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WHY IS TYPE S HYDRATED LIME SPECIAL? [*]

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Abstract

Type S hydrated lime is defined by high early plasticity, high water-retention values, limited oxide content, and minimal coarse fraction. These qualities are highly valued for plaster and mortar. At the turn of the 19th Century in the United States, lime calcined from dolomitic limestone in Ohio was recognized as the best lime for interior plaster use. Starting about 1910, The American National Bureau of Standards, in collaboration with The National Lime Association and other masonry material producers, started what was to become a 30-year effort to characterize the nature of hydrated lime for building construction. They developed most of the methods of testing and definitions of key properties used in today's specifications. Commercial awareness of the value of producing a hydrated lime that would achieve all these properties in a reproducible manner led to two patented technologies that are used today. No other lime industry or standards development organization in the world has looked at hydrated lime in the same manner. The original characterization effort plays a continued important role in both the plaster and mortar industries of today.

Key-Words

Emley plasticity, workability, lime, type S hydrated lime, finishing lime, masonry mortar, plaster

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1 Introduction

The “S” in Type S hydrated lime, as defined by ASTM C 206 and ASTM C 207, was coined because the hydrated lime was considered to be “Special”. Its special qualities include high early plasticity, high water-retentivity values, limited oxide content, and minimal coarse fraction. These properties enhance the performance of both mortar and plaster. The same descriptor and emphasis on plasticity and water retentivity do not occur in any other national standard hydrated lime specification. Other national standard hydrated lime specifications describe hydrated lime for building construction by their chemical composition (Tate, 2005 [this volume], eg. EN 459-01 Building Lime Part 1: Definitions, Specifications and Conformity Criteria).

In the today’s plaster and masonry industries in the United States, Type S hydrated lime is used almost exclusively. In 1977 in the United States, no more than 2% of the building market used pulverized quicklime (Boynton, 1980) and the remaining 98% used hydrated lime. Of the 98% that used hydrated lime, over 95% are estimated to have used Type S hydrated lime. These values are not much different today. Unlike other nations at the same stage of industrial development, hydrated lime remains a significant material in the United States building construction industry. For many countries in Western Europe, use of lime in building construction is limited to restoration of medieval castles; and is not used for building new masonry buildings and their rendering.

The objectives of this paper are:

- to explore the historical development of Type S hydrated lime in the United States;
- to review the technical implications of that development; and
- to review the economic implications of that development.

2 Commercial impetus for development of Type S hydrated lime

The roots of Type S hydrated lime are bedded in the interior plaster industry. At the end of the 19th Century in Europe and America, most interior walls of houses and offices were plastered (Millar, 1897). The finish coat of the plastering job is the most demanding of material, craftsman, and budget. Cowper (1927) observes that:

> *“Lime used in plaster-work is generally slaked with an excess of water to form a putty, and this putty is then stored in a covered pit or trough until used. Practically all authorities, both ancient and modern, are unanimous in demanding an adequate length of storage time for tempering this slaked lime before it is actually used…”* (p 30)

He goes on to say,

> *“Whilst it is hardly practical at the present time to afford always so long a time as the traditional three months or a year for the tempering process, it is evident, that for good permanent plaster-work great care should be taken in slaking to avoid unslaked particles of appreciable size, and to remove any over burnt residues; a reasonable time should also be allowed between slaking and actual use. With mechanically hydrated lime, particularly if stored dry some time, and made into putty the day before use, the danger of the presence of large, unslaked particles is very small.”* (p 31)

