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STUDIES ON CEMENTITIOUS MATERIALS
Part I. Fat Limes and Portland Cement Mixes

M. Arshad Ali Beg, T.H. Usmani, Tamoor Wahab and S. Zafar Ahmed

PCSIR Laboratories, Karachi-39

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The effect of intergrinding fat limes of different origins as dry hydrates and in putty forms on the compressive strength of Portland cement has been studied and compared with standard Portland cement mortar. 30 % Portland cement mixes with hydrated lime in putty form have an average compressive strength of 725 and 1070 psi compared with 645 and 1020 psi after 7 and 28 days respectively for dry hydrates. These results are in conformity with ASTM specifications and suggest that such mixes can substitute upto 30 % of Portland cement in masonry mortars.

Key words: Cementitious materials, Fat lime, Portland cement.

INTRODUCTION

The blending of Portland cement with 10-35 % finely ground sand, limestone and dolomite rocks, has been practised occasionally in some countries, mainly for reducing cement consumption [1]. Lime cement mixes have been used to take advantage of the added plasticity, water retentivity, high sand carrying capacity, flexibility and bond strength to masonry mortars [2]. The use of these mortars is normally preferred in waterlogged and salinity stricken areas. Lime is employed either alone or in varied proportions with Portland cement or as an ingredient in mortar mixes with a graded sand aggregate for the preparation of masonry units [3]. It may be used as a dry hydrate or a putty from a dry hydrate that is soaked or from slaked quicklime [4].

Lime was the main cementing material in the past until the production of Portland cement became possible on industrial scale. Lime has been used in concrete works like foundations, footings and in the construction of underwater piers for harbour construction such as that at the Karachi Port. Lime mortars have been used in historical buildings like the Pyramids of Egypt, Great Wall of China and the Taj Mahal. Lime therefore has a history of producing eminently satisfactory mortars and durability experience extending over several centuries. The use of lime has declined in favour of cement only during recent years due to lack of quality assured lime, its low compressive strength and slow setting qualities of its mortars [5]. Furthermore, production of lime has become highly energy intensive due to the use of traditional fuel. It is estimated that the production of lime needs 2.7 million Btu/ton which is 50 to 75 % of the energy required for cement making (5.9 and 3.5 million Btu/ton for wet and dry processes respectively) and as such the use of the former could be retrieved if the fuel could be efficiently utilized and appropriate applications could be found in the construction industry. One such application could be as lime-cement mixtures whereby cement usage could be substantially reduced.

Pakistan has extensive deposits of limestone which outcrop over large areas throughout the country. They differ widely in their chemical composition. Salient features of some of the famous deposits are recorded in Table 1 [6]. It may be seen from the analytical data that the nature of limestone varies from pure limestone of

Table 1. Chemical analysis of limestones of different origin [6].

Sr.	Constituent present	D.I. Khan	Bholari	Saeedpur (Distt. Hyderabad)	Rohri	Multan	Peshawar	Quetta	Karachi	
									Murli Hills	Manghopir
1.	Loss on ignition	43.46	42.29	43.59	43.30	39.00	43.07	42.20	34.73	42.10
2.	SiO2	0.26	4.08	0.39	2.10	12.55	2.29	1.24	11.42	3.00
3.	CaO	55.50	51.88	54.96	53.70	47.50	43.55	52.23	41.62	52.70
4.	Al_2O_3		0.10	0.21	1.00	2.00	1.50	1.30	8.51	1.20
5.	Fe_2O_3	0.75	0.19	0.11	0.50	1.05	0.65		0.51	
6.	MgO	0.09	2.93	0.41	0.30	1.43	8.80	0.25	2.06	0.80

D.I. Khan and Saeedpur (CaO, 54.9-55.5 %) to hydraulic lime of Murli Hills and the Multan region (SiO_2, 11.4-12.5 %) and dolomitic lime of the Peshawar region (MgO 8.8 %).

The present study reports the substitution of fat limes of different origin, viz. Saeedpur, Bholari, Jangshahi and Manghopir in varying proportions with Portland cement. Dry hydrated lime as well as lime hydrate putty in a wet plastic paste form containing 80 % moisture have been used for substitution experiments. Commercial hydrated lime is obtained by the classical solid-liquid phase reaction through dry or wet hydration. The former is a dry pulverulent hydrate while the latter is a putty or a wet plastic paste containing free water [2].

