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Deriving Mix Proportions For Different Grades Of Phosphogypsum Based Self Compacting Concrete

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Abstract

This paper demonstrates that Phosphogypsum which is a waste by product of fertilizer industry can be successfully used as an admixture in the preparation of Self-Compacting-Concrete (SCC). In order to prepare suitable mix proportions for different grades of Phosphogypsum based Self Compacting Concrete, investigations were undertaken replacing cement with 0%, 10%, 20% and 30% of Phosphogypsum and with different percentages of Super-plasticizer (Glenium B233) and Viscosity Modifying Agent (Glenium stream 2). As per EFNARC guidelines Slump flow test, V-funnel test and L-box test have been carried out on fresh Phosphogypsum based self compacting concrete. The compressive strength, split tensile strength and flexural strengths of the specimens have been analyzed for 7 days and 28 days of curing. And finally Mix proportions have been recommended for M40, M25 and M15 grades of Phosphogypsum based self compacting concrete. The various steps involved in the preparation of suitable mix proportions for Phosphogypsum based Self Compacting Concrete are discussed at length in this paper.

Keywords*:* Self-Compacting concrete, Phosphogypsum, EFNARC, Mix Design, Fresh properties, Strength tests, Super-plasticizer (SP) , Viscosity Modifying Agent (VMA)

1. INTRODUCTION

Though concrete possess high compressive strength, stiffness, low thermal and electrical conductivity, low combustibility and toxicity, two characteristics, have limited its use. It is brittle and weak in tension. To overcome these limitations, several researchers are trying different methodologies. In this process the evolution of FRC (Fibre Reinforced Concrete) and SIFCON (Slurry Infiltrated fibrous Concrete) took place. As new methods are coming in Concrete Technology, new problems are also posed. Compaction of Concrete particularly in areas of heavy reinforcement, beam-Column junctions has become a major issue. To overcome this difficulty of compaction of concrete, a new Concrete called as Self Compacting Concrete (SSC) has been proposed very recently.

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete. In the production of SCC several types of admixtures such as Fly ash, Blast Furnace Slag and Silica Fume have been tried. Mineral admixtures are added to concrete as part of the total cementitious system. They may be used in addition to or as a partial replacement of Portland cement in concrete depending on the properties of the materials and the desired effect on concrete (Mindess et al., 2003). Mineral admixtures are used to improve a particular concrete property such as workability, strength or compactability. The optimum amount to use should be established by testing to determine (1) Whether the material is indeed improving the property, and (2) The correct dosage rate, as an overdose or under dose can be harmful or not achieve the desired effect, because they react differently with different cements (Kosmatka et al., 2002).

In the present work it is proposed to use Phosphogypsum as admixture in the production of Self Compacting Concrete and mix proportions are recommended for M40, M25 and M15 grades of Phosphogypsum based Self compacting concrete.

2. LITERATURE SURVEY

In 1986, Hajime Okamura started a research project on the flowing ability and workability of this special type of concrete, later called self-compacting concrete. In his study, Okamura has fixed the coarse aggregate content to 50% of the solid volume and the fine aggregate content to 40% of the mortar volume, so that self-compactability could be achieved easily by adjusting the water to cement ratio and super plasticizers dosage only. The water-cement ratio was taken between 0.4 and 0.6 depending on the properties of the cement. The super plasticizer dosage and the final water-cement ratio were determined so as to ensure the self-compactability, evaluated subsequently by using the U-type test. During his research, Okamura found that the main cause of the poor durability performances of Japanese concrete in structures was the inadequate consolidation of the concrete in the casting operations. By developing concrete that self-consolidates, he eliminated the main cause for the poor durability performance of the concrete. After Okamura began his research in 1986, other researchers in Japan have started to investigate self-compacting concrete, looking to improve its characteristics. One of those was Ozawa (1989) who has done some research independently from Okamura, and in the summer of 1988, he succeeded in developing self-compacting concrete. By using different types of super plasticizers, Ozawa studied the workability of concrete and developed a concrete which was very workable. It was suitable for rapid placement and had a very good permeability.

