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CONCRETE MIX PROPORTIONING USING EMMA SOFTWARE

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ABSTRACT

Concrete mix proportioning by conventional, methods consumes substantial amount of cement. The huge utilization of cement in concrete will cause serious environmental degradation of earth. This emphasizes the need to find alternate methods for concrete mix design, in the interest of sustainable development of waste resources. Pozzocrete fly ash is a byproduct of thermal power plant, if not attempted properly the disposal of fly ash will create number of problems in disposal of fly ash. The theoretical methods available for the analysis of concrete mix design, it becomes very much essential to examine the behaviour of these mixes experimentally and then verify the same using suitable software. The aim of this paper is to highlight the behaviour of concrete in fresh and hardened state which was modeled and analyzed using EMMA software with certain assumptions made and also provide the comparison between experimental and software results.

KEYWORDS: EMMA, Pozzocrete 60, Particle Packing**,** Castable

INTRODUCTION

Particle packing consists of selection of appropriate sizes and proportions of particulate materials in order to obtain a compact mixture. The optimization of the packing-density of granular components of concrete has become an important factor in achieving improvements in mechanical properties of conventional concrete. Granular components of concrete, i.e. aggregates and fillers occupy as high as 70 to 85% of the concrete volume. Hence, controlling the granular mixture proportion will help in minimizing the volume of void space and thereby ensuring higher strength and better workability due to improved macro-mechanical properties.

Again, with the same w/c ratio, smaller amount of water as well as lesser cement paste is needed when the granular fraction is more densely packed, which in turn reduces the occurrence of weak interface between the aggregate and the cement paste ,increasing the strength and durability of the concrete. Since high strength concrete mix is made with a low w/c, they require a large amount of cement which may cause severe creep and drying shrinkage and other associated problems. Theoretical studies suggest that with better packing of the ingredients of concrete, one can achieve a higher compressive strength (up to 20 %) for the same mix composition and w/c ratio.

PARTICLE PACKING

Producing concrete of a desired proportion using the available resources is still a trial and error process. Various attempts are being made to make the process more scientific. The basic concept of particle packing was extended further to incorporate the various parameters affecting the packing characteristics of the particle assembly, which led to the development of the different packing theories. The particle packing theories can be described by the two different approaches i.e. Discrete approach & Continuous approach .

The Need for Particle Packing

The commonly practiced conventional concrete mix proportioning methods have certain flaws rendering them inefficient in case of mix designing of special concretes such as HPC, RPC, RMC, etc. Commonly used mix design methods make use of some empirical relations and ideal grading curve in deciding the relative proportion of the ingredients in the mix. However, this ideal grading curve basically considers the particle size distribution of coarser and fine ingredients (coarse and fine aggregates) only and not of finer ingredients such as cement and cementitious materials. This is a limitation of these conventional methods as in achieving optimum packing of ingredients and for optimizing concrete mixes these finer particle sizes must be included in the ideal grading curve. Due to this, these methods prove to be inefficient in optimization of dense concrete mixes, which satisfy necessary strength, workability and durability requirements at a lower cementitious material content.

Software Based on Particle Packing Theory

EMMA

In EMMA the particle size distribution of a combination of materials chosen by the user is compared to the Andreasen Model. By computer simulation, it has been shown that 0% voids (i.e. 100% packing) is possible if an exponent in Andreasen model is equal to or less than 0.37.

MixSim

Using MixSim, concrete designs may be prepared combining as many as 3 cementitious components, 3 fine aggregates or fillers and 3 coarse aggregates together with 3 liquid ad-mixtures. An account is taken of any required air entrainment, strength producing benefits of additions and water reducing benefits of plasticizers. Concretes are adjusted automatically for adequate cohesion. Provision is made for an input of any concrete trials data for comparison purposes.

COMPASS

COMPASS stands for Concrete Mixture Performance Analysis System. COMPASS is a windows-based application system that can be used to optimize the materials selection and proportions of paving concrete based on job-specific conditions.

Principle

The basic concepts of the theory of particle mixtures are that, when two particulate materials of different sizes are mixed together, the volume of voids between the larger particles will be reduced, but the structure of both coarse and fine material will be disrupted by particle interference creating some additional voids partially offsetting the reduction.

