Research and Industry
Vol. 27, March 1982, pp. 11-14

Utilization of Phosphogypsum in Masonry Mortar

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Received 9 *April* 1981; *accepted* 18 *December* 1981

Phosphogypsum, a waste-product of fertilizer plants, can be used for making plaster or as an additive to cement clinker after its purification. The cost of processing is so high that it is not economical to use it in purified state. The experiments conducted by the Central Building Research Institute, Roorkee, have shown that raw phosphogypsum can replace lime in composite mortars or can be used directly for making masonry cement.

Phosphogypsum is a waste-product of wet process phosphoric acid plants. In India, about 1.4 million tonnes of phosphogypsum is available per annum from the fertilizer industry. Phosphogypsum contains impurities of phosphates, fluorides and organic matter which render it unsuitable for making gypsum-plaster. These impurities prolong the setting-time and retard early strength-development of gypsum-plaster produced after calcination and also of portland cement, when used as an additive to cement clinker. Several purification methods for processing phosphogypsum have been developed in various countries[1,2]. But the investment on plant and machinery and the cost of processing of phosphogypsum are so high, that they are not economically viable for adoption in India. It was, therefore, considered necessary to explore the possibility of mixing phosphogypsum as such (without calcination or beneficiation) in masonry mortars as an additive or for making masonry cement, where a longer setting-time is desirable and initial strength-development is not very important.

As an additive in mortar

When freshly made, a good mortar should hang on the trowel, spread easily, should not lose water rapidly and stiffen in contact with absorptive units. It should also remain plastic long enough so that the walling units may be easily adjusted to the line and level. Straight portland cement-sand mortar lacks these properties although strength-development is quite good. Addition of lime to portland cement in the proportion of 1:1 or 2:1 by volume with 6 to 9 parts of sand has been found to be effective in improving these properties to a great extent. However, the cost of lime has gone up so tremendously that it is not economical to use for this purpose. The philosophy of mix design of mortar is based on the premise that the voids in the sand used, which are generally 33% of volume of sand, have to be filled with binder[3]. It may be noted that the ratio of binder to aggregates, i.e. cement plus lime to sand, is 1:3 in composite mortars. Addition of finely powdered phosphogypsum to cement-sand mortar to meet the above requirement was therefore thought about. Addition of fine inert materials is known to increase the workability and strength of low-strength lean concrete or mortar[4,5].

Experimental procedure—Before understanding the effect of addition of phosphogypsum to portland cement-sand mortar, routine tests such as the chemical analysis of phosphogypsum and physical tests for hydraulic cement (IS:4031-1968) were conducted. The results of such tests are shown in Table 1 and Table 2 respectively.

Table 1—Chemical Analysis of Phosphogypsum

	(%)
Total P_2O_5	0.42
CaO	32.07
SO_3	45.08
F	1.12
Alkalies	0.39
Organic matter	0.59
Water of crystallization	19.68

Table 2—Physical Characteristics of Portland Cement

Surface area, cm^2/g	4100
Setting time, min	
Initial	126
Final	271
Compressive strength, kg/cm^2	
3 days	208
7 days	275

Sand of fineness modulus 1.75 was used in all the mortars. Mortar samples were then cast at $110 \pm 5\%$ flow, using tap water for mixing.

The portland cement - phosphogypsum - sand mortar thus prepared was tested for its two important physical properties, namely, water-retention and compressive strength. The results of the tests are given in Table 3.

Discussion—These results show that phosphogypsum, when added as such to cement-sand mortar, increases water retention, in other words its workability, although it is less than the cement-lime-sand mortar. The effect on compressive strength is negligible.

Use in masonry cement

Gypsum is normally added to cement clinker during grinding to regulate setting-time of cement. It also influences the strength-development, shrinkage and expansion during moist curing. Optimum quantity of gypsum to be mixed is normally related to C_3A content, fineness and alkali content of cement. Hobbs has shown[6] that with the exception of cement with very low C_3A content, a sharp increase in expansion during the 7-day period is generally observed when SO_3 content is raised above a particular level which varies with the fineness and composition of cement. At still higher levels the expansion is independent of SO_3 content. Similarly, the rate of hardening increases with increasing gypsum content up to a certain limit after which addition of more gypsum causes decrease in the rate of hardening.

