25} = -141.073 \times OPC + 6.901 \times FA + 205.173 \times ADM + 7.995 \times W/C + 99.259$$
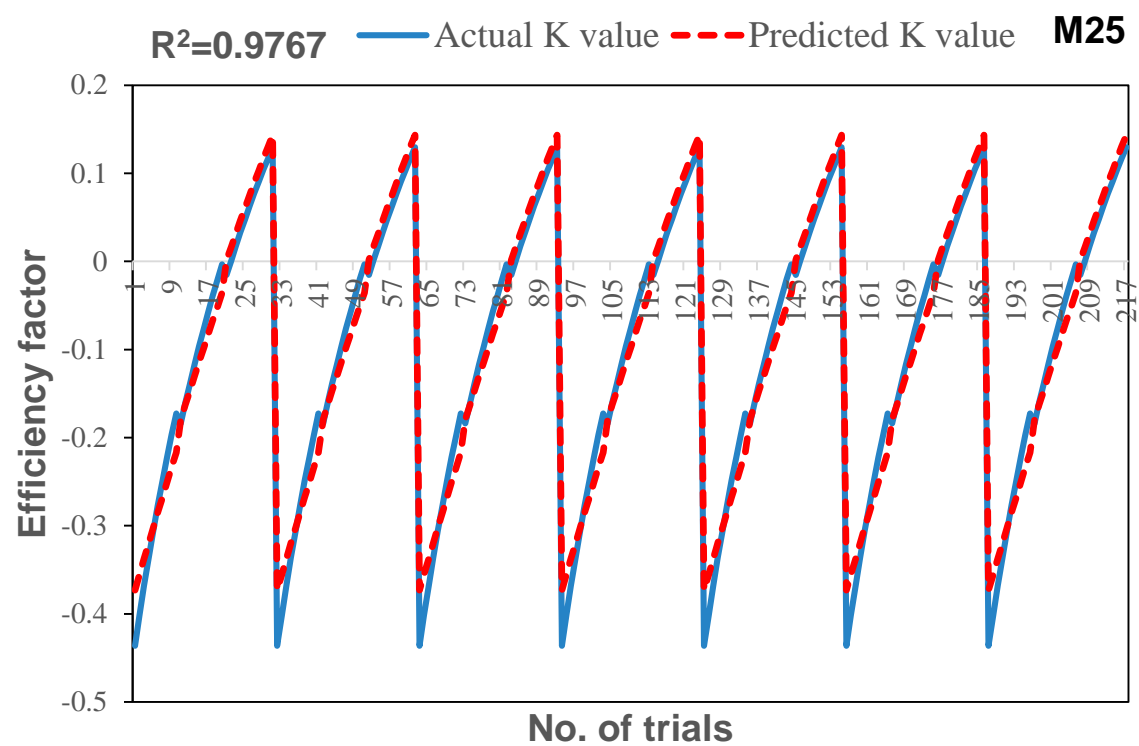
$$k_{m20} = -85.582 \times OPC + 5.009 \times FA + 129.053 \times ADM + 7.015 \times W/C + 55.776$$