Lime putty was progressively being displaced by hydrated lime, which was more convenient and already slaked (Lovewell, 1975). For commercial use, quicklime slaked to hydrated lime was more attractive than quicklime slaked to lime putty. Transporting water was and is expensive. However, quicklime slaked directly to lime putty and stored for an appropriate length of time (not defined), would produce a more plastic lime than quicklime slaked to hydrated lime and then to a putty, with one exception: Ohio finishing lime. Ohio finishing lime, which was dolomitic quicklime slaked to hydrated lime and then wetted to a putty and stored for twenty-four hours, was considered as plastic as quicklime slaked directly to a putty. There were probably 20 producers or more at the time, working one regionally-extensive geologic unit: the Lockport (Dolomite) Formation of the Niagara Group, which is middle Silurian in age. Emley (1920) indicates that Ohio finishing lime commanded as much as $26/ton and was transported as far as Los Angeles in 1915. Ohio finishing lime was prized for its white color and high plasticity. Like anything profitable, there was considerable interest in making Ohio finishing lime more readily available by making the process more efficient.

In 1918, Charles and Irving Warner of Willmington, Delaware submitted a patent titled "Method of Hydrating Dolomitic or Magnesian Lime", which states:

> *"Our invention relates to a process of hydrating dolomitic or magnesian quick-lime and has for its object to secure, as far as possible, the hydration of a material or part or all of the magnesium oxide, in addition to the hydration of all the calcium oxide in order to secure additional strength in mortars made from such hydrated limes. A further object is to maintain the plasticity and for working under the trowel of mortar made from magnesian lime.*

In his patent, Corson (1943) makes the following comments on the nature of lime in the United States in the early part of the 20th Century:

- *"Until the early part of this century nearly all lime used was in the lump of pulverized quicklime form to which sufficient water was added on the job to produce a wet slaked quicklime which was then mixed with sand for plastering or mortar work. Quicklime is a perishable product and its conversion on the job to a quicklime putty is laborious, expensive, time consuming and the quality of the product varied considerably. Hence in the later part of the last century and the early part of this century, dry powdered hydrated lime was generally introduced on the market. It was made by adding only a small amount of water to the lime so as to form a dry powder which was then bagged and delivered to the job."*

- *"In general, hydrated limes made in the foregoing conventional manner are, however, noticeably lacking in plasticity, that is, they do not spread easily under a trowel and tend to stick and pull…"*

- *"…nearly all of the lime used for finishing purposes is made from high magnesium hydrates and, as produced by present day methods of hydration, it contains practically no, or very little, magnesium hydroxide when delivered on the job. However, upon being soaked in water overnight the lime develops considerable plasticity and of course apart from this, some of the magnesia does hydrate."*

The objective of both these patent submissions was to produce a hydrated lime that was completely slaked and had high early plasticity. The theme of plasticity for lime putties is consistent. Many years of research investigating the measurement of plasticity came next.

3 Quantifying Plasticity.

3.1 Emley Plasticimeter

Dr. Warren E. Emley is the father of quantifying plasticity in building limes (Emley, 1917; Emley, 1920). He states, "*A plastic material is one which works freely and easily under the trowel and has marked ability to hold its water*." (p 7) He defines plasticity based on the applications of mortar and plaster, and considers two factors:

- "…*the plasticity of a material depends directly upon its ability to hold its water against the suction of the surface to which it is applied*" (p 6), and
- "…*material is the more plastic which requires the less work to spread it*." (p 7).

Emley developed the Emley Plasticimeter after 10 years of work and developing more than 20 different prototypes. Godbey and Thomson (2002) give a review of Emley's work and the current work by the ASTM C 7 Lime Committee in developing precision and bias for the test procedure.

The test procedure is simple, but demands attention to detail and nuance. ASTM C 110 describes the current test method: The hydrated lime is mixed with water to a certain consistency, then molded to shape on an absorptive base plate. The instrument measures the degree of stiffening of the lime putty as water is withdrawn. The machine operator records the scale values indicating the degree of stiffening at 1-min. intervals until the test ends. The test is considered over when one of three conditions exists:

1) the scale reading reaches 100;
2) any reading is less than the one before; or,
3) the scale reading remains constant for three consecutive readings and the specimen has visibly ruptured or broken loose from the base plate.

