

PAPER • OPEN ACCESS

Experimental studies on utilization of Coarser Fly Ash in Concrete

To cite this article: V.G. Meshram *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1170** 012006

View the [article online](#) for updates and enhancements.

You may also like

- [Utilization of Fly Ash in Construction](#)
Norhaiza Ghazali, Khairunisa Muthusamy
and Saffuan Wan Ahmad
- [Examination of water absorption of low volume fly ash concrete \(LVFAC\) under water immersion conditions](#)
Grzegorz Ludwik Golewski
- [Assessment of the compressive strength and strength activity index of cement incorporating fly ash](#)
Nguyen Trong Lam



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Experimental studies on utilization of Coarser Fly Ash in Concrete

Dr. V. G. Meshram¹, Dr. A.M. Pande^{2,b}, Dr. S. B. Borghate^{3,c}

¹Associate Professor, Department of Civil Engg., Yeshwantrao Chavan College of Engineering, Nagpur, India,

²Professor, Department of Civil Engg., Yeshwantrao Chavan College of Engineering, Nagpur, India,

³Associate Professor, Dept. of Applied Mechanics, Visvesaraya National Institute of Technology, Nagpur, India;

^ameshramvg@gmail.com,

^banantpande.ycce@gmail.com,

^csbborghate@apm.vnit.ac.in

Abstract: Fly ash is abundantly available in India. IS 3812 Part I & II regulate its usage in cement and concrete. It is well known fact that fineness of fly ash goes on increasing from boiler end to chimney, however the output goes on reducing. Past research normally indicate usage of finer (Hopper no. 4 & 5) fly ash in cement and concrete. Japan has upgraded its standards and specifications to accommodate all grades of fly ash available. The present research by the authors on all grades of fly ash samples through compressive strength development indicate all grades of fly ash can be used in concrete with a precaution that their performance should be investigated before use. Through graphical representations of test results presented in the paper, it is justified that coarser fly ash can very well be used in concrete making as per strength requirements.

Keywords: Coarse fly ash, Fineness, Physical and Chemical Properties, Compressive strength, Regression Analysis

1. INTRODUCTION

Fly ash is a byproduct which results from the burning of bituminous or sub-bituminous coal. Out of the total fly ash produced, about 80% is finely divided. This fine fly ash gets out to boiler along with flue gases. The Fly ash which is separated out of the flue gases is entrapped in electrostatic precipitators (ESP). The ESP normally consists of four to six fields (hoppers). The field at the boiler end is first and the one at the stack (chimney) end is last hopper. The output of fly ash vary hopper wise which depends on the partial pressures in each hopper of the ESP. The approximate output and fineness of fly ash from hopper from the boiler end to stack end of ESP is explained in Table 1.[1] . This trend is common for all power plants.

Table 1. Hopper-wise output and fineness of Flyash [1]



Field No.(Hopper)	Specific surface area m ² /kg	Approximate output %
1(Boiler end)	229	55-65
2	320	20-25
3	474	5-10
4	576	2-3
5 (Stack end)	607	1-2

Normally fly ash used in concrete mixes is from either hopper No. 4 or 5 and fly ash available in hopper No. 1, 2 & 3 is overlooked in making concrete due to fineness which governs most of the properties as reported by various researchers.

Kalgal M et. al. [2] explained the significance of physical characteristics like particle size distribution and fineness on the reactivity of the ash. The pozzolanic activity of fine fly ash is more as more reactive surface area is available to react with lime [1]. The water demand using fine is reduced as fly ash particles fill the void replacing water within the concrete mix [3,4]. The workability of concrete at a given water cementitious material ratio is improved as smooth surface and the ball bearing effect due to spheroid shape of fly ash accelerate the easy mobility of water [5]. The fine fly ash produces mortars with good strength and low porosity [6]. The inclusion of fly ash increases the workability and air content of concrete while decreasing unit weight and compressive strength of concrete [7]. All these improved properties of concrete lead to the increase in compressive and tensile strength as fly ash fineness increased [8].

