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EXPERIMENTAL ANALYSIS ON HIGH PERFORMANCE CONCRETE USING BINARY PACKING DENSITY MODULUS

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ABSTRACT

With the increase in complexity of the structures and the requirement for high strength materials for the critical structures like prestressed concrete girders and deck panels, blast resistant structures and military structures, the design and use of high strength concrete had been highly practised. However designing high strength concrete had contrary effects on the workability and durability of the concrete. To overcome the above problem, high performance concrete has evolved which maintains a right balance between the two conflicting objectives. The first objective of this study is to design a concrete with a compressive strength of 60 MPa and the second is to design a concrete which has fluidity so that it is easily workable and also a stable mixture to prevent segregation. The high strength can be achieved by dense structure and low capillary pores. This was achieved by right selection of aggregate size, ratio of fine aggregate to coarse aggregate and the ratio of binder to total aggregate (0.4,0.45,0.5). The fluidity of the concrete was achieved by using high quality superplasticizer and the stable mix was achieved by selecting proper type of the binder and their proportions. The project focused on designing a binary mix with 5%, 10% and 15% replacement of OPC with silica fume, 25% and 50% replacement of OPC with GGBS. The test results were checked to determine the best mix with silica fume-GGBS and a ternary mix was made. The size of aggregate and the ratio of the aggregates was fixed for the highest packing denity. Consistency, initilal and final settting time of binders for different mixes were found to understand the minimum water requirement and rate of setting of the binders. The type of curing was decided based on the strength developed in the trial mixes and the desired properties of ultra high performance concrete has been achieved.

Key Words – silicafume, GGBS, consistency, setting time, binary mix.

1. INTRODUCTION

Bouygues made the initiative to start research in Reactive Powder Concrete which was first of the kind in High Performance Concrete (HPC) to meet the demand for high strength construction materials in the year 1990. UPHC is mainly characterized with the high strength in the order of 60 MPa or above. But the ductility properties gets affected in HPC, as the concrete becomes highly brittle with the increase in strength of the concrete. It leads to sudden blasting failure of the concrete elements as there is no post peak load carrying capacity by the concrete element. Hence HPC is generally reinforced with the steel fibres which have better ductile properties. HPC can only be developed by enhancing the mechanical behavior of the concrete by choosing the right materials, particle size of the materials and material proportioning. A concrete with high strength can only be achieved by altering the mechanical properties of the material used in the concrete so that any micro defects possible shall be minimized. This study mainly focuses on achieving the maximum possible interlocking of the materials, so as to reduce the micro defects and to achieve a higher density with a closely packed nature. To increase the homogeneity of the concrete, smaller sized coarse aggregate is used. Generally HPC can be produced only with lower water to binder ratio (W/B) to achieve the higher strength. Thus high quality superplasticizer is required to increase the workability. The ideal design of a HPC is to maintain a balance between the fluidity and the stability of the matrix. The right fluidity is achieved using high quality superplasticizer and the stability of the mix shall be achieved selecting the proper cement replacement materials like Silica Fume, Rice Hush Ash, Ground Granulated Blast furnace Slag and Flyash. However Silica Fume (SF) and Ground Granulated Blast furnace Slag (GGBS) is used in this study in various proportions to determine the mix with best stability and higher strength. A highly dense mix shall be achieved only by interlocking the right materials in proper gradation. Hence sub micrometer particles is the key to fill the pores between the larger particles of cement. Thus the use of SF and GGBS becomes essential to increase the interlocking of the materials.

HPC is more efficient because the concrete elements can be produced of smaller and thinner sections due to its denser nature; the concrete elements are less susceptible to harsh environments as the permeability is highly reduced.

Chong Wang, Changhui Yang, Fang Liu, Chaojun Wan, Xincheng Pu (2012) used smaller coarse aggregate to enhance the property of the concrete and steel fibres was introduced to increase the ductility of the concrete. In the study superplasticizer and large quantities of superfine silica were added to achieve low W/B ratio to reduce porosity and to improve strength. Also steam curing was adopted to achieve the higher strength.The test results shows that with extremely low W/B, high binder content, multi addition of silica fume, GGBS, limestone powder and high standard SP, HPC can be prepared with common technology.

Highest compressive strength of 175.8 Mpa at 90 days and 182.9 at 365 days were achieved. It was found that with W/B of 0.16, binder content of 900 kg/m^3 which contained 50% cement, 10% SF, 20% GGBS and 20% limestone powder with appropriate dosage of SP were required for the successful mix.The study made by Nguyen Van Tuan, Guang Ye, Klaas van Breugel, Oguzhan Copuroglu (2011) focussed on the use of the rice husk ash in HPC. But the hydration and microstructure formation of RHA was expected to vary from the commonly used admixture like silica fume. Hence the objective of this research was to study the effect of RHA on the hydration and microstructure development of HPC and to compare with the results obtained from the controlled and the sample with silica fume. BSE image analysis showed that the addition of the RHA increases the degree of cement hydration in HPC in later ages, which may be caused by the porous structure of RHA and the uptake of water in the pore structure resulted in a kind of internal curing RHA modified mixes. With RHA, HPC of 175 MPa at 28 days 185 MPa at 91 days were achieved. Tina Oertel, Frank Hutter, Ricarda Tanzer, Uta Helbig, Gerhard Sextl-(2013) compared the commonly used silica fume to the wet chemically synthesized silica. The spherical particles had a purity of 99.97%(SiO2), and a particle size of 72 nm to 720 nm. The focus of the study was to determine the effects of the particle characteristics on calculated particle packing densities, the microstructure and the compressive strength of HPC. From the study it was found that nearer the dispersion of the silica comes to the primary particle sizes, the higher is the compressive strength. It was clear that the dispersion of the silica into primary particle sizes or the smaller agglomerates possible is mandatory for the further improvement of compressive strength.