As shown in Equation [1], the resulting plasticity value (P) is a function of the force (F) on the scale readings and time (T), with time having a larger influence.

$$P = \sqrt{F^2 + (10)T^2} \quad (1)$$

The plasticity value, P, is unit-less, and is now referred to as Emley Units, in deference to its developer.

In Figure 2, Emley (1920) plots the two measurements of the plasticimeter (force and time) for a number of different materials. Curve 8 is masons hydrate before soaking and curve 6 is the same hydrate after soaking. (Mason's hydrate is probably a hydrated lime that is slaked under atmospheric conditions, and would have been high-calcium, not dolomitic). The force value determined by testing increases with soaking, but the time to failure is not much different. Curve 5 is finishing hydrated lime (Ohio finishing lime, dolomitic) before soaking, and Curve 2 is finishing lime after soaking. The force values for the finishing lime also increase with soaking, but the difference in time is significant. The finishing hydrate has a higher plasticity value before soaking, but a greater value after soaking. The soaking slakes the magnesium oxide portion to hydroxide, which apparently results in the high plasticity value.

3.2 Inclusion of plasticity in the standard specification development

The first ASTM Standard for Hydrated Lime was issued in 1913, with the designation C 6. It defined four categories of hydrated lime: high-calcium, calcium, magnesium, and high-magnesium (ASTM, 1915). The standard contained no chemical or property specifications -- there were more instructions given on how to mark the bag than on the contents of the bag.

Hool and Johnson (1929) describe hydrated lime by reference to the C 6-26 specification as,"…*calcium hydroxide, or a mixture of calcium hydroxide and magnesium oxide*" (p 978). They also describe "masons' hydrate" and "white finishing hydrate" as two classes of lime that are distinguished primarily by the plasticity or workability of the white finishing hydrated lime. Although they do not indicate if the plasticity value is the Emley plasticity value, it most likely is.

