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MIX PROPORTIONING OF HIGH PERFORMANCE CONCRETE USING FLY ASH AND SILICA FUME

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Abstract— Mix proportioning is the process which involves the determination of correct combination of its ingredients such that the resulting mix yields desired characteristics at its lowest possible cost. The proportioning of HPC requires a special method of mix design as compared to NSC because of its lower water-binder ratio and use of different chemical admixtures and supplementary cementitious materials that would change the properties of concrete in both fresh and hardened state. Chemical admixture is a must for the production of HPC to achieve the desired strength. The effect of admixture on the type of cement should be verified using trail mixes, as HPC uses both chemical and mineral admixtures (SCM). For the strength greater than 70 MPa, silica fume is a must for the production of HPC. BIS method of mix design is applicable for a maximum compressive strength of 40Mpa hence it cannot be applied directly for HPC. The mix proportions for the present study is carried out by the popular method proposed by Aitcin [Mehta P.K. and Aitcin P.C, 1990; Aitcin P.C, 1998]. Concrete of strengths 60, 80 and 100 MPa were developed by using locally available FA and CA with OPC 53 grade cement, SCM and superplasticizer.

Keywords— High Performance Concrete, Flyash, Silica fume, High Strength

I. INTRODUCTION

The process of proportioning of the constituents of concrete like cement, water, FA, CA, SCM and chemical admixtures is defined as mix-design. The quality of these constituent materials, water/ cement ratio and the mixing procedure plays a very important role in achieving the targeted strength and durability of the concrete mix, which finally controls the cost of the project.

The proportioning of HPC requires a special method of mix design as compared to normal concrete because of lower water-binder ratio and use of different chemical admixtures and supplementary cementitious materials that would change the properties of concrete in both fresh and hardened state.

The proportioning of HPC involves proper procedure as summarized in the following steps;

1. Selection of materials: This involves selecting good quality, local available constituent materials.

2. Mix-proportioning: This involves decision for mix-proportioning of selected materials from the available literature or guidelines.

3. Optimizing the materials: This involves optimizing the proportioning by using empirical or theoretical concepts.

4. Testing of sample: This involves finally evaluating the rheological properties and the mechanical properties of the optimized mix.

II. MATERIALS

The production of HPC requires selection of materials of proper quality. In addition to the normal ingredients of concrete like cement, FA, CA and water, constituents like SCM and chemical admixtures are a must for the production of HPC.

2.1 Cement

Selection of cement is more important since its physical and chemical characteristics govern the compressive strength of concrete. The development of the strength of concrete largely depends on characteristics and content of cement. The grade of cement is selected either 43 or 53 depending upon the strength and durability of the concrete mix, confirming to IS: 8112-1989 and IS: 12269-1987. For higher strength of concrete, higher grade of cement is preferred so as to economize the mix proportions for HPC.

2.2 Fine aggregate

The particle shape and grading of FA are the important factors for the production of HPC. FA with rounded particle shape and smooth texture requires lesser water demand. Volume of FA should be kept minimum to increase workability and compaction. The fineness modulus of FA less than 2.5 should not be used, as it is difficult to compact.

2.3 Course aggregate

In HPC, course aggregate may also affect the concrete strength. Smaller size of aggregates known to produce higher strength of concrete. However for optimizing modulus of elasticity, creep and drying shrinkage, higher size of aggregates are preferred. Usually the maximum size of CA may be kept a minimum of 10mm or 12mm.

2.4 Mineral admixtures (SCM)

Commonly used mineral admixtures in HPC are fly-ash, silica-fume and blast furnace slag. These mineral admixtures have higher surface area as compared to cement and act as micro fillers and supplementary cementitious materials. Addition of these materials reduces the porosity of both matrix and transition zone, thus enhances strength and durability characteristics.

