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Use of M Sand in High Strength and High Performance Concrete

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Abstract

Due to rapid development in urban area, use of high strength concrete in the construction industry is increasing rapidly. Mineral admixtures such as Ground Granulated Blast furnace Slag (GGBS), Metakaolin, Silica fume and Alccofine are become unavoidable in high strength concrete because of their effects in hardened concrete properties. Replacing the Ordinary Portland Cement (OPC) by mineral admixtures is retaining the natural resources for future generation. In present scenario, replacement of river sand with manufactured sand is almost mandatory due to scarcity of the river sand. Superplasticizers are used to improve the workability of concrete at low water-cement ratio and increase the compressive strength by reducing it. In urban infrastructure development, the high strength concrete is mandatory to reduce the size of structural member, and to increase the utility space to carry heavier load. In this study M100 grade concrete mix was designed with replacement of OPC by different types of mineral admixtures using river sand and manufactured sand along with Polycarboxylate Ether (PCE) based superplasticizer. The Compressive strength, flexural strength and split tensile strength at various curing periods such as 28 and 56 days. The durability properties such as Rapid Chloride Penetration test, Water penetration test and water absorption test were carried out on the specimens at 28 and 56 days. Also, the Drying shrinkage of the concrete was tested at 14 days. From the experimental test results it is observed that, all the mixes were achieved the target mean strength, among these the Alccofine with Manufactured sand combination has achieved 21% higher than the target strength at age of 56 days and other strength parameters such as split tensile and flexural strength also slightly increased in this combination comparatively. The durability tests (Rapid chloride penetration, water penetration and drying shrinkage) were conducted and the obtained values at the age of 56 days are within permissible limit as per the codal provisions and the concrete with manufactured sand shows slightly higher value than concrete with river sand.

Keywords: Alccofine, Durability, High Performance Concrete, High Strength Concrete, M Sand, Metakaolin, Silica Fume

1. Introduction

Concrete is a widely used construction material for various types of structures due to its structural stability and strength. All the materials required for producing such huge quantities of concrete come from the earth's crust. Thus it depletes its resources every year creating ecological strain. On the other hand human activities on the earth produce solid waste in considerable quantities including industrial wastes. Amongst the solid waste the major ones are fly ash, GGBS, silica fume and demolished construction materials. These solid wastes can be used as a mineral admixture which is used in the production of High Performance and High strength concrete.

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Experimental investigations done by Aticin states that the spectacular increase in compressive strength is directly related to a number of recent technological developments, in particular the discovery of the extraordinary dispersing action of superplasticizer with which flowing concrete can be made with about the same mixing water that is actually required to hydrate all the cement particles are even less. The reduction in water/cement ratio results in a hydrated cement paste with a microstructure so dense and strong that coarse aggregates can become the concrete's weakest constituent. Silica fume, a highly reactive pozzolana, considerably enhances the paste/aggregate interface and minimizes de bonding. Lastly, the use of supplementary cementitious materials such as fly ash and especially slag helps solve slump loss problems which become critical at low w/c ratios[1].

Experimental investigations conducted by Xincheng Pu and Chong Wang predicts that the pozzolanic effect of Silica fume contributes to the strength consists of about one third of the total strength of 150 MPa concrete[2]. Similarly studies conducted by Umesh Sharmaa states the microsilica contributes for both compressive strength and durability[3]. The durability cement concrete is defined as its ability to resist weathering action, chemical attack and any other process of deterioration. Study investigated by Patel states that the performance of concrete mixture in terms of Compressive strength, Chloride Attack tests, Seawater test and accelerated corrosion test at age of 28 and 56 days. Result show that concrete incorporating Alccofine and fly ash have higher compressive strength and Alccofine enhanced the durability of concretes and reduced the chloride diffusion[4]. Investigations done by Dinakar revealed that the incorporation of 10% Metakaolin improved the compressive strength in High grade concrete[5]. Studies done by Patil revealed that the use of Metakaolin as a mineral admixture enhances the durability aspects of concrete[6]. Test results conducted by Mohammad Abdur Rashid and Mohammad Abul Mansur suggests the use of quality materials, smaller water-binder ratio, larger ratio of Coarse Aggregate (CA) to Fine Aggregate (FA), smaller size of coarse aggregate, and suitable admixtures with their optimum dosages are found necessary to produce HSC[7]. Christian Vernet studied the performance of Ultra-High Performance Fibre-Reinforced concretes and results obtained for porosity, permeability, chloride and other ions penetration or diffusivity, freeze-thaw behaviour, acid and leaching resistance[8].

