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Utilization of Phosphogypsum as Partial Replacement of Fine Aggregates & Cement in Concrete Pavements

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Abstract— By the speedy growth of human requirements in many sectors, a considerable decrease in the availability and feasibility of the natural resources was forever faced. Neither the less, the high amount production is forever coupled with considerable amount of waste resources, which may unfavourably impacts the nearby environment. Efforts on by-passing such circumstances were newly intensified in several countries and global establishments looking for recent rules and legislations to reduce and reuse the generated waste. One of the foremost waste generating is the fertilizer and chemical manufacturing industries, with high amount of phosphogypsum (PG) as a by-product waste is generated worldwide. PG generated from chemical and fertilizer plants is being dumped and stacked in open yards, empty pits, pasturelands and landfill leading to extensive dispersal of environmental pollution. PG is a solid by-product material resulting from the manufacture of phosphoric acid, a major constituent of many fertilizers. Depending upon the source of rock approximately 4.5-5.0 tons of PG are generated per ton of phosphoric acid (H_3PO_4) produced. PG primarily mainly consists of calcium sulphate ($CaSO_4$) up to 93%; rest is a combination of impurities such as phosphate, soluble salts, fluoride, sand and organic compounds. The aim of my study is based on proper utilization of PG as a partial replacement of (a) fine aggregates in cc-pavements (b) cement in cc-pavements. The study includes the material characterization of PG sieve analysis, specific gravity, moisture content, workability, compressive strength, flexural strength, unit weight, normal consistency, and initial and final setting time.

Keywords- Phosphogypsum (PG), utilization, replacement, compressive strength, flexural strength, natural sand (NS)

I. INTRODUCTION

Phosphorus in the form of phosphate (expressed as P_2O_5) is a nutrient for plants and a building bloc in food production. Agriculture zone uses large amount of chemical fertilizers to refill and supplement the nutrients that growing plants take up from the soil. Recent demanding agriculture boosts natural phosphate levels in the soil through addition of the phosphate fertilizers. Phosphoric acid is an essential raw material for the production of fertilizers-88%, detergents-6%, and other farming products. World manufacturing consists of approximately 25 million tons per year of phosphoric acid. In India, there are 11 numbers of phosphoric acid industrializing units located in states namely Andhra Pradesh, Gujarat, Rajasthan, Kerala, Maharashtra, Orissa, Tamil Nadu and West Bengal. The total production of phosphoric acid (H_3PO_4) is about 1.4 million tons during year 2012-2013. In the year 2015-2016, it reaches to a limit of 6.5 million tons per annum. In Rajasthan the rock phosphate deposits are available in districts viz. Udaipur (largest in the country), Banswara, Chittorgarh, Jaisalmer and Jaipur. The current market rates of phosphogypsum and sand in Rajasthan are 400-450 per ton and 800-850 per ton respectively.

Rock phosphate is the naturally occurring source for P_2O_5. The PG essentially "Calcium sulphate ($CaSO_4$)" is generated as a waste from the phosphoric acid plants by the reaction of rock phosphate with sulphuric acid. If PG is disposed in open yards, it may cause danger to the surroundings, particularly during rainy season if appropriate measures are not taken. Besides environmental causes, handling and management of PG is a major problem in phosphoric acid plants because of the large volume of generated and large area required as well as the potential for release of dust, fluoride and heavy metals. PG generated from phosphoric acid plants is presently stacked and a few amounts are used by other industries especially in cement manufacturing, as a raw substitute for mineral gypsum and plaster board manufacturing.

In order to have minimal impacts on the environment; there is a need for evolving the guidelines for safe handling, including transportation, storage space, dumping and proper utilization of PG.

II. Material

A. *Phosphogypsum (PG)*

The material is collected from J.S Minerals and Chemical Pvt. Ltd. Lakadwas girwa Udaipur Rajasthan. The plant is located 13kms from Udaipur city. The total production of PG waste is about 60-70 tons per day. The rate of phosphogypsum in that area is 400-450 per ton. The PG waste generated from phosphate industry is stockpiled in chuck yards, very diminutive are using by other fertilizer factories in that neighbouring area, exclusive of being utilized in construction purposes of different pavement layers.

Fig. 1 Phosphogypsum (PG) Sample

B. *Natural Sand (NS)*

The material is collected from the Banas River (Bani), Tonk, Jaipur, Rajasthan, about 100 km's from the Jaipur city. This is a naturally occurring granular material extracted from the Bani, and composed of finely alienated rock and mineral particles.

