Optimising the Cement Content in HVFA Concrete for Durability and Sustainability

Jagath Kumari.Dungi, and K.Srinivasa Rao

***Abstract*—**Cement is the main component of concrete and one of the most important materials for all kinds of construction due to its easy availability and adequate engineering properties. As the Cement content controlling the strength of mix design in the concrete construction industry, due to certain reasons it is expensive and not sustainable. Mainly the principal binder in concrete is Portland cement the production of cement emits approximately 5% of global carbon dioxide (CO2) and 5% of global energy consumption, which is a major contributor to greenhouse gas emissions that are concerned in global warming and climate change [11]. Next, it consumes huge quantities of virtuous materials and many concrete structures suffer from lack of durability which has an adverse effect on the resource productivity of the industry. The concern for sustainability along with the need for the durability, High-volume fly ash concretes (HVFAC) have been proposed as one potential approach for achieving extensive reductions in cement usage. The current industry limitation is that Portland cements are generally only optimised for their performance in pure cement mix (OPC), as the high cement content will cause the mixture to become sticky and may lead to increased risk of shrinkage and cracking problems. Therefore, the cement content should be balanced to achieve the required performance, for minimising risk of these problems.

In this paper, a new approach of optimising the cement content in a nominal grade concrete M20 mix of conventional concrete and 50% replacement of fly ash with cement (HVFA), in which the compressive strengths are investigated at appropriate water-to-cement ratio (w/c) to meet the target strength, workability, and durability requirements, in order to prevent negative impact on durability, and environment.

***Keywords*—** High-volume fly ash concrete, workability, Optimisation, sustainable, target strength.

I. Introduction

IN India Coal, thermal power plants are producing huge quantity of fly ash. This huge quantity is being stored/ disposed of in ash pond areas. The ash ponds attain large area of agriculture land. Therefore, the conversion of industrial by product fly ash, as resource material is indispensable. In the course of literature, fly ash use in the concrete improves many of its properties. Its use reduces heat of hydration, permeability and improves workability, increased resistance to sulphate attack and corrosion thus making concrete mass more strong and durable [3]. Besides these advantages, its use also reduces requirement of cement for the same strength and thus reduces cost of concrete. World over, in many of the developed countries, fly ash is used as one of the essential ingredient of durable and sustainable concrete mix. In order to increase considerable utilization of fly ash, it is necessary to use large volumes of fly ash. The large volumes of fly ash can be used in concrete as useful material by encouraging high volume fly ash (HVFA) concrete, where 50% or more than 50% of cement can be replaced with fly ash. The present research has investigated the strengths of HVFA concrete mixture with 50%, 0% replacement of cement (OPC), by optimizing the cement content constraint in the design mix of I.S code method with desired workability.

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II. Literature Review

Michael D.A Thomas [3] discussed the impact of fly ash on the properties of concrete with a view of optimising the level of fly ash use for a given application. The optimum fly ash content will vary on case-by-case basis. Fly ash content up to 50% may be suitable for most of the elements provided that adequate moist curing can be ensured. If not or the concrete exposed to freezing and thawing in the presence of deicer salts, the amount of fly ash should be limited to 25%.

Dale P. Bentz et al [4] conducted an experimental programme on mortar cubes compressive strengths with three variables of particle size distribution, volume of fly ash content 20% to 65% and at six ages of strengths which show the significant influence on compressive strengths. Mixtures with 20% fly ash were able to develop compressive strengths exceeding those of the control mixture at all six testing ages. Mixtures with 35% fly ash approached, and in a few cases equalled, the performance of the control mix. Mixtures with either 50% or 65% fly ash provided compressive strengths that were significantly below those of the control mix at all testing ages.

Kumar Mehta [5] presented that the HVFA concrete is possible to produce sustainable, high performance concrete mixtures, containing 50% or more fly ash. Such concrete reduces the water demand, improves the workability, minimizes cracking due to thermal and drying shrinkage, and enhances durability to reinforcement corrosion, sulphate attack, and alkali-silica expansion.

III. MATERIAL PROPERTIES

The materials for the experimental work are as follows.

A. Cement

Ordinary Portland Cement (OPC) of 43 grade has been used in the present work. Its specific gravity is 3.13. Properties of cement are shown in Table 1.

B. Fine aggregate

Locally available river bed sand conforming to Zone II of IS: 383-1970 [6] with specific gravity 2.66 is used as fine aggregate. The fine aggregate is coarse sand with fineness modulus 2.65.

TABLE I
PHYSICAL PROPERTIES OF CEMENT

S. No	Physical Properties	Test results
1.	Fineness (as residue left on IS 90 micron sieve) %	91.8
2.	Standard Consistency (%)	31.0
3.	Setting Time a) Initial (minutes) b) Final (minutes)	 124 274
4.	Compressive strength a) 3 days (MPa) b) 7 day (MPa) c) 28day (MPa)	 29.6 40.3 62.4

C. Coarse aggregate

The coarse aggregate used in concrete mix is saturated surface dried aggregate which is dark Blue Granite and angular in shape with specific gravity 2.78. The fineness modulus is 7.76. Grading of coarse aggregate is made so as to get optimum density. The fraction of coarse aggregate passing through 20 mm and retained on 10 mm is taken as 70% of total aggregate. The remaining 30% fraction is, aggregate passing through 10 mm and retained on 4.75 mm.

