Plasticity and Water Retentivity of Hydrated Limes for Structural Purposes

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Plasticity and Water Retentivity of Hydrated Limes for Structural Purposes

Ernest M. Levin, Walter F. Clarke, and Lansing S. Wells

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Ernest M. Levin, Walter F. Clarke, and Lansing S. Wells [1]

Workability characteristics imparted to plasters and mortars by hydrated lime are of importance to the plasterer and to the mason. Emley plasticity values were determined for putties prepared from 65 hydrated limes of the various types, after soaking them for 30 minutes and for 1 day. Water-retentivity values, defined as the ratio of the flow after suction to the flow before suction, were obtained for lime-sand mortars prepared in the proportions of 1:3 by weight, 1:3 by volume, and 1:3 by volume using lime putty aged overnight. It was found that acceptable plasticity was associated with acceptable water retentivity, but that acceptable water retentivity did not necessarily imply acceptable plasticity. Results are discussed with relation to the improvement of specifications.

1. Introduction

For the plasterer and for the mason, workability is a most important consideration with respect to hydrated lime to be used for structural purposes. Such workability concerns primarily the ease of troweling of the wet mix during its application to an absorbent base. The continuous removal of water by such a base causes a stiffening of the mix and complicates the measurement of workability, for which no direct method is available. The usual methods of measuring viscosity and plastic flow are so designed that these properties remain constant during the period of testing. Methods have been developed, however, for testing the plasticity and the water retentivity of hydrated lime, and the values so obtained are an indirect measure of the workability.

The Emley plasticimeter [1] [2] has been for many years the accepted instrument for measuring the relative plasticity [3] of hydrated lime. Although the Emley plasticimeter shows that there are great differences in the plasticities and in the water-retaining capacities of lime putties, it is not well adapted to indicate these differences when the putties are incorporated with sand and other materials as mortars. The water-retaining capacity of mortars, however, can be determined with the apparatus developed by J. S. Rogers [2] and described by L. A. Palmer and D. A. Parsons [3].

The objectives of the present investigation were fourfold: (1) to determine relative plasticities and water retentivities of different types of commercial hydrated lime; (2) to study the relation between plasticities of lime putties and water retentivities of lime-sand mortars; (3) to consider these properties in relation to plastering and to masonry construction; and (4) to relate these results to the possible improvement of specifications.

2. Materials

2.1. Hydrated Lime

The investigation included tests of 65 structural hydrated limes obtained from several widely separated lime-producing centers in the United States. The limes were part of the group used in previous studies [4, 5]. For convenience of identification and comparison, these lime samples have been assigned the same numbers in the present paper as in those publications.

The chemical analyses were made (as part of the previous studies) in accordance with Federal Specification SS–L–351 for hydrated lime [1], and the percentage of unhydrated oxide was calculated in accordance with Proposed Amendment 1 to that specification [6]. The analytical data are repeated herein in table 1, columns 2 through 10.

On the basis of the chemical analyses, the hydrated limes were classified as high-calcium, dolomitic, and magnesian. Those containing less than 5 percent of total magnesia were arbitrarily classified as high-calcium, series A; those with more than 25 percent as dolomitic, series B and C; and four limes, having between 5 and 25 percent of magnesia, as magnesian, series D. The hydrated dolomitic limes were further subdivided into "regularly hydrated" (normal hydrated dolomitic), series B, in which the major portion of the magnesia had been left unhydrated, and "highly hydrated", series C, in which the major portion of the magneisa had been hydrated. The designation "highly hydrated" follows the terminology already used in previous publications [4, 5] and seems preferable to such terms as "autoclaved" or "pressure hydrated limes." In each series the hydrated limes are arranged in table 1 in the order of increasing percentage of calculated unhydrated oxides.

2.2. Sand

The sand used in preparing lime-sand mortars was natural silica sand from Ottawa, Ill., graded to pass a No. 20 sieve and to be retained on a No. 30 sieve [7].

[1] Deceased.

[2] Figures in brackets indicate the literature references at the end of this paper.

[3] Throughout this paper, "plasticity" denotes the relative values as determined by the Emley plasticimeter.

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TABLE 1. *Chemical analysis and calculated percentage of unhydrated oxides for 65 hydrated limes, together with the plasticity of putties prepared from these limes after soaking the samples for 30 minutes and 1 day, and the water retentivity of sand-lime mortars prepared in the proportions of 1 lime:3 sand by weight; 1 lime:3 sand by volume; and 1 lime:3 sand by volume using lime putty aged overnight.*