The void ratio, that is, the ratio of the volume of voids between the aggregates particles to the bulk volume occupied by the aggregate may be obtained from the packing density. As the voids between the aggregates can be filled by the cement paste, the voids ratio determines the minimum volume of cement paste needed to produce concrete using the aggregate. A higher packing density leads to smaller voids ratio and thus a smaller quantity of cement paste is required.

Selection of Various Parameters

As per specifications given in IS 456-2000, quantity of cement greater than 450 Kg/m^3 cannot be used in the mix unless certain precautions are taken in the design to counteract durability problems that might unresolved due to greater cement content. Therefore, whenever cement content was likely to exceed the maximum cement content limit (i.e. 450 Kg/m^3), it is replaced with cementitious material i.e. Pozzocrete Fly-Ash. The cement content of the mix is limited to 450Kg/m^3. In case of the concrete mixes designed for the lower w/c ratios required cement content is higher than 450 Kg/m^3. In these cases, quantity of cement higher than prescribed limit is replaced by Pozzocrete Fly-Ash.

Mix Design

The mix design methods being used in different countries follow the same basic principles and only minor variations exist in the different mix design methods in the process of selecting the mix proportions.

Nowadays, engineers demand HPC mixes that have not only high strength but also all round high performance in terms of other attributes such as workability, dimensional stability and durability. Because of the conflicting requirements of these performance attribute (e.g. increase in strength often leads to decrease in workability and increase in both strength and workability may have to be achieved at the expense of lower dimensional stability etc), HPC is much more difficult to produce than HSC. To overcome the flaw in commonly used mix design methods, a concept of particle packing is introduced in the mix proportioning of the concrete.

In India mostly IS method is used for concrete mix proportioning. Therefore, it was aimed to compare the IS method and particle packing approach of concrete mixture proportioning. IS method and software EMMA (based on Andresen particle packing model and developed by Elkem Materials) was used for mixture proportioning. The experiment was carried out in two phases. In the initial phase mixes were proportioned by IS method for the various water/cementitious material (w/cm) ratios and compacting factors (CF) for varying workability requirements. These mixes were compared with mixes proportioned by EMMA, for various 'q' values depending upon different workability requirements, using particle size distribution curves. In the latter phase of the work, for validation of the theoretical observations obtained in the initial phase, experimental work was undertaken to study behavior of concrete mixes in the fresh and hardened state

Mix Proportioning by is method

IS method of concrete mix design is based on the guidelines given by IS: 10262-1982 (reaffirmed in 1989 and 1999) [4].

In the present work, the IS method is used to design the concrete mixes for different w/c ratios (i.e. 0.30, 0.40, and 0.50). For each w/c ratio the mixes were proportioned for different CF values (i.e. 0.85, 0.90 and 0.95)

Mix Proportioning by Software EMMA [2]

Nowadays, particle size distributions of different building products, ceramics, concrete etc. are determined using this software. One can create a customized library of particle size distributions for different materials. Then the particle size distribution for any combination of these materials can be determined. After the quantity of the individual materials has been entered, the distribution is given in numbers as well as presented in a graphical format. This graph is compared to the Andreasen model.

A castable, in the simplest case, is a mixture of raw materials from the grog, sand, gravel or aggregate to the superfine like fly-ash and micro silica, which has particle size in microns. The significance of a proper particle size distribution has been widely recognized in lately. A precise grading of the particle sizes enables to make a castable which is easily mixed and placed and also has the desired mechanical properties. The mix with a particle size distribution that follows this model will be either self-flowing or vibratable, depending on the chosen q-value (assuming constant water addition and a well dispersed system). As per EMMA manual q = 0.25 is the approximate limit for self flow contra vibrant flow. A q-value lower than 0.25 gives a self flowing mix, which may be done by adding the sufficient amount of superfine material.

Objectives of the Study

- To design the concrete mixes for the various w/cm ratios with varying CF values by IS method specified by Bureau of Indian Standards.
- To design the concrete mixes for the various 'q' values (0.22, 0.27, 0.32 and 0.37) by software EMMA.
- To compare the packing characteristics of the concrete mixes proportioned by the IS method and EMMA.