Compressive strength of mortrars is more important in load bearing walls than in the non-load bearing ones. It is estimated that a mortar with a compressive strength of 80 psi can support a four-storey building of solid brick masonry [7]. The present study shows that the limes produced in Pakistan yield mortars having adequate compressive strength.

EXPERIMENTAL

For the experiments described here, four samples of limestone, namely, A (Saeedpur), B (Bholari), C(Jangshahi) and D(Manghopir) were collected and calcined in the traditional veritical gas fired kiln at temperature of 1000 to 1100°C and slaked by the batch method [8].

Hydrated limes in dry and putty form capable of mixing with water to any desirable consistency were prepared in closed circuit systems to prevent recarbonation [9].

Detailed chemical analysis of the Portland cement, four hydrated lime samples and their mixtures in different proportions were carried out by the Standard Method [10]. Slaking and settling rates of these samples were determined by the usual method [11].

The above four hydrated limes in dry form and in the form of putty were used for preparing substituted cements. The parent cement was the ordinary Portland cement (OPC) of which 10 to 40 % was substituted by each of the two forms of lime separately, bringing the total number of substituted cement to 32. Standard mortars of Portland cement and lime samples were also prepared by mixing them with sand in the ratio of 1:2.75.

Compressive strength of the standard mortars and substituted cements was determined at the age of 7 and 28 days in accordance with ASTM C-109. The amount of water was adjusted to give the mix a constant flow of 0 ± 5. Consequently the water/substituted cement ratio remained virtually constant (0.57-0-61) in all mixes while the water/cement ratio varied from 0.61-1.18.

RESULTS AND DISCUSSIONS

Four samples of lime from Saeedpur, Bholari, Jangshahi and Manghopir designated A,B,C and D were used as substituents for ordinary Portland cement. The chemical analysis of the limes and Portland cement carried out by ASTM specification appears in Table 2 which shows that samples of the former contains 69-70 % calcium oxide. They thus fall in the category of pure or fat lime (92-98 % CaO on dry weight basis).

A comparison of results in Table 2 with Table 3 those given in shows the dependence of slaking and sedimentation rates on the percentage of silica and magnesia [12]. It may be seen that the slaking and settling rates of sample A are the lowest. This can be attributed to its high purity

Table 2. Chemical analysis of Portland cement and hydrated limes.

Sr. No.	Consstituents analysed	Portland lime sample cement	A %	B %	C %	D %
1.	Loss on ignition	1.48	28.57	26.58	28.95	22.32
2.	SiO_2	22.18	0.28	1.24	0.42	3.31
3.	CaO	63.96	70.20	70.40	69.52	70.14
4.	Al_2O_3	6.06	0.21	0.10	0.55	1.66
5.	Fe_2O_3	4.21	0.11	0.14	0.19	0.32
6.	MgO	1.41	0.32	1.77	0.80	1.80
7.	SO_3	1.05	0.12	0.20	0.15	1.31

A = Saeedpur (Distt. Hyderabad); B = Bholari ; C = Jangshahi; D = Manghopir.

Table 3. Slaking and settling rates of limes.

Sr. No.	Lime sample	Slaking rate (min.)	Settling rate (ml/24 hr.)
1.	A	6.00	23.00
2.	B	7.50	29.50
3.	C	6.75	26.00
4.	D	8.00	30.00

and large surface area, both being responsible for increase in the degree of its reactivity [2]. These two aspects are supported by their micro-structure which comprises small loose clusters or amorphous nature for A while others are in the form of small tight clusters [13]. Sedimentation rate which is a measure of surface area of lime suspension is comparatively higher in samples B and D which may be due to the higher percentage of magnesium oxide present therein [14]. It is well known that amorphous lime has higher chemical reactivity. Accordingly, having higher purity it is more reactive.

For comparing the compressive strength of lime samples A,B,C and D their hydrates were made to pass through 72 mesh sieve to ensure the removal of the coarse and unslaked aggregates and complete interaction of the lime particles with cement.