River sand has become almost extinct in the urban areas and as thus we have started using manufactured sand in all most all our concreting activities. However the use of manufactured sand in a high strength concrete is still not gained any confidence. Research done by investigate the effect of M-Sand in structural concrete by replacing river sand and development high performance concrete and also compare the differences in properties of concrete containing river sand and M-sand[9].

High strength concrete helps in building tall structures, important monuments, reduces the structural thickness and increase the carpet area. High strength concrete is more durable and hence it can be used for marine structures, nuclear reactor buildings and many such important Structures.

1.1 Importance of Study

Since concrete uses more than 35 percent of fine aggregate the requirement for fine aggregate is huge because of increase in construction activities throughout the world. River sand was used as fine aggregate in many parts of the world and thus the requirement for it is more. But continuous quarrying of river sand from river bed has led to many environmental problems. To solve the above problem an alternate to river sand is very much the need of the day. Manufactured sand which is a processed product of fine aggregate form various rock sources is the most suitable and economically viable option. Although the practice of using manufactured has been there for quite a while it is only used in the lower grades of concrete. To use manufactured sand in high grade concrete such as M100 and compare with the river sand in strength and durability parameters will be helpful in understanding the usage of Manufactured sand in high strength high performance concrete.

2. Experimental Programme

The experimental programme involves testing of materials and designing of mix for M100 grade using the three mineral admixtures Silica fume, Metakaolin and Alccofine in both M.sand as well as R.sand. The mixes were compared for strength properties such as Compressive strength, Flexural Strength and Split Tensile strength and also durability properties such as Rapid Chloride Penetration Test (RCPT), Water Penetration test and Drying Shrinkage test. For all the strength and durability studies of various curing periods, 3 specimens of each were cast to conduct the tests. The materials used in this study are shown in Figures 1 to 6.

Figure 1. Silicafume.

Figure 2. Metakaolin.

Figure 3. Alccofine.

Figure 4. GGBS.

Figure 5. Fibres.

Figure 6. Chemical admixture.

2.1 Properties of Fine Aggregate

Aggregate gives the dimensional stability and form bulk part of the concrete. Particularly in high strength concrete it is pertinent to use good quality aggregate to get the desired properties. Crushed granite with a nominal grain size of 10 mm was Since the grade of concrete is very high (M100) and also the cementitious content is more coarse aggregate of 10 mm size was used in the study. Since 10 mm aggregate will have a large specific surface area it will have a better bonding with the cementitious materials. Fine aggregate used was manufactured sand (M. sand) for mixes 1, 2 and 3 and river sand (R. sand) for the mixes 4, 5 and 6. All the aggregate confirm to the IS 383: 1970[9]. The properties[10-12] of fine aggregate is given below in the Table 1.

Table 1. Properties of fine aggregate

Properties	Manufactured sand	River sand
Specific gravity	2.720	2.660
Water absorption (%)	2.40	1.20
Dry loose bulk density (kg/m^3)	1630	1550
Materials finer than 75 micron (%)	9	1
Fineness Modulus	2.53	2.98
Organic impurities	Nil	Nil

2.2 Mix Design for M100 Concrete

The mix design was carried by absolute volume method. First three mixes were with manufactured sand (M.sand) and the next three mixes were with river sand (R.sand). In both the fine aggregate each mix was made with a 10% substitution of mineral admixture Silica fume, Metakaolin and Alccofine respectively. The water binder used in all the mixes used in the study is 0.2.

