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An Evaluation of the Physical Effects of Sandblasting on Architectural Brick

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AN EVALUATION OF THE PHYSICAL EFFECTS OF SANDBLASTING ON ARCHITECTURAL BRICK

Ana Maria Sanchez

A THESIS

in

Historic Preservation

Presented to the Faculties of the University of Pennsylvania in
Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

1999

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To my father

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ACKNOWLEDGMENT

I owe a debt of gratitude to Frank Matero, for his unending patience and guidance through the completion of this thesis. His dedication to the profession and the enthusiasm he brings to conservation are inspiring.

I would also like to thank Jan Anderson, who many years ago set me on the road which introduced me to conservation. It has been a rich and rewarding journey. Thank you.

Now the whole earth had one language and few words.

And as men migrated in the east, they found a plain in the land of Shinar and settled there.

And they said to one another, "Come, let us make bricks, and burn them thoroughly." And they had brick for stone, and bitumen for mortar.

Then they said, "Come, let us build ourselves a city, and a tower with its top in the heavens, and let us make a name for ourselves, lest we be scattered abroad upon the face of the whole earth."[1]

Genesis 11: 1-4

INTRODUCTION

Brick is among the oldest construction materials. It is not known when brickmaking first developed but it easily predates the Bible[1]. It is quite probable that subsequent ceramic technology, developed in tandem with the experience gained in the use of clay for the making of sun-dried brick lead to an understanding of properties gained from firing. Bricks are the most basic of all ceramic products, the word ceramic is derived from the Greek word, *keramos*, which means "burnt stuff."[2] Yet the term *Ceramics* has been applied by material scientists to both naturally occurring and man-made materials which share common properties. In the broadest application, ceramics are defined as a solid, composed of a mixture of metallic or semi-metallic, and nonmetallic elements in such proportions as to give the properties of hardness, resistance, and durability.[3] [4] This definition does not refer to the firing process which is commonly associated with ceramics

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[1] Bible, Old Testament.

[2] Cowan, Henry and Peter R. Smith, *The Science and Technology of Building Materials,* New York: Van Nostrand Reinhold Co., 1988, 11.

[3] Cotterrill, Rodney, *The Cambridge Guide to the Material World,* Cambridge, New York, etc.: Cambridge University Press, 1985, 120.

[4] Cowan, Henry and Peter R. Smith, *The Science and Technology of Building Materials,* New York: Van Nostrand Reinhold Co., 1988, 11.

In everyday language, the word ceramic is used for porcelain, pottery, tiles, and bricks. All these are made from clay, which is chemically defined as hydrated aluminum silicate, that is, a compound of metal and non-metal. In Materials Science, the term ceramic has a wider meaning: for example, all metallic ores are classed as ceramics, not only brick but natural stone and concrete are also considered to be ceramics.

and due to this omission, includes a wide range of natural and artificial materials, such as stone, brick, concrete, sand, diamond, glass, clay and quartz.

For the purpose of this thesis the definition of ceramics will be considerably narrowed. As it is commonly used and defined by the American Society for Testing and Materials, (ASTM): "a brick is any solid, structural masonry unit, manufactured by the molding or forming of plastic clay into a rectangular prism which is then allowed to dry and subsequently burned or fired in a kiln."[5] The characteristics and physical properties of brick are determined by the wide range of raw materials, forming methods, and firing conditions used in production. The material's individual properties, their collective uses in construction, the environmental conditions in which they are used and the maintenance or neglect the structure receives will determine the performance and hence durability of brick. Although an understanding of the firing process, and the subsequent chemical and physical alterations of the clay body it induces, are critical in characterizing brick and specifying its properties, it is important to remember that all the steps in the manufacturing process will determine the properties and durability of the final product.

The scope of this thesis works backwards in the sense that it derives its hypothesis, testing, and protocol from the commonly held belief that the abrasive, mechanical cleaning of brick will accelerate its deterioration. Abrasive cleaning is a broad term which includes

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[5] ASTM "Standard Definitions of Terms Relating to Structural Clay Products," Designation C 43-89, Philadelphia: American Society for Testing and Materials, 1989, 26.

a wide category of aggregates which can range from the most common: silica sand to crushed walnut shells[6]. The pound per square inch, (psi) at which this material is used can also vary considerably, along with use of air or water as a vehicle for the grit. Typical pressures may range between 90 and 100 psi, but in reality the actual psi is difficult to gage; the ability and experience of the operator and the distance the nozzle is kept from the wall must also be accounted for and will affect the actual psi delivered. Concern over the health hazards inherent in airborne silica dust has increased the use of crushed slag products as abrasives, the combination of water washing with aggregates, and most recently the use of patented containment methods for example *Facade Gommage* by Thomann-Hanry or the low-pressure vortex process patented by JOS, etc. This process, sometimes referred to as hydroblasting, essentially reduces the silica dust generated during sandblasting and in addition claims to *cushion* the impact of the abrasive on the substrate.[7] While the addition of water will replace dust with mist, the notion that it will also soften the impact is questionable.

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[6] Boyer, D.W., "Masonry Cleaning -- The State of the Art," *Cleaning Stone and Masonry, ASTM STP 935*, J.R. Clifton, Ed., American Society for Testing and Materials, Philadelphia, 1986, 40.

Comments on Abrasive Cleaning: Carefully controlled abrasive cleaning (micropeening) techniques are employed in some conservation programs for removal of damaging surface crusts which are otherwise impossible to remove. Employing softer, less damaging abrasives (such as crushed cornhusks, walnut shells, glass beads, and others) and precision-controlled application apparatus, such techniques are costly and more time-consuming than traditional methods and are generally not considered to be practical for large scale cleaning operations.

[7] Ibid, 38.

Beginning with its commercial application in the 1870's sandblasting was considered an acceptable cleaning technique; a wholesale solution to a myriad of soiling conditions and as such was used indiscriminately on a wide range of building materials. During the 1970's the deleterious effects of sandblasting, namely visible surface abrasion and a perceptible increase in deterioration, were cited as reasons against its use on older brick masonry.[8] It is widely believed that: "Abrasive cleaning significantly increases the exposed surface area of the treated substrates to the effects of atmospheric corrosion, water absorption, and related decay processes."[9]

Abrasive blasting results in visible, irreversible physical alterations to the brick. But what is the actual effect of this alteration? Does the partial or full loss of the outer brick surface, (the so-called "fire-skin") and the resultant increased surface area, significantly

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[8] London, Mark, *Masonry: How to Care for Old and Historic Brick and Stone*, Washington D.C.: The Preservation Press, 1988, 107.

The use of abrasive or mechanical cleaning techniques is generally discouraged since these techniques have the potential to destroy the appearance, original materials and physical well-being of a building. Abrasive cleaning of masonry causes the following problems:

- Damage to and often destruction of decorative detailing or texture;
- Removal of the hard-fired exterior surface of brick or terra cotta or the hard skin of stone, thus exposing the softer interior to weathering and rapid deterioration;
- Destruction of pointing and joints details, leading to water penetration;
- Roughening and pitting of the surface, increasing the possibility of water and dirt accumulation and causing rapid and uneven soiling as the masonry ages;
- Damage to other parts of the building because abrasive techniques are hard to control.

[9] Boyer, D.W., "Masonry Cleaning -- The State of the Art," *Cleaning Stone and Masonry, ASTM STP 935*, J.R. Clifton, Ed., American Society for Testing and Materials, Philadelphia, 1986, 40.

alter critical physical properties related to weathering such as water absorption and durability? To what degree will the application of water repellants correct the problem, i.e., reduce water absorption. It is within the scope of this thesis to explore these basic questions and assumptions through a review of the literature and a rudimentary test program measuring the effects of sandblasting on a variety of bricks, both new and old, grouped by method of manufacture, i.e., machine made or hand made.

Chapter 1: Abrasive Cleaning

1.1 The Effects of Sandblasting: Abrasive Cleaning with Silica / Sand

It is a common, professional belief that sandblasting will cause irreversible harm to brick by removing the "hard, outer protective surface,"[10] [11] often referred to as the "fireskin," (the outer surface of the brick which has a greater density and lower permeability than the core of the material.) Visually, sandblasted brick appears abraded, the surface is pitted and occasionally there is a color change that gives the brick a "raw" appearance. "Sand," silica, or grit blasting cleans a surface by mechanically impacting the substance that is to be removed with a granular material. The "hardness," (as determined by the *Moh's Hardness Scale*) and shape of the abrasive used, (e.g., sand, silica, glass beads, walnut shells, etc.), and the pressure will vary significantly, determining the effectiveness of the "cleaning" and the potential to wear down and abrade the masonry substrate.[12]

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[10] Grimmer, Anne E, "Dangers of Abrasive Cleaning to Historic Buildings," *Preservation Brief 6*, 1979, 2.

[11] London, Mark, *Masonry: How to Care for Old and Historic Brick and Stone*, Washington D.C.: The Preservation Press, 1988, 107.

[12] Boyer, D.W., "Masonry Cleaning--The State of the Art," Cleaning Stone and Masonry, ASTM STP 935, J.R. Clifton, Ed., American Society for Testing and Materials, Philadelphia, 1986, 38.

These mechanical techniques are difficult to control, as it is virtually impossible with this process for the operator / mechanic to differentiate between the substrate and the material to be removed. As a result indiscriminate removal of soiling or overpaint and substrate occurs. It is widely believed that the removal of the outermost surface or "fire skin" will accelerate the weathering and deterioration of the brick. These assumptions are empirical.[13] [14] [15]

Although to a great extent, the practice of sandblasting as a generic cleaning method for masonry is no longer advocated, there has been a recent resurgence in the market of "micro" blasting cleaning techniques designed specifically for building conservation.[16]

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[13] Ibid, 38.

Boyer states in his paper: "Thousands of buildings have been severely damaged, exposed to accelerated erosion and decay, with the use of abrasive cleaning techniques."

[14] Grimmer, Anne, "Dangers of Abrasive Cleaning to Historic Buildings," *Preservation Brief 6*. (1979), 3.

Although Grimmer alludes to the fact that removing the "protective outer surface" will accelerate deterioration, no conclusive tests have been done to confirm this.

[15] London, Mark, *Masonry: How to Care for Old and Historic Brick and Stone*, Washington D.C.: The Preservation Press, 1988, 61.

"The fused outer skin of the brick is its main line of defense against water. Water can penetrate to the more porous interior when this hard outer surface is removed by sandblasting." This reference is made without any reference to actual lab or field tests.

[16] Two examples of market of "micro" blasting cleaning techniques currently on the market include:

JOS, a patented low-pressure vortex process described in the product literature from 1995 as follows: "A mixture of a low air pressure, very little water (1.5 to 12 gallons per hour)

These methods are being marketed with limited research data into the effects of these procedures and products on the material. While they may very well represent the "future of cleaning in the industry"[17] they have yet to be tested in an extensive and exhaustive manner on a range of masonry materials with varying types and extent of soiling.

In light of these developments, there is a certain contemporary relevance in understanding the physical effects of abrasive cleaning, or "sandblasting." Along with the removal of surface dirt or unwanted coatings, how has the surface been altered? Information on the structure and properties of the outer surface of a fired brick is limited; as difficult to define as it is to refute. Yet attempting to define it goes a long way in understanding the effects of sandblasting. If there is no or negligible protection derived from the fireskin then the implication of the resulting alteration as damage changes. It is important to

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and a fine inert safe abrasive powder is developed into a rotating vortex. When directed onto a surface to be cleaned this swirling vortex gently yet effectively, removes unwanted matter such as different kinds of paints, stubborn dirts, scale and graffiti from many types of materials including stone, brick, metals - even wood and plaster. JOS is unique in it's efficiency and gentleness in cleaning as the substrate's surface is left undamaged."

It should be noted that no "fine inert powder" is safe from the stand point of health, used improperly this material is a health hazard.

Thomann-Hanry, a patented dry procedure external building cleaning described in the product literature from 1995 as: "*Facade Gommage*. This French term refers to the process of gently cleaning masonry by projecting very fine powders with low pressure compressed air. No chemicals, water, or detergents are used. The facade gommage process removes unsightly dirt and pollution deposits from interior and exterior surfaces of limestone, sandstone, granite, marble, brick, concrete aggregate stone, slate and stucco. It does not damage historic building fabric in the short or long term and includes a dust containment system to ensure nuisance-free cleaning."

[17] APT Training Course on Masonry, February 27, 1995.

remember that "damage" is a broad term, the visual alteration which is associated with abrasive cleaning does represent a loss, the material has been altered irrevocably. In addition, it is quite possible that the resultant mechanical abrasion and increased surface area may simply afford greater opportunities for water to enter and with it the introduction of all the decay mechanisms of porous and permeable materials. In addition, no research has been discovered to date which has measured the changes in deterioration once this surface has been removed.

1.2 Defining the Fireskin

"Fire-skin" is a term which has been traditionally reserved for terra cotta and faience and has been liberally borrowed, in a vernacular sense, in reference to brick. Terra cotta and faience are molded clay products made from fine, pure clays mixed with other materials such as sand and pulverized fired clay. They are usually well-vitrified and have hardness, compactness and sharpness of detail not normally obtained with brick.[18] The natural surface of terra cotta and faience is a *fireskin*, defined as a hard thin, vitreous, unglazed skin formed from a surface concentration of fine colloidal clay particles upon firing after the clay has been hand-smoothed or finished.

As mentioned before, the raw material used to form terra cotta is a pure and more refined clay mixture than what is used in the manufacture of bricks. The method used to form terra cotta is still a manual and labor intensive process which due to the nature of its design has not significantly changed due to industrialization.

Pieces are formed by pressing the clay into Plaster of Paris or rubber molds, then the clay is worked into corners and crevices by hand. Once the pieces have set, the mold is removed and the surface is further worked by hand or with a leather tool to a smooth finish. This process will promote the concentration of fine colloidal clay particles to the

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[18] Ashurst, John and Nicola, *Practical Building Conservation, Vol. 2, Brick, Terra cotta and Earth*, Hants, England: Gower Technical Press, 1988, 66.

surface. The terra cotta piece is allowed to dry and then fired. It is this outermost surface which is recognized as the "fireskin."

Maintenance of the fireskin is critical to the durability of terra cotta and faience as the clay bodies it protects are less durable.[19] While this is a consistent property for terra cotta and faience, it is a less precise property in terms of brick. There are too many differences between terra cotta and brick to qualify the appropriate use of this term, yet there is certain validity to this notion. In the words of George Robinson, a ceramic engineer for Glen Gery, "it is a half truth, it cannot be discounted or guaranteed."[20] When it occurs it is due to the "fines" in the clay being slicked to the surface during the molding process and before firing. This phenomenon is dependent on the mineralogical composition of the clay, the percentage of water in the mix, and the method of manufacturing employed. If and when the fireskin occurs in brick it is incidental.

Salmang provides one of the few detailed explanations of the existence of the fireskin on ceramic bodies.[21] This definition has been crucial in characterizing the fireskin or

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[19] Ibid. 70.

[20] Conversation with George Robinson, Glen Gary ceramic engineer. February 1993.

[21] Salmang, Hermann, *Ceramics Physical and Chemical Fundamentals,* London: Butterworths, 1961, 141-142.

Every ceramic shard, even that made from finely divided material, e.g. earthenware or porcelain, consists of a conglomeration of crystals, glassy substance and pore spaces or voids. In addition there is a recognizable spatial arrangement of the solid substances and the pores which depends on the particular shaping method employed. ... The externalC

protective outer surface of brick. First, the notion of a fireskin is in part a misnomer, the name implies that firing alone produces a "skin," therefore the position of the brick in the kiln will to some extent predetermine its durability. While the range and duration of the temperatures applied during the firing process are integral in the fusion of the clay particles which converts a clay body into a dense vitrified material, these elements are not solely responsible for the existence of the so-called fireskin. According to Salmang, the clay body will densify:

> "Wherever the wet, plastic body has been subjected to pressure, be it through pressing, sticking-up, sponging, scraping, stamping, etc., there will it be densified. ... This pressure is sufficient to bring about a parallel arrangement of the clay particles and to densify the biscuit locally; the effect persists after firing."[22]

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layer which has been in contact with the plaster of Paris mold is always dense, because the water being sucked out of the slip deposits the suspended clay particles in parallel layers on the plaster mold. The arrangement of the same particle in the body of the slip is chaotic. Zwetsch (Ber. dtsch. keram. Ges. 29 (1952) 73), using dilatometric methods, observed the same parallel arrangement of particles in clay wads extruded through an orifice. Not only are the surfaces formed in contact with plaster of Paris dense but also those formed in contact with air or in the slip itself. This is partly an effect of the surface tension of water in the clay, partly it is due to the subsequent drying. In drying, the capillary flow of water carries dissolved salts, e.g. humates, and colloidal clay to the surface from which water is evaporating. Here they are deposited and, on firing, cause localized vitrification of the surface of the biscuit, the so-called "firing skin". It is not necessary for the surface to be exposed directly to the flames: a firing skin formed by direct impingement of flames on the surface of the ware is extremely rare in modern ovens. The interior of the shard is the most porous part of the article. Wherever the wet, plastic body has been subjected to pressure, be it through pressing, sticking-up, sponging, scraping, stamping, etc., there will it be densified. Its own weight exerts a pressure on the lowest part of an article, e.g. the foot of a lavatory bowl. This pressure is sufficient to bring about a parallel arrangement of the clay particles and to densify the biscuit locally; the effect persists after firing. The firing itself does not cause local alterations in texture; it densifies generally, though parts nearer the fire are rendered more dense than those remote from it.

[22] Ibid. 142.

In the production of brick there are essentially two opportunities for this to happen: (1) The arrangement of particles on the surface due to the process of moisture being sucked out as when the brick is shaped in a wooden mold; (2) The parallel arrangement of particles in clay wads when extruded through an orifice. Both these processes will be discussed in 2.2 Shaping and Molding. In addition, Ries describes a similar process which occurs when bricks are repressed. [23]

The subject of ceramics is complex and vast in scope but inevitably, the resistance of a ceramic material to abrasion depends on a certain number of circumstances which are all intricately interrelated. Grimshaw lists them as follows:

a. the nature of the material, and especially its texture and hardness;
b. the mode of preparation;
c. the nature of the bond (if any);
d. the amount of the bond (if any);
e. the extent of vitrification;
f. the temperature of the material when it is examined.[24]

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[23] Ries, Heinrich, *Building Stones and Clay Products: A Handbook for Architects.*, New York: John Wiley & Sons, 1912, 276.

The pressure which the brick get, together with the use of some lubricant and the slipping in and out of the mold, polishes the surface so at times as to form a tough exterior skin which strengthens their resistance to disintegrating influences.

[24] Grimshaw, Rex W., *The Chemistry and Physics of Clays and Allied Ceramic Materials*, 4th Edition, New York: Wiley Interscience, 197, 900.

The above factors have been considered in designing a test to measure the quantitative effects of abrasive cleaning a variety of brick, as a function of water absorption, specifically the permeability of the brick before and after the outer surface, i.e., fireskin, have been abrasively removed.

Chapter 2: Brick: The Manufacturing Process

There are five basic steps in manufacturing brick: mining the raw material, (winning), grinding and mixing, molding (soft-mud, stiff-mud, and dry-pressed), drying, and firing.[25] These steps are all interdependent; the properties of the final product such as strength, porosity, resistance to moisture and chemicals, thermal expansion, thermal conductivity, and hardness are determined by the interaction of these steps and to a large extent by the various phases resulting from the firing process. The firing processes convert a compacted mixture of clay and quartz sand into a strong, hard and stable product.

The advent of the Industrial Age changed the production of bricks to a precise technology,[26] but the underlying chemical and physical processes have remained the same. In fact, although assembly line practices have been adopted and today computers determine the proportions which traditionally were established by empirical knowledge, there are still sufficient nuances left in the process to guarantee that no two "batches" will be identical. The area from which the clay is mined, the mineralogical composition of the clays used, the method employed to mold the brick, the temperature at which the clay is dried and then fired, and the location of the brick in the kiln will determine the properties of the final product.

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[25] Gurke, Karl, *Bricks and Brickmaking*, Moscow, Idaho: University of Idaho Press, 1987, 4.

[26] Brownell, W.E., *Structural Clay Products*, New York: Springer-Verlag, 1976.

2.1 Mining the Material

2.1.1 Clays

To develop an understanding of the final product it is necessary to start at the beginning, that is, considering the clay material which forms and shapes any ceramic object. Clays can be gathered from river-deposited clay beds or often the raw material used is mined locally from shale deposits and then ground to the desired fineness by crushing and then tempering. "The tempering or mixing is an important stage in the process in order to mix and disintegrate the clay, any lumps left will tend to cause cracking during drying and firing."[27] Traditionally tempering was done by leaving the material outdoors for a winter or more to allow the natural elements to break down the clays. Today, to expedite the process, the mined material is ground down to a powder prior to mixing.

Clay is the result of the chemical weathering of rock, and of silicates, in particular feldspar, mica, amphiboles, pyroxene, etc. Large clay molecules (or micelles) are fine crystals of an irregular or hexagonal shape. Crystal micelles are made up of thin sheets or wafers, which is why argillaceous minerals are referred to as phyllites (*phyllon* being the Greek word for leaf.)[28] Clay is a term which refers to any fine-grained, natural, earthy, argillaceous material. They are essentially composed of extremely small crystalline particles of one or

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[27] Ries, Heinrich, *Building Stones and Clay Products: A Handbook for Architects.*, New York: John Wiley & Sons, 1912, 265.

[28] Torraca, Giorgio, *Porous Building Materials*, Third Edition, Rome: ICCROM, 1988.

more members of a small group of minerals that are commonly known as the clay minerals. These minerals are essentially hydrous aluminum silicates, with magnesium or iron substituting wholly or in part for the aluminum in some minerals, and with alkalies or alkaline earths also present as essential constituents in some of them.[29] The raw materials for structural clay products contain from 40% to 80% of these minerals; therefore, they are bound to have an important influence on the final product.[30] These minerals are inherent in the shale or can be added to the ground mix.

The main groups of the clay minerals are kaolinite, illite, and montmorillonite. Kaolin is a very pure clay which contains no iron and has a two-layer wafer composed of "a layer of oxygen tetrahedrons with a silicon center and a layer of oxygen or hydroxide octahedrons with an aluminum center,"[31] (Figure 1)[32].

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[29] Grim, Ralph E., *Applied Clay Mineralogy*, New York: Mc-Graw-Hill Book Co., Inc., 1962, 2.

[30] Brownell, W.E., *Structural Clay Products*, New York: Springer-Verlag, 1976, 126.

[31] Grim, Ralph E., *Applied Clay Mineralogy*, New York: Mc-Graw Hill Book Co., Inc., 1962, 11.

[32] Ibid, 11.

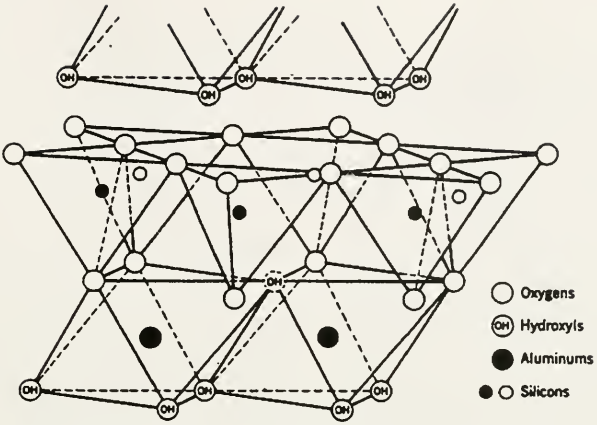

Figure 1: Diagrammatic sketch of the structure of the kaolinite layer, after Gruner (1932). The crystalline structure of kaolinite is made up of a layer of oxygen (or hydroxide) octahedrons with an aluminum center. Kaolinite is generally stable in water.

In the more common clays, montmorillonite and illite, the wafer is composed of two layers of silica and one layer of alumina interposed between them (Figure 2)[33]. Brick clays are essentially a combination of these clay minerals depending on geographical location and the geological age of the mines. "The principal minerals in brick clays are disordered kaolinite, chlorite and illite, with quartz and organic matter. Brick clays have been examined that appear to contain little or no kaolinite but may depend for their clay-like properties on chlorite or illite."[34]

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[33] Ibid, 15.