Scope of the Study

- Production of the concrete mixes proportioned by the IS method for a w/cm ratio to achieve the compressive strengths of about 40 MPa and 60 MPa.
- Production of the concrete mixes proportioned by EMMA for 'q' value of 0.27

MATERIALS

Various materials used for the present experimental work are as below.

Aggregates

Aggregates of size 20mm and 10mm were used as coarse aggregates. The quality of aggregates used was checked against the specifications given in the IS 383-1970. Sieve analysis of the aggregates were carried out as per the specifications given in IS 2386 (Part-I)-1963. The air-dry sample was weighed and sieved successively on the appropriate sieves starting with the largest. On completion of sieving, the material retained on each sieve, together with material cleaned from the mesh, was weighed.

- **Sieve Analysis For 20 Mm Aggregates**
- Total weight = 5.0 kg

Table 1: Sieve Analysis of Coarse Aggregate (20 Mm) Fraction

I.S.Sieve	Weight Retained (Gms)	Cumulative Weight Retained (Gms)	Cumulative % Wt. Retained	% Passing
20	1.780	1.780	35.6	64.4
12.5	2.735	4.515	90.3	9.7
10	0.225	4.740	94.8	5.2

Table 1: Contd.,				
4.75	0.260	5.000	100	00
2.36	0000	5.000	100	00
1.18	0000	5.000	100	00

Total = 520.7

Fineness Modulus = 5.20

Table 2: Sieve Analysis of Coarse Aggregate (20 mm) Fraction

Is Sieve Sizes	Coarse Aggregates (20 Mm Fraction)			
	Wt. Retained (Kg)	Cumulative Wt. Retained (Kg)	Cumulative Percentage Retained	Cumulative Percentage Passed
20 mm	0	0	0	100
10 mm	1.075	1.075	53.75	46.25
4.75 mm	0.911	1.986	99.3	0.70
Lower than 4.75 mm	0.014	2	100	0

Sieve Analysis For 10 Mm Aggregates

Total weight = 5000gms

Table 3: Sieve Analysis of Coarse Aggregate (10 Mm) Fraction

I.S.Sieve	Weight Retained (Gms)	Cumulative Weight Retained (Gms)	Cumulative % Wt. Retained	% Passing
20	12	12	0.24	99.76
12.5	23	35	0.70	99.30
10	610	645	12.9	87.1
4.75	4012	4657	93.14	6.86
2.36	265.3	4922.3	98.45	1.55
1.18	77.7	5000	100	00

Total = 305.43

Fineness Modulus = 3.065

Table 4: Sieve Analysis of Coarse Aggregate (10 Mm) Fraction

Is Sieve Sizes	Coarse Aggregates (10 Mm Fraction)			
	Wt. Retained (Kg)	Cumulative Wt. Retained (Kg)	Cumulative Percentage Retained	Cumulative Percentage Passed
10 mm	0	0	0	100
4.75 mm	0.995	0.995	99.5	0.50
< 4.75 mm	0.005	1	100	0

Sieve Analysis for River Sand

Table 5: Sieve Analysis of Fine Aggregate Total Weight of Sample: 500 Gms

I.S. Sieve	Weight Retained (Gms.)	Cumulative Wt. Retained (Gms.)	Cumulative % Wt. Retained	% Passing
10 mm	--	--	--	100
4.75 mm	16.5	16.5	3.3	96.7
2.36 mm	54	70.5	14.1	85.9

Table 5: Contd.,				
1.18 mm	61.70	132.2	26.44	73.56
600 microns	123.5	255.7	51.14	48.86
300 microns	171.0	426.7	85.34	14.66
150 microns	73.3	500	100	000

Total = 280.32

Fineness modulus of sand: 2.80

Table 6: Sieve Analysis of Fine Aggregate

IS Sieve Sizes	Fine Aggregates			
	Wt. Retained (Gm)	Cumulative Wt. Retained (Gm)	Cumulative Percentage Retained	Cumulative Percentage Passed
4.75 mm	11	11	2.2	97.8
2.36 mm	37	48	9.6	90.4
1.18 mm	109	157	31.4	68.6
600 micron	185	342	68.4	31.6
300 micron	120	462	92.4	7.6
150 micron	28	490	98	2
< 150 micron	10	500	100	

