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Mix Design Curves for High Volume Fly Ash Concrete

S. S. Awanti, Aravindakumar B. Harwalkar

Abstract**—**Concrete construction in future has to be environmental friendly apart from being safe so that society at large is benefited by the huge investments made in the infrastructure projects. To achieve this, component materials of the concrete system have to be optimized with reference to sustainability. This paper presents a study on development of mix proportions of high volume fly ash concrete (HFC). A series of HFC mixtures with cement replacement levels varying between 50% and 65% were prepared with water/binder ratios of 0.3 and 0.35. Compressive strength values were obtained at different ages. From the experimental results, pozzolanic efficiency ratios and mix design curves for HFC were established.

Keywords**—**Age factor, compressive strength, high volume fly ash concrete, pozzolanic efficiency ratio.

I. Introduction

RECENTLY, there is a general trend to replace higher levels of Portland cement in concrete with fly ash due to the increased pressure that stems from three main aspects. The first aspect is economics. In most markets fly ash is less expensive than Portland cement. The second aspect and arguably the most important is the environment. From an environmental perspective, the more fly ash being utilized in concrete, lesser will be the demand for Portland cement production which results in lower CO_2 emissions. The third and final aspect influencing the use of higher replacement levels is the technical benefits of HFC. The main difference between the HFC and the usual fly ash concrete is that in the former concrete, the amount of ordinary Portland cement is minimized through proper mixture proportioning using large amounts of fly ash and judicious selection of materials and chemical admixtures while maintaining, and often improving its performance as compared to conventional concrete. As per literature [1], a concrete having a minimum cement replacement level of 50% with fly ash is termed as HFC. The use of HFC has recently gained popularity as a resource efficient, durable, cost-effective, sustainable option for many types of Portland cement concrete applications. Various researchers [2]-[5], have developed different methods for the design of fly ash concrete. The strength of fly ash concrete was found to obey Abram’s law. The water to cement ratio for the fly ash concrete was determined on the basis of the “cementing efficiency factor” for fly ash. This factor was found to vary significantly with the curing period, the strength of the mix and type of fly ash [2]. Canon [3] suggested that the difference in the yield due to a larger volume of cementitious material in the fly ash mix should be balanced by the reduction in sand content. The demand for water in such mixes depends on the mix itself. Hansen’s modified DOE (British Department of Environment) method [4] and the more recent approach of Papclakis et al. [5] are both based on the cementing efficiency factor of fly ash, a parameter to be established for the type of fly ash used.

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II. Research Significance and Scope

The current work is aimed at determining the mix proportions of HFC mainly for pavement applications. Cube specimens of size 150 mm x 150 mm x 150 mm were used for determining compressive strength of different concrete mixes. Six specimens were used for determining each parameter. A total number of 180 cube specimens were cast for determining the compressive strength property. From the experimental results, important factors for mix design process such as age factor and pozzolanic efficiency ratios were established. Also mix design curves for HFC were determined.

III. Laboratory Investigation

A. Materials

TABLE I
Physical Properties of Fly Ash

Properties	Laboratory values	Requirements as per IS 3812-2003
Particles retained on 45 µm IS sieve (wet sieving) in percent	29	maximum 34
Lime reactivity in N/mm^2	4.9	minimum 4.5
Compressive strength at 28 days	88% of the strength of corresponding plain cement mortar cubes	minimum of 80% of the strength of corresponding plain cement mortar cubes
Specific gravity	2.01-2.19	------

OPC 53 grade cement from a single batch confirming to IS: 12269-1987 [6] was used throughout the course of the project work. Locally available river sand with maximum particle size of 4.75 mm confirming to zone II of IS: 383-1970 [7] was used as fine aggregate. Crushed basalt stone aggregates of nominal size 20 mm and 12.5 mm confirming to IS: 383-1970 [7] were used in equifractions. Potable water fulfilling the requirements of IS: 456-2000 [8] was used in the present investigation for both casting and curing. Low calcium fly ash satisfying the criteria of fineness, lime reactivity and compressive strength requirements [9] has been used in the investigation. Properties of fly ash are listed in Table I. Polycarboxylic based superplasticizer was used as high range water reducing admixture to get the desired workability. The optimum dosage of superplasticizer was fixed by carrying out compaction factor test. Since the mixes with high levels of cement replacement levels were sticky, target compaction factor was kept in the range of 0.90 to 0.92.