Other experiments carried out by Ozawa (1989) focused on the influence of mineral admixtures like fly ash and blast furnace slag on the flowing ability and segregation resistance of self-compacting concrete. He found out that the flowing ability of the concrete improved remarkably when Portland cement was partially replaced with fly ash and blast furnace slag. After trying different proportions of admixtures, he concluded that 10-20% of fly ash and 25-45% of slag cement, by mass, showed the best flowing ability and strength characteristics.

Subramanian and Chattopadhyay concentrated to arrive at an approximate mix proportion of self-compacting concrete which would give the procedure for the selection of a viscosity modifying agent, a compatible super plasticizer and the determination of their dosages. The Portland cement was partially replaced with fly ash and blast furnace slag, in the same percentages as Ozawa (1989) has done before and the maximum coarse aggregate size did not exceed 2.5cm. The two researchers were tried to determine different coarse and fine aggregate contents from those developed by Okamura. On the basis of their trials, it was discovered that self-compactability could be achieved when the coarse aggregate content was restricted to 46 percent instead of 50 percent tried by Okamura (1997). In order to show the necessity of using a viscosity-modifying agent along with a super plasticizer, to reduce the segregation and bleeding, the mixture proportion developed by the two researchers was used to cast a few trial specimens. In these trials, viscosity-modifying agent was not used. The cast specimens were heavily reinforced slabs having 2400x600x80 mm and no vibration or any other method of compaction was used. However, careful qualitative observations revealed that the proportions needed to be delicately adjusted within narrow limits to eliminate bleeding as well as settlement of coarse aggregate. It was difficult to obtain a mixture that was at the same time fluid but did not bleed. This led to the conclusion that slight changes in water content or granulometry of aggregate may result either in a mixture with inadequate flowing ability, or alternatively one with a tendency for coarse aggregate to segregate. Therefore, it became necessary to incorporate a viscosity-modifying agent in the concrete mixture. Viscosity-modifying agents can be a natural polymer such as guar gum, a semi-synthetic polymer such as hydroxyl propyl methyl cellulose, or water-soluble polysaccharides, including those derived from a microbial source such as welan gum. They discovered that with a combination corresponding to 0.1 percent of welan gum and 0.53 percent by weight of water acrylic copolymer type super plasticizer, a satisfactory self-compacting mixture could be obtained.

Khayat (1997) et al. found out that all cores from both types of concrete (SCC and conventional concrete) exhibited little variation in compressive strength and modulus of elasticity in relation to height of the wall, indicating a high degree of strength uniformity. However, compressive strength and modulus of elasticity were greater for SCC samples than those obtained from the medium fluidity conventional concrete. Dehn et al. (2000) have focused their research work on the time development of SCC compressive and splitting tensile strength and the bond behavior between the reinforcing bars and the self-compacting concrete compared to normal concrete. Experimental results showed higher compressive strengths (36%) and splitting tensile strengths (28%) of the SCC specimens compared to normal concrete specimens. Also, the bond behavior measured at 1, 3, 7 and 28 days after concreting was better for self-compacting concrete than that of normally vibrated concrete.

3. EXPERIMENTAL INVESTIGATIONS:

The steps involved in the investigations for Phosphogypsum based Self compacting concrete are explained in the following sections.

3.1 Materials used in this investigation:

- Cement: Commercially available Ordinary Portland cement (OPC) 53 grade manufactured by Ultratech Company was used

- Coarse aggregate: The coarse aggregate from a local crushing unit having 20mm normal size well-graded aggregate according to IS-383 is used in this investigation. The coarse aggregate procured from quarry was sieved through 20mm, 16mm, 12.5mm, 10mm and 4.75mm sieves. The material retained on 12.5mm, 10mm and 4.75mm sieves was filled in bags and stacked separately and used.

- Fine Aggregate: The fine aggregate that falls in zone-I was obtained from a nearby river course. The sand obtained was sieved through all the sieves (i.e.4.75mm, 2.36mm, 1.18mm, 600µ, 300µ, 150µ). Sand retained on each sieve was filled in different bags and stacked separately for use. To obtain zone-I sand correctly, sand retained on each sieve is mixed in appropriate proportion

- Phosphogypsum : The Phosphogypsum used in the investigation was obtained from Coromandel international Ltd, Ennore, Chennai. The Phosphogypsum passing through 90µ sieve was used throughout the experiment. The specific gravity of Phosphogypsum was found to be 2.34. The chemical composition is presented below.