2.2.1 Absolute Volume Method of Mix Design

The absolute volume method of mix design was used to arrive at the quantity of mix ingredients as per IS10262:2009[13]. Here the absolute volume of materials are calculated according to their specific gravity. The total quantity of materials amount to $1m^3$.The target strength required will be $100 + (1.65 \times 5) = 108.25$ N/mm^2. Total cementitous content of $900kg/m^3$ was used with a free water content of 180 liters per m^3. The free water binder ratio was 0.2.

An example calculation to arrive the mix ingredients for the Mix 1 is shown below.

Cement	= 530kg	= $0.1683m^3$
GGBS	= 280kg	= $0.1000m^3$
Silica fume	= 90kg	= $0.0375m^3$
Free Water	= 180kg	= $0.1800m^3$
Admixture	= 9.00kg	= $0.0083m^3$
Total Volume	= $0.4940m^3$	

Remaining Volume of aggregate is 1-0.4940 = 0.5060 m^3

The weighted specific gravity is $(70\times2.80 + 30\times2.72)/100 = 2.776$

Volume of aggregate = 0.5060 m^3 which is equal to $0.5060 \times 2.776 = 1405$ kg

The aggregate are divided as

Coarse aggregate 10 mm	= 1405× 70%	= 983 kg
Manufactured sand	= 1405× 30%	= 421 kg

Water absorption is added to free water as

10 mm	= 671 × 0.35%	= 4.92 kg
Manufactured sand	= 447 × 0.50%	= 10.11 kg
Total water absorption is		= 15.03 kg
Total water		= 180 + 15.03 = 195.03 kg

The above mix design calculation was carried out for mix 1 using manufactured sand and Silica fume. Similarly the quantity of materials in M100 concrete are arrived with both manufactured sand and river sand using three different mineral admixtures such as Silica fume, Metakaolin and Alccofine. They are presented in Table 2. The Figures. 7 to 10 shows some of the specimen prepared for testing.

Table 2. Quantity of materials for M100 concrete per m^3

Ingredients	Unit	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6
OPC 53G	kg	530	530	530	530	530	530
GGBS	kg	280	280	280	280	280	280
M. Sand	kg	421	423	426	-	-	-
R. Sand	kg	-	-	-	419	420	424
Silica fume	kg	90	-	-	90	-	-
Metakaolin	kg	-	90	-	-	90	-
Alccofine	kg	-	-	90	-	-	90
Free Water	kg	180	180	180	180	180	180
Coarse aggregate	kg	983	986	995	977	980	989
Total Water	kg	195	195	195	190	190	190
Admixture	kg	9	9	9	9	9	9
Fibres	kg	0.9	0.9	0.9	0.9	0.9	0.9

Figure 7. Specimen casted.

Figure 8. Specimen under curing.

Figure 9. Core cut specimen for RCPT.

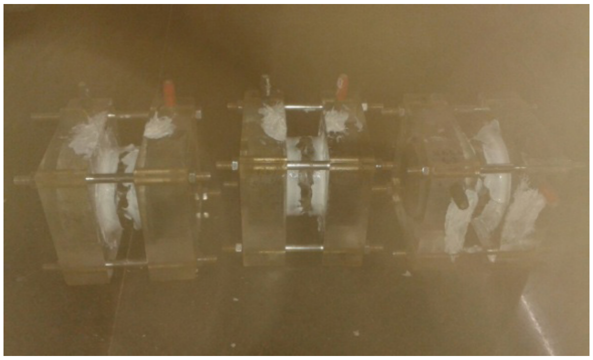

Figure 10. Specimen prepared for RCPT.

3. Results and Discussions

The results of strength tests[14-16] and durability tests[17-20] results using both the fine aggregates M.sand and R.Sand are given below in the following sections.

