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TRADITIONAL ARCHITECTURAL RENDERS ON EARTHEN SURFACES

Maria Isabel G. Beas

A THESIS

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MASTER OF SCIENCE

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INTRODUCTION

Earth, one of the first building materials used in many parts of the world, has been traditionally used to construct not only simple dwellings but also large and elaborate monumental structures decorated with paintings, sculptural reliefs, and mosaics. Although earth constructions have the reputation of being unstable and inferior, this is something of a myth that must be refuted. They are remarkably durable and in most cases, the fragility of the material is not structural but merely superficial. As a result of their natural composition, all earthen buildings share common problems of deterioration particularly due to water, weather and poor maintenance; however, when protected and periodically maintained, their durability is remarkably improved.

Surface coatings such as mud, gypsum and lime plasters or limewashes have been traditionally applied to the exterior of earth constructions for protection and decoration, retarding surface deterioration by offering a renewable surface to the walls. In the past, methods to protect earthen surfaces were inexpensive and easily available but unfortunately, many of the traditional construction techniques developed by ancient cultures have been lost or are hardly practiced any longer.

In the last several decades, deterioration from natural weathering, neglect from increased labor costs and changes in cultural and socio-economic values have caused many adobe building owners to abandon the material or seek longer lasting materials as alternatives to these traditional surface coatings. More permanent waterproof surfaces have been attempted to try to reduce the frequent maintenance necessary for traditional surfaces. These waterproof materials, such as cement stucco, carry many disadvantages. Not only are they more expensive, but they also contain and trap moisture, which creates long term maintenance problems and destruction of the earthen support.

For the conservation of significant historic and archaeological sites, synthetic resins have been used with mixed results to improve surface characteristics. Many conservation programs are being carried out in historical and archaeological sites such as Pueblo in Mesa Verde, New Mexico; Chan-Chan in Trujillo, Perú; and at Gordion, Turkey; in order to control the deterioration of fragile fragments of earth-based renderings and mural paintings. Although several new synthetic protective coating systems are being tested, so far the only successful alternative available is to protect the finishes with a temporary covering of soil or remove them from the site to a controlled environment such as a museum.

Conclusions on the best coatings or methods to protect earthen walls can not be drawn yet. The solution for the preservation of adobe surfaces requires an understanding of the differences in intervention between retaining and conserving historic fabrics and replicating or restoring them. Both options may benefit from looking to the past for the traditional techniques and materials applied, and to find the best methods to protect our earthen constructed heritage through a careful understanding of the properties of earth as a building system and other materials used with it.

The purpose of this thesis is to explore the materials and function of traditional renders applied to earthen buildings, and methods for their conservation. Although this study deals with earthen buildings, their construction techniques and overall deterioration are outside the scope of this study. The mentioned plasters prepared from representative traditional recipes -- appended at the end of the study, and found to be used since ancient times in many parts of the world -- have been compared through laboratory testing for their most important physical and mechanical characteristics: adhesion to the surface, water vapor permeability, capillarity, and abrasive resistance both in dry and wet conditions. Since there are no recorded standard procedures to evaluate the effectiveness of surface treatments on earthen renders, the experimental tests have been designed based mainly on those of the ASTM (American Society for Testing Materials) and CRATerre (Centre International de la Construction en Terre).

In addition, three consolidants, reported in recent conservation literature for the stabilization of porous materials -- specially clays -- were included in the testing program:

- a natural plant mucilage extracted from the Tuna Cactus. It was decided to test this material mainly because this natural product has been recently used in trial tests for the conservation of walls in Chan-Chan, Perú with reported good results; although the properties conferred to the treated surfaces are unqualified.

- a synthetic organic resin, an isobutyl methacrylate co-polymer, Acryloid B-67, produced by Rohm and Haas, USA. Although this product has not been used for the conservation of adobe surfaces specifically it has many properties that may be desirable as a consolidant on earthen constructions.

- a synthetic inorganic resin, a tetraethylorthosilicate (Ethyl Silicate) in solvents (Acetone and Methyl Ethyl Ketone); Conservare OH, produced in USA by ProSoCo Inc. -- using the same formula as Stone Strengthener Wacker OH, produced in Germany by Wacker Chemie. This silicic acid ester appears to be very promising for the consolidation of adobe walls.

CHAPTER 1: TRADITIONAL RENDERS

Render is the layer or film of material placed over a wall in order to enhance its appearance, protect it from external elements and increase its durability. On earthen walls, many types of renders such as plasters, slurries or paints, have been traditionally used generally depending on both the natural and technological resources of the area, and the traditional craftsmanship.

In this chapter a survey of the traditional materials used on earthen building surfaces, are presented

1.1 NATURAL CLAY SURFACES

One of the traditional methods of finishing the walls of earthen buildings is to leave them with no covering or rendering at all. When the masonry texture of the wall is exposed, more care is exercised in the laying of the wall, maintaining level brick courses and carefully filling the joints. The texture can range from a struck finish, where mud mortar joints are trimmed with a trowel, to raked mortar joints, where each brick is clearly defined. In either case, additional detailing is required at the juncture of windows and frames and non similar materials such as wood beams, in order to achieve an agreeable finish at the conjunction of two different materials.

Heavy rain can severely erode and damage the surface of an unprotected mud wall because the clay content of the wall will resist wetting except at the surface. If the earth material has a reasonable amount of clay (10%-20%), the surface will partially resist erosion from ambient rainfall. If the clay content is too low and the surface material not sturdy, wind driven rain can cause severe erosion. Therefore, rain erosion tends to be more pronounced on the side of the building that is exposed to prevailing wind and storm patterns.

Natural erosion rates for exposed vertical clay surfaces have been determined to be approximately 1 inch (2.5 cm.) in 20 years[1]. In tropical or semi-tropical climates, the exterior of an earth wall will usually become partially baked by the sun, so that the hardened surface gives sufficient protection to keep it in good condition without the need of any other covering.

As stated in one modern handbook:

> *Without plaster, good Pisé work is found successfully to withstand exposure to the weather, and after the lapse of many years to be so compact and hard as to be picked down with difficulty.*[2]

---

[1] Paul Graham McHenry Jr. Adobe and Rammed Earth Buildings: design and construction. (Albuquerque, New Mexico: Willey Interscience Publication, 1983), p. 119.

[2] Lyle A. Wolfskill; Wayne A. Dunlap; and Bob M. Gallaway. Handbook for Building Homes of Earth. Texas Transportation Institute. (Texas: Texas A&M University, 1963), p. 14.

1.2 PLASTERS

Plasters[3] have been important architectural components since early recorded history. They have been used in interior and exterior surfaces not only for decorative purposes but also as protective coatings, providing resistance to penetration by wind, rain, cold, dust and fire. Plasters are composed of a binder, an aggregate and additives combined in various proportions depending on the use. The aggregates and additives usually behave as inert materials, while the binder is the active ingredient responsible for setting and hardening the mixture and preserving the form or texture imposed in a rigid state during the period of plasticity.[4] The properties of the binder determine to a large extent the characteristic qualities of a plaster mix, while the aggregates may affect the properties of plasters according to their physical characteristics: gradation from coarse to fine particles, shape and density of particles, and particle surface characteristics such as roughness and porosity.

Some of the desirable properties of plasters are good workability for easy application, an adequate cure strength to resist impact damage without cracking and shelling, a good bond in order to withstand differential movements between plaster and substrate, and durability. A plaster is generally applied in a series of layers or coats -- from one to three depending on its use and the desired effect. It is applied directly to the surface of a masonry wall or to a secondary support framework, known as lathing, which has been fastened to the surface of the wall. The layers of plaster applied to the surface can be prepared with the same or often different materials, decreasing the amount of binder from the interface up to the outerface.

The different layers of plaster are termed as follows:

Scratch or rough coat - First coat, applied directly to the supporting wall or lathing and providing a base on which to apply succeeding coats.

Brown or floating coat - Applied over the scratch coat to form a base for the final.

---

[3] Since the last century in the USA, the term plaster has denoted interior finishing while stucco has been used to denote exterior finishing. Also on the West coast of USA, only the final coat is referred to as stucco, both for interior and exterior walls. This document will not make that distinction when referring to plaster; it will mean both interior and exterior wall finishes, as well as any coat or layer applied.

[4] John R. Diehl. Manual of Lathing and Plastering. National Bureau for Lathing and Plastering. (New York: Mac Publishers Association, 1960), pp. 31-32.

White or putty coat - (or sand finish) In addition to providing a flat, smooth and clean finished surface, the plaster is capable of being shaped either in place or in molds, in order to create an almost infinite variety of architectural decoration.

Most traditional plasters contain clay, lime -- alone or in combination -- or gypsum as the principal binder always mixed with an aggregate such as sand or crushed stone; while traditional additives might vary depending on the products available in the area. Additives such as straw, animal hair or wood ashes have been commonly used in the past.

1.2.1. Clay Plaster

A soil is comprised of particles of diverse shapes and sizes. In order to determine its properties, granulometric definitions have been established according to various standards. These granulometric distinctions are based on equivalent particle diameters and are divided into gravel, sand, silt and clays. For this study the USA (ASTM Standards) [5] will be followed:

Clay - Particles with diameter ≤ 5 um
Silt - Particles with diameter 5 um - 75 um
Sand - Particles with diameter 75 um - 4.75 mm
Gravel - Particles with diameter 4.75 mm - 76.2 mm

Clays, the binding materials of soils, are chemically classified as hydrated aluminosilicates, containing as major components: sodium, potassium and calcium, varying amounts of iron oxide and smaller amounts of lime, manganese, alkalies and sulphur[6]. In their natural dry state they are found as fiber-like coagulated masses of molecules. When water is added to the mass, the layered molecules are arranged in parallel strata with water molecules held between the clay layers, causing the material to become plastic. This plasticity allows clays to be molded into almost any shape, which they retain when dry. If water is again added the molecules will disperse. The more active a clay is, the greater its capacity to swell and contract in the presence or absence of water. In terms of unburnt earthen building materials, the more stable the clay is, the less chance of cracking due to expansion and contraction.

---

[5] ASTM 1139-83 : Standard Specification for Crushed Stone, Crushed Slag and Gravel for Single or Multiple Surface Treatment", and ASTM D 1140-54 (Reapproved 1971): "Standard Test Methods for Amount of Material in Soils Finer than No 200 (75 um) Sieve".

[6] Edwin C. Eckel. Building Stones and Clays: Their origin, characters and examination. (New York: John Wiley and sons, 1912), p. 218.

Clay or mud plasters[7] are the most-used traditional surface coating for earthen walls.[8] Precise composition of mud plaster varies from one region to another and its durability is largely dependent on the quality of the raw material used. A durable mixture of clay plaster should ideally contain a high ratio of sand to silt and not more than 10%-15% clay to silt.[9]

As mentioned above, the clay and to some extent the silt act as binding media in the mix. Most good mixes contain about 2 parts of sand to one part of clay. Mud plasters will not last if they contain too much clay, the wrong kind of clay, or when they are too soft. The higher clay content may cause shrinkage and cracks upon drying; the size and severity of the cracks will be proportionate to the clay content and the thickness of the plaster. If the clay content is too high, the shrinkage upon drying may also result in a poor bond to the mud brick surface.

Clay plaster is usually applied in two coats, both for interior and exterior surfaces. The first coat might be compared with the "brown" coat in conventional plaster practice. The initial clay plaster coat is best reinforced through mixing in a small quantity of straw or fibrous material, like selected wheat or oat straws, which will also add protection from rainfall. While the advantages of the use of straw on earthen walls have not been clearly delineated through research yet, traditionally the fibered material is used for two purposes: first, to allow the use of a higher percentage of clay (20%-25%) in the mud plaster mix,[10] and second, to reinforce it, making possible the application of thicker coats for leveling the surface, when necessary.[11] Many other additives have been traditionally used to improve the properties of the plasters. (See Chapter 2: Natural Amendments).

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[7] In some French-speaking areas, it is also called Dagga or Dogga.

[8] Clough Williams-Ellis; John and Elizabeth Eastwick-Field. Building in Cob, Pise and Stabilized Earth. (London: Country Life Limited, 1919), p. 103.

[9] Soils for adobe bricks should contain between 70-80% sand and 20-30% of silt and clay. Elizabeth F. Ruffner; and James W. Garrison. Adobe: Practical and Technical Aspects of Adobe Conservation. (Arizona: Heritage Foundation of Arizona, 1983), p. 6.

[10] Most of the soil available in many parts of the world, is composed of a high percentage of clay, being necessary to add silt or sand in order to avoid shrinkage upon drying. This procedure can be avoided by replacing the coarser material -- which would also add weight to the blocks -- with straw.

[11] Paul Graham McHenry Jr., p. 123.

The final or finish coat is made up of screened fine material also with a moderately high clay content and is applied as thinly as possible to achieve full coverage. If small shrinkage cracks appear in the final coat, these may be easily dealt with by dampening the surface, which recreates the plasticity of the mud so that it can be troweled or refloated for a smooth finish.

Sometimes a conventional sponge rubber float, deerskins, sheepskins or small slightly rounded stones, are used to smooth the plaster to create a "polished" surface. Creating a polished surface is not only aesthetically pleasing, but also implies the denseness of the wall. When the wet mud plaster is applied under hand pressure, smoothing it and making the surface even tends to align the micaceous plates in the clays, making the wall denser and more coherent, and consequently, more resistant to penetration by external factors like wind, dust and water.

When the render used is a clay plaster, both surface and substrate contain the same materials; therefore they exhibit sympathetic properties and natural bonding. Thus, rendering in clay plaster is one of the best known techniques for preserving the structural earth wall. Also, if any problems occur inside the structure, they become immediately apparent, and the wall can be treated before it becomes irreparable. Naturally surfaced earth walls will absorb and give off air borne moisture, allowing the wall to breathe. The weathered appearance of mud plaster lends a naturalistic, earth integrated sincerity that later cement stucco finishes cannot hope to replicate. Clay plaster is subject to water damage and needs frequent renewal (generally every two years) to keep the surface in repair. This application requires little skill but the process demands a great amount of time and labor.