Where k represents efficiency factor, $m40$, $m35$, $m30$, $m25$, $m20$ are the grade of concrete at different replacement levels of fly ash respectively, OPC is ordinary portland cement in *kg/m³*, FA is fly ash in *kg/m³*, ADM is admixture in *kg/m³* and W/C is water by cement ratio.
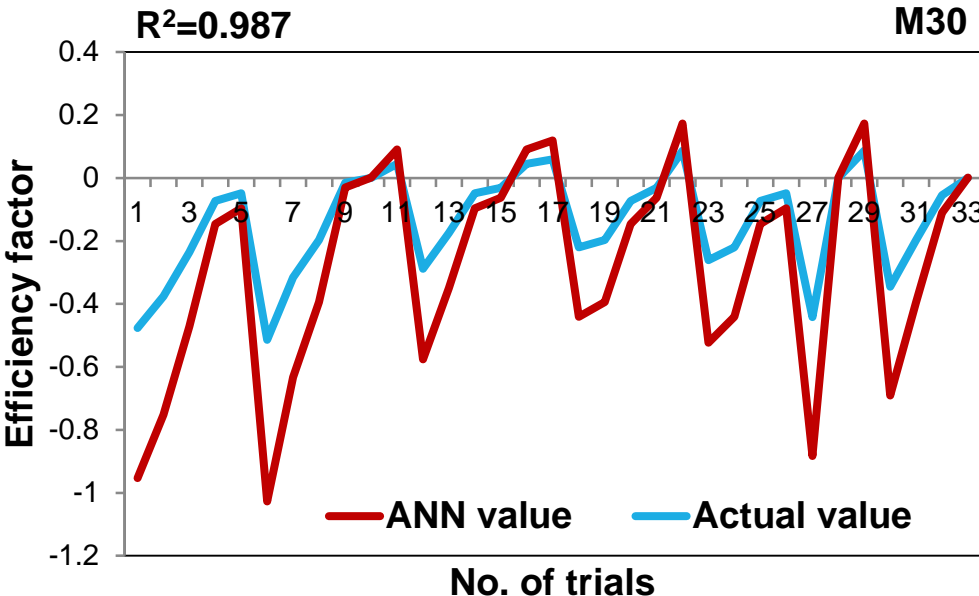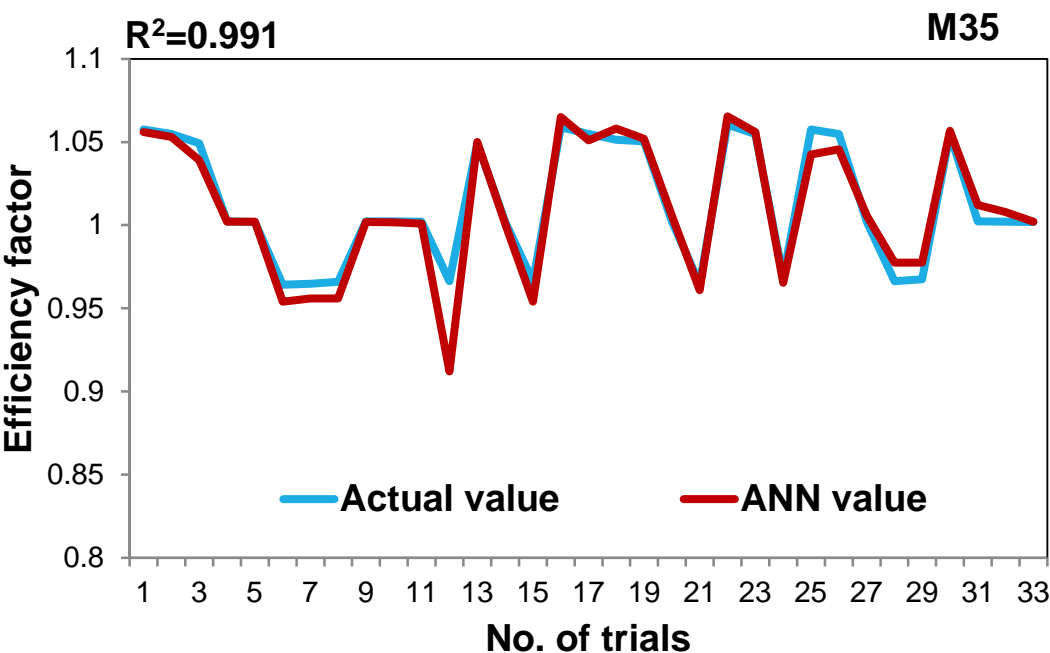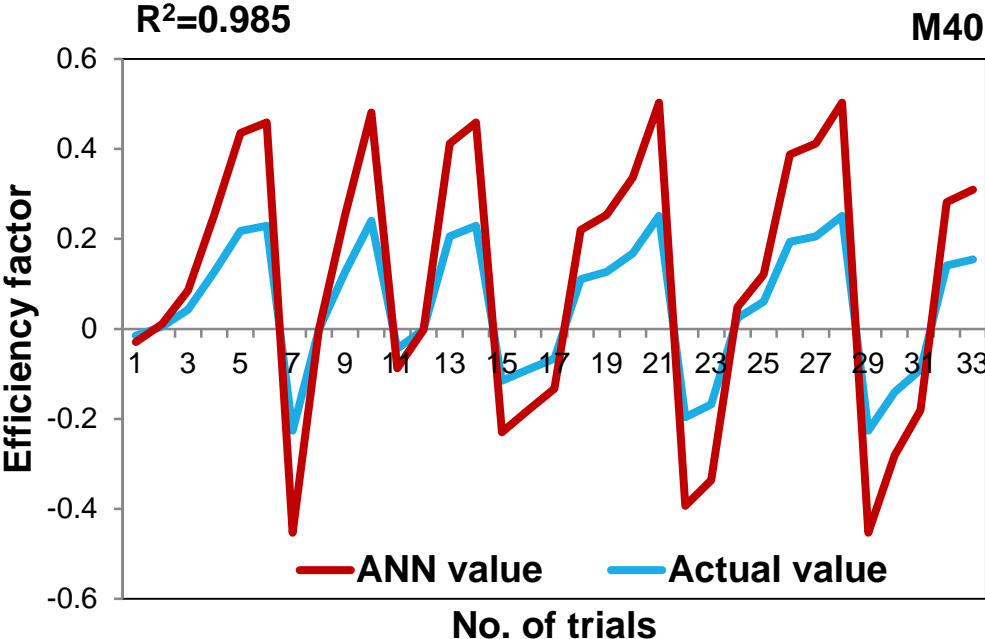