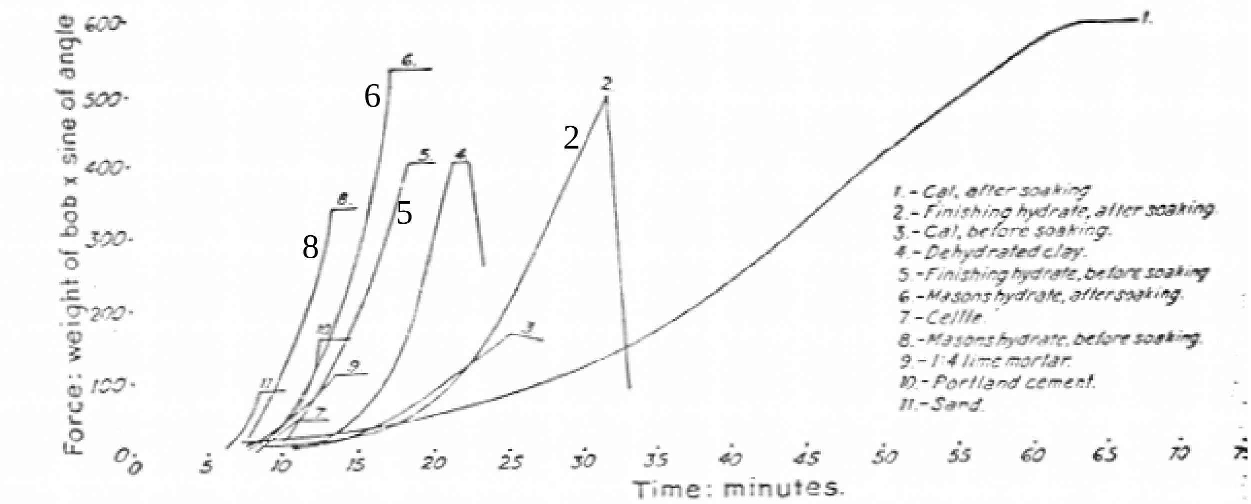


FIG. 6.—*Plasticity curves of miscellaneous materials*

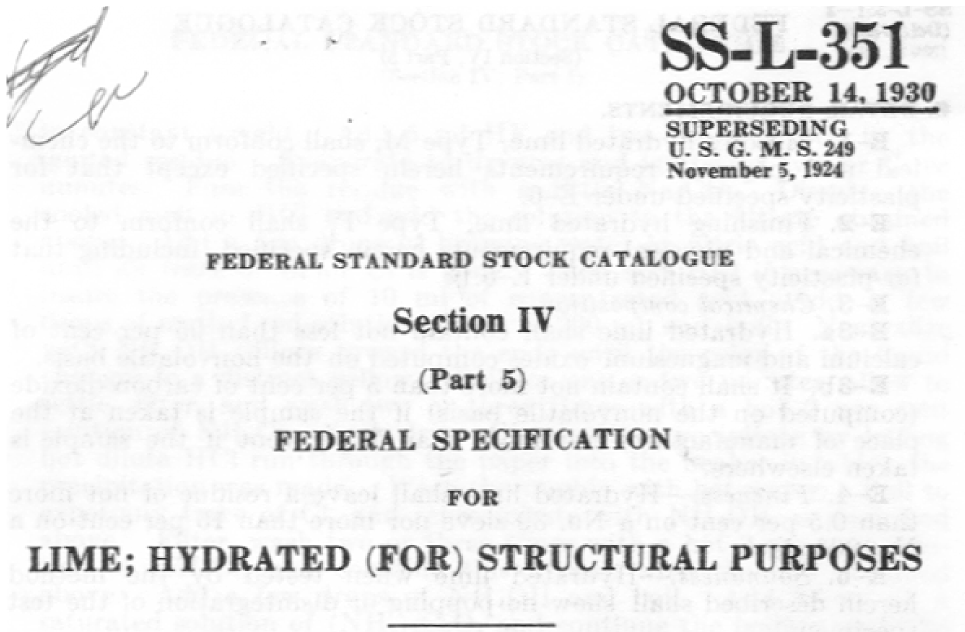
Figure 2. Force versus time curves for different materials (Emley, 1920)
Note: "Cal" is a proprietary material used to accelerate early hardening in concrete. Celite is diatomaceous earth.

The 1930 Federal Specification for Hydrated Lime for Structural Purposes (SS-L-351) is the first standard specification that is detailed in its requirements. It describes Type M hydrated lime for masons and Type F for finishing (Figure 3). Both the Type M and Type F hydrated limes have the chemical composition of 95% of calcium and magnesium computed on the non-volatile basis, not more than 5% carbon dioxide, and no more than 0.5% retained on a No. 30 mesh sieve nor more than 15% on a No. 200 mesh. The Types differ only in that Type F has a required plasticity value of 200 (Emley Units). The plasticity testing required that the hydrate be made into a stiff putty and be allowed to soak for not less than 16 and not more than 24 hours.

The year 1946 was very significant for the use of hydrated lime for building construction. The term Type S – Special hydrated lime was first used and the modern standard numbers were adopted: ASTM C 206 – 46T, ("Tentative Specification for Special Finishing Hydrated Lime") and C 207-46T ("Tentative Specification for Hydrated Lime for Masonry Purposes"). The tentative specifications became standard specifications in 1949. A note in the scope of C 207 reads, "*special hydrated lime for masonry purposes is differentiated from type N – normal hydrated lime for masonry purposes principally by its ability to develop high, early plasticity and higher water retentivity and by a limitation on its unhydrated oxide content.*"

Although the Warner (1918) process was available, it was the Corson Pressure Hydrator, patented in 1943, that was the most significant technological advance. It gave the lime industry the ability to make sound and highly-plastic hydrated lime (when a putty) from dolomitic quicklime in a continuous process. This innovation drove the definition of Type S hydrated lime as being "special". Hydration did not occur at atmosphere, but rather at high pressure. However, this does not preclude a high-calcium hydrate that is processed at atmospheric conditions from being a Type S hydrated lime.