2. EXPERIMENTAL METHODOLOGY

A. Materials

The binder material used in the study is Ordinary Portland Cement (OPC) of 53 Grade, Silica Fume and GGBS. The binders are collected from the nearby local source and their physical and chemical properties are shown in Table 1 & Table 2.

Table 1 Physical Properties of Binders

Physical Properties	SF	GGBS
Specific Gravity	2.2	2.9
Bulk Density (Kg/m^3)	640	1100
Average Particle Size (µm)	0.5	1.8
Specific Surface Area (m^2/kg)	17000	500

Table 2 Chemical Properties of Binders

Mineral Admixtures	Chemical Composition (%)			
	SiO_2	Al_2O_3	Fe_2O_3	CaO
Silicafume	91	0.06	0.03	0.5
Slag	39	13.5	1.8	39.2

Chemical Admixtures: High range water reducing admixture of Cera hyperplast XR W40 having a specific gravity of 1.09-1.11 was used to maintain the workability of mix.

B. Mixture Proportions

There are six different mix combinations with Silica Fume and GGBS at different percentages. The details of mix combinations were shown in Table 3.

Table 3 Details of Mix combinations and Mix ID's

Mix	Ratio
A	95% OPC +5% SF
B	90% OPC +10% SF
C	85% OPC +15% SF
D	100% OPC
E	75% OPC +25% GGBS
F	50% OPC +50% GGBS

C. Methods

Packing density is found for the coarse and fine aggregate separately for different particle size and a comparison is made to determine the particle size which gives a higher packing density. With the results of packing density obtained for different particle size of coarse aggregate and fine aggregate, packing density is calculated for the binary mix. Consistency test is carried out to know the water requirement for the different mix. Consistency gives the water percentage required for a binder, at which the mix shall be easily workable.

The Standard Consistency Test for all 6 mix combinations were carried out. The Initial Setting Time and Final Setting Time for all the mixes have been found out. The density of concrete and the binder content required for the mix was found by adopting the Binder to Total aggregate ratio (B/TA). The B/TA ratio adopted in the study is 0.40, 0.45 and 0.50, the corresponding density is 2331 kg/m^3 , 2414 kg/m^3 , 2497 kg/m^3 and the binder content is 666 kg/m^3, 750 kg/m^3, 833 kg/m^3. The cubes of size 100mmx100mmx100mm were casted for different W/B ratios and different superplasticizer (SP) dosage with the three B/TA ratios to arrive at the optimum W/B ratio and the dosage of SP. From the compressive test results obtained, the four best mixes were casted by replacing cement with GGBS by 25%. The best mix is selected from the mix with 25% of GGBS as binder and concrete cubes of size 100mmx100mmx100mm were casted for all the mixes A, B, C, D, E and F under normal water curing, oven curing and steam curing.

3. EXPERIMENTAL TEST RESULTS AND DISCUSSIONS

A. Test for Packing Density

Packing density is found for the different particle sizes for both fine and coarse aggregate. The test is carried out to know the particle size which gives the possible denser package. From Fig. 1 it is found that packing density is found higher for proportion 3 and 4, however proportion 4 is considered in the study for the coarse aggregate passing through 4.75 mm and retaining on 2.36 mm. The packing density is found higher for proportions 6 and 7, the fine aggregate passing through 2.36 mm and retaining on 75µ is considered for the study.

Table 4 Packing Density of Coarse and Fine aggregate

	S.NO	PASSED	RETAINED	DENSITY (kg/m3)
COARSE AGGREGATE	1	10	4.75	1355
	2	9.5	4.75	1344
	3	4.75	2.8	1363
	4	4.75	2.36	1363
FINE AGGREAGTE	5	4.75	75 µ	1522
	6	2.8	75 µ	1578
	7	2.36	75 µ	1578
	8	1.7	75 µ	1506
	9	1.18	75 µ	1427
	10	4.75	150 µ	1538
	11	2.8	150 µ	1506
	12	2.36	150 µ	1506
	13	1.7	150 µ	1492
	14	1.18	150 µ	1502