Lime number	Chemical analysis (oxide composition)								Calculated unhydrated oxides	Plasticity of putties after—		Water retentivity of mortars proportioned—		
	H_2O		CO_2	SiO_2	R_2O_3	CaO	MgO	Total		30 min	1 day	1:3 by wt	1:3 by vol	1:3 by vol (aged putty)
	Free	Combined												
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SERIES A—HIGH-CALCIUM HYDRATED LIMES														
	%	%	%	%	%	%	%	%	%			%	%	%
1	0.57	23.74	0.51	0.54	0.20	73.92	0.46	99.94	0.0	130	170	90	85	90
2	.41	23.18	1.58	.58	.38	72.82	.67	99.62	0	130	480	82	78	96
3	.24	23.59	1.02	.44	.32	73.97	.33	99.91	0	250	250	92	88	92
4	.36	23.68	0.56	.60	.42	73.90	.35	99.87	0	210	240	91	88	93
5	.29	23.90	.39	.50	.30	73.62	.82	99.82	0	150	440	92	82	91
6	.66	23.42	.99	.56	.14	73.17	.60	99.54	0	140	210	88	85	94
7	.59	23.66	.70	.16	.55	73.65	.69	100.00	.1	130	310	84	73	92
8	.83	23.26	1.10	.20	.55	73.47	.72	100.13	.5	160	260	83	74	92
9	.54	23.26	0.68	.86	.48	73.31	.81	99.94	.8	150	180	90	86	94
10	.54	22.96	1.56	.42	.24	73.22	.96	99.90	.8	150	150	88	80	94
11	.53	23.06	0.70	.74	.60	72.60	1.04	99.27	1.0	130	380	78	74	94
12	.29	23.00	.97	.80	.50	73.29	0.61	99.46	1.1	120	160	75	64	---------
13	.75	22.95	.67	1.14	.78	71.35	1.82	99.46	1.1	130	150	89	84	88
14	.68	22.58	1.27	1.02	.64	71.89	1.19	99.27	1.2	150	160	87	78	90
15	.44	23.07	0.33	1.09	.50	72.78	1.06	99.27	1.6	120	120	76	69	81
16	.34	22.88	1.19	0.58	.38	73.00	1.41	99.78	1.7	120	140	89	83	90
17	.58	22.99	0.65	1.00	.46	71.55	2.41	99.64	1.8	120	200	88	81	94
18	.30	23.23	.27	0.70	.46	73.68	1.18	99.82	2.2	120	130	82	77	89
19	.40	22.20	1.37	1.88	.92	72.02	1.09	99.88	2.3	140	140	87	87	89
20	.33	22.48	0.87	0.86	.16	71.23	3.02	98.95	3.2	120	200	78	72	94
21	.70	22.01	1.01	1.31	.76	72.42	1.29	99.50	3.9	120	150	82	64	87
SERIES B—REGULARLY HYDRATED DOLOMITIC LIMES														
23	0.19	18.21	1.64	1.75	1.07	45.17	31.83	99.86	22.1	120	120	75	63	75
24	.25	17.51	2.57	0.82	0.36	52.58	25.79	99.88	22.1	130	160	87	77	92
25	.30	19.03	0.45	1.04	.48	46.14	32.54	99.98	22.7	130	260	87	79	94
27	.30	17.96	.63	0.94	.36	46.72	33.08	99.99	25.9	130	300	90	83	95
28	.13	17.90	1.01	.12	.16	47.41	33.09	99.82	26.2	180	460	87	80	92
29	.28	16.63	3.13	.20	.18	46.98	32.51	99.91	26.2	230	540	90	85	94
30	.28	17.58	1.18	.28	.22	47.58	32.62	99.74	26.4	240	500	87	83	91
31	.22	17.41	1.73	.14	.14	47.00	33.30	99.94	26.5	140	470	85	75	93
32	.15	16.63	2.79	.26	.16	46.81	32.93	99.73	26.8	200	460	85	79	94
34	.20	17.01	1.79	.40	.28	47.06	33.24	99.98	27.4	150	380	82	79	96
35	.20	17.26	0.88	.34	.22	47.43	32.98	99.31	27.7	160	440	85	74	94
36	.19	17.25	.50	.54	.48	47.29	33.53	99.78	28.5	130	120	90	80	87
37	.24	16.94	.94	.20	.18	47.43	33.97	99.90	29.3	180	550	89	87	95
38	.04	16.56	.98	.20	.10	48.43	32.98	99.29	29.9	130	230	76	72	88
39	.21	15.96	2.09	.14	.10	47.76	33.69	99.95	30.4	140	480	88	77	95
40	.17	16.65	0.90	.20	.12	47.83	34.10	99.97	30.4	140	570	83	79	95
41	.23	16.53	1.02	.24	.12	47.79	34.06	99.99	30.5	140	480	84	84	93
42	.16	15.97	1.59	.37	.53	48.45	33.05	100.12	30.7	120	200	87	76	95
43	.20	16.29	1.31	.18	.16	47.85	34.01	100.00	30.8	170	530	87	77	94
44	.22	16.28	0.75	.80	.54	47.63	33.63	99.85	30.8	140	130	88	75	87
45	.43	15.81	1.45	.10	.12	46.78	35.21	99.90	31.2	150	600	91	84	95
46	.04	15.91	1.05	.14	.18	48.32	34.30	99.94	32.5	130	380	83	69	96
47	.30	15.45	0.79	1.42	.46	47.70	33.82	99.94	32.8	140	240	87	83	---------
48	.50	14.58	1.25	1.34	.68	48.27	33.00	99.62	34.3	120	130	82	70	91
SERIES C—HIGHLY HYDRATED DOLOMITIC LIMES														
50	0.21	25.28	1.72	0.24	0.18	42.58	29.75	99.96	2.2	270	320	91	88	93
51	.16	25.52	1.32	.23	.35	43.01	29.65	100.24	2.3	310	420	92	90	96
52	.00	25.41	1.33	.26	.36	42.47	29.88	99.71	2.3	220	260	93	90	95
53	.51	24.56	1.87	1.56	.50	41.83	29.09	99.92	2.6	460	550	94	92	---------
54	.04	25.31	1.56	0.18	.18	42.59	30.08	99.94	2.6	250	350	92	90	92
57	.09	25.14	1.75	.26	.10	42.68	30.04	100.06	2.9	280	320	93	90	94
59	.17	24.47	2.79	.18	.14	42.49	29.75	99.99	3.0	280	320	93	---------	93
61	.23	24.58	1.98	.18	.16	42.91	29.14	99.18	3.2	440	500	94	93	94
62	.25	24.37	2.00	1.45	.62	42.10	29.46	100.25	3.4	230	360	96	91	96
63	.17	25.18	0.37	1.82	.44	42.12	29.82	99.92	3.4	370	400	93	93	95
64	.09	25.67	.38	0.14	.08	43.22	30.17	99.75	3.5	220	320	92	86	92
65	.19	23.66	3.12	.16	.20	42.78	29.09	99.20	4.0	360	450	90	88	93
66	.08	24.82	0.87	.02	.19	43.41	30.24	99.63	5.1	210	310	89	85	94
69	.09	22.72	3.40	.22	.16	42.89	29.93	99.41	6.8	210	360	94	88	95
70	.20	23.35	1.18	2.18	.89	42.89	29.43	100.12	6.9	200	220	90	86	93
72	.13	23.83	1.06	0.20	.12	43.73	30.58	99.65	7.7	270	350	92	83	94