In 1980, ASTM C 6, Standard Specification for Normal Finishing Hydrated Lime was withdrawn and Type N finishing hydrated lime requirements were incorporated into C 207.



SS-L-351

OCTOBER 14, 1930

SUPERSEDING
U. S. G. M. S. 249
November 5, 1924

FEDERAL STANDARD STOCK CATALOGUE

Section IV

(Part 5)

FEDERAL SPECIFICATION

FOR

LIME; HYDRATED (FOR) STRUCTURAL PURPOSES

Figure 3. 1930 Federal Specification

4 Another property is required - water retentivity

The National Bureau of Standards was instrumental in developing the apparatus and beginning the current techniques to determine water-retentivity of mortars (also called water-retention or water-retaining capacity). Palmer and Parsons (1932) and Rogers and Blaine (1934) describe the apparatus and refer to it as the Rogers Device. A 1932 study by Palmer and Parsons investigated the rate of stiffening. They described the work as "*The rate of stiffening of mortars on a porous base is one phase of an investigation at the Bureau of Standards that is being sponsored by the American Face Brick Association, the National Lime Association, and a group of masonry cement producers*." (p 18) They used the Rogers Device to withdraw water at 1-minute intervals and determined the flow of the mortar using the same type of flow table that is used today. They investigated 50 mortars and their findings included the fact that lime contributed significantly to reducing the rate of water withdrawal from a portland cement-lime mixture (Figure 4).

Rogers and Blaine (1934) studied the water-containing capacity of 41 different mortars. They defined this as the percentage of water that was withdrawn by the Rogers Device at one minute and three minutes (Figure 5). They found that "*the least amount was retained by a cement largely portland, and the greatest by a* [portland] *cement-hydrated lime mixture*." (p 848).

The current test methodology for water retention (ASTM C 110) combines those two approaches. It determines the percent loss in flow at one minute for a mortar subjected to the withdrawal of water using the Rogers Device. The 1946 ASTM Standard C 207-46T Hydrated Lime for Masonry Purposes and the 1945 National Lime Association Specifications for Lime and Its Uses include water-

