

Empirical Equation for Concrete Made With PPC or OPC with Fly Ash by Accelerated Mix Design Method

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Abstract. Assessment of 28 days strength from accelerated strength (1 day) can be extremely helpful. Early prediction of 28 days compressive strength is required basically for two purposes. First, to finalize the concrete mix proportions in the laboratory and secondly, for quality control purpose during construction. Through this concept designers can easily identify the uncalculated errors during mix design or variations in materials and exposure conditions etc. and take necessary correction and modification measures to attain the desired strengths at 28 days. As per IS: 9013 methodology to predict the 28 days strength of concrete from accelerated cured strength are indicated only for normal/control concrete. In the past few year focus has shifted from Ordinary Portland Cement (OPC) to Portland Pozzolana Cement (PPC). Fly ash is also being used widely at sites as replacement of OPC. However, there is no such guideline available by which the assessment of 28 days strength of Indian fly ash concrete can be made from accelerated strength tests. In the present study an attempt has been made to predict the expected 28 days compressive strength of concrete having PPC or OPC with fly ash using accelerated temperature regime methods. The experimental study includes the use of 2 brands of PPC, 5 brands of OPC and 2 sources of fly ash for replacement of OPC ranging from 20% to 45 %. Two temperature regimes 90°C and 82°C were used for accelerated curing. The samples were cured for 7.5 hours and 20 hours respectively in each regime for expected 28 day compressive strength. The mathematical equations to estimate the 28 days compressive strength of concrete, cured at 90°C for 7.5 hours for mixes having PPC, OPC mixed with fly ash 20% to 35% is $f_{exp28} = 1.223 f_{acs} + 2.024$. The mathematical equations to estimate the 28 days compressive strength of concrete, cured at 90°C for 7.5 hours for mixes having PPC, OPC mixed with fly ash more than 35% and up to 45% is $f_{exp28} = 0.993 f_{acs} + 6.044$.

Keywords: Mix Design, Accelerated Method, PPC, Compressive Strength, Mathematical Equation.

1. Introduction

According to Indian Standard acceptance and rejection of any type of concrete should be done by determining 28 days compressive strength (IS- 456, 2000). It was observed that normal concrete achieve its potential strength within this time period. But for fly ash concrete, 28 days strength does not yield its potential strength as its rate of strength development is significantly slower compared to normal concrete. Potential strength of fly ash concrete may develop at 90 days or even after 180 days (Tokuy, 1999). It is also known that the strength of normally cured concrete at 28 days is considered for structural design. This time difference may lead to loss of valuable time and money. Accelerated curing of normal concrete by warm water method and boiling water method provided by IS:9013 (1978) are helpful to predict 28 days strength of control concrete with respect to accelerated cured strength by means of correlation between accelerated strength and normal curing strength. For the prediction of 28 days strength of fly ash concretes no such correlation is available. In this current paper provides some strength prediction models have been proposed (Jayanta and Jaydeep, 2016).

Construction projects go through time overrun and cost overrun, due to delay in decision making in appropriate time frame. Many activities are involved in execution of a project. Finalization of concrete mix proportions is the most important activity. Usually 28 days moist cured compressive strength test results are required to finalize concrete mix proportions (Udoeyo et al., 2010). The guidelines and procedures given in IS 9013: 1978 which is based on elevated temperature curing method helps in early decision making about mix proportions within 48 to 72 hours when mix has OPC as cementing material.

In past few years, focus has shifted from OPC to a wider application of blended cement such as PPC, PSC etc. Many industrial by products are being used as supplementary cementitious materials and fly ash is one of them. Fly ash is used in two ways, one in cement industry as part of cement itself i.e. as PPC and another as part replacement of OPC during concrete mix design. However no empirical formula or guidelines are available for predicting 28 days moist cured compressive strength concrete having PPC or OPC with fly ash as binder (Nikitha and Kameswara, 2019).

It is well established that an increase in curing temperature increases the rate of hydration of cement. The increase in rate of hydration reaction and strength development of OPC, at elevated curing temperature is also well documented in existing literatures (Shelke and Gadve, 2013). The use of fly ash and other supplementary cementitious material is increasing not only due to an economic and sustainability point of view but also these materials improve the rheology of concrete and other engineering properties of hardened concrete. However the rate of strength gain in OPC with fly ash concrete is slower than in concrete with OPC only (Bhanja and Pan, 2013; Jayadevan et al., 2014).

