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THE HISTORY OF MASONRY MORTAR IN AMERICA
1720-1995

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ABSTRACT

The evolution of masonry mortar over the last 275 years in America has been very interesting. Inventions and discoveries over this time period, in both Europe and America, directly impacted the way mortar is manufactured and used in today's construction industry. Among the notable discoveries were Smeaton's discovery of hydraulic lime in 1756, Joseph Aspdin's development of portland cement in 1824, and the introduction of masonry cement mortar in the late 1920s. Mixing mortar at the construction site has evolved from the hoe and shovel of the 1800s, to the gasoline and electric mortar mixers of the 1940s, to the highly sophisticated bulk silo systems of the 1990s. The standards that govern masonry mortars in the United States under The American Society for Testing and Materials have played an important role in the development of mortar, its use, and its applications. These standards and specifications have evolved as the technical knowledge of mortar has increased and, at the same time, the testing methods have improved.

INTRODUCTION

For centuries architects, builders, and masons have been using mortar to construct masonry structures. The ingredients, methods of production, and the way mortar is specified and mixed have all seen changes over the centuries. The ultimate purpose of mortar, however, still remains the same as it did in ancient Egypt: to hold the masonry units together.

"Mortar" is a term applied to the material used for bedding, jointing, and rendering brickwork and stonework. Mortar normally consists of cementitious or other binding material, usually with a suitable filler or fine aggregate. The oldest mortar used for the first masonry shelters in ancient Egypt was mud. Later came gypsum mortar, then clay mortar (Davey 1961). It was discovered that excellent mortar resulted from burning limestone at high temperatures, letting the limestone cool, then soaking it in water. This material was then mixed with volcanic ash, sea shells, or river sand to produce the first lime mortars. "Lime burning

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had apparently been practiced in Mesopotania at least as early as 2450 B.C. for the remains of a lime-kiln are recorded from Khafaje" (Davey 1961). The use of lime in mortars has been well established in historical structures around the world. In the United States, lime-sand mortars were used extensively until 1871 when portland cement became available for the first time. The development and commercial availability of portland cement after 1871 changed the way mortar was specified and used.

At one extreme, a straight lime-sand mortar has excellent workability and high water retention. At the other extreme, a straight portland cement-sand mortar has poor workability and low water retention. Between the two extremes, various combinations of portland cement and lime provide a balance with a wide variety of properties (ASTM C-270 1993).

Buildings that were constructed during the end of the 19th century that used lime along with portland cement in the mortar are still performing well today. Portland cement-lime mortars were widely used in the United States after 1886 until the development of masonry cements in the late 1920s (Stehly 1992). Masonry cement was formulated with the intent to simplify the mixing process, requiring only one ingredient to be mixed with the sand and water instead of two, as with portland cement and lime. The masonry cement mortar product was also designed to eliminate the need for lime by replacing it with various additives. Since the development of masonry cement mortar in the United States, the use of mortars containing lime has declined over the last six decades.

The purpose of this paper is to offer a historical overview on masonry mortar development in America. This paper is not intended to be all -inclusive from a historical perspective; only the historical highlights are contained herein. This paper includes information on the historical development of masonry mortar ingredients, methods of production, and specifications, while focusing on the last 275 years (1720-1995).

INGREDIENTS OF MORTAR

Lime

The term "lime" comes from the word *lime*stone. Limestone is converted to lime when it is heated. Burning (calcining), limestone has been well documented archaeologically. It has been established that the production of lime is the oldest industrial process of mankind, dating back many thousands of years (Davey 1961). In fact, 3,650 years ago Moses instructed the people of Israel, after they crossed the Jordan River, to set up large stones and whitewash them with lime and write the laws of God in the lime (The Living Bible 1971).

Lime is made by heating or burning the limestone (calcium carbonate) to 1650 degrees F. The heat burns off the carbon dioxide, leaving calcium oxide, more commonly known as quicklime, which is white and usually in the original shape of the limestone before burning. Prior to 1935, the quicklime was soaked in water for weeks and sometimes months converting it to lime putty which was mixed with three parts sand to make lime-sand mortar. The primary reason for producing lime was to make mortar.

Evidence of lime mortar's durability can be found in the historical structures throughout the United States such as the Massachusetts Hall at Harvard University (Fig. 1). Prior to the advent of portland cement in the United States in the latter part of the 19th century (1871 on), all of the masonry mortar was a straight lime-sand mix that inherently possessed very low compressive strength ranging between 50 to 300 p.s.i. in 28 days (Boynton et al. 1964). This low compressive strength was beneficial by allowing the masonry walls to "flex" without cracking.