The Indian fly ash from hoppers 1, 2 & 3 do not qualify for consideration as an ingredient in concrete mainly due to the stringent provision of IS 3812-2000 Part I & II [15,16]. However, the era of High Volume Fly Ash Concrete supplements the usage of coarser ashes in concrete. Use of all grades of fly ash in concrete is recommended in Japan and The Japanese Code JIS 6201 A supplements the uses. Performance of all grades of fly ash has been recorded in literature from this country (S. Nagataki et al.[9]). V. Sivasundaram [10] showed that almost all of the Indian fly ashes are suitable for use in the high-volume fly ash (HVFA) concrete system. B. Fournier et. al.[11] used coarse fly ash to evaluate their suitability for use in the manufacture of HVFAC.

A.M. Pande and L.M. Gupta [12] discussed the significance of properties of concrete ingredient in the compressive strength development. Chai et. al. [13] compared the compressive strengths and the strength activity indices of fly ash cement mortars and showed that coarse fly ash resulted in slow strength development. V. Sivasundaram [10] showed that the concrete made with the cement and fly ash showed a lower early strength but the strength gain with age was very rapid. Rafat Siddique [14] indicated that the use of high volumes of Class F fly ash as a partial replacement of cement in concrete decreased its 28-day compressive. However, strength properties showed continuous and significant improvement at the ages of 91 and 365 days.

The present paper gives focus on the performance of fly ash from first three hoppers and their comparison with the performance of fly ash from last two hoppers. The outcome of this paper may induce an idea of starting use of the coarse ashes for fly ash concrete.

2. Experimental and Research Methodology

- A. Collection:** The fly ash under study is collected From Khaparkheda Thermal Power Station, near to Nagpur, Maharashtra. The fly ash was collected from all the hoppers.

B. Physical and Chemical Properties of Fly ash: All samples were tested for physical and chemical properties. For each test minimum three samples were tested. Tests were performed as per provisions of IS 1727[17]. The physical properties of Fly ash are given in Table 2 and the chemical properties of Fly ash are given in Table 3.

Table 2. Physical Properties of Fly ash

Sr. No.	Test conducted	Requirement as per IS: 3812 Part 1-2003	Test Result				
			Hopper No. 1	Hopper No. 2	Hopper No. 3	Hopper No. 4	Hopper No. 5
1	Consistency %	***	27.5	27.5	25	24	25
2	Specific Gravity	***	2.04	2.06	2.17	2.19	2.28
3	Setting Time (In minutes)						
	Initial	***	250	245	240	205	180
	Final		330	325	325	280	270
4	Soundness(mm) By Autoclave Expansion method	Max 0.8	-0.0516	-0.0502	-0.0312	-0.0473	-0.0576
5	Fineness % by weight By Sieving (% Retention on 45 micron sieve - wet sieving)	Not more than 34	45.55	24.45	2.7	6.7	0.5
6	Fineness (Specific Surface) (Sq. m. / kg) By Blain Air Permeability	Min 320	229	320	474	536	607
7	Flow %	***	15.00	14.00	12.00	12.00	12.00
8	Compressive Strength(N/sq. mm)	Not less than 80 % of cement at 28 Days (Min 33)					
	i) 7 Days		19	20	31.5	24	28
	ii) 28 Days		31	34	47	45	57
	iii) 90 Days		46	58	67	67	72

Table 3. Chemical Properties of Fly ash

Sr. No.	Test conducted	Requirement as per IS: 3812 Part 1-2003	Test Result				
			Hopper No. 1	Hopper No. 2	Hopper No. 3	Hopper No. 4	Hopper No. 5
1	Loss on Ignition %	Max. 5.0	1.43	2.52	4.11	1.9	2.09
2	Silicon dioxide (SiO ₂) in percent by mass	Min. 35	56.02	56.05	53.11	54.63	51.73
3	Silicon dioxide (SiO ₂) + Aluminium Oxide (Al ₂ O ₃) + iron oxide (Fe ₂ O ₃) in percent by mass	SiO ₂ + Fe ₂ O ₃ + Al ₂ O ₃ Min. 70%	88.89	88.76	85.2	86.21	91.21

4	Magnesium oxide (MgO) content- %	Max. 5.0	0.55	0.19	0.54	0.43	0.15
5	Total Sulphur as Sulphur trioxide(SO ₃) in percent by mass	Max. 3.0	Below 0.1	0.32	0.24	0.7	0.66
6	Calcium oxide(CaO) content-%	***	1.53	0.95	0.29	0.25	1.92

C. Mix Design: Mix design for a concrete was done for various grades as per IS 10262- 2019 [18]. Three grades of concrete namely The M20, M25 and M30 and Grade 43 (OPC) cement was used. The fine and coarse aggregates were used in the Mix Design as per IS 383-2016 [19]. Concrete samples with 0%, 12.5 %, 25 % and 37.5 % replacement of cement with fly ash from each of the hopper 1 to 5 were casted. Water-cement ratio for all percentages of fly ash was kept constant.