- a) CaSO4.2H2O : 92.0-94.0
- b) SiO2+insolubles : 4.0 max
- c) Fe2O3+Al2O3 : 0.3 max
- d) CaO : 30.0-31.0
- e) MgO : 0.1 max
- f) Na2O+K2O : 0.3-0.4 (0.5 max)
- g) Total P2O5 : 0.6-1.0
- h) Total SO3 : 42.8-44.0
- i) Fluorides as F : 0.4-0.5(0.7 max)
- j) Chlorides as C : 0.3-0.5(0.6 max)
- k) pH of 10% solution : 5.0-6.0(4 min)
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- Super-Plasticizer : The super plasticizer used in this experiment is Glenium B233. It is manufactured by BASF construction chemical India pvt.ltd, Mumbai. It complies to IS: 9103-1999 standards.

- Viscosity Modifying Agent (V.M.A) : Glenium Stream 2 which is manufactured by BASF construction chemical India pvt.ltd, Mumbai and it is a premier ready-to-use, liquid, organic, viscosity-modifying admixture (VMA) specially developed for producing concrete with enhanced viscosity and controlled rheological properties. Concrete containing GLENIUM STREAM 2 admixture exhibits superior stability and controlled bleeding characteristics, thus increasing resistance to segregation and facilitating placement.

- Water

3.2 Mix Proportioning: Based on the Mix design procedures and considering the EFNARC guide lines and "The European Guidelines for typical ranges of proportions and quantities" the following conclusions were made and used in the Mix designing process for preliminary mix design trials in this investigation.
1) Total powder content (Cementitious material i.e. Cement + Phosphogypsum) is taken as 600kg per cubic meter.
2) Water/powder ratio by volume of 0.80 to 1.10 and by weight 0.32 to 0.40.
3) Weight of coarse aggregate as 50% by volume of total aggregate
4) Weight of fine aggregate as 50% by volume of total aggregate.
5) A dosage range of 500 ml to 1500ml per 100kg of cementitious material is considered for Super-Plasticizer (Glenium B233)
6) A dosage range of 50 to 500 ml/100 kg of cementitious material is considered for . Viscosity Modifying Agent (Glenium Stream 2)

3.3 Preparation of SCC Mixes : Self Compacting Concrete mixes were prepared with various percentages of Super Plasticizer, Viscosity modifying agent and water/Powder ratio for each percentage replacement of cement with Phosphogypsum (0%, 10%, 20% and 30%). In this test program a total of Twelve Mixes were prepared and the mix proportions are presented in Table 1.

Table 1 : Details of mix proportions

Tr .no	Mix ID	% Replacement of PG	Cement (Kg)	PG (Kg)	FA (Kg)	CA				w/p	Water (Li)	SP (Kg)	VMA (Kg)
						Total (Kg)	16-12.5mm (Kg)	12.5-10mm (Kg)	10-4.75mm (Kg)				
1	TR1	0	600	-	673.32	708.61	177.15	177.15	354.3	0.4	240	9	0.3
2	TR2	10	540	60	732.6	770	462	123.2	184.8	0.32	192	3	0.6
3	TR3	10	540	60	731.44	768.64	461.18	122.98	184.4	0.32	192	4	0.6
4	TR4	10	540	60	730.31	767.34	306.94	184.1	276.2	0.32	192	5	0.6
5	TR5	10	576	64	554.04	582.03	232.81	139.68	209.53	0.5	320	5.6	0.6
6	TR6	10	576	64	629.92	662.94	265.1	159.1	238.6	0.4	256	8.16	0.6
7	TR7	10	576	64	633	665.55	266.22	159.7	239.5	0.4	256	9	0.3
8	TR8	10	540	60	666.6	700.8	280.32	168.1	252.2	0.4	240	9	0.3
9	TR9	10	540	60	666.6	700.8	175.2	175.2	350.4	0.4	240	9	0.3
10	TR10	20	480	120	659.68	694.26	173.56	173.56	347.13	0.4	240	9	0.3
11	TR11	30	420	180	652.24	686.43	171.6	171.6	343.2	0.4	240	10	0.3
12	TR12	30	420	180	648.52	682.52	170.6	170.6	341.3	0.4	240	12	0.3