1.2.2. Lime Plaster

Non-hydraulic lime is the principal binder of most traditional mortars, plasters and renders.[12] To obtain lime from limestone it is necessary to burn or calcine the rock in order to remove carbon dioxide and any water, changing its form to either calcium or magnesium oxide, or both. The product is termed "quicklime", sometimes described as "unslaked lime", or rather misleadingly as "lump lime". *(See Glossary).*

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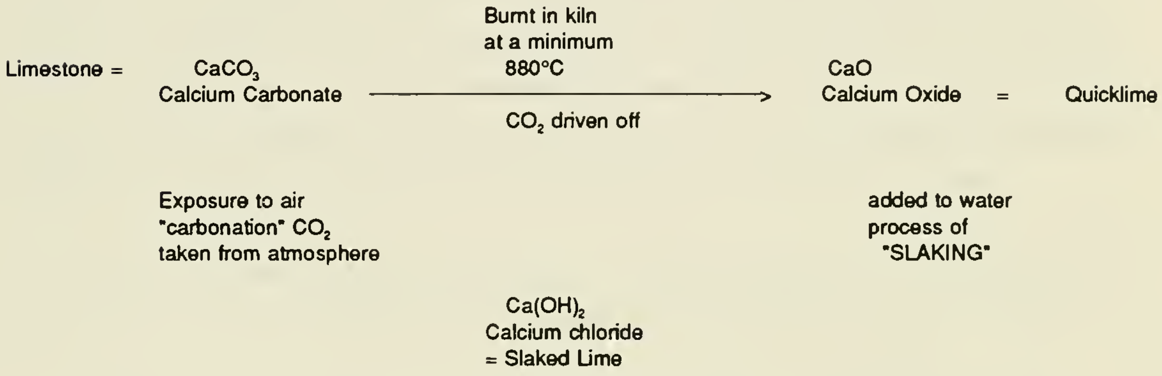
[12] John and Nicola Ashurst. Mortars, Plasters and Renders - English Heritage Technical Handbook. Volume 3, (London: Halsted Press, 1988), p. 1.

When this powder is mixed with water through a process called "slaking" or hydrating, a chemical reaction releases heat, expanding the mass 2 or 3 times its original volume. After slaking for 24 hours, the mixture is considered ready for use. At this point the chemical change redefines the mix to calcium hydroxide.

The "lime cycle"[13] can be summarized as follows:



"THE LIME CYCLE": burning, slaking and hardening non-hydraulic lime

Building limes may be manufactured from calcitic limestone or shells naturally high in calcium carbonate, or from dolomitic limestone which normally contains substantial amounts of magnesium carbonate. Building limes are generally classified in quicklimes and hydrated limes. Quicklime requires slaking and soaking for approximately 1 to 2 weeks to hydrate oxides and to make a plastic putty usable in mortars or plasters, while hydrated lime can be used either dry or as lime putty after brief soaking, depending on the type.

Lime plaster consists of lime and sand, generally in a rate of 1:3 mixed with water so as to be applied in heavy coats with trowels or brushes. Lime confers properties of excellent workability and water retentivity to the plaster so that it is easy to obtain first class alignment and finish at a high level of productivity.

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[13] John and Nicola Ashurst. Mortars, Plasters and Renders. p. 2.

Lime based plasters are gauged to achieve early strength with gypsum and cements, and can be applied in a wide variety of compositions to suit particular applications. Several traditional formulas consist of lime thoroughly slaked and thinned to a cream to which various additions are made, such as salt, alum, powdered glue, casein (skimmed milk), etc. The effect of salt is probably to hold the moisture during drying and facilitate the carbonation of the lime.

The use of lime plasters on earthen buildings -- both as exterior and interior coatings -- date to the earliest known civilizations. This plaster is much harder and more durable than mud plaster, but it is less flexible and cracks easily. To make the lime plaster adhere to adobe, walls are often scored diagonally with hatchets, making grooves about ½ inch deep. The grooves are filled with a mixture of lime mortar and small chips of stone or broken roof tiles, over which is trowelled a heavy coat of the plaster. The final coat may be applied in a thin slip (soup-like consistency), or finished with stones and sheepskins, for a polished finish. Limewash is painted directly onto the mudbrick or plaster.

A common traditional external protection for earth walls was rendering of lime roughcast. The Encyclopedia or Universal Dictionary of Arts, Sciences and Literature,[14] describes such a render:

> *To prepare the walls for plastering, indent them with the point of a hammer, or hatchet, without being afraid of spoiling the surface left by the mould; all those dents must be made as close as possible to each other, and cut in from the top to bottom, so that every hole have a little rest in the inferior part, which will serve to retain and support the plaster. If you happen to lay the plaster over them before the dampness is entirely gone, you must expect that the sweat of the walls will cast off the plaster.*
>
> *The wall surface having been duly hammer-chipped, the work must be scoured with a stiff brush to remove all loose earth and dust, and finally to prepare it for roughcasting. Roughcast consists of a small quantity of mortar, diluted with water in a tub, to which a trowel of pure lime is added, so as to make it about the thickness of cream.*
>
> *One workman and his laborers are sufficient; the workman on the scaffold sprinkles with a brush the wall he has indented, swept, and prepared; after that he dips another brush, made of bits of reed, box, etc.., into the tub which contains roughcast against the wall.*
>
> *Roughcast, which is attended with so little trouble and expense, is, notwithstanding, the best cover that can be made for Pisé walls, and for all other constructions; it contributes to preserve the buildings. It is the peculiar advantage of these buildings that all the materials they require are cheap, and all the workmanship made simple and easy.*

---

[14] Encyclopedia Londinensis or Universal Dictionary of Arts, Sciences and Literature. Compiled, digested and arranged by John Wilkes of Millard House, Volume XX. (London: Encyclopedia Office, 1825), p. 625.

1.2.3. Gypsum Plaster

Gypsum[15] is a naturally occurring mineral gray, white or pink in color, deposited in vast beds between limestone strata and in association with various other minerals, by the precipitation of calcium sulfate crystals from evaporating sea water.[16] Deposits are found in abundance throughout the world and are either quarried in open pits or mined underground. Varieties include a fibrous type (satin spar), fine-grained translucent rocks (alabaster), or colorless transparent crystals (selenite).

Two forms of gypsum are used to create plaster for walls: hemihydrate and calcined gypsum. Both are created basically through the same process of dehydration. The first process to artificially dehydrate the calcium sulphate, involves heating it in open kilns to a temperature of 270 to 340 degrees F. for about three hours, losing about three-fourths of its water through crystallization, until it becomes a hemihydrate. After cooling, lumps of hemihydrate are ground into a fine powder. The second process is to heat the calcium sulphate to 390 degrees Fahrenheit, until it loses all of its water through crystallization. This gypsum is also ground to as fine a powder as possible, and again heated (calcined) to drive off any remaining water content. Both forms of plaster are mixed with sand and water to form a plaster paste that can be trowelled on the wall.

Gypsum's chemical reaction[17] can be summarized as follows:

$$\underset{\text{GYPSUM}}{CaSO_4 . 2H_2O} \xrightarrow[\text{from 130°C in kiln}]{} \underset{\text{hemi-hydrate}}{CaSO_4 . \tfrac{1}{2}H_2O} + \underset{\text{water driven off}}{1\tfrac{1}{2}H_2O}$$

---

[15] The word "gypsum" is derived from the Greek gypsos meaning gypsum or chalk. Gypsum plaster is sometimes called "Gesso" or "Yeso" from the Spanish, in the Spanish Southwest of the USA.

[16] John R. Diehl, pp. 31-32.

[17] John and Nicola Ashurst. Mortars, Plasters and Renders. p. 27.

Many types of gypsum are used for building construction, being one of them Plaster of Paris,[18] a calcined gypsum ($CaSO_4 \cdot H_2O$) obtained by heating the hemi-hydrate at temperatures of between 150°C and 160°C. When plaster of Paris is mixed with water sets in about 20 minutes to form a hard crystalline gypsum. Gypsum has been used to make walls and pavements in places sheltered from rain but its primary use is in making plaster for interior walls, ceilings, ornamental work, and even for floor covering.

Gypsum plaster can be gauged with lime in order to increase its durability and strength; and slow its setting time to facilitate its application. Gypsum plaster is used on interior earthen walls since it is not particularly water resistant.

---

[18] The term "Plaster of Paris", which denotes calcined gypsum, was derived from an unusually large bed of very pure gypsum which underlies the city of Paris, France.

1.3 SLURRIES

Slurries are liquid mixtures of water and a binder material -- generally clay, cement or lime -- usually brushed on a wall in thin coats like paint. Durability is about 5 to 10 years. Slurries brushed on earth walls make economical surface coatings, but must be applied to the proper kind of earth wall. Earth walls that shrink and swell will cause slurries to crack and peel off.

Mud slurries are usually made to repair wall cracks on earth walls, nevertheless some of the best are made from equal parts of cement and lime mixed with enough water to make a thick liquid. Adding a small amount of clean, fine sand will give the slurry a gritty texture.

Before a slurry is applied, the earth wall must be moistened, and then two coats brushed on, at intervals of 24 hours. The slurry must be occasionally mixed during application or some of the materials may settle to the bottom of the container.

1.4 PAINTS

Among the different types of paints that can be applied to an earth surface -- both as a decorative and as protective coating -- are emulsions, cementitious paints, and lime-based products.

1.4.1 Cementitious Paints

Cementitious paints are water-thinned combinations of finely ground cement and pigments of high hiding power and great color retention. They do not contain lime, glue, casein or any organic binding materials that are affected by alkalies or water, but rather set by crystal formation.

Cementitious paints must be applied over a pre-wetted surface, and although they do not form the most desirable bond with clay surfaces, due to their high water resistance they are often used as a render.

1.4.2 Organic Binder Paints

Depending on the type of binder used, two types can be found:

- oleoresinous paints; oil or alkyd resin based, and
- synthetic polymer emulsions or latex paints, both form flexible hydrophobic films.

The most frequently used interior paints are the acrylic latex emulsion paints, because they dry rapidly, have no paint odor, develop a very good scrub resistance, and may be applied easily.

1.4.3 Lime casein paints

Lime casein[19] consists of a mixture of casein, hydrated lime, inert pigments, and tinting pigments.[20] Made by the oldest known method of producing casein glue, casein may be produced from cottage cheese or casein powder soaked in water mixed with slaked lime putty -- taken from a lime pit or sometimes powdered calcium hydroxide -- which acts as the hydrolyzing agent.[21]

---

[19] The preparation and uses of casein are explained in the next chapter.

[20] Theodore Zuck Penn. Decorative and Protective Finishes, 1750-1850: Materials, Process, and Craft. Thesis submitted to the Faculty of the University of Delaware, Master of Arts in History. (Delaware: June 1966), p. 82.

[21] Kurt Wehtle. The Materials and Techniques of Painting. (London: Van Nostrand Reinhold Company, 1975). p. 221.

Often used in mural paintings; lime-casein is preferred to borax casein not only because it is more stable, but also because it is more suitable, since it bonds securely with lime plaster, and requires no preparatory treatment. Untreated lime plaster is the ideal ground for lime-casein painting. Gypsum plaster can be covered with a very diluted casein solution, but gypsum does not provide as excellent a ground as lime plaster for this technique; least satisfactory of all is smooth pure gypsum plaster. Lime casein paints also work quite well on stone and clays, especially slightly absorbent stones like sandstone.

Some of casein's drawbacks are that it dries slightly brittle and with relatively high tension, and is prone to biological attack. For this reason, casein can not be used on fabrics or paper. The rougher the texture of the surface, the better it adheres.

1.4.4 Limewashes

Limewashes are a combination of hydrated lime (or slaked quicklime), water and other materials to be used as painting coating.[22] Whiting (calcium carbonate prepared as powder by grinding chalk) were traditionally mixed with glue or water, to bind them and improve adhesion.[23] Limewash, one of the simplest and most effective external paints, is a very suitable treatment for earth buildings as a finish coating. It is a fairly inexpensive protection against rain, but is most suitable for interior or sheltered walls outside. It can be easily improved with organic additives to last for several years outside. Limewash is either brushed on the adobe wall or applied with large pieces of coarse fabric such as burlap. However, it has to be renewed frequently about every year or two.

Limewashes should be applied to clean, dust-free surfaces, in at least 2 coats, but 3 or 4 are preferable. The earth wall should be moistened with lime water, but without soaking the surface with water. Drying should be slow and excessively thick coats should be avoided.[24] some modern versions include cement:

> *Whitewash, a common low-cost paint, can be prepared as a wall color by mixing equal parts of lime and white cement, adding 1 lb. of sodium chloride (common salt) per 100 lbs. of lime, and mixing with water to make a liquid of pint consistency which can be applied to earth walls or wood surfaces.* [25]

---

[22] "Standard Definitions of Terms relating to Lime and Limestone" - ASTM C-51-71, 1981, p. 3.

[23] Mixes which include tallow are not recommended for interiors, because they may inhibit the drying out of a damp plastered wall.

[24] Earth Construction Primer. (USA: United Nations Center for Human Settlements, 1984), p. 13.

[25] Paul Graham McHenry Jr., p. 134.

Limewashes' primary asset -- aside from making interior spaces lighter than earth tone adobe plaster and have disinfectant attributes -- is to act as a water repellant, providing a higher quality coating to the wall, while still allowing the transpiration of water which might otherwise cause structural damage. Initially, limewash was considered inexpensive and easy to apply, but its impermanence and the cost of annually renewing it has made it less popular as a surface coating in recent years.

1.5 PIGMENTS

Among the most suitable pigments for earthen wall's surfaces are the earth pigments -- found and used since prehistoric times as natural deposits of colored clays -- which occur in a variety of shades and intensities or minerals. For the most part the large variety of yellow, red and brown pigments are either taken from the earth as clays, such as yellow ochre and raw sienna, or derived from mineral rocks such as hematite and limonite. Blue pigments like ultramarine and azurite are rather few in number and only found in mineral rocks.