3.1 Compressive Strength

Compressive strength is by far the most important property checked for the concrete and even more important in high strength concrete. The compressive strength was carried out as per IS 1199: 1959 Figure 11 shows the compressive strength testing in progress. The tests were conducted on 3rd, 7th, 28th and 56th days and the test results are tabulated in the Table 3.

Figure 11. Compressive strength testing.

It is evident from the Table 3, that the compressive strength has been achieved well above the target strength of 108.25 N/mm^2. The strength of the concrete depends upon water cement ratio and porosity. Since the water cement ratio used was very less (0.2) and also by the use of finer mineral admixtures the compressive strength was very high in the tests. The compressive strength was more in manufactured sand concrete than river sand concrete in all the mixes with 3 different mineral admixtures (Silica fume, Metakaolin, and Alccofine). Also the rate of gain in strength with continuous curing was found to be more in M.sand concrete of the three mineral admixtures, Alccofine gave the maximum compressive strength in manufactured sand as well as river sand.

3.2 Flexural Strength

A concrete beam of size (150×150×700 mm) is supported on a steel roller bearing near each end is loaded through similar steel bearings placed at the third points on the top surface (2-point loading). Test details are as described in IS 1199:1959. The tests were conducted on 28th and 56th days and the test results are tabulated in the Table 4.

The flexural strength usually varies between 8-10% of compressive strength in normal strength concrete. But in high strength concrete the flexural strength will be comparatively less. The average flexural strength was about

Table 3. Compressive strength of concrete

Age in Days	Unit	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6
3	N/mm^2	65.67	60.33	68.00	64.67	59.67	64.67
7	N/mm^2	80.33	78.00	82.33	80.00	78.67	83.33
28	N/mm^2	109.00	106.00	110.00	107.33	106.00	108.00
56	N/mm^2	126.33	118.67	131.67	123.33	115.33	129.33

Table 4. Flexural strength of concrete

Age in Days	Unit	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6
3	N/mm^2	65.67	60.33	68.00	64.67	59.67	64.67
7	N/mm^2	80.33	78.00	82.33	80.00	78.67	83.33
28	N/mm^2	109.00	106.00	110.00	107.33	106.00	108.00
56	N/mm^2	126.33	118.67	131.67	123.33	115.33	129.33

6.23 percent of compressive strength at 28 days. The flexural strength was more in manufactured sand concrete than river sand concrete in all the mixes with 3 different mineral admixtures (Silica fume, Metakaolin, and Alccofine). Alccofine gave the maximum flexural strength among the 3 mineral admixtures. Also the 56 days flexural strength was more by 12% to the 28 day flexural strength.

3.3 Split Tensile Strength

The split tensile strength was tested on 150mm diameter × 300 mm length cylinders. The tests were conducted on 28th and 56th days and the test results are tabulated in the Table 5.

Table 5. Split tensile strength of concrete

Age in Days	Unit	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6
28	N/mm^2	6.41	6.27	6.13	6.18	6.13	6.18
56	N/mm^2	7.26	7.02	7.59	6.98	6.79	7.45

The split tensile strength usually varies between 8-10 % of compressive strength in normal strength concrete. But in high strength concrete the split tensile strength will be comparatively less. The average split tensile strength was about 5.77 percent of compressive strength at 28 days. Also the split tensile strength was marginally less than the flexural strength at the same age. The split tensile strength was found to be slightly higher in manufactured sand concrete than river sand concrete in all the mixes with 3 different mineral admixtures (Silica fume, Metakaolin, and Alccofine). Alccofine gave the maximum split tensile strength among the 3 mineral admixtures. The split tensile strength was found to be more by 15% at the end of 56 days compared to 28 days strength.

3.4 Rapid Chloride Penetration Test

The chloride penetration is harmful to the durability of concrete and thus it has to be test for its penetration level. Rapid Chloride Penetration Test (RCPT) is one method of evaluating the performance and was tested on the specimens of size 100 mm diameter × 50 mm length. The specimens were core cut from the cubes of size 150×150 ×150 mm. The tests were carried out in accordance with ASTM C1202:2012. Figure 12 shows the RCPT test under progress. The tests were conducted after 28 and 56days and the test results are tabulated in the Table 6.