TABLE 1.—Continued

Lime number	Chemical analysis (oxide composition)								Calculated unhydrated oxides	Plasticity of putties after—		Water retentivity of mortars proportioned—		
	H_2O		CO_2	SiO_2	R_2O_3	CaO	MgO	Total		30 min	1 day	1:3 by wt	1:3 by vol	1:3 by vol (aged putty)
	Free	Combined												
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SERIES D—MAGNESIAN HYDRATED LIMES														
77	0.38	21.67	0.67	2.26	0.82	67.78	6.24	99.82	5.9	150	160	93	89	90
78	.39	21.92	.96	0.76	.78	62.96	11.88	99.67	7.2	250	430	96	85	94
79 [a]	.99	17.60	4.95	2.47	3.13	64.61	6.25	100.00	9.8	120	160	78	64	90
80 [a]	.52	19.79	1.10	2.64	1.30	57.13	16.88	99.36	12.7	140	180	94	83	94

[a] Failed to meet the requirement of Federal Specification SS–L–351 that the total CaO plus MgO shall be not less than 95 percent, calculated on nonvolatile basis.

3. Apparatus and Procedure

3.1. Plasticity

As masonry materials, portland-cement mortars, in general, are harsh to work. For actual construction purposes, therefore, lime is often added to cement with the intention of improving plasticity and water-retaining capacity of the mortar mix.

With the Emley plasticimeter [1], measurement is made of the torque exerted on a steel disk bearing against a pat of lime putty as the pat is slowly raised and revolved. During the process the putty stiffens because of the removal of water by a standardized absorbent plate on which the pat rests. Plasticity is calculated from the empirical formula

$$P=\sqrt{F^2+(10T)^2},$$

in which P is the plasticity value (to the nearest 10 units), F is the scale reading (torque) at the end of the test, and T is the time in minutes from the moment of initial contact of the paste with the absorbent plate to the end of the determination. The test is considered complete when (a) the scale reading (F) is 100, (b) any reading becomes and remains less than the one before, or (c) the scale reading remains constant for three consecutive readings (2 min) and the specimen is visibly ruptured. Calculated according to the formula above, a plasticity value of 200 is the specification minimum for an acceptably plastic lime.

Two series of plasticity determinations were made on putties prepared from each of the limes. One series was made on stiff putties soaked overnight (20±4 hr), according to the time requirement in Federal Specification SS–L–351 [1]. For the purpose of obtaining a measure of early plasticity, the other series was made on stiff putties soaked for only 30 min. Immediately prior to testing, the stiff putties were stirred for 5 min. and then with vigorous stirring were brought to standard consistency [1] by the addition of water in small amounts. This procedure gave reproducible results.

3.2. Water Retentivity

Whereas the Emley plasticimeter removes water from a pat of lime putty by capillary absorption into a base plate, the Rogers apparatus removes water from a sanded mix by means of suction. In the latter case, the flow of a mortar is determined before and after suction. The ratio of the flow after suction to the flow before suction, expressed as a percentage, defines the so-called water retentivity.

In the present study, the procedure for determining water retentivity was essentially that described in detail in Federal Specification SS–C–181b [8].[4] The apparatus for applying suction consists basically of a perforated dish resting on a funnel connected to a mercury-column relief valve and to a water aspirator.

Three sets of mortars were prepared; in these the proportions of hydrated lime to standard Ottawa sand (20 to 30) were, respectively, as follows:

(1) 1:3 by weight; specifically, 500 g of dry hydrated lime to 1,500 g of dry sand.

(2) 1:3 by volume; on the practical basis, one bag of dry hydrated lime to 3 ft ^{3} of loose damp sand. Proportioning was, actually, on a weight basis. One bag of dry hydrated lime (approximately 1 ft ^{3}) weighs 50 lbs, and 1 ft ^{3} of loose damp sand contains approximately 80 lbs of dry sand; so the proportion by weight of hydrated lime to sand in this series was 50 to 240 (i. e., 1 to 4.8 by weight). For test purposes, 350 g of lime was mixed with 1,680 g of Ottawa sand.

(3) 1:3 by volume with aged putty, using hydrated lime which had been soaked overnight as

[4] Since completion of the work, this specification has been superseded by SS–C–181c.

a stiff putty. The weight proportion on a dried-putty basis was the same as for (2).

For preparing and testing the water retentivity of the 1:3 by volume aged-putty mortars, the procedure was modified as follows: 350 g of dry hydrated lime was weighed into a porcelain casserole, and sufficient water was added, with stirring, to produce a stiff putty. The putty was aged overnight (16 to 24 hr) in a moist closet maintained at a temperature of 70°±3° F and at a relative humidity not less than 90 percent. At the end of that aging period, the putty was stirred for 5 mins. The contents of the casserole were then transferred to a mixing bowl, and 1,680 g of sand in 2 portions were mixed into the putty, as prescribed in Federal Specification SS–C–181b (F–3 g(3)). In almost every instance it was necessary to add more water in order to obtain the desired initial flow of 100 to 115; however, neither the rate nor the manner of addition of the water was found to be critical. If in the event of misjudgment too low a flow value was obtained, more water was added to the mortar. It was quickly remixed for a period of 30 sec, and another flow determination was made. When the flow value obtained was too high, water was removed with an absorbent plate. The remainder of the procedure followed that used for the other sets of mortars.