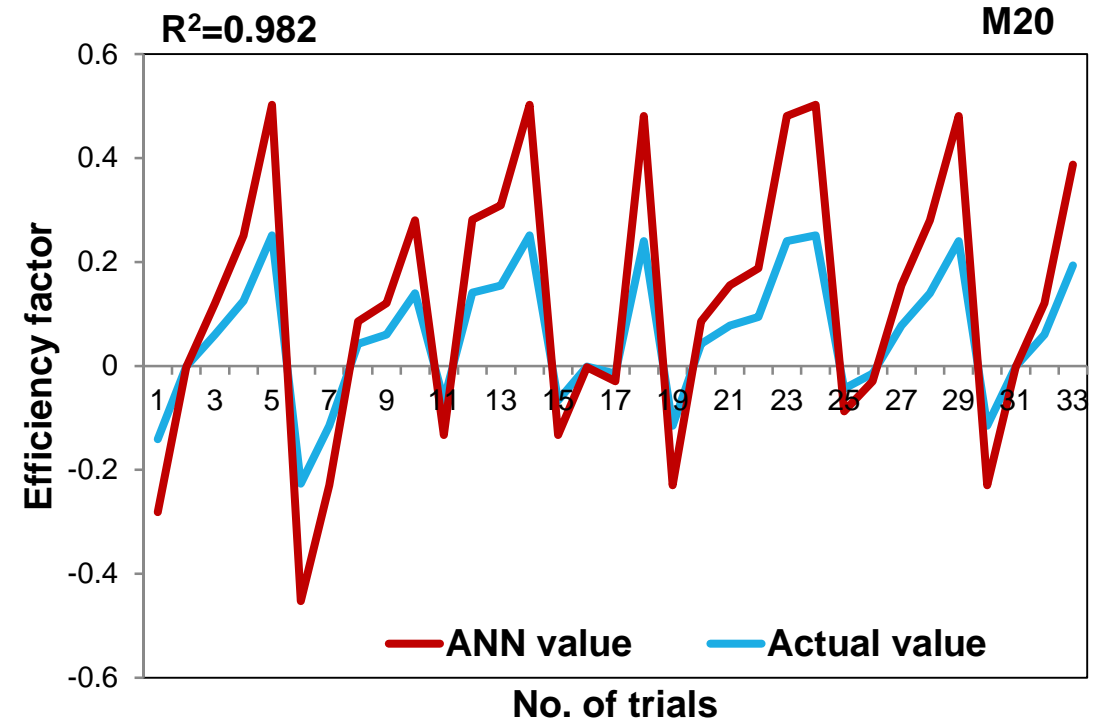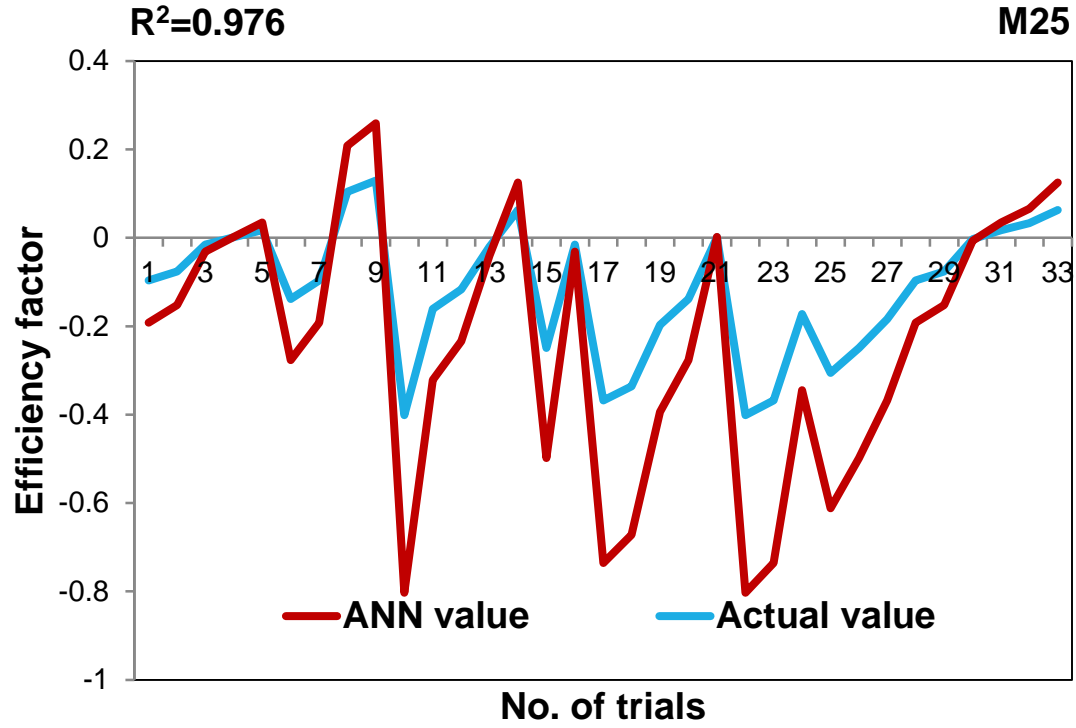
MLR: Actual VS Predicted Efficiency Factor
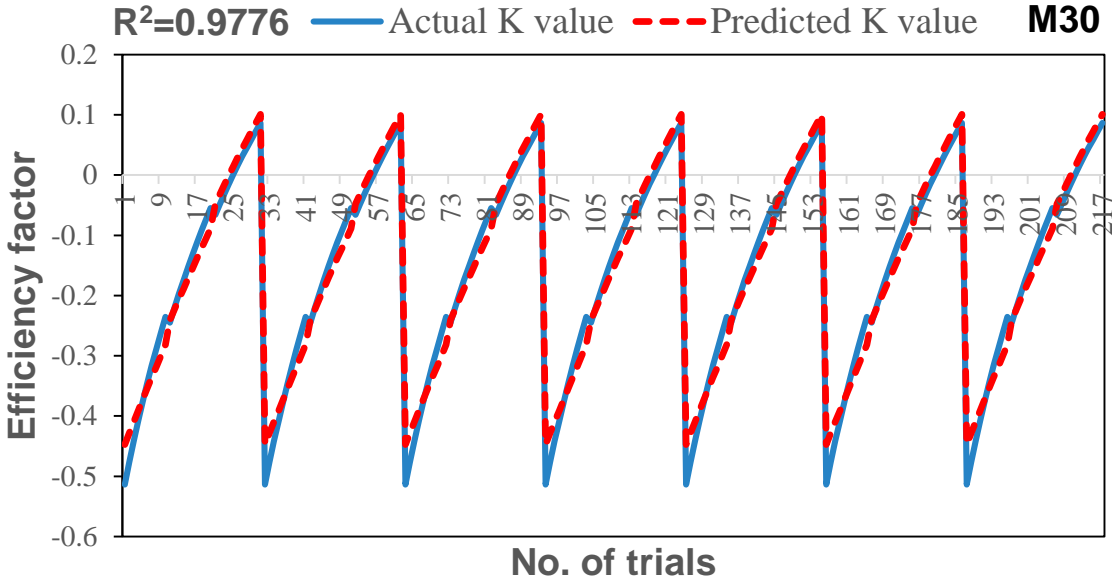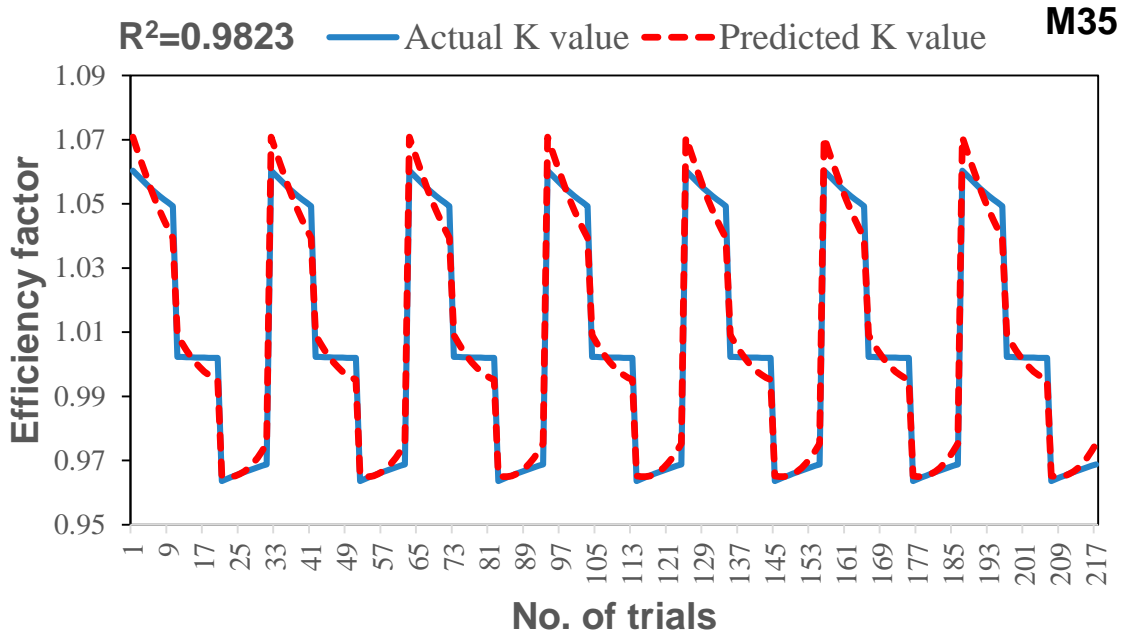