Fig. 1 Massachusetts Hall, Harvard University, built in 1720 with straight lime-sand mortar. The mortar has never been replaced, repaired, or tuckpointed. (Boynton et al. 1964)

Lime slowly gains strength over time in the masonry wall, absorbing $C0_2$ from the air and converting itself back to limestone. As the lime absorbs $C0_2$ from the air, the masonry wall gains an extra benefit. If a hairline crack develops between the brick and mortar joint, the lime acts as a "self healer" in sealing the crack in a process identified as autogenous healing. This proven healing process is well documented in various research studies available through the National Lime Association, in Arlington, Virgina.

Types of Limestone

Figure 2 illustrates the three types of limestone: high calcium, magnesian and dolomitic. The types are distinguished by their levels of magnesium carbonate. Dolomitic limestone is preferred in making lime for mortar. The high levels of magnesium in dolomitic limestone gives the lime very good water retention and plasticity that cannot be obtained in the high calcium or magnesian types. In addition, the particle size of dolomitic lime is more beneficial in creating a good mechanical bond between the masonry units.

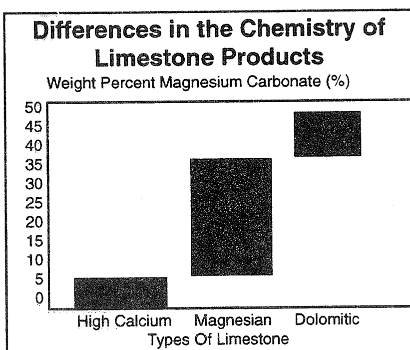

Fig. 2 Limestone types as distinguished by the level of magnesium carbonate.

Dolomitic limestone deposits are found in isolated geographic areas throughout the world. One of the worlds purest dolomitic deposits is located just east of Toledo, Ohio, in Ottawa County.

Manufacturing Lime

Lime kilns, as shown in (Fig. 3) below left, were commonly used around 1825. The reason some were built into the side of a hill was to avoid expending the energy to lift the limestone into the kiln at the top if it were constructed free standing. By the beginning of the 20th century, shaft kilns were the method of choice, as seen below in (Fig. 4).

Most lime manufacturers today utilize rotary kilns to fire the limestone. Rotary kilns range from 8 to 20 feet in diameter and are built of steel and lined with firebrick. They can have lengths of up to 500 feet. Once the limestone is fired, the quicklime is then sized and hydrated. Hydration is the process by which water is added to the quicklime. The commercial availability of double hydrated lime after 1932 allowed the lime to be mixed directly into the mortar without the required soaking time. Prior to 1932, lime was delivered to a construction jobsite in the quicklime form and thus had to be hydrated, or slaked in order to use it as a mortar ingredient. Today, dolomitic hydrated lime is produced by eight companies operating nine manufacturing plants throughout the United States. These plants produce 164,000 tons of lime annually (Francis 1994).

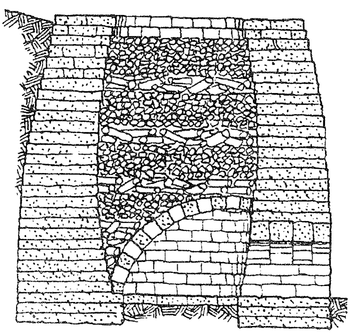

Fig. 3 Lime Kilns 1825.
Common type, built into a hillside. Often lined with firebrick in the 19th century. Sometimes wood or coal and lumps of limestone were placed in alternate layers, as shown here; other times fuel was burned only at the bottom (McKee 1973).

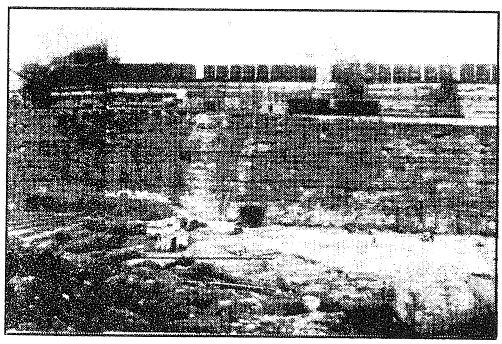

Fig. 4 United States Gypsum Company, Genoa, Ohio. Photograph shows quarry operations and 40 shaft kilns in 1925. The far left shaft kilns can be seen burning limestone in the manufacturing of lime. (Courtesy of GenLime Group, L.P., Genoa, Ohio)

Hydraulic Lime

In 1756, John Smeaton, an English engineer, was experimenting with limes in search of a reliable mortar to be used in the construction of the Eddystone lighthouse off the coast of England. Smeaton found that limestone which contained clay when calcined (fired) had a much harder and stronger resistance to water. This momentous discovery put to rest over 2000 years of opinions that the best mortars came from the whitest and hardest limestone. Smeaton proved that it was the clay in the stone that caused the desired cementing action, the process by which the mortar hardens, and stays hard even under water (Cummings 1898).