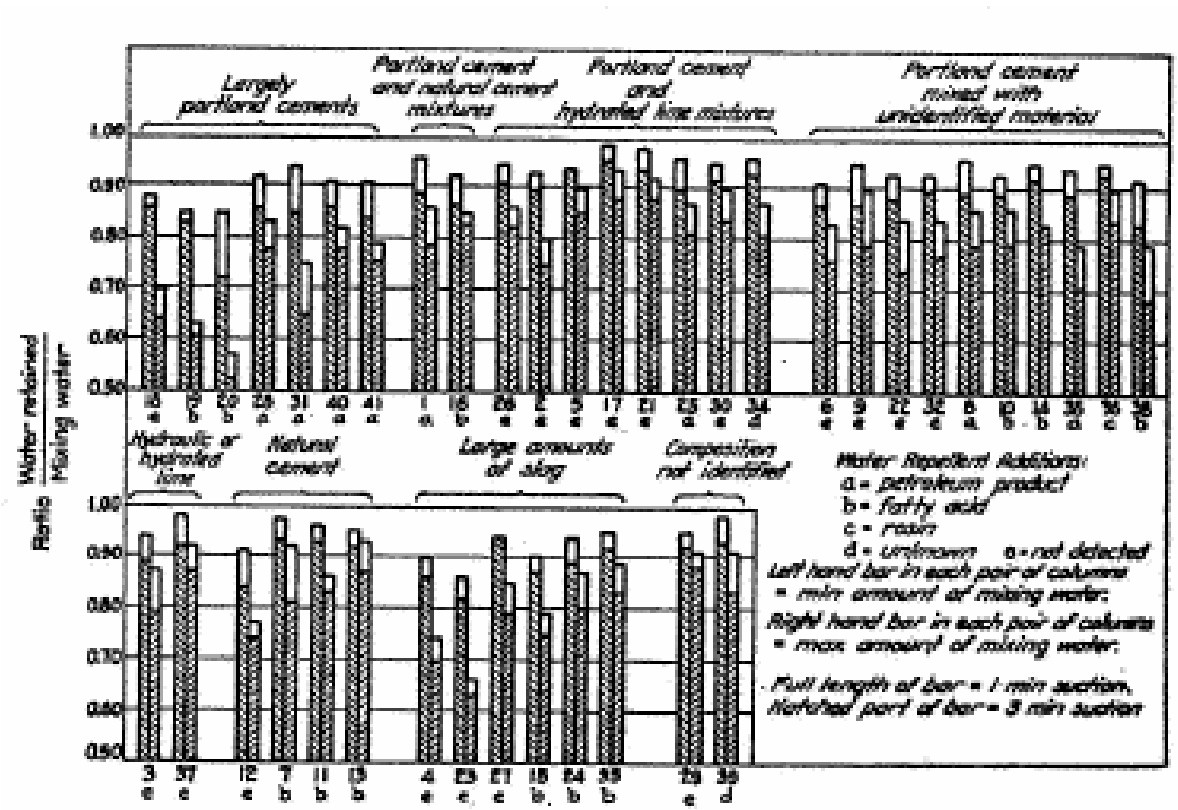


FIGURE 11.—*Water-retaining capacity of cements in type X mortar.*

Figure 5. Water-retaining capacity at 1 and 3 minute intervals. (Rogers & Blaine, 1934)

retention requirements of the lime as a sanded mortar. A value of not less than 75% is required for Type N, normal hydrated lime from a dry hydrate or a putty soaked for 16 to 24 hours, and not less than 85% for Type S, special hydrated lime made from dry hydrate with no soaking. Even today, the finishing hydrated limes (for plaster) have plasticity requirements, but no water-retention requirements, unlike the limes used in mortar.

Levin *et a*l. (1956) investigated the relationship of plasticity and water-retentivity in hydrated lime. They introduce the paper by discussing mason's need for mortar workability. They add "*workability is important, furthermore, because it has a bearing on such properties as strength, water resistance, and workmanship of masonry construction*." They investigated 72 limes, including high-calcium hydrated limes, regularly-hydrated dolomitic limes, highly-hydrated dolomitic limes, and magnesian hydrated limes. Their investigation had the following objectives:

- Determine relative plasticity values and water-retentivities of different types of commercial hydrated limes;
- Study the relationship between plasticity of lime putties and water-retentivites of lime-sand mortars;
- Consider these properties in relation to plastering and to masonry construction; and,
- Relate these results to the possible improvement of specifications (federal).

Figure 6 shows the high plasticity values and high water-rententivity values of the highly-hydrated dolomitic hydrate tested after 30 minutes. Levin *et al.* conclude that a requirement for a plasticity value of 200 at 30 minutes governed over requirements for water-retentivity because highly-plastic limes have high water-retententivity.   They did not recommend removal of the plasticity test, and suggested that water retentivity requirements did not address all the workability issues.

This work shows the transition from highly-hydrated or Type S hydrated lime being restricted to a plaster lime to being used as a mortar lime as well. The same properties that contributed to workability of a plaster had direct relationship to mortars.