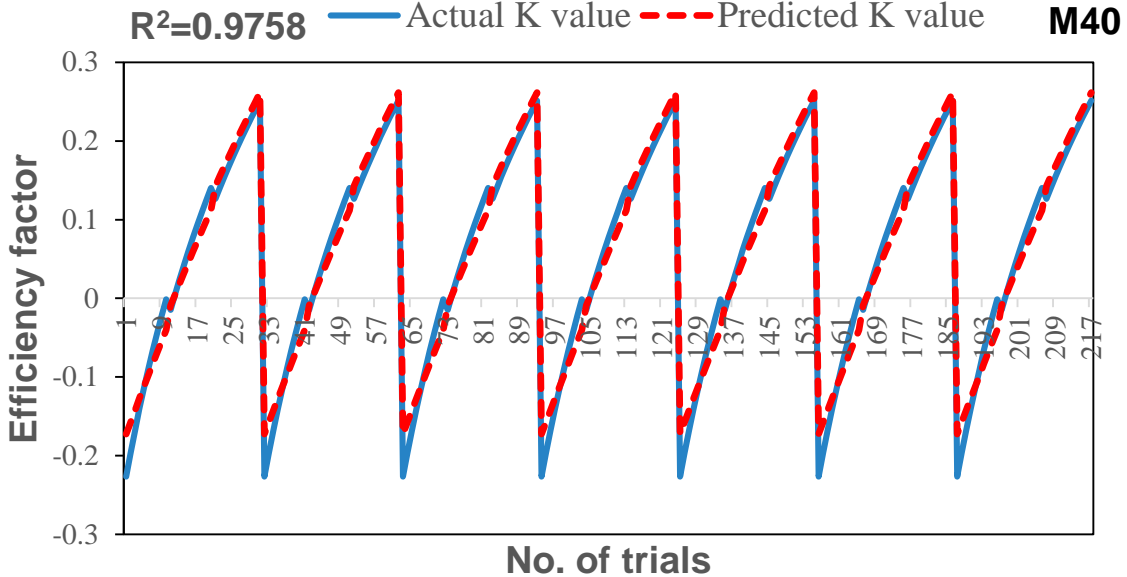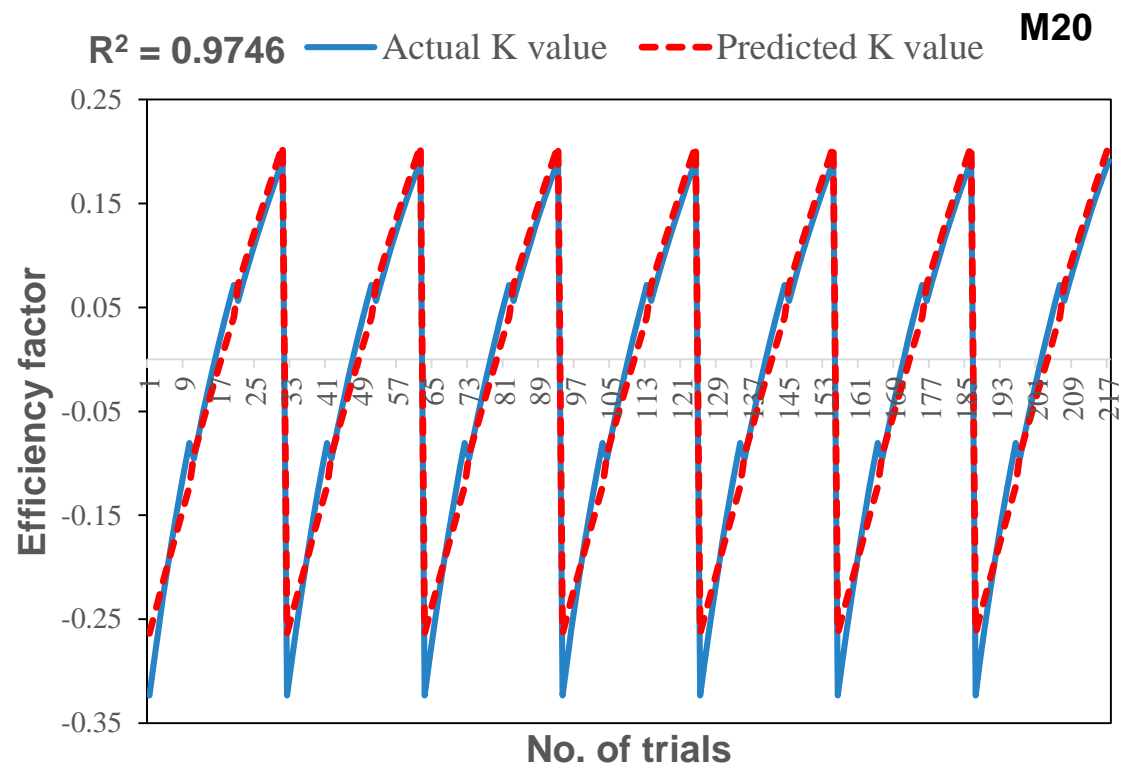
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ANN: Actual VS Predicted Efficiency Factor