[34] Worrall, W.E., *Clays and Ceramic Raw Material, 2nd Edition*, London: Elsevier Applied Science Publishers, 1986, 80.

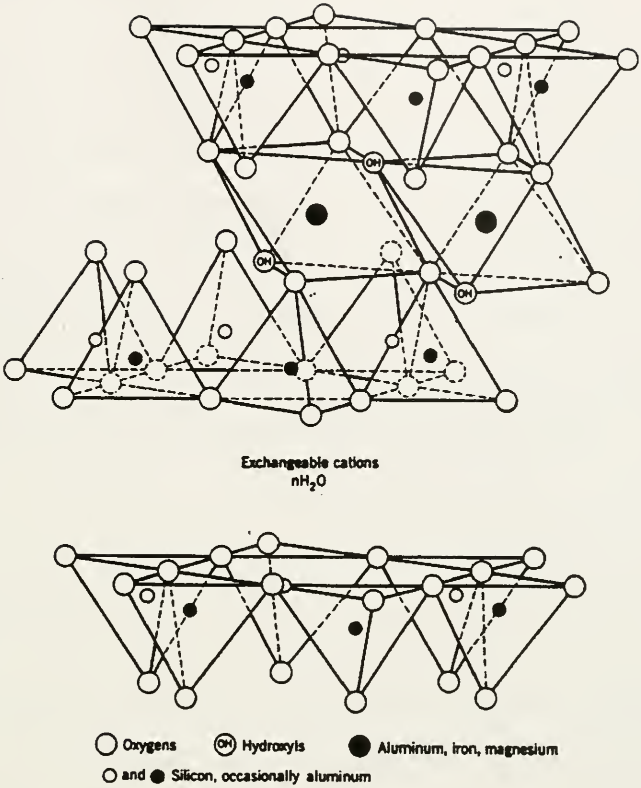

***Figure 2**: Diagrammatic sketch of the structure of the montmorillonite, according to Hofmann, Endell, and Wilm (1933); Marshall (1935); and Hendricks (1942). Clays in both Ilite and Montmorillonite grups have a three layer structure; mainly an aluminous octahedral layer, between two mainly siliceous tetrahedral layers. Ilite is not particularly stable when in contact withwater and it swells. Montmorillonites differ from Ilites due to a substitution which takes place in the octahedral aluminum layer. The sheets are not electrically neutral and are weakly linked. Montmorillonite is not stable. When in contact with water is severely swells.*

2.1.2 Plasticity

The addition of water increases the distance between wafers resulting in the swelling of the clay and achieving plasticity of the material. In other words, the flat crystal structures slide easily over one another under slight pressure without losing cohesion.[35] [36] This binding force allows clay and non clay material to be formed, shaped and to maintain a "green" strength prior to firing. Green strength is also related to the particle size of the clay minerals and to their texture. Texture is defined as the orientation of the particles with respect to each other in space and with respect to non clay minerals.[37]

2.2 Shaping and Molding

There are primarily two methods for manufacturing brick: extruded or molded, also known as stiff mud and soft mud process, respectively. In the soft mud process, water is added to the raw material to attain the desired consistency. In general 20 - 25% water will

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[35] Ibid. 15.

[36] Grim, Ralph E., *Applied Clay Mineralogy*, New York, McGraw-Hill Book Co. Inc., 1962, 54-57.

Plasticity is defined as the property of a material which permits it to be deformed under stress without rupturing and to retain its shape. The relation of the plastic properties to the nature of the exchangeable cations, particle size, and crystalline structure of the clay minerals is best illustrated by Atterbergs limit values.

[37] Ibid. 73.

achieve the necessary plasticity. The paste is then pressed by hand or machine into wooden or metal molds. A lubricant is needed to release the green clay from the molds. The most common lubricants used are water and/or sand, but oil, lard, or soapy water have been used in the past.[38] These lubricants will affect the appearance of the finished brick and further categorize the type of brick as either "water-struck" or "sand-struck." With the "water-struck" method the molds are wetted to act as a release agent, in addition this is done to prevent rapid suction of the water from the clay when wooden molds are used. The "sand-struck" method is similar. The mold is both wetted and sanded to facilitate the removal of the brick and to provide surface texture. Soft-mud brick, unless repressed[39], lacks sharpness of detail along the edges and show five sanded surfaces while one of the bedded planes shows the screed marks of wiping off the excess. The soft-mud process includes both bricks made by hand and those made by soft-mud brick machines.[40]

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[38] Gurcke, Karl, *Bricks and Brickmaking: A Handbook for Historical Archaeology*, Idaho: The University of Idaho Press, 1987, 16.

[39] Ries, Heinrich, *Building Stones and Clay Products: A Handbook for Architects.*, New York: John Wiley & Sons, 1912, 276.

Repressing. Many soft-mud and stiff-mud brick that are to be used for fronts are improved in appearance by repressing. The process consists in putting them in a machine shortly after molding, in which they receive a second pressing. The main object of this is to straighten the edges and smooth the surface, and in many cases some design is imprinted in the surface of the brick. The brick are usually slightly smaller after this treatment.

[40] Gurcke, Karl, *Bricks and Brickmaking: A Handbook for Historical Archaeology*, Idaho: The University of Idaho Press, 1987, 15.

Dry-pressed bricks fall within the molded brick category but use much drier clay, (only about 10% water is added to the mix), and they are only formed with machines. Due to the dry and hard consistency of the paste more pressure (500 psi or more) needs to be exerted to shape the bricks. Dry-pressed bricks have sharp edges and are denser than either soft-mud or stiff mud bricks but are more expensive to produce.

The stiff mud method is the most common technique for the mass production of brick. It is similar to the soft mud process, but differs in several ways. To begin with the consistency of the clay is drier, only about 12% - 15% water will be added to achieve the desired plasticity and resulting in a stiff paste that would not be generally workable by hand. The clay is forced through a die which compresses the clay into a long bar or column stiff enough to hold its shape. This material is then wire cut into brick size units.

Plastic clay extruded through a die creates friction as the center of the clay column moves faster than the sides, this sets up shearing stresses in the clay body.[41] The flake-shaped clay minerals tend to align themselves parallel to each other in relation to this shearing stress.[42] One last aspect to consider during the forming process of a brick is the possibility of "preferred" aggregate orientation developing in the clay particles. The implications of this are twofold: the parallel aggregate orientation may become a potential plane of

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[41] Clews, F.H., *Heavy Clay Technology*, New York, Academic Press, 1969, 95.

[42] Grim, Ralph E., *Applied Clay Mineralogy*, New York, McGraw-Hill Book Co. Inc., 1962, 74-75.

weakness in the brick, although the incorporation of a vacuum chamber "heals the laminations inherently put into the products by this machinery."[43] On the other hand, this laminar arrangement might also create impermeable zones perpendicular to the surface.

2.3 Drying

Prior to firing, the water that has been added to the clay material to achieve plasticity needs to be removed. The clay contracts and shrinks as it drys, reducing the overall porosity of the material. Drying at various temperatures eliminates water in pores and adsorbed on the surfaces of the clay mineral particles, ensuring the removal of all water which is not part of the crystal structure of the minerals.[44] The inherent characteristics of the clay material will determine the shrinkage and cohesion of the green body. The addition of non clay minerals or inert fillers compensates for shrinkage.

Drying complements the molding processes. While drying, the particle arrangement which began to take shape during molding and compaction is further enhanced.[45] Shrinkage also implies a decrease in the concentration and size of the pores. This is a desirable

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[43] Brownell, W.E., *Structural Clay Products*, New York: Springer-Verlag, 1976, 10.

[44] Grim, Ralph E., *Applied Clay Mineralogy*, New York, McGraw-Hill Book Co. Inc., 1962, 75.

[45] Loehman, Ronald E., *Characterization of Ceramics*, Boston: Butterworth-Heinemann, 1993, 79.

characteristic in the finished product, since porosity / permeability is a primary property related to deterioration of the material.[46]

2.4 Firing

Firing[47] is the most critical stage in the brick-making process, to a large extent all the physical characteristics attributed to bricks are dependent on this process. An understanding of this process has also proven to be the most complex. Key terms have been used interchangeably in the research literature, adding to the confusion. Essentially the words to consider are: *fire bond*[48], *fusion* and *incipient fusion*[49], *vitrification,*

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[46] Robinson, Gilbert C., "Characterization of Bricks and Their Resistance to Deterioration Mechanisms", In *Conservation of Historic Stone Buildings and Monuments*, ed. N.S. Baer, Washington, D.C.: National Academy Press, 1982.

Deterioration of masonry results from several mechanisms, including freezing and thawing, salt crystallization, chemical attach by water and other substances, moisture expansion, etc. The susceptibility of brick to each mechanism is determined by pore structure and composition.

[47] ASTM "Standard Definitions of Terms Relating to Structural Clay Products," Designation C 43-89, Philadelphia: American Society for Testing and Materials, 1989, 25

Firing - process of heating the material to elevated temperatures. The temperatures are usually in excess of 930C. The extent of firing is a function of both time and temperature. The firing develops the inter-particulate bond, the strength, the pore structure and the color of the product. The extent of firing should be sufficient to produce the levels of these properties required by the specifications for the particular product.

[48] Ibid, 25.

Fire bond - bond developed between particulate constituents of brick solely as the result

sintering, densification. Since this is not an exercise in semantics, it is safe to assume that these words refer to different phases of the firing process; the task is understanding where one begins and another ends.

Fire bond, as defined by ASTM is the bond developed between particulate constituents of brick solely as the result of the firing process. The bond may result from *fusion* or melting of one or more constituents of the composition or the surface particles. Other thermal mechanisms such as *sintering* and interparticle reaction may be responsible for the bond.[50] This explanation introduces the idea but falls short of explaining the process.

Incipient fusion and *vitrification* describe two phases of one process, both occur due to the presence of fluxes. To make a dense strong body, fluxes are required: minerals that will produce some melting at the firing temperature. These minerals are usually inherent in the clays mined for brick making. On firing, the silicate melts are viscous, this initiates the incipient fusion phase; liquid matter coats the remaining solid particles, upon cooling, these substances produce a glassy phase known as *vitrification*. These glassy material acts

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of the firing process. The bond may result from fusion or melting of one or more constituents of the composition or the surface of particles. Other thermal mechanisms such as sintering and inter-particle reaction may be responsible for the bond.

[49] Ibid, 25.

Incipient fusion - beginning of the development of fire bond.

[50] Ibid, 25.

as a bond, the vitreous material fills in the interstitial spaces in the clay mass and renders it impermeable.[51] [52]

Clay mineral composition determines the point of fusion, in general the fusion point ranges from 1000° to 1500° C with lower values being found in materials relatively rich in iron, alkalies, and the alkaline earth.[53] The vitrification range is the temperature interval between the beginning of the development of the vitric bond in a ceramic body and the fusion of so much of the body that the shape of the ware is lost and the shrinkage is excessive, resulting in deformation and warping of the brick ware.

Sintering is the final desired stage of the firing process. Most ceramics are consolidated by this process. This qualifier allows for the fact that not all ceramic materials achieve this level of densification. Sintering, which is generally considered synonymous with densification, is usually accomplished by heating a powder compact to approximately two-thirds of its absolute melting temperature for a prescribed time. Material transport during sintering decreases the interfacial area of a powder compact and decreases chemical

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[51] Cabana, Michael, "Properties of Clay and Their Effects on the Manufacture of Building Brick" 9.

[52] Worrall, W.E., *Clays and Ceramic Raw Material, 2nd Edition*, London: Elsevier Applied Science Publishers, 1986, 174.

[53] Grim, Ralph E., *Applied Clay Mineralogy*, New York, McGraw-Hill Book Co. Inc., 1962, 121.

potential differences (e.g., between the grain boundary and the bulk) within the system.[54]

Figure 3 [55] helps to illustrate this phenomenon.

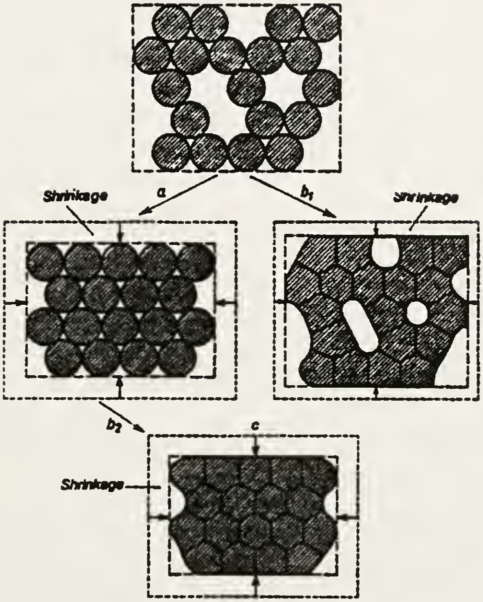

***Figure 3**: Sintering of dispersed systems: (a) rearrangement of grains; (b_1) grain centres approach in a loose grain arrangement; (B_2) grain centers approach in a close packed arrangement of grains. Pampuch describes sintering as a process during which an assembly of fine particles (crystallites, aggregates, agglomerates) of a dispersed system undergoes a spontaneous strain that results in a densification of the particles assembly. The process occurs on heating and takes place at a temperature in the region of .4 to .85 of the temperature at which the material melts.*

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[54] Loehman, Ronald E., *Characterization of Ceramics*, Boston: Butterworth-Heinemann, 1993, 80.

[55] Pampuch, Roman, *Constitution and Properties of Ceramic Materials*, Amsterdam, New York: Elsvier, 1991, 194.

Brownell summarizes the firing processes occurring in clay products as solid-state reactions, solid-liquid reactions, solid-gas reactions, and sintering which results in larger particles by grain growth.[56] [57] [58] During firing, physical and chemical reactions proceed toward some theoretical equilibrium which is never attained, once the desired properties are developed the process is arrested by cooling.[59] It is feasible to assume that the desired properties of brick are largely dictated by their intended uses. In simple terms, the criteria for face brick[60] take into consideration its exposure to weathering; common brick[61] on the

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[56] Brownell, W.E., *Structural Clay Products*, New York: Springer-Verlag, 1976, *133.*

[57] Cotterrill, Rodney, *The Cambridge Guide to the Material World,* Cambridge, New York, etc.: Cambridge University Press, 1985, 132.

Cotterrill defines the process as follows: The heat treatment of clay, known as firing, to produce brick or porcelain, involves atomic diffusion on the crystal surfaces in the raw material. The individual particles are thereby consolidated into larger regions and the end result of this *sintering*, as it is called, is a single polycrystalline piece of solid.

[58] Loehman, Ronald E, *Characterization of Ceramics*, Boston: Butterworth-Heinemann, 1993, 81.

Ceramics are densified by solid-state, liquid-phase, and viscous sintering. Pure alumina, which sinters by solid-state diffusion, requires a relatively high temperature (i.e. 1500 - 1800 C) and a long time (i.e. 1-5 hours) to densifiy.

[59] Ibid. 133.

[60] Grim, Ralph E., *Applied Clay Mineralogy*, New York, McGraw-Hill Book Co. Inc., 1962, 130.

Shales composed of illite and quartz, frequently with some chlorite and kaolinite are widely used in the manufacture of face brick. In general, fireclays become higher in grade as the amount of illite deceases, and those with no illite are classed as high-grade and are used primarily for refractories. The use of montmorillonite is discouraged since its structure contributes to high shrinkage rates.

other hand, will be used as a backing material. These varying demands will determine where the firing process will be arrested. Economy of resources encourages this approach, reinforced by ASTM Standards: "The extent of firing should be sufficient to produce the levels of these properties required by the specification for the particular product."[62]

In order to characterize the firing process, it is important to remember that fusion, vitrification, and sintering are all dependent on the effect of temperature on the rate of all chemical reactions. Primary differences between the wide range of physical properties manifested between objects classified as ceramics begin with a consideration of clay mineral composition, percentages of material, texture and firing. The following table summarizes the most apparent phases in the firing cycle.[63]

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[61] Ibid. 129.

Almost any composition is satisfactory for the manufacture of common brick unless it contains a large percentage of coarse stony material which cannot be eliminated in the preparation process or ground to adequate fineness. Illitic clays are most desired, since kaolinite would raise firing temp. and montmorillonite creates excessive shrinkage.

[62] ASTM Designation C 43-89, "Standard Definitions of Terms Relating to Structural Clay Products" 25.

[63] This information as been synthesized from two textbooks: Brownell, *Structural Clay Products* and Grim, *Applied Clay Mineralogy*.

2.4.1 The Firing Cycle

Temperature Range	**Phase**
100° - 150° C	All mechanical pore water is eliminated.
200° - 300° C	The oxidation of any organic material begins. This phase is an essential factor in firing, the elimination of any gas-forming component, prior to vitrification is crucial. An unsolidified body allows gases to escape without deforming or causing the brick ware to explode.
400° - 500° C	Oxidation of sulfites frequently in the form of pyrite.
500° - 900° C	Hydroxyl water is driven from clay minerals ensuing the collapse of the mineral structure. The exact temperature, rate, and abruptness of the loss of hydroxyls depend on the nature of the clay minerals and their particle size.
900° C	Clay mineral structure is completely dehydrated. The formation of spinel ($MgAl_2O_4$) and hematite (Fe_2O_3) is begun in illitic clays.

1000° C	The presence of the fluxes in the clay material may cause vitrification and fusion at this temperature. Fluxes are primarily impurities found in the clays, namely Na, K, Ca and Mg, derived from the mica and other compounds. When these ions are present, they lower the melting point of the system and, in particular, react with silica at as low as 1000° C to form a viscous liquid, which on cooling does not crystallize but solidifies to form a glass, in which the fluxing ions occupy holes in the Si--O--network. This complex glass is responsible for the vitrification and fired strength of such clays."[64]
1000° - 1250° C	Mullite is formed. (When kaolinitic clays are used for structural clay products, the presence of mullite in the product denotes a well-fired body. Mullite is a hard, chemical resistant phase in clay products, and its elongated crystal structure provides great strength.)[65]

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[64] Worrall, W.E., *Clays and Ceramic Raw Material, 2nd Edition*, London: Elsevier Applied Science Publishers, 1986, 174.

[65] Brownell, W.E., *Structural Clay Products*, New York: Springer-Verlag, 1976, 129.

1050° - 1450° C	Melting begins at 1050°C, the initial three crystalline phases dissolve in the fusion and react with silica to form mullite. The amount of mullite increases as the sample is heated, then, it begins to dissolve in the liquid. The beginning of melting around 1050°C and the appearance of mullite explains why many structural clay products made from predominantly illitic clays are fired from 1038°C to 1082°C. The glass phase resulting from the fusion promotes a strong body with a reduction in porosity, and mullite gives it strength and durability.[66]

Two topics need to be mentioned to conclude this discussion on the firing process. More than any other factor, the importance of solid-gas reactions in firing clay products leads to the concept that kilns are chemical-reaction vessels and not simply heat-generating machines. This concept must be deeply ingrained in those responsible for quality products, since there is always a temptation to move straight to the most economical

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[66] Ibid. 130.

application of heat, which is not always compatible with the chemistry involved.[67] The gases in the atmosphere of the kiln will affect the rate of the reactions and determine color.

2.4.2 Flashing

On this note let us consider the practice of flashing. Flashing is accomplished by reducing the air supply to the deficiency side of perfect combustion by either decreasing the air supply to the fuel or introducing excessive fuel. After flashing the ware goes immediately into the cooling period where atmospheric air provides a much higher oxygen content, and there is a tendency to reoxidize the exposed surface from muted colors back to shades of red. The reduced state can be maintained if the top firing temperature is high enough to flux the iron into a glassy phase.[68] This procedure suggests the development of an impermeable exterior surface on the brick but flashing is not practiced for "all" bricks so this characteristic is limited to a certain group. Flashing is generally done to alter the color of the brick.

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[67] Ibid. 143.

[68] Ibid. 150.

2.5 Preliminary Conclusions

The questions remain: does any of the preceding information imply the existence of a fireskin? Does method of production and manufacture affect formation of fireskin? Does sintering begin after the vitrification phase is completed or does the presence of fluxes impede sintering from occurring? Do the temperatures at which bricks are fired allow for sintering? Although the intent of the firing process is to produce a homogeneous product, should we assume that bricks are completely vitrified, or for that matter, are they sintered? Without further research it would be careless to attempt an answer.

Sandblasting abrades the surface of a brick, and increases the surface area dramatically. Whether or not any fireskin has been removed may not be as crucial as the fact that the surface area has been increased and possible stress micro cracks induced; the opportunities for water to enter the system have been multiplied. If in addition the brick has not been completely vitrified or sintered, then its primary line of defense has been diminished and compromised. These two factors are responsible for the apparent accelerated deterioration that ensues.

The scope of this thesis has been limited to studying the effects of sandblasting on brick, isolating this component from the masonry wall system that includes mortar. By design, mortar is the sacrificial cushion that bonds the bricks together and absorbs stresses that may crack the masonry units. By this definition it is less durable in nature than brick and

therefore more prone to the harmful effects of sandblasting. Mortar joints represent approximately 5% of the surface of any brick wall; as such, the effects of sandblasting on this material will affect the overall condition of the wall. For the scope of this thesis the research has concentrated on one material. The testing program adopted concentrates on the effects of sandblasting on brick surfaces measured as a function of the water absorption of the material before and after sandblasting and with the addition of a water repellant.

Chapter 3: Water Repellants

The application of a water repellant is often associated as the final step of masonry rehabilitation. Once the brick has been cleaned, repointed, and generally stabilized, protecting the masonry from the effects of moisture seems the next logical step. In cases where the brick has been abraded by harsh cleaning methods it seems even more relevant. But there are basic questions that should be asked: is it necessary, and if so how long will it last?

Water repellant coatings are applied in order to create a surface that repels water. Reducing the amount of water is an attempt to slow down the deterioration processes which are exacerbated by excessive moisture. Unlike a sealant, which true to its name, 'closes' all the surface pores, a water repellant works by changing the surface tension of the material, the coating eliminates the capillary suction of the pores. Liquid water will bead on the surface but water vapor can pass freely through the substrate which has been treated with a water repellant. In this manner the masonry wall is allowed to "breathe," resist the intrusion of water but allow any water which enters the wall to escape.[69]

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[69] McGettigan, Edward, "Selecting Clear Water Repellents," *The Construction Specifier,* **47**(6), (June 1994), 124.

Although there are many water repellants on the market, there are actually only a few active ingredients which are used in the formulations, so the products tend to be similar. The key components are silanes, siloxanes, or siliconates. In broad terms, water repellants are characterized as either film formers or penetrants. Film formers deposit their primary components on the substrate surface; they form a film by filling the substrate pores. Penetrants enter the pore structure of the substrate and attach to the walls of the pores. Penetrants are favored over film formers since they are less likely to visually alter the appearance of the substrate, i.e., yellow, darken, or be shiny.

Film formers are usually acrylics;[70] penetrants are reactive types of silanes, siloxanes and siliconates.[71] Siliconates tend to be poor water repellents since they bond to the substrate slowly and have the potential to wash out. Both silanes and siloxanes will chemically bond with silica or alumina containing materials quickly; this presents a unique advantage over

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[70] Ibid, 122.

Acrylics, the main type of film formers used in clear water repellents, are manufactured by the polymerization or copolymerization of acrylic acid, methacrylic acid, or acrylonitrile and then esterified. The type of alcohol used in the esterification determines the physical properties of the acrylic resin. For example, esterification with methanol produces a hard resin film.

[71] Ibid, 124.

In general, the reactive penetrants silanes, siloxanes, and siliconates - do not plug masonry pores. These products have an organo-functional group that provides water-repellent properties and a silicon functional group that controls the bonding to the substrate. The water repellent performance of these products depends on the alkyl group (organofunctional portion).

the other reactive water repellents. Silanes and siloxanes go through three reactions when applied to a masonry substrate: hydrolysis, condensation, and bonding.[72]

Brick is a permeable material and therefore should be able to withstand a certain amount of water. Sound initial construction detailing and subsequent routine upkeep such as repointing to maintain sound mortar joints are clearly the most effective "waterproofing" techniques for the longevity of the structure. Water repellants weather away quickly therefore the application of the material becomes a maintenance issue for the building if the water repellant is to have any substantial, long term results. All water repellent coatings should be selected based on field evaluation. Variables that will affect performance are substrate, surface contaminants, extent of surface preparation, and weather conditions during the application.