4. Results and Discussion

4.1. Plasticity of Lime Putties

For the two sets of hydrated-lime putties tested after soaking the specimens for 30 min and overnight, respectively, plasticity values are given in table 1 and are plotted in figure 1. In most cases, each value represents a single measurement. From previous experience it is known that, for putties having plasticity values close to 200, duplicate measurements generally agree to within 10 units. The limes in figure 1, within each class, are arranged according to increasing values of the overnight plasticity. The level of the 200 plasticity value is specially denoted in the figure, for it is the accepted minimum for a finishing lime [1].

Regarding overnight plasticities, all of the highly hydrated and most of the regularly hydrated dolomitic limes showed values of 200 or higher; about half of the high-calcium and magnesian limes showed such high values.

As regards 30-min plasticities, not one of the 16 highly hydrated dolomitic limes tested gave a value of less than 200. Of a total of 49 limes of the other three types, however, 43 gave values of less than 200; whereas only 6, one or more of each type, gave values ranging from 200 to 250.

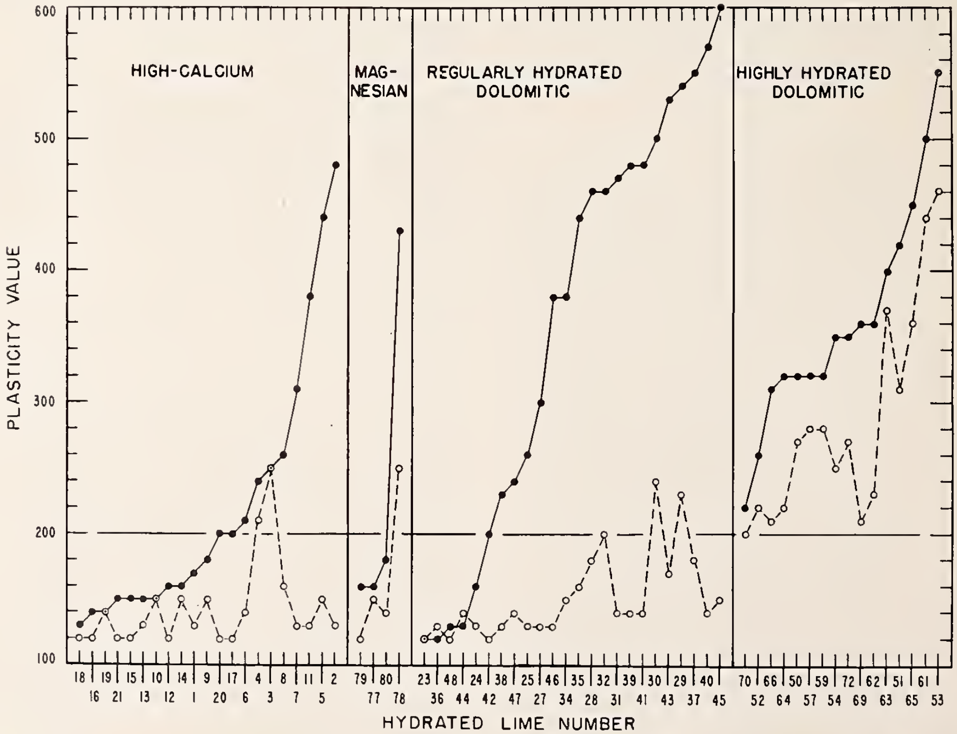

Figure 1. *Emley plasticity values of 65 hydrated limes of various types after aging for two time periods.*

○, 30 min; ●, 20 ±4 hr.

Comparison of the 30-min with the overnight plasticities fails to show good correlation, but in nearly all cases the overnight plasticities were greater than the 30-min values. The highly hydrated dolomitic limes having comparatively high 30-min plasticity values gave the least increases in plasticity after overnight soaking. In contrast, the majority of the regularly hydrated dolomitic limes gave greatly increased plasticity values for putties soaked overnight.

Two points of special interest might be emphasized. The first is that as a result of the special manufacturing processes involved, the highly hydrated dolomitic limes yielded putties that were plastic after only 30 min of soaking. The second is that some of the hydrated high-calcium limes were found to yield plastic putties after overnight soaking.

4.2. Water Retentivity of Lime-Sand Mortars

The water-retentivity values for the mortars are given in table 1 and are plotted in figure 2, by classes of limes. Most of the water-retentivity values for mortars proportioned 1 lime to 3 sand by volume are the averages of at least two values obtained by two operators. The standard deviation measuring the spread of replicate determinations was found to be 2 units for mortars proportioned either on a weight or a volume basis. Reproducibility for mortars prepared from the putty aged overnight, as determined in a few instances, appears to be of the same order of magnitude.