D. Compressive strength Test: Testing for compressive strength was carried out in three stages i. e. after 7, 28 and 90 days. The test procedure was as per IS 516-1959(Reaffirmed 2018) [20]. The test results are presented in Table 4.

Table 4. Compressive strength of concrete

Mix Grade	FA %	Hopper No.	Avg. Compressive Strength		
			7 days	28 Days	90 Days
M20	0		20.15	27.71	28.3
M25	0		21.63	35.85	36.89
M30	0		31.11	41.78	43.26
M20	12.50%	1	18.22	26.89	26.23
M20	12.50%	2	17.77	24.6	27.56
M20	12.50%	3	20	24.6	28.15
M20	12.50%	4	19.26	28	29.78
M20	12.50%	5	19.55	28.08	30.37
M20	25%	1	17.92	24.67	28.89
M20	25%	2	18.37	27.27	29.78
M20	25%	3	19.11	28.3	31.56
M20	25%	4	19.26	26.82	31.11
M20	25%	5	20	27.71	31.85
M20	37.50%	1	17.92	22.97	25.34
M20	37.50%	2	17.77	25.34	26.52
M20	37.50%	3	18.07	24.6	26.97
M20	37.50%	4	20.11	24.3	28.44
M20	37.50%	5	18.22	26.82	29.19
M25	12.50%	1	17.63	30.82	34.79
M25	12.50%	2	21.56	32.6	35.71
M25	12.50%	3	23.64	36.6	39.26
M25	12.50%	4	22.07	35.41	40.89
M25	12.50%	5	22.22	35.41	42.38
M25	25%	1	17.92	31.41	35.12
M25	25%	2	20.74	32.23	37.04
M25	25%	3	21.48	31.56	38.07

M25	25%	4	22.37	33.04	39.70
M25	25%	5	21.34	35.56	40.15
M25	37.50%	1	18.96	31.26	31.7
M25	37.50%	2	23.41	26.52	31.41
M25	37.50%	3	18.82	29.04	32.45
M25	37.50%	4	19.7	29.78	33.78
M25	37.50%	5	21.34	33.63	34.52
M30	12.50%	1	29.03	32.15	35.7
M30	12.50%	2	30.67	35.7	37.49
M30	12.50%	3	29.78	33.64	43.26
M30	12.50%	4	30.08	35.11	44.30
M30	12.50%	5	31.41	41.78	43.85
M30	25%	1	27.7	34.97	40.59
M30	25%	2	30.22	32.89	41.03
M30	25%	3	29.48	36.89	42.97
M30	25%	4	31.11	38.38	43.49
M30	25%	5	31.56	39.71	43.97
M30	37.50%	1	20.74	28.75	40.00
M30	37.50%	2	20.74	29.19	41.04
M30	37.50%	3	22.52	32.45	41.18
M30	37.50%	4	21.34	34.82	42.22
M30	37.50%	5	28	34.23	41.93

E. Data Analysis: The data containing information of cement content, fine aggregate, water content, fineness of fly ash and compressive strength at 7, 28 and 90 days of age was compiled. Similar data available in various literatures was added to this data. The Regression analysis was carried out treating compressive strength at various ages as dependent variable and other ingredients including fineness of fly ash as independent variables. The regression equations are presented below:

$$y_7 = 0.109 x_1 + 0.086 x_2 - 0.289 x_3 + 0.008 x_4 + 31.264 \quad (R^2 = 0.687)$$

$$y_{28} = 0.145 x_1 + 0.133 x_2 - 0.429 x_3 + 0.015 x_4 + 46.603 \quad (R^2 = 0.694)$$

$$y_{28} = 0.112 x_1 + 0.093 x_2 - 0.640 x_3 + 0.010 x_4 + 103.47 \quad (R^2 = 0.779)$$

Where, y_7 (Comp. Strength at 7 days of age), x_1 = Cement, x_2 = Fly ash, x_3 = Water quantity in liters and x_4 = Blain's fineness of Fly ash.