The water-repellant used for this test is Cheme-trete BSM-40, produced and distributed by Hüls. It is a silane-based product whose main active ingredient is Isobutyltrialkoxysilane.

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[72] Ibid, 124.

Hydrolysis: The silanes and siloxanes react with water to form the silanols.
Condensation: The silanes and siloxanes react with each other via the silonal groups
Bonding: The silanes and siloxanes react with silanol groups on the substrate.

Chapter 4: Testing Program

The Laboratory Testing Program designed to evaluate the quantitative effects of sandblasting on a variety of brick types is based on ASTM Standard Test Method-C 67-89a: Water Absorption. This test measured the permeability of the brick before and after the removal of the exterior surface, and with the application of the water repellant as a function of water absorption.

This thesis tests the commonly held belief that the use of abrasive cleaning methods, such as sandblasting, will increase the rate of deterioration of the brick. The presence of water is the most common source of deterioration in architectural materials. This test isolates one property of the material: permeability, as the source of the perceived accelerated deterioration which ensues after sandblasting. The hypothesis presented by this thesis and which this test measures, assumes a relationship between the outermost surface of the brick and the percentage of water absorption. If the outermost surface of the brick is less permeable than the core then removal of this surface should result in an increased percentage of water absorption. Subsequently, if the material is subject to an increase in water absorption then the application of a water repellant should reduce water absorption and therefore retard the process of deterioration.

The test compares one physical property, permeability, within a series of varying brick samples. The test samples were selected to compare and evaluate the affect, if any, of

various manufacturing techniques in relation to the water absorption of the brick. Each time the water absorption test was executed one variable was changed for all the test samples. The variable for each test was the treatment to one surface of the brick sample, i.e., the original brick, grinding, sandblasting, and applying a water repellent to one face of the brick.

4.1 Bricks Samples

The brick samples selected include two categories, new and salvaged brick. Both were used to compare results from unweathered vs. weathered materials. Limited information was available for the salvaged brick and the data sets served mostly as a control between new and old.

Within these two categories the methods of manufacture are the prevailing characteristic: hand molded, machine molded, and extruded wire-cut. The new samples were all acquired at a Glen Gary Brick Manufacturing Plant in Reading, Pennsylvania. These bricks differ only in the molding process since the raw material is mined locally from a shale deposit adjacent to the Brick Plant and all the bricks are fired in the same oven.

Less information was available for the salvaged brick. These bricks were salvaged from buildings that were demolished in New York and New Jersey.

Table: 4.1 Brick Samples

Type	No.	Date	Method of Manufacture	Origin
New Brick	**1.**	1993	Hand Molded	Glen Gary Plant Reading, PA
	2.	1993	Machine Molded	Glen Gary Plant Reading, PA
	3.	1993	Extruded, wire-cut (Cored brick with sand slurry applied)	Glen Gary Plant Reading, PA
Salvaged Brick	**4.**	Circa 1870	Molding method unknown	Upsala College West Orange, NJ
	5.	Circa 1885	Machine Molded and Frogged	Cold Spring, NY
	6.	Circa 1885	Molding method unknown (Flue Brick)	Cold Spring, NY

Manufacturing information for the salvaged brick was determined by visual observation of telltale features which indicated the manufacturing process. The lack of factual information for the salvaged brick limited the effectiveness of cross-comparing the data sets. The firing temperature for all the brick samples is unknown.

For the absorption determinations, averages of five bricks were tested from each brick category, with one exception, only four samples of the "Flue Brick" from Cold Spring, New York were available.

4.2 Experimental Design: Water Absorption (ASTM C 67-89a)

This test method is based on ASTM C67-89a, Standard Test Methods of Sampling and Testing Brick and Structural Clay Tile. The test conducted measured the water absorption of the different types of bricks listed above. The test was run for each varying condition, i.e., grinding, sandblasting, and applying a water repellant to one surface.

4.2.1 Initial Preparation

4.2.1.1 Drying: Test specimens were dried in a ventilated oven at 230° to 239° F (110° to 115° C) for not less than 24 hours, until two successive weighing at intervals of two hours show an increment of loss not greater than 0.2% of the last previously determined weight of the specimen.

4.2.1.2 Cooling: After drying, the specimen was cooled in a room maintained at a temperature of 75° ± 15° F, with a relative humidity between 30% and 70%. The bricks were stored free from drafts, unstacked, with separate placement, for a period of at least four hours. No specimen, noticeably warm to the touch was used for any test.

4.2.2 Twenty-four (24) Hour Cold Water Submersion

4.2.2.1 Saturation: The dry, cooled specimens, were submerged, without preliminary partial immersion, in clean water (soft water) at 60° to 86° F for the specified time. After twenty-four (24) hours the specimens were removed, excess water wiped off the surface with a damp cloth and weighed within 5 minutes after removing the specimens from the bath. This weight was recorded.

4.2.3 Five (5) Hour Boil

4.2.3.1 Test Specimen: The same test specimens used in the twenty-four hour cold water submersion test were used in the five hour boil. The five hour boil was begun at the end of the twenty-four hour cold water submersion test; the specimens were used in the state of saturation existing at the completion of the previous test.

4.2.3.2 Procedure: The specimen from the cold-water submersion test was returned to the bath, and subjected to the boiling test. The specimen was submerged in clean water (soft water) at 60° to 86°F in such a manner that water can circulate freely on all sides of the specimen. The water was brought to a boil and then allowed to boil continuously for the specified time. The water was then cooled to 60° to 86° F by natural loss of heat.

The specimen was removed, excess water was wiped off the surface and then weighed. The weight of the specimen was recorded.

4.2.4 Calculations For Absorption and Saturation Coefficient

4.2.4.1 Absorption. The absorption of each specimen was calculated as follows:

Absorption % = 100 $(W_s - W_d) / W_d$.

4.2.4.2 Saturation Coefficient. The saturation coefficient for each specimen was calculated as follows: Saturation Coefficient = $(W_{s24} - W_d) / (W_{b5} - W_d)$

4.2.4.3 Values. For both calculation listed above, the following values were used:

W_d = dry weight of specimen;

W_{s24} = saturated weight of the specimen after submersion in cold water for twenty-four (24) hours;

W_{b5} = saturated weight of the specimen after submersion in boiling water for five (5) hours.

4.3 Experimental Variables

4.3.1 Grinding

A power grinder was applied to one surface of each brick until the outer surface was completely removed. The grinding provided a smooth surface. Each brick sample was then run thru the water absorption test, both the Twenty-Four (24) Hour Cold Submersion and the Five (5) Hour Boil. The results were recorded.

4.3.2 Sandblasting / Abrasive Cleaning

The ground face of each brick was then sandblasted with Black Beauty, a 20/40 grit slag at 90 to 100 psi. The brick was treated to four passes with the nozzle approximately a twelve (12") from the surface. Each brick sample was then run thru the water absorption test, both the Twenty-Four (24) Hour Cold Submersion and the Five (5) Hour Boil. The results were recorded.

4.3.3 Application of Water Repellant

4.3.3.1 Products and Materials

The water-repellant used for this test is Cheme-trete BSM-40, it is silane based, the main active ingredient is Isobutyltrialkoxysilane.

4.3.3.2 Application Procedure

The test specimens were dried and cooled as specified in Section 4.2.1.1 and 4.2.1.2. The water repellant was applied with a brush on the sandblasted surface only. The brick samples where then allowed to dry for Twenty-Four (24) Hours.

Each brick sample was then run through the water absorption test, both the Twenty-Four (24) Hour Cold Submersion and the Five (5) Hour Boil. The results were recorded.

Chapter 5: Test Conclusions and Recommendations

5.1 Test Conclusions

The purpose of the test program was to gage the effect removing one face of each brick sample would have on the units resistance to absorb water. As stated throughout this thesis the protective outer surface of the brick, or what is commonly, but often inconclusively referred to as the "fireskin" is presumed to be the primary defense of the material against the elements. Therefore removing this surface should make the brick more susceptible to water ingression through increased permeability of the exposed core. Increased moisture is generally believed to promote accelerated deterioration.

The tests compared four conditions for each sample group: original condition, single ground face, single sandblasted face, and the application of a water repellent. The tests were designed under the assumption that abrasive cleaning or sandblasting would increase the water absorption of the unit. The application of the water repellent was introduced to address the presumed damage. Furthermore the two different methods of removing the exterior surface where executed in order to further quantify the nature of the damage to the surface of the brick. Grinding removes the surface of the brick but leaves a smooth surface. Sandblasting or abrasive cleaning results in a "raw" appearance, visually the surface of the brick has been abraded, the surface is often lighter in color and sometimes

pockmarked. This physical damage is irreversible. It is a commonly held belief that a building which has been sandblasted will deteriorate faster due to this procedure. Although there might not be a "fire skin" surface on the brick which is more impermeable than the center of the material, sandblasting or abrasive cleaning alters the brick by increasing surface area, thus multiplying the opportunities for water to enter the material and contribute to decay.

The research for this thesis uncovered two interesting facts. First, although the term "protective outer surface" appears repeatedly throughout the texts in the bibliography, the term fire skin appeared only once in Hermann Salmang's text: *Ceramics, Physical and Chemical Fundamental,*[73] and it is in a broad context: Salmang refers to ceramic bodies. In this reference the fire skin is not attributed to the location of the brick in the kiln as the name would suggest, i.e. the bricks closer to the fire but it is more a function of the molding of the brick. Where ever the brick, prior to firing, has been subjected to pressure that has "brought about a parallel arrangement of the clay particles and densified the biscuit locally." George Robinson, the ceramic engineer for Glen Gery, reiterated this in his comments[74].

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[73] Salmang, Hermann, *Ceramics Physical and Chemical Fundamentals,* London: Butterworths, 1961, 141-142.

[74] Conversation with George Robinson, Glen Gary ceramic engineer. February 1993.

Second, and no less important, there have been no tests conducted to measure or quantify this perceived increased deterioration of brick which has been abrasively cleaned.

The test samples were divided into two main groups: new and old. Within the "new" group the bricks were divided into three subsets determined by molding method. The three methods included: hand molded, machine molded, and extruded. All the "new" bricks were made from the same clay material and fired in the same kiln at the same temperature.

The "old" brick salvaged from buildings which were demolished and in varying states of deterioration. The information available on these bricks was limited. There were collected from buildings in New York State and New Jersey. Judging from the date of the buildings they were most likely produced in the late nineteenth century. This set was used for two reasons, first, sandblasting is usually executed on older building where the material under the best conditions has already undergone numerous freeze thaw cycles and is most likely in some state of deterioration. Second, as a necessary comparison and control for the "new" group.

The test measured the water absorption of the initial samples, the brick sample then had one face ground off and the test was repeated. The same procedure was followed when the surface was sandblasted and then treated with water repellant. The results were recorded and computed to calculate the percentage of water absorption for both the

Twenty-Four (24) Hour Soak and Five (5) Hour Boil for each specimen and the Saturation Coefficient. The mean and the standard deviation for each group are recorded in the following tables.

5.1.1 Water Absorption Tables

Table 5.1.1.1: Percentage of Water Absorption after 24 Hour Soak

1. Hand Molded Brick	Initial Weight	Grind one face	Sandblast	Water Repellant
Mean (% Water Absorption)	4.05	4.12	3.98	1.19
Standard Deviation	±0.77	±0.71	±0.65	±0.23
2. Machine Molded Brick				
Mean (% Water Absorption)	5.76	5.43	5.51	2.45
Standard Deviation	±0.89	±0.94	±0.92	±0.47
3. Extruded Wire Cut				
Mean (% Water Absorption)	4.94	4.65	5.30	3.43
Standard Deviation	±0.27	±0.30	±0.37	±0.23
4. Upsala College				
Mean (% Water Absorption)	7.38	7.14	7.39	4.00
Standard Deviation	±3.01	±3.19	±3.92	±1.55
5. Frogged Brick				
Mean (% Water Absorption)	14.58		14.56	11.89
Standard Deviation	±0.54		±0.61	±0.55
6. Flue Brick				
Mean (% Water Absorption)	10.26		10.39	6.24
Standard Deviation	±2.36		±1.26	±3.30

Table 5.1.1.2: Percentage of Water Absorption after 5 Hour Boil

1. Hand Molded Brick	Initial Weight	Grind one face	Sandblast	Water Repellant
Mean (% Water Absorption)	6.76	7.07	6.51	7.33
Standard Deviation	±0.76	±0.73	±0.75	±0.63
2. Machine Molded Brick				
Mean (% Water Absorption)	8.86	9.25	9.40	9.27
Standard Deviation	±0.92	±0.83	±0.94	±0.82
3. Extruded Wire Cut				
Mean (% Water Absorption)	6.15	5.84	6.27	5.04
Standard Deviation	±0.32	±0.29	±0.38	±0.34
4. Upsala College				
Mean (% Water Absorption)	11.41	12.30	11.78	11.06
Standard Deviation	±1.70	±1.65	±2.24	±1.42
5. Frogged Brick				
Mean (% Water Absorption)	15.50		15.48	12.80
Standard Deviation	±0.45		±0.52	±0.64
6. Flue Brick				
Mean (% Water Absorption)	13.20		13.61	14.19
Standard Deviation	±.95		±.30	±1.00

5.1.1.3: Saturation Coefficient

1. Hand Molded Brick	Initial Weight	Grind one face	Sandblast	Water Repellant
Mean	0.58	0.56	0.59	0.16
Standard Deviation	±0.05	±0.05	±0.03	±0.04
2. Machine Molded Brick				
Mean	0.62	0.56	0.55	0.24
Standard Deviation	±0.03	±0.05	±0.04	±0.02
3. Extruded Wire Cut				
Mean	0.79	0.79	0.83	0.66
Standard Deviation	±0.03	±0.01	±0.01	±0.02
4. Upsala College				
Mean	0.61	0.53	0.58	0.35
Standard Deviation	±0.19	±0.20	±0.20	±0.18
5. Frogged Brick				
Mean	0.93		0.93	0.91
Standard Deviation	±0.03		±0.02	±0.03
6. Flue Brick				
Mean	0.75		0.74	0.40
Standard Deviation	±0.13		±0.11	±0.19

5.1.2 Statistical Analysis

The test results were statistically analyzed using the F-test and t-test. Within each sample group the water absorption for the initial weight of the sample was compared to the results after one face was sandblasted. The F-test and the t-test were calculated for both the 24 Hour Soak and the 5 Hour Boil. The result are included in Appendix A.

The F-test was used to verify the accuracy of the test results. The F-test compared the standard deviation between the initial sample and the sandblasted one, it determined that no significant variation occurred within each sample group. In a similar manner, the t-test was used to determine if there were significant differences in the percentage of water absorption for the samples. The levels of probability of significant differences between the means are recorded in the following table:

Table 5.1.2.1 Significant differences between samples as reflected by the t-test.

Sample Group: Comparison b/t initial sample and single face sandblasted	t-test Levels of Probability
1. Hand Molded Brick	not significant; 5%
2. Machine Molded Brick	not significant; 5%
3. Extruded Wire Cut	not significant; 5%
4. Upsala College	not significant; 5%
5. Frogged Brick	not significant; 5%
6. Flue Brick	not significant; 5%

5.1.3 Hand Molded Brick

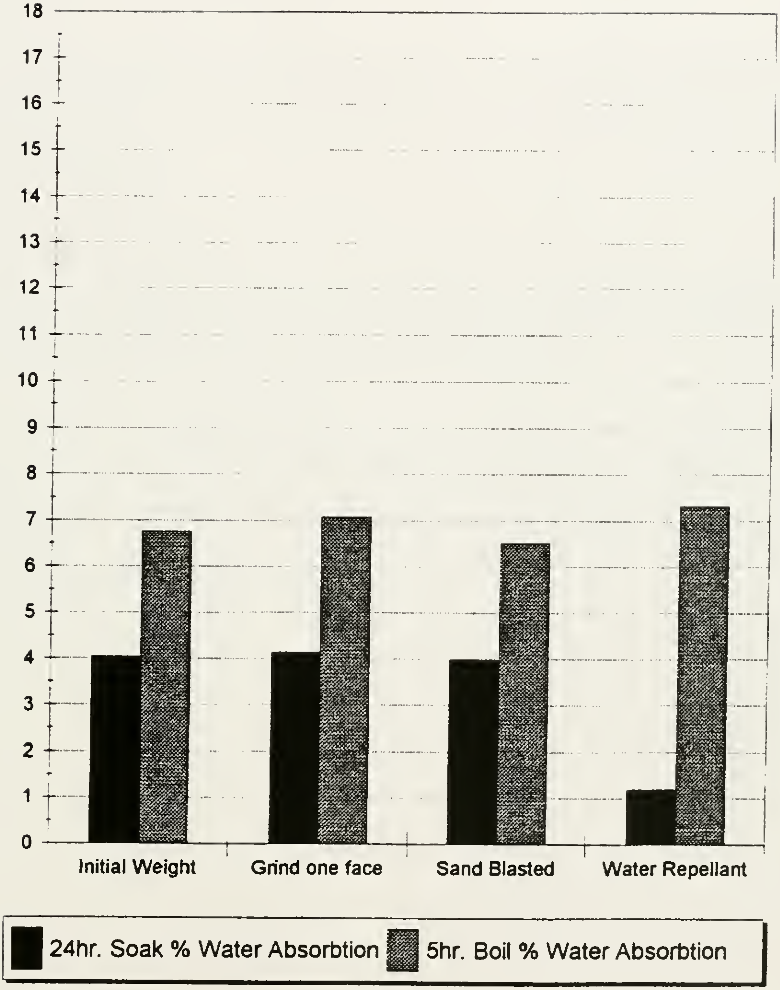
The initial Mean Water Absorption (MWA), for the five samples of this brick was 4%. This was increased to approximately 7% after the 5 Hour Boil.

Although there was a small increase in the MWA for the brick when one face was removed with a grinder, it is minimal. After the 24 Hour Soak the rounded off MWA was 4% and 7% after the 5 Hour Boil.

There was no significant change after this same surface was sandblasted. The MWA was 3.98% rounded off to 4%. The MWA has actually decreased after the 5 Hour Boil to 6.5% but this is most likely attributed to the accuracy of the test than any other reason.

The brick with the application of a water repellant initially drops to 1% MWA but increases back to the "standard" MWA of 7% after the 5 Hour Boil. These results are shown in graph form on the following page.

Hand Moulded Brick



5.1.4 Machine Molded Brick

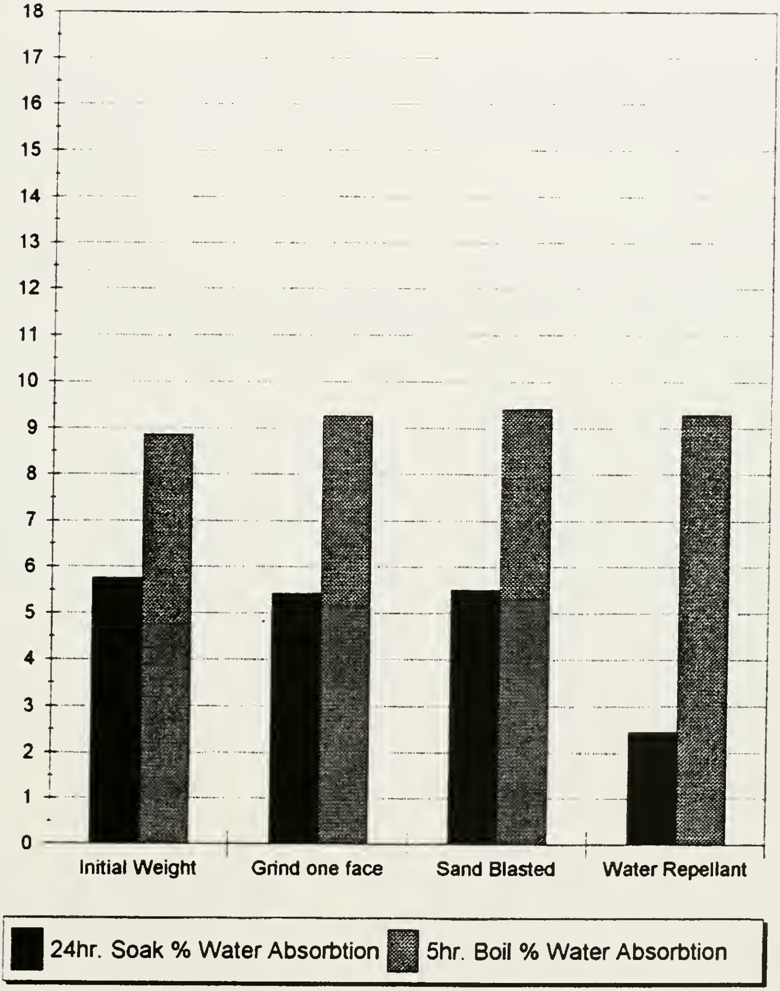
The initial Mean Water Absorption (MWA), for the five samples of this brick was 6%. This was increased to approximately 9% after the 5 Hour Boil.

There was a small decrease in the MWA for the brick when one face was removed with a grinder, it is minimal. After the 24 Hour Soak the rounded off MWA was 5% and 9% after the 5 Hour Boil.

There was no significant change after this same surface was sandblasted. The MWA was 5.5% rounded off to 6%. The MWA after the 5 Hour Boil is 9%.

The brick with the application of a water repellant initially drops to 2% MWA but increases back to the "standard" MWA of 9% after the 5 Hour Boil. These results are shown in graph form on the following page.

Machine Moulded Brick



5.1.5 Extruded Wire Cut Brick

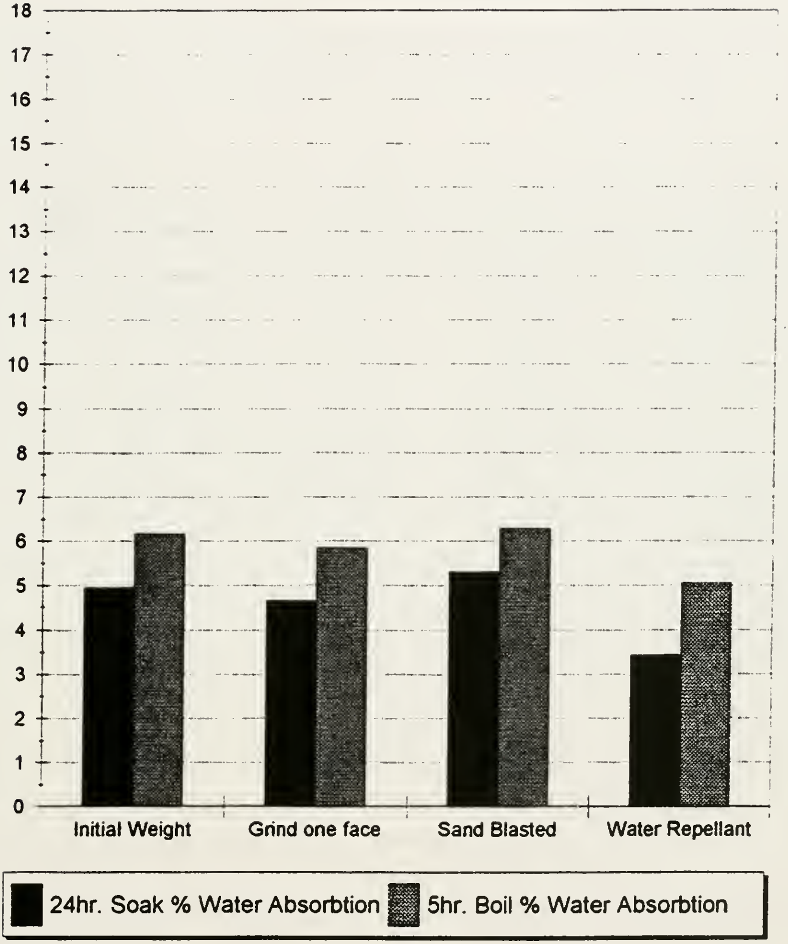
The initial Mean Water Absorption (MWA), for the five samples of this brick was 5%. This was increased to approximately 6% after the 5 Hour Boil.