Fig. 2 Natural Sand (NS) from Bani

III. Experimental programme

In order to determine the gradation of the PG and NS, sieve analysis test were performed as per IS 2386 (Part I)-1963 (methods of test for aggregates for concrete) reprinted in august 1997. In current analysis the moisture content (MC) was performed by oven dry method as per IS: 2720(Part II)-1973, specific gravity (SG) was determined by pycnometer method as per IS: 2720(Part III)-1980, workability was determined by compaction factor test as per IS: 1199-(1959), compressive strength test (CST) by compressive testing machine (CTM) of capacity 2000 KN as per IS: 516-(1959), flexural strength test (FST) by universal testing machine (UTM) of capacity 600 KN as per IS: 516-(1959), Normal consistency (NC) as per IS: 4031(Part4) 1988, and Initial and Final setting time as per IS: 4031(Part5) 1988.

IV. RESULTS AND DISCUSSION

A. Gradation of Particles

This test is performed as per IS 2386 (part I) 1963 (methods of test for aggregates for concrete) reprinted in august 1997. This test is performed to give the exact idea regarding gradation of the PG and NS. In this analysis 200 grams of the sample (PG & NS) were taken and kept for drying in an electrical oven for a period of 24 hours. After 24 hours of drying the sample were taken from the oven and kept for cooling in a tray. After the cooling of the sample, the materials placed in the IS sieves arranged in descending order as shown in the table I. The whole setup is placed on the sieve shaker for sieving for a time period of 10 minutes. After sieving is done, the weight of the each sieve is recorded and noted down for further calculation. The test results were expressed in the tubular form.

Table: I Results of grain size analysis on PG

(Passing 4.75 mm sieve)

Type of Sieve analysis: Dry

Total weight of PG= 200g

Weight of dish = 2888g

IS Sieve Opening, mm,µ	Weight of dish, (g)	Weight of dish +PG retained (g)	Weight of PG retained(g)	Cumulative wt. Retained(g)	Cumulative % retained	Cumulative % finer
4.75	375	375	0	0	0	0
2.36	311	312	01	01	0.5	99.50
1.00	397	403	06	07	3.5	96.50
600	415	424	09	16	8.0	92.00
300	373	386	13	29	14.5	85.80
150	352	372	20	49	24.5	75.50
75	336	398	62	111	55.5	44.50
Pan	327	416	89	200		

Table: II Results of grain size analysis on NS

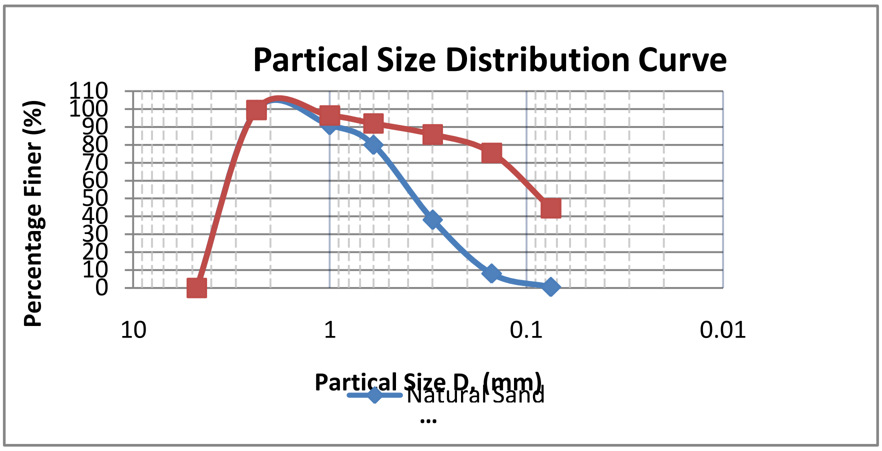
(Passing 4.75 mm sieve)

Type of Sieve analysis: Dry

Total weight of sand = 200g

Weight of dish = 2888g

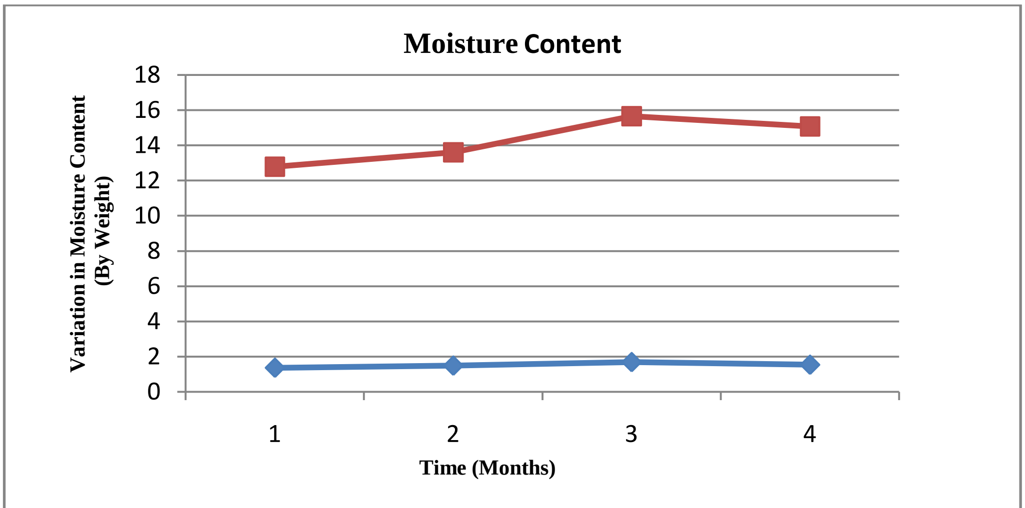
IS Sieve Opening, mm,µ	Weight of Dish, g	Weight of Dish + Sand retained (g)	Weight of Sand Retained (g)	Cumulative wt. Retained (g)	Cumulative % Retained	Cumulative % Finer
4.75	375	375	0	0	0	0
2.36	311	312	01	01	0.50	99.50
1.00	397	414	17	18	9.00	91.00
600	415	438	23	41	20.00	80.00
300	373	456	83	124	62.00	38.00
150	352	412	60	184	92.00	08.00
75	336	351	15	199	99.50	00.50
Pan	327	330	03			