Fly ash is used in concrete mix generally to reduce the heat of hydration but because of this there is reduction in early strength development of concrete. Many parameters affect the strength of concrete such as quantum of fly ash, quality and quantity of binder material, aggregate size, curing regime, chemical effect, concrete grade used and mix proportions. Hydration itself is affected by the temperature (Khan et al., 2019; Krishna et al., 2010). To accelerate the strength gain at early age and to relate it to the 28-days compressive strength, proper trend lines and calibration curves are needed. For the accelerated curing of concrete, different methods and techniques have been classified earlier also such as maturity methods, curing in oven, curing in heated water and expanded polystyrene molds method (Amritkar and More, 2015, Shah and BhavnaShah, 2011). In such scenario, there is need to develop the mathematical equations to determine strength of concrete which will generate confidence to the construction fraternity for use of concrete made with blended cement by using accelerated curing method.

A number of methods of accelerated and early age testing of cubes have been developed that allow early prediction to be made of strength development at later ages. Indian standard IS: 9013 covers two methods. In warm water method the concrete specimens are cured at elevated temperature of $55\pm 2^{\circ}\text{C}$ for 19 hours 50minutes and in boiling water method the concrete specimens are cured at elevated temperature of 100°C for $3.5\text{h}\pm 5\text{minutes}$. Expected 28 days compressive strength is calculated by empirical formula given in the code. It is found that the above two methods are useful for prediction of expected 28 days compressive strength when concrete is made using OPC.

BS 1881(1983) covers three methods of accelerated curing, under which the concrete specimens are cured at elevated temperature of 35°C , 55°C and 82°C for 24hours $\pm 15\text{minutes}$, 20hours $\pm 10\text{minutes}$, and 14hours $\pm 15\text{minutes}$ respectively.

Similarly ASTM C-684 (ACI 214.1R, 1987; ASTM C 684, 1999) covers 4 procedures for estimation of 28 days compressive strength. In warm water method concrete specimens are cured at elevated temperature of 35°C for 23.5hours $\pm 30\text{minutes}$, in boiling water method at 100°C for

3.5hours \pm 5minutes, in Autogenous method at $21\pm 6^{\circ}\text{C}$ for 48hours \pm 15minutes and in high temperature and pressure method, the concrete specimens are cured at 150°C & 10.3 ± 0.2 MPa pressure for 5 hours \pm 5 minutes.

Canadian standard CSA A23.1 (1970) has an establish procedure, which is independent of cement type, mix proportion and admixture type. In this method, the concrete specimens are cured at elevated temperature of 100°C for 16 hours once the concrete is finally set after casting.

The methods given in BS: 1881 & ASTM C 684 recommend, to develop appropriate correlation using accelerated compressive strength and actual 28 days compressive strength for the materials and mix used. They do not provide any general empirical relationship to predict the expected 28 days compressive strength.

NCB has conducted this experimental study to develop a simple empirical relationship between accelerated compressive strength and 28 days moist cured compressive strength of concrete cubes. The objective of this research is to develop guidelines to determine the expected 28 days compressive strength of concrete having PPC or OPC with fly ash as cementitious material using accelerated curing. The developed method can also be used at site for quality control purposes.

2. Materials

2.1. Cement

Five brands of OPC-43 grade cements designated as OPC-I, OPC-II, OPC-III, OPC-IV and OPC-V conforming to IS: 269 (2015) and two brands of PPC designated as PPC-I & PPC-II conforming to IS: 1489 (2015) were used for the experimental work. All the cements were tested as per IS: 4031 and IS: 4032. The test results of physical and chemical analysis are given in Table-1.

2.2. Flyash

Two flyash samples from different sources designated as Fly ash 1 and Fly ash 2 were used in the experimental work. The fly ash samples were tested as per IS: 1727: 1967 and the results were conforming to IS 3812 (2013). The tests results are given in Table-2.