B. Mix Proportions

Pavement concretes are designed mainly from the criteria of flexural tensile strength. A minimum concrete grade of M30 with a minimum flexural strength of 3.8 MPa has been specified for pavement concrete for rural roads by the Indian Roads Congress [10]. Hence, for the current work, it was aimed to achieve M35 grade HFC which satisfies the flexural strength requirements also.

Three basic mix proportioning techniques used for fly ash concrete mixes are: one by partial replacement of fly ash on a direct weight to weight basis; second by direct addition of fly ash to the mix as fine aggregate and third being the partial replacement of cement with an excess amount of fly ash.

Water to cementitious ratios (w/cm) of 0.35 and 0.3 was used in the investigation. Trial mixes were developed for HFC mixes with cement replacement levels of 50%, 55%, 60% and 65% at each w/cm ratio. Two trial mixes having zero fly ash were used as reference concrete mixes. For determining the mix proportions for first trial mix of HFC with 60% cement replacement having w/cm ratio of 0.35, mix design methodology developed by [11] for optimal strength development was adopted. For other mixes material quantities were determined by using absolute volume method. In all the trial mixes partial replacement of cement with fly ash was done on a direct weight to weight basis. The mix proportions for different trail mixes are presented in Tables II and III.

TABLE II
MIX PROPORTIONS OF CONCRETE MIXES WITH W/CM = 0.35

Mix designation/ Ingredients	P.35	50F.35	55F.35	60F.35	65F.35
ater in kg/m^3	154	154	154	154	154
Cement in kg/m^3	440	220	198	176	155
Fly ash in kg/m^3	0	220	242	264	285
Fine aggregate in kg/m^3	871	807	800	794	787
Coarse aggregate in kg/m^3	1059	1059	1059	1059	1059
Superplasticizer in liter/m^3	9.9	1.76	1.76	1.76	1.76

TABLE III
MIX PROPORTIONS OF CONCRETE MIXES WITH W/CM = 0.30

Mix Designation/ Ingredients	P.30	50F.30	55F.30	60F.30	65F.30
Water in kg/m^3	132	132	132	132	132
Cement in kg/m^3	440	220	198	176	155
Fly ash in kg/m^3	0	220	242	264	285
Fine aggregate in kg/m^3	937.6	871.0	864.80	858.2	851.8
Coarse aggregate in kg/m^3	1059	1059	1059	1059	1059
Superplasticizer liter/m^3	15.4	3.52	3.52	3.52	3.52

IV. RESULTS AND DISCUSSIONS

A. Effect of Fly Ash on Compressive Strength

The variations of compressive strength values of different mixes are shown in Figs. 1 and 2. From the figures, it was evident that the compressive strength increases with the age of concrete and decreases as the amount of fly ash increases. Despite the reduction in compressive strength for fly ash concretes a compressive strength of 27.7 MPa was obtained at 28 days even at a cement replacement level of 65% for w/cm ratio of 0.3 which can be considered as a structural grade concrete [8]. Compressive strengths of 40.8 and 35.2 MPa were obtained at 28 days for fly ash content of 60% with w/cm ratios of 0.30 and 0.35 respectively. All the HFC mixes up to 60% cement replacement level with w/cm of 0.3 have satisfied the flexural strength criteria of pavement concrete [12]. In case of HFC mix with the w/cm ratio of 0.35 mixes up to 55% fly ash content satisfied the flexural strength requirement of pavement concrete [12]. The compressive strength values indicate the significant strength development rate in fly ash concretes at later ages i.e., at 28 days and 90 days. It can also be concluded that the fly ash is much more effective at lower water/cementitious material ratio, a fact which is also reported in the literature [13]. Compressive strength values, ratios of 7 day strength (f_{c7}) to 28 day strength (f_{c28}) and 90 day strength (f_{c90}) to 28 day strength (age factor) are presented in Table IV. It is evident that the rate of strength gain is significantly higher for HFC mixes when compared with reference mixes at both w/cm ratios. Strength gain was insignificant after 28 days for PCC mixes. But for HFC mixes there was considerable strength gain, even up to the age of 90 days. The rate of strength gain was highest for HFC mix with 50% cement replacement level at both w/cm ratios as compared to other replacement levels. The strength gain mechanism is mainly due to pozzolanic activity. Since age factor for HFC mixes is varying from 1.14 to 1.22 due consideration has to be given for strength gain mechanism in the design of structures using HFC.