The gradation of particles in the PG and NS are nearly analogous. Due to the resemblance in the gradation of the particles of the PG, it is concluded that PG can be utilized for the replacement of the natural sand.

B. *Moisture Content (MC)*

Moisture content of PG was determined by oven dry method as per IS: 2720 (Part II)-1973. The weight of the sample of PG and NS was taken as 30 grams. By determining the MC of the phosphogypsum and natural sand at certain intervals, behaviour of the PG and NS with respect to water content can be analysed.



Graph 2: Graph Between Moisture Content Of Sand & Phosphogypsum

During the time period (gap) of one month the MC of both the phosphogypsum (PG) and natural sand (NS) were calculated by an oven dry method. The moisture content of PG is more than that of the NS at every examination, which is 11.43, 12.12, 13.97, 13.54 in case of PG and 1.36, 1.48, 1.68 and 1.53 for natural sand respectively. Therefore, it is concluded that there is an increase of moisture content of PG 0.03-0.07 grams by weight and slight decrease in the NS by 0.004-0.006 respectively.

C. *Specific Gravity (SG)*

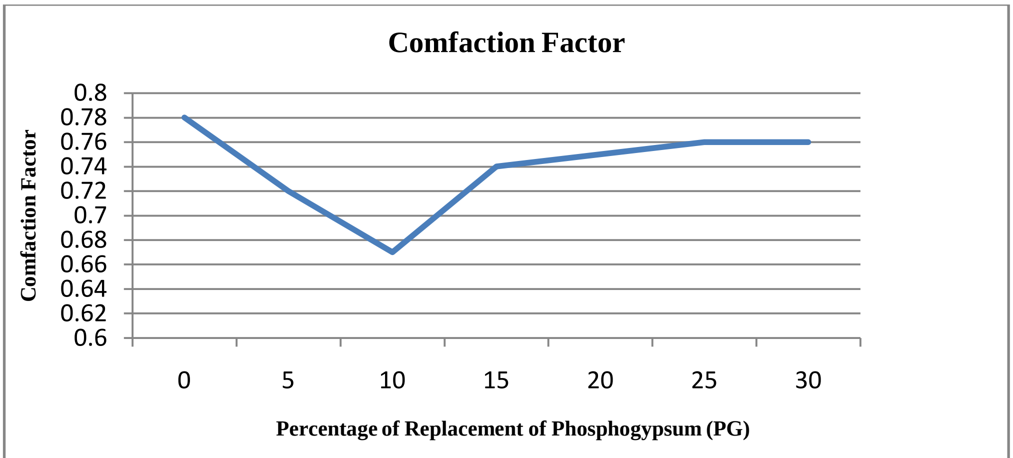
This test is performed as per IS: 2386 (III) 1963 in order to find out the specific gravity of the phosphogypsum (PG) and natural sand (NS). The specific gravity is calculated by pycnometer method. The specific gravity calculated for PG and NS are 2.41 and 2.77 respectively. The specific gravity of PG is slightly lesser than that of NS therefore, it is concluded that both the results are comparable.

D. ***Compaction Factor Test (CFT)***

This test is performed as per IS: 1199 (1959) in order to find out the workability of concrete. The test is designed mainly for use in the laboratory, but if conditions permit, it may also be used in the field. It is more precise and quick to respond than the slump test and is mainly useful for concrete mixes of very low workability as are normally used & when concrete is to be packed in by vibration, such concrete may consistently fail to slump.