Table 1. Test results of cement sample Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC)

S.No.	Properties	OPC1	OPC2	OPC3	OPC4	OPC5	PPC1	PPC2
1	Blain's fineness, (m^2/kg)	282	355	292	336	306	379	358
2	Setting time, (in minutes)							
	Initial	230	115	160	120	160	135	140
	Final	280	180	215	195	210	205	210
3	Compressive Strength (N/mm^2)							
	3 days	34.5	36.5	31.5	35.5	39.5	30.0	27.5
	7 days	45.0	44.5	41.0	45.0	49.0	41.5	39.0
	28 days	55.5	55.0	47.5	53.5	60.0	55.5	53.5
4	Soundness by Autoclave,	0.01	0.05	0.09	0.04	0.01	0.07	0.08
	% Le Chatelier Exp (mm)	1.50	0.50	1.0	1.0	1.0	2.00	2.00
5	Specific Gravity	3.15	3.15	3.15	3.15	3.15	2.85	2.87

Table 2. Test results of fly ash sample

Sl No.	Properties	Fly ash Source 1	Fly ash Source 2
1	Blain's fineness, m^2/kg	403	329
2	Specific Gravity	2.20	2.20
3	Lime Reactivity, N/mm^2	8.0	4.92

2.3. Coarse Aggregate:

Crushed angular coarse aggregate with 20mm maximum size were used in the experimental work. The coarse aggregates were tested as per IS: 2386 and were found to conform to IS: 383 (2016). The test results are given in Table - 3

2.4. Fine Aggregate

The fine aggregate from natural source i.e. river sand conforming to Zone-I was used in the experimental work. The fine aggregate was tested as per IS: 2386 and were found to conform to IS: 383 (2016). The test results are given in Table-4

Table 3. Test results of coarse aggregate sample

Sl No.	Test Carried out	Results Obtained For 20 mm	Results Obtained For 10 mm
1	Specific gravity	2.79	2.81
2	Water absorption %	0.60	0.40
3	Abrasion Value %	25.00	30.00
4	Crushing value %	25.00	25.00
5	Impact value %	16.00	20.00
6	Flakiness index %	17.00	21.00
7	Elongation index %	14.00	13.00
8	Soundness (Na ₂ SO ₄) %	0.30	1.20
9	Grading	Percentage Passing	
	Sieve Size	20mm	10mm
	40 mm	100.00	
	20 mm	98.00	-
	12.5 mm	-	100.00
	10 mm	1.00	68.00
	4.75 mm	0	2.00
	2.36 mm	-	0.00

Table 4. Test results of fine aggregate sample (Natural)

Sl No.	Test Carried out	Results Obtained
1	Specific gravity	2.63
2	Water absorption, %	1.0
3	Silt wet Sieving %	2.0
4	Grading	
	Sieve Size	Percentage Passing
	10 mm	100
	4.75 mm	74
	2.36 mm	54
	1.18 mm	38
	600 micron	22
	300 micron	8
150 micron	4	

2.5. Chemical Admixture

Superplasticizer (Normal type) conforming to IS: 9103 (1999) was used in the experimental work.

3. Experimental programme

3.1. Initial Trials

To get the early age compressive strength through accelerated curing, some initial trials were conducted. The mix proportions used for initial trials are given in Table-5A & Table-5B. The following parameters were fixed for initial trials:

- Three temperature regimes for accelerated curing were selected for initial trials
 - i. Boiling water with time duration of 3.5h, 5.5 h and 7.5 hours.
 - ii. Hot water at 90°C temperature with time duration of 3.5h, 5.5h and 7.5hours.
 - iii. Hot water at 82°C temperature with time duration of 16h, 18h, 20h, 22h and 24hours.
- One brand of OPC and fly ash from one source were used.
- Two brands of PPC were used.
- 25% OPC cement was replaced with fly ash (by weight of total cementitious materials).

Water-cement/cementitious ratio was kept 0.50, 0.45 and 0.40.

Table 5.A. Mix proportion used for initial trials using PPC

Mix Constituents (kg)		For One Cubic Meter		
W/c ratio		0.50	0.45	0.40
Water		165	165	165
Cement		330	367	412
Chemical Admixture(Kg/cum)		3.30	3.70	4.10
Fine Aggregate(Kg/cum)		829	804	723
Coarse Aggregate (Kg/cum)	20mm	672	665	690
	10mm	451	446	463

Table 5.B. Mix proportion used for initial trials using OPC mixed with 25% flyash

Mix Constituents (kg)		For One Cubic Meter		
Water/cementitious ratio		0.50	0.45	0.40
Water		165	165	165
Cement		248	275	309
Fly ash (25% as replacement)		82	92	103
Chemical Admixture(Kg/cum)		3.30	3.70	4.10
Fine Aggregate(Kg/cum)		829	796	750
Coarse Aggregate (Kg/cum)	20mm	672	671	673
	10mm	451	451	452

Based on initial trials, the results of the two methods were found encouraging:

- Accelerated curing in hot water at 90°C and time duration of 7.5 hrs.
- Accelerated curing in hot water at 82°C for longer duration of 20 hrs.