(Note: The Values are for One Cubic metre of Self Compacting Concrete)

3.4 Conducting standard flow tests on SCC Mixes : The standard flow tests like Slump test, L-Box test, V- funnel test were conducted on the twelve mixes (TR1 to TR12)and the results were compared with the values as per EFNARC guidelines. Among these trails TR1 (SCC1), TR9 (SCC2), TR10 (SCC3) and TR12 (SCC4) mix proportions satisfy all the properties of self compaction concrete. The results are shown in Table 2.

S NO	Mix ID	Slump Dia (mm)	T50cm Slump (sec)	V-Funnel (sec)	V-Funnel at T5 min(sec)	L-Box (h2/h1)
1	TR1 (SCC1)	650	3.4	7.1	10	0.92
2	TR2	-	-	-	-	-
3	TR3	-	-	-	-	-
4	TR4	-	-	-	-	-
5	TR5	900	2.30	-	-	-
6	TR6	865	2.0	-	-	-
7	TR7	745	2.5	11.0	14.2	0.95
8	TR8	660	5.1	10.1	13.4	0.81
9	TR9 (SCC2)	715	4.2	9.0	12.0	0.87
10	TR10 (SCC3)	665	4.1	8.20	11.1	0.91
11	TR11	522	7.2	-	-	-
12	TR12 (SCC4)	678	3.1	8.85	11.5	0.95

Table 2: Fresh concrete properties of SCC

3.5 Casting specimens and conducting strength tests : For those mix proportions which satisfy all the properties of self compaction concrete i.e. for TR1 (SCC1), TR9 (SCC2), TR10 (SCC3) and TR12 (SCC4), specimens were prepared and tested to know compressive strength, split tensile strength and flexural strength. The results of these tests are shown in Tables 3, 4 and Table 5.

S NO	MIX ID	% of Phospho gypsum	Compressive strength in N/mm2	
			7 days	28 days
1	SCC1	0	32.80	47.95
2	SCC2	10	41.50	52.45
3	SCC3	20	32.25	33.20
4	SCC4	30	19.20	25.15

Table 3: Average Compressive strengths of cubes

S NO	MIX ID	% of Phospho gypsum	Split tensile strength in N/mm2
1	SCC1	0	3.50
2	SCC2	10	3.61
3	SCC3	20	2.82
4	SCC4	30	2.15

Table 4: Split Tensile strength test results on cylinders

S NO	MIX ID	% of Phosphogypsum	Flexural strength in N/mm2
1	SCC1	0	4.92
2	SCC2	10	6.74
3	SCC3	20	3.87
4	SCC4	30	2.92

Table 5: Flexural Strength test results on beams

3.7 Discussion of test results

It can be observed from Table 3 that the increase in Percentage replacement of cement with Phosphogypsum from 0% to 10% causes increase in the compressive strength of concrete from 32.80MPa to 41.50MPa and from 47.95MPa to 52.45MPa for 7 days and 28 days curing respectively. Further increase in percentage replacement of cement with Phosphogypsum from 10% to 30% causes decrease in the compressive strength of concrete from 41.50MPa to 19.20MPa and from 52.45MPa to 25.15MPa for 7days and 28days curing respectively. Table 4 reveals that the increase in Percentage replacement of cement with Phosphogypsum from 0% to 10% causes slight increase in the split tensile strength of concrete from 3.50MPa to 3.61MPa. Further increase in percentage replacement of cement with Phosphogypsum from 10% to 30% causes decrease in the split tensile strength of concrete from 3.61MPa to 2.15MPa. It can be observed from Table 5 that the increase in percentage replacement of cement with Phosphogypsum from 0% to 10% causes increase in the flexural strength of concrete from 4.92MPa to 6.74MPa. Further increase in percentage replacement of cement with Phosphogypsum from 10% to 30% causes decrease in the flexural strength of concrete from 6.74MPa to 2.92MPa. From the crack patterns it is observed that the width and number of cracks are increased with the 20% and 30% replacement of Phosphogypsum. Comparing the Target Mean Strengths of M35, M40, M25, and M15 grades of Concrete with the 28 days Compressive Strengths of SCC1, SCC2, SCC3, SCC4 mixes the following observations can be made with regard to comparable grade of concrete.