TABLE IV
COMPRESSIVE STRENGTHS OF DIFFERENT CONCRETE MIXES

Mix designation	Cube compressive strength of concrete in MPa at the age of			Ratio of 7 day compressive strength to 28 day strength	Age factor (Ratio of 90 day compressive strength to 28 day compressive strength)
	7 days	28 days	90 days		
P.35	42.44	56.1	60.39	0.76	1.08
50F.35	27.25	42.44	51.81	0.64	1.22
55F.35	25.65	40.62	48.03	0.63	1.18
60F.35	21.65	35.17	42.36	0.62	1.20
65F.35	15.11	24.42	28.56	0.62	1.17
P.30	47.31	62.28	66.20	0.76	1.06
50F.30	30.59	52.1	62.93	0.59	1.21
55F.30	29.07	47.31	56.03	0.61	1.18
60F.30	25.07	40.84	46.43	0.61	1.14
65F.30	19.77	27.69	32.34	0.71	1.17

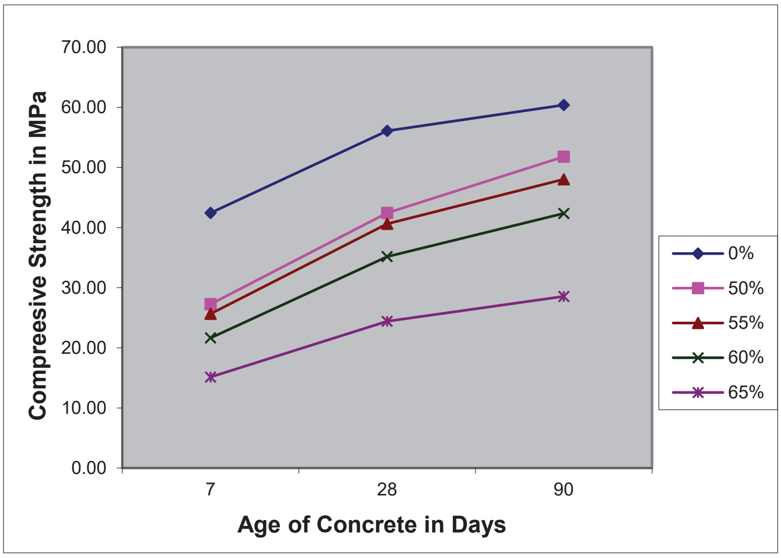

Fig. 1 Variation of compressive strength with age for concrete mixes with w/cm=0.35

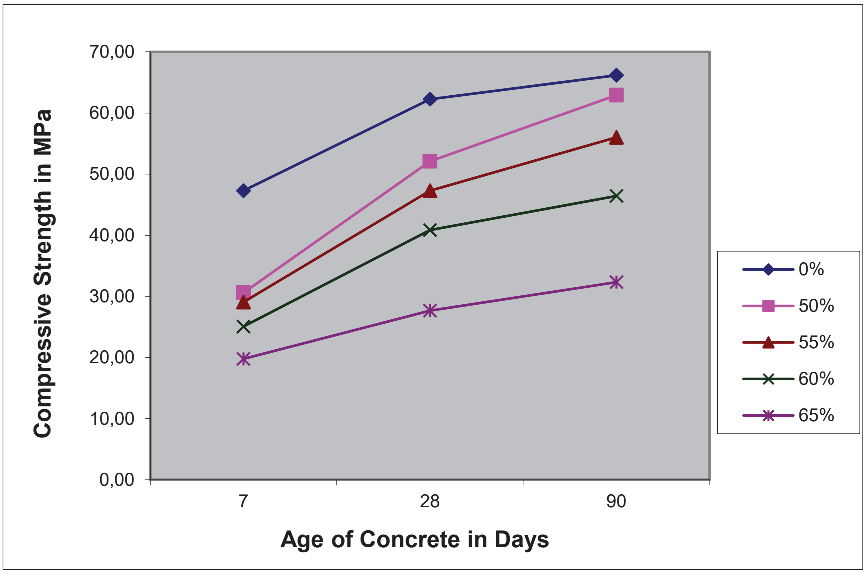

Fig. 2 Variation of compressive strength with age for concrete mixes with w/cm=0.30