3.2. Detailed Trials

The detailed trials were carried out by fixing following parameters for accelerated curing.

- Accelerated curing in hot water at 90°C and time duration of 7.5 hrs.
- Accelerated curing in hot water at 82°C for longer duration of 20 hrs.

- Five brands of OPC and flyash from two sources were used.
- Two brands of PPC were used.
- Fly ash, ranging from 20% to 45% was added (as replacement of OPC) by weight of cementitious materials.
- Water cement/cementitious ratio were kept ranging from 0.35 to 0.55.

The mix proportions used for detailed trials are given in Table-6A to Table-6G.

Detail trials

The detail trials were carried out with two brands of PPC and five brands of OPC. Two sources of fly ash were used with 20% to 45% replacement in increment of 5%. Five water-cementitious ratios were selected from 0.35 to 0.55 for detail trials. Normal type chemical admixture @1 % by weight of cementitious material was used for all the trials.

With 5 OPC, 2 sources of fly ash and 6 replacement levels of OPC by fly ash (20% to 45%) a total 300 nos. of samples (one sample comprising 3 cube specimens of 150 mm size) were cast at various water cementitious ratios ranging from 0.55 to 0.35. Similarly with 2 PPC, 10 samples were cast at same water cement ratios for accelerated curing under each temperature regime i.e. 310 nos. of samples were cast for regime I & 310 nos. of samples were cast for regime II. Corresponding to accelerated cured samples, 310 nos. of samples were also cast and tested for determination of 28 days compressive strength of moist cured samples.

When accelerated curing was done the following procedures were followed:

- All specimens were cured at 27°C and more than 90% humidity for first 24 hours.
- All accelerated curing specimens were kept in open case after de-molding in accelerated curing tank. When accelerated curing was completed as given regime I and regime II above, they were cured at 27°C for two hours. Then compressive strength was determined as per procedure given in IS: 516.

Corresponding to each temperature regime, the specimens were also kept for moist curing at 27+2°C for 28 days and after 28 days compressive strength was determined as per procedure given in IS :516.

Table 6A. Mix proportions used for detailed trials using PPC cement

Mix Constituents (kg)	For One Cubic Meter					
W/c ratio	0.55	0.50	0.45	0.40	0.35	
Water	165	165	165	165	165	
Cement	300	330	367	412	471	
Chemical Admixture(Kg/cum)	3.00	3.30	3.70	4.10	4.70	
Fine Aggregates (Kg/cum)	861	829	804	723	674	
Coarse Aggregates (Kg/cum)	20mm	669	672	665	690	685
	10mm	449	451	446	463	460

Table 6A. Mix proportions used for detailed trials using OPC mixed with 20 % fly ash

Mix Constituents (kg)	For One Cubic Meter					
Water/cementitious ratio	0.55	0.50	0.45	0.40	0.35	
Water	165	165	165	165	165	
Cement	240	264	293	330	377	
Fly ash (20% as replacement)	60	66	73	83	94	
Chemical Admixture(Kg/cum)	3.00	3.30	3.70	4.10	4.70	
Fine Aggregates (Kg/cum)	863	831	798	753	704	
Coarse Aggregates (Kg/cum)	20mm	671	674	673	675	672
	10mm	451	452	452	453	451

Table 6C. Mix proportions used for detailed trials using OPC mixed with 25 % fly ash

Mix Constituents (kg)	For One Cubic Meter				
Water/cementitious ratio	0.55	0.50	0.45	0.40	0.35
Water	165	165	165	165	165
Cement	225	247	275	310	353
Fly ash (25% as replacement)	75	83	92	103	118
Chemical Admixture(Kg/cum)	3.00	3.30	3.70	4.10	4.70
Fine Aggregates (Kg/cum)	861	829	795	750	700
Coarse Aggregates (Kg/cum)	20mm	669	671	671	672
	10mm	449	451	450	451