Most of the black pigments used on earthen walls are organic carbonaceous pigments which use the carbon obtained by calcining vegetable material. However, a few black or dark gray substances are used as pigments without preliminary treatment, amongst which are black lead, black chalk and coal -- all of which contain carbon.

White pigments are mainly provided by kaolin (china clay), as well as ground gypsum, shell and chalk (whiting). Oxides, metallic sulphates and carbonates are also used to prepare white pigments.

Pigments can be classified into the following four categories:

Natural Organic Pigments are obtained from animal or vegetable products. The coloring material is produced by evaporation and desiccation.

Synthetic Organic Pigments may be derivatives of aniline, phenols, quinones, or organic dyes from coal tar. Although used in the production of colored fabrics, they are avoided in walls because their resistance to light is definitely inferior to that of mineral pigments.

Artificial Inorganic Pigments are products obtained by the use of heat or chemical techniques on metals and produce compounds like lead white.

Natural Inorganic Pigments are the most important pigments, derived from clays and rock minerals and frequently used on earthen walls.

1.5.1 Natural Inorganic Pigments:

Natural inorganic pigments are found in the ground or mined in the form of oxides, sulphites, carbonates, sulphates, etc. After extraction the mineral is usually washed, before it is dried in the sun, ground and sieved to eliminate impurities and then ground to powder, cleaned and dried. Further grinding allows a finer granulation to be obtained if required.

1.5.1.1 Earth pigments

Earth pigments are present in most geographic areas, in soils containing iron compounds (iron oxides and iron hydroxides), along with varying amounts of such impurities as clay, chalk, and silica.[26] Because earth pigments occur so widely, they have always been relatively inexpensive and easy to obtain. Their color, transparency and strength tend to vary with the different deposits, some yielding more desirable colors than others. Although their collective color character tends toward a brown quality (brick reds, sandy yellows, burnt oranges), they have sufficient life and variety to produce very rich harmonies. If used in its natural state, with water as a diluting agent, the clay pigment will bond readily to earth building surfaces.

- **Ochres:** Used as pigments since early times, ochres consist essentially of hydrated ferric oxides ($Fe2O3$) and natural impurities. Different shades occur in surface deposits in many parts of the world -- the place of origin is sometimes incorporated in the name of the ochre -- as soft rocks or hard earths, and are retrieved predominantly by open-cast mining. The natural product is refined by levigation, grinding and sifting.

Ochres' colors may range between a dull yellow, red and brown, varying very little in chemical composition, so that the difference between iron oxides may be difficult to define. Some English writers of the past tend to group all ochres together, as yellow pigments,[27] because many red and brown ochres were prepared by calcining yellow.

- **Yellow Ochre:** Siliceous clay composed of weathering products of iron-bearing rocks or minerals, its coloration is produced by the hydrous iron oxides. Among its secondary components are clay (aluminum silicates) and calcium compounds. Yellow ochre is available in a great variety of shades ranging from a pale, broken yellow to brown. It is a somewhat dull pigment, but cheap and durable, therefore widely used.

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[26] Reed Kay. The Painter's Guide to Studio Methods and Materials. Prentice-Hall, Inc. (New Jersey: Englewood Cliffs, 1983), p. 6.

[27] R.D. Harley. Artists' Pigments c. 1600-1835. Second Edition, (New York: Butterworth Scientific, 1982), p. 119.

- **Red Ochre, Ruddle, Natural Red Chalk:** Composed of a mixture of iron oxide minerals and related hydrous compounds, clay and silica and natural impurities of yellow ochres, red ochre's is in great demand as a pigment because it is quite inexpensive, of a bright color, and does not fade. It can be mined directly from earth or made by calcining yellow ochre.

Different red earth pigments have been named after their place of origin, such as Armenian Red, Persian Gulf Oxide, Spanish Red Oxide, Pozzouli Red, Indian and Venetian Red.

. **Armenian Bole, Bole, Brown Red, Red Bole** (Fe2O3) This soft red ochre is composed by aluminum silicate with iron sesquioxide, rich in clay and silica -- approximately 20% Fe2O3. This pigment appears occasionally as a synonym for red ochre, but is generally associated with Armenian bole.

. **Pozzouli Red** is rich in clay and silica, contains approximately 20% Fe_2O_3. Occurs in soft earthy lumps which allows it to be reduced relatively easy to a homogeneous, soft powder.

. **Persian Gulf Oxide** may contain up to ninety-five percent ferric oxide. Very hard, almost rocklike and sometimes violet in color.

. **Indian Red, Colcothar, Rouge** is a native red ochre consisting for the most part of iron oxide, generally found in very pure hematite[28] deposits located in the East Indies, India, or the Isle of Ormas in the Gulf of Persia. It is a heavy pigment, and one of the few pigments available that inclined more towards purple than red. When it is artificially manufactured, it has a less purple cast.[29]

. **Spanish Brown** may contain up to 90 percent ferric oxide. It is a coarse native ochre, nearly the same color as Venetian Red, but contaminated. Is primarily used for coarse work by house-painters.

. **Venetian Red** is a naturally occurring red ochre. Spanish Brown is coarser than Venetian Red; Venetian Red coarser than Indian Red.

. **Burnt Sienna** Reddish-brown ferric oxide containing silicates. It is prepared by heating of the brown pigment raw sienna until it becomes orange-red. It is a very good grade of ochre, often consisting of more than 50 percent hydrated iron oxide mixed with alumina and silica. It is often used as a glaze for other colors or as a wood stain because of its transparency.

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[28] Hematites are iron oxides which occur as fibrous crystals or in masses of rounded shape, can be grey to black or reddish-black.

[29] Theodore Zuck Penn, cites G. Gregory. A Dictionary of Arts and Sciences. Vol. I, (London: Richard Phillips, 1806), p. 691.

- **Brown Ochre:** is an earthy iron oxide pigment, available in a wide range of tints from "warm" browns to "foul" oranges[30]. Once dug up, it only needs to be washed and ground before use. It is a very stable pigment although commonly used for coarser purposes.
- **Green Earth, Terra Verte, Verona Green:** Hydrosilicate ferrous and ferric silicate with clay. It is a natural blue-green ochre composed of the green minerals celadonite and glauconite, which are both generally known as Terra Verte, and occurs in a variety of shades from pale, cool greenish-gray to a warmer yellowish-or-brownish-green.

- **Other earth pigments**

- **Raw Sienna, Sienna, Terra di Sienna:** Natural earth pigment composed by a bright yellow hydrated iron oxide, differing in composition from the ochres by a considerable content of colloidal silica. The shade appears as an artificial iron oxide containing some manganese dioxide of moderate darkness with somewhat higher saturation.
- **Raw and Burnt Umber:** (no definite formula) This very stable brown natural earth bears some similarity to ochres, but in addition to hydrated iron oxide, silica, alumina and lime, it contains manganese dioxide, which imparts both its brown appearance and different characteristics than the ochres. While unburned, raw umber is light in color; when calcined it takes on a warmer reddish-brown color. Burnt umber is slightly easier to grind than raw umber; otherwise their physical characteristics change very little.
- **Burnt Green Earth:** Iron-III-silicate combined with alumina. It is a blue-green ferrous oxide which changes to a reddish ferric oxide when artificially calcined, resulting in a light brown.
- **Terre Noir:** A mixture of the carbonates of calcium, iron and manganese with clay.
- **China Clay, Pipe Clay, Kaolin, Bougival White, Rouen White:** ($Al_2O_3 . 2SiO_2 . 2H_2O$) Consists essentially of hydrated silicate of alumina in a complicated chemical composition. China clay is mined directly from naturally occurring deposits and requires little more than washing and dying before it is used.

There are also other inert white substances that seem to be part clay and part chalk, such as Bougival and Rouen white but they are not as good as purer clay pigments.

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[30] R.D. Harley, p. 134.

- Calcium compounds: Among naturally occurring sources of white pigments based on calcium are chalk[31] or lime (calcium carbonate), and gypsum (hydrated calcium sulphate).

Calcium carbonates ($CaCO_3$) are used as body colors for distemper paints, and whiting could be of any white pigment made from a clay, chalk, or marble dust base.[32] In the past it was broken up under a runner stone, then washed and formed into cakes and dried before use as common white-washing for apartments. Calcium sulphate ($CaSO_4 . 2H_2O$) Gypsum, Plaster of Paris.

1.5.1.2. Rock Mineral Pigments

Rock minerals will be referred as the mineral pigments that have to be laboriously crushed and in many cases refined before use.

- Cadmium Yellow: (CdS) Cadmium sulfide. Its occurs extremely rarely as the natural mineral greenockite, being artificially prepared by various precipitation processes. Its appearance ranges from pale, cool yellow to warm orange -- similar to chrome yellow.

- Orpiment: (As_2S_3) Arsenic Trisulphide. It is a natural bright yellow mineral pigment that occurs only in a few places in Eastern Europe, Central Asia and China. It is one of the most unpopular of all natural colors because of its poisonous nature, dangerous fumes and offensive smell. Also made artificially from arsenic trichloride and sodium thiosulfate, the product is called King's Yellow.

- Realgar, Arsenic Orange: (As_2S_2) Arsenic Sulphide. Natural mineral orange-red pigment which occurs naturally in monoclinic crystals. Since Reagar is closely associated with Orpiment -- another sulphide of arsenic usually found with it in the same deposits although in smaller quantities -- it is also referred to as red orpiment. Realgar is highly poisonous and can also be artificially made with a slight tooth into a powder.

- Vermillion, Cinnabar: (HgS) Mercuric sulphide. Naturally occurring red mercuric sulphide of a bright red tone, sometimes with a yellow tinge, which is rare in natural products. Generally the natural mineral is called Cinnabar, while vermillion is the name given to the artificially prepared sulphide of mercury. It is found either in the form of small rust-colored crystals that when ground yield brilliant red vermillion, or in the form of bright red deposits in certain rocks.

- Lapis Lazuli: (approximate formula $Na_8 (Al_6Si_6O_{24}) S_4$) It is a blue pigment made from the naturally occurring mineral lazurite which may vary from extremely hard, cleavable plates of semi-precious stone to calcareous rock in which silica is interspersed with blue fragments of various sizes.

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[31] The general term chalk might indicate any calcium carbonate in its crude white or yellowish state.

[32] Theodore Zuck Penn, p. 19.

- **Natural Ultramarine, Ultramarine Ashes:** ($3Na_2O$. $3Al_2O_3$. $6SiO_2$. $2Na_2S$) Ultramarine is prepared from the blue part of the semi-precious stone Lapis Lazuli, a mineral of the sodalite group which occurs in many parts of the world. [33] It is a pigment particularly difficult to make because it is hard to grind fine enough to use. It is prepared by heating, quenching in acetic acid and crushing the lapis lazuli in order to free the mineral as far as possible from natural impurities like quartz, calcite, mica and pyrites. Although it is an extremely bright blue and very stable, the mineral is not used in large areas on buildings because it is very expensive.

Ultramarine ashes is the pigment made from the residue left from making ultramarine.

- **Azurite:** ($2CuCo_3$. Cu $(OH)_2$) Basic copper carbonate. A rare and prized natural mineral pigment resulting from the weathering of copper sulfide minerals, found in close association with malachite.
- **Malachite, Chrysocolla:** ($CuCO_3$. $Cu(OH)_2$) Basic copper carbonate. Naturally mineral pigment, made by laboriously crushing, grinding and pulverizing the hard mineral. Malachite is a semi-precious stone, closely related chemically to azurite and rarely used in large quantities on walls.
- **Manganese Black:** (MnO_2) Manganese dioxide. Its natural impurities are removed by grinding. Very deep neutral gray.
- **Mineral Black:** Aluminum silicate with up to thirty percent carbon. This black slate occurs throughout the world generally in a blue-gray tone, but in some locations it is almost black, depending on the content of aluminum silicate.
- **Barytes, Permanent White:** ($BaSO_4$) Barium sulphate compound found in the mineral Terra Ponderosa. The process is described by William Partridge for preparing the natural barium sulphate, in the USA. The first step was to separate the whiter portions of Terra Ponderosa from the yellower, then the mineral was

> *...ground in large flat stone mills under water till the material is perfectly fine... The ground material ...is conveyed into settling tanks...so that any coarse particles are separated out and ground over again...*[34]

After bleaching to remove any iron in the mineral, barytes became perfectly white. Then, it was washed, dried, and ready to use. Often used as a extender or in binding media, barytes are also artificially made by precipitation from barium chloride and sulfuric acid.

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[33] R.D. Harley, p. 43

[34] William Partridge. Practical Treatise on Dying Woollen, Cotton, and Silk.... (New York: William Partridge, 1834), pp. 32-33.

CHAPTER 2: NATURAL AMENDMENTS ON EARTHEN SURFACES

Natural products have been traditionally used since ancient times on earthen buildings surfaces in order to improve their resistance to rainfall or as stabilizing agents. These natural amendments are extracted from vegetal, animal or mineral products, and include bitumens, plant extracts, and even fresh animal blood.

Opinions on their efficiency are diverse and often contradictory. As discussed in this chapter, some studies assert the effectiveness of certain amendments for specific cases and others report -- based on laboratory tests -- no considerable improvement on the properties of buildings made with some of the additives as compared to those without them.[1]

Although there is no question about the influence of organic substances on clay minerals and accordingly many natural products have been traditionally used as stabilizers and consolidants since prehistoric times, their stabilizing mechanism is hardly known, and almost no scientific data on the evaluation of these techniques and materials on earthen plasters has been drawn yet.

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[1] At the Universidad Católica, Perú; three different natural stabilizers were tested, having hardly any result for two of the products tried. Povindar K. Mehta; Julio Vargas Neumann; Ernesto Heredia Zavoni; and Juan Bariola Bernales, Preservación de las construcciones de adobe en áreas lluviosas. Proyecto financiado por la agencia para el desarrollo internacional, Publicación DI-86-02, (Lima: Pontificia Universidad Católica del Perú, Mayo 1986) .