2.4.1 Fly-ash

Fly-ash are the by-product of power generating plants, which are produced from burning of coal during power generation. Depending upon the type of coal, the fly-ash formed will have different chemical compositions and accordingly they are classified as Class-C and Class-F. The major difference between both the classes is the total content of SiO_2, Al_2O_3 and Fe_2O_3. Class-F has total content greater than 70%, while Class-C has a total content between 50-70%. The remaining content is CaO. Hence according to the American Society for Testing Materials (ASTM) classification, Class-C and Class-F represents high and low calcium content respectively. According to BIS [IS: 3812, 1981], fly-ash is a pulverized fuel ash, classified as Grade-I and Grade-II, depending upon physical and chemical properties, for both the grades the total content of SiO2, Al_2O_3 and Fe_2O_3 should be 70%.

2.4.2 Microsilica (Silica fume)

Silica fume or microsilica is the by-product of industry producing silicon and ferrosilicon alloy. Silica fume has very high surface area of the order of 15,000 to 30,000 m^2/kg measured as per nitrogen adsorption method. The average particle diameter of silica fume is 0.15μm which is approximately 100 times smaller than average size of the cement particle. The total silica content in the microsilica ranges between 85-97% as compared to 21.9% in the Portland cement. [Holland and Terence C, 2014]. Microsilica is said to be very effective pozzolanic material because of its extreme surface area and high content of silica as compared to any other SCM. The use of microsilica enables the production of very high strength concretes and it is very useful in attaining high early age concrete strength. Hence silica fume or microsilica is a must for the production of HPC with strength greater than 70 MPa.

2.5 Chemical admixtures

Chemical admixtures are used to reduce water demand in concrete, accelerate strength gain and extend the setting time of concrete, control the rate of hardening, improve the workability and durability, air entrainment. These chemical admixtures content lignosulphates, hydroxylated carboxylic acid, melamine, carbohydrates and naphthalene condensates and organic and inorganic accelerators in various compositions to produce different types. As HPC uses both chemical and mineral admixtures (SCM), its effect on the type of cement should be verified using trail mixes.

III. DESIGN OF HPC MIXES

Bureau of Indian Standards (BIS) method of mix design suggesting the general water cement ratio is applicable for a maximum compressive strength of 40Mpa [BIS-IS:456-2000]. Hence BIS method of mix design cannot be applied directly for HPC [Gopalkrishnan et.al, 2001]. Earlier in 1980's, there were no standard mix proportions for HPC, based on several successful mix proportions, Neville presented typical mix proportions [Neville-1983]. This typical mix proportions are presented for different countries.

Now as such there are many mix design methods available based on various published literature like Mehta and Aitcin [Mehta, P. K., and Aitcin, P. C, 1990], ACI method [ACI -211.4R-1993], Aitcin method [Aitcin, 1998], a new method which takes into account the rheological properties at the design stage itself [A. Islam, 2008], a modified mix design procedure, which utilises optimum water content and the efficiency factor of mineral admixture [B.H Bharatkumar et al, 2001] and many more. There are also guidelines for the use of HPC in various projects of transportation [Guidelines BS-89, 2008].

The one among the popular method proposed by Aitcin [Mehta P.K. and Aitcin P.C, 1990; Aitcin P.C, 1998] consisting of empirical results and mathematical calculations is very simple which follows the standard practice for selecting proportions for Normal, Heavy weight and Mass Concrete. The design steps are explained as follows.

Step-1. Water/binder ratio

The water/binder ratio is determined from Fig. 1 for a given 28 day's compressive strength (measured using 150 mm×300 mm cylinders). Owing to variations in the strength, efficiency of different supplementary cementitious materials, the curve in Fig. 1 shows a broad range of water/binder values for a given strength. If the efficiency of the different supplementary cementitious materials is not known from prior experience, the average curve can be used to give an initial estimate of the mix proportions.