Table: III Results of Compaction Factor Test

S. No.	Percentage (%) of Replacement of NS	w/c Ratio	Compaction Factor
1	0	0.47	0.78
2	5	0.47	0.72
3	10	0.47	0.67
4	15	0.49	0.74
5	20	0.50	0.75
6	25	0.51	0.76
7	30	0.52	0.76



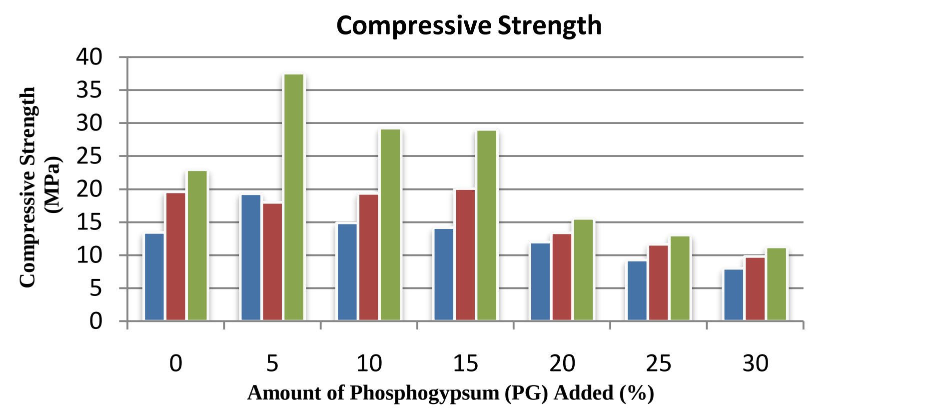
Graph 3: Graph between Percentage of Replacement of PG & Compaction Factor

The compaction factor of conventional concrete (i.e. M-20 mix) comes out to be 0.78 with a w/c ratio of 0.47. After substitution of NS with phosphogypsum i.e.; at the interval of 5% (in case of fine aggregate replacement), the compaction factor comes out to be 0.72, 0.67, 0.74, 0.75, 0.76, 0.76 respectively. Graph 3 shows the variation in compaction factor and percentage of replacement of PG. When the percentage of phosphogypsum (PG) is increased more than 5%, the workability of concrete mix decreases this leads to segregation and honeycombing. So, the water cement (w/c) should be increased by 1% at higher percentage ranges of phosphogypsum in order to retain the workability in concrete. Further Graph 3 shows that at 25% and 30% replacement of natural sand the compaction factor remains constant equal to the value of 0.76 irrespective of increase in the w/c ratio. Also, at 15% the water-cement ratio is increased by 2% (i.e. from 0.47 to 0.49). In order to make a mix of proper workability for higher percentage of PG the water-cement ratio is increased by 1% for every increment of PG to maintain the workability in the mix.

To limit w/c ratio and maintain the workability some water reducing admixture may be use in future.

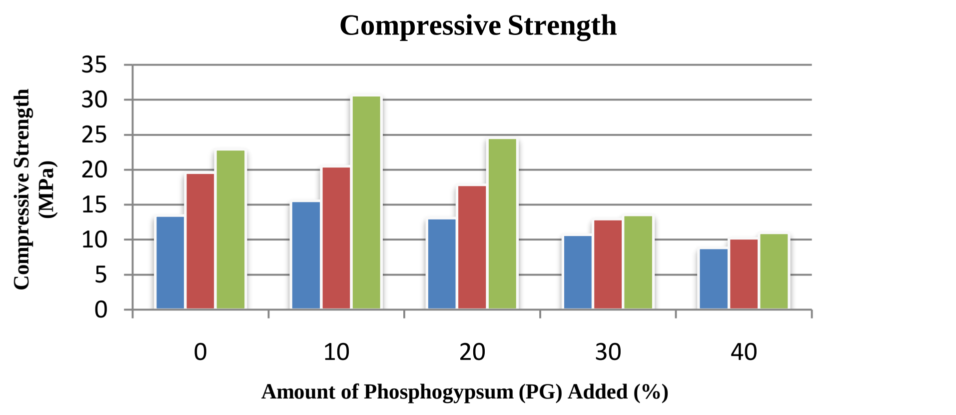
D. Compressive Strength Test (CST)

This test is performed as per IS: 516-1959 in order to determine the compressive strength of the cubes casted by replacing (a) the natural sand with PG (b) cement with PG (c) natural sand and cement with PG, by a variable percentage. This test is performed by compressive testing machine of capacity 2000KN.