3. Results and Discussion

- A. Test results of physical and chemical properties of fly ash indicate that,
- The specific gravity of fly ash obtained from hopper no. 1 is least one (2.04). It gradually increases and maximum specific gravity is found for hopper no. 5 (2.28).
 - Initial and Final setting time for coarser fly ash is on higher side as compared to finer fly ash.
 - Fineness when tested by Blain Air Permeability apparatus increases from 1st hopper to 5th hopper.
 - Water requirement for maintaining flow as specified in IS 1727 is higher for coarser fly ash.
 - There is no significant difference, which can be attributed for compressive strength development in relevance to chemical properties

B. Based on the data of table 4, various important graphs are presented in figure 1 to figure 3.

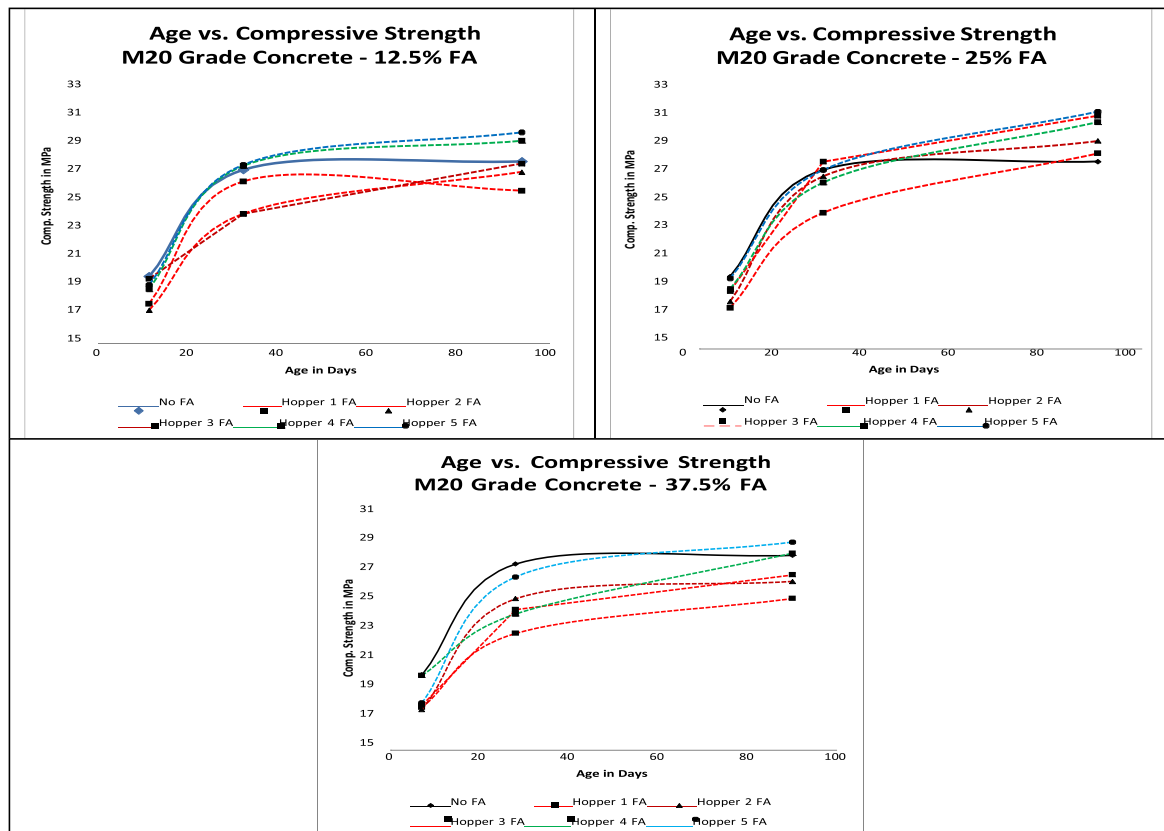


Figure 1. Relationship between age and compressive strength for M20 Grade concrete

