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Importance of Maximum Size, Gradation of Aggregate and Grade of Cement on Compressive Strength of Concretes

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***Abstract* – The present experimental investigation has been carried out to demonstrate the effectiveness of tailored aggregates over market available aggregates for M20 grade of concrete using 43 grade cement with reference to minimum cement content (i.e. 300 kg/m^3) on plain and 20% cement replaced with flyash concretes. The compressive strength of plain concrete with maximum cement content (i.e. 450 kg/m^3) and 20% flyash replaced concretes have also been studied. Investigations have also carried out on 53 grade cement with 20mm and 12 mm maximum size tailored aggregates along with maximum cement content and flyash in 0%, 20% and 30%.**

Investigations with 43 grade cement revealed that plain and flyash workable mix of M20 grade concrete with tailored aggregates could be produced with 412 kg/m^3 and 365 kg/m^3. Super plasticized plain workable M20 grade concrete can be produced with 337 kg/m^3. Workable mixes with 450 kg/m^3 cement content give compressive strength of 32 MPa and 33.7 MPa for plain and flyash concretes respectively. It is also revealed that a maximum strength of 47 MPa with no slump can be achieved with 43 grade of cement.

Investigations with 53 grade cement demonstrated that workable plain mixes with 20mm and 12 mm maximum size tailored aggregates give strengths of 55.1 MPa and 60.3MPa, while 20% and 30% flyash concrete with these aggregates have given the compressive strengths of 59.2 MPa, 60.2 MPa and 62.1 MPa and 63.4 MPa respectively. Also, a maximum strength of 72 MPa has been achieved on no slump concrete prepared with 20mm maximum size aggregates.

***Keywords* – Tailored Aggregates, Fineness Modulus, Flyash, Compressive Strength.**

I. Introduction

The concrete is most widely used construction material, which is commonly prepared by mixing of ordinary Portland cement, fine aggregate, coarse aggregate and water. Our aim is to produce economical concrete either by using relatively lesser cement content for producing it of the same compressive strength because cement is the costliest among all of its constituent materials or by producing a concrete of relatively higher compressive strength with the same cement content. A smaller cross-section area of structural elements may fulfill the requirement, if it is of higher strength, which needs lighter supporting structure/foundation and reduces the consumption of resources.

We have specifications available from Bureau of Indian Standards on construction of plain and reinforced concrete [1]. For conventional construction work, we use medium strength concrete of slump ranging from 50mm to 100mm. While for high strength concrete we have to do a more sacrifice on strength if we recommend the same slump, therefore we accept a concrete of relatively lower slump, which of course needs more effort for its compaction. It also recommends that minimum cement content for reinforced concrete (RC) inclusive of pozzolanic materials (flyash, rice husk ash, silica fume etc.) should not be less than 300 kg/m^3 and maximum cement content exclusive of flyash etc. should not be more than 450 kg/m^3.

The present research work was planned to exploit full potential of IS: 456-2000 on plain workable concretes by using cement of different grades, fine and coarse aggregates of different fineness and maximum size with and without flyash.

II. Research Significance

Present research output will improve the confidence of beginners, which will result in reducing the number of trials for preparing a workable concrete of appropriate grade with least cement content and aggregates of appropriate fineness. It also provides starting point for the development of high strength concretes.

III. Experimental Investigations

Materials

Materials used in preparing concrete of different strengths are discussed herewith:

Cement

Two grades of ordinary Portland cement, C43 (trade name-Binani) and C53 (trade name-Ultra tech) conforming to IS: 8112-1989 [2] and IS: 12269-1987 [3] respectively are used for preparing mixes of workable concretes after conducting tests on them.

Water

Potable tap water available in the laboratory is used in mixing and curing of all types of concrete.

Coarse Aggregate (CA)

Mainly two types of coarse aggregates (CA1 and CA2) were procured from the market to study the effect of variability in various properties of these aggregates on strength. In addition to these two types, three types of tailored coarse aggregates (CAT1, CAT2and CAT3) were also prepared in the laboratory by designing their grading [4]. Specific gravity of the aggregates was varying from 2.63 to 2.69 and water absorption of the aggregates was varying from 0.5% to 1.5% respectively. Sieve analysis test results and other properties of all these five type coarse aggregates used in the study are given in Table-1.

Fine Aggregate (FA)

Three types of fine aggregates (FA1, FA2 and FA3) were procured from nearby market and two types of fine aggregates (FAT1 and FAT2) were tailored for desired grading [4], to achieve the maximum compressive strength with different grade of cements. Moisture content of fine aggregates was between 0.2% and 0.5%. Gradation and other properties of fine aggregates not only for the three different types, which were procured from the market but also for two tailored fine aggregates are given in Table-2.