There was a small decrease in the MWA for the brick when one face was removed with a grinder, it is minimal. After the 24 Hour Soak the rounded off MWA was 5% and 6% after the 5 Hour Boil.

There was a small increase after this same surface was sandblasted. The MWA was 5.3% rounded off to 5%. The MWA after the 5 Hour Boil is 6%.

The brick with the application of a water repellant initially drops to 3% MWA but increases to a MWA of 5% after the 5 Hour Boil, slightly lower than the previous MWA for the 5 Hour Boil. These results are shown in graph form on the following page.

Extruded, Cored, Wire Cut Brick

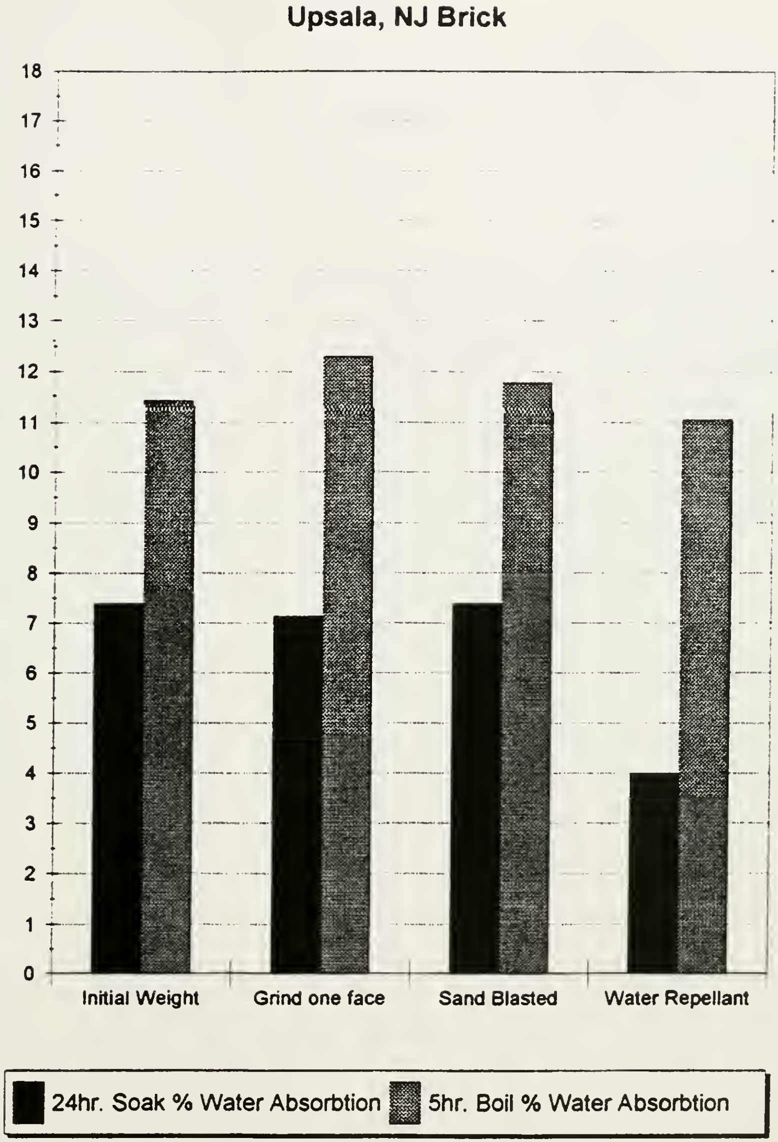


5.1.6 Salvaged Brick, Upsala College, New Jersey

The initial Mean Water Absorption (MWA), for the five samples of this brick was 7%. This was increased to approximately 11% after the 5 Hour Boil.

There was no significant change after grinding one surface and then sandblasting. After the 24 Hour Soak the rounded off MWA was 7% and 12% after the 5 Hour Boil.

The brick with the application of a water repellant initially drops to 4% MWA but increases to a MWA of .11% after the 5 Hour Boil. These results are shown in graph form on the following page.


Upsala, NJ Brick
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Initial Weight
Grind one face
Sand Blasted
Water Repellant
24hr. Soak % Water Absorbtion
5hr. Boil % Water Absorbtion

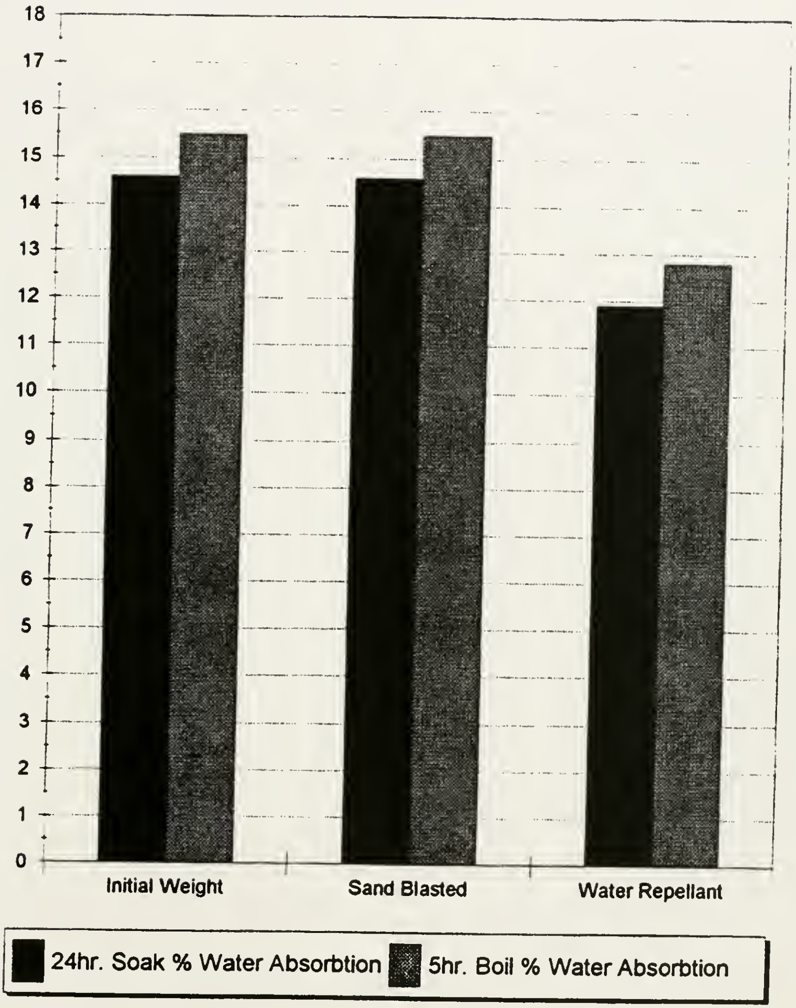
5.1.7 Frogged Brick, Cold Spring, New York

The initial Mean Water Absorption (MWA), for the five samples of this brick was rounded off to 15%. There is almost no change after the 5 Hour Boil, the MWA was 15%.

The surface of these bricks were not ground. There was no significant change in the MWA for the brick when one face was removed by sandblasting. After the 24 Hour Soak the rounded off MWA was 15% and 15% after the 5 Hour Boil.

The brick with the application of a water repellant drops to 12% MWA and 13% after the 5 Hour Boil. These results are shown in graph form on the following page.

Frogged Brick



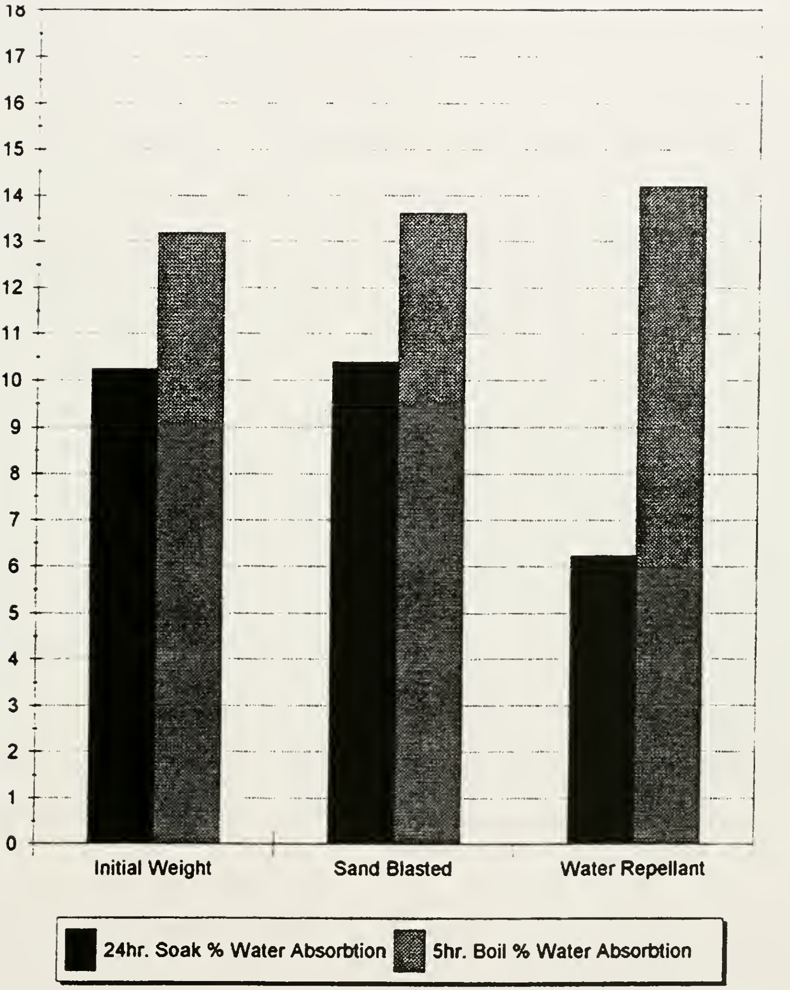
5.1.8 Flue Brick, Cold Spring, New York

The initial Mean Water Absorption (MWA), for the five samples of this brick was 10%. This was increased to approximately 13% after the 5 Hour Boil.

The surface of these bricks were not ground. There was no significant change in the MWA for the brick when one face was removed by sandblasting. After the 24 Hour Soak the rounded off MWA was 10% and 14% after the 5 Hour Boil.

The brick with the application of a water repellant initially drops to 6% MWA but increases back to the "standard" MWA of 14% after the 5 Hour Boil. These results are shown in graph form on the following page.

Flue Brick


18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Initial Weight
Sand Blasted
Water Repellant
24hr. Soak % Water Absorbtion
5hr. Boil % Water Absorbtion

5.2 General Conclusions

This thesis looked at one material property: the permeability of brick as a function of water absorption. In a similar manner it selected the samples with only one variable: molding method. As noted above, all the new samples were molded from the same clay and fired in the same kiln. The tests were devised to examine two related hypotheses: First, if the outer surface of a brick is protective, then the removal will result in a higher percentage of water absorption. Second, if a "fireskin" were to exist, it is most likely due to the molding method involved. The results indicate that the removal of the outer surface of the brick did not increase the percentage of water absorption.

The results of this thesis are surprising in light of the commonly held beliefs regarding the relationship between the protective nature of brick surfaces and the higher permeability of the materials core. The percentage of water absorption for each of the samples did not vary in any dramatic way after one of the surfaces was sandblasted. The F-test and t-test compared the initial sample to the sand-blasted sample and illustrated that there are no significant differences between means. The tests indicate that there is not significant increased water absorption in the brick samples after one of the sides is both ground and sandblasted. This is a consistent for both the new and the old brick samples.

It is interesting to note that the sample with the lowest water absorbance was the hand molded brick. The manual manufacture of this brick presents a greater opportunity for the

clays to be slicked to the surface as noted by both George Robinson[75] and Salmang[76]. The fire skin most likely occurs during the molding process.

The higher water absorbance for the old brick that was tested can be simply attributed to the fact that the bricks were in an advanced state of deterioration. The perceived notion that historic brick will deteriorate faster when sandblasted may also be accounted for in the same way. Sandblasting visually alters the surface and exposes brick that already has a high permeability ratio.

These results do not imply that sandblasting is not damaging, but do indicate that the nature of the damage is not understood. Although these findings appear to shift the argument against sandblasting from one which claims inducing the physical deterioration of the material to an aesthetic issue, this is a broad and dangerous assumption to make. Clearly the material has been visually altered. In terms of historic relevance, altering a surface of a building material to a texture and color that it was never intended is destructive. In addition, these tests were designed to consider only one relationship, and as such, the possibility that the physical properties of the material have been diminished cannot be discounted.

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[75] Ibid.

[76] Salmang, Hermann, *Ceramics Physical and Chemical Fundamentals,* London: Butterworths, 1961, 141-142.

Further studies are required to confirm the results from this thesis beyond the shadow of a doubt. It is also important to look at the entire building system, i.e. brick wall, mortar, openings, flashing, etc. If accelerated deterioration does occur it may be another part of the wall system that has failed. What this thesis does indicate is that brick, as manufactured with modern technology, is a homogeneous product.

Chapter 6: Selected Bibliography

6.1 Annotated Bibliography on Masonry

Ashurst, John and Nicola Ashurst. *Practical Building Conservation, Vol. 2, Brick, Terra cotta and Earth.* Hants, England: Gower Technical Press, 1988.

A comprehensive, practical text for the conservation of brick and other architectural clay materials. Includes discussions / definitions of the material, deterioration, and maintenance and preservation methods. Brief, but useful introduction to the subject.

Beall, Christine. *Masonry Design and Detailing.* Englewood Cliffs: Prentice Hall, Inc., 1984.

Provides a basic overview of the processes of brickmaking and brickbuilding – primarily for builders and designers, but useful for a general understanding of brick construction.

Burke, J.E. "A History of the Development of a Science of Sintering" In *Ancient Technology to Modern Science,* ed. W.D. Kingery. Ohio: The American Ceramic Society, Inc.,

This paper presents the development of understanding of the mechanisms of solid-state sintering. It defines sintering in terms of the profession using it, includes both past and present context and establishes the parameters in which this occurs. "At present, the word sintering is largely used in ceramics to refer to solid-state sintering or to those processes where it is assumed that no liquid is formed during sintering, although one may actually be present as in the fabrication of beta alumina. *Very recently, it has sometimes been used to refer to the consolidation of conventional silicate ceramics on heating.*" p.316

Brownell, W.E. *Structural Clay Products.* New York: Springer-Verlag, 1976.

According to the Brick Institute of America, this is the Bible of brick manufactures -- a blend of the theoretical and technical. History and classification of brick, clay mineralogy and properties, structure, raw materials, industrial production, and firing process. Useful text but the information is dense, *Applied Clay Mineralogy* has more assessable information to cross reference with.

Cabana, Michael. "Properties of Clay and Their Effects on the Manufacture of Building Brick." Materials Diagnostics, HSPV 550, University of Pennsylvania. Fall 1992.

Good synthesis of the manufacture of brick, complete bibliography.

Cotterrill, Rodney. *The Cambridge Guide to the Material World,* 119-134. Cambridge, New York, etc.: Cambridge University Press, 1985.

Broad introduction to ceramics, concise text and comprehensive information. Brief explanations of complex topics such as sintering.

Cowan, Henry J. and Peter R. Smith. *The Science and Technology of Building Materials*, 140-146. New York: Van Nostrand Rienhold, 1988.

Material science presentation to architectural materials. Reinforces the information found in many of the other texts.

Davis, Charles Thomas. *A Practical Treatise on the Manufacture of Brick Tiles and Terra-Cotta.* Philadelphia: Henry Carey Baird & Co., 1895.

Grim, Ralph E. *Applied Clay Mineralogy.* New York, McGraw-Hill Book Co. Inc., 1962.

Grimmer, Anne. "Dangers of Abrasive Cleaning to Historic Buildings." *Preservation Brief 6.* (1979).

This article provided the one reference to "protective outer surface", that in itself suggests that the information presented is not as thorough as it should be.

Grimshaw, Rex W. *The Chemistry and Physics of Clays and Allied Ceramic Materials.* 4th Edition. New York: Wiley Interscience, 1971.

Gurke, Karl. *Bricks and Brickmaking.* Moscow, Idaho: University of Idaho Press, 1987.

Interesting chapter on brick manufacturing. Did not provide thorough information on the firing process but that is not its scope.

Hamilton, David. *Architectural Ceramics.* London: Thames and Hudson, 1978.

Handbook describing techniques related to the methods of making bricks, tiles, faience, terra cotta and large scale sculpture, as well as roofing tiled, chimney post and decorative features. Interesting but not technical.

Loehman, Ronald E. *Characterization of Ceramics.* Boston: Butterworth-Heinemann, 1993.

This book presents a broad overview of high-tech ceramics and glass and the application of characterization techniques. There is a direct correlation between understanding the consolidation process for these ceramics and brick.

Pampuch, Roman. *Constitution and Properties of Ceramic Materials.* Amsterdam, New York: Elsevier, 1991.

Material science approach to the study of ceramics. Defines ceramics as: solid-state materials manufactured from inorganic, non-metallic substances that exhibit high thermal stability. The book is divided into two parts:
Part I - The Constitution of Ceramic Materials, discusses correlation between mineralogy and ceramics.
Part II - The Properties of Ceramic Materials.

Ries, Heinrich. *Building Stones and Clay Products: A Handbook for Architects.* New York: John Wiley & Sons, 1912.

Robinson, Gilbert C. "Characterization of Bricks and Their Resistance to Deterioration Mechanisms. In *Conservation of Historic Stone Buildings and Monuments*, ed. N.S. Baer, 142-162. Washington, D.C.: National Academy Press, 1982.

A concise discussion of the durability, susceptibility and rate of deterioration of brick and mortar systems -- from a combined stand-point of ceramic engineering and conservation science. Rate of deterioration is a function of the properties of

the material: composition, pore structure, manufacturing procedures, structural design, cleaning procedures Topics include: raw materials, shaping, firing, coloration, aging, water penetration, mortar bond, freeze-thaw conditions, salt and chemical attack, expansion, coating, design, material compatibility, cleaning and restoration.

Salmang, Hermann. *Ceramics, Physical and Chemical Fundamentals.* London: Butterworths, 1961.

Torraca, Giorgio. *Porous Building Materials.* Third Edition. Rome: ICCROM, 1988.

A basic introduction to the technology of building materials. Porous stone, brick and mortar undergo deterioration processes when exposed to the aggressive actions of the environment. The rate and symptoms of such processes are influenced by a number of variables, including the properties of the material and the environmental factors which act upon it. In the model presented deterioration is shown as resulting form chemical processes (corrosion) acting in conjunction with mechanical stresses (both external and internal). Information is present in an accessible and readable way. Instrumental in my understanding of the characteristics of the clay mineral groups.

West, H.W.H. "Clay Product" in *Weathering and Performance of Building Materials.* ed. John W. Simpson and Peter J. Horrobin. New York: Wiley-Interscience, 1970.

This article discusses the primary sources of deterioration in brickwork: frost, efflorescence, dimensional changes (thermal and moisture movement), mortar decay and the importance of good design and proper detailing. No characterization of the material was included but the notion that deterioration is a function of porosity is implied.

Wilson, Forrest. *Building Materials Evaluation Handbook.* New York: Van Nostrand Reinhold Company, 1984.

Worrall, W.E. *Clays and Ceramic Raw Material, 2nd Edition.* London: Elsevier Applied Science Publishers, 1986.

6.2 American Society for Testing and Materials: Standards

ASTM "Standard Definitions of Terms Relating to Structural Clay Products." Designation C 43-89. Philadelphia: American Society for Testing and Materials, 1989.

Glossary of key terns which relate to brick. Define words commonly used to refer to: general definitions, raw material, manufacture procedures, brick, surface features, and performance properties. It is interesting to note that no mention of the "fireskin" is made. Fire-bond, firing and incipient-fusion are defined but vitrification and sintering are not. The one reference to sintering is brief, sketchy, and non-committal at best. For example: "Other thermal mechanisms such as sintering and inter-particle reaction *may* be responsible for the bond." page 25

ASTM "Standard Specification for Building Brick (Solid Masonry Units Made From Clay or Shale)." Designation C 62-89a. Philadelphia: American Society for Testing and Materials, 1990.

Provides accepted industry definition or standard for brick including grade requirements, physical requirements and permissible variations in dimensions.

ASTM "Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water." Designation C 20-80. Philadelphia: American Society for Testing and Materials, 1980.

As the title suggests, this article presents standard test methods for specific properties of brick. It was interesting to note that the test required the "use of a quarter-brick specimen obtained by halving the brick along a plane parallel to the 9" by 2 ½" or 3" face and along a plane parallel to the 4 ½" by 2 ½ or 3" face. Four of the surfaces of the resultant quarter-brick specimen include part of the original molded faces." In other words, these tests measure the properties of the whole without making any allowances for the possibility that the exterior surface of the brick may function as a protective surface.

ASTM "Standard Test Methods of Sampling and Testing Brick and Structural Clay Tile." Designation C 67-89a. Philadelphia: American Society for Testing and Materials, 1990.

Test methods presented include modulus of rupture (flexure test), compressive strength, absorption, freezing and thawing, initial rate of absorption (suction), efflorescence, measurement of size, measurement of warpage. Once again tests are conducted on brick specimens, implying that these properties should be inherent in the brick and are not necessarily a function of the whole.

6.3 Journal of the American Ceramic Society

These articles represent primary research, many of them were listed as references in the books listed above. Without an understanding of the firing process, the information presented was almost impossible to assimilate. The article are highly technical.

Burke, J.E. "Role of Grain Boundaries in Sintering." *Journal of the American Ceramic Society.* **40** 80-85 (1957).

Hefter, Jesse, et. al. "Microstructural Characterization of Structural Ceramics Using Image Processing and Analysis." *Journal of the American Ceramic Society.* **76**(6) 1551-57 (1993).

Greskovich, C. and K.W. Lay. "Grain Growth in Very Porous Al_2O_3 Compacts." *Journal of the American Ceramic Society.* **55**(3) 142-146 (197-).

Rossi, Giulio and J.E. Burke. "Influence of Additives on the Microstructure of Sintered Al_2O_3 Compacts." *Journal of the American Ceramic Society.* **56**(3) 655-660 (197-).

Robinson, G.C., J.R. Holman and J.F. Edwards. "Relation Between Physical Properties and Durability of Commercially Marketed Brick." *Journal of the American Ceramic Society.* **56**(12) 1071-1076 (1976).

6.4 Water Repellents

Binda, Luigia; Giulia Baronio, and Thea Squarcina. "Evaluation of the Durability of Bricks and Stones and of Preservation Treatments." Delgado Rodriques, J.; Henriques, Fernando; Telano Jeremias, F., Editors. *7th International Congress on Deterioration and Conservation of Stone*. Lisbon, Portugal, 15-18, June, 1992. Laboratorio Nacional de Engenharia Civil. pg. 753-761.

Clarson, S.J. and J.A. Semlyen. *Siloxane Polymers.* Englewood Cliffs, New Jersey: PRT Prentice Hall, 1993.

Clear Water Repellents. Kansas City, Missouri: Sealant, Waterproofing & Restoration Institute (816) 561-8230.

Grimm, C.T. "Clear Consequences." *The Construction Specifier.* **46**(5) 143-152 (May 1993).

Mattys, J.H., et al. "Initial Rates of Absorption of Clay Brick Considering both Bed Surfaces in the As Received Condition After Outside Exposure." *Masonry: Components to Assemblages, ASTM STP 1063.*

McGettigan, Edward. "Selecting Clear Water Repellents." *The Construction Specifier.* **47**(6) 120-32 (June 1994).

Noll, W. *Chemistry and Technology of Silicones.* San Diego, California: Academic Press, Inc.

Vale, J. F. and R. Villegas. "Evaluation of the Behavior of Water Repellent Treatments for Stone." Delgado Rodriques, J.; Henriques, Fernando; Telano Jeremias, F., Editors. *7th International Congress on Deterioration and Conservation of Stone*. Lisbon, Portugal, 15-18, June, 1992. Laboratorio Nacional de Engenharia Civil. pg. 1253-1263.

Weismantel, G.E. *Paint Handbook.* New York: McGraw-Hill Book Company, 1981.