The tests for determination of specific gravity, absorption /moisture content and bulk density of the aggregates was carried out as per the specifications given in the IS 2386 (Part-III)-1963. The saturated surface dry aggregates were used for tests. These properties of aggregates are necessary to decide proportions of the concrete mix. These properties are given below:

Table 7: Specific Gravity, Bulk Density, Voids Ratio and Absorption of Aggregates

Material		Specific Gravity	Bulk Density (Kg/M^3)	Voids Ratio	Absorption (%)
Coarse aggregate	20 mm	2.873	1618.43	0.437	1.726
	10 mm	2.845	1641.06	0.423	2.01
Fine aggregate		2.732	1812.72	0.336	1.2

Cementitious Materials

- **Cement**

A 53 Grade Ordinary Portland Cement, manufactured by Ambuja Cement was used. During experimental work the cement was stored in a suitably weather-tight compartment so as to protect it from dampness and warehouse deterioration.

- **Fly Ash in Portland cement Concrete**

Raw Fly-Ash (as brought from the source) can not be used as it requires processing to work efficiently in concrete. Therefore a processed Fly-Ash named ‘Pozzocrete 60’is used. It is manufactured by DIRK India Pvt. Ltd., Nashik and satisfies the specifications given in IS: 3812(part I)-2003.Specific gravity of the cement and Fly-Ash was obtained from the manufacturers.

Table 8: The Specific Gravity of Cementitious Materials

Cementitious Material	Specific Gravity	28 Day Compressive Strength (Mpa)
Cement	3.15	57.46
Pozzocrete 60	2.5	----

Figure 1: Pozzocrete 60

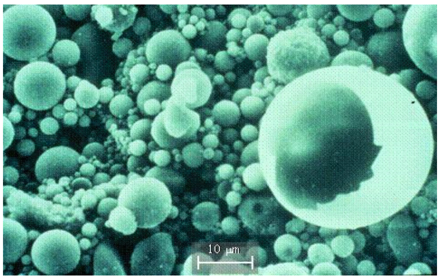

Figure 2: Fly Ash Consists of Spherical Glassy Particles

TESTS ON CONCRETE MIXES

As per objective of the study, behavior of the concrete mixes was studied in the fresh and the hardened state. For this purpose, the Slump Test to study the behavior of the freshly mixed concrete and the Compression Test to study the strength aspects of the hardened concrete was carried out.

Test on Fresh Concrete

The nature of concrete mixes in the fresh state i.e. whether the mix is cohesive or non-cohesive and whether there was any segregation or bleeding, etc. was observed visually. To study the behavior of the freshly mixed concrete, the workability of concrete was measured by the slump test. Table No. 20 and 22 given in the Handbook of Concrete Mixes (SP 23- Based on Indian Standards) [10] presents the relative values of slump, compacting factor and Vee-Bee time for different levels of workability. Using these tables, the workability of concrete mixes, initially proportioned for different compacting factors, was studied through a Standard Slump Test.

Table 9: Comparison of Consistency Table Measurements by Various Methods (Table 20, SP23) [10]

Workability Description	Slump (mm)	Vee-Bee Time	Compacting Factor
Extremely dry	------	32-18	------
Very Stiff	------	18-10	0.70
Stiff	0-25	10-5	0.75

Table 9: Contd.,			
Stiff Plastic	25-50	5-3	0.85
Plastic	75-100	3-0	0.90
Flowing	150-175	------	0.95

Also, 'q' value (varying in the range 0.22-0.37) in the Andreasen and the Modified Andreasen Model represents the level of the workability. In the present study, for the comparison of the behavior of the freshly mixed concrete mixes, proportioned by the IS method and EMMA; the relative values of 'q' and the compacting factor (CF) are

Used for a certain level of workability (referring EMMA manual & table 20 and 22 in SP 23 Handbook)[2, 10]. The relative values of 'q' and CF are given below:

Table 10: Relative Values of CF and 'q'

Degree of Workability	CF	'q'
Very Low	0.80	0.37
Low	0.85	0.32
Medium	0.90	0.27
High	0.95	0.22

For these 'q' values the EMMA mixes were proportioned for desired level of workability. Using these tables, the behavior of the concrete mixes, proportioned by the IS method and LISA, in the fresh state was easily compared.