In the figure the limes of each class are arranged according to the increasing water-retentivity values of the 1:3 by volume mortars. The figure

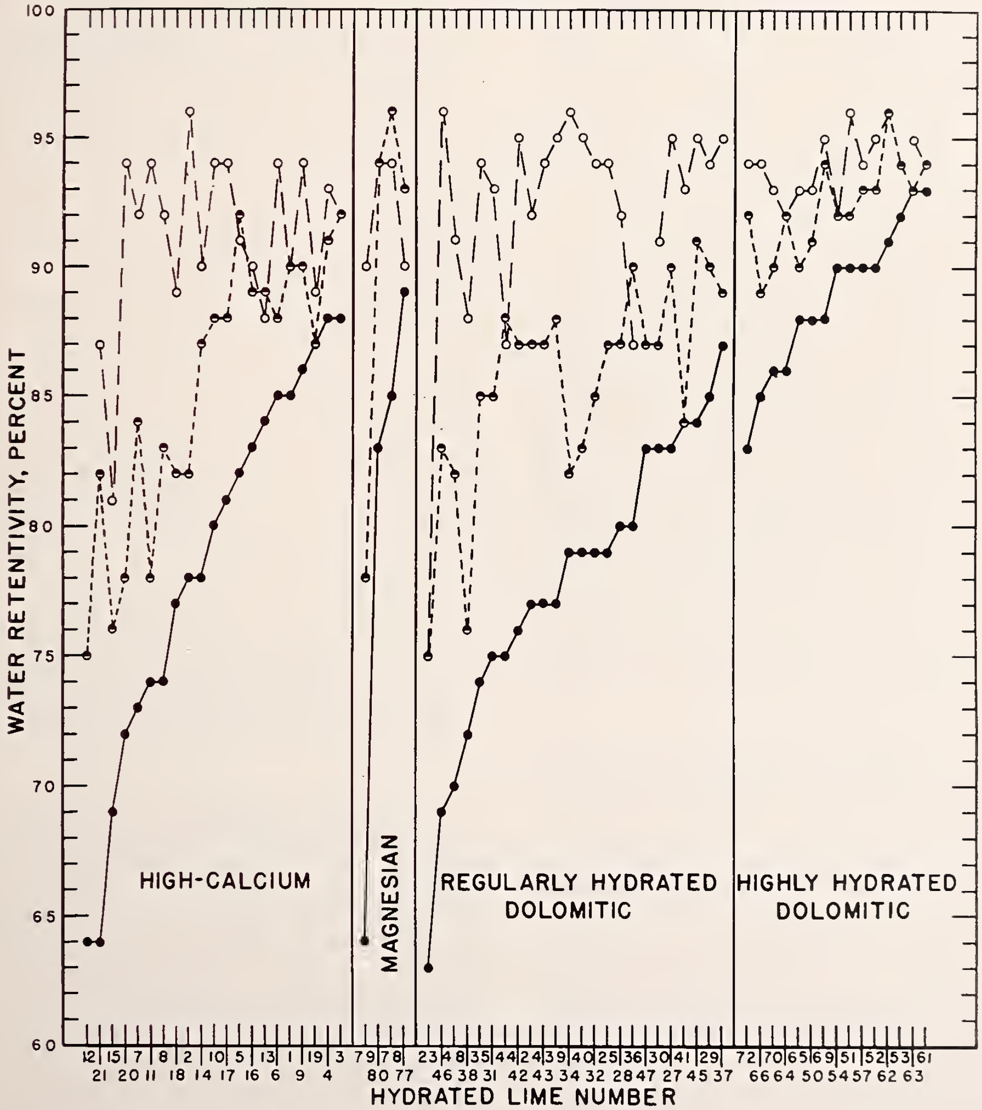

FIGURE 2. *Water-retentivity values for three different sets of lime-sand mortars prepared from 65 hydrated limes of the four types.*

●, 1 lime:3 sand, by volume; ◓, 1 lime:3 sand, by weight; ○, 1 lime:3 sand, by volume using lime putty aged overnight.

shows a wide over-all range in values (from 63 to 96 percent). In general, for any one lime the 1:3 by volume mortar had the lowest retentivity; the 1:3 by weight mortar, an intermediate value; and the 1:3 by volume aged-putty mortar, the highest value. As a class, the magnesian limes, of which there were only four, were in one respect an exception; two of them showed slightly higher water-retentivity values for the 1:3 by weight mortars than for the 1:3 by volume aged-putty mortars. The figure shows that every 1:3 by weight mortar had a water-retentivity value of 75 percent or greater. It should be emphasized that, regardless of the class of lime tested, the water-retentivity values for aged-putty mortars, with only two exceptions, were greater than 85 percent.

The highly hydrated dolomitic limes differed notably from the others in having relatively high water-retentivity values for the three sets of mortars: for the 1:3 by volume mortar, no value was below 83 percent; for the 1:3 by weight mortar, none was below 89 percent; and for the 1:3 by volume aged-putty mortar, none was below 92 percent. The regularly hydrated dolomitic limes, as a class, showed, over all, the widest and the most distinct separations for the three sets of retentivity values.

In summary, for each class of lime two variables are represented in the figure: (1) change of lime-sand ratio and (2) aging of the lime putty. As to the first, it is seen that on nonaged putty, for any one class, the 1:3 by volume mortar shows, in general, lower water retentivity, with greater spread in values, than does the 1:3 by weight mortar. The lower values are attributed to the fact that a 1:3 by volume mortar has a lower lime-sand ratio than a 1:3 by weight mortar. As to the second variable, that of aging, it is seen that the 1:3 by volume aged-putty mortar shows higher water retentivity, with lesser spread in values, than does the 1:3 by volume mortar made from nonaged putty. It is even true that, with the exception of three magnesian limes, the 1:3 by volume aged-putty mortar, in spite of a leaner lime ratio, shows a higher value than does the 1:3 by weight mortar.