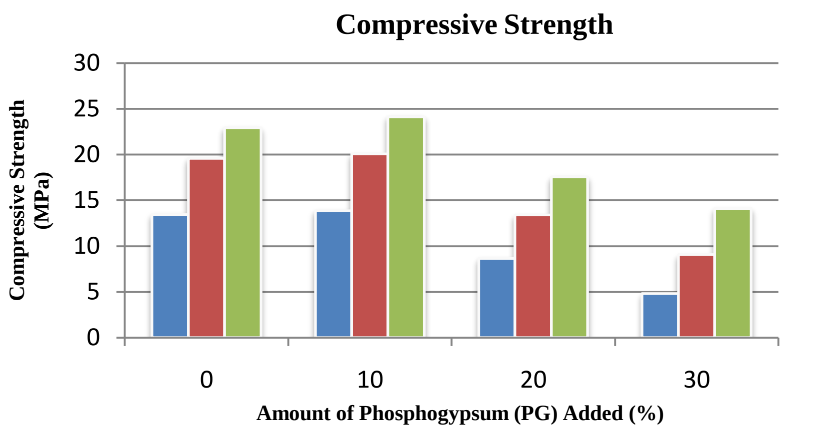
Graph 4 (a) : Graph between Percentage of PG added & Compressive Strength By Replacing NS

The compressive strength of M-20 mix design at 7, 14, 28 days are 13.44 MPa, 19.58 MPa, 22.93 MPa respectively. In the present analysis {case D (a)} of replacement of natural sand by phosphogypsum (PG), the compressive strength of the cube samples increases up to the value of 15% replacement of natural sand at 7, 14, 28 days are 14.88 MPa, 20.07 MPa, 29.03 MPa respectively as shown in graph 4 (a). Beyond 15% replacement of fine aggregate the compressive strength decreases with respective to the conventional concrete (M-20 mix). Therefore, it is concluded that up to 15% replacement of natural sand by PG, the concrete behaves fine with compressive strength and hence can be used in construction of cc-pavements.



Graph 4 (b) : Graph between Percentage of PG added & Compressive Strength By Replacing Cement

The compressive strength of M-20 mix design at 7, 14, 28 days are 13.44 MPa, 19.58 MPa, 22.93 MPa respectively. In the present analysis {case D (b)} of replacement of cement by phosphogypsum (PG), the compressive strength of the cube samples increases up to the value of 20% replacement of cement at 7, 14, 28 days are 13.11 MPa, 17.85 MPa, 24.59 MPa respectively as shown in graph 4 (b). Beyond additional (i.e. 20%) replacement of cement by PG the compressive strength decreases with respective to the conventional concrete (M-20 mix). Therefore, it is concluded that up to 20% replacement of cement by PG, the concrete behaves fine with compressive strength and hence can be used in construction of cc-pavements. Also, helps in conserving the conventional material like cement and thus overall reduces the cost of construction of cc-pavements.



Graph 4 (c) : Graph between Percentage of PG added & Compressive Strength By Repacing Both NS and Cement

The compressive strength of M-20 mix design at 7, 14, 28 days are 13.44 MPa, 19.58 MPa, 22.93 MPa respectively. In the present analysis {case D(c)} of replacement of both materials (natural sand and cement) in equal percentages by phosphogypsum (PG), the compressive strength of the cube samples increases up to the value of 10% replacement of natural sand and cement at 7, 14, 28 days are 13.25 MPa, 16.81 MPa, 24.15 MPa respectively as shown in graph 4(c).

Beyond 10% replacement of both the materials (i.e. natural sand and cement), compressive strength decreases with respective to the conventional concrete (M-20 mix). Therefore, it is concluded that up to 10% replacement of both natural sand and cement by PG, the concrete behaves fine with compressive strength and hence can be used in construction of cc-pavements.

D. Unit Weight (γ)

The compactness of concrete is a measure of its unit weight. The unit weight of concrete varies depending on the amount and density of the aggregate, the water and cement content, and the amount of entrained air (and entrapped air). The concrete weight can differ depending on the air and moisture content it contains. The Unit weight (γ) is calculated as weight per unit volume i.e. γ= w/v.

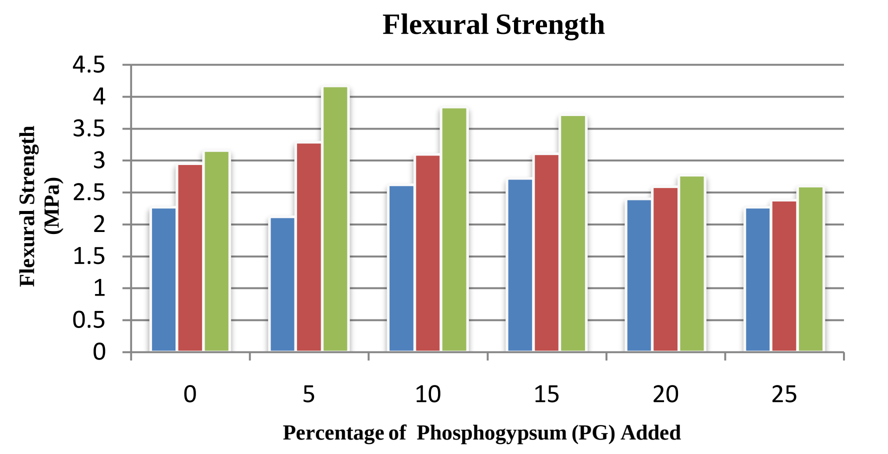
Table: IV Results of Unit Weight (γ)