Table 6D. Mix proportions used for detailed trials using OPC mixed with 30 % fly ash

Mix Constituents (kg)	For One Cubic Meter				
Water/cementitious ratio	0.55	0.50	0.45	0.40	0.35
Water	165	165	165	165	165
Cement	210	231	257	289	330
Fly ash (30% as replacement)	90	99	110	124	141
Chemical Admixture(Kg/cum)	3.00	3.30	3.70	4.10	4.70
Fine Aggregates (Kg/cum)	858	826	792	746	697
Coarse Aggregate (Kg/cum)	20mm	667	669	668	669
	10mm	448	449	449	450

Table 6E. Mix proportions used for detailed trials using OPC mixed with 35 % fly ash

Mix Constituents (kg)	For One Cubic Meter				
Water/cementitious ratio	0.55	0.50	0.45	0.40	0.35
Water	165	165	165	165	165
Cement	195	214	239	269	306
Fly ash (35% as replacement)	105	116	128	144	165
Chemical Admixture(Kg/cum)	3.00	3.30	3.70	4.10	4.70
Fine Aggregate(Kg/cum)	856	824	789	743	693
Coarse Aggregate (Kg/cum)	20mm	666	667	666	667
	10mm	447	448	447	448

Table 6F. Mix proportions used for detailed trials using OPC mixed with 40 % fly ash

Mix Constituents (kg)	For One Cubic Meter				
Water/cementitious ratio	0.55	0.50	0.45	0.40	0.35
Water	165	165	165	165	165
Cement	180	198	220	248	282
Fly ash (40% as replacement)	120	132	147	165	189
Chemical Admixture(Kg/cum)	3.00	3.30	3.70	4.10	4.70
Fine Aggregate(Kg/cum)	853	821	786	740	690
Coarse Aggregate (Kg/cum)	20mm	664	665	664	664
	10mm	446	447	446	446

Table 6G. Mix proportions used for detailed trials using OPC mixed with 45 % fly ash

Mix Constituents (kg)	For One Cubic Meter				
Water/cementitious ratio	0.55	0.50	0.45	0.40	0.35
Water	165	165	165	165	165
Cement	165	181	202	227	259
Fly ash (45% as replacement)	135	149	165	186	212
Chemical Admixture(Kg/cum)	3.00	3.30	3.70	4.10	4.70
Fine Aggregate(Kg/cum)	851	818	784	737	687
Coarse Aggregate (Kg/cum)	20mm	662	663	661	661
	10mm	444	445	444	444

3.3. Specimen Cast and Curing

150mm cube specimens were cast for compressive strength. The specimens were kept at $27 \pm 2^\circ\text{C}$ and relative humidity more than 90% for 24 hours initially. For accelerated curing the specimens were submerged in hot water immediately after demoulding in open cage, at different temperature regimes and for different time duration. After the completion of accelerated curing specimens were taken out from hot water and were kept in water at $27 \pm 2^\circ\text{C}$ for 1½ hour. The specimens were tested for accelerated compressive strength after 1 ½ hour as per IS 516. For 28 days' compressive strength, the specimens were kept in water at $27 \pm 2^\circ\text{C}$ for curing up to 28 days.

4. Methodology adopted to develop empirical relationship

Following steps were followed for the development of empirical relationship between accelerated compressive strength and 28 days moist cured compressive strength:

- i. All the trial results of accelerated compressive strength and 28 day compressive strengths are tabulated and standard deviation is calculated.
- ii. Two categories of data sets corresponding to each temperature regime are taken for analysis of the trial results as given below.

Category 1: Hot water at 90°C for 7.5 hours

- a) 20-35% fly ash replacement at 90°C and 7.5hours
- b) 40-45% fly ash replacement at 90°C and 7.5hours

Category 2: Hot water at 82°C for 20 hours

- a) 20-35% fly ash replacement at 82°C and 20hours
- b) 40-45% fly ash replacement at 82°C and 20hours

- iii. Best fit line is plotted and expected 28 days strength is calculated by this best fit line equation.
- iv. Upper and lower control limits were fixed as per criteria given below and the points above/below upper/lower limits were treated as outliers

Criteria for fixing outliers:

- a. Mean \pm Se (Standard Error) X 2.5 (considering 98 % confidence level)
- b. Mean \pm 15%

(both the criteria were nearly matching)

It was seen that total outliers were less than 10% of total data.