Super-plasticizer (SP)

Two types of super-plasticizers namely CEMWET SP-3000 (SR) and CEMWET SP-3000 (PCE) brought from Asian laboratories were used for preparation of plain and flyash high strength concretes. The former product is sulphonated polymer of Naphthalene Formaldehyde condensate and latter is polycarbo-ether based. Marsh cone test has revealed that 2.0% of former and 1.5% of latter are optimum dosage for 53 grade ordinary Portland cement for water cement ratio of 0.38 [5]. Therefore, a maximum dose of 1.5% superplasticizer was used in all such cases wherever it was required to use for enhancement of workability.

Table-1: Gradation and other properties of Coarse Aggregates

Property	CA1	CA2	CAT1	CAT2	CAT3
Percentage Passing on Sieves					
40 mm	100.0	100.0	100.0	100.0	100.0
20 mm	91.2	91.9	90.0	100.0	100.0
12.5 mm	-	-	-	-	100.0
10 mm	3.5	3.5	20.0	30.0	40.0
4.75 mm	1.6	0.5	0.0	0.0	0.0
2.36 mm	1.6	0.5	0.0	0.0	0.0
1.18 mm	1.6	0.3	0.0	0.0	0.0
600 µ	1.4	0.2	0.0	0.0	0.0
300 µ	0.4	0.2	0.0	0.0	0.0
150 µ	0.3	0.1	0.0	0.0	0.0
Fineness modulus (F.M.)	7.00	7.00	6.90	6.70	6.60
Flakiness index	29.3%	16.3%	21.2%	20.6%	29.7%
Elongation index	25.7%	28.2%	24.8%	26.0%	25.2%

Table-2: Gradation and other properties of Fine Aggregates

Property	FA1	FA2	FA3	FAT1	FAT2
Percentage Passing on Sieves					
10 mm	100.0	100.0	100.0	100.0	100.0
4.75 mm	98.5	97.5	93.4	98.5	95.0
2.36 mm	81.1	94.4	75.9	83.5	80.0
1.18 mm	56.2	87.1	51.9	53.5	50.0
600 µ	44.3	72.6	35.9	26.5	25.0
300 µ	24.5	30.8	18.7	13.5	10.0
150 µ	3.5	9.3	5.2	4.0	2.0
Specific gravity	2.76	2.58	2.70	2.65	2.65
Water absorption	1.5	4.5	1.5	1.0	1.0
Fineness modulus	2.92	2.10	3.19	3.21	3.38

Flyash

Flyash collected from Indraprastha Thermal Power station, New Delhi conforming to IS: 1727 – 1967 (Reaffirmed 2004)[6] and IS: 3812 (Part 1) – 2003 [7] is used in the present experimental investigations. The specific gravity of flyash is 2.14 and gradation curve is shown in Fig. 1.

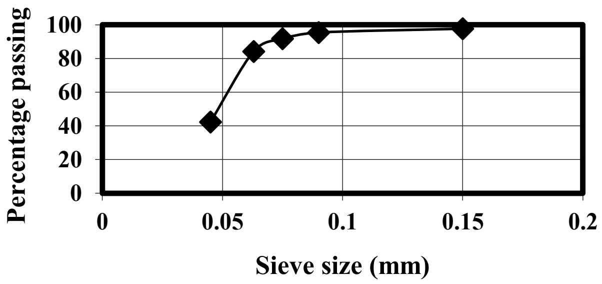

Fig.1 Gradation curve of flyash

IV. Details of Investigations

The aim of the work is to study the effects of variation in fine aggregate, coarse aggregate and cement of different grades available in the market on design concrete mixes [8,9]. The concrete prepared is workable (i.e. ready to use at site), medium strength concrete of slump 50±25 mm and high strength concrete of equivalent slump 30±15 mm measured in terms of compaction factor ranging between 0.75 and 0.80. All concrete mixes were prepared by hand mixing. 150 mm size cubes were cast and tested. Vibrating table was used to compact the mixes.

The work has been completed in the following sequence:

After procurement of constituent materials from various sources, tests were conducted on them to find out their basic properties and suitability for use in normal and high strength concretes.

In the next stage, trial mixes were prepared, cubes were cast and cured in tap water/ warm water (i.e. accelerated curing method) to find out strength without wasting any time and also to finalize the maximum dose of super-plasticizer, which can be used in concrete. At this stage, much attention was not paid to achieve the desired workability.