2.1 PLANT EXTRACTS

2.1.1 Natural resins, gums and mucilages

Natural resins[2] are obtained from the species of plants that exude a liquid whenever the leaf stems or young shoots are cut, from the aqueous extract of empty fruit pods, as well as from boiling the bark of some trees. The elastic liquid obtained solidifies when dried and has been traditionally used as a protective coating in various areas of the world.

In northern Ghana, walls are plastered with mud stuccos mixed with manure and an extract obtained by boiling pods from the locust bean tree.[3] In South America and Africa, latex from the rubber plant *(Hevea Euphorbiacex)* is used as a waterproofing coating. In other areas, coatings are made by boiling the stem and leaves of the banana plant.[4]

Another natural substance used by some cultures in desert regions as an amendment to adobe plaster is the mucilage obtained from cacti such as Agave and Tuna. In Perú a viscous fluid is obtained from a cactus plant (tuna) mixed with clay and used for plastering adobe walls. Among the extensive variety of natural substances used as additives in plasters, the most used are:

2.1.1.1 Agave

Many species of Agave cactus *(Leuchtenbergia principis, Lophanta,* Mexican variation: *Caeruslens* and *Lechuguilla)* are native from arid and semi-arid warm regions of the western hemisphere, like Mexico[5] and the Southwestern U.S.

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[2] The terminology of natural gums and resins is inconsistent and often confusing. The word "gum", often used as an adjective, seems to acquire a different meaning from the noun. Resins are complex mixtures insoluble in water, while gums are compounds that can be represented by a formula and generally soluble or dispersible in water. It is probable that the confusion originated in the casual use of "gum" to refer to any soft sticky product derived from trees. (For appropriate definitions, refer to the Glossary). Hawley's Condensed Chemical Dictionary, Eleventh edition revised by N. Irving Sax and Richard J. Lewis, Sr. (New York: Van Nostrand Reinhold Company, 1987), p. 581.

[3] Hannah Schreckenbach. Construction Technology for a Tropical Developing Country. Department of Architecture, Published by the German Agency for Technical Cooperation. (Kumasi, Ghana: University of Science and Technology, 1984), p. 83.

[4] Ibid, p. 112.

[5] In Mexico, these agave species furnish food, drink, fiber, and soap. Hortus - A concise dictionary of gardening and general horticulture. Compiled by L.H. Bailey and Ethel Zoe Bailey. New revised edition with supplement (New York: The Mac Millan Co., 1953), p. 29.

The agave cactus extract, has been used as a consolidant for earthen plasters by some desert cultures, extracting the mucilage[6] from the cactus leaves by boiling and pounding the pulp. The undiluted extract is steeped for approximately two or three weeks before use and after this period of time mixed with mud plaster.[7]

2.1.1.2 Arabic Gum

Arabic gum is produced by several species of Acacia *(Leguminosae Arabica)*, a tree or shrub mostly of the tropics or warm temperate regions, particularly Australia, Sudan and California (USA).[8] The exudation of the gum is stimulated by making incisions of about 5 to 10 cm. in the bark of the trunk when the tree is between six and thirty years old.

Arabic gum is a carbohydrate polymer, complex and highly branched, composed of calcium, magnesium or potassium salts to which are attached sugars such as 1-arabinose and 1-rhamnose.[9] Soluble in hot and cold water and insoluble in alcohol, arabic gum acts as an impermeabilizing agent. Its lumps vary in size and the color may range from pale, brownish-yellow to light reddish-brown.

Used as a traditional fixative when added to a sandy soil, arabic gum produces a good interior protective coating which is hard, does not crack and adheres well. It is also an excellent protective colloid and for this reason is often used to stabilize emulsions or dispersions and as a thickening agent. However, it performs poorly if exposed to exterior moisture because of its high sensitivity to humidity, vulnerability to biological agents, and discoloration.

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[6] As described in the Hawley's Condensed Chemical Dictionary, p. 800; mucilages are plant products extracted from seeds, roots or other parts of the plant by the use of either hot or cold water. Mucilages are closely related to gums, although the distinction between them is not always clear. (See Glossary)

[7] This mixture was used by Michael Romero Taylor in panel test walls at Fort Selden, New Mexico, USA in two versions: undiluted, and mixed in a 1:1 solution with water resulting in moderate to serious erosion in both cases and no change in color comparing the treated samples with the untreated plaster.
Michael Romero Taylor. "Fort Selden Test Wall Status Report", Fifth International Meeting of Experts on the Conservation of Earthen Architecture. (Roma: ICCROM / CRATerre, 1987), pp. 91-102.

[8] Bailey and Bailey. Hortus - A concise dictionary of gardening and general horticulture, p. 31

[9] Hawley, R., p. 95.

2.1.1.3 Banana and Plantain Stalks and Leaves

Banana *(Musa Paradisiaca)* is a tropical tree extensively grown for local use.[10] Two products are extracted from this tree for its use as earthen buildings amendments: a thick mucilage, produced from boiling the stalks and leaves and used as a waterproofing agent, and the fibers present in the substance, which control the formation of surface cracks during drying. *(See 2.1.4 Fibers)*

In Ghana, where banana and plantain are cultivated, this mucilage is applied as a wash on the plastered mud walls to enhance its water resistance.[11] One way to prepare this substance is to remove the stalks and leaves from the plant, cut them into very small pieces, and submerge them in a 40-gallon drum in a ratio of 2 parts of cut-up pieces to one part of water. The mixture is boiled and the ingredients mashed periodically until the substance thickens. The remaining heavy material is then filtered and applied achieving a good protection of the rendering walls for about three years before re-application becomes necessary.[12]

2.1.1.4 Caoutchouc (polyisoprene (C_5H_8)x)

Caoutchouc derives from latex[13] obtained from the Para-Rubber tree *(Hevea Brasiliensis* and *Hevea Euphorbiacex)* a rubber tropical tree that grows in South America and Tropical Africa, and is the most important natural source of rubber[14] Caoutchouc is comprised of globules of rubber hydrocarbon coated with protein in a suspension stabilized by electric charges and its composition is about 60% water, 35% hydrocarbon, 2% protein and low percentages of sugars and inorganic salts.[15]

Caoutchouc is soluble in acetone, carbon tetrachloride and most organic solvents. Due to its high tensile strength and relatively low permanent set, it has been used as an adhesive and waterproof coating, as a binder in interior and exterior paints, and replacing drying oils.

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[10] Bailey and Bailey, p. 38.

[11] Hannah Schreckenbach, p. 112.

[12] Ibid, p. 112.

[13] Hawley, R., (p. 684), defines latex as a white, tacky, aqueous suspension of a hydrocarbon polymer occurring naturally in some species of trees, shrubs or plants.

[14] Webster, R.H. Webster's Third New International Dictionary of the english language unabridged. (Springfield, Massachusetts: A. Merrion Webster Inc. Publishers, 1986), p. 305.

[15] Hawley, R., p. 684.

2.1.1.5 Dammar

Dammar is the general name given to a group of natural resins originating from the *Diopterocarpaceae* family of trees -- especially from evergreen trees of the genus *Agathis, Sharea, Balanocarpus* and *Hopea* -- that grow mainly Malaya, Indonesia and the East Indias.[16] The most used varieties are obtained by making incisions in the trunks of trees, but the harvesting of the resin is often very difficult because the trees have to be 50 years or older in order to produce well.

Dammar has excellent adhesive properties and is only slightly acidic, but the films obtained from this resin are soft, have low resistance, and tend to become slightly sticky. It is soluble in white spirit, aromatic solvents and turpentine. The use of this resin for rendering mud and reed-walls waterproof appears to have had a set tradition. From the various references cited below, it would be evident that dammar was in use as a waterproofing medium for a long time.

In Bayiman, Afghanistan, a bituminous substance that was found used on clay plasters, turned out to be an organic resinous matter presumably obtained from the pine (pinus longifolia) wood available locally. From the account of the *Cullavaga*,[17] it may be assumed that during the time of the Buddha, people were aware of the efficacy of Dammar.

A report done by Dr. B.B. Lal, Chief Archaeological Chemist at the Bayiman ruins, observes:

> *On the separation from the plaster, the tarry matter was found to liquify when heated to about 138 °C, although it was found to soften at much lower temperature. The tarry matter has been found to be mixed up with straw and vegetable fibers. It is probable that this organic resinous matter swells on treatment with water, finally producing an aqueous emulsion. It is therefore, probable that the mud plaster was prepared by incorporating in the clay an appreciable amount of an aqueous emulsion of this material.*[18]

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[16] Robert L. Feller; Nathan Stolow; and Elizabeth H. Jones. On Picture Varnishes and their Solvents. Third Edition. (Washington D.C.: National Gallery of Art, 1985), pp. 120-121.

[17] Cullavaga, VI, 3, 2 .

[18] R. Sengupta. "Use of Dammar as a waterproofing medium for painting at Bayiman", Indo-Asian Culture 4. Vol. XVII, (October 1968): 39-42.

In the *Cullavaga* the Buddha is said to have advised his followers to apply slime of trees (*ikkasa*) and astringent liquid (*kasayam tuamalka haritakiyam kasayam*) on the surface of mud walls before painting, obviously to render the wall damp-proof. The slime of trees can be identified as a kind of gum or dammar which was used in the plaster called vajralepa for similar results. Pliny, the Roman naturalist, (24 A.D.) also refers to the production of wood tar and wood-tar pitch and used for waterproofing pottery, chalking ships and as a paint for roofs and walls.[19]

2.1.1.6 Locust Bean

Locust Bean (Ceratona Siliqua, Parkia Clappertoniana, West African Locust Bean, or Carob Tree), is a leguminous tree that grows in the Mediterranean region. It produces a purple brown gummy mucilage from boiling its empty fruit pods.[20] Locust bean gum (or carob-seed gum) is a polysaccharide plant mucilage -- essentially galactomannan (carbohydrate) and tannin acid -- that swells in cold water and increases in viscosity when heated.

Locust bean gum is insoluble in organic solvents and combustible,[21] and can be used as a stabilizer, thickener, emulsifier and sizing agent. Sometimes the locust tree's bark is also boiled out and the extract used for the same purposes. In Ghana Locust bean gum has been used on earthen building materials, often applied on top of the freshly plastered or decorated walls, as a waterproofing agent and to harden laterite walls and floors.[22]

2.1.1.7 Manilla

Manilla resin is a natural type of copal resin *(Musa lexlilis)* imported from the Philippine Islands and East Indies, used specially in the production of varnishes. It is soluble in ether, methanol, amyl alcohol and insoluble in water, and contains about 80% of monophalolic acid. Manilla resin can be used as a sealer for absorbent ground,[23] as an isolating varnish over tempera underpainting, or as a varnish, paint or lacquer.

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[19] Herbert Abraham. Asphalts and Allied Substances. Sixth Edition, Vol. I. (Princeton, New Jersey: Van Nostrand, 1960), p. 58.

[20] Webster's Third New International Dictionary, p. 434.

[21] Hawley, R., p. 226.

[22] Hannah Schreckenbach, p.83.

[23] Jefferey R. Stewart. The National Paint Dictionary. (USA: Stewart Research Laboratory, 1940), p. 69.

2.1.1.8 Rye Flour

Rye flour *(Secale Cereale or Elymus)* forms a water soluble vegetable glue[24] which increases surface hardness and abrasion resistance.

2.1.1.9 Tuna Cactus

Tuna cactus *(Prickly-Pear, Cholla or Opuntia Ficus Indica)* is a spineless, large, and bush-like or sometimes tree-like cactus of undetermined nativity, widely spread over the world, that produces a mucilage extracted by boiling its leaves. This mucilage is composed of sulfuric acid esters -- contained in the vesicular cells of the parenchymatic structure of the cactus -- has conglomerating properties and avoids the formation and proliferation of bacteria, promoting the consolidation of materials.[25]

The mucilage is prepared by removing the spines from the cactus leaves, slicing them and submerging the cut pieces in water. This mixture must be soaked for several days (14 to 25) until the color of the solution changes from clear to green, becomes thicker and darker, and has a strong smell of decomposed organic matter. During this period, the pulp of the plant has dissolved completely, leaving only the skin remnant.[26] This mucilage has been traditionally used both as an additive[27] and as a consolidant on earthen constructions in many areas of South America, particularly in Perú.[28] One way of application is explained by a widely distributed Peruvian guidebook:[29]

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[24] Hawley, R. (p. 197), defines glue as a colloidal suspension of various proteinaceous materials in water.

[25] Ana María Hoyle. "Chan-Chan: Aportes para la conservación de la arquitectura de tierra", 6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints. (Las Cruces, New Mexico: The Getty Conservation Institute, October 1990), p. 226.

[26] In Chan-Chan, Peru; Ana Maria Hoyle describes another method, soaking the pulps for only 24 hours and using the substance after that period of time. This solution has only a 48 hour life upon soaking. After that period of time its cells decompose causing on 85% of loss of viscosity.(See Case Study).

[27] In order to protect the mud plaster and increase its resistance to rain and weathering.

[28] Povindar Mehta; Julio Vargas Neumann; Ernesto Heredia; and Juan Bariola, p. 25.

[29] Pontificia Universidad Católica del Perú. "Nuevas casas resistentes de Adobe" Cartilla de difusión No. 2, Región de la Costa. Agencia para el desarrollo Internacional USAID / Perú, (Lima, Perú: Servicio Nacional de Capacitación para la industria de la construcción, 1979), pp. 13-17.