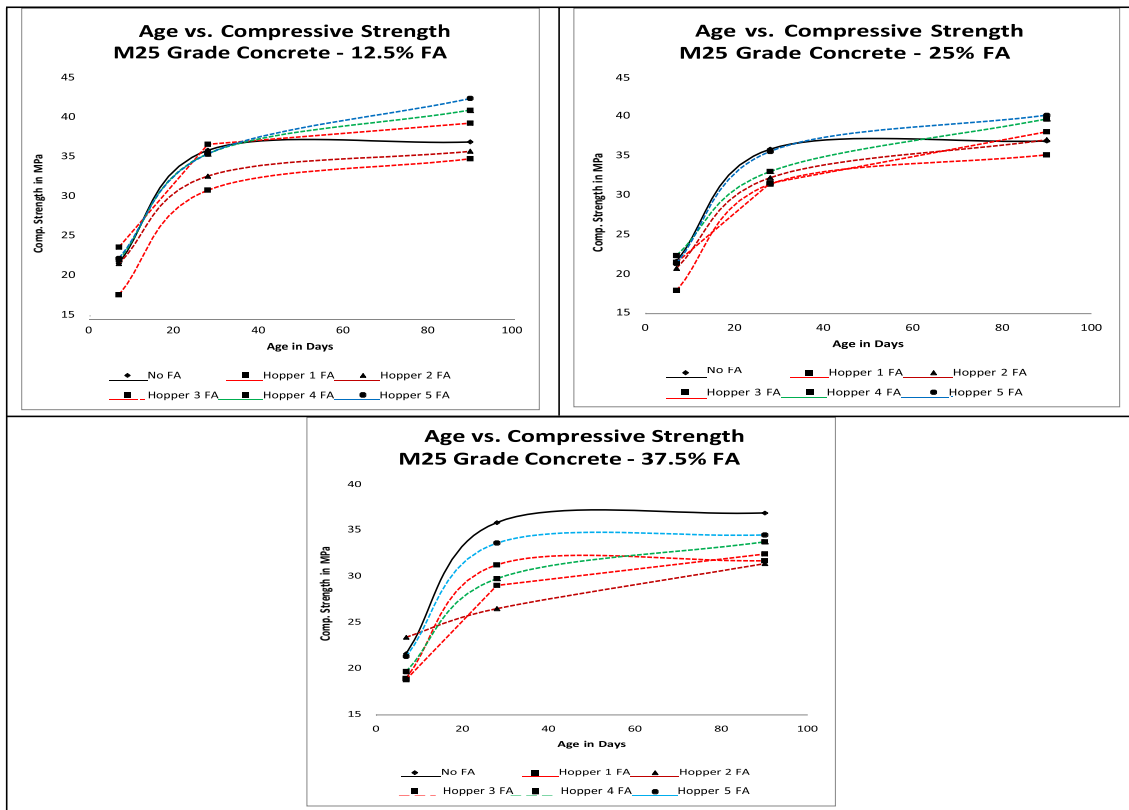
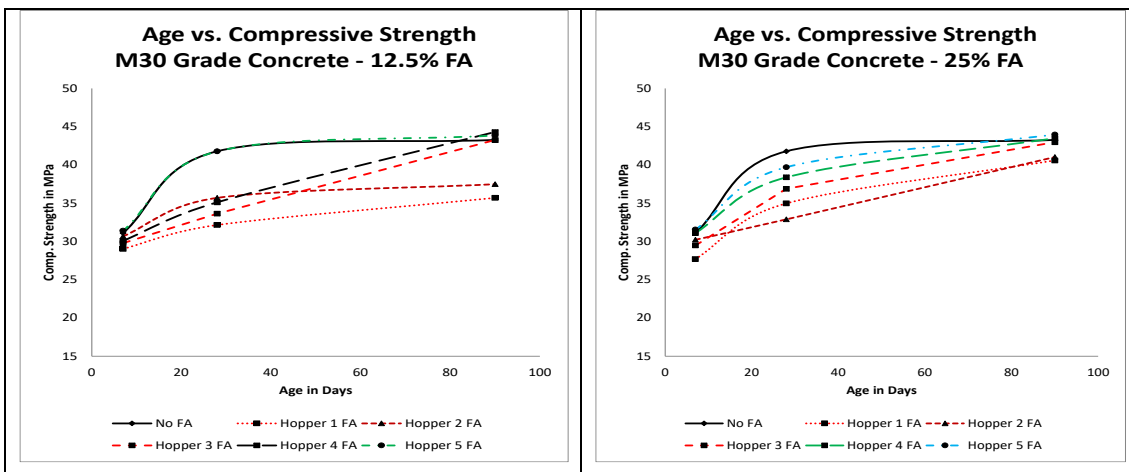