6.5 General Reference to Masonry (Stone and Brick)

Amoroso, Giovanni and Vasco Fassina. *Stone Decay and Conservation.* New York: Elsevier Science Publishing Co., Inc., 1983.

The book analyzes and develops the most recent studies in the field of conservation and restoration of stone in buildings and monuments of historical, archeological and artistic value. Particular attention has been given to the deleterious influence upon stone of the industrial urban environment, which adds its effects to those of natural degradation agents. Fundamental importance has been given to the study of environmental deterioration agents, including carbon dioxide, sulphuric acid, and their reaction with building materials. Special emphasis has also been given to those meteorological parameters in stone degradation that have a bearing on the transport, diffusion, accumulation and deposit of atmospheric pollutants.

Ashurst, John. "Cleaning and Surface Repair: Past Mistakes and Future Prospects," *Association for Preservation Technology Bulletin*, Vol. 17, No. 2 (1985), pp. 39-41.

A survey of the condition of thirty exterior architectural surfaces in urban England that were cleaned by various methods ten years prior. Discussions and observations.

Ashurst, John and Francis G. Dimes. *Conservation of Building and Decorative Stone.* Volumes I & II. London: Butterworth - Heinemann, 1990.

These two volumes discuss the theory and practice of conservation with an objective comparison of different methods and approaches to the discipline. Volume I provides an introduction to the restoration, conservation and repair of building stone along with chapters on the nature, geology and weathering of masonry. Volume II discusses various treatments in conservation.

Baer, N.S. editor. *Conservation of Historic Stone Buildings and Monuments.* Washington DC: National Academy Press, 1982.

Proceedings of a conference of scientists, preservationists, architects, engineers and architectural historians interested in the problems of historic masonry structures held in 1981. The series of papers describe an up-to-date account of stone conservation. The conference was designed to achieve three goals: to

summarize the state of research on stone conservation, to define research needs and priorities, and to interest scientist from many disciplines in the problems of conservation. The coverage of the papers is broad but not comprehensive. The papers provide the scientist with a basic introduction to historic preservation while giving the preservation architect a general introduction to the relevant scientific and engineering disciplines. Topics range from the "Geological Sources of Building Stone" to "The Evaluation of Stone Preservatives."

Bidwell, T.G. *Conservation of Brick Buildings: The Repair, Alteration and Restoration of Old Brickwork.* London: Brick Development Association, 1977.

This report discusses the conservation of brick buildings: survey, structural failures to brickwork, brick failure, water penetration, biological growth, alterations to historic fabric, surface appearance and treatments.

Blades, Keith, Gail Sussman and Martin Weaver. *Masonry Conservation and Cleaning.* Ottowa, Ontario: The Association for Preservation Technology, 1985.

A collection of published materials dealing with various aspects of masonry cleaning: its chemistry and suitable methods, with discussion of the various cleaning systems; control of damp in masonry buildings; stone decay and preservation: a review of available treatment methods; masonry repointing; repair of brick work; grouting walls. Water repellents; and coatings for masonry surfaces. Bibliography.

Ciabach, J., Editor. *Sixth International Congress on Deterioration and Conservation of Stone.* Torun: Nicholas Copernicus University, 1988.

Papers presented at the Sixth International Congress on Deterioration and Conservation of Stone, held in Poland. Topics include stone cleaning and consolidation. Bibliographic references are listed.

Feilden, Bernard M. *Conservation of Historic Buildings.* London: Butterworths, 1982.

Handbook on architectural conservation. Divided into four parts: structural aspects of historic buildings; causes of decay (earthquakes, biodeterioration, environment); the work of the architectural conservator; building repairs and special techniques. Glossary and bibliography.

Grimmer, Anne E. *A Glossary of Historic Masonry Deterioration Problems and Preservation Treatments.* Washington D.C.: Department of the Interior, National Park Service, Preservation Assistance Division, 1986.

An illustrated glossary providing an explanation of all terms likely to be used to describe conditions of masonry deterioration, repair techniques, and treatments for historic masonry preservation. The first section lists and defines masonry deterioration problems in alphabetical order, the second one describes preservation treatments, grouped according to maintenance and repair techniques.

Harris, Harry A. "Masonry Materials: Design, Construction and Maintenance." *ASTM Special Technical Publication.* Philadelphia: ASTM, 1988.

Contains 12 papers presented at the Symposium on Masonry held in New Orleans on December 2, 1986. Contributions deal with current technologies in four major areas: 1. testing procedures and properties of masonry materials and assemblage; 2. design of masonry construction; 3. masonry construction problems; 4. maintenance.

Torraca, Giorgio. *Porous Building Materials.* Third Edition. Rome: ICCROM, 1988.

A basic introduction to the technology of building materials. Porous stone, brick and mortar undergo deterioration processes when exposed to the aggressive actions of the environment. The rate and symptoms of such processes are influenced by a number of variables, including the properties of the material and the environmental factors which act upon it. In the model presented deterioration is shown as resulting form chemical processes (corrosion) acting in conjunction with mechanical stresses (both external and internal).

Grimm, Clayford T. "Water Permeance of Masonry Walls: A Review of the Literature." Edited by J.G. Borchelt. *Masonry: Materials, Properties and Performance; A Symposium* held December 9, 1980. American Society for Testing and Materials Special Technical Publication #778. Philadelphia: ASTM, 1982.

Technical literature review on the permeance of brick and concrete walls to wind-driven rain: design, movement, materials, sealants and repairs.

Handisyde, C.C. and B.A. Haseltine. *Brick and Brickwork.* London: Brick Development Association, n.d.

A general reference on the properties and uses of brick: appearance, durability, strength, water exclusion, fire resistance, sound and thermal insulation, manufacture, topology, walling, paving, mortar, ties, pointing and re-pointing, damp control, cracking, rendering, structural movement and safety, and maintaining appearance.

Hueck-Van Der Plas, Eleonora H. "Microbiological Deterioration of Porous Building Materials," *International Biodeterioration Bulletin*, No. 1 (1968), pp. 11-28.

A survey of technical literature on micro-biodeterioration of stone, brick, concrete and plaster. Table listing organisms, morphology and protective compounds.

Lauersdorf, Lynn R. and Albert W. Isberner. "Masonry: Preventative and Corrective Maintenance," *Construction Specifier*, Vol 42, No. 9 (September 1989), pp. 84-92.

This is a general review of the required maintenance to exterior masonry envelopes focusing on excess water, differential movement and the expansion and contraction units and a discussion of specific causes of deterioration in conjunction with proposed solutions.

Simpson, John W. and Peter J. Horrobin. *The Weathering and Performance of Building Materials*. New York: Wiley Interscience, 1970.

Basic information on what can and will go wrong with building materials, including brick and mortar.

Smith, Baird M. "Diagnosis of Nonstructural Problems in Historic Masonry Buildings." *Conservation of Historic Stone Buildings and Monuments.* Edited by N.S. Baer. Washington DC: National Academy Press, 1982.

This paper discusses the deterioration of stone and brick in historic structures caused by secondary sources like design, specification or material flaws.

Stambolov, T. and J.R.J. Van Asperen de Boer. *The Deterioration and Conservation of Porous Building Materials in Monuments: A Review of the Literature.* Third edition. ICOM 6th Triennial Meeting Supplement, Ottawa, September 1981. Rome: ICCROM, 1981.

Discussion of published contributions to the study of masonry deterioration and preservation since 1978.

Tomassetti, Albert A. "Problems and Cures in Masonry." American Society for Testing and Materials conference proceedings: *Masonry: Components to Assemblages* held December 5, 1989, Orlando, FL. (ASTM Special Technical Publication #1063). Philadelphia: ASTM, 1990.

This document provides a general review of problems in masonry construction including, but not limited to, efflorescence, blush, creep, staining, cleaning, lime deposit, metal corrosion, and mortar failure. Specific buildings are cited and illustrated as examples.

Volz, John R. "Brick Bibliography," *Association for Preservation Technology Bulletin*, Vol. 7, No. 4 (1975), pp. 38-49.

Compiled for the National Trust for Historic Preservation conference: Preservation of Ghost Towns and Mining Camps held in Flagstaff, AZ in 1975.

2. Deterioration Mechanisms

Army Engineers Experiment Waterways Station, Structures Lab. *Investigation of Deterioration of Brick in Navigation Lock Control House Structures, Tulsa District.* Vicksburg, MS: US Army Corps of Engineers, 1980.

The deterioration of brick at five house structures characterized by partial or complete exfoliation from moisture intrusion. Damaged and nondamaged samples were evaluated by physical testing and petrographic examination. Six model walls were coated with different protective coatings and observed for performance.

Brown, Maureen T. and Brick Institute of America. "Critical Review of Field Adapting ASTM E514 Water Permeability Test Method," American Society for Testing and Materials conference proceedings: *Masonry: Components to Assemblages* held December 5, 1989, Orlando, FL. (ASTM Special Technical Publication #1063). Philadelphia: ASTM, 1990.

This paper is an experimental investigation into a field adaptation of the ASTM lab test for permeability in brick masonry.

Collepardi, M. "Degradation and Restoration of Masonry Walls of Historic Buildings," *Materials and Structures*, Vol. 23, No. 134 (March 1990), pp. 81-102.

Collepardi, of the University of Ancona, Italy, has published a general review of the chemical deterioration mechanisms to brick, mortar and other masonry materials based upon the performance of the walls of fifty historic buildings. Conservation techniques and materials are discussed in terms of their compatibility to the original masonry.

Hoffmann, Dirk, and Konrad Niesel. "Moisture Movement in Brick." Felix, G. Editor. *Fifth International Congress on the Deterioration and Conservation of Stone.* Lausanne, 1985. Switzerland: Presses Polytechniques Romandes, Ecole Polytechnique Federale de Lausanne, 1985.

Hoffman, Dirk and Konrad Niesel. "Pore Characteristics and Moisture in Brick Masonry." *7th International Congress on Deterioration and Conservation of Stone*. Lisbon, Portugal, 15-18, June, 1992. Laboratorio Nacional de Engenharia Civil. pg. 735-743.

Kralj, B., G.N. Pande and J. Middleton. "On the Mechanics of Frost Damage to Brick Masonry," *Computers and Structures*, Vol. 41, No. 1 (1991), pp. 53-66.

This is a theoretical experiment from the University of Wales, Swansea, presenting a computer-calculated model for the assessment of frost damage to brick masonry. The model is applied to the problem of a partially saturated free-standing wall subjected to frost damage. Actual results obtained qualitatively agree with frost damage observed in the simulated tests.

Livingston, Richard A. "X-ray Analysis of Brick Cores from the Powell-Waller Smokehouse, Colonial Williamsburg," Conference proceedings: *Third North American Masonry Conference* held June 3-5, 1985, Arlington, TX.

A report upon the accuracy of the non-destructive measurement of salt and moisture by prompt gamma neutron method -- as compared to the destructive testing method of taking cores for more traditional instrumental analysis.

Robinson, Gilbert C. "Characterization of Bricks and their Resistance to Deterioration Mechanisms." *Conservation of Historic Stone Buildings and Monuments*. Edited by N.S. Baer. Washington DC: National Academy Press, 1982.

A concise discussion of the durability, susceptibility and rate of deterioration of brick and mortar systems -- from a combined stand-point of ceramic engineering and conservation science. Topics include: raw materials, shaping, firing, coloration, aging, water penetration, mortar bond, freeze-thaw conditions, salt and chemical attack, expansion, coating, design, material compatibility, cleaning and restoration.

Torraca, Giorgio. "Brick, Adobe, Stone, and Architectural Ceramics: Deterioration Processes and Conservation Practices," *Preservation and Conservation: Principles and Practice*. Edited by S. Timmons. Washington DC: The Preservation Press, 1976.

Wickersheimer, D.J. "Brick Expansion," *Forensic Engineering*, Vol. 2, No. 1-2 (1990), pp. 294-95.

This article reviews the unique moisture and temperature related expansion characteristics of fired clay brick and its potential deleterious effect on structures, regardless of meeting ASTM standards. Useful information if replacement bricks are a consideration.

3. Treatment and Repair

Ashurst, John and Nicola. *Practical Building Conservation: Vol. 2 Brick, Terra cotta and Earth.* Aldershot: Gower Technical Press, for English Heritage, 1988.

A comprehensive, practical text for the conservation of brick and other architectural clay materials. Includes discussions of: rising damp and damp-proofing, salt formation and damage, desalination techniques and analysis, mortar analysis and repointing, brick composition and classifications, and maintenance and preservation methods. Numerous diagrammatic illustrations

Bidwell, Timothy G. *The Conservation of Brick Buildings: The Repair, Alteration and Restoration of Old Brickwork.* London: Brick Development Association, 1977.

Guidelines for the assessment and conservation of brick buildings: survey, failures, water penetration, organic growth and appearance.

Bullock, Orin M. "Brick, Adobe, Stone, and Architectural Ceramics: Problems and Techniques of Preservation," *Preservation and Conservation: Principles and Practices.* Conference proceedings, North American International Regional Conference, Williamsburg held September 10-16, 1972. Washington DC: The Preservation Press, 1976.

A general survey of the preservation problems and techniques of bricks masonry unit systems.

Clifton, James R., Editor. *Cleaning Stone and Masonry - ASTM Special Technical Publications, No. 935*. Philadelphia: ASTM, 1986.

Nine papers cover various problems of cleaning stone and masonry buildings, both ordinary and historic. The papers are divided into four sections: selection of cleaning methods and materials; historic structures; case studies; determining the effects of cleaning.

Collier, Richard. "Guidelines for Restoring Brick Masonry," *Parks*, Vol. 8, No. 4 (1984), pp. 15-21.

A serious discussion of the hazards of surface blasting with specifics about replacements, rebuilding, repointing, mortar composition matching, cleaning, detergents, paint removal, stucco repair and replacement, painting and sealing.

Grimmer, Anne E. "Dangers of Abrasive Cleaning to Historic Buildings." *Preservation Brief No. 6*. Washington D.C.: Heritage Conservation and Recreation Service, 1979.

Brief explanation of abrasive cleaning methods, how they can be physically and aesthetically destructive and why they are generally not accepted as preservation treatments for being responsible of damage to building material. Alternative methods are mentioned, however, it would be impossible to state definitively which of these will be the most effective. There is no formula that will be suitable for all building surfaces and meantime, cleaning must be approached with caution through trail and error, "using the gentlest means possible."

Grimmer, Anne E. *Keeping it Clean: Removing Exterior Dirt, Paint, Stains, and Graffiti from Historic Masonry Buildings*. Washington D.C.: U.S. Government Printing Press, 1988.

A publication from the Preservation Assistance Division of the National Park Service addressing issues of restoring historic structures. Part I discusses factors to consider before cleaning including identification of both substrate and materials to be removed, preservation consultant and contractor, testing, scheduling, and hazards. Part II describes selection of the "gentlest means possible" for removing dirt, paint, stains, and bird droppings using water, chemical cleaners, or poultices. A full-page chart summarizes techniques.

Harity, Michael H. and Janet L. Hansen, edited by Lee S. Tabor. *Masonry Conservation Technology*. Charlestown: Massachusetts Masonry Institute, 1976.

A short history of masonry materials and techniques, brick manufacture and bonding patterns, mortar materials and joint work, deterioration, cleaning, paint removal, waterproofing and repairs.

Hutchins, Nigel. *Restoring Houses of Brick and Stone*. Scarborough: Van Nostrand Reinhold, 1982.

A practical guide to the repair and preservation of old stone and brick houses, covering all the relevant topics, form historical aspects to the inspection process, and the various intervention techniques. Individual chapter deal with interior finishes, chimney, fireplaces, and stoves, while others are devoted to period landscape and the conversion of non-domestic buildings. Recipes are provided for mixes, washes, and plaster. The basic questions on historic masonry building repair are answered.

Ireson, A.S. *Masonry Conservation and Restoration*. Painscastle: Attic Books, 1987.

A practical concise guide to masonry restoration including a bibliography and masonry glossary.

Johnson, Byron. "Towards a Decision-Making Strategy." *ASTM Special Technical Publications No. 971*. edited by J.T. Conway and J.C. Grogan. Philadelphia: ASTM, 1983.

The author proposes a decision chart for the use of building owners, designers and contractors to assist with the selection of an appropriate technique for cleaning masonry walls. The decision chart considers the nature of the masonry, the source of the soiling, and most importantly, the reason for the cleaning initiative. The decision chart is presented as a suggested approach and the author requests constructive criticism.

Jones, Gordon. "Brick Cleaning: The Pressure is on," *Construction Specifier*, Vol. 40, No. 5 (May 1987), pp. 133,135.

A discussion of the pros and cons of high-pressure water cleaning to bricks and mortar -- stressing the selection of appropriate cleaning processes and apparatus based on methodical test cleaning.

Lewin, Seymour Z. and Elizabeth J. Rock. "Chemical Considerations in the cleaning of Stone and Masonry." *The Conservation of Stone I: Proceedings of the International Symposium*. held June 19-21, 1975, Bologna. Edited by Raffaella Rossi-Manaresi. Bologna: Centro per la Conservazione delle Sculture all'aperto, 1976.

Determination of materials, staining agents and cleaning treatments. Recipes given.

National Park Service. *Masonry Products for Historic Buildings. Technical Preservation Database*. Washington DC: U.S. Government Printing Office, 1988.

A list of proprietary products used on the exterior of historic masonry buildings compiled by the Center For Architectural Conservation at Georgia Institute of Technology and based on MSDS. The listing-which is not comprehensive and will continue to be updated and expanded- contains ninety-nine entries, arranged alphabetically by product name, and intended to give as much information as possible on each product in order to aid the consumer in making informed preservation decisions. Individual treatment categories include: bonding agents, chemical cleaning products, consolidants, paint removers, water-repellant and waterproof coatings. Indexes by product name and product type.

Pepi, Raymond M. "Masonry Cleaning in Practice Today." *Preprints from Bronze and Masonry in the Park Environment. New York City, October 20-21, 1983.* New York, Center for Building Conservation, 1983, pp. 1-16.

Gives a summary of each of the most commonly employed masonry cleaning techniques and their suitability for monument and building conservation: chemical cleaning; chemical paint stripper; cold water soaking, misting, rinsing; steam and hot water; poultices; mechanical methods; protective coatings. Six references.

Powys, A.R. *Repair of Ancient Buildings*. London: Society for the Protection of Ancient Buildings, 1981.

Methods for repairing historic buildings. Included are masonry walls, foundation defects and treatment; surface decay of buildings; ancient timber roofs and roof coverings; church bells, window glazing, ceilings, wall paintings are also dealt with.

Prudon, Theodore. "Removing Stains from Masonry." *The Old- House Journal Compendium.* Woodstock: The Overlook Press, 1980, pp. 97-98.

The importance of selecting the appropriate solvent in cleaning stained masonry is stressed. Techniques for the removal of different stains (iron, lichens, copper, oil, asphalt and tar, manganese, vanadium), with the recipes of the various poultices are described.

Ritchie, Thomas. "Cleaning of Brickwork," *Canadian Building Digest.*, No. 4 (1978).

Discussion of using acid and alkali washes over sandblasting with specific information on the removal of metallic stains, paint, tar and plant growth.

Rossi-Manaresi, Raffaella and Giorgio Torraca. "The Treatment of Stone." *Proceedings of the Meeting of the joint Committee for the Conservation of Stone, Bologna. October 1-3, 1971.* Bologna: Centro per la conservazione delle sculture all'aperto, 1972.

Sixteen papers presented at the meeting. The main topics are cleaning and consolidation of stone masonry and objects, and protection of terra cotta facades.

Sowden, A.M. *The Maintenance of Brick and Stone Masonry Structures.* London: 1990.

A series of papers following maintenance of masonry from initial identification of defects and their diagnoses to treatment and monitoring cost efficiency. Limited to civil engineering structures.

Spry, Alan H. "Principles of Cleaning Masonry Buildings: A guide to assist in the cleaning of masonry buildings." *Technical Bulletin*, No. 3, 1982. Victoria: National Trust of Australia, 1982.

Reasons for cleaning buildings and monuments, nature of soiling and urban grime. Treatment of limestone, marble and render. A review of methods. Selection of treatment.

Thomas, James Cheston. "Restoring Brick and Stone: Some Do's and Don'ts, " *History News*, Vol. 30, No. 1 (January 1975). Reprinted by the American Association for State and Local History as Technical Leaflet #81.

Brick and stone restoration: identifying and treating deterioration, defining types of mortar joints and cleaning methods. Building Research Establishment. "Cleaning External Surfaces of Buildings." *BRE Digest*, n.280. London: Her Majesty's Stationery Office, re 1988.

Surface cleaning techniques are described: water washing, water lances, steam, chemical (acid and alkali), dry and wet grit blasting, mechanical, poultices and laser. Advice for the choice of the best technique are given according to the material and importance of the surface. Actions before and after cleaning are recommended.

Weber, Helmut and Klaus Zinsmeister. *Conservation of Natural Stone, Guidelines to Consolidation, Restoration and Preservation.* Germany: Expert-Vertag, 1990.

This book defines conservation technology as an area which comprises different disciplines in science and technology, including chemistry, mineralogy, physics, architecture etc. The text identifies those points of each discipline which are essential and vital to conceive a restoration strategy for historically valuable, architectural building stone. Discussions include both the classification, physical properties and deterioration of building stone and conservation techniques ranging from consolidation to cleaning.