> *A first coating of the mucilage is applied to the adobe wall and left to dry. After three days, a second coat is applied, followed by the mud plaster which has been prepared by mixing clay, the cactus stabilizer and straw in the proportions 6:3:2. The stucco is then applied in two layers: the first coat -about 12 mm. thick- must be trowelled and left to dry. The second mud plaster coating must be thinner -3 mm.- in order to cover the cracks left by the first coat and to obtain a better finish.*
>
> *Finally, the surface is first rubbed with a granitic stone giving the wall a coarse surface, which is followed by a basaltic stone which gives the definitive smooth one. At this point the surface is painted with the cactus extract. This polished surface has the property of increasing the resistance of adobe walls to rain.*

It has been observed that in Chan-Chan -- La Libertad, Perú -- one of the largest archaeological ruins dating from 800 to 1400 A.D. constructed of unbaked earth, the same technique of polishing the earthen stucco with hot stones was used to both dry the plaster and "bake" the cactus stabilizer, producing a more resistant finish.[30] It has been reported that the Tuna Cactus extract used as a consolidant does not form a water repellent film. The solution can be re-applied, therefore allowing other substances to be applied over it. Unfortunately, it loses its cohesion properties after some time (not yet determined through research), making it necessary to frequently repeat the treatment.

Case Study

Tuna Cactus Extract *(Opuntia Ficus Indica)*[31]
Location: Chan-Chan, Trujillo, Perú
Period: 1987-1990
Solution: 350 gr. from the interior of the cut leaf, left under 0.5 lt of water for 24 hrs, mixed with water at 5-10%, in order to achieve a lower viscosity and a better penetration into the wall. This solution has been used as a consolidant and as an additive for mortars.
Penetration: About 3 cm.

It would be premature to draw conclusions about the consolidation properties of this Cactus extract, after three years of treatment. Only at the "Tschudi Palace" a consolidation treatment was attempted, consisting on application of the solution at 5% with a brush. There was an initial color variation, but after some time the walls returned to their original color.

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[30] María Teresa Patiño-Patroni Baronio. El mejoramiento de la construcción con tierra o suelo. Tesis de Grado para optar el título de Ingeniero Civil (Lima, Perú: Universidad Nacional de Ingeniería, 1986), p. 9.

[31] Ana María Hoyle, pp. 225-229.

2.1.2. Organic Acids

Although opinions on the efficiency of organic amendments on earthen finishes is questionable, one hypothesis on the use of organic stabilizers suggests that the organic activity promotes the multiplication of bacteria and the formation of amino acids (thus modifying the acidity index), and creates better conditions for the flocculation of the finest particles of the soil.[32]

Among the organic acids employed on traditional construction that might confer a stabilizing action to earthen materials, are tannic acid and humic acid.[33]

2.1.2.1 Humic Acid

Humic Acid is a brown polymeric constituent of soils, lignite and peat which contains the brownish-black pigment of melanin. It is soluble in bases, but insoluble in mineral acids and alcohols, and is an excellent chelating agent.[34]

2.1.2.2 Tannic Acid

Tannic acid is a natural substance widely found in nutgalls, tree barks, and other plant parts. Tannins are known to be gallic acid derivatives. A solution of tannic acid will precipitate albumin. It is lustrous, faintly yellowish, darkens on exposure to air, and is soluble in water, alcohol and acetone.[35]

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[32] Jeanne Marie Teutonico and Alejandro Alva. "Notes on the Manufacture of Adobe blocks for the restoration of Earthen Architecture", (unpublished paper, Rome: ICCROM, 1983), p. 50.

[33] Patrice Doat; Alan Hays; Hugo Houben; Matuk Silvia; and Francois Vitoux, Construire en Terre. (Paris: Editions Alternatives, 1979), p. 217.

[34] Hawley's Condensed Chemical Dictionary, p. 609.

[35] Hawley's Condensed Chemical Dictionary, pp. 1118-1119.

2.1.3 Vegetable Oils

Vegetable oils are obtained from plants, especially from seeds, fruits or nuts, and generally considered to be a mixture of glycerides. Many types are edible used as shortenings, salad dressings, margarine, soaps, in paints (as drying oils), rubber softeners, and pesticide carriers.[36]

2.1.3.1 Abrasin Oil

Abrasin oil is a pale yellow pungent drying oil obtained from the seeds of the Aleurites tree *(Fordii Euphorbiacex)*[37] which is native to southern China and Indo-China, being extremely close in all its properties to tung oil.[38]

This oil is composed of glycerides especially of eleostearic acid and other unsaturated acids that polymerize to a hard gel on long standing or on heating. It is used as an additive for quick drying and as a waterproofing agent.[39]

2.1.3.2 Castor oil (or ricinus oil)

The castor oil plant *(Ricinus Communis or Palma Christy)* grows in tropical Africa and India.[40] Its fruit contains three large bean-shaped seeds rich in oil which is clear, colorless and relatively high viscosity. It would be an ideal painting medium since it does not yellow but it dries so slowly that it cannot be counted among the drying oils. Used extensively for medical purposes and as a plasticizer in lacquers, aniline inks and artificial leather, castor oil is classified under non-drying oils.[41]

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[36] Hawley's Condensed Chemical Dictionary, p. 1219.

[37] Bailey and Bailey, Hortus A concise dictionary of gardening and general horticulture. p. 8.

[38] Although Jefferey R. Stewart specifies abrasin and tung oils are two distinct types of oil, he does not describe the differences between tung and abrasin oils. Other sources consulted refer to both as analogous oils.

[39] Bailey and Bailey, Hortus A concise dictionary of gardening and general horticulture. p. 8.

[40] Bailey and Bailey, Hortus A concise dictionary of gardening and general horticulture. p. 45.

[41] Jefferey R. Stewart, p. 22.

2.1.3.3 Coconut Oil

Coconut oil is a non-drying oil extracted from the "Copra", the dried nut meat of a widespread palm *(Cocos Nucifera)*, of Asiatic or Polinesian origin.[42] It is a white, semi-solid fat containing C_{12} to C_{15} and constituted of glycerides of lauric acid and of capric, myristic, palmitic and oleic acids. It is soluble in alcohol, ether, chloroform, carbon disulfide and immiscible in water.[43]

2.1.3.4 Hempseed Oil

Hempseed oil is a light green to brownish yellow drying fatty oil obtained from the Hempseed herb *(Cannabis Sativa, Moracex or Agnus Castus)* native from Asia and East North America.[44] Similar in properties and uses to linseed oil, hempseed oil is a very combustible, non-toxic and edible oil, that contains about 10% saturated fatty acids (palmitic and stearic). The unsaturated acids present in this oil are linoleic, linolenic and oleic.[45]

2.1.3.5 Linseed Oil

Linseed Oil is a golden-yellow, amber or brown drying oil with peculiar odor and bland taste, derived from seeds of the flax plant *(Linum Usitatissium)*, an erect herb or subshrubs furnishing fiber and linseed oil) through expression or solvent extraction.[46] It is soluble in ether, chloroform, carbon disulfide and turpentine, and has the tendency to turn yellow and eventually brown when used as a binding medium for pigments, especially on oily grounds.

Used as an additive on paints and varnishes for its drying properties, when linseed oil is added to limewash, it improves the material for painting large areas.[47] Linseed oil also improves the durability and adhesion properties of materials and withstands variations in humidity.

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[42] Bailey and Bailey, Hortus A concise dictionary of gardening and general horticulture. p. 49.

[43] Hawley's Condensed Chemical Dictionary, p. 297.

[44] Bailey and Bailey, Hortus A concise dictionary of gardening and general horticulture. p. 105.

[45] Hawley's Condensed Chemical Dictionary, p. 591.

[46] Hawley's Condensed Chemical Dictionary, p. 591.

[47] Kurt Wehlte. The materials and techniques of painting. (London: Van Nostrand Reinhold Company, 1975), p. 213.

Linseed oil has been used in clay plaster consolidation -- earth walls treated with linseed oil and subsequently polished can be satisfactory and very agreeable -- and in mud floor consolidation.[48] In Fort Selden, New Mexico, USA, it was used in panel test walls in order to observe its consolidation properties, in a solution of 1 part linseed oil to 5 parts mineral spirits, resulting in moderate to serious erosion and darkening the wall surface.[49]

2.1.4. Fibers

Many fibers such as straws, animal hairs, yucca or pine needles, bark and wood shavings, [50] chopped to fairly short lengths (1" to ½") and added to plaster mixtures act as tensile reinforcements. The amount of fibers required in a plaster mixture is proportional to the "strength" of the material and the quantity of aggregate and water used. One modern West Country builder[51] states that,

> *...the straw makes the cob less sticky. You should add water and straw to the material gradually. Too much straw and the cob gets weak, like dung...*

2.1.4.1 Straw

Many early bibliographic references describe straw as an additive for earthen buildings. A reference in the Old Testament[52] suggests that it was known and used on earthen buildings since ancient times:

> *That very day Pharaoh ordered the people's overseers and their foremen not to supply the people with straw used in making bricks, as they had done hitherto...*

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[48] William Lumpkins, "A distinguished architect writes on adobe" Adobe Past and Present, p. 7.

[49] Michael Romero Taylor. "An evaluation of the New Mexico State monuments adobe test walls at Fort Selden", 6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints. (Las Cruces, New Mexico: The Getty Conservation Institute, October 1990), p. 385.

[50] Lyle Wolfskill and Wagne Dunlop, p. 77.

[51] J.R Harrison. "The 'slow' method of construction of traditional wet mixed and placed mass sub-oil walling in Britain", 6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints. (Las Cruces, New Mexico: The Getty Conservation Institute, October 1990), p. 66.

[52] Exodus 5, 6-7.

Another reference from The Home Missionary[53], asserts:

> *All soils are acceptable except for pure sand or pure gravel. The best material is two thirds of clay and one third of sand, with the straw and water requisite...*

In Improvements in Agriculture and the Arts[54],

> *After selecting a suitable spot of ground, as near to the place of the building as practicable, let a circle of ten feet or more be described. Let the loam be removed, and then the clay dug up one foot thick, or, if the clay is not found on the spot, let it be carted in to that depth. Any ordinary clay will answer. Tread this clay over with cattle, and add some straw cut six or eight inches long...*

Although the straw's action as a stabilizer is quite questionable since it has been proved that the amino acid formed when the straw putrefies in the mud has no improving effects, it is still considered a good reinforcement agent with multiple roles:

- Enhances tension resistance and prevents cracks on drying by distributing on all the mass the tensions resultant of the shrinkage of clay, a mechanical function of the aggregate during the dehydration (drying) of the clay. The fibers compensate for the stresses induced by the shrinkage and fractures.[55] For binding purposes within the material, the longer fibers were better.[56]
- Accelerates the drying, since the straw's canals drain the humidity to the exterior of the wall.
- Lightens the weight of the material. The volume of straw used generally overtakes half the volume of clay, resulting in a less dense and better thermal insulation material.

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[53] The Home Missionary 5. Vol. XVII, (September 1844): 33.

[54] Henry Levitt Ellsworth. Improvements in Agriculture and the Arts of the United States from 1791- Jan. 1830. (New York: Greeley and McElrath, 1843).

[55] Alejandro Alva and Jeanne Marie Teutonico, p. 50.

[56] J.R. Harrison, p. 67.

2.2 ANIMAL PRODUCTS

2.2.1 Animal Fats: Tallow

Clarified animal fats from cattle, sheep, horses and pigs, generally obtained from a slaughterhouse, are composed of glycerides and contain oleic acid, palmitic acid, stearic acid, myristic acid and linoleic acid, in addition to a small amount of cholesterol and other fatty acids.[57] Traditionally used as a binding and weatherproofing medium adding 10% by weight to lime, tallow has the property of increasing plasticity and adhesion.

2.2.2. Animal Glues

The most common animal glues used as coatings and stabilizers for earth are rabbit and fish glue. These glues are collagens (water soluble proteins), the basic material used as a fixative, as a binding medium and for traditional consolidant mixtures. Unfortunately, these additives have many drawbacks: they eventually lose solubility, have a tendency to darken and contract upon ageing, impart a low permeability thus forming surface films, and finally induce biological attack in moist conditions.

One traditional glue consolidant has the following ingredients: animal glue (adhesive) mixed with siccative oil (plasticizer), vinegar (fluidifier) and ox gall (wetting agent). The application of the heated solution would be done by brush.

2.2.3 Blood

The use of blood with clay and lime finishes is extensively quoted. The addition of fresh blood -- a complex liquid tissue comprised of erythrocytes, leucocytes, platelets, plasma, proteins and serum -- to earth, earth-lime or lime concrete floors improves water resistance and creates a hard-wearing surface which can take a certain amount of polish. Molecules of the blood protein and hemoglobin apparently are responsible for the strong bond between the various particles after air-drying.[58]

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[57] Liliane Masschelein-Kleiner. Ancient binding media, varnishes and adhesives. Translated by Janet Bridgland. (Rome: ICCROM, 1985), p. 43.

[58] Erhard Winkler. "The effect of blood on clays", Soil Science 82. (September 1956): 157-164.

Generally used for adobe floors, fresh blood is best used with lime or hydraulic lime binder. Because there is a risk of mould growth the entire area should be spray treated with a biocide when cured.

One traditional belief on the use of blood for protecting houses, is described by Erhard Winkler:[59]

> *...the use of blood with clay probably goes back to the ancient cult of Mithras which originated in Asia Minor. In the belief that Mithras' slaying of the bull brought life to the earth, bull's blood became a symbol of the sap of life with a power to protect houses (of clay) from the attack of Ahriman, the evil power. As a matter of fact clay houses which had been treated with blood did withstand better the sudden cloudbursts of semi-arid Asia Minor...*

One English recipe describes a blood and lime mortar:

> *Mix the hydrated lime with 2 ½ parts (by volume), well graded sharp sand and grit. Water until damp, but not yet plastic. Add fresh blood obtained from a local abattoir, slowly, turning over the mix until it is fat and easily workable, but not too wet. Wet the substrate so that it does not take moisture for the screed and tamp the blood mortar. Level firmly and uniformly with a board. Finish the screed by working it with a wood float. If a polish is required this can be formed by alternatively scouring and floating with a little water as the set begins to take.*[60]

Two laboratory studies have been done on the use of blood on plasters: Erhard Winkler in 1956[61] tested nine different types of clays, concluding that mixtures of clay with blood generally increase plasticity, water resistance, and dry compressive strength and that the tight monolayer coats of blood wrapped around the clay crystals may be responsible for increase and hardness and water repellency. It was also found that the crystals lattices of clays are not affected by the presence of blood.[62]

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[59] Ibid, p. 157.