S.No.	Unit Weight of Normal Concrete (M-20 Mix) (KN/m^3)	Unit weight of concrete using PG after 28 days of curing (KN/m^3)					
		5%	10%	15%	20%	25%	30%
01	2484	2440	2410	2378	2360	2338	2306

The experimental analysis shows that the unit weight of normal concrete (M-20) is 2484 KN/m^3 and that of PG based concrete after 28 days of curing at 5%,10%,15%,20%,25%,30% replacement are as 2440 KN/m^3,2410 KN/m^3, 2378 KN/m^3,2360 KN/m^3,2338 KN/m^3, and 2306 KN/m^3 respectively. Test results shows that there is drop off in the unit weight of concrete cube samples as compared to that of conventional concrete.

F. Flexural Strength Test (FST)

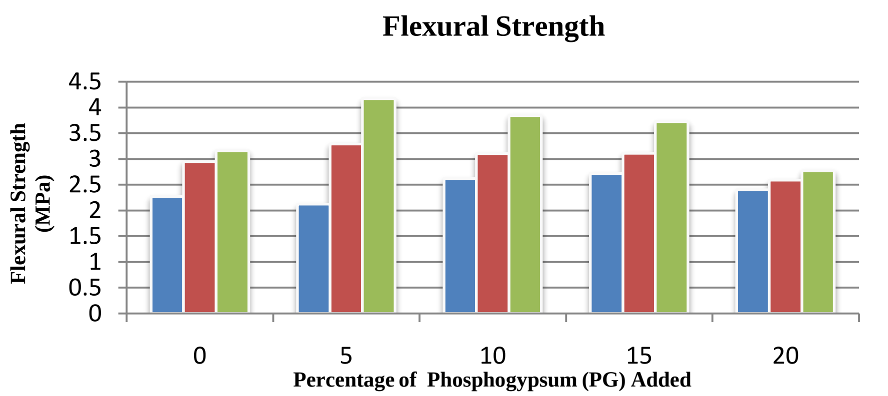
This test is performed as per IS: 516-1959 in order to determine the flexural strength of the beams casted by replacing (a) the natural sand with PG (b) cement with PG (c) both natural sand and cement with PG, by a variable percentage. This test is performed by universal testing machine (UTM) of capacity 400KN.



Graph 5 (a) : Graph between Percentge of PG & Flexural Strength By Replacing NS

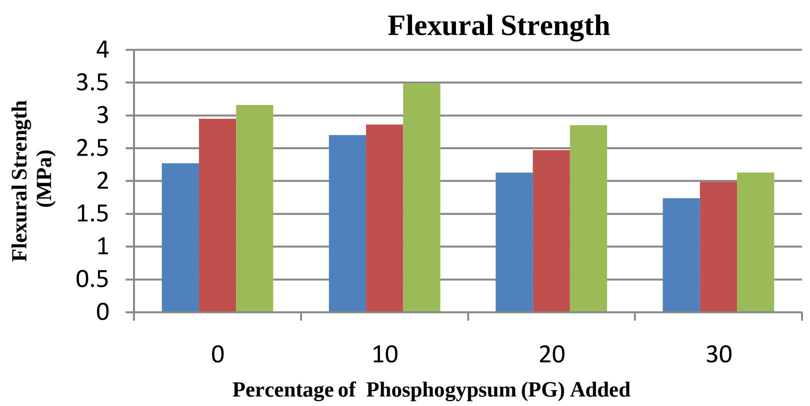
The flexural strength of conventional concrete (M-20 mix) after 7, 14, 28 days of curing are 2.17 MPa, 2.95 MPa, 3.16 MPa respectively. In the present analysis {case F (a)} replacement of natural sand (NS) by phosphogypsum (PG), the flexural strength of the concrete increases after 7, 14, 28 days of curing as 2.72 MPa, 3.11MPa and 3.72MPa respectively by 15% replacement as shown in graph 5 (a). Ahead of 15% replacement of NS by PG, the flexural strength decreases endlessly. Therefore, it is concluded that up to 15% replacement of natural sand by PG, the concrete behaves fine with flexural strength and hence can be used in construction of cc-pavements.

Also, at 15% substitution of NS by PG the water-cement ratio is increased by 2% (i.e. from 0.47 to 0.49). In order to make a mix of proper workability for higher percentage of PG the water-cement ratio is increased by 1% for every increment of PG to maintain the workability in the mix.