- v. Data beyond the upper limit and lower limit was eliminated.
- vi. The best fit line was plotted again by adopting the same procedure as given in step no. (iii) & (iv).
- vii. In the case of hot water procedure using temperature regime of 90°C for 7.5 hours, the best fit line was lowered by 8% to bring more than 90% data above this line as shown in Fig.1 and Fig. 2.
- viii. In the case of hot water procedure using temperature regime of 82°C for 20 hours, the best fit line was lowered by 10% to bring more than 90% data above this line as shown in Fig.3 and Fig. 4.

- ix. The line (after lower down) where less than 10 % data remain below is adopted for calculating the expected 28 days compressive strength.

The validation of equation was done for temperature regime 90°C for 7.5 hours only as the best fit line was lower down 8 % only in comparison to 10% in the case of temperature regime of 82°C for 20 hours, to bring more than 90% results above best fit line plotted.

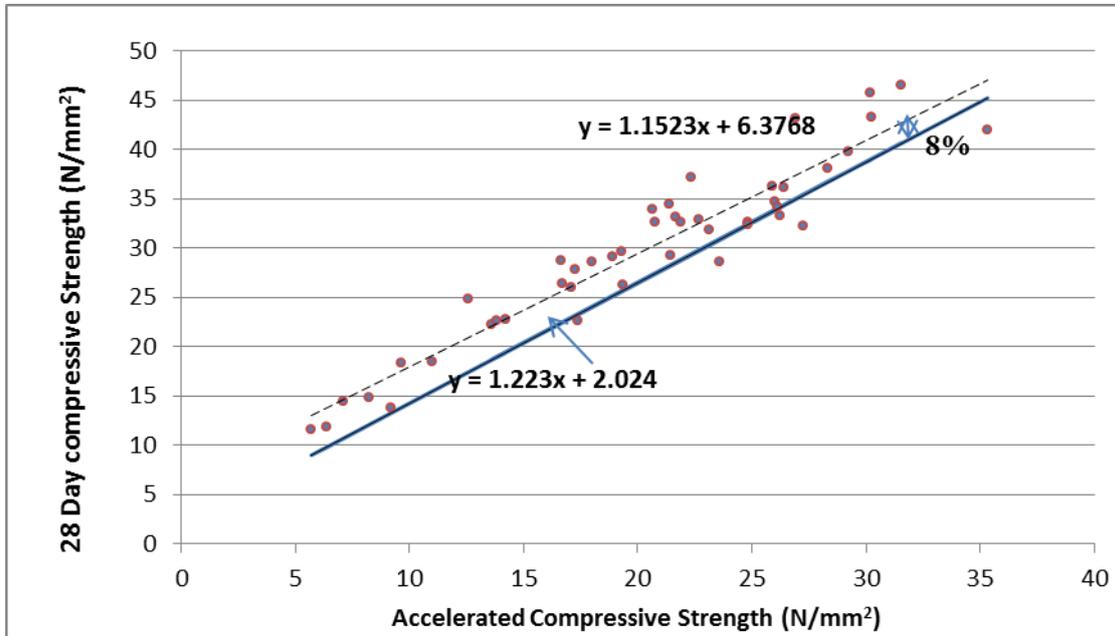


Fig. 1. Proposed 90°C 7.5 hours graph for PPC and OPC + Flyash (15% to <35%)