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Comparison of MLR and ANN results with respect to k-value
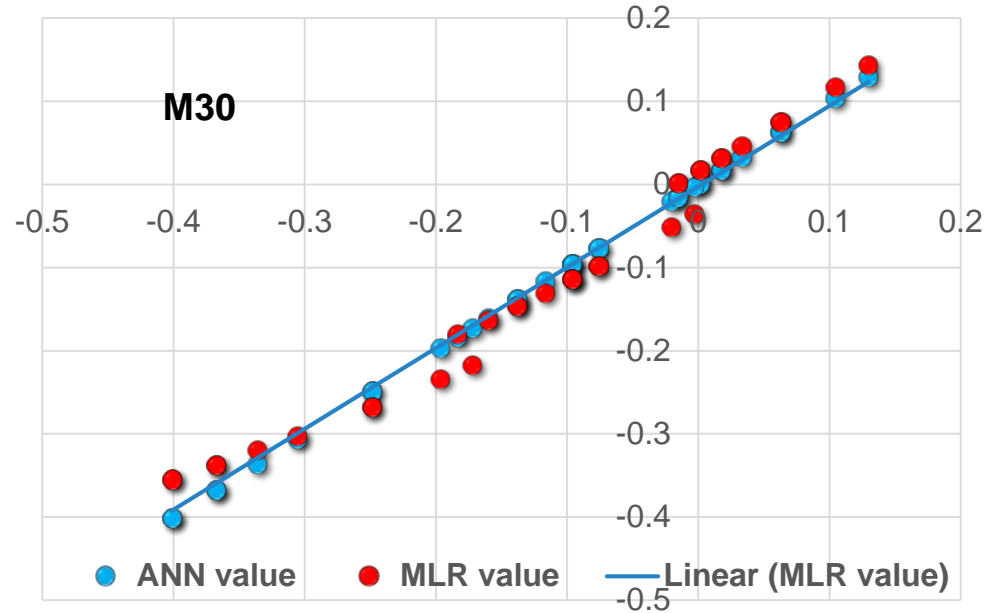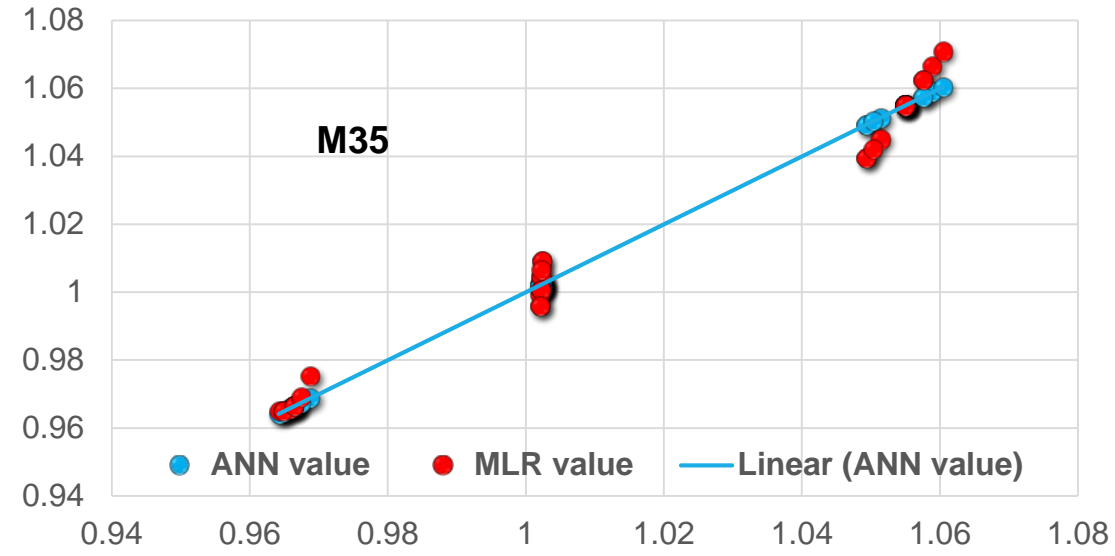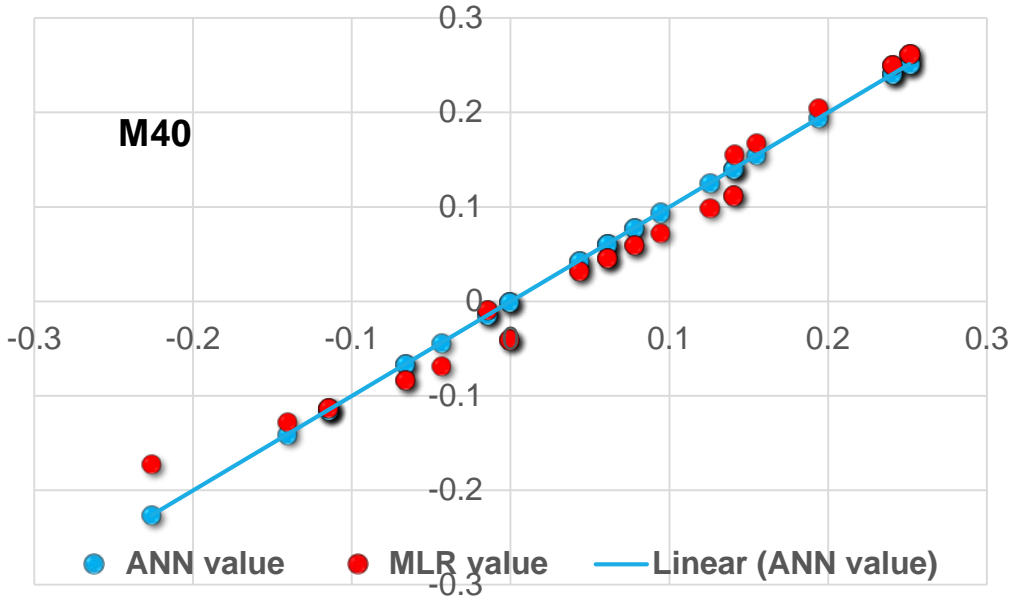
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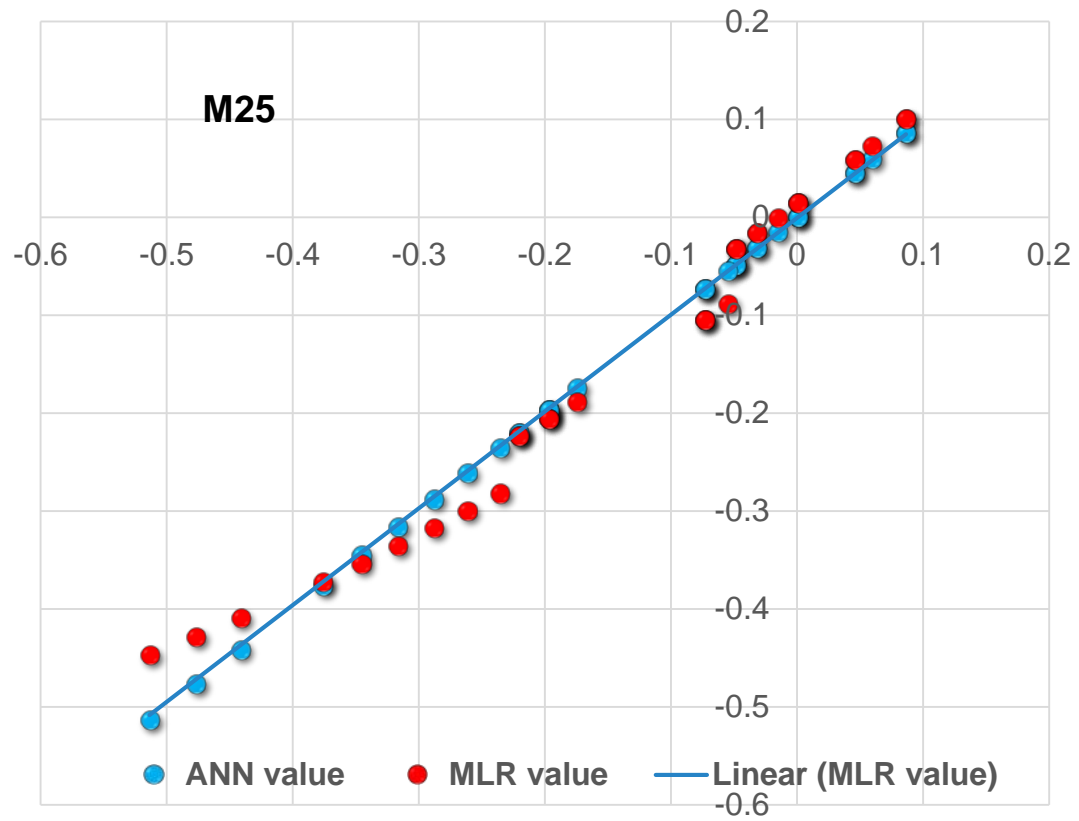
Cost Economic Analysis- Unit rates of Materials