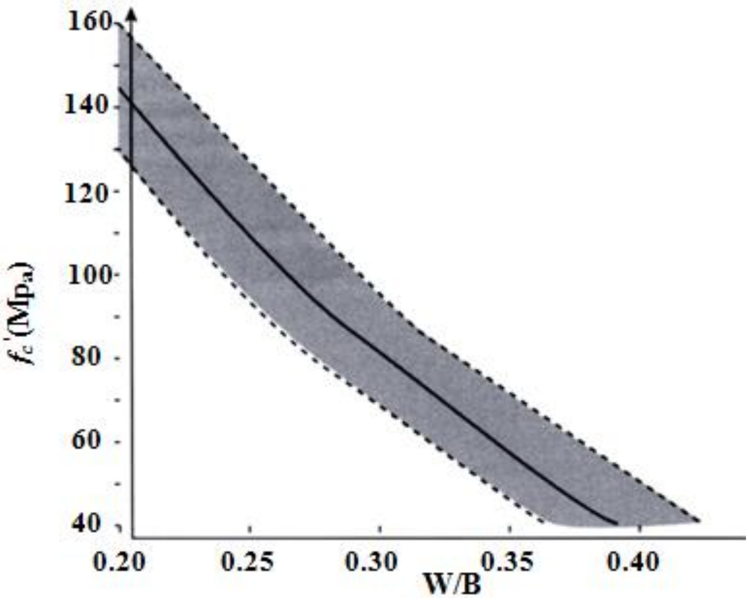

Fig 1. W/B and Compressive strength relationship

Step-2. Water content

The amount of water required to be used is determined by simplified approach based on the concept of the saturation point as given in Fig. 2. To design a very safe mix, 5 l/m^3 of water can be added to the values presented in Fig. 2. If the saturation point of the super-plasticizer is not known, it is suggested starting with a water content of 145 l/m^3.

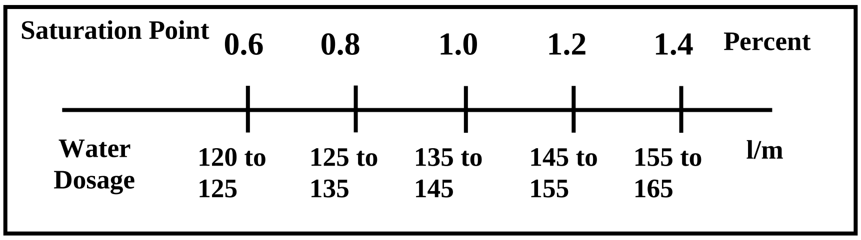

Fig 2. Determination of the minimum water content

Step-3. Binder Content

Knowing water content and water/binder ratio, the binder content is obtained. By considering the percentage replacement of cement content with the SCM, the content of cement and SCMs are obtained.

Step-4. Coarse aggregate content

The coarse aggregate content as a function of the typical particle shape is determined from Fig. 3. If the shape of CA if not known or there is any doubt about its shape, to start with it is suggested to use 1000 kg/m^3 of CA content.

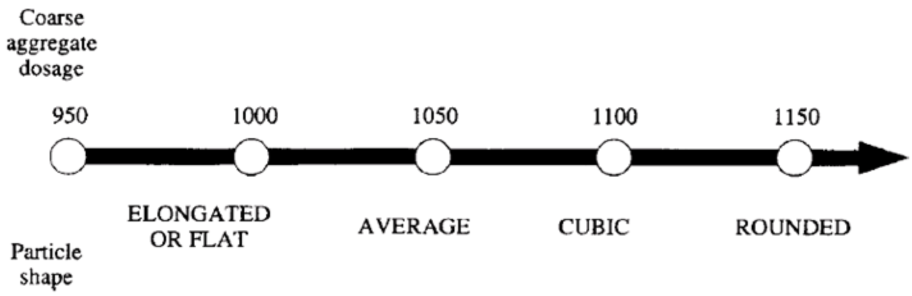

Fig 3. Coarse aggregate content

Step-5. Air content

The author suggests using an initial estimate of entrapped air content of 1.5% and then adjusting it on the basis of the result obtained with the trial mix.

Step-6. Super plasticizer dosage

The dosage of super plasticizer can be found from the dosage at the saturation point. If the saturation point is not known, it is suggested to start with a trial dosage of 1.0%.