Graph 5 (b): Graph between Percentge of PG & Flexural Strength By Repacing Cement

The flexural strength of conventional concrete (M-20 mix) after 7, 14, 28 days of curing are 2.17 MPa, 2.95 MPa, 3.16 MPa respectively. In the present analysis {case F (b)} of replacement of cement by phosphogypsum (PG), the flexural strength of the concrete increases after 7, 14, 28 days of curing as 2.49MPa, 3.01MPa, and 3.40MPa respectively by 10% replacement as shown in graph 5(b). Ahead of 20% replacement of cement by PG, the flexural strength decreases endlessly. Therefore, it is concluded that up to 20% replacement of cement by PG, the concrete behaves fine with flexural strength and hence can be used in construction of cc-pavements.



Graph 5 (c) : Graph between Percentge of PG & Flexural Strength By Replacing Both NS and Cement

The flexural strength of conventional concrete (M-20 mix) after 7, 14, 28 days of curing are 2.17 MPa, 2.95 MPa, 3.16 MPa respectively. In the present analysis {case F (c)}of replacement of both materials (fine aggregates and cement) in equal percentages by phosphogypsum (PG), the flexural strength of the concrete increases after 7, 14, 28 days of curing as 2.70MPa, 2.86MPa, and 3.49MPa respectively by 10% replacement as shown in graph 5 (c). Ahead of 10% replacement of cement by PG, the flexural strength decreases endlessly. Therefore, it is concluded that up to 10% replacement of both natural sand and cement by PG, the concrete behaves fine with flexural strength and hence can be used in construction of cc-pavements.

G. Normal Consistency (NC)

This test is performed as per IS: 4031(Part4) 1988 in order to find out the standard consistency of the phosphogypsum (PG). Individual this test shall be conducted at a temperature 27 ± 20°C and the relative humidity of laboratory should be 65 ± 5%.

Table: IV Results of Normal Consistency

Weight of PG = 300g

S.No.	Water Content (%)	Needle Penetration (mm)
1	28	9.5
2	30	6.0

Consistency physically means that how much percentage of weight of water to be added to sample to make a paste of standard consistency. This test helps to determine the water content required for conducting the tests like initial and final setting time, soundness and compressive strength. The amount of water required for IST and FST is (0.85 P), for compressive strength is (P/4 +3%) and for soundness (0.78 P), (where P = Consistency of standard paste). Experimental analysis shows that the normal consistency of phosphogypsum (PG) is 30%, as shown in the table IV above as compared to that of Ordinary Portland Cement (OPC) is 26 to 33%.

H. Initial Setting Time (IST)

This test is performed as per IS: 4031(Part5) 1988 in order to find out the initial setting time (IST) of the phosphogypsum (PG). Individually specified this test shall be conducted at a temperature of 27 ± 20°C and 65 ± 5% of relative humidity of the laboratory.

Table: V Results of Initial Setting Time

Weight of PG = 300g

S.No.	Time (minutes)	Needle Penetration (mm)
1	0	-
2	10	-
3	20	-
4	30	-
5	40	-
6	50	0.5
7	60	2.5
8	70	7.0

The initial setting time period is required to delay the process of hardening and hydration or in other words, it is the time from the moment you added water to the binding material and even enter in the sample paste vicat needle for a distance of 5mm to 7mm from the bottom of the template. Test results shows that the initial setting of sample (PG) is 70 minutes which is more that the IST of Ordinary Portland Cement (30 min). This concludes that the phosphogypsum behaves as a retarder to increase the initial setting time of the cement in the mix.

I. Final Setting Time (FST)

This test is performed as per IS: 4031(Part5) 1988 in order to find out the final setting time (FST) of the phosphogypsum (PG). Individually specified this test shall be conducted at a temperature of 27 ± 20℃ and 65 ± 5% of relative humidity of the laboratory.

Table: VI Results of Final Setting Time

Weight of PG = 300g

S.No.	Time (minutes)	Remark
1	0	Clear visible outer ring and dot
2	30	″
3	60	″
4	90	″
5	120	″
6	150	″
7	180	Clear visible outer ring and dot
8	210	″
9	240	″
10	270	″
11	300	″
12	330	″
13	360	″
14	390	″
15	420	″
16	450	″
17	480	Low visible outer ring and clear dot
18	510	″
19	540	″
20	570	″
21	600	″
22	630	″
29	660	″
24	690	″
25	720	″
26	750	″
27	780	Outer ring disappears & only dot is visible

Final setting time is the period at which the concrete lose its plasticity when placed finally, so that it is least vulnerable to damages from exterior agencies. Test results shows that the FST of phosphogypsum is 780 minutes (13 hours) which is higher as compared to that of Ordinary Portland Cement (not more than 10 hours). Therefore, it is concluded that the PG having higher FST can be used with cement, as an admixture (retarder) in the concrete, so as to reduce the FST of cement as well as overall cost of the concrete mix.

V. CONCLUSIONS

The gradation of particles in the PG and NS are nearly analogous. Due to the resemblance in the gradation of the particles of the PG, it is concluded that PG can be utilized for the replacement of the natural sand.