Smeaton in his "Narrative of the Eddystone Lighthouse" says: "It remains a curious question which I must leave to the learned naturalist and chemist, why an intermediate mixture of clay in the composition of limestone of any kind, either hard or soft, should render it capable of setting in water in a manner no pure lime I have yet seen, from any kind of stone whatsoever, has been capable of doing" (Cummings 1898).

Roman Cement

On July 27, 1796 James Parker of Northfleet, England, was granted patent number 2120 for a cement he discovered to be superior to any other cement or mortar product produced at that time. Parker made the cement by reducing to powder certain stones of clay then burning them to make mortar. Initially the new cement was known as "Parkers Cement", but later was named, "Roman Cement" by Parker himself (Lesley 1924).

Artificial Hydraulic Lime

In 1818 Dr. John Berlin and M. Vicat of France, working from the Smeaton truth, came up with the first "artificial hydraulic lime." The discovery was labeled "artificial" because the formula was not from a single limestone source, but a combination of limestone and clay. It was called hydraulic lime because it would remain unchanged when tested underwater (Cummings 1898).

Portland Cement

In 1824, Joseph Aspdin, a Hunslet Leeds bricklayer, was granted patent number 5022 for a cement he discovered after he mixed a calcined hard limestone with clay, ground it down, mixed it into a slurry, and then burned the mixture a second time. Aspdin called his product "portland" cement because the mortar made from the cement resembled in color a widely used building stone quarried on the Isle of Portland off the coast of England (Lesley 1924).

Portland cement achieved very quick setting times, but strengths were much lower than good quality Roman cement; thus, it had little commercial advantages in the first few decades after its development. By the late 1860s, European portland cement manufacturers began to take notice of the increasing use of cement in the United States. Recognizing a good market, they began to ship portland cement to the United States, in wooden barrels as ballast in ships, at very low freight rates. This does not mean that the United States did without cement until that time. On the contrary, a large and flourishing natural cement industry had emerged. Natural cement rock was limestone that contained the appropriate amounts of clay to give it hydraulic properties.

The growth of the natural cement rock industry was originally stimulated by the great period of canal building in the early 1800s. Construction of the Erie Canal, begun in 1817, led to the discovery of natural cement rock in the Rosendale district of New York in 1818. Large quantities of this natural cement were used in the construction of the canal at a price of 20 cents a bushel. The bushel size was slightly more than a present day bag of mortar (History 1995). The early growth of the United States portland cement industry started in the Lehigh Valley district in Pennsylvania. David 0. Saylor was the first to make portland cement in the United States in 1871 (Lesley 1924).

All of the portland cement used in the United States prior to 1871 was imported from England and France. Natural cement and portland cement competed for market share. As cement testing equipment became more sophisticated, enabling cements to be tested at increasingly higher load limits, it was soon acknowledged that portland cement developed much higher strengths much sooner than natural cement rock. Manufacturers could realistically expect twice the compressive strength in one year (Cummings 1898). The building industry soon accepted the thinking that stronger cement was better and as a result the portland cement industry grew rapidly as many of the natural cement rock manufacturers converted their operations to produce portland cement. The rapid growth occurred between 1871-1920 (Fig. 5).

The Production of Portland Cement in the U.S. 1871-1920

Years	Barrels	Value	Price per Barrel
1871-1879	82,000	$246,000	$3.00
1880-1889	1,477,000	$2,930,750	$1.98
1890-1899	17,282,834	$27,837,816	$1.61
1900-1909	339,240,000	$444,890,000	$0.98
1910-1920	945,107,000	$1,113,777,000	$1.20

Fig. 5 Growth of the portland cement industry (Lesley 1924)

Interestingly enough, the addition of portland cement to lime-sand mortars in the late 19th century was to speed up the construction process. Portland cement was initially considered an additive to enhance the setting characteristics of lime-sand mortars (Boynton 1964). With the thought that stronger mortar was better, portland cement was increasingly added in larger and larger volumes to the lime-sand mixture, in some cases eliminating the lime altogether by the turn of the century.

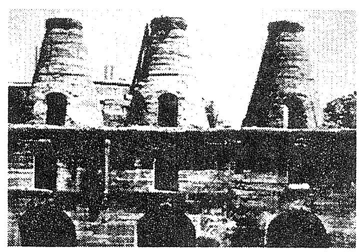

Fig. 6 Bottle Kilns from 1825. (Courtesy of Portland Cement Association, Skokie, IL)

Manufacturing Portland Cement

The manufacturing of portland cement is similar to that of lime in that the process requires the heating of raw materials through a kiln. The earliest kilns in which cement was burned in batches were called bottle kilns (Fig. 6), followed by chamber kilns, and then shaft kilns. The shaft kiln is still used in some counties, but the dominant means of burning cement today is continuous rotary kilns (Fig. 7). These kilns, up to 660 feet long and 20 feet in diameter, are made of steel and lined with firebrick.