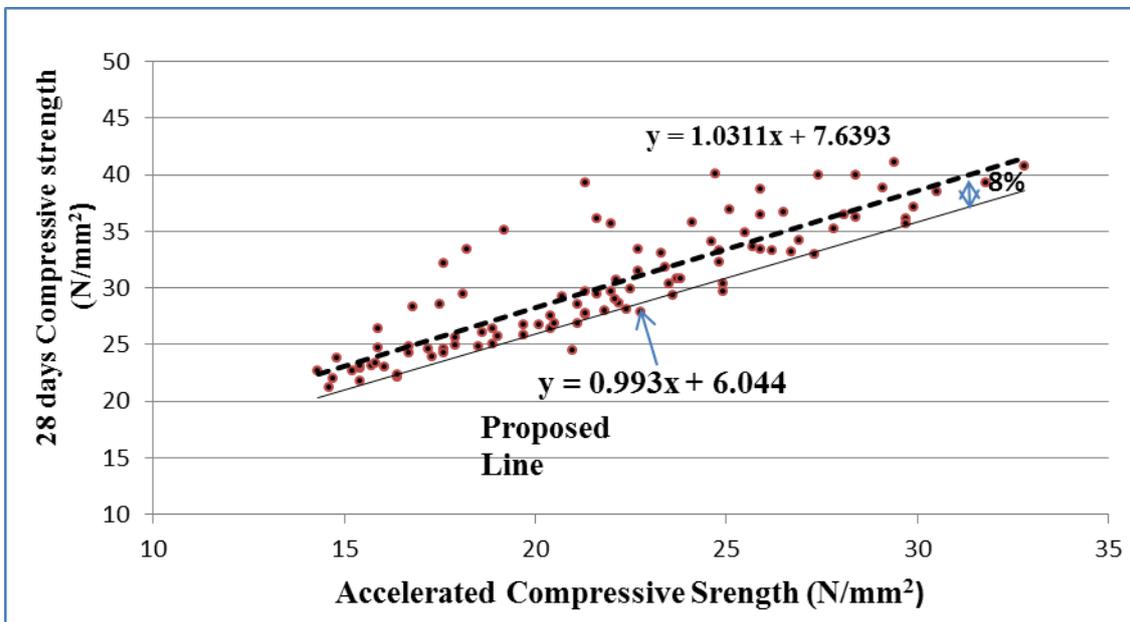


Fig. 2. Proposed 90°C 7.5 hours graph for PPC and OPC + Flyash (>35% to 45%)

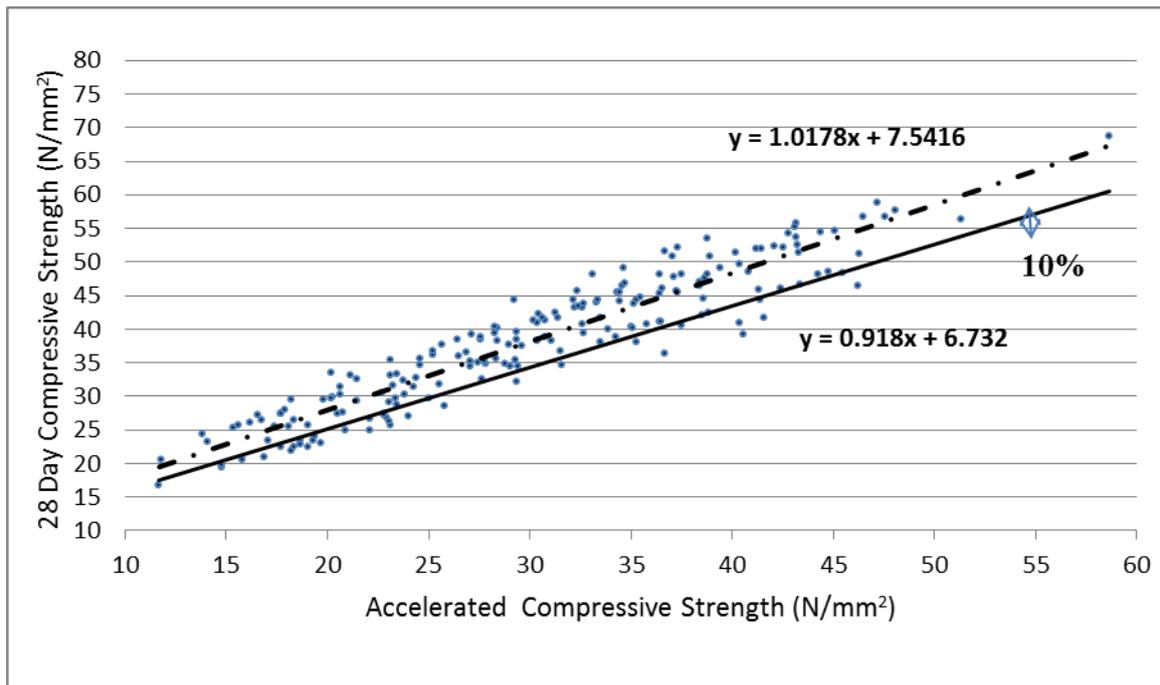


Fig. 3. 82°C 20h graph for PPC Cement and OPC + flyash (20% to <35%)