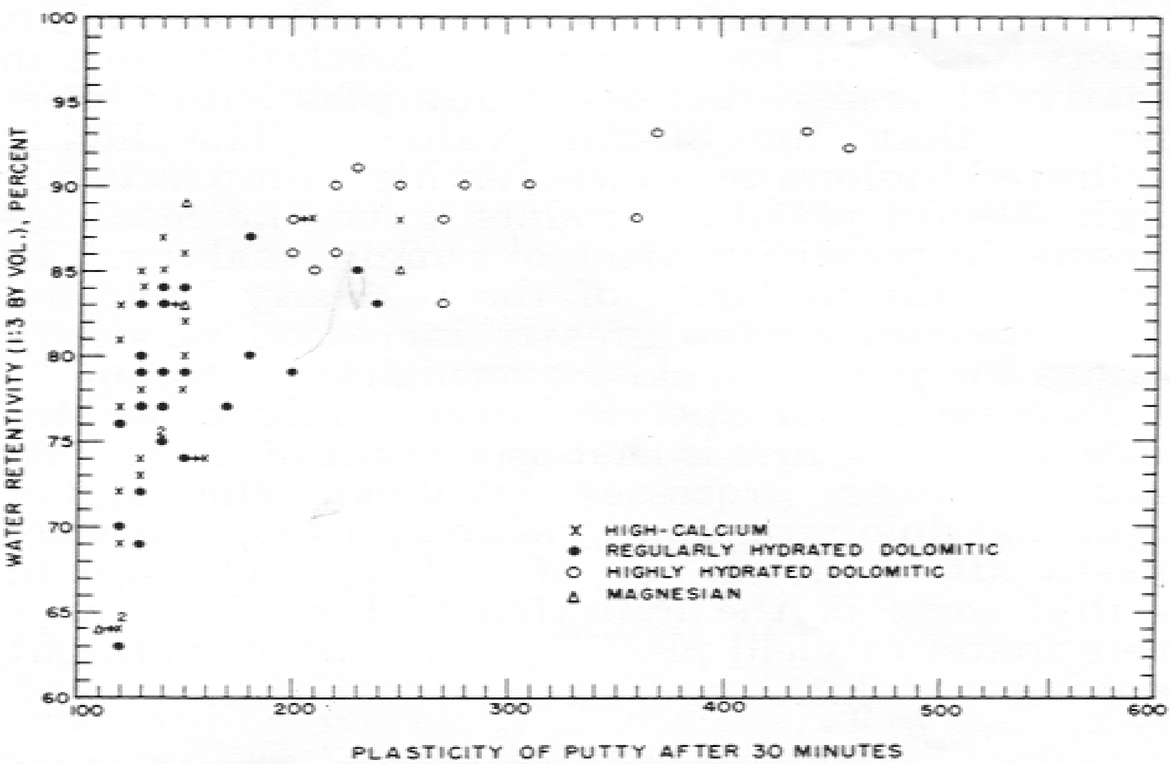


FIGURE 3. *Relation between water retentivity of lime-sand mortar proportioned on a volume basis and plasticity of corresponding hydrated-lime putty after soaking for 30 minutes.*

Figure 6 Water Retentivity vs. Plasticity (Levin et al., 1956)

5 The status of specification today

The specification requirements for hydrated lime for mortar (C 207) and for finishing plaster (C 206) are summarized in Table 1. The chemical specifications for C 207 and C 206 hydrate types are the same. They require that the product contain no less than 95% combined values of calcium or magnesium and not more than 5% carbon dioxide. These values dictate that the source rock must be pure and that the calcination must be virtually complete.

The physical specifications limit the amount and nature of the coarse fraction for hydrates for mortar (C 207). The amount is limited to not more than 0.5 percent (by weight) held on a 30 mesh screen (600µm), but more is allowed if no pits or pops occur during testing. This differs from the finishing lime application (C 206), which requires no more than 0.5% on a 30 mesh screen, no more than 15% on a 200 mesh screen (75µm), and no pits or pops. The requirements for the mortar application indicate that a small amount of coarse fraction can be tolerated only if it is essentially inert, that is, no pits or pops. A finishing lime for plaster requires that there be very little (< 15%) hydrated lime coarser than the 200 mesh or 75 µm, and that there is no component that can cause pits or pops.