4.3. Relation of Plasticity of Lime Putties to Water Retentivity of Lime-Sand Mortars

For masonry-construction purposes, hydrated lime is used, in many cases, immediately after being mixed. Its "immediate" workability, therefore, is of importance. As regards finishing lime, also, the question of immediate use needs to be considered. Pertinent to the subject of immediate workability, figure 3 shows the relation between the water retentivities of the 1:3 by volume (nonaged) mortars and the 30-min (immediate) plasticities of putties made from the corresponding limes. It can be seen that the limes that showed acceptable (200 or greater) plasticities had, with one exception, water retentivities of 83 percent or greater, and that those which showed low water retentivities had low plasticities; but some of the limes that gave low plasticities had high water retentivities. The highly hydrated dolomitic limes gave 30-min plasticities of 200 or more and water retentivities of 83 percent or greater. The other types of limes showed a wide distribution of water retentivities (63 to 89 percent), but only six showed plasticities of 200 or greater.

A plot of the water retentivities of the 1:3 by weight mortars versus the 30-min plasticities of putties made from the corresponding limes is shown in figure 4. The relations between them are similar to those shown in the plot of the 30-min plasticities versus the water retentivities on the 1:3 by volume basis (fig. 3). It may be noted that

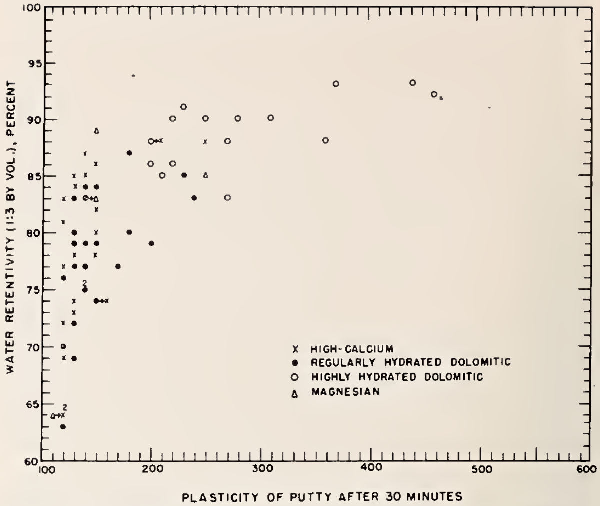

FIGURE 3. *Relation between water retentivity of lime-sand mortar proportioned on a volume basis and plasticity of corresponding hydrated-lime putty after soaking for 30 minutes.*

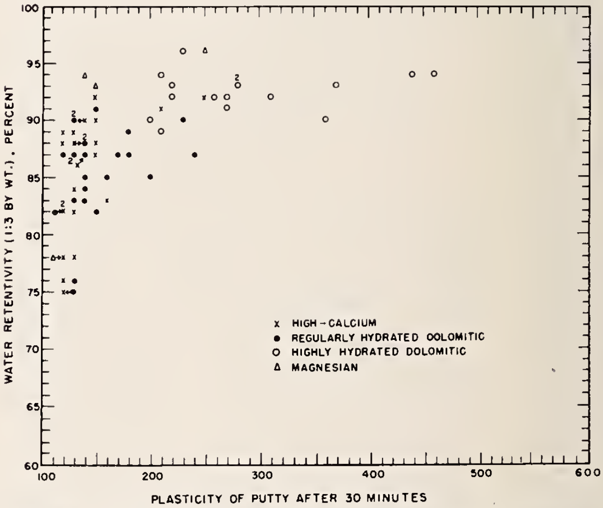

FIGURE 4. *Relation between water retentivity of lime-sand mortar proportioned on a weight basis and plasticity of corresponding hydrated-lime putty after soaking for 30 minutes.*

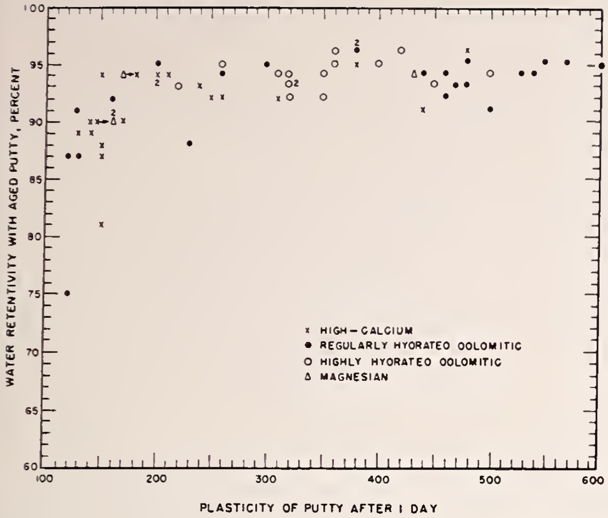

FIGURE 5. *Relation between water retentivity of lime-sand mortar proportioned on a volume basis using aged putty and plasticity of corresponding hydrated-lime putty after aging for 20 ±4 hours.*

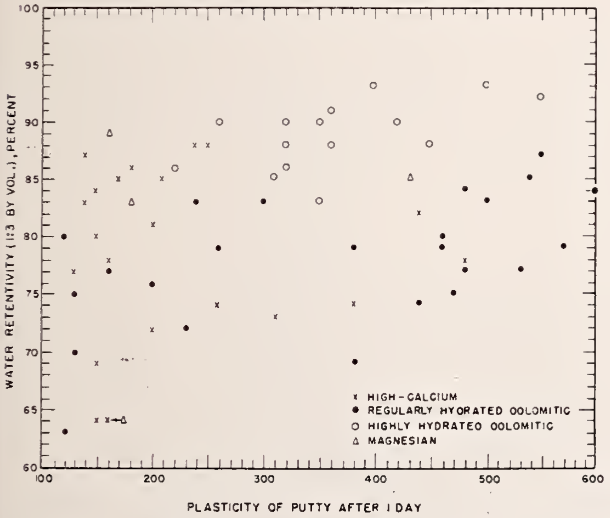

FIGURE 6. *Relation between water retentivity of lime-sand mortar proportioned on a volume basis and plasticity of corresponding hydrated-lime putty after aging 20 ±4 hours.*

every lime with a plasticity (30-min) figure of 200 or greater had a water-retentivity value (1:3 by weight) of 85 percent or greater.