Further studies were carried out on medium strength concrete, workability measured in terms of slump 50±25 mm using minimum cementious materials (not less than 300 kg/m^3) with various fine and coarse aggregates to produce M20 grade concrete. Not only plain mixes but also flyash concrete mixes by replacing 20% cement with flyash (by weight) were studied.

In the next stage, the effect of maximum cement content (i.e.450 kg/m^3) with various fine and coarse aggregates has been included. Not only plain mixes but also flyash concrete mixes were investigated, by adding 20% flyash (by weight of cement) and making necessary adjustments in other constituents.

High strength concrete was prepared with 53 gradeordinary Portland cement by using maximum allowing cement content of 450kg/m^3 with super-plasticizer to maintain low water / cement ratio. In this mix, 20 mm maximum size aggregate was used and later flyash was also included at 20% and 30% level.

In the final stage, plain and flyash high strength concretes were also investigated by replacing only 20 mm maximum size aggregates with 12 mm maximum size aggregates and keeping other constituents at the same level as in the above. The details of mix proportions, workability and compressive strengths are given in Table-3.

V. Results and Discussion

No slump mixes were investigated only in series A, which reveals that a maximum strength one can achieve with the available material when designed for M20 grade concrete. On comparison of test results A1 and A2, it is found that increase in flakiness index of coarse aggregates from 16.3% to 29.3% reduces compressive strength of M-20 grade concrete by 5.6% having grading zone II sand and elongation index of coarse aggregate of comparable value. While, test results A3 and A4 demonstrate that change in grading zone of fine aggregates (i.e. use of grading zone III sand of F.M. 2.10 in place of grading zone II sand of F.M. 2.92) reduces compressive strength by 13.2% and 18.8% for flakiness indexes of 16.3% and 29.3% respectively. It is clear that grading zone III sand needs more cement content than grading zone II sand for producing concrete of the same compressive strength. Comparison of test results of A1 and A2 concluded that cumulative effect of flakiness index and grading of sand may reduce compressive strength of concrete up to 23.3% for the same cement content and water cement ratio. Mix A5 demonstrates that one can not only save cement content about 10% but can also expect better compressive strength by properly grading of the aggregates. A minimum of 373 kg/m^3 cement content is required for grading zone II sand to produce concrete of compressive strength greater than 26.6 MPa (i.e. M20 grade concrete) with available market sand, which one can reduce up to 10% by using proper gradation of aggregates, while additional means (i.e. super plasticizer etc.) may be used to improve the workability of concrete. Mixes A6 and A7 demonstrate, the maximum value of compressive strength in plain concrete which one can achieve with 43 grade and 53 grade cements respectively. In this series, workability has not been given due consideration, therefore one has to use/ enhance the dose of super plasticizer to produce workable mix otherwise one has to compromise on compressive strength in absence of required additional compacting efforts. Of course, mixes A6 and A7 were only cured in warm water (at 55$\pm$1 ^{0}C for 20 hour $\pm$ 10 minute as per IS: 9013) to curtail the duration of project.

In series B, workable mixes were investigated with reference to minimum cement content and minimum grade of concrete to be used in reinforced concrete (RC) construction. Mixes B1 and B2 revealed that grading zone III sand of F.M. 2.10 have more water absorption capacity than the sand of grading zone II and also produces concrete of little smaller compressive strength with nearly same cement content. Both concretes are not meeting the strength requirement of M20 grade concrete. While tailored coarse and fine aggregates have produced concrete of compressive strength 11.7% higher than the compressive strength of the concrete produced by the sand as procured of zone II(F.M. 3.19). Of course, we have used here little more cement content and got slump of higher value. A minimum of 412 kg/m^3 cement content is required to produce a workable mix of M20 grade concrete without super plasticizer and with properly graded aggregates.

In series C, mixes of series B are modified using flyash as replacing material to cement by 20% (weight) with reference to minimum cement content explained in IS: 456-2000. It is found for all mixes that 28 day compressive strength of flyash concrete is smaller by 4.5 to 10.5% while 56 day strength of flyash concretes are higher than predicted 90 day compressive strength of plain concretes. Therefore, flyash concrete at lowest grade of concrete i.e. M20 for RC can save cement up to 20%, if structures are fully loaded after 2 month of concreting. Use of flyash as 20% replacement to cement with properly graded aggregates gives 28 day compressive strength in workable mix of M20 grade concrete less than the required strength by about 4.5%, which improves with time and surpasses 90 day compressive strength (predicted) of plain concrete at 56 days by C2 and C3 mixes.