Materials	Rates (Rs)	Unit
OPC	6.5	Per Kg
Fly ash	2.53	Per Kg
Crushed sand	4,600	Per brass
10 mm	3,350	Per brass
20 mm	3,350	Per brass
Water	0.2	Per Kg
Polycarboxylic ether (Admixture)	165.3	Per Kg

Cost analysis for different grades of concrete

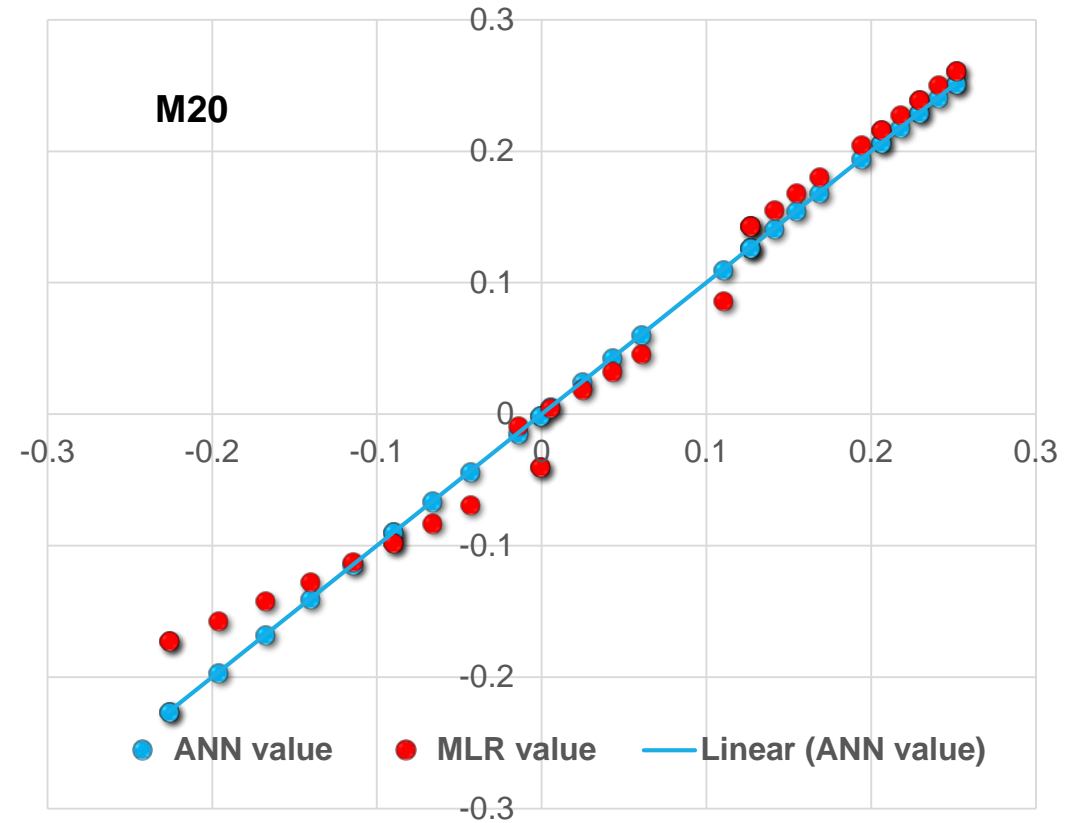| Mix Code	M40	M35	M30	M25	M20
FA (%)	30	30	35	35	30
OPC (Rs)	2,412	2,139	1,775	1,648	1,547
FA (Rs)	402	357	372	345	258
C/sand (Rs)	580	782	736	828	851
CA I (Rs)	302	238	348	281	335
CA II (Rs)	492	496	459	462	439
Admixture (Rs)	1,051	932	833	774	674
Water (Rs)	36	35.2	32.8	32.8	32
Total Cost (Rs)	**5,275**	**4,978**	**4,556**	**4,371**	**4,136**
Strength (MPa)	42.49	36.51	32.68	28.58	22.61
k-factor	0.18	1.04	0.14	0.18	0.12

