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High Strength Concrete of M60 Grade for Highway Pavements for Heavy Vehicles

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Abstract- The cost of concrete is governed by the cost of material, plant and labour. The cost of cement is several times higher than the aggregate. Therefore, the objective is to produce the concrete mix as lean as possible and should be economical. That is why designed mixes are preferred to nominal mix. Generally in nominal mixes, cement in higher quantity is used than the designed mixes. Since in production of concrete, the cost of cement is governing factor, therefore, to minimize the cost of concrete, it is essential that concrete mixes must be designed.

Index Terms- High Strength High Performance Concrete, designed mixes, cement, fly ash, Super Plasticizer.

I. Introduction

Mix design can be defined as the process of selecting suitable ingredient of concrete and determining their relative proportions with the objective of producing concrete of certain minimum strength and durability as economically as possible. The purpose of designing mix is two-fold. The first objective is to achieve the stipulated minimum strength and durability. The second object is to make the concrete in the most economical manner. Since main cost governing material is cement, therefore, much attention is given to the use of cement as little as possible consistent with strength and durability.

With the given material, the four variable factors to be considered in connection with specifying a concrete mix are- 1)Water-cement ratio 2) Cement content or cement aggregate ratio3) Gradation of aggregate 4) consistency.

With the advent of plasticizer and super plasticizer, it has now been possible to produce the concrete of much higher strength than the normal concrete. Concrete of strength approximately 138 MPa is commercially available as High Performance Concrete (HPC).HPC are very common in North America, Japan and other European countries. High performance high strength concrete is very commonly used in building column, bridge super structures and decks. In India, the first prestressed concrete bridge was built in 1949 for Assam Rail Link at Silliguri. In fifty's a number of prestressed concrete structures were built using concrete of strength from 35MPa to 45MPa. But strength of concrete more than 35MPa was not commonly used in general construction practices. Probably concrete of strength more than 35MPa was used in large scale in Konkan Railway project during early 90's and construction of Mumbai Municipal Corporation roads. It is during 90's use of high strength concrete has taken its due place in Indian construction scenario. Of late concrete of strength from 45MPa to 60MPa has been used in high rise buildings at Mumbai, Delhi and other metropolitan cities. High strength concrete was also employed in bridges and fly overs. Presently (year 2000) in India concrete of strength 75MPa is being used for the first time in one of the flyovers at Mumbai. Other notable example of high strength concrete in India is in the construction of Containment Dome at Kaiga power project. They have used high performance concrete of strength 60MPa with silica fume as one of the constituents. The different properties of high strength concrete have now been well understood. High strength concrete has not been used in the area of highway rigid pavement. Due to higher durability and low permeability of HSHPC, the pavement could be designed for longer design period. In the present research work, author has developed high strength high performance concrete of M60 grade using fly ash for highway pavement.

II. High Strength High Performance Concrete (HSHPC)

As mentioned by P.K. Mehta (2004), according to a paper by Aitcin, what was known as high strength concrete in the late 1970s is now referred to as high performance concrete (HPC) because it has been found to be much more than simply stronger. High performance concrete has one or more of the properties like as low shrinkage, low permeability and high modulus of elasticity or high-strength. According to Henry Russel, ACI defines high performance concrete as concrete that meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing and curing practices. The requirements may involve enhancement of placement and compaction without segregation, long term mechanical properties, early age strength, toughness, volume stability or service life in severe environments.

A major criticism presented by P.K. Mehta (2004) against the ACI definition of HPC is that durability of concrete is not mandatory. It is one of the options. Earlier, it was assumption that high strength concrete is durable, probably this assumption lead to cracks in many structures.

As per Indian Standard, the concrete having strength 60 MPa or more, are known as high strength concrete.

Typically, these mixtures are composed of a high cement content viz. 450-500 kg/m^3 Portland or blended Port land cement containing relatively small amount of silica fume and fly ash or slag, a low water/cement ratio of the order of 0.3 (with the help of super plasticizer admixture) and an air entraining agent when it is necessary to protect the concrete from cycles of freezing and thawing.

In this regard, an earlier definition proposed by Mehta and Aitcin stated that the term HPC should be applied to concrete mixtures possessing the following three characteristics: high workability, high strength, and high durability.

The advantages of using high strength high performance concrete balance the increase in material cost. The use of HSC permits significant reduction in column dimensions, which gives 30% more free space in high rise building parking area. By using HSC it reduces the dimensions of members and hence reduction in dead weight accompanying with saving due to lighter foundation. With reduction in dimensions, directly saving in concrete volume and form work. Due to early gain in strength, form work could be removed earlier and hence speedy construction. Due to low creep, axial shortening of compression member is reduced. High strength high performance concrete has resistance to freezing and thawing, chemical attack and significantly improved long term durability and less maintenance work. By using HSC, the number of beams in bridge construction is reduced and longer span could be provided. In high strength high performance concrete, generally cement content is higher compared to normal strength concrete. Due to higher cement content it releases substantial amount of heat due to hydration reactions between cement and water. Each kilogram of cement added into concrete mix results in approximately 150 KJ of heat. Consequently, temperature rises significantly when more cement is mixed for HSC, especially for mass concrete structures. This problem leads to high temperature inside the concrete structures and is the main cause of cracks in concrete structures, especially, during early age. To reduce the cracks the concrete must be cured carefully. As a result, expenditure for curing work is significant and contributes to raise the total cost of concrete. Secondly, high cement binder content used for concrete creates free calcium hydroxide compound in cement paste. This lead to unstable volume as well as low water resistance of concrete structure. There is some inconvenience in using high strength high performance concrete, namely brittle failure, higher autogenous shrinkage and low fire resistance.