[60] John & Nicola Ashurst. Brick, Terracota and Earth - Practical Building Conservation. Volume 2 (Great Britain: English Heritage Technical Handbook, 1988), p. 114.

[61] Erhard M. Winkler, p. 164.

[62] Ibid, p. 162.

A more recent laboratory study done by Lauren-Brook Sickels in 1980 using blood as an additive for mortars[63] found that blood was not a good waterproofing mixture for limes, since the material treated (made up of 1 part lime to 3 parts sand) broke into several pieces after exposure to a one-minute rainfall.

2.2.4 Casein

Casein is a colloidal aggregate composed of several identifiable proteins together with phosphorous and calcium[64] occurring in mammals' milk as an heterogeneous complex called calcium caseinate, which can be isolated by coagulation under the influence of certain acids or of rennet.

Pure casein can be obtained in the form of a yellowish white tasteless and odorless powder which is called "cold glue", but commercial casein is contaminated with several impurities, which gives the powder a yellowish-grey color with a slight cheese odor. Insoluble in water, alcohol and other neutral organic solvents, casein is soluble in the carbonates and hydroxides of the alkali and alkaline earth metals as well as in ammonia. If the alkali is lime, the product is highly water-resistant, improving its resistance to rain. Unfortunately, the use of casein is irreversible having a tendency to form films and contract on aging. In moist conditions, there is also risk of biological attack.

Casein has been used by wood workers as a glue and by artists principally as a fixative for drawings and as a binder for color and grounds.[65] The employment of casein for architectural purposes has a long tradition dating back to the Egyptians where lime-casein has been used to protect renders. Caseins and glues give greater binding properties to clay and lime mixtures. These coatings are inexpensive and easy to apply, provide at least temporary surface protection, and are still readily available. On earthen buildings, it has occasionally been used as a mixture of a small amount of milk and ox's blood.

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[63] Lauren-Brook Sickels. "Organics vs. Synthetics: Their use as Additives in Mortars", Mortars, Cements and Grouts used in the Conservation of Historic Buildings. Symposium 3-6.11.81, Rome (Rome: ICCROM, 1982), pp. 25-52.

[64] Hawley's Condensed Chemical Dictionary, p. 228.

[65] Jefferey R. Stewart, p. 22.

2.2.5 Excrement

Excrement has been extensively used as a traditional amendment on earthen buildings and plasters. One of the significant constituents of dung -- especially cow's dung -- is a mucus that may add plasticity to earths, therefore, potentially useful in soils with low clay content, as well as flocculating soils with an over-expansion clay fraction.[66] This mucus reacts with lime to form a gel that has the desirable effect of supporting the lime and sand until strength due to carbonation is achieved, and stabilizes the clay mineral wafers contained in the soil.[67] Dung also contains short fibers which act as tensile reinforcement in earth plasters.

Dung is applied to the mud plasters when partially dry and is effective in filling the hair cracks and voids in the plaster, and helping in stopping further cracks in the plaster.[68] In India, Gohber (cow dung) leaping has been reported on earth surfaces as a waterproofing material:

> *After the plaster has almost dried, a gohber leap consisting of one part of cow dung and 5 parts of soil by weight, made to thin paste with water, is applied on the surface to fill up the cracks and to give smooth appearance. Five percent bitumen cut back by weight of dry soil and cow dung mixture prepared above may be added to the Gohber Mixture before applying on the surface to make it more water resistant.* [69]

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[66] J.R. Harrison, p. 66.

[67] John and Nicola Ashurst. Brick Terracota and Earth. (p. 96) report that while some stabilizing effects are achieved by the use of dung on lime and clay finishes, due to a reduction in vapor transmission on surfaces, condensation takes place into the earth wall breaking down the internal strength of the material. These coatings also promote the activity of bacteria, and "should never be applied" on earthen buildings' finishes.

[68] S.N. Mehrotra. "Non-erodable mud plaster on mud wall for rural houses", Building Research Note 12. India: Central Building Research Institute (June 1983): 3-10.

[69] HUDCO- Housing and Urban Development Corporation. Mud Architecture. Report of the first interaction organized by HUDCO in June 1986 and useful technical information. (New Delhi, India: Communications Consultants, 1980), p. 36.

2.2.6 Hair

Hair is used as a tensile reinforcement material in lime and gypsum plasters. Ox hair is the most common, but horse, goat and even human hair have been used as substitutes. The best hair is long, strong and free from grease and other impurities, therefore, the use of human hair is rare because of its fineness and poor strength.[70] Short cropped hair is frequently found, and failures from "lumps" of hair sometimes occur where they have caused weak spots. In South America, llama hair has been used, but may be too soft and silky for good reinforcement.[71]

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[70] John and Nicola Ashurst, Mortars, Plasters and Renders. p. 30.

[71] Ibid, 28-29.

2.3 MINERAL PRODUCTS

2.3.1 Hydrated Salts

2.3.1.1 Alkaline Silicates

A low cost treatment of good cementing action, but like all inorganic consolidants only voids up to ca. 50 microns are consolidated. A stable mineral -silica- is formed. The formation of dangerous soluble salts as secondary products is possible, mostly with sodium silicates or sodium carbonates (deflocculants that can be added to clay soil in the order of 0.1 to 0.4% by weight), where the formation of sodium salts during the hydrolysis may cause damage on treated surfaces.

Two of the alkaline silicates most used on clays, are sodium and potassium silicates. Sodium silicate, which was used extensively in the second half of the last century, forms by hydrolysis of hydrated silica and sodium hydroxide. The sodium hydroxide leads to formation of sodium salts, and after condensation and polymerization, silica is formed.

Its basic reaction is:

$Na_2SiO_3 + H_2O = Si(OH)_4 + 2NaOH$ (hydrolysis)

$Si(OH)_4 - (H_2O) = O{=}Si{=}O$ (condensation and polymerization)

Potassium silicates, are sometimes still used as consolidants.

2.3.1.2 Alum

A double sulphate of potassium and hydrated aluminum. A small quantity should be boiled in water for one hour, then added to the mix immediately before use. The effect is to increase workability and surface hardness. Added to lime-tallow washes, it assists in emulsifying the fat.

2.3.1.3 Lime Water

Saturated solution of calcium hydroxide which forms on top of lime putty. It is applied to the surface by brush or spray, forming calcium carbonate, the binder material in lime renders. It has a very poor consolidating power because of the low concentrations that can be achieved: only a maximum of 1.7 g of calcium hydroxide can be dissolved in 1 lt. of water at 20 °C.

Its basic reaction is:

$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$ (carbonation)

2.3.2 Asphalt Emulsions

Asphalt emulsions are petroleum based products that have been used in earthen construction in the Near East for thousands of years. In the United States, asphalt emulsion gained widespread use as early as the 1950s and continues to be a popular amendment for stabilized brick used for construction. Its use in preservation has been criticized for it makes the plaster much darker than the original material.

2.3.3 Bituminous products

Three bituminous products are used as amendments on earthen walls: Bitumen (natural or synthetic), coal tar, and pitch *(See Glossary)*. They resist the passage of water and water vapor and are in general, resistant to acids and alkalis.

2.3.3.1 Bitumen

General term applied to natural combustible materials rich in carbon and hydrogen. Although bitumens are derived from petroleum, they present very similar physical and chemical properties as tars, which can be either vegetable or mineral products. It is soluble in drying oils, hydrocarbons, petroleum spirit and ether. In building construction, bitumen is used as a damp-proof membrane, an adhesive to wood-block flooring, insulating linings and felts, as a saturant for roofing felts and different water-proof building papers and joint fillers. It has been traditionally used as a damp-proof coating and as a dye, although without much success except in the short term, due to the leaching out of the volatile oils.

2.3.3.2 Coal tar

Coal tar is a dark, hard substance obtained by the destructive distillation of coal. Contains aromatic compounds: benzene, toluene, xylene; phelonic compounds: phenol, cresols, xylenols; pirinide bases, derivatives of naphthalene, anthracene, etc.

Its use in earthen buildings was described earlier in the century:[72]

> *A well-established, but different method of waterproofing is to apply hot coal tar well blended with sand. When tar is available this is perhaps the best of all the treatments, as it is known to be efficient, and while only semi-permanent, is nevertheless relatively cheap to renew. Frequently, tarred walls were limewashed to avoid the dark color, but this practice may lead to disappointment unless precautions are taken to prevent the tar from bleeding through. The main point to remember is that the limewash should not be applied for as long as possible- that is, several months after the walls have been tarred, and then only on a well-sanded surface.*

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[72] Clough Williams-Ellis; John and Elizabeth Eastwick-Field, p. 109.

CHAPTER 3: SYNTHETIC CONSOLIDANTS

Although natural polymers offer many possibilities in the consolidation of structures, due to their composition they can suffer from variations in the individual batch of material collected from the natural sources, from darkening or discoloration caused by age, and are prone to oxidative decomposition. To substitute and improve the physical and chemical properties of these natural consolidants, synthetics[1] -- which have a relatively new use in building technology -- offer new possibilities to the conservator: they are much more stable than natural consolidants, can be more controlled, and are easily available. But no single product is ideal or absolutely permanent. Synthetic consolidants are theoretically reversible, have a high cost, and are susceptible to a variety of side effects which can occur after their application, such as the formation of salts.

Whereas an extensive bibliography on the use of consolidants in general exists, almost no study has been carried out on the conservation of earth plasters or finishes, being at the present most of the consolidants used on earthen buildings, those developed for stone conservation, namely synthetic thermoplastic resins, and ethoxysilanes.[2] Research on the subject is still at an experimental stage. While at the moment some studies' results are promising -- like the work at Chan-Chan in Perú and Fort Selden in USA -- very few laboratory tests on earth consolidants have been conducted. It is therefore fundamental to establish research programs in order to find successful solutions for the consolidation and stabilization of adobe structures and finishes.

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[1] For the purposes of this study, "synthetic" is a term used to describe man-made materials.

[2] Giacomo Chiari. "Chemical surface treatments and capping techniques of earthen structures: a long term evaluation", 6th International Conference on the Conservation of earthen Architecture: Adobe 90 Preprints. (Las Cruces, New Mexico: The Getty Conservation Institute, 1990), p. 267.

Some of the properties required of consolidants used on adobe surfaces:

- Good penetration (low viscosity): Consolidants should be able to penetrate as deeply as possible into the pores of the material in order to impregnate completely the deteriorated parts and anchor them to the sound parts.
- Water vapor permeability: should be water resistant but not water repellent in order to allow water migration both in liquid and vapor phase, not filling the pores but coating their walls. The pores and capillaries should be left open and allow for other impregnations, even with different products. (retreatibility).
- Confer mechanical strength and abrasive resistance both in dry and wet conditions.
- Restore sufficient adhesion power.
- Possess chemical stability and resistance to stresses caused by other environmental agents, such as acids, alkalies, salt crystallization, capillary rise of ground water, photo-oxidation (UV-light: change of color or gloss), and microorganisms.
- Should not form films on the surface, nor show abrupt planar boundary with respect to the untreated core.
- Thermal expansion coefficient similar to adobe.
- Easily applied, possibly also in damp conditions.
- Should not be harmful to the operators and environment.[3]

No consolidant used in conservation fulfills all of these requirements. For every specific treatment, it is necessary to determine the most important properties and select case by case the most suitable product, testing each individual product on the specific material. Even this cannot assure that a consolidant which has given good results in a laboratory test program would behave equally well in the long-term field application.

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[3] Ibid, p. 268.

3.1 ORGANIC CONSOLIDANTS

Synthetic polymers used for the conservation of stone may be divided in two types: thermoplastics and thermosets. Thermoset polymers consist of monomeric units linked together by chemical bonds to form a three-dimensional network; infusible and insoluble in all solvents, although they may swell to form a gel with certain solvents, or be chemically broken down by certain reagents to form soluble products.[4] Although originally thermosetting materials were characterized because under the influence of heat polymerization would accelerate and produce a permanent set of the material,[5] some of the new resins in this category can be produced without the application of heat, and are referred to as cold setting resins.[6] Polyesters, epoxies[7] and polyurethanes are thermosets and because of its intrinsic nature such as non-solubility -- they cannot be applied as solutions -- and non-reversibility, they are not applicable to painted and unpainted adobe plasters.[8]

Thermoplastic polymers consist of long chain polymers combined with various other molecules that modify their properties.[9] As its name implies, these materials become plastic, capable of being molded as they are heated. On cooling, they become rigid but soften again on reheating.[10] Thermoplastic polymers are also soluble in an appropriate solvent or range of solvents and remain permanently fusible.

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[4] Giorgio Torraca. "Synthetic materials used in the conservation of cultural property", Appendix to The Conservation of Cultural Property. - Museums and Monuments. (Rome: The UNESCO Press, 1983), p.306.

[5] C.V. Horie. Materials for Conservation - Organic consolidants, adhesives and coatings. (London: Butterworths, 1987), p. 39.

[6] Giorgio Torraca, p. 306.

[7] Epoxies can not be used on adobe surfaces because its high viscosity and quicker drying time makes it less suitable than other thinner substances which permit multiple applications and therefore create better adhesion. Carlos Rua, p. 174.

[8] Constance S. Silver. Architectural finishes of the Prehistoric Southwest: A Study of the Cultural Resource and Prospects for its Conservation. (Masters Thesis: Columbia University, 1987), p. 134.

[9] C.V. Horie, p. 63.

[10] Conservation Science Teaching Series. Adhesives and Coatings - Science for Conservators. Book 3. (London: Museum and Galleries Commission, 1987), p. 39.