Mix ID	% replacement of cement with Phosphogypsum	28 Days Compressive strength	Comparable Grade of Concrete	Target Mean Strength
SCC1	0	47.95 N/mm^2	M35	43.25 N/mm^2
SCC2	10	52.45 N/mm^2	M40	48.25 N/mm^2
SCC3	20	33.20 N/mm^2	M25	31.60 N/mm^2
SCC4	30	25.15 N/mm^2	M15	20.775 N/mm^2

For preparing M40 grade Self Compacting concrete, SCC2 Mix proportion (10% of cement replacement with Phosphogypsum) can be used. For preparing M25 grade Self Compacting concrete, SCC3 Mix proportion (20% of cement replacement with Phosphogypsum) can be used. For preparing M15 grade Self Compacting concrete, SCC4 Mix proportion (30% of cement replacement with Phosphogypsum) can be used.

4. Conclusions

1) The increase in Percentage replacement of cement with Phosphogypsum from 0% to 10% causes increase in the compressive strength of concrete from 32.80MPa to 41.50MPa and from 47.95MPa to 52.45MPa for 7 days and 28 days curing respectively. Further increase in percentage replacement of cement with Phosphogypsum from 10% to 30% causes decrease in the compressive strength of concrete from 41.50MPa to 19.20MPa and

from 52.45MPa to 25.15MPa for 7days and 28days curing respectively.

2) The increase in Percentage replacement of cement with Phosphogypsum from 0% to 10% causes slight increase in the Split tensile Strength of concrete from 3.50MPa to 3.61MPa. Further increase in percentage replacement of cement with Phosphogypsum from 10% to 30% causes decrease in the Split tensile strength of concrete from 3.61MPa to 2.15MPa.
3) The increase in Percentage replacement of cement with Phosphogypsum from 0% to 10% causes increase in the flexural strength of concrete from 4.92MPa to 6.74MPa. Further increase in percentage replacement of cement with Phosphogypsum from 10% to 30% causes decrease in the flexural strength of concrete from 6.74MPa to 2.92MPa. From the crack patterns it is observed that the width and number of cracks are increased with the 20% and 30% replacement of Phosphogypsum.
4) SCC mix requires high powder content, lesser quantity of coarse aggregate, high range Super plasticizer and VMA to give stability and fluidity to the concrete mix.
5) SCC can be obtained for widely differing Phosphogypsum contents or cement contents as long as the paste volume constituted by the water cement ratio is kept constant.
6) The workability of SCC is equilibrium of fluidity, deformability, filling ability and resistance to segregation. This equilibrium has to be maintained for a sufficient time period to allow for transportation, placing and finishing.
7) An industrial waste like phosphogypsum impairs the strength development of calcined products and hence it can be used in construction industry for preparation of concrete replacing some quantity of cement, which is a valuable ingredient of concrete to achieve economy.
8) With 10% replacement of cement with phosphogypsum not only the compressive strength increased significantly with age but also the split tensile strength at 28 days increased. However, further replacement of cement with phosphogypsum lead to drastic reduction in compressive strength.
9) 10% replacement of cement with phosphogypsum gives maximum flexural strength than the other replacement of cement with phosphogypsum. The width and number of cracks also increases with the 20% and 30% replacement of phosphogypsum.
10) The Mix proportions for different grades of Self Compacting Concrete with Phosphogypsum are recommended as follows.

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Grade of Concrete	% Replacement of cement with Phosphogypsum	Cement (Kg)	PG (Kg)	FA (Kg)	CA				w/p	Water (L)	SP (Kg)	VMA (Kg)
					Total (Kg)	16-12.5mm (Kg)	12.5-10mm (Kg)	10-4.75mm (Kg)				
M40	10	540	60	666.6	700.8	175.2	175.2	350.4	0.4	240	9	0.3
M25	20	480	120	659.68	694.26	173.56	173.56	347.13	0.4	240	9	0.3
M15	30	420	180	648.52	682.52	170.6	170.6	341.3	0.4	240	12	0.3

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