Compressive strength data listed in Table 4 shows that Portland cement blended with 30 % sample D gives an average compressive strength of 699 and 1142 psi at 7 and 28 days respectively which is higher than that of A, B and C. It may be due to the relatively higher silica present in this sample. The compressive strength data obtained for plain lime mortars also support these results. Standard cement-sand mortars have a compressive strength of the order of 2030 and 2880 psi at 8 and 28 days respectively while the ASTM Specification C-91 for masonry cements requires a minimum strength of 500 psi at 7 days and 900 psi at 28 days. Results in Table 4 suggest that all the four dry hydrated limes at 30 % substitution have compressive strength adequate for general masonry work.

All the lime samples were also used in putty form for making substituted mortars. Since lime in putty form should have at least 30 to 45 % free water in addition to 24 to 27 % chemically combined water [15], putty of hydrated lime samples with 80 % moisture content were used for the substitution experiments. The water/solid in different putty mortars of 10 to 40 % substitution is in the range of 1:3.6 to 1:3.3.

Table 5 shows the compressive strength of hydrated lime-putty-Portland-cement mixes. Putty was mixed with coarse aggregates of sand in the first instance, then with Portland cement and finally with additional water required to make a uniform mix. The average compressive strength obtained at 30 % substitution of the four samples for 7 and 28 days is 725 and 1070 psi respectively while it is 645 and 1020 psi in dry hydrated form (Fig. 1-2). The compressive strength achieved for the above two forms is within the ASTM permissible limits. It may be seen that substitution with putty has only marginal advantages over the dry form as far as compressive strength is concerned. However, the use of hydrated lime in putty form has lost favour because of the inconvenience of slaking on the job and the danger of burns to workers. Additionally it possess problems of packing and transportation.

Different factors based on the analytical composition of Portland cement, limes and their mixture are listed in Table 6 and 7. Lime saturation factor, which depends upon he purity of the calcareous sample, decreases from A

Table 4. Compressive strength (psi) of hydrated lime (dry) – cement mortar.

	A				B			
% Lime substituted	10	20	30	40	10	20	30	40
7 days	1250	1041	583	400	1466	1091	675	430
28 days	1808	1216	906	541	1950	1408	1033	600
	C				D			
% Lime substituted	10	20	30	40	10	20	30	40
7 days	1308	1066	608	400	1525	1124	699	460
28 days	1766	1466	1000	517	2060	1522	1142	692

	7 Days	28 Days
Compressive strength (psi) of Standard Portland cement-sand mortar	2030	2880
Compressive strength (psi) of standard lime sand mortar	A.50	155
	B.62	164
	C.56	159
	D.65	170

Table 5. Compressive strength (psi) of Hydrated lime (Putty) – cement mortar.

	A				B			
% Lime substituted	10	20	30	40	10	20	30	40
7 days	1276	975	610	341	1550	1116	741	500
28 days	1866	1388	1006	440	2050	1433	1050	641
	C				**D**			
% Lime substituted	10	20	30	40	10	20	30	40
7 days	1375	1041	725	440	1620	1185	755	512
28 days	1810	1450	1083	620	2140	1524	1140	730

	7 Days	28 Days
Compressive strength (psi) of standard Portland cement-sand mortar	2030	2880
Compressive strength (psi) of standard lime-sand mortar	A: 55	160
	B: 65	170
	C: 59	165
	D: 70	181

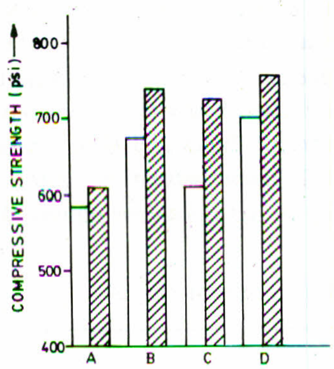

Fig. 1. Compressive strength of lime cement mortars (7 days) 30 % substitution Hydrated lime (Dry)-OPC □ Hydrated lime (Putty) - OPC □.