Index

Appendix A: Test Data Tables

HAND MOULDED BRICK. INITIAL TEST

COLD WATER SUBMERSION				BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	2001.40	2104.30	4.89	2163.50	7.49	0.63
2	2003.40	2096.20	4.43	2157.10	7.13	0.60
3	2014.10	2077.70	3.06	2135.90	5.70	0.52
4	2009.80	2074.50	3.12	2135.80	5.90	0.51
5	1998.00	2091.20	4.46	2154.50	7.26	0.60
6	1984.00	2073.60	4.32	2135.30	7.09	0.59
MEAN			4.0458		6.7615	0.5770
STANDARD DEVIATION			0.7657		0.7601	0.0483
VARIENCE			0.5863		0.5778	0.0023

HAND MOULDED BRICK. ONE FACE REMOVED WITH GRINDER

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1978.80	2080.60	4.89	2144.20	7.71	0.62
2	1971.50	2063.10	4.44	2131.00	7.48	0.57
3	1992.30	2058.50	3.22	2120.90	6.06	0.51
4	2003.00	2070.30	3.25	2135.50	6.20	0.48
5	1983.00	2077.40	4.54	2144.20	7.52	0.59
6	1984.80	2076.20	4.40	2144.70	7.46	0.57
MEAN			4.1243		7.0734	0.5564
STANDARD DEVIATION			0.7116		0.7345	0.0510
VARIENCE			0.5064		0.5396	0.0026

HAND MOULDED BRICK, SANDBLASTED

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1937.00	2023.60	4.28	2083.85	7.05	0.59
2	1923.60	2013.20	4.45	2064.70	6.83	0.64
3	1962.50	2023.85	3.03	2076.80	5.50	0.54
4	1964.40	2031.90	3.32	2081.00	5.60	0.58
5	1939.30	2023.50	4.16	2082.60	6.88	0.59
6	1922.30	2016.20	4.66	2071.50	7.20	0.63
MEAN			3.9836		6.5118	0.5929
STANDARD DEVIATION			0.6535		0.7544	0.0360
VARIENCE			0.4271		0.5691	0.0013

HAND MOULDED BRICK, SANDBLASTED and TREATED WITH WATER REPELLANT

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1937.40	1959.60	1.13	2101.35	7.80	0.14
2	1924.50	1944.80	1.04	2083.80	7.64	0.13
3	1962.90	1988.15	1.27	2098.25	6.45	0.19
4	1965.00	1991.10	1.31	2104.00	6.61	0.19
5	1939.50	1970.40	1.57	2099.10	7.60	0.19
6	1923.00	1939.00	0.83	2087.30	7.87	0.10
MEAN			1.1918		7.3298	0.1558
STANDARD DEVIATION			0.2537		0.6303	0.0413
VARIENCE			0.0644		0.3973	0.0017

HAND MOULDED BRICK WATER ABSORBTION COMPARISON

	Initial Test	Grind one face	Sand Blasted	Water Repellant
24hr Soak % Water Absorbtion	4.05	4.12	3.98	1.19
5hr Boil % Water Absorbtion	6.76	7.07	6.51	7.33

MACHINE MOULDED BRICK INITIAL TEST

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1973.60	2109.40	6.44	2182.45	9.57	0.65
2	1987.50	2121.00	6.29	2195.60	9.48	0.64
3	1984.50	2122.50	6.50	2194.30	9.56	0.66
4	1968.10	2068.10	4.84	2137.45	7.92	0.59
5	1970.50	2068.60	4.74	2136.75	7.78	0.59
MEAN			5.7623		8.8624	0.6260
STANDARD DEVIATION			0.8924		0.9247	0.0331
VARIENCE			0.7964		0.8551	0.0011

MACHINE MOULDED BRICK. ONE FACE REMOVED WITH GRINDER

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1945.20	2072.40	6.14	2155.00	9.74	0.61
2	1957.20	2083.10	6.04	2171.80	9.88	0.59
3	1966.40	2095.50	6.16	2183.50	9.94	0.59
4	1943.30	2032.30	4.38	2121.50	8.40	0.50
5	1968.90	2060.30	4.44	2147.00	8.30	0.51
MEAN			5.4316		9.2509	0.5601
STANDARD DEVIATION			0.9359		0.8289	0.0498
VARIENCE			0.8759		0.6871	0.0025

MACHINE MOULDED BRICK, SANDBLASTED

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1891.60	2018.40	6.28	2105.10	10.14	0.59
2	1897.35	2018.30	5.99	2108.40	10.01	0.57
3	1939.10	2069.10	6.28	2157.20	10.11	0.60
4	1926.40	2016.90	4.49	2104.90	8.48	0.51
5	1944.60	2037.10	4.54	2120.00	8.27	0.53
MEAN			5.5171		9.4032	0.5595
STANDARD DEVIATION			0.9236		0.9410	0.0403
VARIENCE			0.8530		0.8855	0.0016

MACHINE MOULDED BRICK, SANDBLASTED and WATER REPELLANT

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1892.20	1941.00	2.51	2097.50	9.79	0.24
2	1898.00	1956.20	2.98	2105.70	9.86	0.28
3	1940.10	1996.75	2.84	2154.60	9.96	0.26
4	1927.00	1965.00	1.93	2103.50	8.39	0.22
5	1945.15	1985.55	2.03	2122.65	8.36	0.23
MEAN			2.4590		9.2720	0.2450
STANDARD DEVIATION			0.4659		0.8197	0.0267
VARIENCE			0.2171		0.6719	0.0007

MACHINE MOULDED BRICK WATER ABSORBTION COMPARISON

	Initial Weight	Grind one face	Sand Blasted	Water Repellant
24hr Soak % Water Absorbtion	5.76	5.43	5.51	2.45
5hr Boil % Water Absorbtion	8.86	9.25	9.40	9.27

EXTRUDED, CORED, WIRE CUT BRICK, INITIAL TEST

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1806.20	1906.20	5.25	1935.40	6.68	0.77
2	1799.20	1892.50	4.93	1918.60	6.22	0.78
3	1811.40	1910.10	5.17	1927.50	6.02	0.85
4	1802.50	1889.10	4.58	1915.40	5.89	0.77
5	1820.80	1912.60	4.80	1936.30	5.96	0.79
MEAN			4.9454		6.1563	0.7935
STANDARD DEVIATION			0.2700		0.3151	0.0333
VARIENCE			0.0729		0.0993	0.0011

EXTRUDED, CORED, WIRE CUT BRICK, ONE FACE REMOVED WITH GRINDER

COLD WATER SUBMERSION				BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	W'd	W's24	Absorbtion %	W'b5	Absorbtion %	Coefficient
1	1793.70	1889.00	5.04	1913.10	6.24	0.80
2	1779.30	1865.20	4.61	1888.50	5.78	0.79
3	1792.50	1884.20	4.87	1908.10	6.06	0.79
4	1781.50	1862.80	4.36	1886.60	5.57	0.77
5	1820.40	1903.80	4.38	1928.20	5.59	0.77
MEAN			4.6525		5.8487	0.7850
STANDARD DEVIATION			0.2996		0.2942	0.0112
VARIENCE			0.0898		0.0865	0.0001

EXTRUDED, CORED, WIRE CUT BRICK, SANDBLASTED

COLD WATER SUBMERSION				BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1739.35	1845.20	5.74	1865.15	6.74	0.84
2	1697.50	1785.90	4.95	1805.00	5.96	0.82
3	1715.40	1818.70	5.68	1837.10	6.62	0.85
4	1725.20	1816.75	5.04	1834.70	5.97	0.84
5	1750.00	1844.25	5.11	1863.00	6.07	0.83
MEAN			5.3032		6.2718	0.8365
STANDARD DEVIATION			0.3746		0.3817	0.0098
VARIENCE			0.1403		0.1457	0.0001

EXTRUDED, CORED, WIRE CUT BRICK, SANDBLASTED and WATER REPELLANT

COLD WATER SUBMERSION				BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1745.70	1808.50	3.47	1842.60	5.26	0.65
2	1697.50	1760.60	3.58	1788.60	5.09	0.69
3	1722.20	1788.00	3.68	1821.80	5.47	0.66
4	1732.30	1787.50	3.09	1816.70	4.65	0.65
5	1756.45	1816.80	3.32	1844.10	4.75	0.69
MEAN			3.4293		5.0436	0.6688
STANDARD DEVIATION			0.2327		0.3431	0.0204
VARIENCE			0.0542		0.1177	0.0004

UPSALA, NJ BRICK, INITIAL TEST

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1735.70	1832.00	5.26	1916.70	9.44	0.53
2	1711.40	1809.60	5.43	1897.50	9.81	0.53
3	1737.90	1892.20	8.15	1990.00	12.67	0.61
4	1780.50	2031.20	12.34	2051.40	13.21	0.93
5	1791.40	1900.40	5.74	2034.50	11.95	0.45
MEAN			7.3832		11.4148	0.6091
STANDARD DEVIATION			3.0106		1.6980	0.1861
VARIENCE			9.0636		2.8833	0.0346

UPSALA, NJ BRICK, ONE FACE REMOVED WITH GRINDER

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1714.50	1802.00	4.86	1920.00	10.70	0.43
2	1685.30	1769.70	4.77	1882.30	10.47	0.43
3	1697.50	1844.70	7.98	1975.20	14.06	0.53
4	1758.10	2006.00	12.36	2034.80	13.60	0.90
5	1740.40	1846.00	5.72	1992.80	12.67	0.42
MEAN			7.1366		12.2985	0.5397
STANDARD DEVIATION			3.1932		1.6453	0.2044
VARIENCE			10.1964		2.7071	0.0418

UPSALA, NJ BRICK, SANDBLASTED

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation Coefficient
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	
1	1613.75	1694.10	4.74	1792.70	9.98	0.45
2	1609.50	1693.35	4.95	1777.90	9.47	0.50
3	1584.00	1715.95	7.69	1816.80	12.81	0.57
4	1658.80	1930.80	14.09	1951.60	15.00	0.93
5	1597.00	1689.40	5.47	1807.05	11.62	0.44
MEAN			7.3882		11.7789	0.5765
STANDARD DEVIATION			3.9238		2.2384	0.2034
VARIENCE			15.3965		5.0103	0.0414

UPSALA, NJ BRICK, SANDBLASTED and WATER REPELLANT

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation Coefficient
No	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	
1	1613.60	1670.00	3.38	1796.70	10.19	0.31
2	1609.80	1659.80	3.01	1795.70	10.35	0.27
3	1584.20	1646.70	3.80	1825.65	13.23	0.26
4	1714.50	1838.10	6.72	1899.80	9.75	0.67
5	1596.70	1647.70	3.10	1809.80	11.77	0.24
MEAN			4.0009		11.0595	0.3484
STANDARD DEVIATION			1.5529		1.4285	0.1798
VARIENCE			2.4114		2.0406	0.0323

UPSALA, NJ BRICK   WATER ABSORBTION COMPARISON

	Initial Weight	Grind one face	Sand Blasted	Water Repellant
24hr. Soak % Water Absorbtion	7.38	7.14	7.39	4.00
5hr. Boil % Water Absorbtion	11.41	12.30	11.78	11.06

FROGGED BRICK INITIAL TEST

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1759.45	2075.60	15.23	2093.30	15.95	0.95
3	1735.20	2021.90	14.18	2058.10	15.69	0.89
4	1756.20	2044.55	14.10	2063.20	14.88	0.94
5	1724.70	2024.45	14.81	2040.35	15.47	0.95
MEAN			14.5803		15.4970	0.9309
STANDARD DEVIATION			0.5365		0.4555	0.0290
VARIENCE			0.2878		0.2075	0.0008

FROGGED BRICK, SANDBLASTED

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1731.30	2045.80	15.37	2065.20	16.17	0.94
3	1687.00	1969.70	14.35	1997.35	15.54	0.91
4	1684.70	1956.60	13.90	1980.40	14.93	0.92
5	1696.80	1987.50	14.63	2002.90	15.28	0.95
MEAN			14.5621		15.4800	0.9305
STANDARD DEVIATION			0.6187		0.5217	0.0183
VARIENCE			0.3828		0.2722	0.0003

FROGGED BRICK, SANBLASTED AND WATER REPELLANT

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1730.50	1947.70	11.15	1971.90	12.24	0.90
3	1687.00	1927.70	12.49	1955.30	13.72	0.90
4	1684.00	1912.50	11.95	1928.70	12.69	0.93
5	1696.10	1926.60	11.96	1939.10	12.53	0.95
MEAN			11.8874		12.7956	0.9198
STANDARD DEVIATION			0.5507		0.6443	0.0254
VARIENCE			0.3032		0.4152	0.0006

FROGGED BRICK WATER ABSORBTION COMPARISON

	Initial Weight	Sand Blasted	Water Repellant
24hr. Soak % Water Absorbtion	14.58	14.56	11.89
5hr. Boil % Water Absorbtion	15.50	15.48	12.80

FLUE BRICK. INITIAL TEST

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1878.20	2066.10	9.09	2154.45	12.82	0.68
3	1846.20	2037.40	9.38	2120.50	12.94	0.70
4	1911.50	2095.25	8.77	2183.50	12.46	0.68
5	1727.50	2003.40	13.77	2022.50	14.59	0.94
MEAN			10.2551		13.2002	0.7470
STANDARD DEVIATION			2.3577		0.9461	0.1258
VARIENCE			5.5589		0.8951	0.0158

FLUE BRICK, SANDBLASTED

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1740.70	1927.20	9.68	2020.00	13.83	0.67
2	1789.45	1982.70	9.75	2064.80	13.34	0.70
3	1812.45	2010.80	9.86	2105.20	13.91	0.68
4	1714.60	1954.80	12.29	1979.10	13.36	0.91
MEAN			10.3940		13.6082	0.7388
STANDARD DEVIATION			1.2648		0.3001	0.1138
VARIENCE			1.5998		0.0901	0.0129

FLUE BRICK SANBLASTED AND WATER REPELLANT

	COLD WATER SUBMERSION			BOILING TEST		
	Initial Weight	24 Hour		5 Hour		Saturation
No.	Wd	Ws24	Absorbtion %	Wb5	Absorbtion %	Coefficient
1	1738.20	1818.00	4.39	2016.20	13.79	0.29
2	1786.00	1857.50	3.85	2063.20	13.44	0.26
3	1809 10	1917.70	5.66	2101.30	13.91	0.37
4	1655.00	1860.70	11.05	1962.00	15.65	0.67
MEAN			6.2392		14.1942	0.3967
STANDARD DEVIATION			3.2993		0.9891	0.1885
VARIENCE			10.8857		0.9784	0.0355

FLUE BRICK WATER ABSORBTION COMPARISON

	Initial Weight	Sand Blasted	Water Repellant
24hr. Soak % Water Absorbtion	10.26	10.39	6.24
5hr. Boil % Water Absorbtion	13.20	13.61	14.19

HAND MOULDED BRICK: COMPARISON B/T INITIAL TEST AND SANDBLASTED

24 HOUR SOAK

t-Test Two-Sample Assuming Unequal Variances	Initial Test Variable 1	Sandblasted Variable 2
Mean	4.05	3.98
Variance	0.59	0.43
Observations	6.00	6.00
Pearson Correlation	0.89	
Pooled Variance	0.51	
df	10.00	
t	0.15	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.81	
P(T<=t) two-tail	0.88	
t Critical two-tail	2.23	

F-Test: Two-Sample for Variances	Variable 1	Variable 2
Mean	4.05	3.98
Variance	0.59	0.43
Observations	6.00	6.00
df	5.00	5.00
F	1.37	
P(F<=f) one-tail	0.37	
F Critical one-tail	5.05	

5 HOUR BOIL

t-Test Two-Sample Assuming Unequal Variances	Initial Test Variable 1	Sandblasted Variable 2
Mean	6.76	6.51
Variance	0.58	0.57
Observations	6.00	6.00
Pearson Correlation	0.97	
Pooled Variance	0.57	
df	10.00	
t	0.57	
P(T<=t) one-tail	0.29	
t Critical one-tail	1.81	
P(T<=t) two-tail	0.58	
t Critical two-tail	2.23	

F-Test: Two-Sample for Variances	Variable 1	Variable 2
Mean	6.76	6.51
Variance	0.58	0.57
Observations	6.00	6.00
df	5.00	5.00
F	1.02	
P(F<=f) one-tail	0.49	
F Critical one-tail	5.05	

HAND MOULDED BRICK: COMPARISON B/T SANDBLASTED & WATER REPELLANT

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	3.98	1.19
Variance	0.43	0.06
Observations	6.00	6.00
Pearson Correlation	-0.51	
Pooled Variance	0.25	
df	6.00	
t	9.75	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.94	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.45	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	6.51	7.33
Variance	0.57	0.40
Observations	6.00	6.00
df	5.00	5.00
F	1.43	
P(F<=f) one-tail	0.35	
F Critical one-tail	5.05	

5 HOUR BOIL

t-Test Two Sample Assuming Equal Variance

	Variable 1	Variable 2
Mean	3.98	1.19
Variance	0.43	0.06
Observations	6.00	6.00
Pooled Variance	0.25	
Hypothesized Mean Difference	0.00	
df	10.00	
t	9.75	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.81	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.23	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	6.51	7.33
Variance	0.57	0.40
Observations	6.00	6.00
df	5.00	5.00
F	1.43	
P(F<=f) one-tail	0.35	
F Critical one-tail	5.05	

MACHINE MOULDED BRICK: COMPARISON B/T INITIAL TEST AND SANDBLASTED

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	5.76	5.52
Variance	0.80	0.85
Observations	5.00	5.00
Pearson Correlation	1.00	
Pooled Variance	0.82	
df	8.00	
t	0.43	
P(T t) one-tail	0.34	
t Critical one-tail	1.86	
P(T t) two-tail	0.68	
t Critical two-tail	2.31	

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	5.76	5.52
Variance	0.80	0.85
Observations	5.00	5.00
df	4.00	4.00
F	1.07	
P(F f) one-tail	0.47	
F Critical one-tail	4.11	

5 HOUR BOIL

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	8.86	9.40
Variance	0.86	0.89
Observations	5.00	5.00
Pearson Correlation	1.00	
Pooled Variance	0.87	
df	8.00	
t	-0.92	
P(T< t) one-tail	0.19	
t Critical one-tail	1.86	
P(T t) two-tail	0.39	
t Critical two-tail	2.31	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	8.86	9.40
Variance	0.86	0.89
Observations	5.00	5.00
df	4.00	4.00
F	1.04	
P(F<=f) one-tail	0.49	
F Critical one-tail	4.11	

MACHINE MOULDED BRICK: COMPARISON B/T SANDBLASTED & WATER REPELLANT

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	5.52	2.46
Variance	0.85	0.22
Observations	5.00	5.00
Pearson Correlation	0.89	
Pooled Variance	0.54	
df	6.00	
t	6.61	
P(T t) one-tail	0.00	
t Critical one-tail	1.94	
P(T t) two-tail	0.00	
t Critical two-tail	2.45	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	5.52	2.46
Variance	0.85	0.22
Observations	5.00	5.00
df	4.00	4.00
F	3.93	
P(F f) one-tail	0.11	
F Critical one-tail	6.39	

5 HOUR BOIL

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	9.40	9.27
Variance	0.89	0.67
Observations	5.00	5.00
Pearson Correlation	0.99	
Pooled Variance	0.78	
df	8.00	
t	0.24	
P(T< t) one-tail	0.41	
t Critical one-tail	1.86	
P(T< t) two-tail	0.82	
t Critical two-tail	2.31	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	9.40	9.27
Variance	0.89	0.67
Observations	5.00	5.00
df	4.00	4.00
F	1.32	
P(F f) one-tail	0.40	
F Critical one-tail	6.39	

EXTRUDED BRICK: COMPARISON B/T INITIAL TEST AND SANDBLASTED

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	4.95	5.30
Variance	0.07	0.14
Observations	5.00	5.00
Pearson Correlation	0.85	
Pooled Variance	0.11	
df	7.00	
t	-1.73	
P(T<=t) one-tail	0.06	
t Critical one-tail	1.89	
P(T<=t) two-tail	0.13	
t Critical two-tail	2.36	

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	4.95	5.30
Variance	0.07	0.14
Observations	5.00	5.00
df	4.00	4.00
F	1.93	
P(F<=f) one-tail	0.27	
F Critical one-tail	4.11	

5 HOUR BOIL

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	6.16	6.27
Variance	0.10	0.15
Observations	5.00	5.00
Pearson Correlation	0.62	
Pooled Variance	0.12	
df	8.00	
t	-0.52	
P(T<=t) one-tail	0.31	
t Critical one-tail	1.86	
P(T<=t) two-tail	0.62	
t Critical two-tail	2.31	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	6.16	6.27
Variance	0.10	0.15
Observations	5.00	5.00
df	4.00	4.00
F	1.47	
P(F<=f) one-tail	0.36	
F Critical one-tail	4.11	

EXTRUDED BRICK: COMPARISON B/T SANDBLASTED & WATER REPELLANT

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	5.30	3.43
Variance	0.14	0.05
Observations	5.00	5.00
Pearson Correlation	0.49	
Pooled Variance	0.10	
df	7.00	
t	9.50	
P(T t) one-tail	0.00	
t Critical one-tail	1.89	
P(T t) two-tail	0.00	
t Critical two-tail	2.36	

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	5.30	3.43
Variance	0.14	0.05
Observations	5.00	5.00
df	4.00	4.00
F	2.59	
P(F f) one-tail	0.19	
F Critical one-tail	6.39	

5 HOUR BOIL

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	6.27	5.04
Variance	0.15	0.12
Observations	5.00	5.00
Pearson Correlation	0.79	
Pooled Variance	0.13	
df	8.00	
t	5.35	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.86	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.31	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	6.27	5.04
Variance	0.15	0.12
Observations	5.00	5.00
df	4.00	4.00
F	1.24	
P(F<=f) one-tail	0.42	
F Critical one-tail	6.39	

UPSALA BRICK: COMPARISON B/T INITIAL TEST AND SANDBLASTED

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	7.38	7.39
Variance	9.06	15.40
Observations	5.00	5.00
Pearson Correlation	0.99	
Pooled Variance	12.23	
df	7.00	
t	-0.00	
P(T<=t) one-tail	0.50	
t Critical one-tail	1.89	
P(T<=t) two-tail	1.00	
t Critical two-tail	2.36	

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	7.38	7.39
Variance	9.06	15.40
Observations	5.00	5.00
df	4.00	4.00
F	1.70	
P(F<=f) one-tail	0.31	
F Critical one-tail	4.11	

5 HOUR BOIL

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	11.41	11.78
Variance	2.88	5.01
Observations	5.00	5.00
Pearson Correlation	0.94	
Pooled Variance	3.95	
df	7.00	
t	-0.29	
P(T<=t) one-tail	0.39	
t Critical one-tail	1.89	
P(T<=t) two-tail	0.78	
t Critical two-tail	2.36	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	11.41	11.78
Variance	2.88	5.01
Observations	5.00	5.00
df	4.00	4.00
F	1.74	
P(F<=f) one-tail	0.30	
F Critical one-tail	4.11	

UPSALA BRICK: COMPARISON B/T SANDBLASTED & WATER REPELLANT

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	7.39	4.00
Variance	15.40	2.41
Observations	5.00	5.00
Pearson Correlation	0.98	
Pooled Variance	8.90	
df	5.00	
t	1.79	
P(T<=t) one-tail	0.07	
t Critical one-tail	2.02	
P(T<=t) two-tail	0.13	
t Critical two-tail	2.57	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	7.39	4.00
Variance	15.40	2.41
Observations	5.00	5.00
df	4.00	4.00
F	6.38	
P(F<=f) one-tail	0.05	
F Critical one-tail	6.39	

5 HOUR BOIL

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	11.78	11.06
Variance	5.01	2.04
Observations	5.00	5.00
Pearson Correlation	0.09	
Pooled Variance	3.53	
df	7.00	
t	0.61	
P(T<=t) one-tail	0.28	
t Critical one-tail	1.89	
P(T<=t) two-tail	0.56	
t Critical two-tail	2.36	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	11.78	11.06
Variance	5.01	2.04
Observations	5.00	5.00
df	4.00	4.00
F	2.46	
P(F<=f) one-tail	0.20	
F Critical one-tail	6.39	

FROGGED BRICK: COMPARISON B/T INITIAL TEST AND SANDBLASTED

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	14.58	14.56
Variance	0.22	0.38
Observations	5.00	4.00
Pearson Correlation	NA	
Pooled Variance	0.29	
df	5.00	
t	0.05	
P(T<=t) one-tail	0.48	
t Critical one-tail	2.02	
P(T<=t) two-tail	0.96	
t Critical two-tail	2.57	

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	14.58	14.56
Variance	0.22	0.38
Observations	5.00	4.00
df	4.00	3.00
F	1.77	
P(F<=f) one-tail	0.33	
F Critical one-tail	5.34	

5 HOUR BOIL

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	15.50	15.48
Variance	0.16	0.27
Observations	5.00	4.00
Pearson Correlation	NA	
Pooled Variance	0.21	
df	6.00	
t	0.05	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.94	
P(T<=t) two-tail	0.96	
t Critical two-tail	2.45	

F-Test: Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	15.50	15.48
Variance	0.16	0.27
Observations	5.00	4.00
df	4.00	3.00
F	1.75	
P(F<=f) one-tail	0.34	
F Critical one-tail	5.34	

FROGGED BRICK: COMPARISON B/T SANDBLASTED & WATER REPELLANT

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	14.56	11.89
Variance	0.38	0.30
Observations	4.00	4.00
Pearson Correlation	-0.74	
Pooled Variance	0.34	
df	6.00	
t	6.46	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.94	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.45	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	14.56	11.89
Variance	0.38	0.30
Observations	4.00	4.00
df	3.00	3.00
F	1.26	
P(F<=f) one-tail	0.43	
F Critical one-tail	9.28	

5 HOUR BOIL

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	15.48	12.80
Variance	0.27	0.42
Observations	4.00	4.00
Pearson Correlation	-0.21	
Pooled Variance	0.34	
df	6.00	
t	6.48	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.94	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.45	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	15.48	12.80
Variance	0.27	0.42
Observations	4.00	4.00
df	3.00	3.00
F	1.53	
P(F<=f) one-tail	0.37	
F Critical one-tail	5.39	

FLUE BRICK: COMPARISON B/T INITIAL TEST AND SANDBLASTED

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	10.26	10.39
Variance	5.56	1.60
Observations	4.00	4.00
Pearson Correlation	0.99	
Pooled Variance	3.58	
df	5.00	
t	-0.10	
P(T<=t) one-tail	0.46	
t Critical one-tail	2.02	
P(T<=t) two-tail	0.92	
t Critical two-tail	2.57	

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	10.26	10.39
Variance	5.56	1.60
Observations	4.00	4.00
df	3.00	3.00
F	3.47	
P(F<=f) one-tail	0.17	
F Critical one-tail	9.28	

5 HOUR BOIL

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	13.20	13.61
Variance	0.90	0.09
Observations	4.00	4.00
Pearson Correlation	-0.67	
Pooled Variance	0.49	
df	4.00	
t	-0.82	
P(T<=t) one-tail	0.23	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.46	
t Critical two-tail	2.78	

F-Test: Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	13.20	13.61
Variance	0.90	0.09
Observations	4.00	4.00
df	3.00	3.00
F	9.94	
P(F<=f) one-tail	0.05	
F Critical one-tail	9.28	

FLUE BRICK: COMPARISON B/T SANDBLASTED & WATER REPELLANT

24 HOUR SOAK

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	10.39	6.24
Variance	1.60	10.89
Observations	4.00	4.00
Pearson Correlation	0.98	
Pooled Variance	6.24	
df	4.00	
t	2.35	
P(T<=t) one-tail	0.04	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.08	
t Critical two-tail	2.78	

F-Test Two-Sample for Variances

	Variable 1	Variable 2
Mean	10.39	6.24
Variance	1.60	10.89
Observations	4.00	4.00
df	3.00	3.00
F	6.80	
P(F<=f) one-tail	0.07	
F Critical one-tail	5.39	

5 HOUR BOIL

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	13.61	13.61
Variance	0.09	0.09
Observations	4.00	4.00
Pearson Correlation	1.00	
Pooled Variance	0.09	
df	6.00	
t	0.00	
P(T<=t) one-tail	0.50	
t Critical one-tail	1.94	
P(T<=t) two-tail	1.00	
t Critical two-tail	2.45	

F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	13.61	14.19
Variance	0.09	0.98
Observations	4.00	4.00
df	3.00	3.00
F	10.86	
P(F<=f) one-tail	0.04	
F Critical one-tail	5.39	

Appendix B: ASTM C67-89a

Designation: C 67 - 89a

American Association State Highway and Transportation
Officials Standard
AASHTO No.: T 32-70

Standard Test Methods of Sampling and Testing Brick and Structural Clay Tile[1]

This standard is issued under the fixed designation C 67; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 These test methods cover procedures for the sampling and testing of brick and structural clay tile. Although not necessarily applicable to all types of units, tests include modulus of rupture, compressive strength, absorption, saturation coefficient, effect of freezing and thawing, efflorescence, initial rate of absorption and determination of weight, size, warpage, length change, and void area. (Additional methods of test pertinent to ceramic glazed facing tile are included in Specification C 126.)