Step-7. Mix-proportions
The mix proportions are determined by absolute volume method.

IV. MATERIALS USED IN THE PRESENT STUDY

The various materials and its properties used for the production of HPC for the present study are explained as follows.

4.1 Cement

Commercially available Ultratech ordinary Portland cement of 53 grade is used throughout the investigation for the present study. This cement conforms to the relevant IS code specifications [IS 12269, 1987]. The chemical and physical properties of the cement used as per the laboratory investigations are given in the Table 1.

Table 1 Chemical and physical properties of Cement

Particulars	Experimental test results	Standard values as per IS 12269-1987
Chemical Properties		
Tri-calcium Silicate (C_3S) (%)	45.35	-
Di-calcium Silicate (C_2S) (%)	27.0	-
Tri-calcium Aluminate (C_3A) (%)	7.03	-
Tetra-calcium Aluminoferrate (C_4AF) (%)	13.42	-
Alumina Iron Ratio (Al_2O_3 / Fe_2O_3) (%)	1.11	0.66 Min
Insoluble Residue (% by mass)	2.37	3.00 Max
Magnesia (% by mass)	1.06	6.00 Max
Sulphuric Anhydride (% by mass)	2.60	3.00 Max
Total Loss on Ignition (% by mass)	2.73	4.00 Max
Total Chlorides (% by mass)	0.009	0.10 Max
Physical Properties		
Fineness (Specific surface) (m^2/kg)	286	225 Min
Specific gravity	3.15	-
Normal Consistency (%)	32.67	28 to 33
Setting time (Minutes)		
a. Initial	60	30 Min
b. Final	155	600 Max
Soundness test		
a. By Le Chatelier (mm)	0.50	10.0 Max
b. By Autoclave (%)	0.30	0.80 Max
Compressive strength (MPa)		
a. 3 days	29.40	27.0 Min
b. 7 days	39.33	37.0 Min
c. 28 days	57.64	53.0 Min

4.2 Fine aggregate (Sand)

Locally available silica sand quarried from Krishna River, Karnataka was used in the present study. This silica sand is black colored. This sand conforms to grading zone II of Table 4 of IS code specification [IS: 383-1970]. The physical properties and the particle size distribution of FA (Sand) are as shown in Table 2 and 3 respectively.

Table 2 Physical properties of FA

Particulars	Experimental test results	Standard values as per IS 383-1970
Fineness modulus	2.83	-
Specific gravity	2.63	-
Bulk density (kg/m^3)	1603	-
Grading zone	II	-

Table 3 Particle size distribution for FA (Sand)

Sieve size (mm)	Mass of sand retained (g)	Percentage mass retained	Cumulative percentage mass retained	Percentage passing	% passing standard values as per IS 383-1970
4.75	94	9.4	9.4	90.6	90 to 100
2.36	82	8.2	17.6	82.4	75 to 100
1.18	196	19.6	37.2	62.8	55 to 90
0.60	268	26.8	64	36	35 to 59
0.30	246	24.6	88.6	11.4	8 to 30
0.15	91	9.1	97.7	2.3	0 to 10
0.075	23	2.3	100	0	-
pan	-	-			-
Total mass	**1000 gm**				

4.3 Course aggregate

Locally available crushed basalt stone aggregates quarried from local stone crushers, Karnataka was used in the present study. The maximum size of the course aggregate used was limited to 12 mm to produce 60, 80 and 100 MPa HPC. The course aggregates used conforms to IS code specifications [IS 383, 1970; IS 2386, 1963]. The physical properties of the course aggregates used as per the laboratory investigations are as given in Table 4.

Table 4 Properties of Coarse aggregates used

Particulars	Experimental test results	Standard values as per IS 383-1970 IS 2386-1963
Max. Size of coarse aggregates (mm)	12	-
Aggregate crushing value (%)	21	30 Max
Aggregate Impact Value (%)	18	30 Max
Specific Gravity	2.81	-

4.4 Fly ash

The fly ash from Raichur thermal power plant, Karnataka was used in the present study throughout the investigations. The fly ash used in the present study conforms to IS code specifications [IS: 3812, 1981].