D. Fly ash

The fly ash used for the experimental program is low calcium Class-F Fly ash procured form NTPC, Visakhapatnam, which is locally available.

E. Water

Locally available potable water conforming to IS: 3025-1986 [7] with a pH value 7.65 is used.

F. Chemical admixture

Chemical admixture (Comp last SP 430), used to achieve workability for HVFA mix, is conforming to IS: 9103-1999 [8]. The specific gravity is 1.220 to 1.225 at 300C without any chloride content. The dosage used in the present study is 250 ml per 50 kg of cement

IV. EXPERIMENTAL PROGRAM

According to IS: 456-2000 [2], grade of concrete M20 is designated as ordinary or normal grade concrete. Mix proportions are achieved for ordinary concrete (M20) based on the guidelines of IS: 10262-2009 [9]. The target strength is 27.6 MPa as per Mix design.

TABLE II
MIX DESIGN PROPORTIONS PER M3 OF M20 GRADE CONCRETE

S. No	Ingredients	Conventional Concrete M20 (OPC)	HVFA concrete M20 (HVFAC)
1.	Cement used	387.50 kg/m^3	193.75 kg/m^3
2.	Fine Aggregate	623.95kg/ m^3	623.95 kg/m^3
3.	Coarse Aggregate	1211.0 kg/ $m^{3.}$	1211.0 kg/m^3
4.	Water to binder ratio	0.52	0.45
5.	Fly Ash	0%	50% (193.75 kg/m^3)
6.	Super plasticizer SP430	NIL	250 ml per 50kg of cement

A. Casting and curing of concrete specimens

A total of 96 concrete cubes of 150 mmx150 mm x150 mm size were caste and cured for 7 days and 28 days through 6 cubes for each batch of mix. The ingredients of concrete are initiated into a rotating drum type laboratory mixer. The total mixing is done for time 2 minutes. Workability of fresh mix is measured with slump cone apparatus, and then the concrete is filled into cube moulds and compacted by means of a table vibrator for 45 seconds. After 24 hours, the specimens were demoulded, marked and are kept in a curing tank with fresh water for a period of 7 and 28 days. After specified curing period, the specimens were tested in compression testing machine (CTM 100T) on surface drying of the specimens. No chemical admixture is added for controlled concrete mix whereas 250 ml per 50 kg of cement is added in the HVFA mix

V. RESULTS AND DISCUSSIONS

Out of first six mixes 3 mixes with w/c ratios of 0.48, 0.5, and 0.53 for no (0%) fly ash OPC mix and other 3 mixes with w/c ratios of 0.4, 0.42, and 0.45 for 50% fly ash of HVFA mix were examined for the workability of concrete and compressive strengths of cubes at 7 days and 28 days of curing. The values are tabulated in Table IV.

TABLE IV
VARIATION OF SLUMP WITH W/C FOR REQUIRED WORKABILITY

	Controlled Concrete (0% fly ash)			HVFA concrete (50% fly ash)		
W/C ratio	0.48	0.5	0.53	0.4	0.42	0.45
Slump in mm	35	45	60	30	50	70

The test results presented in Table 4 show that slump is a function of w/c ratio. The strength decreases with w/c ratio for both concretes. Fig.1 shows workability enhances with increase in w/c ratio. The low water cement ratio mixes illustrates low workability in both concretes. It is recognized in concrete structures the strength characteristics of the concrete greatly influence its resistance to collapse. As workability is prior parameter with respect to strength for all structural elements, it is necessary to predetermine the w/c ratio for a desired workability of a particular mix. Therefore w/c ratio is fixed at 0.53 for controlled concrete (OPC) mix and 0.45 for HVFA concrete mix. The compressive strength (28 days) attained at these w/c ratios is 51.85 MPa for OPC mix which is more than the target strength and 22.9 MPa which is less than the target strength for HVFA mix respectively. As these two results are distant to the designed target strength of M20 mix, are not desirable. Therefore it is possible to optimise the cement content without sacrificing the desired workability to attain target strength in the both concretes. Table 5, Fig.2, Fig.3, Fig.4 illustrate the results, on optimising the cement content from 387.5 to 300 kg/m3. As per IS: 456-2000 [2] the minimum cement content in a concrete mix for RCC is 300 kg/m3, accordingly the optimisation is considered. On optimising the cement content to 320 kg/m3, both mixes of M20 grade concrete achieved more than the target strength and required workability. The better performance of HVFA concrete in comparison to the control concrete can be attributed to the fact that the fly ash reacts with lime and offers mineralogy to OPC that is conducive to strength development. The crystalline matter of fly ash which is not reactive gives a packing effect to concrete, filling up pores and thus contributing to intense strength to HVFA concrete.