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 43 Definitions of Terms Relating to Structural Clay Products[2]

C 126 Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units[2]

C 150 Specification for Portland Cement[3]

E 4 Practices for Load Verification of Testing Machines[4]

E 6 Definitions of Terms Relating to Methods of Mechanical Testing[4]

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions E 6 and C 43 shall be considered as applying to the terms used in these methods.

4. Sampling

4.1 *Selection of Test Specimens*—For the purpose of these tests, full-size brick, tile, or solid masonry units shall be selected by the purchaser or by his authorized representative. Specimens shall be representative of the whole lot of units from which they are selected and shall include specimens representative of the complete range of colors, textures and sizes in the shipment.

4.2 *Number of Specimens:*

4.2.1 *Brick*—For the modulus of rupture, compressive strength and absorption determinations, at least ten brick shall be selected from each lot of 250 000 brick or fraction thereof. For larger lots, five individual brick shall be selected from each 500 000 brick or fraction thereof contained in the lot. In no case shall less than ten brick be taken. Additional specimens may be taken at the discretion of the purchaser.

4.2.2 *Structural Clay Tile*—For the weight determination and for compressive strength and absorption tests, at least five tile shall be selected from each lot of 250 tons (226.8 Mg) or fraction thereof. For larger lots, five additional specimens shall be tested for each 500 tons (453.6 Mg) or fraction thereof. In no case shall less than five tile be taken. Additional specimens may be taken at the discretion of the purchaser.

4.3 *Identification*—Each specimen shall be marked so that it may be identified at any time. Markings shall cover not more than 5 % of the superficial area of the specimen.

4.4 *Weight Determination:*

4.4.1 *Drying*—Dry the test specimens in a ventilated oven at 230 to 239°F (110 to 115°C) for not less than 24 h and until two successive weighings at intervals of 2 h show an increment of loss not greater than 0.2 % of the last previously determined weight of the specimen.

4.4.2 *Cooling*—After drying, cool the specimens in a drying room maintained at a temperature of 75 ± 15°F (24 ± 8°C), with a relative humidity between 30 and 70 %. Store the units free from drafts, unstacked, with separate placement, for a period of at least 4 h. Do not use specimens noticeably warm to the touch for any test requiring dry units.

4.4.2.1 An alternative method of cooling the specimens to approximate room temperature may be used as follows: Store units, unstacked, with separate placement, in a ventilated room for a period of 4 h, with a current of air from an electric fan passing over them for a period of at least 2 h.

4.4.3 *Calculations and Report:*

4.4.3.1 Calculate the weight per unit area of a specimen by dividing the total weight in pounds by the average area in square feet of the two faces of the unit as normally laid in a wall.

4.4.3.2 Report results separately for each unit with the average for five units or more.

4.5 *Removal of Silicone Coatings from Brick Units*—The silicone coatings intended to be removed by this process are any of the various polymeric organic silicone compounds used for water-resistant coatings of brick units. Heat the

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[1] These methods are under the jurisdiction of Committee C-15 on Manufactured Masonry Units and is the direct responsibility of Subcommittee C15.02 on Clay Brick and Structural Clay Tile.

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[2] *Annual Book of ASTM Standards*, Vol 04.05.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

brick at 950 ± 50°F (510 ± 10°C) in an oxidizing atmosphere a period of not less than 3 h. The rate of heating and oling shall not exceed 300°F (149°C) per h.

5. Modulus of Rupture (Flexure Test)

5.1 *Test Specimens*—The test specimens shall consist of whole dry full-size units (see 4.4.1). Five such specimens shall be tested.

5.2 *Procedure:*

5.2.1 Support the test specimen flatwise unless specified and reported otherwise (that is, apply the load in the direction of the depth of the unit) on a span approximately 1 in. (25.4 mm) less than the basic unit length and loaded at midspan. If the specimens have recesses (panels or depressions) place them so that such recesses are on the compression side. Apply the load to the upper surface of the specimen through a steel bearing plate ¼ in. (6.35 mm) in thickness and 1½ in. (38.10 mm) in width and of a length at least equal to the width of the specimen.

5.2.2 Make sure the supports for the test specimen are free to rotate in the longitudinal and transverse directions of the test specimen and adjust them so that they will exert no force in these directions.

5.2.3 *Speed of Testing*—The rate of loading shall not exceed 2000 lbf (8896 N)/min. but this requirement may be considered as being met if the speed of the moving head of the testing machine immediately prior to application of the load is not more than 0.05 in. (1.27 mm)/min.

5.3 *Calculation and Report:*

.3.1 Calculate the modulus of rupture of each specimen as follows:

$$\text{Modulus of rupture, } S = 3\,Wl/2\,bd^2$$

where:

S = stress in specimen at midspan, lb/in.^{2} (or kg/cm^2) or (Pa·10^4),

W = maximum load indicated by the testing machine, lbf, (or kgf) (or N),

l = distance between the supports, in., (or mm),

b = average overall width, face to face, of the specimen, in., (or mm), and

d = average overall depth, bed surface to bed surface, of the specimen, in. (or mm).

5.3.2 Report the average of the modulus of rupture determinations of all the specimens tested as the modulus of rupture of the lot.

6. Compressive Strength

6.1 *Test Specimens:*

6.1.1 *Brick*—The test specimens shall consist of dry half brick (see 4.4.1), the full height and width of the unit, with a length equal to one half the full length of the unit ±1 in. (25.4 mm), except as described below. If the test specimen, described above, exceeds the testing machine capacity, the test specimens shall consist of dry pieces of brick, the full height and width of the unit, with a length not less than one rter of the full length of the unit, and with a gross oss-sectional area perpendicular to bearing not less than 14 in.^{2} (90.3 cm^2). Test specimens shall be obtained by any method that will produce, without shattering or cracking, a specimen with approximately plane and parallel ends. Five specimens shall be tested.

6.1.2 *Structural Clay Tile*—Test five dry tile specimens in a bearing bed length equal to the width ± 1 in. (25.4 mm); or test full-size units.

6.2 *Capping Test Specimens:*

6.2.1 All specimens shall be dry and cool within the meaning of 4.4.1 and 4.4.2 before any portion of the capping procedure is carried out.

6.2.2 If the surface which will become bearing surfaces during the compression test are recessed or paneled, fill the depressions with a mortar composed of 1 part by weight of quick-hardening cement conforming to the requirements for Type III cement of Specification C 150, and 2 parts by weight of sand. Age the specimens at least 48 h before capping them. Where the recess exceeds ½ in. (12.7 mm), use a brick or tile slab section or metal plate as a core fill. Cap the test specimens using one of the two procedures described in 6.2.3 and 6.2.4.

6.2.3 *Gypsum Capping*—Coat the two opposite bearing surfaces of each specimen with shellac and allow to dry thoroughly. Bed one of the dry shellacked surfaces of the specimen in a thin coat of neat paste of calcined gypsum (plaster of paris) that has been spread on an oiled nonabsorbent plate, such as glass or machined metal. The casting surface plate shall be plane within 0.003 in. (0.076 mm) in 16 in. (406.4 mm) and sufficiently rigid; and so supported that it will not be measurably deflected during the capping operation. Lightly coat it with oil or other suitable material. Repeat this procedure with the other shellacked surface. Take care that the opposite bearing surfaces so formed will be approximately parallel and perpendicular to the vertical axis of the specimen and the thickness of the caps will be approximately the same and not exceeding ⅛ in. (3.18 mm). Age the caps at least 24 h before testing the specimens.

NOTE 1—A rapid-setting industrial type gypsum, such as Hydrocal or Hydrostone, is frequently used for capping.

6.2.4 *Sulfur-Filler Capping*—Use a mixture containing 40 to 60 weight % sulfur, the remainder being ground fire clay or other suitable inert material passing a No. 100 (150-µm) sieve with or without plasticizer. The casting surface plate requirements shall be as described in 6.2.3. Place four 1-in. (25.4-mm) square steel bars on the surface plate to form a rectangular mold approximately ½ in. (12.7 mm) greater in either inside dimension than the specimen. Heat the sulfur mixture in a thermostatically controlled heating pot to a temperature sufficient to maintain fluidity for a reasonable period of time after contact with the surface being capped. Take care to prevent overheating, and stir the liquid in the pot just before use. Fill the mold to a depth of ¼ in. (6.35 mm) with molten sulfur material. Place the surface of the unit to be capped quickly in the liquid, and hold the specimen so that its vertical axis is at right angles to the capping surface. The thickness of the caps shall be approximately the same. Allow the unit to remain undisturbed until solidification is complete. Allow the caps to cool for a minimum of 2 h before testing the specimens.

6.3 *Procedure:*

6.3.1 Test brick specimens flatwise (that is, the load shall be applied in the direction of the depth of the brick). Test

structural clay tile specimens in a position such that the load is applied in the same direction as in service. Center the specimens under the spherical upper bearing within 1/16 in. (1.59 mm).

6.3.2 The testing machine shall conform to the requirements of Methods E 4.

6.3.3 The upper bearing shall be a spherically seated, hardened metal block firmly attached at the center of the upper head of the machine. The center of the sphere shall lie at the center of the surface of the block in contact with the specimen. The block shall be closely held in its spherical seat, but shall be free to turn in any direction, and its perimeter shall have at least 1/4 in. (6.35 mm) clearance from the head to allow for specimens whose bearing surfaces are not exactly parallel. The diameter of the bearing surface shall be at least 5 in. (127.00 mm). Use a hardened metal bearing block beneath the specimen to minimize wear of the lower platen of the machine. The bearing block surfaces intended for contact with the specimen should have a hardness not less than HRC60 (HB 620). These surfaces shall not depart from plane surfaces by more than 0.001 in. (0.03 mm). When the bearing area of the spherical bearing block is not sufficient to cover the area of the specimen, place a steel plate with surfaces machined to true planes within ± 0.001 in. (0.03 mm), and with a thickness equal to at least one third of the distance from the edge of the spherical bearing to the most distant corner between the spherical bearing block and the capped specimen.

6.3.4 *Speed of Testing*—Apply the load, up to one half of the expected maximum load, at any convenient rate, after which, adjust the controls of the machine so that the remaining load is applied at a uniform rate in not less than 1 nor more than 2 min.

6.4 *Calculation and Report:*

6.4.1 Calculate the compressive strength of each specimen as follows:

$$\text{Compressive strength, } C = W/A$$

where:

C = compressive strength of the specimen, lb/in.^{2} (or kg/cm^2) (or Pa·10^4)

W = maximum load, lbf, (or kgf) (or N), indicated by the testing machine, and

A = average of the gross areas of the upper and lower bearing surfaces of the specimen, in.^{2} (or cm^2).

NOTE 2—When compressive strength is to be based on net area (example: clay floor tile), substitute for A in the above formula the net area, in in.^{2} (or cm^2), of the fired clay in the section of minimum area perpendicular to the direction of the load.

7. Absorption

7.1 *Accuracy of Weighings:*

7.1.1 *Brick*—The scale or balance used shall have a capacity of not less than 2000 g, and shall be sensitive to 0.5 g.

7.1.2 *Tile*—The balance used shall be sensitive to within 0.2 % of the weight of the smallest specimen tested.

7.2 *Test Specimens:*

7.2.1 *Brick*—The test specimens shall consist of half brick conforming to the requirements of 6.1.1. Five specimens shall be tested.

7.2.2 *Tile*—The specimens for the absorption test shall consist of five tile or three representative pieces from each of these five tile. If small pieces are used, take two from the shell and one from an interior web, the weight of each piece being not less than 227 g. The specimens shall have had their rough edges or loose particles ground off and, if taken from tile that have been subjected to compressive strength tests, specimens shall be free of cracks due to failure in compression.

7.3 *5-h and 24-h Submersion Tests:*

7.3.1 *Procedure:*

7.3.1.1 Dry and cool the test specimens in accordance with 4.4.1 and 4.4.2 and weigh each one.

7.3.1.2 *Saturation*—Submerge the dry, cooled specimen, without preliminary partial immersion, in clean water (soft, distilled or rain water) at 60 to 86°F (15.5 to 30°C) for the specified time. Remove the specimen, wipe off the surface water with a damp cloth and weigh the specimen. Complete weighing of each specimen within 5 min after removing the specimen from the bath.

7.3.2 *Calculation and Report:*

7.3.2.1 Calculate the absorption of each specimen as follows:

$$\text{Absorption, \%} = 100(W_s - W_d)/W_d$$

where:

W_d = dry weight of the specimen, and

W_s = saturated weight of the specimen after submersion in cold water.

7.3.2.2 Report the average absorption of all the specimens tested as the absorption of the lot.

7.4 *1-h, 2-h, and 5-h Boiling Tests:*

7.4.1 *Test Specimens*—The test specimens shall be the same five specimens used in the 5-h or 24-h cold-water submersion test where required and shall be used in the state of saturation existing at the completion of that test.

7.4.2 *Procedure:*

7.4.2.1 Return the specimen that has been subjected to the cold-water submersion to the bath, and subject it to the boiling test as described in 7.4.2.2.

7.4.2.2 Submerge the specimen in clean water (soft, distilled or rain water) at 60 to 86°F (15.5 to 30°C) in such a manner that water can circulate freely on all sides of the specimen. Heat the water to boiling, within 1 h, boil continuously for specified time, and then allow to cool to 60 to 86°F (15.5 to 30°C) by natural loss of heat. Remove the specimen, wipe off the surface water with a damp cloth, and weigh the specimen. Complete weighing of each specimen within 5 min after removing the specimen from the bath.

7.4.2.3 If the tank is equipped with a drain so that water at 60 to 86°F (15.5 to 30°C) can be passed through the tank continuously and at such a rate that a complete change of water takes place in not more than 2 min, make weighings at the end of 1 h.

7.4.3 *Calculation and Report:*

7.4.3.1 Calculate the absorption of each specimen as follows:

$$\text{Absorption, \%} = 100(W_b - W_d)/W_d$$

where:

W_d = dry weight of the specimen, and

W_b = saturated weight of the specimen after submersion in boiling water.

7.4.3.2 Report the average absorption of all the specimens tested as the absorption of the lot.

7.4.4 *Saturation Coefficient: Calculate the saturation coefficient of each specimen as follows:*

$$\text{Saturation coefficient} = W_{s2} - W_d / W_{b5} - W_d$$

where:

W_d = dry weight of the specimen,
W_{s2} = saturated weight of the specimen after 24-h submersion in cold water, and
W_{b5} = saturated weight of the specimen after 5-h submersion in boiling water.

8. Freezing and Thawing

8.1 *Apparatus:*

8.1.1 *Compressor, Freezing Chamber, and Circulator* of such design and capacity that the temperature of the air in the freezing chamber will not exceed 16°F (−9°C) 1 h after introducing the maximum charge of units, initially at a temperature not exceeding 90°F (32°C).

8.1.2 *Trays and Containers*, shallow, metal, having an inside depth of 1½ ± ½ in. (38.1 ± 12.7 mm), and of suitable strength and size so that the tray with a charge of frozen units can be removed from the freezing chamber by one man.

8.1.3 *Balance*, having a capacity of not less than 2000 g and sensitive to 0.5 g.

8.1.4 *Drying Oven* that provides a free circulation of air through the oven and is capable of maintaining a temperature between 230 and 239°F (110 and 115°C).

8.1.5 *Thawing Tank* of such dimensions as to permit complete submersion of the specimens in their trays. Adequate means shall be provided so that the water in the tank may be kept at a temperature of 75 ± 10°F (24 ± 5.5°C).

8.1.6 *Drying Room*, maintained at a temperature of 75 ± 15°F (24 ± 8°C), with a relative humidity between 30 and 70 %, and free from drafts.

8.2 *Test Specimens:*

8.2.1 *Brick*—The test specimens shall consist of half brick with approximately plane and parallel ends. If necessary, the rough ends may be smoothed by trimming off a thin section with a masonry saw. The specimens shall be free from shattering or unsoundness, visually observed, resulting from the flexure or from the absorption tests. Additionally, prepare specimens by removing all loosely adhering particles, sand or edge shards from the surface or cores. Test five specimens.

8.2.2 *Structural Clay Tile*—The test specimens shall consist of five tile or of a cell not less than 4 in. (101.6 mm) in length sawed from each of the five tile.

8.3 *Procedure:*

8.3.1 Dry and cool the test specimens as prescribed in 4.4.1 and 4.4.2 and weigh and record the dry weight of each.

8.3.2 Carefully examine each specimen for cracks. A crack is defined as a fissure or separation visible to a person with normal vision from a distance of one foot under an illumination of not less than 50 fc. Mark each crack its full length with an indelible felt marking pen.

8.3.3 Submerge the test specimens in the water of the thawing tank for 4 ± ½ h.

8.3.4 Remove the specimens from the thawing tank and stand them in the freezing trays with one of their head faces down. Head face is defined as the end surfaces of a whole rectangular brick (which have the smallest area). A space of at least ½ in. (12.7 mm) shall separate the specimens as placed in the tray. Pour sufficient water into the trays so that each specimen stands in ½ in. depth of water and then place the trays and their contents in the freezing chamber for 20 ± 1 h.

8.3.5 Remove the trays from the freezing chamber after 20 ± 1 h and totally immerse them and their contents in the water of the thawing tank for 4 ± ½ h.

8.3.6 Freeze the test specimens by the procedure in 8.3.4 one cycle each day of the normal work week. Following the 4 ± ½ h thawing after the last freeze-thaw cycle of the normal work week, remove the specimens from the trays and store them for 44 ± 1 h in the drying room. Do not stack or pile units. Provide a space of at least 1 in. (25.4 mm) between all specimens. Following this period of air drying, inspect the specimens, submerge them in the water of the thawing tank for 4 ± ½ h, and again subject them to a normal week of freezing and thawing cycles in accordance with 8.3.4 and 8.3.5. If a laboratory has personnel available for testing 7 days a week, the requirement for storing the specimens for 44 ± 1 h in the drying room following the 4 ± ½ h thawing after the last freezing cycle of the week may be waived. The specimens may then be subjected to 50 cycles of freezing and thawing on 50 consecutive days. When a normal 5-day work week is interrupted, put specimens into a drying cycle which may extend past the 44 ± 1 h drying time outlined in the procedures of this section.

8.3.7 Continue the alternations of drying and submersion in water for 4 ± ½ h, followed by 5 cycles of freezing and thawing or the number of cycles needed to complete a normal work week, until a total of 50 cycles of freezing and thawing has been completed. Stop the test if the test specimen has been broken or appears to have lost more than 3 % of its original weight as judged by visual inspection.

8.3.8 After completion of 50 cycles, or when the test specimen has been withdrawn from test as a result of disintegration, dry and weigh the specimen as prescribed in 8.3.1.

8.4 *Calculations, Examination, Rating and Report.*

8.4.1 *Calculation*—Calculate the loss in weight as a percentage of the original weight of the dried specimen.

8.4.2 *Examination*—Reexamine the surface of the specimens for cracks (see 8.3.2) and record the presence of any new cracks developed during the freezing-thawing testing procedure. Measure and record the length of the new cracks.

8.4.3 *Rating*—A specimen is considered to fail the freezing and thawing test under any one of three circumstances:

8.4.3.1 Weight Loss—A weight loss of greater than 0.5 %.

8.4.3.2 Breakage—The specimen separates into two or more significant pieces, or

8.4.3.3 Cracking—A specimen develops a crack during the freezing and thawing procedure that exceeds in length the minimum dimension of the specimen.

If none of the above circumstances occur, the specimens are considered to pass the freezing and thawing test.

8.4.4 *Report*—The report shall state whether the sample

passed or failed the test. Any failures shall include the rating and the reason for classification as a failure and the number of cycles causing failure in the event failure occurs prior to 50 cycles.

9. Initial Rate of Absorption (Suction)

9.1 *Apparatus:*

9.1.1 *Trays or Containers*—Watertight trays or containers, having an inside depth of not less than ½ in. (12.7 mm), and of such length and width that an area of not less than 300 in.^{2} (1935.5 cm.^{2}) of water surface is provided. The bottom of the tray shall provide a plane, horizontal upper surface, when suitably supported, so that an area not less than 8 in. (203.2 mm) in length by 6 in. (152.4 mm) in width will be level when tested by a spirit level.

9.1.2 *Supports for Brick*—Two noncorrodible metal supports consisting of bars between 5 and 6 in. (127.00 and 152.5 mm) in length, having triangular, half-round, or rectangular cross sections such that the thickness (height) will be approximately ¼ in. (6.35 mm). The thickness of the two bars shall agree within 0.001 in. (0.03 mm) and, if the bars are rectangular in cross section, their width shall not exceed 5⁄16 in. (1.94 mm).

9.1.3 *Means for Maintaining Constant Water Level*—Suitable means for controlling the water level above the upper surface of the supports for the brick within ± 0.01 in. (0.25 mm) (see Note 3), including means for adding water to the tray at a rate corresponding to the rate of removal by the brick undergoing test (see Note 4). For use in checking the adequacy of the method of controlling the rate of flow of the added water, a reference brick or half brick shall be provided whose displacement in ⅛ in. (3.18 mm) of water corresponds to the brick or half brick to be tested within ± 2.5 %. Completely submerge the reference brick in water for not less than 3 h preceding its use.

NOTE 3—A suitable means for obtaining accuracy in control of the water level may be provided by attaching to the end of one of the bars two stiff metal wires that project upward and return, terminating in points; one of which is ⅛ − 0.01 in. (3.18 − 0.25 mm) and the other ⅛ + 0.01 in. (3.18 + 0.25 mm) above the upper surface or edge of the bar. Such precise adjustment is obtainable by the use of depth plates or a micrometer microscope. When the water level with respect to the upper surface or edge of the bar is adjusted so that the lower point dimples the water surface when viewed by reflected light and the upper point is not in contact with the water, the water level is within the limits specified. Any other suitable means for fixing and maintaining a constant depth of immersion may be used if equivalent accuracy is obtained. As an example of such other suitable means, there may be mentioned the use of rigid supports movable with respect to the water level.