4.5 Microsilica (Silica fume)

The silica fume or microsilica used through the investigation in the present study is obtained from Nuchems India, Bangalore with product name NUSIL-50. Nuchems is in the forefront of microsilica industry. This microsilica is directly collected from Silicon and ferrosilicon metal factories. These have stable SiO_2 content with high pozzolanic strength activity. The SiO_2 content of this product range from 90% to 97%. Silica Fume Nusil-50 meets the requirements of ASTM [ASTM C1240–15] and contains a minimum of 88% silicon dioxide (SiO2).

The silica fumes dosage recommended by the industry ranges from 7 to 8% replacement by weight of cementitious material. For HPC the dosage may be further increased to 10% replacement by weight of cement. The technical specifications of microsilica used are summarized in Table 5.

Table 5 Technical specifications of microsilica

Particulars	Values	Standard values as per ASTM C1240-15
Amorphous SiO_2 (%)	93	90 Min
H_2O (humidity) (%)	1.0	3.0 Max
Retained 45micron (%)	0.58	2.5 Max
Bulk Density (kg/m^3)	400-720	-
Specific surface (m^2/g)	23.36	15 to 28

4.6 Alccofine 1203

Alccofine-1203 is a SCM of Ambuja Cements Limited (ACL) used for the production of high strength and high performance concretes. It is proprietary low calcium silicate based mineral additive. Addition of this enhances the hydration process and improves packing density of the concrete. This helps in improving strength and durability of HPC at all ages. The dosage as per the literature ranges from 4 to 8% by weight of cement. The chemical and physical properties of the Alccofine 1203 used are given in the Table 6.

Table 6 Chemical and physical properties of Alccofine 1203

Particulars	Values
Chemical Properties	
SiO_2 (%)	34.2
Al_2O_3 (%)	23.1
Fe_2O_3 (%)	0.80
CaO (%)	34.0
SO_3 (%)	0.08
MgO (%)	6.1
Physical Properties	
Bulk Density (kg/m^3)	600-700
Specific gravity	2.86 ±0.02
Specific surface (cm^2/g)	12000
Average particle size (μ)	4 to 6

4.7 Superplasticizer

HRWR admixtures of Glenium series product manufactured from BASF, Bangalore is used throughout the investigations in the present study. Early manufactured as Glenium B233 and later named as Master Sky Glenium B233 was used. This superplasticizer has long lateral chains based on carboxylic ether polymer. The specifications of the superplasticizers used in the present study are shown in Table 7.

Table 7 Specifications of superplasticizers

Particulars	Values
Superplasticizer base	Polycarboxylic ether
Appearance	Light brown
Density	1.09
pH Value	8
Specific gravity	1.1
Solid content	30%
Recommended dosage	0.5 to 1.5%

4.9 Reinforcing Steel

The longitudinal reinforcement and the lateral stirrups for casting of beams in the present study, grade Fe 500 with yield strength 500MPa was used. The rebars of different diameters were tested in a 1000 kN capacity universal testing machine (UTM). The steel rebar samples of length 750mm are gripped in the jaws of the UTM machine. The load and the corresponding axial displacement is noted.

V. MIX PROPORTIONS

The mix proportions for the production of HPC are carried out using one among the popular method proposed by Aitcin [Mehta P.K. and Aitcin P.C, 1990; Aitcin P.C, 1998]. The mix proportions are evolved for three different grades of HPC 60, 80 and 100. The design steps are summarized in Table 8. The final mix proportions and its compressive strength are presented in Table 9.