Figure 5 shows the relation between the plasticities of aged-lime putties and the water retentivities of the 1:3 by volume aged-putty mortars. For the relatively wide plasticity range of 200 to 600, the limes had, with one exception (an 88-percent value), the comparatively narrow retentivity range of 91 to 96 percent. For the narrow plasticity range of 110 to 200, they had the wide retentivity spread of 75 to 94 percent.

Figure 6 shows the relation of the plasticities for lime putties soaked overnight to the water retentivities of the 1:3 by volume (nonaged) mortars. It should be noted that here the treatments of the lime prior to the plasticity and to water-retentivity determinations were not comparable; the lime was soaked overnight in the former case but not in the latter. Doubtless for this reason, no over-all trend was found; however, as contrasted to the regularly hydrated dolomitic and to the high-calcium limes, the highly hydrated dolomitic limes showed acceptable plasticity and water retentivity greater than 82 percent.

A comparison of the plasticities for lime putties soaked overnight with the water retentivities of the 1:3 by weight (nonaged) mortars is not shown because this case is essentially the same as for the data shown in figure 6, except that the spread in water retentivities is less.

For the procedures involved in figures 3, 4, and 5, the results indicated that acceptable plasticity was associated with acceptably high water retentivity, but that acceptable water retentivity did not necessarily imply acceptable plasticity. In figure 6, the first relation holds only for highly hydrated dolomitic lime.

5. Application of Results to Formulation of Specifications

5.1. Present Specifications

Hydrated lime for structural purposes is classified broadly as finishing lime and as masons lime. Specifications (table 2) of the American Society for Testing Materials and of the National Lime Association further classify both kinds of lime as type N (normal) and type S (special). Type S lime, both finishing and masons, is characterized chemically by a limitation of 8 percent on unhydrated oxides [9, 10, 11, see also 6]. Type N lime and types meeting present Federal Specifications are not subject to an unhydrated oxide limitation; but for white-coat (finish) plaster there is serious objection [12] to the use of limes containing more than 8 percent of unhydrated oxides. Some doubt exists, however, as to whether the same objection is valid with respect to limes intended for masonry purposes. As an alternative to the 8-percent-unhydrated-oxides requirement, an accelerated performance test has been suggested [4]. In this connection, it is interesting to note that a tentative autoclave expansion test for hydraulic lime is given in the 1953 Supplement to Book of ASTM Standards [13]. Tentatively specified is an expansion limit of 1 percent for a blend of 1 of portland cement to 3 of hydraulic lime.

Plasticity and water-retentivity requirements in the various specifications are given in table 2.

Type F, type N-normal finishing hydrate, and both type S limes must meet a minimum plasticity requirement of 200, although there is some variation between the different specifications in the length of time the lime putty must be soaked

Table 2. *Comparison of plasticity and water-retentivity requirements in various specifications for hydrated lime for structural purposes*

Specification	Designation	Plasticity: Value	Plasticity: Aging (of lime putty)	Water retentivity: Value	Water retentivity: Proportions (lime: standard sand)
				%	
American Society for Testing Materials [1, 9, 11].	Type N-normal finishing hydrate	200	16 to 24 hr		
	Type S-special finishing hydrate	200	0 to 24 hr		
	Type N-normal hydrated lime for masonry purposes.			75	1:3 by dry weight, or from putty [a] aged 16 to 24 hr.
	Type S-special hydrated lime for masonry purposes.	200	0 to 30 min	85	1:3 by dry weight.
National Lime Association [10].	Type N-"normal" finishing hydrate	200	16 to 24 hr		
	Type S-special finishing hydrate	200	0 to 8 hr or 16 to 24 hr. [b]		
	Type N-masons hydrated lime			75	1:3 by dry weight, or from putty [a] aged 16 to 24 hr.
	Type S-masons hydrated lime	200	0 to 15 min	85	1:3 by dry weight.
Federal [1]	Type F: Finishing	200	16 to 24 hr		
	Type M: Masons				

[a] The lime putty proportioned on a dry-weight basis.
[b] If 200 plasticity is not developed in 0 to 8 hr.

prior to test. The plasticity requirement for type S special finishing hydrated lime provides that the lime may be tested or retested after mixing with water and after aging for any period not exceeding 24 hr. Type F and type N-normal finishing hydrates, however, must be aged for 16 to 24 hr before testing. Type S hydrated lime for masonry purposes must be tested within 15 min [10] or 30 min [11] after mixing with water. In addition, type S lime for masonry purposes must meet a minimum water-retentivity requirement of 85 percent, when tested as a mortar made from the dry hydrate in the proportion, by weight, of 1 of lime to 3 of standard Ottawa sand (20 to 30). Type N lime for masonry purposes must meet only a 75-percent water-retentivity requirement and may be tested either as a dry hydrate or as an aged (16 to 24 hr) putty. In the present Federal Specifications, lime for masonry purposes, whether type M or type F, is not subject to a water-retentivity requirement. Existing requirements for plasticity and water retentivity of hydrated limes will now be considered with relation to the results of the present investigation.