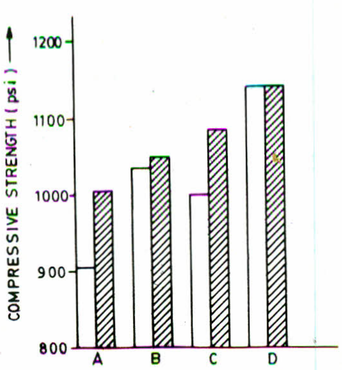

Fig. 2. Compressive strength of lime cement mortars (28 days) 30 % substitution Hydrated lime (Dry)-OPC □ Hydrated lime (Putty)-OPC □.

to D viz: from 63.24 to 6.04 and gets near the specified range of OPC (0.66-1.02, BS: 12: 1958) on 10 % substitution in the four samples.

Cementation index (silica modulus) of all of the samples shows that they are pure or fat limes and their hydraulicity is quite negligible (feeble: 0.30-0.50, moderate: 0.50 – 0.70; eminent: 0.70-1.1 [5]. Their admixtures with OPC produce from eminent to moderate hydraulicity limes. Table 7 shows that samples A,B,C and D are eminent in their hydraulic character upto 30 % substitution and their corresponding compressive strength (Tables 4 and 5) is also within the specified ASTM limits in this particular case of substitution. Low silica and alumina con-

Table 6. Characterisitics* (Factors) of Portland cement and lime samples.

Sr. No.	Characteristics	Portland cement	A	B	C	D
1.	C_3A	8.94	0.37	0.09	1.13	3.86
2.	C_4AF	12.77	0.33	0.33	0.58	0.97
3.	L.S.F.	0.87	63.24	19.08	35.59	6/04
4.	C.I.	1.09	0.012	0.05	0.03	0.15

*C_3A Tricalcium aluminate; C_4AF = Tetra calcium Alumino Ferrate; L.S.F. = Lime saturation factor; C.I. = Cementation index.

Table 7. Characteristics (Factors) of substituted lime-cement mixtures.

	A				B			
% Lime substituted	10	20	30	40	10	20	30	40
Characteristics								
C_3A	8.09	7.19	6.35	5.51	8.06	7.16	6.26	5.39
C_4AF	11.52	10.27	9.05	7.81	12.88	10.33	9.09	7.84
L.S.F.	0.98	1.11	1.28	1.51	0.98	1.10	1.26	1.47
C.I.	0.97	0.86	0.75	0.64	0.97	0.87	0.75	0.65
	C				D			
% Lime substituted	10	20	30	40	10	20	30	40
Characteristics								
C_3A	8.15	7.38	6.63	5.82	8.56	7.90	7.40	6.92
C_4AF	11.55	10.36	9.15	7.94	11.58	10.43	9.24	8.06
L.S.F.	0.98	1.11	1.27	1.49	0.96	1.07	1.21	1.37
C.I.	0.97	0.85	0.75	0.65	0.99	0.89	0.79	0.69

tents of the limes results in very high LSF and CAAF values. Large substitution in OPC, particularly in those exceeding 30 %, would therefore yield inferior cement.

Tricalcium aluminate (C_3A) possesses pronouced hydraulic setting properties with water and it is one of the strongest cementing components [16]. It may be seen in Table 6 that the C_3A content of Portland cement is 8.94, whereas in the case of pure lime samples it falls between 0.09 to 3.86 showing its inferior cementing nature when used alone in mortars. It is further confirmed by the fact that as the percentage substitution of lime increases in the mortar, C_3A gradually decreases in all of the four cases, (Table 7). Their compression strength data also confirm the observation that as the C_3A of the substituted mortars decrease their compressive strength also decreases in the same pattern.

A detailed study of pure lime samples indicates that the sample from Manghopir hills has better cementing properties compared with the others. It may be due to its slightly siliceous and hydraulic nature. It was also observed that lime putty mixes have shown slightly better strength than that of dry hydrates. These studies suggest that the safe limit for hydrated lime substitution is upto 30 % of Portland cement in masonry mortars. From these data, it is possible to conclude that intergrinding 10 to 30 % hydrated lime with Portland cement would make more cementitious material available for making mortars at a reduced cost while providing compressive strength of 600-700 psi at 7 days and 900-1150 psi at 28 days storage in water which is within ASTM limits. These hydrated limes OPC mortars have more plasticity, greater water retaining power and lower shrinkage as compared to plain OPC mortars and may better be used in brick construction.

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