III. THE MYTH ABOUT HIGH STRENGTH HIGH PERFORMANCE CONCRETE

According to Aitcin, Pierre-Claude, and Neville, Adam, high strength concrete differs from normal strength concrete in that it invariably contains a high-range water reducer(or super plasticizer), while normal strength concrete contains it only sometimes. All the other basic ingredients are the same-namely, Portland cement, aggregate, water and admixture. As for as other ingredients are concerned, such as retarders, fly ash, blast furnace slag and silica fume, they may or may not be present in either type of concrete.

IV. EXPERIMENTAL PROGRAMME

The experimental work has been planned for development of high strength high performance concrete mix of M60 grade. Number of specimen having different water cementitious material ratio were prepared. For each water cementitious material ratio, six cubes for compressive strength, six beams for flexural strength and three cylinders for modulus of elasticity were prepared. Finally water cementitious material ratio 0.29 was adopted. Locally available materials were used throughout the experiment, which have the following properties

A. Coarse aggregate

Locally available crushed stone coarse aggregate of maximum size 20 mm was used confirming to IS: 383:1970 was used. The fineness modulus of coarse aggregate in the study is 6.7. The gradation of coarse aggregate used and other properties are given in Table-2.

Table-1 Grading and other physical analysis for Coarse Aggregate

1. Sieve analysis			
IS Sieve Size	weight retained in gm	%age weight retained	Cumulative Percentage weight retained
20 mm	126	2.52	2.52
10 mm	3224	64.48	67
4·75 mm	1572	31.44	98.44
2·36 mm	78	1.56	100
1·18 mm	0	0	100
600 µ	0	0	100
300 µ	0	0	100
150µ	0	0	100
Total			667.96
F.M			6.7
2. Specific gravity			2.656
3. Aggregate Crushing Value			10.81%
4. Soundness Test			Negligible loss of weight in Na_2SO_4 saturated solution
5. Water absorption			0.20%
6. Unit Weight			1631.72 Kg/m^3

B. Fine aggregate

Locally available fine aggregate confirming to IS: 383-1970 was used. The fineness modulus in the study used is 2.89. The gradation of fine aggregate and other properties are given in Table-3as below-

Table-2 Grading and other physical analysis for Coarse Sand

1. Sieve analysis			
IS Sieve Size	weight retained	Percentage weight	Cumulative Percentage

	in gm.	retained	weight retained
4.75mm	310	15.5	15.5
2.36mm	106	5.3	20.8
1.18mm	199	9.95	30.75
600 µ	228	11.4	42.15
300 µ	841	42.05	84.2
150µ	226	11.3	95.5
Total			288.9
F.M			2.89
2. Specific gravity			2.69
3. Moisture content			2.30%
4. Unit Weight			1834.24 Kg/m^3

C. Cement

Ordinary Portland cement, grade-43, confirming to IS 8112-1989 was used throughout the investigation. The cement used in the experiment has the properties given in Table-4.

Table-3 Physical tests of cement

Type and Brand Cement		OPC- 43 Grade Jay Pee	
Colour of cement		Grey	
S. No.	Name of tests	Test results	Indian Standard Specifications as per IS 8112-1989
1	Standard Consistency Percentage mixing water by wt. of cement	30%	30%
2	Fineness Specific Surface by Blaine's air permeability method (M^2 /Kg)	290	Not less than 225 M^2 /Kg
3	Soundness Expansion by Le-Chatelier method (mm)	1.0 mm	Not more than 10 mm
4	Specific Gravity	3.15	3.15
5	Setting Time(minutes)		
	a. Initial	65	Not less than 30 minutes
	b. Final	158	Not more than 600 minutes
6	Compressive Strength(MPa)		
	a. 72 ± 1 hour	28.3	Not less than 23
	b. 168 ± 2 hour	35.5	Not less than 33
	c. 672 ± 4 hour	43.8	Not less than 43

D. Fly ash

Class F type fly ash, according to ASTM was used throughout the experiment. High fineness, low carbon content, good reactivity are the essence of good fly ash. The fly ash used in the experiment has the properties given in Table-5.

Table- 4: Properties of fly ash

S. No.	Property	
1	Fineness,cm^2/gm	3500
2	Specific gravity	2.24
3	% coarser than 45 µm	5.6
4	Average particle size, µm	10.10
5	Silicon dioxide,SiO_2,percent by mass	57.5
6	SiO_2+Al_2O_3+Fe_2O_3,by mass	91
7	Loss on ignition, percent by mass	0.57

E. Super plasticizer

Sikament N-170 was used. It is modified naphthalene formaldehyde sulphonate type. It is dark in brown and specific gravity is around 1·16 to 1·20. It complies with IS: 9103, ASTMC 494 Type F and BS: 5075 part 3.