Moisture content of natural sand (NS) is found in the range from 1.36-1.68 and that of phosphogypsum is in the range from 11.43- 13.97. After collection from the plant it is not varying and is in the workable/practicable range.

The specific gravity calculated for PG and NS are 2.41 and 2.77 respectively. The specific gravity of PG is slightly lesser than that of NS therefore, it is concluded that both the results are comparable.

When the percentage of phosphogypsum (PG) is increased more than 5%, the workability of concrete mix decreases this leads to segregation and honeycombing. So, the water cement (w/c) should be increased by 1% at higher percentage ranges of phosphogypsum in order to retain the workability in concrete. Further Graph 3 shows that at 25% and 30% replacement of natural sand the compaction factor remains constant equal to the value of 0.76 irrespective of increase in the w/c ratio. Also, at 15% the water-cement ratio is increased by 2% (i.e. from 0.47 to 0.49). In order to make a mix of proper workability for further higher percentage of PG the water-cement ratio is increased by 1% for every increment of PG to maintain the workability in the mix. To limit w/c ratio and maintain the workability some water reducing admixture may be use in future.

The compressive strength of the cube samples increases by replacement of natural sand (NS) up to the value of 15% at 7, 14, 28 days are 14.88 MPa, 20.07 MPa, 29.03 MPa respectively. Beyond 15% replacement of fine aggregate the compressive strength decreases with respective to the conventional concrete (M-20 mix). Therefore, it is concluded that up to 15% replacement of natural sand by PG, the concrete behaves fine with compressive strength and hence can be used in construction of cc-pavements. In second case, the compressive strength of the cube samples increases up to the value of 20% replacement of cement at 7, 14, 28 days are 13.11 MPa, 17.85 MPa, 24.59 MPa respectively. Beyond additional (i.e. 20%) replacement of cement by PG the compressive strength decreases with respective to the conventional concrete (M-20 mix). Therefore, it is concluded that up to 20% replacement of cement by PG, the concrete behaves fine with compressive strength and hence can be used in construction of cc-pavements. In the third case, the compressive strength of the cube samples increases up to the value of 10% replacement of natural sand and cement at 7, 14, 28 days are 13.25 MPa, 16.81 MPa, 24.15 MPa respectively. Beyond 10% replacement of both the materials i.e. (cement and natural sand), the compressive strength decreases with respective to the conventional concrete (M-20 mix).

The experimental analysis shows that the unit weight of normal concrete (M-20) is 2484 KN/m^3 and that of PG based concrete after 28 days of curing at 5%,10%,15%,20%,25%,30% replacement are as 2440 KN/m^3, 2410 KN/m^3, 2378 KN/m^3, 2360 KN/m^3, 2338 KN/m^3, and 2306 KN/m^3 respectively. Test results shows that there is drop off in the unit weight of concrete cube samples as compared to that of conventional concrete.

The flexural strength of the concrete cube samples increases after 7, 14, 28 days of curing as 2.72MPa, 3.11MPa, and 3.72MPa respectively by 15% replacement of natural sand. Ahead of 15% replacement of NS by PG, the flexural strength decreases endlessly. Therefore, it is concluded that up to 15% replacement of natural sand by PG, the concrete behaves fine with flexural strength and hence can be used in construction of cc-pavements. In second case, the flexural strength of the concrete cube samples increases after 7, 14, 28 days of curing as 2.49 MPa, 3.01MPa, and 3.40MPa respectively by 20% replacement of cement. Ahead of 20% replacement of cement by PG, the flexural strength decreases endlessly. In third case, the flexural strength of the concrete cube samples increases after 7, 14, 28 days of curing as 2.70MPa, 2.86MPa, and 3.49MPa respectively by 10% replacement of both cement and natural sand. Ahead of 10% replacement of cement and natural by PG, the flexural strength decreases endlessly.

Experimental analysis shows that normal consistency of phosphogypsum (PG) is 30%, as compared to that of cement (OPC) is 26 to 33%.

Experimental analysis shows that the initial setting time (IST) of phosphogypsum (PG) is 70 minutes which is more than IST of OPC (30 min). This concludes that the phosphogypsum behaves as a retarder to increase the initial setting time of the OPC in the mix.

Experimental analysis shows that the final setting time (FST) of phosphogypsum (PG) is 780 minutes (13 hours) which is higher as compared to that of OPC (not more than 10 hours). Therefore, it is concluded that the PG having higher FST can be used with cement, as an admixture (retarder) in the concrete, so as to reduce the FST of cement as well as overall cost of the concrete mix.

Use of PG helps in conserving the conventional material like sand, cement and thus overall reduces the cost of construction of cc-pavements.

The cost of the PG is suitably low as compared to the conventional materials, thus overall cost of the construction of pavement is minimised.

Utilization of PG in road construction helps us to solve the problems of environmental contamination as well as profitable for disposal of industrial waste.

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