(Poly)vinylchlorides, (poly)ethylenes, nylon, (poly)styrenes, (poly)methylmethacrylate, polyvinyl acetates, acrylics, and polyisocyanates[11] are thermoplastics generally used in solution in organic solvents or in water emulsions[12]. The polymerization can also be obtained in situ by the use of catalysts or by reaction with atmospheric moisture; whereas solutions are best suited for surface consolidation because the products are then pure, show good aging properties and penetration. The above mentioned thermoplastics, have been used in the conservation of adobe.[13]

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[11] Polyisocyanates and derivatives are frequently applied in solution can be used dissolved in anhydrous solvents and are frequently added to alkyd resins to improve their properties of toughness and adhesion. C.V. Horie, p. 168.

[12] Giacomo Chiari indicates that water is not a good consolidant carrier in the case of adobe, since it causes swelling of the clay particles and decreases the mechanical properties with the risk of material detachment during the treatment. Therefore, water emulsions should only be applied as adhesives, by injection inside the walls, and not on the surface because the liquid has a high viscosity and penetration is low.
Giacomo Chiari. "Chemical surface treatments and capping techniques of earthen structures: a long term evaluation", 6th International Conference on the Conservation of earthen Architecture: Adobe 90 Preprints. (Las Cruces, New Mexico: The Getty Conservation Institute, 1990), pp. 267-273

[13] See Case Studies: Acrylics

3.1.1. Acrylic Resin

Acrylics -- the most widely used resins in the conservation of earthen building materials -- are thermoplastic resins constituted of long chains of organic polymers (esters of acrylic and methacrylic acid polymerized) derived from a vast range of monomers in a linear structure. Numerous artificial aging tests show that there are no tendencies to yellowing or crosslinking -- which implies insolubility -- rather the acrylic resin remains quite stable and reversible,[14] most acrylics have high thermal expansion (of one order of magnitude larger than adobe), are able to consolidate in damp conditions -- using trichloromethane as solvent -- and are of easy application.

Some of the drawbacks of acrylics when applied to earthen materials are: unacceptable changes in optical qualities -- such as glossy surfaces or dramatic change in color -- may occur; impermeable surfaces can result from applying the solution either in too high a concentration and/or with a solvent with a high evaporation rate; the depth of penetration on earthen surfaces is generally very shallow, reversibility can rarely be affected, and since it is an organic substance it can serve as a nutrient for microorganisms.[15]

Consolidation with acrylic resins is usually achieved by spraying or brushing it on the surface in very low concentrations (5% - 10%) dissolved in aromatic solvents (naphtha, xylenes, toluene), trichloromethane or acetone, according to the task.

3.1.1.1 Commercial Products

The acrylic resins most used on the conservation of earthen building materials, their basic composition and manufacturer are listed as follows:

- **Paraloid B-72 / Acryloid B-72 (USA)** : (Manufactured in USA by Rohm & Haas Company, Independence Mall West-Philadelphia, PA 19105). a 70/30 copolymer of methyl acrylate and ethyl methacrylate. It is the most used and tested acrylic resin; in the 1970s its composition was slightly changed by the manufacturer: the new type dissolves even in ethyl alcohol.

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[14] The long term in situ experience shows that Paraloid B-72 treatments executed in the 1960's are still reversible with solvents like acetone and xylene.

[15] Giacomo Chiari, p. 268.

- **Primal AC-33 / Rhoplex AC-33 (USA):** (Manufactured in USA by Rohm and Haas). Methyl acrylate / ethyl acrylate (40/60) copolymer dispersion, with shallow penetration and weak mechanical properties both before and after ageing.[16] The formation of a thin glossy film on treated areas is very difficult to avoid when this acrylic emulsion is used.

- **Acryloid B-67:** (Rohm and Haas) isobutyl methacrylate polymer, improves properties of medium and long-oil alkyd and oleo-resinous varnishes. Produced in two versions: Acryloid B-67 and Acryloid B-67MT (similar to B-67 but dissolved in mineral thinner).

- **Buvtar B79:** (Monsanto Chemical Company, 800 N. Linbergh Boulevard, St. Louis, Missouri 63167, USA.) a polyvinyl butyral resin with low hydroxyl content.

- **Acrysol WS-24:** (Rohm and Haas) Acrylic emulsion, colloidal dispersion tough, glossy, air dry, and alkali-removable.

- **Neocryl BT-520:** (ICI Resins US, 730 Main Street Wilmington Massachusetts 01887-0677) alkali soluble acrylic copolymer emulsion, contains 40% of resin solids, having a acid number of 65.

- **El Rey Superior 200:**[17] an acrylic modifier that is used commercially in cementitious applications. It is a methyl methacrylate/acrylate resin at 47% solids in water.

- **Rhoplex MC-76:** (Rohm and Haas) identical to El Rey Superior 200 with the exception that a de-foaming agent has been added to it.

- **Rhoplex E-330:** (Rohm and Haas) slightly modified version of Rhoplex MC-76 has been used as an amendment to mud mortar in stone masonry at Chaco Canyon, Aztec, and Wupatki National Monuments.

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[16] Paolo and Laura Mora; and Paul Phillipot. Conservation of Wall Paintings. Blantyre Printing and Binding. (Glasgow, Scotland: ICCROM, 1984), p. 236.

[17] Used in Bents Old Fort National Monument, no manufacturer name is available in the literature. (See Case Studies)

- **Soil Seal Concentrate:**[18] soil stabilizer used commercially for soil surface erosion control. Composed primarily of latex acrylic balanced copolymers prepared in an emulsion form. Usually mixed with water and used as an spray. Consists of 40% methacrylate and acrylate, 1% poly ethoxylated ethanol, and 3.5% silicates.

3.1.1.2 Case Studies

After an extensive bibliographic research, the following case studies were considered of significance for the purposes of this investigation, and were examined in order to determine the type of acrylic resin to be used though the laboratory work.[19]

A. Primal AC 33 [20]

Location:	Huaca Garay, Chavin - Ancash, Perú
Period:	1975-1979
Solution:	Solution at 10%
Application:	Several applications were performed a few days apart to allow the wall to dry and reassume the porosity necessary to absorb the next application. Three applications were accomplished.

Since ethyl silicate did not fix pigments used in Garay, a later application of Paraloid B-72 was necessary. It is not able to attach together the pieces of adobe already detached. A series of injections of Primal AC 33 (10%) were performed.

B. Acryloid B-72 [21]

Location:	Curahuara de Carangas, Bolivia
Period:	1984 - 1987
Solution:	Acryloid B-72 (5%) Solvent: toluene

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[18] No manufacturer name is available (See Case Studies).

[19] Roberto Samanez Argumedo, describes many other chemicals and techniques used for the conservation of mural paintings with earthen substrates, executed in Perú.
Roberto Samanez Argumedo "Mural Painting on Adobe Walls during Peruvian Colonial times-Its restoration and Conservation" Case Studies in the Conservation of Wall Paintings, IIC Bologna Congress, 21-26 September, 1986. (London: IIC, 1986);

[20] Giacomo Chiari. "Treatment of adobe friezes in Perú", Third International Symposium on Mudbrick (adobe) preservation. (Ankara: ICOM/ICOMOS, 1980), pp. 39-45.

[21] Carlos Rua and Anton Rajer. "Restoration of the sixteenth Century church at Curahuara de Carangas, Bolivia: A case study", 6th International Conference on the Conservation of earthen Architecture: Adobe 90 Preprints. (Las Cruces, New Mexico: The Getty Conservation Institute, 1990), pp. 171-175.

Application: Interior consolidation of walls. To solve the problem of adhesion between adobe and plaster layers, polyvinyl alcohol was injected into the voids behind the plaster limewash. Then, a 5% solution of Acryloid in toluene was brushed onto the murals to consolidate the paint layer.
A penetration of 2 - 3 cm. a day was achieved.

C. Rhoplex MC-76 and E-330 [22]

Location: Bents Old Fort National Monument, New Mexico, USA.
Period: 1985 - present
Solution: 10% solution (no solvent is specified)
Application: Test walls at Bents Old Fort, after three years of exposure, the walls showed little erosion.

D. Soil Seal Concentrate [23]

Location: Bents Old Fort National Monument, New Mexico, USA.
Period: 1985 - present
Solution: 5% and 10% solution. (no solvent specified)
Application: Test walls at Bents Old Fort, after three years of exposure, the walls showed little erosion. Portions of panels with the 5% solutions exhibit slightly more erosion than the 10% solution.

E. Neocryl BT-520

Location: Laboratory Research under a Smithsonian Institution National Act Grant, Washington D.C.
Period: August 1985-July 1986
Solution: 10% resin solids
20% isopropanol
70% water
Application: After a laboratory test on alkali-soluble acrylics for plasters, this resin was found to work better than others, demonstrating a high degree of resistance to yellowing, oxidative crosslinking, a good rate of penetration, and consolidating effect.[24]

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[22] Michael Romero Taylor, "Fort Selden Wall Status Report", pp. 91-101.

[23] Ibid, pp. 91-101.

[24] Morgan W. Phillips, "Alkali Soluble Acrylic Consolidants for Plaster: a Preliminary Investigation", Studies in Conservation, 4. Vol XXXII (1987): 145-152.

3.2 INORGANIC CONSOLIDANTS

3.2.1 Ethyl Silicates

Ethyl silicates (tetraethoxysilanes) are some of the most effective consolidants for stone, especially siliceous stones, bricks and renders. The monomer consists of a silicon atom to which four ethoxy groups are bonded, $Si(OCH_2CH_3)_4$. When a water molecule reacts with an alcoholic residue, hydrolysis takes place: one ethyl alcohol molecule is formed (which evaporates) and an acidic residue remains attached to the silicon atom to form Si-OH. By hydrolysis, hydrated silica and ethyl alcohol are formed; in a second step a strong O=Si=O bond is formed by condensation and polymerization. A small amount of acid acts as a catalyst for hydrolysis. The silica deposited within the treated material acts as the consolidant.

$$Si(OC_2H_5)_4 + 4H_2O = Si(OH)_4 + 4C_2H_5OH \qquad \text{(hydrolysis)}$$

$$Si(OH)_4 - H_2O = O = Si = O \qquad \text{(condensation and polymerization)}$$

Because both adobe and clay plaster contain a high percentage of siliceous material, ethyl silicates are used as consolidants for these materials. The ethyl silicate treatment on earthen buildings, adds strong bonds between the clay particles - which are generally separated by water - preventing clay platelets from being separated and therefore giving the material the necessary water resistance. There is no need to increase the speed of the reaction, and better results are obtained without the addition of acid.[25] Ethyl silicates reach a very good penetration because they are readily absorbed upon application -- either by spray or brush -- to the surface of the material under treatment. They also form stable silica, cause only a minor decrease of the open porosity and do not change the hydrophilic properties of the treated material.

Unfortunately, the drawbacks of these consolidants are numerous. The time for effective consolidation is very long, up to one month depending on the product; during that time the treated surface has to be protected against liquid water because the setting reaction is very sensitive to thermohygrometrical changes of the microclimate.[26]

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[25] Giacomo Chiari. "Chemical surface treatments and capping techniques of earthen structures: a long term evaluation", p. 269.

[26] Optimal conditions: temperature ca. 20 °C and Relative Humidity ca. 60%.

Similarly, it cannot be applied to wet surfaces, since hydrolysis would occur before polymerization, forming a crust which crumbles without making the connections with clay particles; the deposition of silica might reduce the pore size, contributing in the long run to salt crystallization and entrapment of water.

Another drawback is that since ethyl silicate is not an adhesive but only a consolidant, it is necessary to achieve adhesion between the elements before its application. Finally, the treatment is very expensive and the solvents toxic. Although the fact that not only the surface appearance of the material but also its intimate structure undergo so little modification, may in part justify the irreversibility.

The application of ethyl silicate is made by percolation. In the case of materials with very low porosity, it should be applied by poultice with continuous supply of the consolidant. Application by spray has the advantage of obtaining a larger penetration in those parts that are more porous than others, leaving a very irregular separation between treated and untreated parts, therefore reducing the chance of detachment of the strengthened layer. Ethyl silicates are commercially available, dissolved in solvent (mainly ethyl alcohol or white spirits) and contain a catalyst for hydrolysis.

3.2.1.1 Commercial Products:

- **Silester ZNS:** (Monsanto Chemical Company, 800 N. Lindbergh Boulevard, St. Louis, Missouri 63167, USA). Ethyl silicate 40 partially condensed (about 10 molecule of monomer). Consists of a partially polymerized molecule containing an average of 40% in weight of Si atoms.[27]

- **Ethyl Silicate 40:** (Union Carbide Corporation. 270 Park Ave., NY 10017 (USA) TEOS, a monomer Tetraethyl-ortho silicate.[28]

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[27] Giacomo Chiari. "Consolidation of adobe with Ethyl Silicate: Control of long term effects using SEM." 5th International Meeting of Experts on the Conservation of Earthen Architecture. Rome, 22-23 October 1987. (Roma: CRATerre/ICCROM, 1987), p. 27.

[28] Both TEOS and Silester ZNS are normally applied by diluting them in an equal amount of ethyl alcohol (96% in volume), with or without the addition of 1% of hydrochloric acid as a catalyst.

- **Stone Strengthener Wacker H / Conservare H (USA):** (Wacker Chemie GmbH, Prinzregentenstrasse 22, Mungen, Germany). Tetraethylorthosilicate (ethyl silicate) dissolved in Methyl Ethyl Ketone and Acetone, and a catalyst. (75% silicic acid ester with a water repellent). [29]

- **Stone Strengthener Wacker OH / (Conservare OH):** (75% silicic acid esther) similar to Stone Strengthener without the water repellent.[30]

(Conservare H and Conservare OH use the same formula, and are available in the USA from ProSoCo, Inc., P.O. Box 1578, Kansas City, Kansas 66117)

The use of methyl silicates is not advisable because the methyl alcohol which is liberated during hydrolysis is highly toxic even by inhalation.