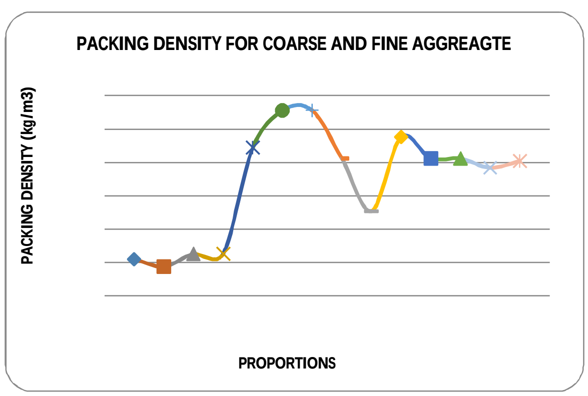

Figure. 1 Packing Density of Coarse and Fine Aggregate

The packing density for the binary filler materials is found by adopting coarse aggregate to fine aggregate ratio as 60:40, 50:50 and 40:60.It was found that the higher packing density is achieved for a mix with 50:50 ratio of coarse and fine aggregate.

Table 5 Packing Density of Binary Filler Material

S.NO	MIX C.A:F.A	DENSITY (Kg/m3)
1	60:40	1655
2	50:50	1665
3	40:60	1661

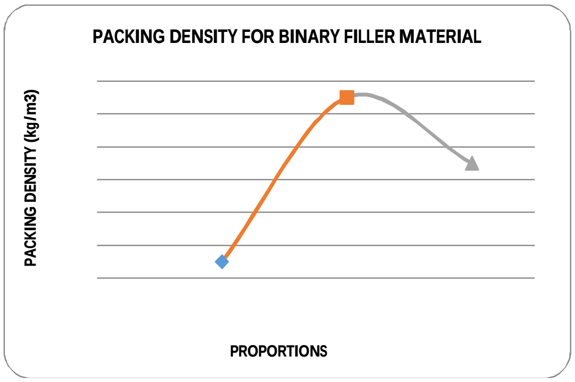

Figure. 2 Packing Density of Binary Filler Material

B. Standard Consistency Test

Standard consistency test is carried out for all the 6 mixes and the consistency values are found as shown in the Table 6.

Table 6 Consistency Test Results

MIX	CONSISTENCY (%)
A	30
B	31
C	31.5
D	29.5
E	31
F	31.5

C. Initial and Final Setting Time

The initial and final setting time for all the six mix is found as shown in Table 7.

Table 7 Initial and Final Setting Time

MIX	RATIO	IST (MIN)	FST (MIN)
A	95 % CEMENT + 5% SF	40	150
B	90 % CEMENT + 10% SF	40	135
C	85 % CEMENT + 15% SF	45	150
D	100 % CEMENT	45	165
E	75 % CEMENT + 25 % GGBS	100	220
F	50 % CEMENT + 50 % GGBS	165	275

D. Compressive Strength Test

The cubes of size 100mm x100mm x100mm were casted with varying W/B ratio, B/TA ratio and dosage of SP. The test results obtained are given in Table 8.

MIX ID	W/B RATIO	SP %	B/TA	STRENGTH (7 DAYS)	STRENGTH (28 DAYS)
TM1	0.3	2	0.4	15.2	38.3
TM2	0.3	2	0.45	16.5	42.8
TM3	0.3	2	0.5	14.8	41.6
TM4	0.25	2	0.4	29.9	48.3
TM5	0.25	2	0.45	35.4	45.2
TM6	0.25	2	0.5	40.1	46.7
TM7	0.3	1	0.4	18.7	45.4
TM8	0.3	1	0.45	21.5	38.9
TM9	0.25	1	0.5	41.2	47.1
TM10	0.21	1.5	0.5	31.3	48
TM11	0.22	1.5	0.5	21.9	44.2
TM12	0.23	1.5	0.5	30.3	44
TM13	0.21	1.5	0.45	38.2	45.7
TM14	0.22	1.5	0.45	31.4	49.1
TM15	0.23	1.5	0.45	30	45.6
TM16	0.21	1	0.5	34	24.5
TM17	0.22	1	0.5	34.6	14.1
TM18	0.23	1	0.5	34.9	28

From the test results as obtained in Table 8, four mixes with better strength results were chosen and casted with 25% replacement of OPC with GGBS and the strength results were obtained as in Table 9.

MIX ID	W/B RATIO	SP %	B/TA	Strength in N/mm² (28 DAYS)
TM19	0.25	2	0.4	51.7
TM20	0.25	1	0.5	49.3
TM21	0.21	1.5	0.5	54.8
TM22	0.22	1.5	0.45	59.4

4. CONCLUSION

1. Using the packing density modulus the strength could be achieved up to 59.4 MPa

2. It is observed that the strength can be enhanced by selecting well graded materials which provides proper interlocking and hence a dense mix with least micro defects.

3. The highest strength is achieved for the mix with B/TA ratio of 0.45 which has a density of 2414 kg/m^3 and binder content of 750 kg/m^3.

4. The strength is enhanced by 20.97% with the use of GGBS when compared to conventional concrete; this is due to the packing of micro particles of GGBS in the cement which increases the packing modulus of concrete as a whole.

5. The optimum dosage of SP required and the W/B ratio is found to be 1.5% and 0.22

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