Figure 2. Relationship between age and compressive strength for M25 Grade concret



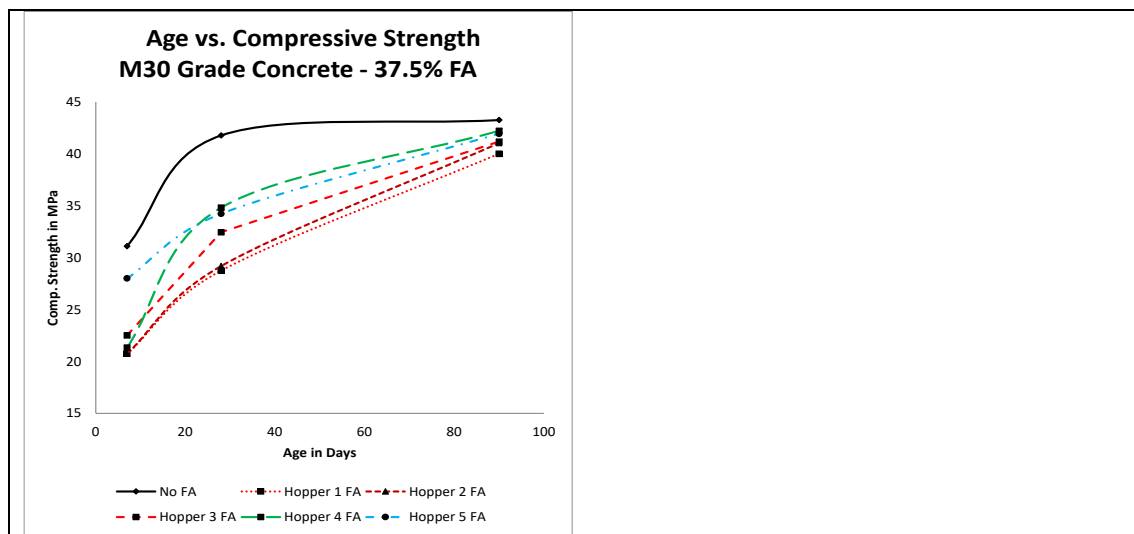


Figure 3. Relationship between age and compressive strength for M30 Grade concrete

From the figure 1 to figure 3, it observed that,

- In M20 grade concrete, performance of coarser fly ash is relatively lower than finer fly ash samples at all levels of replacement. At 25% replacement of cement by fly ash, it is observed that, fly ash from all hoppers have performed better than plain concrete at 90 days of age. At 37.5 % replacement level, the performance of coarser fly ash is less than plain concrete at all days of age.
- Similar trends have been observed in case of M25 grade concrete.
- In M30 grade concrete, the 12.5 % replacement of cement by coarser fly ash, 90 days strength is significantly lower than plain concrete. At 37.5 % replacement level, the performance of all samples is considerably lower than plain concrete at 7 & 28 days of ages. However, it is considerably close to plain concrete.
- For all ages of concrete, the compressive strength of fly ash concrete increases as the percentage of fly ash increases upto 25% and the downward trend is observed beyond 25% replacement level for all hoppers.