NOTE 4—A rubber tube leading from a siphon or gravity feed and closed by a spring clip will provide a suitable manual control. The so-called "chicken-feed" devices as a rule lack sensitivity and do not operate with the very small changes in water level permissible in this test.

9.1.4 *Balance*, having a capacity of not less than 3000 g, and sensitive to 0.5 g.

9.1.5 *Drying Oven*, conforming to the requirements of 8.1.4.

9.1.6 *Constant-Temperature Room*, maintained at a temperature of 70 ± 2.5°F (21 ± 1.4°C).

9.1.7 *Timing Device*—A suitable timing device, preferably a stop watch or stop clock, which shall indicate a time of 1 min to the nearest 1 s.

9.2 *Test Specimens*, consisting of whole brick. Five specimens shall be tested.

9.3 *Procedure:*

9.3.1 Dry and cool the test specimens in accordance with one of the following procedures.

9.3.1.1 Oven-dried Procedure—Dry and cool the test specimens in accordance with 4.4.1 and 4.4.2.

9.3.1.2 Ambient Air-dried Procedure—Store units unstacked, with separate placement in a ventilated room maintained at a temperature of 75 ± 15°F (24 ± 8°C) with a relative humidity between 30 % and 70 % for a period of 4 h, with a current of air from an electric fan passing over them for a period of at least 2 h. Continue until two successive weighings at intervals of 2 h show an increment of loss not greater than 0.2 % of the last previously determined weight of the specimen.

9.3.2 Measure to the nearest 0.05 in. (1.27 mm) the length and width of the flatwise surface of the test specimen of rectangular units or determine the area of other shapes to similar accuracy that will be in contact with the water. Weigh the specimen to the nearest 0.5 g.

9.3.3 Adjust the position of the tray for the absorption test so that the upper surface of its bottom will be level when tested by a spirit level, and set the saturated reference brick (9.1.3) in place on top of the supports. Add water until the water level is ⅛ ± 0.01 in. (3.18 ± 0.25 mm) above the top of the supports. When testing tile with scored bed surfaces, the depth of water level is ⅛ ± 0.01 in. plus the depth of scores.

9.3.4 After removal of the reference brick, set the test brick in place flatwise, counting zero time as the moment of contact of the brick with the water. During the period of contact (1 min ± 1 s) keep the water level within the prescribed limits by adding water as required. At the end of 1 min ± 1 s, lift the brick from contact with the water, wipe off the surface water with a damp cloth, and reweigh the brick to the nearest 0.5 g. Wiping shall be completed within 10 s of removal from contact with the water, and weighing shall be completed within 2 min.

NOTE 5—Place the brick in contact with the water quickly, but without splashing. Set the brick in position with a rocking motion to avoid the entrapping of air on its under surface. Test brick with frogs or depressions in one flatwise surface with the frog or depression uppermost.

9.4 *Calculation and Report:*

9.4.1 The difference in weight in grams between the initial and final weighings is the weight in grams of water absorbed by the brick during 1-min contact with the water. If the area of its flatwise surface (length times width) does not differ more than ± 0.75 in.^{2} (4.84 cm^2) (±2.5 %) from 30 in.^{2} (193.55 cm^2), report the gain in weight in grams as the initial rate of absorption in 1 min.

9.4.2 If the area of its flatwise surface differs more than ± 0.75 in.^{2} (4.84 cm^2) (±2.5 %) from 30 in.^{2} (193.55 cm^2), calculate the equivalent gain in weight from 30 in.^{2} (193.55 cm^2) as follows:

$$X = 30\,W/LB \text{ (metric } X = 193.55\ W/LB)$$

where:

X = gain in weight corrected to basis of 30 in.^{2} (193.55 cm^2) flatwise area,

W = actual gain in weight of specimen, g,

L = length of specimen, in., (cm), and
B = width of specimen, in., (cm).

.3 Report the corrected gain in weight, X, as the initial rate of absorption in 1 min.

9.4.4 If the test specimen is a cored brick, calculate the net area and substitute for LB in the equation given in 9.4.2. Report the corrected gain in weight as the initial rate of absorption in 1 min.

9.4.5 If specimen is non-prismatic, calculate the net area by suitable geometric means and substitute for LB in the equation given in 9.4.2.

9.4.6 Report the method of drying as oven-dried (in accordance with 9.3.1.1) or ambient air-dried (in acordance with 9.3.1.2).

10. Efflorescence

10.1 *Apparatus:*

10.1.1 *Trays and Containers*—Watertight shallow pans or trays made of corrosion-resistant metal or other material that will not provide soluble salts when in contact with distilled water containing leachings from brick. The pan shall be of such dimensions that it will provide not less than a 1-in. 25.4-mm) depth of water. Unless the pan provides an area such that the total volume of water is large in comparison with the amount evaporated each day, suitable apparatus shall be provided for keeping a constant level of water in the pan.

10.1.2 *Drying Room*, conforming to the requirements of 8.1.6.

10.1.3 *Drying Oven*, conforming to the requirements of

10.2 *Test Specimens:*

10.2.1 The sample shall consist of ten full-size brick.

10.2.2 The ten specimens shall be sorted into five pairs so that both specimens of each pair will have the same appearance as nearly as possible.

10.3 *Preparation of Specimens*—Remove by brushing any adhering dirt that might be mistaken for efflorescence. Dry the specimens and cool them as prescribed in 4.4.1 and 4.4.2.

10.4 *Procedure:*

10.4.1 Set one specimen from each of the five pairs, on end, partially immersed in distilled water to a depth of approximately 1 in. (25.4 mm) for 7 days in the drying room. When several specimens are tested in the same container, separate the individual specimens by a spacing of at least 2 in. (50.8 mm).

NOTE 6—Do not test specimens from different sources simultaneously in the same container, because specimens with a considerable content of soluble salts may contaminate salt-free specimens.

NOTE 7—Empty and clean the pans or trays after each test.

10.4.2 Store the second specimen from each of the five pairs in the drying room without contact with water.

10.4.3 At the end of 7 days, inspect the first set of specimens and then dry both sets in the drying oven for 24 h.

10.5 *Examination and Rating*—After drying, examine and compare each pair of specimens, observing the top and all four faces of each specimen from a distance of 10 ft. (3 m) under an illumination of not less than 50 footcandles (538.2 m^2) by an observer with normal vision. If under these conditions no difference is noted, report the rating as "not effloresced." If a perceptible difference due to efflorescence is noted under these conditions, report the rating as "effloresced." Record the appearance and distribution of the efflorescence.

11. Measurement of Size

11.1 *Apparatus*—Either a 1-ft (or metric) steel rule, graduated in 1/32-in. (or 1-mm) divisions, or a gage or caliper having a scale ranging from 1 to 12 in. (25 to 300 mm), and having parallel jaws, shall be used for measuring the individual units. Steel rules or calipers of corresponding accuracy and size required shall be used for measurement of larger brick, solid masonry units and tile.

11.2 *Test Specimens*—Measure ten dry full-size units. These units shall be representative of the shipment and shall include the extremes of color range and size as determined by visual inspection of the shipment. (The same samples may be used for determining efflorescence and other properties.)

11.3 *Individual Measurements of Length, Width, and Depth*—Measure the length along both beds and along both faces from the midpoints of the edges bounding the units. Record these four measurements to the nearest 1/32 in. (or 1 mm) and record the average to the nearest 1/64 in. (or 0.5 mm) as the length. Measure in like manner across both ends from the midpoints of the edges bounding the faces. Record these four measurements to the nearest 1/32 in. (or 1 mm) and record the average to the nearest 1/64 in. (or 0.5 mm) as the width. Measure the depth across both faces and both ends from the midpoints of the edges bounding the beds. Record these four measurements to the nearest 1/32 in. (or 1 mm) and record the average to the nearest 1/64 in. (or 0.5 mm) as the depth. Use either the steel rule or the gage described in 11.1. Retest by the same method when required.

12. Measurement of Warpage

12.1 *Apparatus:*

12.1.1 *Steel Straightedge:*

12.1.2 *Rule or Measuring Wedge*—A steel rule graduated from one end in 1/32-in. (or 1-mm) divisions, or alternatively, a steel measuring wedge 2.5 in. (60 mm) in length by 0.5 in. (12.5 mm) in width by 0.5 in. (12.5 mm) in thickness at one end and tapered, starting at a line 0.5 in. (12.5 mm) from one end, to zero thickness at the other end. The wedge shall be graduated in 1/32-in. (or 1-mm) divisions and numbered to show the thickness of the wedge between the base, AB, and the slope, AC, Fig. 1.

12.1.3 *Flat Surface*, of steel or glass, not less than 12 by 12 in. (305 by 305 mm) and plane to within 0.001 in. (0.025 mm).

12.2 *Sampling*—Use the sample of ten units selected for determination of size.

12.3 *Preparation of Samples*—Test the specimens as received, except remove any adhering dirt by brushing.

12.4 *Procedure:*

12.4.1 Where the warpage is concave, place the straightedge lengthwise or diagonally along the surface to be measured, selecting the location that gives the greatest departure from straightness. Select and measure the maximum warpage as shown by the greatest distance of the unit surface from the edge of the straight- edge either by the steel rule or wedge. Measure this distance to the nearest 1/32 in. (or

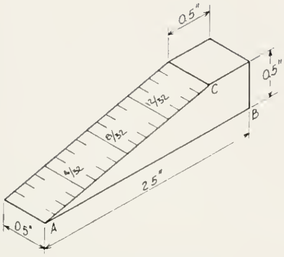

FIG. 1 Measuring Wedge

1 mm), and record it as the concave warpage.

12.4.2 When the warpage is convex, lay the unit with the convex surface in contact with a plane surface and with the corners approximately equidistant from the plane. Take measurements from the plane surface to the four corners of the unit. Record the average of the four measurements as the convex warpage of the unit.

13. Measurement of Length Change

13.1 *Apparatus*—A *dial micrometer* or other suitable measuring device graduated to read in 0.0001-in. (or 0.001-mm) increments, mounted on a stand suitable for holding the specimen in such a manner that reproducible results can be obtained, shall be used for measuring specimen length. Provisions shall be made to permit changing the position of the dial micrometer on its mounting rod so as to accommodate large variations in specimen size. The base of the stand and the tip of the dial micrometer shall have a conical depression to accept a 1/4-in. (6.35-mm) steel ball. A suitable reference instrument shall be provided for checking the measuring device.

13.2 *Preparation of Specimen*—Remove the ends of deeply textured specimens to the depth of the texture by cutting perpendicular to the length and parallel to each other. Drill a hole in each end of the specimen with a 1/4-in. (6.35-mm) carbide drill. Drill these holes at the intersection of the two diagonals from the corners. Place 1/4-in. (6.35-mm) steel balls in these depressions by cementing in place with a calcium aluminate cement. Any equivalent method for establishing the reference length is permissible.

13.3 *Procedure*—Mark the specimen for identification and measure to the nearest 0.0001 in. (or 0.001 mm) in a controlled environment and make subsequent measurements in the same controlled environment, ± 2°F and ± 5 % relative humidity. Record the temperature and relative humidity. Apply a reference mark to the specimen for orientation in the measuring device. Check the measuring device with the reference instrument before each series of measurements.

14. Initial Rate of Absorption (Suction) of Standard Size Brick (Field Test)

14.1 *Scope*—This test method is intended to serve as a volumetric means of determining the initial rate of absorption of standard size brick when weighing determination described in Section 9 of this standard is impractical. This test method is applicable to quality control verification of units and assessment of the need for prewetting.

14.2 *Apparatus:*

14.2.1 *Pycnometer*—A glass or plastic volumetric container with a capacity of 350 ± 5 mL. The neck of the container shall have a capacity of 100 mL and shall be graduated in 1-mL increments (see Fig. 2).

14.2.2 *Absorption Test Pan*—A watertight rectangular pan of noncorrodible metal construction with a flat bottom, an inside depth of 1 1/2 ± 1/16 in. (38.1 ± 1.6 mm), an inside length of 10 ± 1/16 in. (254 ± 1.6 mm), and an inside width of 5 ± 1/16 in. (127 ± 1.6 mm). One end of the pan shall be constructed to facilitate transfer of water from the pan to the pycnometer. Two noncorrodible metal rectangular brick supports 4 ± 1/8 in. (101.6 ± 3.2 mm) in length, 1/4 ± 1/64 in. (6.4 ± 0.4 mm) in height and 1/4 ± 1/32 in. (6.4 ± 0.8 mm) in width shall be permanently affixed to the bottom of the pan 2 ± 1/16 in. (50.8 ± 1.6 mm) from the ends.

14.2.3 *Timing Device*—A suitable timing device that shall indicate a time of 1 min to the nearest 1 s.

14.3 *Test Specimen*—A whole brick, measuring approximately 3 5/8 in. (92 mm) in width, 2 1/4 in. (57 mm) in height and 7 5/8 in. (194 mm) to 8 in. (203 mm) in length.

14.4 *Procedure:*

14.4.1 Measure to the nearest 1/16 in. (1.59 mm) the length and width of the test specimen at the surface that will be in contact with water. If the test specimen is cored, determine the area of the cores at the same surface.

14.4.2 Pre-wet and drain the absorption test pan and place on a flat, level surface.

14.4.3 Fill the pycnometer with water to the top graduation on the neck of the container. A plastic squeeze bottle will aid in filling the pycnometer exactly to the desired level. Pour the water from the pycnometer into the absorption test pan.

14.4.4 Set the test specimen squarely in place on the brick supports, counting zero time as the moment the brick

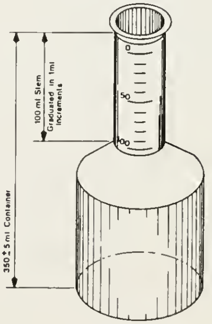

FIG. 2 Pycnometer

Appendix C: Material Safety Data Sheet

CHEM-TRETE® BSM 40

WATER REPELLENT

Product Data and Test Information

PRODUCT NAME

CHEM-TRETE BSM 40

High performance water repellent for concrete, masonry and stone

MANUFACTURER

hüls

HÜLS AMERICA INC.

80 Centennial Ave., Piscataway, NJ 08855-0456,
1 (800) 828-0919

PRODUCT DESCRIPTION

A clear, penetrating, breathable water repellent for use on exterior above-grade concrete, brick masonry, concrete masonry units and some natural stones. It penetrates the surface and bonds chemically to the substrate, resulting in permanent attachment of the water repellent molecule. CHEM-TRETE BSM 40 is not a coating and as a result will not discolor or change the surface appearance in any way

By reducing the amount of water entering the substrate, CHEM-TRETE BSM 40 reduces the intrusion of water carrying contaminants such as salt and dirt, and reduces the deteriorating effects of these contaminants such as rebar corrosion, spalling, scaling, efflorescence, leaching and staining.

APPROPRIATE APPLICATIONS

For use on concrete to protect the reinforcing steel from corrosion due to the effect of water, deicing salts and other water borne chemicals

For use on brick masonry to protect against the ingress of wind-driven rain.

For use on highways, airport runways and concrete pavement to reduce scaling due to deicer chemicals.

To reduce the effects of mildew, efflorescence, and stains on vertical concrete and masonry buildings

To impart water repellency to a substrate for an extended time

ADVANTAGES

CHEM-TRETE BSM 40 is an isobutyltrialkoxy silane in an alcohol carrier The silane is designed to penetrate deep into the substrate and impart a high level of water and chloride ion screening This provides the substrate with long lasting protection Because of the purity of the CHEM-TRETE BSM 40 it will not leave a residue on non-porous substrates such as glass windows, metal frames and painted surfaces

CHEM-TRETE BSM 40 has an unprecendented track record in protecting concrete, masonry and natural stone structures from deterioration due to water and water borne contaminants. Structures treated in the 1970's are still protected and these results are documented by state, federal and private agencies.

The main benefits of the product are:

- Excellent resistance to water intrusion
- Excellent resistance to chloride ion ingress
- High resistance to wind-driven rain
- 100% breathable
- Deep penetration into the substrate
- No masking of windows necessary
- No blushing, peeling, or yellowing
- High resistance to alkali attack
- Reduced efflorescence
- No change in surface appearance

LIMITATIONS

Not intended for below-grade waterproofing Should not be applied if the surface temperature is below 20°F or above 100°F, if rain is expected within two hours following application, or if high winds or other conditions prevent proper application. If rain has preceded the application, the surface should be allowed to dry at least 24 hours. Caution should be taken with specialty coated glass or plastic windows. Check compatibility before application.

TECHNICAL DATA

CHEM-TRETE BSM 40 is a clear, colorless liquid containing 40% isobutyltrialkoxy silane in alcohol.

Color	water white
Active Substance	isobutyltrialkoxy silane
Active Content	40% by weight
Solvent	denatured ethyl alcohol
Flash point	54°F
Density	7.0 lbs/gal

TEST DATA

NCHRP #244

Series II	84% Reduction in Water Absorption
Series II	88% Reduction in Chloride Absorption
Series IV	97% Reduction in Chloride Absorption

ASTM C 642
"Water Absorption of Concrete"

24 hours	0.45%
48 hours	0.85%
50 days	1.4%

ASTM C 672
"Deicer Scaling"
60 cycles (non-air entrained Concrete) 0 rating

DC MATERIAL SAFETY DATA SHEET RECORD NO.: M37

ÜLS AMERICA INC. : EMERGENCY (CHEMTREC) - (800)424-9300
TURNER PLACE, P.O. BOX 365 : 24 HOUR PHONE - (201)763-7173
ISCATAWAY, NJ 08855-0365 : INFORMATION - (908)981-5016

SECTION 1. NAME AND PRODUCT M37

AME: CHEM-TRETE(R) BSM-40
SYNONYMS: DYNASYLAN (R) BSM 40
AS REG.NO.: NA FORMULA: NA
RODUCT NUMBER: 4131450

SECTION 2. HAZARDOUS INGREDIENTS M37

COMPONENT ACGIH TLV OSHA PEL

sobutyltrialkoxysilane (Trade Secret)

JTSR No. 56705700001-5318P
NA NA
Methanol [67-56-1] (21.6%) (+)(+++) TWA
200ppm(skin) 200 ppm
STEL

250ppm(skin) 250ppm

EGEND:
(+) This chemical is subject to the reporting requirements of SARA Title III Section 313 and 40CFR Part 372, and is potentially at the maximum concentration listed.
(++) SARA Title III Section 302 Extremely Hazardous Substance
(+++) CERCLA Hazardous Substance
00000-00-0] Chemical Abstracts Services Registry Number.

If no marks appear with a listed ingredient, then the ingredient is not included in any of the regulatory categories appearing in the Legend of this Material Safety Data Sheet.

SECTION 3. PHYSICAL DATA M37

PPEARANCE: Clear liquid
dor of alcohol
B.PT.(deg.C/mm): 78.3/760 VAPOR PRESSURE(mm/deg.C): 74/22
.PT.(deg.C): NA
APOR DENSITY(AIR=1): 1.46 % SOLUBLE IN WATER: Reacts
SPECIF.GRAVITY: 0.8 % VOLATILE BY VOLUME: NA

SECTION 4. FIRE AND EXPLOSION HAZARD M37

LASH POINT: 44.6 F.
LAMMABLE LIMITS (STP IN AIR)
LOWER LIMITS: 4.3 - 6.7%
UPPER LIMITS: 19 - 36%
IRE EXTINGUISHING MEDIA: Water spray or fog
'Alcohol' foam, dry chemical, CO2.
Use water spray to keep fire-exposed containers cool.

SPECIAL FIRE FIGHTING PROCEDURES: Avoid water streams which may splash and pread flaming liquid. Vapors are heavier than air and may flow along surfaces

o distant ignition sources and flash back. Vapors persist in the air and should be knocked down with water spray (fog). Vapors are harmful; avoid breathing of vapors and contact with eyes or skin.

ERSONAL PROTECTION FOR FIGHTING FIRE: Fire fighters must wear positive-pressure, self-contained breathing apparatus and full protective clothing.

SECTION 5. REACTIVITY DATA M37

STABILITY (UNDER NORMAL CONDITIONS): Stable

ONDITIONS TO AVOID:
- Contact with water or moist air.
- Contact with oxidizing agents.
- Contact with alkali & acid.
- Exposure to heat, sparks, or other source of ignition

HAZARDOUS POLYMERIZATION: Will not occur

ONDITIONS TO AVOID:
NA

HMIS RATINGS (Scale 0-4)
HEALTH: 2 FLAMMABILITY: 3 REACTIVITY: 1

SECTION 6. SPILL OR LEAK PROCEDURES M37

N CASE OF SPILL:
- Absorb spilled material with suitable chemical binder.
- Shovel absorbent into suitable waste container.
- Do not contaminate soil, groundwater, or surface water.
- Eliminate all ignition sources.

DISPOSAL METHOD:
Incinerate. Follow all federal, state, and local regulations.

SECTION 7. HEALTH HAZARD DATA M37

OXICITY: NA

ROUTES AND EFFECTS OF EXPOSURE:

EYES: Severely irritating. Conjunctivitis, corneal damage.
Ocular irritation may occur at concentrations well below the TLV for both thanol and Methanol.
SKIN: Irritant. Defatting, rashes, irritation.
NHALATION: Causes irritation or damage to lung.
NGESTION: Irritant.

OTE:
Material may form a siloxane polymer on the skin, eyes, or in the lungs. In the event of direct contact of the liquid with these tissues, seek medical ttention.

NOTE:
Methanol is a tissue irritant that may be absorbed through the skin and roduce systemic toxic effects. Vapors may be inhaled and metabolized to Formaldehyde and Formic acid resulting in systemic acidosis, blindness, and ltimately death from respiratory arrest. Liquid produces effects similar to nhalation overexposure when ingested.

OTE:

Ethanol has an irritating, dehydrating effect on overexposed tissue. Overexposure to Ethanol by skin absorption, inhalation, or ingestion may have a narcotic effect (headache,nausea, drowsiness). Ethanol is metabolized to cetaldehyde and Acetic acid resulting in metabolic acidosis, CNS depression, and death due to respiratory arrest.

FIRST AID PROCEDURES:

EYES: Flush with clean water for at least 15 minutes and consult physician
!!!GET MEDICAL ATTENTION IMMEDIATELY!!!
SKIN: Scrub with soap and water
SKIN: Remove contaminated clothing and shoes
INHALATION: Remove victim to fresh air
INHALATION: Give CPR or oxygen if necessary
INGESTION: Get medical attention

---If symptoms persist, get medical attention---

---Never give anything by mouth to an unconscious person---

CARCINOGEN STATUS: NTP?: No IARC MONOGRAPH?: No OSHA REGULATED?: No

SECTION 8. SPECIAL PROTECTION INFORMATION M37

ENTILATION:
Maintain adequate ventilation
Explosion-proof mechanical ventilation required
Administrative or mechanical means should be used in order to meet TLV requirements.
RESPIRATORY PROTECTION:
If exposure exceeds TLV, use appropriate NIOSH approved respiratory protection
PROTECTIVE CLOTHING:
Use impervious gloves
Use impervious clothing as necessary to protect against skin contact
EYE PROTECTION:
Use chemical goggles

SECTION 9. PRECAUTIONS OR OTHER COMMENTS M37

HANDLING AND STORAGE:
Store in a cool and dry place
Protect from moisture
Protect from heat, direct sunlight, and source of ignition
Containers require grounding during use
Maintain tightly closed container
Store away from alkaline, acidic, and oxidizing materials
Provide adequate ventilation
Do not cut, weld, or grind on or near drum. | Wash thoroughly with soap and water after handling and before eating, drinking, or moking.

DOT INFORMATION:
ROPER SHIPPING NAME: Flammable liquid, n.o.s.
TECHNICAL NAME: (Ethanol, Methanol)
HAZARD CLASS: 3 ID NO.: UN1993 PACKING GROUP: II ERG: 27

HAZARD LABEL(S): Flammable Liquid

Since empty containers retain product residue, follow hazard precautions even after container is emptied.

NA = No applicable or relevant information available
(R) = Registered Trademark owned by or licensed to Hüls America Inc., Hüls A.G. or Hüls Troisdorf A.G.
(TM) = Trademark owned by or licensed to Hüls America Inc., Hüls A.G. or Hüls Troisdorf A.G.

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