B. Pozzolanic Efficiency Ratio

For quantification of pozzolanic activity of the fly ash, pozzolanic efficiency ratio (PER) can be calculated [14], [15]. This ratio depends on the experimental strength and the theoretical strength of the fly ash concrete. The theoretical strength is determined from Feret's equation [16] given by (1) (ignoring the air content):

$$f = k\left[\frac{c}{c+w}\right]^2 \quad (1)$$

where f = compressive strength of concrete; c = absolute volume of cement; w = absolute volume of water; k = constant. Hence, the compressive strength of plain concrete (f_p) and fly ash concrete (f_f) can be estimated from:

$$f_p = k\left[\frac{c_p}{c_p+w_p}\right]^2 \quad (2)$$

$$f_f = k_1\left[\frac{c_f}{c_f+w_f}\right]^2 \quad (3)$$

If fly ash is treated as an inert material and do not contribute to cementing action in concrete, then k can be taken equal to

k_1. Thus the ratio of theoretical strengths of fly ash and plain concrete (T) can be written as:

$$T = \frac{f_f}{f_p} = \left[\frac{\left(c_p + w_p\right) c_f}{\left(c_f + w_f\right) c_p} \right]^2 \quad (4)$$

Experimental strength ratio of fly ash and plain concrete (E) from results of compressive strength test:

$$E = \frac{e_f}{e_p} \quad (5)$$

where e_f is the actual compressive strength of fly ash concrete and the e_p is the actual compressive strength of plain concrete.

The PER (η) is defined as the ratio of experimental strength ratio (E) to the theoretical strength ratio (T):

$$\eta = \frac{E}{T} \quad (6)$$

The η values can be used for the assessment of pozzolanic activity of the fly ash. If η is less than or equal to 1, fly ash is inert. As η value increases more than 1 then fly ash becomes more effective in the cementing action.

The η values for all the concrete mixes at different ages are given in Table V. From these tables it can be seen that the efficiency factor increases with age, which results from the pozzolanic action of fly ash. At later ages, even though compressive strength decreases with increasing fly ash content the η values increase, indicating the contribution of fly ash in strength development. A similar trend has been reported in the literature [13].

TABLE V
PER OF HFC MIXES

Mix designation	PER of concrete		
	7 days	28 days	90 days
50F.35	1.503	1.758	1.994
55F.35	1.654	1.950	2.142
60F.35	1.691	2.001	2.216
65F.35	1.628	1.696	1.842
50F.30	1.418	1.847	2.099
55F.30	1.535	1.930	2.150
60F.30	1.525	1.960	2.096
65F.30	1.289	1.609	1.768

C. Mix Design Curves

From the 7 day and 28 day compressive strength results, mix design curves for HFC mixes similar to that reported in the literature [11] were developed. These curves are shown in Figs. 3 and 4. Also the comparison between the design curves of current investigation and that given in the literature [11] is shown in Figs. 5 and 6. From Figs. 5 and 6, it is evident that the compressive strength value obtained from the current study design curves for a particular fly ash to cement ratio and w/cm ratio is lower than that obtained from the curves of the literature. This may be due to variation in the quality of the fly ash utilized. The profile of the two set of curves exactly matched for 7 day strength. But in 28 day strength curve, the rate of decrease in compressive strength with increase in fly ash to cement ratio at a particular w/cm ratio is higher in the case of curves obtained from the present investigation.

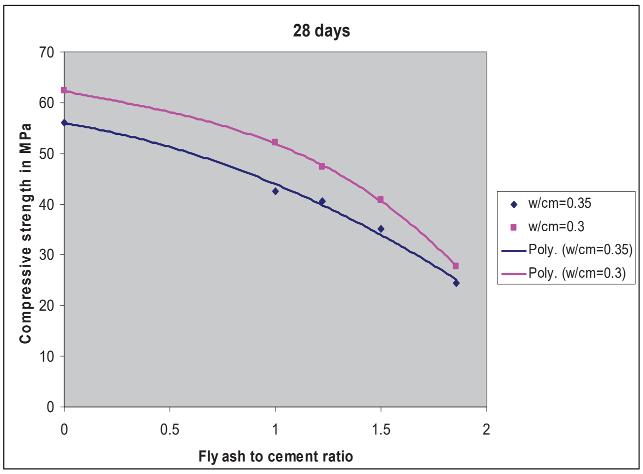

Fig. 3 Mix design curve for 28 day strength

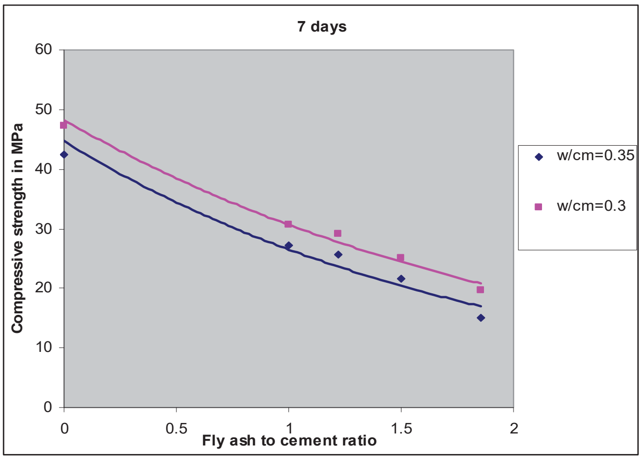

Fig. 4. Mix design curve for 7 day strength

V. CONCLUSIONS

The conclusions obtained from the current study are summarized as follows:

- Fly ash is much more effective at lower water/ cementitious material ratio
- The age factor of HFC was higher than that of conventional concrete. A maximum % increase of 15 was observed in the age factor for HFC mix.
- The PER of HFC increases with age. The PER obtained in the current study will be a useful data for mix design procedure for HFC mixes.
- Mix design curves relating fly ash to cement ratio, w/cm ratio and 28 day compressive strength obtained in the

current investigation will be a useful data for determining mix proportions of HFC.

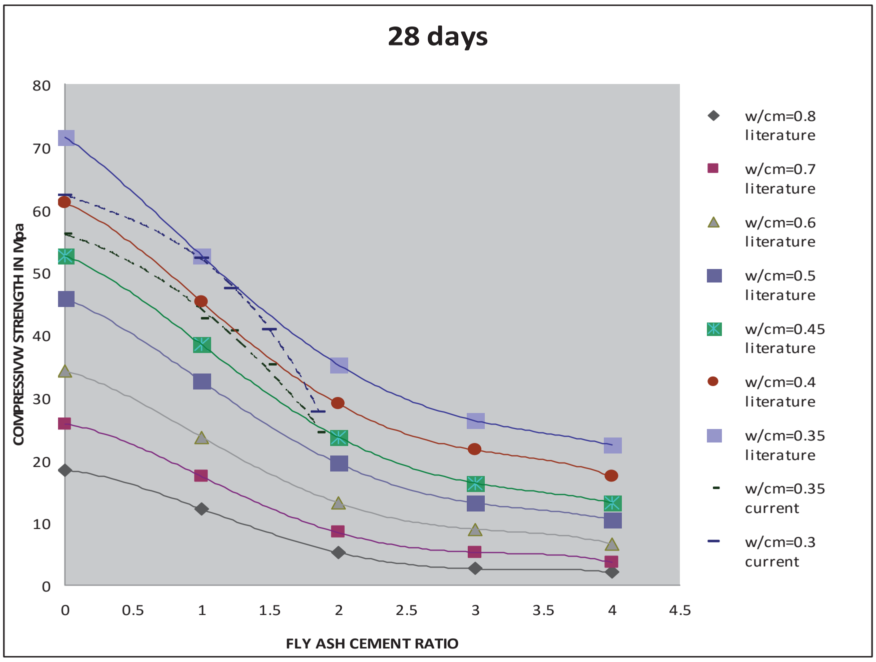

Fig. 5 Comparison of mix design curves of current study and literature [11] for 28 day compressive strength

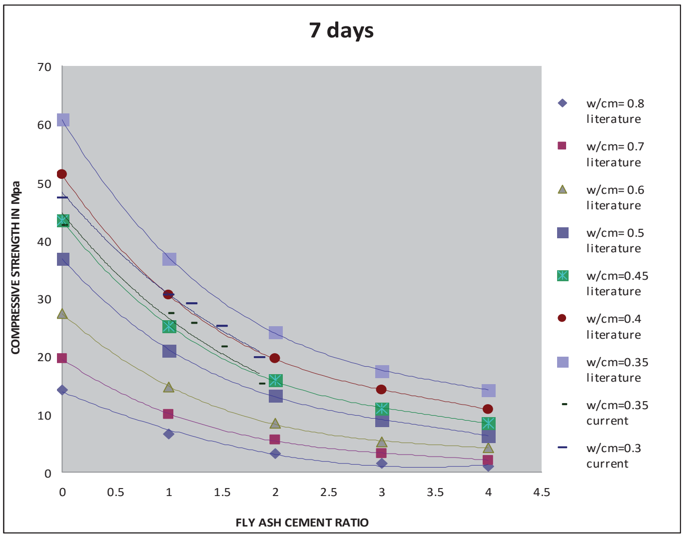

Fig. 6 Comparison of mix design curves of current study and literature [11] for 7 day compressive strength

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