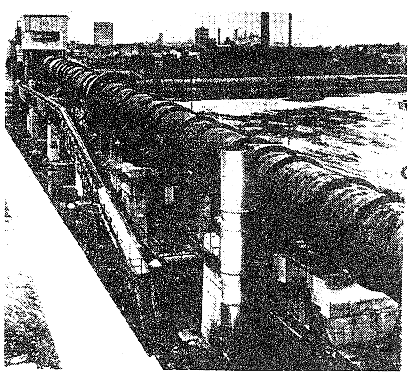

Fig. 7 Peerless Cement Company, Detroit, Michigan 1958. This cement kiln is 425 feet long and 11.5 feet in diameter. (Courtesy of The Michigan Department of State Archives, Lansing, MI)

Portland cement consists of limestone, clay, and small amounts of other minerals. Mixed together, this combination of raw materials enters the kiln to be fired. Often, by-products from other industries, such as fly ash which is generated by power companies in the process of producing electricity, are sometimes used in the formulations.

The material produced after the firing process has been completed is called clinker. Usually the size of a driveway stone, the clinker is then ground down into a fine powder to which five percent gypsum is added to control the setting time of the cement. This well-ground portland cement is then pumped up to holding silos, from which it can be packaged in paper bags or shipped in bulk by trucks or rail cars. Today, portland cement is manufactured by 46 companies operating 119 plants throughout the United States with domestic shipments of 80 million tons annually (Melander 1994).

METHODS OF PRODUCTION

Mixing Mortar

In 1823, thorough mixing, or beating, was emphasized by most authorities. Peter Nicholson recommended a practice in The New Practical Builder, which was probably well agreed upon in England and the United States. He recommended that before the mortar is used, it should be beaten three or four times over, so as to incorporate the lime and sand by reducing all the knobs of lime that may have passed through the sieve. This procedure very much improves the smoothness of the lime by driving air into its pores, making the mortar stronger (Nicholson 1823).

In 1896 F. E. Kidder gave the following recommendations for mortar mixes in his Building Construction and Superintendence. The following mixtures by measure, says Kidder, have been used with excellent results:

1 part cement,	8 parts sand,	1.5 parts lime paste
1 part cement,	6-7 parts sand,	1.0 part lime paste
1 part cement,	8 parts sand,	0.5 part lime paste
1 part cement,	10 parts sand,	2.0 parts lime paste

Actual mixing of the sand, cement, and lime was accomplished usually by hired hands with strong backs. In 1898, using shovels and hoes, the hired hands would mix the ingredients together with water in large wooden boxes (Cummings 1898). This is referred to as "hand mixing" as compared with "machine mixing". Machine mixers of the early 20th century were used by construction crews to mix concrete and not commonly found on jobsites mixing mortar.

Mortar Mixing Machines

Mortar mixing machines were developed after World War II (Rebar 1995). The barrel type (Fig. 8, next page) was the first, followed by the paddle type (Fig. 9) in the 1950s. Mortar mixers are the most common method of mixing mortar today. These machines are powered either by electric or gasoline engines.

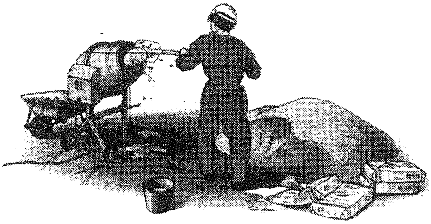

Fig. 8 Barrel type mortar mixer, (Illustration courtesy of Mega® Mix, Phoenix, AZ)

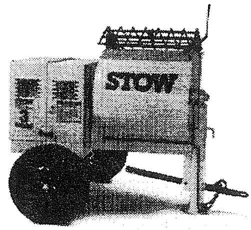

Fig. 9 Paddle type mortar mixer (Courtesy of Stow Manufacturing, Binghamton, NY)

Mortar Admixtures

Mortar admixtures have been used for many centuries to aid in the workability of fresh mortar, as well as the durability of the hardened mortar. The Romans would mix animal blood into the mortar, claiming it made it more durable. In the study of historical mortars, evidence of straw, grass, animal hair, and human hair have also been found. Today, modern day admixtures can be categorized under eight types (Beall 1989).