F. Water

Water used for mixing and curing should be free from injurious and deleterious materials. Throughout the investigation, potable tap water was used.

E. Mix Proportion

Table- 5: Results of Trial Mixes

Sl. No.	Mix Ratio	Water cementi-tious ratio	Super plasticizer in percent	Percent of fly ash	Slump in mm	7 days average compressive strength of five cubes in N/mm^2
1	1:1.2 : 2.3	0.301	2	7	-	17.99
		0.295	2	7	30	16.08
2.	1:1.1 : 1.9	0.29	2	11	80	48.82
		0.30	2	11	130	45.57
		0.31	2	11	180	38.81
		0.31	1.6	11	150	52.10
		0.30	1.6	11	90	44.84
		0.29	1.6	11	35	43.81

Table: - 6: Results of Finally Adopted Trial Mix

SI. No.	Mix Ratio	Water cementi-tious	Super plasti-cizer in	Percent of fly ash	Slump in mm	7 days compre-ssive	28 days compressive strength in
1	1:1.1 : 1.9	0.29	1.6	11	32	43.81 44.25 41.6 42.04 46.02	67.4 63.21 64.0 64.6 67.68
Average						43.54	65.38

Finally, trial mix having mix proportion 1:1·1:1·9 was adopted with water cementitious ratio 0·29. Fly ash was used approximately 11%and 1.6% high range water reducer was used.

V. Experimental Methodology

The batching of ingredients of aggregate and cement was done by weight mix ratio. A mixing machine was used for mixing the various constituent of concrete. A small amount of water was fed first followed by all solid materials simultaneously into the mixer i.e. the sand fed first, then part of coarse aggregate, cement and water and then the finally the remainder of coarse aggregate was fed into the machine so as to break up any modules of mortar. To check the workability, slump test was performed. The specimens were cast in steel mould. To measure the compressive strength, flexural strength and modulus of elasticity, the test specimen were prepared in the standard size 150 mm ×150 mm × 150 mm cast iron cube mould for compressive strength and 150 mm diameter and 300 mm height cast iron cylindrical mould for modulus of elasticity and 100 mm × 100 mm × 50 mm beam for flexural strength. The mould was properly greased by using oil in order to prevent the adhesion of concrete to the mould. The concrete was poured into the mould in three layers and each layer being compacted by standard tamping rod uniformly. After compacting third layer, the upper surface of concrete was leveled. Precautions were taken to avoid over compaction which lead to segregation. After 24 hours in the mould, the specimen were removed and placed in water tank for 7 days and 28 days. The specimens were tested as per IS: 516-2004.

VI. Results and Discussions

The values of compressive strength, flexural strength and modulus of elasticity for high strength high performance concrete are given in Table-6. Average 7 days and 28 days compressive strength found to be 42.5N/mm^2 and 63.5 N/mm^2. The values of flexural strength 7 days and 28 days come out as 4.82N/mm^{2}and 6.4N/mm^2. The modulus of elasticity for high strength concrete is found to be 4.17×10^4 N/mm^2. The workability is measured in terms of slump value and comes out as 30mm.

Table-7 Properties Of High Strength High Performance Concrete

S. No.	Mix	Compressive strength ,N/mm^2		Flexural strength N/mm^2		Modulus of elasticity N/mm^2	Slump mm
		7 days	28 days	7 days	28 days		
1	C:FA: CA 1:1:1.9	41.6	60.63	4.06	6.1	3.82×10^4	30
2		42	62.62	4.9	6.3	3.81×10^4	
3		43.8	67.26	5.5	6.9	4.88×10^4	
4	Average	42.47	63.50	4.82	6.4	4.17×10^4	30

VII. Conclusions

The author has developed high strength high performance concrete of M60 grade using fly ash for his research work. The different properties of fresh and hardened concrete were examined. The following conclusion were drawn-

1. In development of high strength concrete, the aggregate of smaller size play very important role. In the present mix design, the aggregate of 20 mm size is being used.

1. Fineness modulus of aggregate play very important role in development of high strength concrete. It affects the strength greatly. In the present mix design, the fineness modulus of coarse aggregate and coarse sand is 6·7 and 2·89 respectively.
2. 11% fly ash by weight of cement has been used in the mix design, which results in greater saving in cement and reduction in heat.
3. 1.6% Sikament N-170 high range water reducer by weight of cement has been used.
4. 30 mm slump of fresh concrete has been measured with the use of 1.6% high range water reducer.
5. The 7 days and 28 days average flexural strength are 4.82 N/mm^2 and 6·4 N/mm^2 respectively.
6. The 28 days average modulus of elasticity is 4.17×10^4 N/mm^2
7. The mix proportion is 1:1:1:1.9, which give 7 days and 28 days average compressive strength, are 42.50 N/mm^2 and 63.50 N/mm^2 respectively.

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