Series D demonstrates the compressive strength which one can get with the maximum cement content with reference to IS: 456-2000. Mixes D1 and D2 are prepared with the available sands as procured from the market of F.M. 2.1 (zone III) and 3.19 (zone II), while mix D3 was prepared with tailored coarse and fine aggregates. On comparison of compressive strengths it is found that concrete of grading zone III sand is having 3.1% less strength while concrete of tailored aggregates having higher compressive strength by about 8.8% than the concrete produced with grading zone II sand. This has revealed that increase of cement content up to maximum (i.e. 450 kg/m^3) has not improved compressive strength significantly.

In series E, mixes of series D were modified using 20% flyash in addition to maximum cement content of 450 kg/m^3, fine aggregate, coarse aggregates and water contents adjusted in these mixes so as to produce a workable mix and to get the benefit of using flyash. On comparison of test results it is found that there is very little (i.e. 4.6 to 8.2%) increase in compressive strength with reference to plain mixes at 28 day age, while flyash concretes have 56 day compressive strength higher than those predicted at 90 day compressive strength of their respective mixes by 10.8% to 15.3%. One can take this additional strength into account only if, ones structure will be fully loaded after about 2 month of concreting. Addition of 20% flyash with maximum cement content and properly graded aggregates has given compressive strength of 33.7 MPa, which has increased to 39 MPaat the age of 56 days.

In series F, all mixes were prepared using 53 grade cement with tailored fine and coarse aggregates. Mixes F1, F2 and F3 were prepared with 0%, 20% and 30% flyash using maximum cement contents of 450 kg/m^3 and necessary adjustments have been made in quantities of water, fine and coarse aggregates so as to get workable mixes. Super-plasticizer was used by 1.5% weight of cement in all the mixes. Compressive strengths of the mixes F1, F2 and F3 at 28 day are 55.1 MPa, 59.2 MPa, and 60.2 MPa respectively, while 90day predicted compressive strength of plain mix (i.e. without flyash) is 60.6 MPa and 56 day compressive strength of flyash concretes F2 and F3 are 62.1 MPa and 63.7 MPa respectively. Test results of this series revealed that 30% addition of flyash increased compressive strength of concrete at 28 day and 56 day by 9.3% and 15.6% respectively. Also, 28 day compressive strength of 30% flyash concrete is comparable to the predicted 90 day compressive strength of plain concrete of series F.

In series G, mixes of series F were modified by using tailored 12mm maximum size aggregates in place of tailored 20mm maximum size aggregates. On comparison of test results of series F and G it is found that 12 mm tailored maximum size aggregates have increased compressive strength of plain mix by 9.4 % than the compressive strength of plain concrete produced with tailored 20mm maximum size aggregates. It is also found that 30% flyash concrete prepared with tailored 12mm maximum size aggregates has 56 day compressive strength comparable to the predicted 90 day compressive strength of plain concrete of series G.

VI. Conclusions

1. A minimum of 412 kg/m^3 cement content is required to produce a workable plain mix of M20 grade concrete with properly graded aggregates.
2. With superplasticizer, the required minimum cement content may be reduce to 373 kg/m^{3}for producing a workable M20 concrete with market sand of grading zone II. This cement content may further be reduced to 337 kg/m^{3}if one is able to compact at low slump.
3. Use of flyash as 20% replacement to cement, with properly graded aggregates gives 28 day compressive strength little smaller than the required in workable mix of M20 grade concrete, which improves with time and surpasses 90 day predicted compressive strength of plain concrete at 56 days.
4. Increase of cement content up to maximum i.e. 450 kg/m^3, has not improved compressive strength significantly. But, addition of 20% flyash with maximum cement content and properly graded aggregates has given compressive strength of 33.7 MPa, which at the ages of 56 day has increased to 39 MPa. With the use of 43 grade cement and super-plasticizer, one can get a maximum compressive strength of 47 MPa.
5. Properly graded 20mm maximum size aggregates along with maximum cement content of 53 grade and 1.5% of super-plasticizer has given 28 day compressive strengths of 55.1 MPa, 59.2 MPa and 60.2 MPa for 0%, 20% and 30% flyash concretes respectively. The 56 day compressive strengths of 20% and 30% flyash concretes have increased to 62.1 MPa and 63.7 MPa respectively. A maximum compressive strength of 72 MPa is achieved for no slump concrete.
6. Properly graded 12mm maximum size aggregates along with maximum cement content of 53 grade and 1.5% of super-plasticizer has given 28 day compressive strengths of 60.3 MPa, 62.1 MPa and 63.4 MPa for 0%, 20% and 30% flyash concretes respectively. The 56 day compressive strengths of 20% and 30% flyash concretes have increased to 65.6 MPa and 67.4 MPa respectively.