1. Air entrainment - Helps hardened mortar resist freeze-thaw cycles and improves workability of fresh mortar.
2. Accelerators -Reduces the water cement ratio of the mortar mixture, thus creating shorter setting times by 30 to 40%. Generally used in cold weather construction to keep the mortar from freezing.
3. Retarders - Extends board life of fresh mortars as much as 4 to 5 hours. Helps the mortar retain water for longer periods of time. Usually used in hot climates where board life can be a problem.
4. Extended-life retarders - Slows the reaction time of cement and water in stalling the hydration process allowing the mortar to remain in a workable state for up to 72 hours depending on the dosage.
5. Integral water repellents - Reduces water absorption of hardened mortar by as much as 60% without decreasing strength. Used in combination with a concrete masonry unit that contains the admixture which is usually added in the manufacturing process.
6. Bond modifiers - Improves adhesion, surface density and bond strength. Generally used with dense-surfaced units, such as glazed tile or in glass block work.
7. Color Pigments -Purely aesthetic purposes. To blend or accent a color in the wall design, sometimes matching the masonry unit, but not always. Color pigments have been used for many decades in the United States.
8. Corrosion inhibitors - Offsets effects of chloride intrusion and prevents steel from corroding. Usually used in marine environments or where de-icing salts may be used. Only used when steel is present in grout or mortar (Beall 1989).

Silo Mortar Systems
Silo mortar systems are an alternative method of delivering mortar materials to a construction site. Silo systems do away with the conventional jobsite sand pile and pallets of bagged mortar materials. These silo systems offer mortar materials, including the sand, pre-blended and ready to use.

Three types of silo systems introduced since 1988 have been used successfully in the United States. One system (Fig. 10, next page), utilizes a screw type mixing chamber attached to the bottom of the silo which blends the separated dry mortar materials together while adding sufficient water before being discharged into a wheelbarrow or mortar tub. The second system (Fig. 11), also utilizes a screw type mixing system attached to the bottom of the silo; however, the dry mortar materials are all pre-blended in the silo and not separated like illustrated in (Fig. 10). The third system (Fig. 12), is different in that it allows the contractor to use his own mortar mixer which is positioned directly beneath the silo for the actual mixing of the pre-blended mortar materials with water. These silo systems can offer either a portland cement-lime or a masonry cement in any mortar type, i.e., M, S, or N according to ASTM C-270 requirements.

SPECIFICATION STANDARDS

Before 1900, most of the materials to make mortar were purchased within 25-50 miles from the construction site primarily due to the limited transportation services. As a result, many manufacturing facilities, or "works," as they were called, were in operation, producing lime or cement for their local communities.

By 1905 over 1,200 individual lime plants were producing lime for the construction industry (Francis 1994). Some lime companies fired the limestone using wood. Others used coal, some used shaft kilns, some used bottle kilns. The methods of producing lime varied greatly from community to community. Some companies fired the limestone for longer periods of time, creating a harder burned lime, yet other companies fired for shorter times, creating a softer burned lime.

These varying methods of production created different product characteristics of the lime (color, size, and purity). These differences caused confusion in the construction field, resulting in different mixing instructions for different limes. For example, one particular lime may have needed additional sand to create the same desired mortar workability, that another lime product did with less sand. This may or may not have resulted from the by-products of wood ashes or coal ashes used in the firing process that were mixed into the lime accidentally.

ASTM Is Born
A society was organized in 1898 to develop material standards which manufacturers of products for the building industry could follow and architects could refer to in writing construction specifications. In 1902, the American Society For Testing Materials, commonly known as ASTM, was chartered in Philadelphia, Pennsylvania.

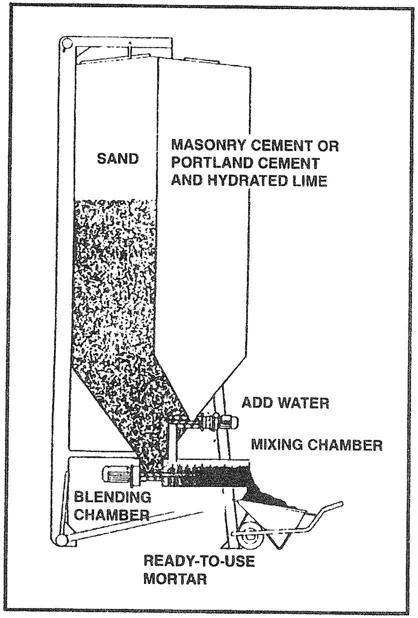

Fig. 10 Silo contains separate ingredients, blending the oven dried sand with the cementitious materials in the mixing chamber.