Table 6. RCPT results

Age in Days	Unit	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6
28	Coulombs	355	329	418	378	370	453
56	Coulombs	170	205	225	205	229	253

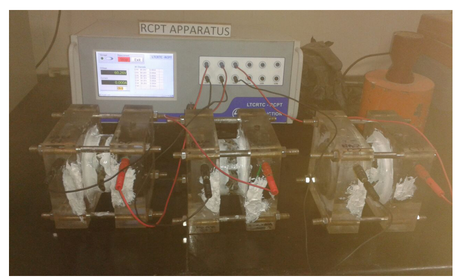

Figure 12. Rapid chloride penetration test

From the Table 6, it is evident that all the test results are fall within the specified limiting value as per ASTM C1202:2012. The lowest value was obtained for Silica fume mix among the different mineral admixtures. Also manufactured sand concrete has least value compared to river sand concrete by around 8 percent. The values are within the limit may be the use of very fine mineral admixtures and improved micro structure of concrete. The RCPT values are low because of high resistivity to percolating chloride ions and thus more durable.

3.5 Water Penetration Test

The water penetration tests were carried out as per the code DIN 1048 part 5: 1991 on the specimen of 150 mm

× 150 mm × 150mm cubes. The tests were conducted on 28th and 56th days and the test results are tabulated in the Table 7.

Table 7. Water penetration test results

Age in Days	Unit	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6
28	mm	1.33	1.37	1.67	1.37	1.47	2.13
56	mm	0.83	0.93	1.07	0.93	1.07	1.43

From the results it was observed that the water penetration was very less compared to the maximum value of 25mm prescribed in code DIN 1048 part 5:1991. The low water penetration values are because of the tight and highly impermeable pore structure. Manufactured sand concrete was found to be more impermeable than river sand concrete by around 13 percent in different mixes. Also as with age the water penetration values became less by 0.5mm from the 28 days value. The water penetration in Silica fume mixes was least among the 3 different mineral admixtures. In general the water penetration values are observed higher in normal strength concrete made with only cement, but for a high strength concrete it will be very less because of use of very fine mineral admixtures.

3.6 Drying Shrinkage Test

Drying shrinkage was tested on the concrete specimen of 70 mm × 70 mm × 300mm size as per IS 1199:1959. The tests were conducted after 14 days and the test results are tabulated in the Table 8.

Table 8. Drying shrinkage test results

Age in Days	Unit	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6
14	%	0.020	0.018	0.014	0.017	0.015	0.011

Drying shrinkage was found to be less in river sand concrete than manufactured sand concrete. However, the decrease is only marginal (0.003%). Among the 3 mineral admixtures Alccofine mixes gave the least drying shrinkage value. The lowest shrinkage was observed for the Alccofine mix with river sand (mix 6) and provides better dimensional stability.

4. Conclusions

- Alccofine with Manufactured sand combination has achieved 21% higher than the target strength at age of 56days and other strength parameters such as split tensile and flexural strength also slightly increased in this combination comparatively.
- The durability tests(Rapid chloride penetration, water penetration and drying shrinkage) were conducted and the obtained values at the age of 56 days are within permissible limit as per the codal provisions and the concrete with manufactured sand shows slightly higher value than concrete with river sand.
- Among the mineral admixtures used in concrete, concrete with Alccofine gave slightly higher the values in all the strength properties. It was 4.5%, 6.7% and 5.6% more than other mineral admixtures in compressive, flexural and split tensile strength respectively.
- The usage of M.sand for high strength high performance concrete provides stronger and durable concrete structures which will be economical as well as environment friendly by preserving natural resources such as river sand.
- Drying Shrinkage was marginally higher in M.sand, however later age behaviour in this aspect needs to be studied further.

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