Table. 1. Specification Requirements for Type N and Type S Hydrated Lime

	C 206 – finishing plaster		**C 207 – mortar**	
Requirement	**Type N**	**Type S**	**Type N**	**Type S**
Chemical Properties:				
Calcium and magnesium oxides (non-volatile basis), min. %	95	95	95	95
Carbon dioxide, min.%	5	5	5	5
Unhydrated oxides, max. %	no value assigned	8	no value assigned	8
Physical Properties:				
No. 30 mesh (600 µm), max. %	0.5	0.5	0.5 or if greater no pits or pops	0.5 or if greater no pits or pops
No. 200 mesh (75 µm), max. %	15	15	no value assigned	no value assigned
Pits or pops	none	none	Not applicable unless No. 30 mesh >0.5%, then none.	Not applicable unless No. 30 mesh >0.5%, then none.
Plasticity, min. Emley value	200 after 16 h soak	200 within 30 min.	no value assigned	200 within 30 min.
Water retention, min. %	no value assigned	no value assigned	75 after 16 h soak	85 within 30 min.

Emley plasticity values over 200 are required within 30 minutes after mixing mortar or finishing plaster withType S hydrated lime. Type N hydrated lime must achieve plasticity values of 200 after 16 hours but before 24 hours of soaking for the finishing lime. There is no plasticity requirement for Type N hydrated lime in mortar applications.

Water retention values are only required for the mortar application. For Type N hydrated lime, a value of 75% must be met after 16 but before 24 hours of soaking. The Type S hydrated lime must meet a water retention value of 85% within 30 minutes after mixing. There is no water retention requirement for finishing lime.

In considering the two specifications and the two hydrate types, a Special hydrated lime for finishing purposes (Type S C 206) can be designated a Type N in either specification, with the addition of the water retention requirement for a Type S in C 207, but not *vice versa*. What makes a Type S hydrated lime different from a Type N is limiting the amount of unhydrated oxides, obtaining a plasticity value of 200 within 30 minutes of mixing, and requiring a water retention value of 85%. No distinction is made based on the nature of the source carbonate. The specification is indifferent to whether the source is limestone (high calcium), magnesium-limestone or dolomite.

ASTM C 1489, Standard Specification for Lime Putty for Structural Purposes, was first published in 2001, almost one hundred years after publication of the quicklime specification, C 5. The authors of this new specification represented the intent of the ASTM C 5 specification, and required that the lime putty be pure in composition, not have significant impurities, and have high water-retentivity and plasticity. Like its ancestors, this specification does not address composition.

6 Modern applications

The dominant use of Type S hydrated lime is for masonry mortar and exterior render and stucco. ASTM C 270, which is the cornerstone standard specification for mortar, allows Type S or SA (air-entrained) hydrated lime. Types N or NA limes are permitted if shown by test or performance record to be not detrimental to the soundness of the mortar. This restriction reflects the lack of restriction on unhydrated oxide for Type N hydrated lime. Type S hydrated lime is used for well over 90% of all the cement-lime mortars produced in the US. Significantly, the masonry building code (MSJC, 2002) requires the use of cement-lime mortars in high seismic zones without stating any performance requirements. Cement-lime mortars are the standard against which other mortar types must perform.

ASTM C 926 (exterior plaster [render]) specification requires that the lime contain no more than 8% unhydrated oxide, but does allow for the use of Type S or Type N hydrated limes. In reality, however, Type S hydrated lime, and specifically finishing lime, is used in the Western United States where exterior stucco is a dominant form of exterior cladding. The plasticity and soundness are valued.

In ASTM C 842, the specification for interior plasters, only Type S special finishing hydrated lime (ASTM C 206) is allowed. This industry has not lost sight of the value that the Ohio Limes, and now Type S hydrated limes, bring to the beauty of interior plasters.

The number of producers of Type S hydrated lime is reduced to 6 in the United States, representing 8 production facilities. Many of these production facilities can trace their origins to the early 1900's, and are approaching over 100 years of continuous production. The National Lime Association was organized in 1902 and the Building Lime Group was there at the beginning. The names of the companies have changed and there has been a reduction in the number of individual facilities. There is, however, a continued commitment to promote and educate each generation on what makes Type S hydrated lime special.

Author's Note

The images reproduced in this paper come form the available original documents. They are less readable than would be liked due to the nature of the initial imaging. Apologies are made. Some of these papers are available on the Proceedings CD.

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