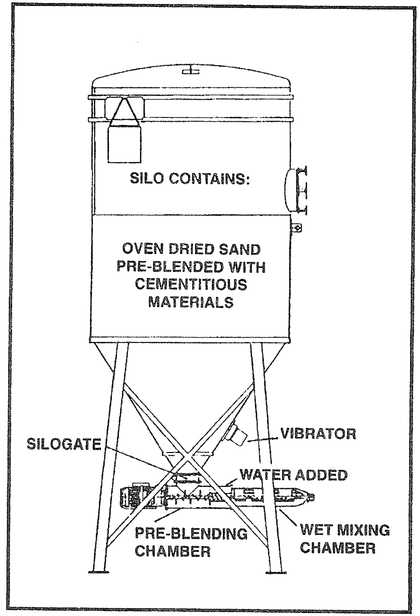

Fig. 11 Silo contains oven dried sand pre-blended with cementitious materials. A wet mixing chamber is used to mix the materials.

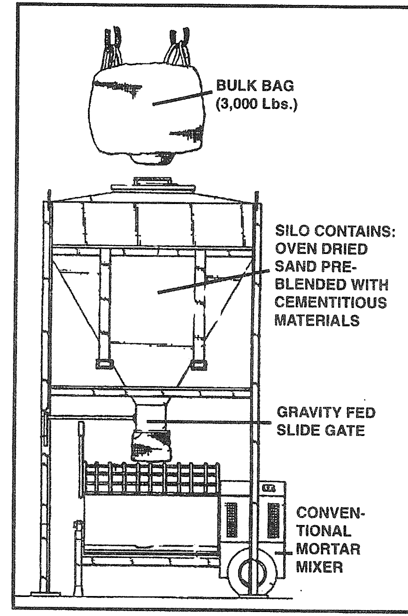

Fig. 12 Silo contains oven dried sand pre-blended with cementitious materials and mixed using a conventional mortar mixer. (Courtesy of Spec Mix, Inc. Vadnais Heights, MN.)

The charter organizers were Charles Dudley, Edgar Marburg, Henry Howe, Robert Lesley, Mansfield Merriman, Albert Colby, and William Webster. Driven by the need for a standard on lime products, the American Society for Testing Materials formed the C-7 committee in 1912 which published 5 building lime standards that same year (Stehly 1992). These voluntary standards were soon accepted by the building industry, and architects began referring to them in their construction documents. The standard for portland cement, C-150, was published in 1940. Volunteer standards from the American Society for Testing and Materials which govern lime and cement products are still recognized by building authorities in the construction industry today.

Once the standards for cement and lime products were established, energies were then turned toward establishing a standard for mortar. Architects wanted to be assured the right mortar was being used for the right building application. A mortar strong in compressive strength (high strength) would be desired for a stone pier holding up a bridge deck, whereas a softer, more flexible mortar would be desired in a tall masonry chimney. If the two desired mortar properties were confused, the bridge deck could collapse due to the soft flexible mortar being washed out from the water pressure of the river current or the tall chimney could fail due to the lack of flexibility it needs to bend with high wind loads . The control of the mortar property, strong or soft, ultimately lay in the hands of the workers on the job site. If mixed with higher amounts of cement, harder mortar could be obtained. The more lime that was added, the softer and more flexible the mortar became.

Masonry Cement Mortar

In the late 1920s, the cement industry, aware of the lack of control in mixing portland cement and lime on the jobsite, took the opportunity to introduce a new mortar product that was easier to use. Masonry cement was the name of the new mortar product, and it was packaged in a single bag (Stehly 1992). One of the biggest changes in the formulation was that it did not contain lime as a major ingredient. The masonry cement mortar product was formulated using different volumes of portland cement to gain desired strengths, along with ground limestone used as a filler and entrained air (microscopic bubbles) to create the desired workability, thus making it possible to produce a soft, flexible mortar as well as a high strength mortar. In 1932, ASTM C-91, the Standard Specification for Masonry Cement was published. The new masonry cement product and its potential for success, were viewed by the lime industry as a threat, making the process of developing a consensus standard on mortar more difficult.

Mortar Type Designations

Nevertheless, representatives from the cement and lime industries and a group of non producers organized ASTM Committee C-12 Mortar for Unit Masonry in 1931. Mortar "types" had to be established to distinguish high strength mortar from soft flexible mortars, so in 1944 the designations using A-1, A-2, B, C, & D were adopted, with minimum compressive strength requirements specified for each mortar type as seen in (Fig. 13, next page). The A-1 mortar type designation was composed of a higher percentage of portland cement (2500 psi) as compared to the K mortar type which composed of a higher percentage of lime (75 psi).

Mortar Type	Compressive Strength	Curing Method
A-1	2500 psi	7 days in moist air, followed by
A-2	1800 psi	21 days in water
B	750 psi	28 days in moist air
C	350 psi	28 days in moist air
D	75 psi	28 days in laboratory air

Fig. 13 1944 Mortar Type Designations. (Davison 1975)

In the United States," A-1" had become synonymous with "the best" or "top quality," and some committee members felt that the designation for the high strength cement mortar was misleading. The possibility existed if an architect or owner wanted a flexible mortar for a particular project, he might mistakenly specify the A-1 mortar type, thinking it was the best. In an effort to avoid confusion, the committee adopted a new mortar type designation in 1954. The new designation letters were taken from the two words, MASON WORK, utilizing every other letter (Stehly 1992).