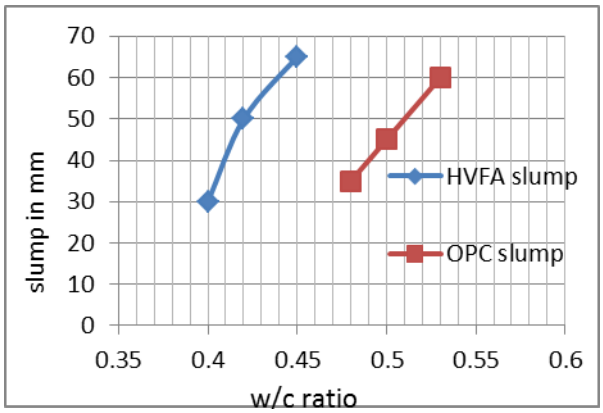

Fig.1 Variation of slump with W/C ratio

TABLE V
CUBE COMPRESSIVE STRENGTHS OF BOTH CONCRETES

	Compressive strength in MPa at 7 days			Compressive strength in MPa at 28 days		
Cement content kg/m^3	Slump in mm	Controlled concrete OPC	HVFA concrete (50% fly ash)	Slump in mm	Controlled concrete OPC	HVFA concrete (50% fly ash)
387.5	60	37.48	13.92	70	51.85	22.9
350	46.5	35.55	18.26	50	43.55	31.4
330	40	33.77	19.26	45	41.2	34.8
320	37.5	30.6	21.77	41.5	39	36.2
300	25	28.44	23.55	30	38.66	37.7

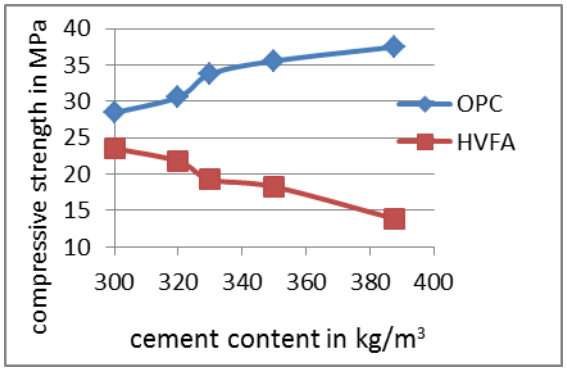

Fig 2 Variation of strengths at 28days with cement

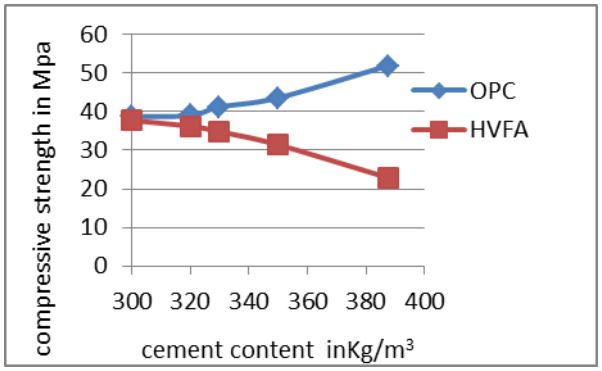

Fig 3 Variation of strengths at 7days with cement content in a mix

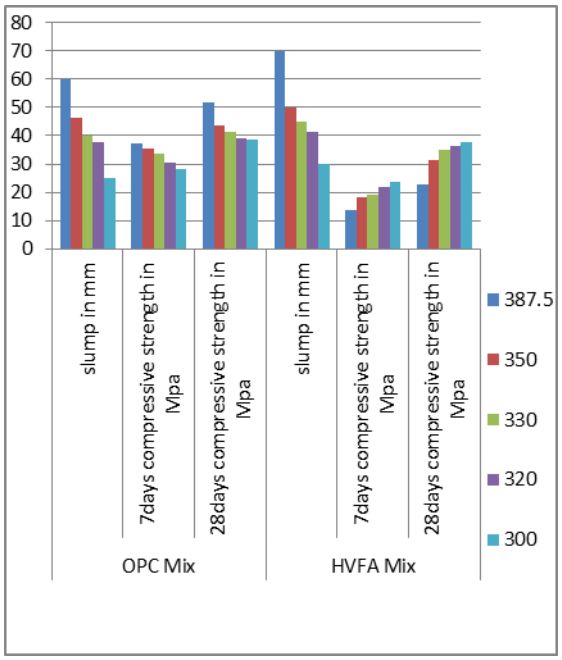

Fig 4 Variation of slump and strengths with cement content kg/m^3 in a mix

VI. Conclusion

1. Workability is a function of w/c ratio, on increasing the w/c ratio, slump of both concretes increases.
2. Workability is also a function of cement content in a mix. Optimizing the cement content in a mix, workability reduces as slump is low.
3. Strength of mix is a function of cement content in a mix. Optimizing the cement content in the mix, strength of conventional concrete (OPC mix) decreases however the strength of HVFA concrete enhances. Early age strength (7 days) of HVFA concrete is low compared to conventional concrete.
4. With the these limitations it can be concluded that HVFA concrete performed better than OPC concrete on optimizing the cement content in a mix, also it offers superior finish and later age strength.

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