C. **Regression analysis:** Validation of regression equations is presented in Fig. 4.

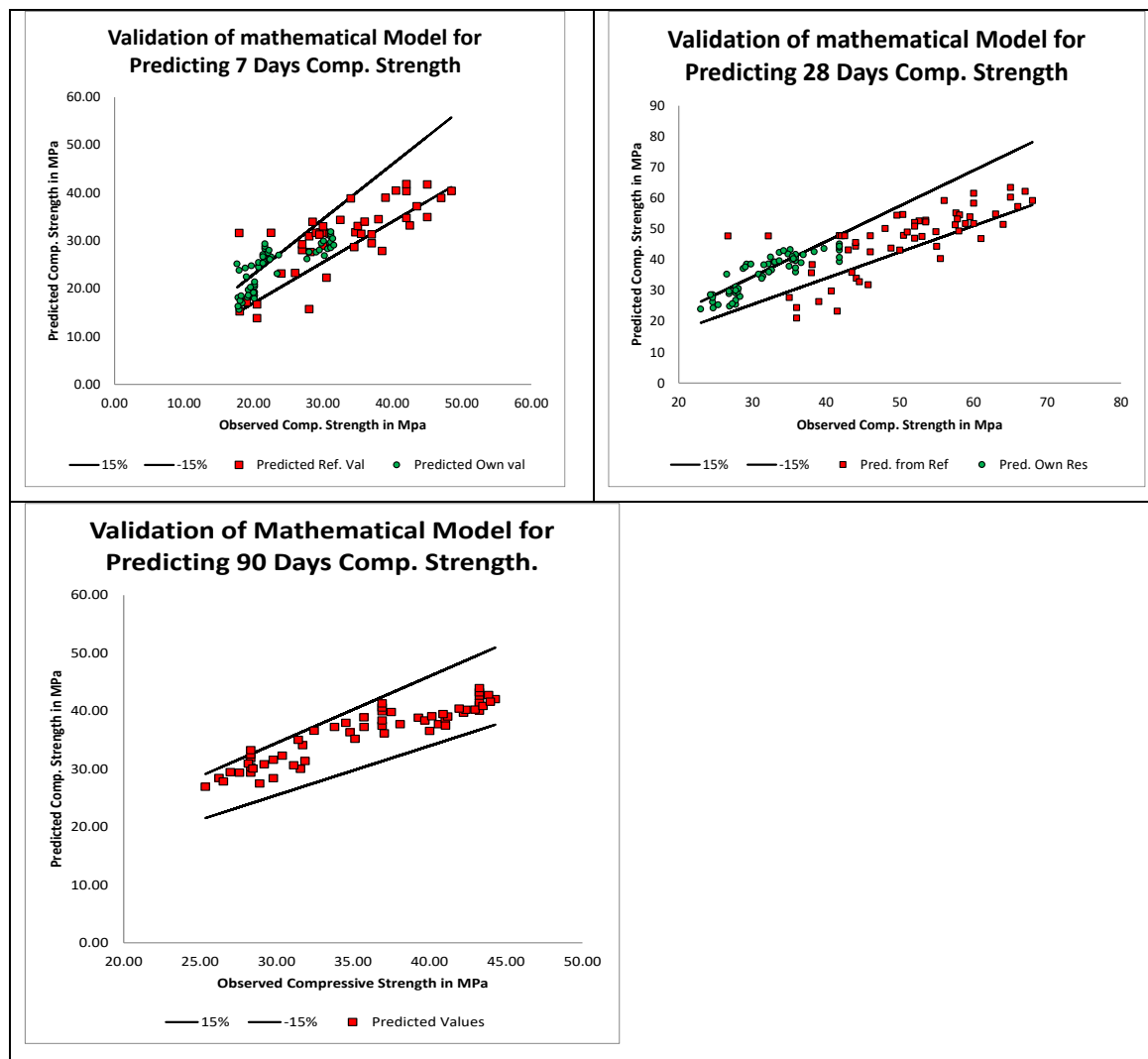


Figure 4. Validation of mathematical model for predicting compressive strength at various age of concrete

From fig. 4, it is observed that majority of predicted values lie within $\pm 15\%$ of the actual values. This also strengthens that the fineness of fly ash has significant contribution in the development of compressive strength.

4. Concluding Remarks

1. Coarser fly ash is abundantly available at all Thermal Power Stations. However the restrictions impose by both the parts of IS 3812 limits its use. Codal provisions in Japan allow cautious use of all grades of fly ash in various applications.
2. Though the water requirement, when tested as per IS 1727 (Flow Test), the coarser fly ash requires more water. But when tested in concrete with the same w / c ratio for the finer ash concrete, there is no significant loss of slump.
3. The relevance of chemical properties on compressive strength development is not found.