Summary and Conclusions

Bolomey's empirical equations

1. The Bolomey's empirical expression can be used to predict the strength efficiency factors of Fly ash in concrete mixes at different percentage of replacement levels.

2. The k factor concept is suitable for Class F fly ash. It is useful for estimating the degree of the pozzolanic activity of high calcium Class fly ash and compressive strength of concrete.

3. The k values obtained from the efficiency estimate equations range from **-0.51** to **1.06** at FA replacement ratios of **20-35%** and water-cement ratio of **0.34-0.47**.

4. The k value obtained from regression analysis can be further used as a means of mix design and quality control of FA concrete.

5. For M35 concrete mix, Efficiency of Fly ash varies between **1.03** and **1.06** for percentage replacement levels varying from **20 to 35%.**

Efficiency factor at different replacement levels

1. Except **M35** grade of concrete the others combinations are having negative value of efficiency factor.

2. **M35** concrete is showing a constant positive value of efficiency factor. this may be due to pozzolanic reaction is faster than cement hydration rate.

3. Higher k values for M35 mix at **20%** replacement of fly ash were found, indicating that fly ash can be efficiently utilized for M35 mix as compared to other mixes.

MLR and ANN

1. Based on the multi-regression analysis results, R square value comes out an average of **0.97**.

2. Based on the ANN predicted results, R square value comes out an average of **0.98** which shows a good co-relation between the input parameters and dependent output variable.

3. Comparing results of ANN and MLR model, it has been observed that ANN models provide better results than MLR models.

4. The models performance, it can be seen that both ANN and MLR model results are closer to the observed results and the majority of result are being located on the line of equality (linear).

Cost Economic Analysis

1. The efficiency factor for all the mixes are positive and on an average **30%** replacement of class F fly ash with OPC is optimum.

2. For M30 and M25 mixes the replacement level of fly ash was 35% and efficiency factor is **0.14** and **0.18** respectively.

3. The cost analysis shows and efficient use of fly ash and economical mixes in case of **M30** and **M25** concrete.

4. The replacement-based efficiency factor may be employed in conjunction with other factors, such as those related to cost for optimization and effective use of an additive in concrete at various replacement levels.

Future Scope

1. The above developed statistical model proved to be reasonable and feasible, showed a satisfactory performance, and demonstrated its ability to predict the efficiency of Fly ash.

2. Further work is required to develop neural network models for predicting the efficiency factor of other SCMs, such as ground granulated blast furnace slag, silica fume, rice husk ash and natural pozzolans.

3. These models will be necessary to establish the reliability of the proposed method, particularly with respect to its incorporation into the design of blended concrete.

4. Further, method of soft computing such as Genetic Algorithm can be applied for optimization of SCMs and developed a reliable model which easily modify the content of mix proportions.

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11. Topc¸u, I. B., and Sarıdemir, M. (2008b), "Prediction of compressive strength of concrete containing fly ash using artificial neural network and fuzzy logic", Computational Materials Science, 41(3), pp. 305–311.

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List of Publications

1. "Efficiency Factor of Supplementary Cementitious Materials: A State of Art", ***International Journal of Optimization in Civil Engineering*** (Under Review, Communicated on 27th March 2017)

2. Experimental Investigation and Prediction of Fly Ash Efficiency Factor in Concrete with Cost Economic Analysis", ***Canadian Journal of Civil Engineering*** (Under Review, Communicated on 30th June 2017)

Thank You...