Table 8. Mix proportioning of HPC

Particulars	60 MPa	80 MPa	100 MPa
Water/binder ratio (W/B)	0.32 to 0.37 Adopt W/B=0.35	0.24 to 0.36 Adopt 0.25	0.24 to 0.28 Adopt 0.23
Water Content (W)	Adopt W=160	156	145
Binder Content (B) (kg/m^3)	457.14	625	630.5
Fly ash content (kg/m^3)	91.0 (20%)	62.5 (10%)	31.52 (5%)
Silica fume (kg/m^3)	-	62.5 (10%)	47.28 (7.5%)
Alccofine-1203	-	-	47.28 (7.5%)
Cement content (kg/m^3)	366.0	500	504.42
Course Aggregate Content (CA) (kg/m^3)	1100	1100	1100
Air Content (1 to 3%)	Adopt 2%	2%	2%
Superplasticizer (SP) dosage	Dosage of SP=1% $M solid = \frac{1.0}{100} \times 457.14$ $= 4.57 kg/m^3$ $V_{liq} = \frac{4.57}{1.1} \times \frac{1}{0.34}$ $= 12.22 \; l/m^3$ $V_w = 12.22 \times 1.1 \times 0.66$ $= 8.87 \, l/m^3$ $V_{sp} = 12.22 - 8.87$ $= 3.34 \, l/m^3$	SP=1.5% M_{solid}=9.375 For 30:70 V_{liq}=28.93 V_w=21.875 V_{sp}=7.055	SP=2.0% M_{solid}=12.61 For 30:70 V_{liq}=38.21 V_w=29.42 V_{sp}=8.8
Mix-proportions (Absolute Volume method)	$V_{cem} = \frac{366}{3.15} \times \frac{1}{1000} = 0.1162$ $V_{fly} = \frac{91}{2.06} \times \frac{1}{1000} = 0.04417$ $V_{CA} = \frac{1100}{2.81} \times \frac{1}{1000} = 0.39146$ $V_{air} = 2\% = 0.02$ $V_{sp} = \frac{3.34}{1.1} \times \frac{1}{1000} = 0.00303$ V_w=0.160 Total Vol=0.735 V_{FA}=1-0.735=0.265 M_{FA}=0.265×2.63×1000 = 696.95 kg/m^3	V_{cem}=0.17857 V_{fly}=0.0284 V_{sf}=0.0284 V_{CA}=0.3914 V_{air}=0.02 V_{sp}=0.0064 V_w=0.156 Total Vol=0.80 V_{FA}=0.20 M_{FA}=526	V_{cem}=0.16013 V_{fly}=0.0153 V_{sf}=0.0215 V_{alco}=0.0165 V_{CA}=0.423 V_{air}=0.02 V_{sp}=0.008 V_w=0.145 Vol=0.809 V_{FA}=0.191 M_{FA}=503

Table 9. Final mix proportions and Compressive strength.

Materials	**Final mix proportions**		
	M_{60} grade	**M_{80} grade**	**M_{100} grade**
Water/binder ratio	0.35	0.25	0.23
Cement (kg/m^3)	366.0	500	504.42
FA (kg/m^3)	696.95	526	503
CA (kg/m^3)	1100	1100	1100
Water (kg/m^3)	160	156	145
Fly ash (kg/m^3)	91.0	62.5	31.52
Silica fume (kg/m^3)	-	62.5	47.28
Alccofine 1203 (kg/m^3)	-	-	47.28
Superplasticizer (%) Master Sky Glenium B233	1.0	1.5	2.0
28-days Compressive strength (MPa)			
Cube compressive strength	84.83	89	106.34
Cylinder compressive strength	70.89	74.85	91.38

VI. CONCLUSIONS

Concrete of strengths 60, 80 and 100 MPa were developed by using locally available FA and CA with OPC 53 grade cement, SCM and superplasticizer. To get consistent and a homogeneous HPC mix during the mix-proportioning, the minimum mixing time was found to be 25-30 minutes. During the trail process of mix- proportioning in the production of HPC, it was found that the mineral admixture Silica Fume is a must for production of HPC above 70 MPa in addition to Fly-ash or GGBS. During the production of 100 MPa HPC, it was possible to achieve the compressive strength with addition of Alccofine 1203 in addition to silica fume, since the mix with higher content of silica fume above 20% was not consistent.

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