4. The compressive strength of fly ash concrete increases as the percentage of fly ash increases upto 25% and the downward trend is observed beyond 25% replacement level for all hoppers.
5. Compressive strength of concrete containing the coarser fly ash is fairly close to that of finer ones. It is recommended that the coarser fly ash can very well be used in concrete upto 25% replacement of cement with appropriate quality control measures.

5. References

- [1] Bhanumathidas N and Kalidas N 2005, "Fly Ash Characterization for use as a Pozzolanic Material", Proceedings of Second International Symposium on "Concrete Technology for Sustainable Development" Hyderabad Feb. 27- Mar. 3 2005, pp 151-164.
- [2] Kalgal M R et.al., (2003), *Characterization of RTPS Fly Ash and Pond Ash for use as Partial Replacement to Cement*, Proceedings of "Innovative World of Concrete" Pune, India, Sept. 2003
- [3] Kraiwood Kiattikomol and Chai Jaturapittakul, (2001), *A study of ground coarse fly ashes with different finenesses from various sources as pozzolonic materials*, Cement & Concrete Composites, Vol. 23, pp 335-343
- [4] Sear L. K. A., (2001), *UK Practice - A Review of Fly Ashes for use in Concrete*, Workshop on Novel Products from Combustion Residues, Morelia, Spain
- [5] Nath P and Sarker P K, (2013), *Effect of Mixture Proportions on the Drying Shrinkage and Permeation Properties of High Strength Concrete Containing Class F Fly Ash*, KSCE Journal of Civil Engineering, Vol. 17(6), pp 1437-1445
- [6] Sumrerng Rukzon and Prinya Chindaprasirt (2008), *Development of classified fly ash as a pozzolonic material*, Journal of Applied Sciences Vol.8 (6) pp 1097-1102
- [7] Osman Gencel et.al., (2012), *Combined effects of fly ash and waste ferrochromium on properties of concrete*, Construction and Building Materials, Vol. 29, pp 633-640
- [8] Ahmaruzzaman M., (2010), A review on the utilization of fly ash, Progress in Energy and Combustion Science, Vol. 36, pp 327-363
- [9] Nagataki S et al 2001, "Classification of Fly Ash According Japan Industrial Standard, JIS A 6201-1999", SP 199- Vol- I, Seventh CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, pp 29-41, American Concrete Institute
- [10] Sivasundaram V., (2004), *Evaluation of Indian fly ashes for the HVFA concrete, Part II: Behaviour in concrete*, The Indian Concrete Journal, Vol 78, Nov. 2004, No 11, pp 41-50
- [11] Fournier B. et.al., (2004), *Evaluation of Indian fly ashes for use in HVFA concrete, Part I: Characterisation*, The Indian Concrete Journal, Vol 78, Nov. 2004, No 11, pp22-30
- [12] Pande A M and Gupta L M 2007, "Properties of Concrete Ingredients and Their Significance in Compressive Strength Development", Indian Concrete Journal, Vol. 81, No. 6, June 2007, pp 15-27
- [13] Chai Jaturapitakkul et.al., (1999), *A Study of Strength Activity Index of Ground Coarse Fly Ash with Portland Cement*, Science Asia, Vol. 25, pp 223-229
- [14] Siddique Rafat, (2004), *Performance characteristics of high-volume Class F fly ash concrete*, Cement and Concrete Research, Vol. 34, pp 487-493
- [15] Indian Standard Code of Practice for Pulverized Fuel Ash – Specification Part 1 for use as

pozzolana in cement mortar and concrete. IS 3812 (Part 1) :2003, Bureau of Indian Standards, New Delhi

[16] Indian Standard Code of Practice for Pulverized Fuel Ash – Specification Part 1 for use as admixture in cement mortar and concrete. IS 3812 (Part 2) :2003, Bureau of Indian Standards, New Delhi

[17] IS 1727:1967 (Reaffirmed 1999) Methods of test for pozzolanic materials, Bureau of Indian Standards, New Delhi

[18] Recommended Guidelines for concrete mix Design. IS 10262-2019, Bureau of Indian standards, New Delhi.

[19] Specification for Coarse and fine aggregates from Natural sources for concrete. IS 383-2016, Bureau of Indian standards, New Delhi.

[20] IS:516-1959 (Reaffirmed 2018) Methods of Tests for Strength of Concrete, Bureau of Indian Standards, New Delhi