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Author's Profile

Dr. Awadhesh Kumar is an Associate Professor in the Department of Civil Engineering of Delhi Technological University (Formerly Delhi College of Engineering), Delhi, India. He obtained his Master of Engineering degree in 1993 from University of Roorkee, Roorkee and Ph.D. from Indian Institute of Technology, Roorkee, in 2001. He has research experience of 12 years and teaching experience of about 11 years. He is member of various committees of Bureau of Indian Standards for formulation and revision of Indian Standards specifications. His areas of research include high temperature effects on reinforced concrete, concrete technology, linear and non-linear analysis of cement composites using finite element method, prestressed cement composites, ferrocement technology and applications. He is life member of India Chapter of American Concrete Institute, the Institution of Engineers (India), Indian Concrete Institute, Material Research Society of India, Indian Society for Construction Materials and Structures, Indian Society for Wind Engineering and Indian Society of Earthquake Technology.

He has supervised many M.Tech Dissertations and supervising three Ph.D. thesis. He has published 14 research papers in Journals and conferences, also co-authored a book on Design of Steel Structures.

Table-3. Details of mix proportions and test results

Mix No.	Type of FA/CA	Cement Content (kg/m^3)	Water (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Flyash/[SP] (%)	Slump (mm)/ C.F.	Compressive strength 28 day(56day/90day*) MPa
A1	FA1/CA1	372.7	205.0	819.9	995.1	-	8	27.2
A2	FA1/CA2	372.7	205.0	819.9	995.1	-	9	28.8
A3	FA2/CA1	372.7	205.0	611.2	1170.3	-	8	22.1
A4	FA2/CA2	372.7	205.0	611.2	1170.3	-	9	25.0
A5	FAT2/CAT1	336.5	176.5	540.1	1296.3	-	10	30.7
A6	FAT1/CAT2	450.0	155.7	541.4	1201.5	0/[1.2]	0.64	47.0$^+$
A7	FAT1/CAT2	450.0	145.4	512.6	1242.0	0/[1.5]	0.62	72.0$^+$
B1	FA2/CA1	408.3	272.3	563.4	1033.0	-	44	24.8 (27.3*)
B2	FA3/CA1	405.0	255.2	732.6	900.3	-	48	25.6 (28.1*)
B3	FAT2/CAT1	411.7	255.3	552.9	1049.8	-	58	28.6 (31.4*)
C1	FA2/CA1	344.0	281.9	485.0	1035.4	20	58	23.8 (28.8)
C2	FA3/CA1	361.3	281.3	588.9	899.6	20	55	24.6 (31.0)
C3	FAT2/CAT1	358.7	276.4	436.9	1048.8	20	46	25.4 (31.8)
D1	FA2/CA1	450.0	271.7	525.2	1034.6	-	32	28.5 (31.3*)
D2	FA3/CA1	450.0	253.8	637.6	960.8	-	58	29.4 (32.3*)
D3	FAT2/CAT1	450.0	253.1	463.0	1112.0	-	42	32.0 (35.2*)
E1	FA2/CA1	450.0	291.1	328.5	1035.0	20	37	29.8 (36.0)
E2	FA3/CA1	450.0	277.5	472.5	900.0	20	38	31.8 (37.3)
E3	FAT2/CAT1	450.0	284.8	405.0	972.0	20	44	33.7 (39.0)
F1	FAT1/CAT2	450.0	177.8	508.5	1220.5	0/[1.5]	0.80	55.1 (60.6*)
F2	FAT1/CAT2	450.0	202.5	481.5	1152.0	20/[1.5]	0.79	59.2 (62.1)
F3	FAT1/CAT2	450.0	218.8	454.5	1084.5	30/[1.5]	0.78	60.2 (63.7)
G1	FAT1/CAT3	450.0	182.8	507.1	1216.9	0/[1.5]	0.80	60.3 (66.3*)
G2	FAT1/CAT3	450.0	208.1	468.0	1129.5	20/[1.5]	0.78	62.1 (65.6)
G3	FAT1/CAT3	450.0	225.2	441.0	1062.0	30/[1.5]	0.78	63.4 (67.4)

$^+$ Cured in warm water.
* predicted strength