Type M	replaced	A-1
Type S	replaced	A-2
Type N	replaced	B
Type O	replaced	C
Type K	replaced	D

Type K has since been eliminated from ASTM C-270 Mortar for Unit Masonry; however, Type K is still sometimes specified for historic preservation projects. The mortar types M, S, N, O and the respective compressive strength requirements for each are still recognized in the current ASTM mortar specification C-270, as seen in (Fig. 14, next page).

Also in (Fig. 14) is evidence of the committee's inability to come to an agreement on how mortars should be specified is apparent in the compromise of two separate specifications, proportion and property. The mortar types can be specified by proportion or properties, but not both. The proportion specifications govern if ASTM C-270 is referenced without noting which specification should be used. ASTM C-270, Mortar for Unit Masonry, was first published in 1951.

Ready Mixed and Ready-To-Use Mortars

In the early 1950s, a company named Colonial Blue Diamond introduced a product called "Ready-Mixed Mortar". The system consisted of delivering lime putty, sand, and water to a jobsite in large boxes after these materials were premixed at a central location. The system, however, did not eliminate jobsite mixing since the portland cement still had to be added. After the portland cement was added, the mortar had to be used within the time limits established by ASTM specifications of 2 1/2 hours. Because of the inconvenience of mixing the portland cement, no advantage was really gained; as a result, the ready-mixed product was soon discontinued (Schmidt et al.1990).

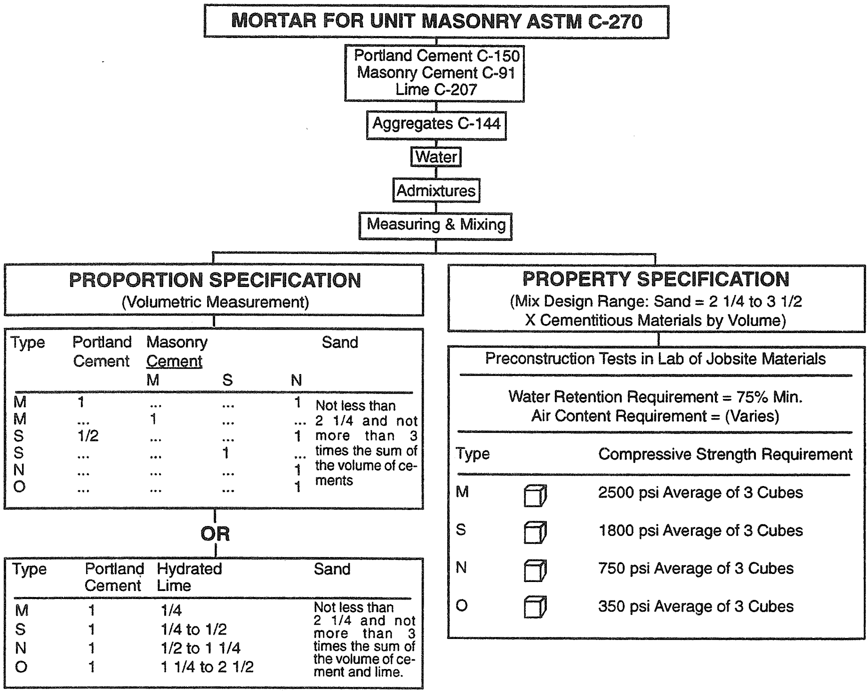

Fig. 14 1993 ASTM Flow Chart. (Melander et al. 1993)

Two decades later, in the early 1970s, a major breakthrough occurred in Germany when a special admixture was developed to retard the hydration process of portland cement enabling a ready-mixed mortar to remain workable for two or three days. A new ASTM standard needed to be developed for this new mortar product, so, in 1983, Committee C-12 on Mortars for Unit Masonry formed a task group to develop a specification. After seven years of extensive research, the Society approved and published ASTM C 1142-90, Specification for Ready-Mixed Mortar for Unit Masonry (Schmidt et al. 1990).

Mortar Cement

On September 14, 1989, the International Conference of Building Officials (ICBO), approved a new mortar classification called "mortar cement". This new classification of mortar is now allowed by the Uniform Building Code (UBC) in seismic zones 1, 2, 3, and 4. Prior to this, UBC allowed only portland cement-lime mortars to be used in structural masonry in these seismic zones because the flexural bond strengths of masonry cement were lower than portland cement-lime mortars.