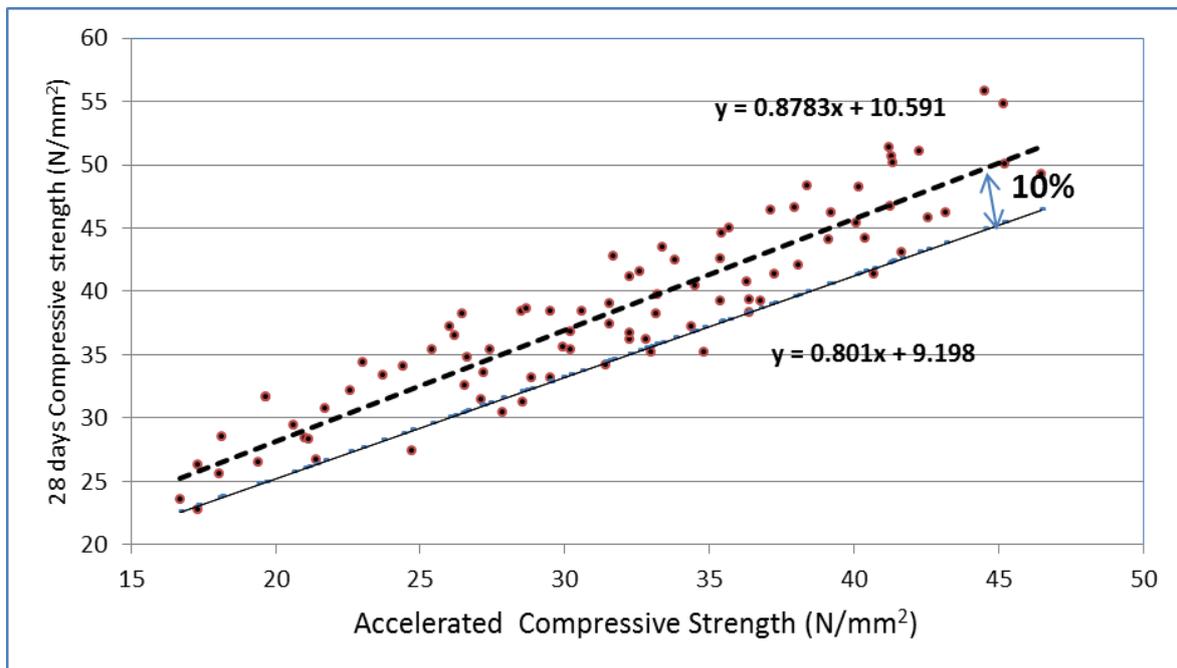


Fig. 4. 82°C 20h graph for PPC and OPC + Flyash (>35%-45%)

5. Conclusions

Early prediction of 28 days compressive strength results through existing codal provision is not possible for concrete mixes having Pozzolana like fly ash, due to the effect of their physical and chemical properties on the rate of strength gain. Based on validation of developed relationships, it is concluded that for PPC and at different replacement level of OPC by flyash (20% to 45%), the elevated temperature curing regime i.e. 90°C for 7.5 hours can be adopted for prediction of expected 28 days compressive strength.

However, since the rate of strength development differs with the level of flyash replacement and therefore, for the following two cases, two separate empirical relationships can be adopted:

- a. For the mixes made with PPC and OPC with flyash up to 35%
- b. For the mixes made with OPC and flyash more than 35% up to 45%.

Mathematical equations for early prediction of 28 days compressive strength of concrete are proposed separately for the mixes having PPC cement, OPC mixed with fly ash (20% to 35%) and the mixes having OPC mixed with fly ash more than 35% and up to 45%. These mathematical equations give the confident level around 90%.

The mathematical equations to estimate the 28 days compressive strength of concrete, cured at 90°C for 7.5 hours for mixes having PPC, OPC mixed with fly ash 20% to 35% is-

$$f_{\text{exp}28} = 1.223 f_{\text{acs}} + 2.024$$

and mixes having OPC mixed with fly ash more than 35% and up to 45% is-

$$f_{\text{exp}28} = 0.993 f_{\text{acs}} + 6.044$$

Where: $f_{\text{exp}28}$ = Expected 28 days' compressive strength of concrete in N/mm²

f_{acs} = Accelerated compressive strength in N/mm²

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