To study the packing characteristics of the IS mixes proportioned for certain w/cm ratio and CF, the actual overall gradation curve (AGC) of the IS mix was compared with ideal grading curve given by the Modified Andreasen Model for the relative 'q' values (e.g. AGC of IS mix with w/cm ratio 0.3 and CF 0.8 was compared with IGC for 'q' = 0.37).

The Compressive Strength Test on the Concrete Specimens

The compressive strength of the concrete mixes was obtained as the average strength of three cube specimens of that mix. The compressive strengths of the concrete mixes proportioned by the IS method and EMMA were then compared.

DISCUSSIONS ON ANALYTICAL INVESTIGATION

It was observed that the sand content of the mixes proportions given by the IS method is very low. Such a low sand content was observed mainly in the case of the mixes with low w/cm ratios. As w/cm ratio was increased, the sand content of the mix was also increased to satisfactory level. Under sanded conditions, segregation might be observed in such mixes, which render mix non-cohesive. Due to segregation in the fresh state and non-cohesive nature of the mix, the desired strength might be difficult to achieve.

While the sand content of EMMA mixes was at a satisfactory level, so as to achieve the desired level of workability and cohesive mixes. Dense pack particle assembly was observed in these mixes.

From the AGCs and the IGCs for the IS mixes it was observed that the AGC closely followed the IGC in the relatively coarser region (20 mm to about 150 micron) and then it suddenly deviated in the finer region. This indicated that the fines content of the IS mixes was much in excess. Excess quantities of cement and fly ash were very large in case of the mixes with low w/cm ratios (HSC). This excess quantity was reduced to a lower value with an increase in level or degree of workability and the w/cm. However, the reduction was not much and therefore the excess quantity was quite large. With increasing level of workability, the gap between the IGC and the AGC widened in the coarser region that indicated that some of the relatively finer particle sizes in the range were absent (i.e. the gradation of the aggregates used for the study did not follow the continuous distribution and might have lacked in some of the particle sizes in the range). Due to these missing particle sizes, particle packing was not efficient in this region. With increasing w/cm ratios, the AGC closely followed the IGC and in some mixes, the two curves almost matched (mixes with w/cm ratios higher than 0.4 and CF 0.8).

On the other hand, in case of all the EMMA mixes, the AGC almost matched the IGC. However, some gaps were present in the relatively coarser region (from about 10 mm to 150 mm). In the present study only two fractions of coarse aggregates i.e. 20 mm and 10 mm were used and the natural (river) sand was used as the fine aggregate. From the sieve analysis of these materials it was observed that the intermediate size fractions were not present in it. Due to this the gap was observed between the AGC and the IGC in case of both IS and EMMA mixes. Also, in case of the highly workable EMMA mix (i.e. q=0.22), the proposed cement content was much higher than the limits prescribed by IS. The gaps between the AGC and the IGC in the coarse region and the high cement could be cut down by incorporating an intermediate particle size in the mix by using an artificial or crushed sand. As EMMA typically works on the particle packing theory and that some of the particle sizes were missing in the gradation, it used the finer particles to fill the voids in the coarser assembly. Therefore, the proposed mix proportion was contained higher quantities of cement. With use of such crushed sand, cement content of other EMMA mixes, would also have cut down considerably.

The efficient use of the particle packing theories in concrete mixture proportioning was understood more clearly when the mixes designed by the IS method and EMMA for nearly the same w/cm ratios and the same level of workability were compared.

Behavior of Concrete Mixes in the Fresh State

When the concrete mixes were freshly mixed, some visual observations were made. It was observed that the concrete mixes M_{13} and M_{33} were extremely dry. The mixes were very stiff and sticking to the hopper during compacting factor test. Under sanded conditions were observed in both the mixes and also, the segregation was prominently observed in these mixes.