5.2. Finishing Lime

For a finishing hydrated lime, the accepted minimum (Emley) value of 200 for plasticity is well established in the construction industry and appears to be a satisfactory limit. As hydrated limes that need no special soaking period are available, requirements for type F, as well as for type S finishing lime (similar to the case of type S masons lime), should provide for the option in which the purchaser desires to use the lime without aging overnight as a putty. For type S finishing hydrated lime, current specifications permit immediate testing but provide for soaking of the putty overnight in the event that the lime fails to pass. At the present time, some commercial limes require aging overnight as putties prior to use. Even though all of the highly hydrated dolomitic limes tested in this study had plasticity values of 200 or greater at 30 min (fig. 1), many of the manufacturers of these limes recommend overnight aging as a putty in order to develop optimum plasticity and working properties. An overnight plasticity requirement, therefore, should be retained for those finishing limes that require aging.

5.3. Masons Lime

Workability of a mortar is of primary concern to the mason because it is a direct measure of the ease with which he can apply the mortar. Workability is important, furthermore, because it has a bearing on such properties as strength, water resistance, and workmanship of masonry construction. In preparing masonry mortar from hydrated lime, the usual procedure is to mix the proper proportions of dry hydrated lime, cement, and sand with water shortly before use. Some masons, however, still prefer to use an aged (overnight) hydrated lime putty in preparing a mortar. For type S lime for masonry purposes, the present specifications require that the lime develop an early plasticity value of 200 after mixing with water but do not provide for overnight aging. For type M and for type N limes for masonry purposes, a plasticity requirement is not specified (table 2). Consequently, if a plasticity requirement be designated for type S masons hydrated lime, two alternative time periods are indicated, as for the case of finishing hydrated lime, the choice to depend on the option of the purchaser.

A water-retentivity test is the standard method of determining water-retaining capacity of mortars in which hydrated lime or lime putty is incorporated with sand and other materials. Wells, Bishop, and Watstein [13] found that flow after suction of cement-lime mortars depends far more on the properties of the lime than on the cement-lime ratio. As mentioned under 5.1, the specifications of the ASTM and of the National Lime Association require that type S-masons hydrated lime shall have a minimum water-retentivity figure of 85, when the dry hydrated lime is tested as a mortar in the proportions of one part dry lime to three parts standard sand by weight. Inspection of figure 4 reveals the interesting fact that, of a total of 65 limes tested, every one which had a plasticity (30-min) value of at least 200 had, also, a water-retentivity (1:3 by weight) value of at least 85 percent. Figure 3 shows that even when the water-retentivity test was made on a 1:3 by volume mortar (from nonaged putty), only one lime with a plasticity (30-min) figure of at least 200 had a water-retentivity figure of less than 83. On the basis of the limes tested, it is evident that acceptable plasticity (30-min) is associated with acceptable water retentivity and that a water-retentivity requirement is unnecessary if a plasticity requirement is specified.

At the present time, the Federal Specification for masons hydrated lime (type M) does not include plasticity nor water-retentivity requirements. From the previous discussion it would follow that a plasticity (30-min) requirement of 200 would obviate a water-retentivity requirement. Such a plasticity requirement, however, would eliminate some limes, in particular, many of the high-calcium hydrated limes, which have been used extensively and satisfactorily in mortars. A water-retentivity requirement could be specified in place of a 30-min plasticity test, although not considered so desirable by the authors with respect to all workability properties. The present water-retentivity requirement of 75 percent for type N lime is too low, inasmuch as mortars prepared from such limes tend to bleed and are harsh to work with coarse sand. A minimum value of 80 on a 1:3 by weight basis would not exclude any limes of adequate (30-min) plasticity, and yet is not so strict as the 85-percent requirement for type S lime. A minimum value of 70, on a 1:3 by volume basis would be equivalent, and the limes are better differentiated at this proportion.

6. Summary

A study has been made of the plasticity and the water retentivity of 65 hydrated limes, comprising 21 high-calcium, 24 regularly hydrated dolomitic, 16 highly hydrated dolomitic, and 4 magnesian limes.

Emley plasticity values were determined for two sets of putties prepared from these limes, after soaking, respectively, for 30 min and for 1 day. Water-retentivity values were obtained for three sets of lime-sand mortars prepared in the proportions of 1 lime:3 sand by weight; 1 lime:3 sand by volume; and 1 lime: 3 sand by volume using lime putty aged overnight.

For most of the limes, the overnight plasticity values were greater than the corresponding 30-min values; the greatest differences were exhibited by regularly hydrated dolomitic limes, and the least differences, by the highly hydrated dolomitic limes. All of the highly hydrated dolomitic limes showed plasticity values of 200 or greater when tested at both time intervals. A number of the high-calcium hydrated limes also showed overnight plasticities greater than 200.

Except for 3 of the 4 magnesian limes, for any one lime, the 1:3 by volume mortar gave the lowest retentivity; the 1:3 by weight, mortar an intermediate value; and the 1:3 by volume, aged-putty mortar the highest value. The highly hydrated dolomitic limes, as a group, gave the highest water-retentivity values for the three different sets of mortars, and the lowest spread in values. The regularly hydrated dolomitic limes gave the widest spread in values for each of the three different sets of mortars.

Plots of 30-min plasticity values versus water-retentitivity values of nonaged mortars tested on a 1:3 by weight and a 1:3 by volume basis, respectively, showed that acceptable plasticity (30-min) was associated with acceptable water retentivity, but that the converse showed numerous exceptions. No lime with a plasticity (30-min) figure of 200 or greater had a water-retentivity value of less than 85 when tested on a weight basis, nor (with one exception) less than 83 on a volume basis. Regardless of the class of lime, the water-retentivity value for the aged-putty mortar was in almost every case greater than 85 percent.

Recommendations are given for improving the present specifications for hydrated lime for building purposes.

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