Cement pastes, mortar and concrete expand when cured in water. Large expansion can occur due to the formation of ettringite by the reaction of C_3A and gypsum in presence of lime[7]. The formation of ettringite is not destructive in the mortar of low-strength and low-stiffness, which is generally used for plastering and laying of

Table 3—Water-retention and Compressive Strength of Portland Cement - Phosphogypsum Mortar

Min. proportion (by vol)			Water retention	Compressive strength (kg/cm^2)			
PC	PG	S	(%)	3d	7d	28d	90d
1	1	6	37	10.00	12.30	20.00	23.40
1	0.5	6	29	10.00	12.00	19.00	23.00
1	—	6	18	9.60	15.40	23.00	25.60
PC	L	S					
1	1	6	46	9.00	14.70	25.00	26.20

PC = Portland cement, PG = phosphogypsum, S = sand (F.M. = 1.75), d = days.

Table 4—Properties of Masonry Cement (Portland Cement and Phosphogypsum Mixtures)

Masonry cement (Batches)	Composition (by wt)		Setting time (min)		Water retention	Compressive strength (kg/cm^2)	
	PC	PG	Initial	Final	(%)	7d	28d
A	50	50	150	310	67	20	32
B	60	40	144	324	66	29	51
C	70	30	140	310	62	49	104
N	60	40	135	300	67	27	52
Requirements as per IS:3466-1967			≯ 90	≮ 1440	≮ 70	≮ 25	≮ 50

PC = portland cement, PG = phosphogypsum, A,B,C = Masonry cement with phosphogypsum, N = masonry cement with natural gypsum, d = days.

Table 5—Compressive Strength of Masonry Mortars (kg/cm^2)

Sand used (fineness modulus)	Period of curing (days)	Masonry cement B		Masonry cement C	
		1:4 by vol or 1:5.6 by wt	1:5 by vol or 1:7 by wt	1:4 by vol or 1:5.6 by wt	1:5 by vol or 1:7 by wt
2.29	7	10.0	7.2	11.0	9.0
	28	15.5	8.8	13.0	13.0
	90	20.5	12.5	22.0	14.5
1.75	7	12.0	9.0	14.0	12.0
	28	17.5	11.5	22.0	15.6
	90	27.0	15.5	27.0	16.5
1.22	7	10.5	9.0	12.0	12.0
	28	17.0	11.0	19.0	16.0
	90	26.0	15.5	26.0	18.0

Loose bulk density of masonry cement = 1000 kg/m^3; loose bulk density of sand = 1400 kg/m^3

bricks. So it was decided to mix phosphogypsum in place of ground limestone generally used for making masonry cement[8]. Addition of 30-50 per cent of phosphogypsum to portland cement further dilutes the C_3A content and thereby curbing the tendency of excessive expansion due to the formation of ettringite.

Experimental procedure—Three masonry cement mixes were prepared by grinding together portland cement and phosphogypsum in the proportion of 50:50 (A), 60:40 (B) and 70:30 (C) by weight. One batch of 60:40 mix was mixed with natural gypsum to see the effect of impurities of phosphogypsum. These three batches of masonry cement were tested as per methods given in IS:4031-1968. Results obtained, along with the Indian Standard requirements are given in Table 4.

In other countries masonry cement is used normally in 1:4 or 1:5 cement-sand proportions. In India masonry mortars were prepared in the same proportions as in foreign countries by mixing sands of three different fineness moduli 1.22,1.75 and 2.25 with the masonry cement mix

batches B and C separately, water was added to each of the six batches of mortar to give the flow 110 ± 5%. Cubes of size 5 cm were prepared from each batch of mortar and cured under 90% R.H. for 7 days, 28 days and 90 days respectively and tested for compressive strength. The results are given in Table 5.

Discussion—The data in Table 4 show that masonry cement batches B and C pass the requirement for setting-time and compressive strength. Water retention is very near to 70%. This, however, can be improved further by more grinding. There is no adverse effect of phosphogypsum on compressive strength which is at par with that of masonry cement produced with natural gypsum (mix N).

The strength of the 1:4 and 1:5 masonry cement-sand mortar is slightly less than 1:6 portland cement-sand mortar. Most of the mortars fall in the grade MM 1.5 of IS:2250-1981, Code of Practice for Preparation and Use of Masonary Mortar.

Conclusion

Phosphogypsum can be used without beneficiation or calcination for making masonry cement or used in place of lime in composite mortars. The use of phosphogypsum will be economical as compared to lime in composite mortars.

Acknowledgement

The work forms part of the research programme of the Institute. The authors are grateful to the Director, Central Building Research Institute, Roorkee, for permitting them to publish this paper.

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