On the other hand, the mix M_{E2} proportioned by EMMA was cohesive in nature. Neither segregation was observed nor any bleeding.The slump test was carried out to measure the workability of the mixes. Results of the slump tests are presented below:

Table 11: The Slump Values for the Concrete Mixes

Mix	Slump value (in mm)
M_{IS13}	0
M_{IS33}	0
M_{E1}	25

In all, as mentioned in the discussions on the analytical investigations, LISA mixes produced more workable concrete than the IS mixes. EMMA mixes produced the concrete of the desired workability and that too at lower cementitious material content.

The explanation for the improved workability and the cohesive mix (overall performance in the fresh state), in case of EMMA mixes, unlike IS mixes, lies in the particle packing characteristics of EMMA mixes. Better packing of ingredients lowered the fines content of the mix and improved its overall performance in the EMMA mixes.

Behavior of Concrete in Hardened State (Compressive Strength Test)

Compressive strength test was carried out at the age of 28 days to study the behavior of concrete mixes in the hardened state. The results of the test are given below:

Table 12: 28 Day Compressive Strength of Various Concrete Mix

Sr. No	Mix	W/C	C/F	T	S	Characteristic Strength (Mpa)	Target Strength (Mpa)	28 Day Characteristic Strength(Mpa)
01	M_{IS11}	0.30	0.85	1.65	7.4	50	62.21	53.20
02	M_{IS12}	0.30	0.90	1.65	7.4	50	62.21	53.14
03	M_{IS13}	0.30	0.95	1.65	7.4	50	62.21	52.01
04	M_{IS21}	0.40	0.85	1.65	6.48	38	48.69	40.31
05	M_{IS22}	0.40	0.90	1.65	6.48	38	48.69	39.77
06	M_{IS23}	0.40	0.95	1.65	6.48	38	48.69	39.30
07	M_{IS31}	0.50	0.85	1.65	5.72	28	37.45	33.89
08	M_{IS32}	0.50	0.90	1.65	5.72	28	37.45	33.91
09	M_{IS33}	0.50	0.95	1.65	5.72	28	37.45	33.79
10	M_{E1}		0.95					56.22
11	M_{E2}		0.90					57.34
12	M_{E3}		0.85					56.55

CONCLUSIONS

- For the same w/c without fly ash the 28 day compressive strength gradually reduces as no particle packing of aggregate is achieved.
- In the EMMA mix due to the proper particle packing considerable increase in compressive strength is attained. It is the maximum for $M_{E2=}$ 57.34 MPa & minimum for $M_{E1=}$ 56.22 MPa
- The selection of the maximum size of coarse aggregates and the gradation control of aggregates are the important factors in influencing the quality and the properties of concrete. Proportioning of coarse aggregates depend on the combined effect of aggregate void, surface area and particle shape.
- Higher compressive strengths may be achieved with more uniform combined gradation of aggregate with the same cement content. The cement content in concrete mixes even can be reduced with more uniform combined gradation of aggregate, to produce a concrete with compressive strength, similar to those achieved by normal mix design methods.
- Providing a more uniform gradation of the combined aggregates does not necessarily achieve a concrete mix with improved workability. Therefore, Pozzocrete Fly-Ash was added in the concrete mix. , Pozzocrete Fly-Ash particles have a smooth and glassy surface due to which the inter-particle friction is lesser, mobility is higher and thus the desired workability is achieved at a relatively low water content.
- The substantial reduction in the cement content for high strength and durable concrete has obvious benefits in

respect of cost. A more important is the reduction in the cement consumption would lead to a decrease in the release of CO_2 and in global warming. The reduced cement content in the concrete also implies reduced heat of hydration. From the present comparison study of the IS method and the particle packing approach of the concrete mixture proportioning the following conclusions were drawn.

- The overall gradation of the IS mixes showed large variation from the ideal grading curve given by Modified Andreasen model. The extent of the variation was increased with the increased characteristic strength of concrete. On the contrary, the grading curve of LISA mixes closely followed the ideal grading curve and the optimum packing of ingredients was achieved in these mixes.
- IS mixes consisted of the excess quantity of fines (i.e. cement and fly ash) than actually required. Also, the sand content of the mix was very low, which might have caused segregation.
- Use of the particle packing approach for mix proportioning resulted in improved behavior of concrete in the fresh state. The workability of the concrete was improved and segregation was eliminated.

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