Development of this new classification started in early 1987, when ICBO members began to consider allowing masonry cement mortar to be used in seismic zones 2, 3, and 4. To qualify as a mortar cement, a masonry cement or any other prepackaged mortar product would have to provide the same bond strength as portland cement-lime mortar. In addition, the standard limits the amounts of additional materials and also requires producers to disclose ingredients to architects or building code officials if requested (Watson 1989).

CONCLUSION

The evolution of masonry mortar in America has undergone many interesting changes over the last two centuries. The ingredients of mortar, methods of producing mortar, and specifications have all changed in some way. Many of these discoveries originated in Europe and eventually reached America many decades later. For example, Smeaton's discovery of hydraulic lime in 1756 was not fully realized in America until the building of the Erie Canal in 1817, some 61 years later. The English discovery of portland cement by Joseph Aspdin in 1824 took 47 years before it was ever manufactured in the United States in 1871.

The development of masonry cement in the 1920s was the most interesting of mortar developments in the United States. The relationship between the cement and lime industries have struggled ever since, due to the fact that masonry cement was the first formulated mortar product that did not contain hydrated lime as a major ingredient. As a result, two sides of the mortar industry have evolved since the early 1930s. Some promote mortar products with hydrated lime, and some promote mortar products that do not contain hydrated lime.

The methods of producing cement and lime changed at the beginning of the 20th century, allowing much more material to be fired in a shorter period of time with the use of rotary kilns. The use of the mortar mixing machine after World War II and the introduction of the mortar silo systems after 1988 were both substantial improvements that directly influenced the methods of mixing mortar at the jobsite.

The American Society for Testing and Materials has been instrumental in providing the construction industry with voluntary standards on mortar products. This society has ultimately pioneered the way to standardization which has lead to better mortar products and more efficient methods of production.

By taking this look into our past, it is hoped that we can gain some insight into our future.

REFERENCES

1. ASTM C-270 Specification (1993), Mortar for Unit Masonry. American Society for Testing and Materials, Washington, D.C.
2. Boynton, Robert S., and Kenneth A. Gutschick (1964), "Durability of Mortar and Masonry." Masonry Mortar Technical Notes #1. National Lime Association, Arlington, VA .
3. Beall, Christine (Oct. 1989), "A Guide to Mortar Admixtures." Aberdeen's Magazine of Masonry Construction.
4. Cummings, Uriah (1898), American Cements. Boston: Rogers & Manson.
5. Davey, Norman (1961), A History of Building Materials. London: Phoenix House.
6. Davison, J.I. (1975), "Development of ASTM Specification for Mortar for Unit Masonry (C-270)." Masonry: Past and Present. ASTM STP 589. American Society for Testing and Materials: pp. 10-24.
7. Francis, Harry (12 Nov. 1994), Telephone interview. National Lime Association, Arlington, VA.
8. Kidder, F.E. (1910), Building Construction and Superintendence. New York: Comstock.
9. Lesley, Robert W. (1924), History of the Portland Cement Industry in the U.S. New York - London: International Trade Press Inc.
10. Living Bible (1971), Deuteronomy 27: 2-4. Tyndale House: Wheaton, IL.
11. McKee, Harley J. (1973), Introduction to Early American Stone, Brick, Mortar and Plaster. Washington, D.C.: The National Trust for Historic Preservation and Columbia University pp. 24-25.
12. Melander, J.M., and Steve Ghosh (1993), "Developing a Standard Performance Specification for Masonry Mortar." Proceedings of the Sixth North American Masonry Conference. Ed. Ahamd A. Hammid and Harry G. Harris. Boulder, CO: The Masonry Society. pp. 1009-23.
13. Melander, J.M. (10 Nov. 1994), Telephone interview. Portland Cement Association, Skokie, IL.
14. Nicholson, Peter (1823), The New Practical Builder. London: Thomas Kelly. pp. 354.
15. Partington, C.F. (1825), The Builders' Complete Guide. London: Sherwood, Gilbert and Piper. pp. 364-65.
16. Portland Cement Association (1995), Skokie, IL. Historical slide presentation.
17. Rebar, Jake (24 Jan. 1995), Telephone interview. Construction Technology Laboratories, Skokie, IL.
18. Schmidt, Sylvester, and Robert L. Nelson (Dec. 1990), "The Future of Masonry Mortars." ASTM Standardization News. pp. 50-53.
19. Stehly, Richard D. (27 Sept. 1992), Principal of American Engineering Testing, Inc., St. Paul, MN. Personal interview at Spec-Mix training school. "The Fundamentals of Masonry Mortar."
20. Watson, Todd (Nov. 1989), "UBC Creates New Mortar Cement Classification." Aberdeen's Magazine of Masonry Construction.