3.2.1.2 Case Studies

A. Silester ZNS [31]

Location:	Seleucia area and Hatra, Iraq
Period:	1969 - 1971
Solution:	(each m2) 1 l. Silester ZNS 3 l. Ethyl alcohol (96°) 1 ml. Hydrochloric Acid (catalyst)
Penetration:	2 - 3 cm. a day.

After two years of application, the treated parts were still in perfect condition, being easily distinguished from the untreated walls. After this, no maintenance work at all was done to the site, which was abandoned. In 1989, the ethyl silicate treatments done at the archives were not visible, since most of the walls were covered with debris. After excavation, the consolidated part was not relocated.

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[29] Giacomo Chiari, "Consolidation of Adobe with Ethyl Silicate: Control of Long Term Effects using SEM" (p. 28), indicates that this product gives long lasting water repellent properties to the treated surface. Water repellency is not a truly desirable property for an adobe treatment and therefore, products based solely on TEOS without silane groups, are more suitable for adobe treatments.

[30] Wacker OH has not been used as yet as an adobe consolidant, but different tests using SEM were developed for comparison by Giacomo Chiari in 1987. (Ibid., p. 28)

[31] Giacomo Chiari. "Chemical surface treatments and capping techniques of earthen structures: a long term evaluation", pp. 270-271.

B. Silester ZNS[32]

Location: Laboratory Tests on Volcanic Tuff
Period: 1979
Solution: Ethyl Silicate diluted 1:2
Ethanol (dilute)
0.5 ml. of Hcl
1 N per liter of final solution,
Application: By immersion (first partial, then total). Treatment repeated three times at intervals of 24 hours.(see below for treatment conclusions)

C. Silester ZNS and Transkote[33]

Location: Laboratory Tests on Volcanic Tuff
Period: 1979
Solution: Ethyl Silicate diluted 1:2
Ethanol (dilute)
0.5 ml. of HCl
1 N per litre of final solution
Aluminum stereate, as supplied by manufacturer.
Application: By immersion (first partial, then total). Treatment repeated three times at intervals of 24 hours. After one month, the aluminum stereate was applied as above, repeating the procedure a second time after a week.

This volcanic tuff was tested with three different solutions, and several laboratory tests were tried on the samples to understand their effectiveness. From the results obtained, it was concluded that both products, applied separately, are effective for the conservation of this stone. Silester is relatively more effective in imparting compactness and mechanical resistance, while Transkote supplies a better water repellency and resistance. It was concluded after the tests, that both products should be applied by separate intervals, with a long period of time between applications.

D. Ethyl Silicate 40 [34]

Location: Chan-Chan, Trujillo, Perú
Period: 1974 - present
Solution: Ethyl Silicate 40
ethyl alcohol at 96%
Chlorhydric Acid

After unusual torrential rains in 1983, it was found that the surfaces treated with ethyl silicate did not erode. Therefore, in some areas, the water evaporated too fast, leaving an impermeable film on the surface, which finally flaked due to humidity and salts crystallization.

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[32] Giacomo Chiari; Rafaella Rossi-Manaresi. "Effectiveness of Conservation treatments of a volcanic Tuff very similar to adobe", Third International Symposium on Mudbrick (adobe) preservation. (Ankara: ICOM/ICOMOS, 1980) pp. 29-38.

[33] Ibid, pp. 29-38.

[34] Ana María Hoyle, pp. 225-226.

E. Ethyl Silicate [35]
Location: Huaca Garay, Chavin - Ancash, Perú
Period: 1975-1979
Solution: Ethyl silicate spraying technique (Torraca, Chiari, Gullini, 1972)
Application: Several applications were performed, a few days apart, to allow the wall to dry and reassume the porosity necessary to absorb the next application. Three applications were accomplished.

Since ethyl silicate could not fix pigments used in Garay, nor was it able to attach them together, later application of Paraloid B-72 was necessary. Ethyl Silicate is not able to attach together the pieces of adobe already detached. A series of injections of Primal AC 33 (10%) were performed in order to achieve attachment.

F. Ethyl Silicate [36]
Location: Masmak, Riyadh; Saudi Arabia
Period: 1980
Solution: 66.6% (by volume) Ethyl Silicate 40
32.6% (by volume) Ethanol 96%, commercial
0.8% (by volume) Hydrochloric Acid (concentrated)
Application: For spraying, the stock solution was diluted (1:1) by volume with 96% commercial ethanol. Normal garden sprayers, in plastic without iron parts which contain 5 to 7 liters of solution have been proved most effective. While applying the solution the force of the spray was regulated so that small droplets (but not so small sa to be dispersed in the air) reduced the impact of the liquid and avoided dripping. About 2 liters per square meter of surface were required to form a weather resistant layer of sufficient consistency.

G. Conservare OH [37] (Wacker OH)
Location: Experimental Program on pueblo architectural finishes
Period: 1987
Solution: Commercially available.
Application: (not explained)

Both a simulation of cement murals to test detachment by stacco methods, and a pilot conservation treatment in order to develop methods for stabilization of finishes on sites in the Southwest, were executed. After a consolidation with Conservare OH and Conservare H, different adhesives and isolating coatings were tested.

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[35] Giacomo Chiari. "Treatment of adobe friezes in Peru", Third International Symposium on Mudbrick (adobe) Preservation. September 29 - October 4, 1980. (Ankara: ICOM/ICOMOS, 1980), pp. 39-45.

[36] Albini, M. "The Masmak Fortress in Riyadh-Saudi Arabia - General Criteria for Restoration", Third International Symposium on Mudbrick (adobe) preservation. September 29 - October 4, 1980. (Ankara: ICOM/ICOMOS, 1980) pp. 119-138.

[37] Constance Silver. "Analyses and conservation of Pueblo Architectural Finishes in the American Southwest", 6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints". (Las Cruces, New Mexico, USA: The Getty Conservation Institute, 1990), pp. 176-181.

3.2.2 Barium Hydroxide

Barium hydroxide is an inorganic consolidant formed through carbonation. It has been used for the consolidation of limestones and renders since the last century, forming stable insoluble minerals highly compatible with the calcite binder of lime plasters, limestones and marbles. When applied to a porous material, the material shows insignificant decrease in its porosity and no change in its hydrophilic properties. There is also a possibility of conversion of calcium sulfates, the most common soluble salt involved in the deterioration of lime-based materials, into insoluble minerals. Although in theory the conversion of the somewhat soluble calcium sulfates into less soluble barium sulfates offered by this technique is advantageous, trials with barium hydroxide have not found much favor among conservators.[38] There are two methods for the use of barium hydroxide: Prof. Lewin Method and Florentine Method.

The drawbacks of barium hydroxide include that it is difficult to apply, the treatment is highly sensitive to environmental factors or may be impossible depending on the conditions of the original material (not possible if there is a presence of nitrates, excessive water content, or former consolidants). The treatment is not durable and may change the appearance and color of the treated material, causing bleaching of the surface. Although barium hydroxide has not been found to produce a marked hardening effect which endures over time, some of the reagents used in this technique have resulted in serious discoloration and alterations in the texture of stone.

Basic Reaction:

$Ba(OH)_2 + CO_2 = BaCO_3 + H_2O$ (carbonation)

Lewin Method:

In the mid 1960s, Professor Lewin modified the barium hydroxide technique, so that it remained in contact with the surface to be consolidated for a longer time.[39] The addition of urea and glycerine -- executed by Lewin -- produced good results on certain marbles and calcitic limestones.

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[38] Notes from class at ICCROM, Rome.

[39] G.G. Amoroso and V. Fassina. Stone Decay and Conservation. (New York: Elsevier, 1983), p. 311.

The urea enables the barium solution to remain in contact with internal pore surface for a prolonged period of time, produces a surface upon which new crystalline growths of barium carbonate can be directly molecularly bonded resulting in the deposition of a mineral phase that is permanently bonded to the original stone, facilitates deep penetration of the hydroxide, regulates pH, and constitutes a source of carbon dioxide.[40] Glycerine has a secondary role and prevents formation of barium hydroxide crystals in the solution.

On the Lewin Method, the following reaction occurred:

$$CaCO_3 + Ba\ (OH)_2 \text{ --- } BaCO_3 + Ca(OH)_2$$

This method has been applied to a number of large scale stone decay problems in the field. The experience with the Lewin method to date suggests that it is a very suitable treatment for certain types of calcareous stones. Trials of the method from more than 10 years field exposure, have produced pronounced reconsolidation and resistance to the action of environmental decay factors without causing any alteration in surface color or texture of stone, and with no loss in hardness or resistance to decay.

Florentine Method:

The Florentine Method accomplishes the consolidation of sulfated lime renders plus the conversion of calcium sulfate into barium sulfate, which is nearly insoluble in water. Barium hydroxide is applied by cellulose pulp poultices and its use requires much skill and experience.[41] On the Florentine Method the conversion of calcium sulfate into ammonium sulfate by application of ammonium carbonate poultices occurs by the following reaction:

$$(NH_4)_2CO_3 + CaSO_4 . 2H_2O = (NH_4)_2SO_4 + CaCO_3 + 2H_2O$$

3.2.2.1 Commercial Products:

Solutions of ammonium carbonate and barium hydroxide have to be prepared, using pure analytic chemicals.

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[40] Ibid, p. 132.

[41] Notes from class at ICCROM, Rome.

CHAPTER 4: LABORATORY TESTING PROGRAM

In order to better understand the nature of the various plaster types used on earthen buildings, and to study the effectiveness of selected consolidants on these plasters, a large testing program of 360 samples was designed and implemented at the Architectural Conservation Laboratory at the University of Pennsylvania. The program included the characterization of the clay used in the tests followed by several standard tests designed to assess the behavior of the plaster systems and three different consolidants applied to the plasters. The consolidants tested were selected after a study of their prior use on adobe structures in recent years, and included a natural organic plant mucilage extracted from the Tuna cactus; and two commercially available consolidants: a synthetic organic resin, Acryloid B-67 (Rohm and Haas) applied at 5% in Diethylbenzene; and a synthetic inorganic silane, Conservare OH, (Wacker Chemie / ProSoCo). The selections were intended to provide an evaluation of three different types of products. *(See Technical Data and Materials Safety Data Sheets for the synthetic products on Appendix B).*

Five different types of plasters traditionally used as external coverings on earthen buildings were tested. The plasters mixtures used -- based on traditional mixes listed on Appendix A -- were clay, gypsum, lime, clay/lime and gypsum/lime.

This chapter describes each of the tests performed, the materials used, and the conditions in which they were used.

4.1 ADOBE BLOCKS

The soil used in the laboratory tests both as a substrate support (adobe blocks) and as a finish coat plaster (clay plasters) was obtained as 12" x 12" x 2 ½" hand-made bricks, from "Aguirre Services", Taos, New Mexico, USA.

The first step in the laboratory research was to characterize the relevant physico-chemical properties of the soil using standard technical and analytical procedures:

- Grain size distribution (ASTM D422-63/BS 1377-75)
- Plastic Limit (ASTM D4318-84/BS 1377-75)
- Liquid Limit (ASTM D4318-84/BS 1377-75)
- X-Ray Diffraction Analysis
- Soluble Salts Content - Quantitative and Qualitative Analysis
- Organic Material Content
- pH
- Color (Munsell Soil Standards)

After characterization of the soil the adobes were prepared for the tests by reconstituting them in molds of different shapes and sizes depending on each test requirement. *(see Chapter 4.2)* Before molding, the original adobes were mixed with enough water to acquire a desirable consistency and allowed to rest for at least 24 hours. After that period of time the clay was placed into the molds and cured.

To create a suitable earthen support for the plasters, the clay was packed into specially constructed wooden molds measuring 3 ½" x 3 ½" x 1" (a reduced scale version of adobe blocks generally used for construction.[1] *(See Fig.1)*

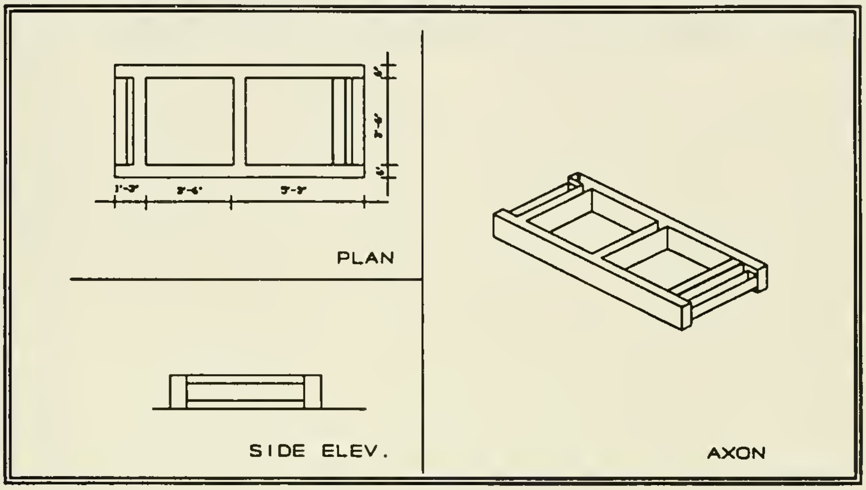

Figure 1

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[1] Ministerio de Vivienda y Construcción. El Adobe Estabilizado. Oficina de Investigación y Normalización (Perú: Programa COBE, 1978), pp. 7-9.

4.1.1 Grain Size Distribution (ASTM D422-63/BS 1377-75)

A soil's particle size distribution is very important in understanding the behavioral characteristics of the material and its durability. In this study the standards used were those delineated by ASTM to determine classification and sieve sizes. *(See Chapter 1.2.1: Clay Plasters).*

The grain size distribution test was executed in three 250 gram samples and determined by using sieving and sedimentation techniques.[2] The data for the various samples are reported in Tables 1 to 6 and Fig. 2.

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[2] Particle Size Analysis: Sieving and Sedimentation Procedures. Jeanne Marie Teutonico. A Laboratory Manual for Architectural conservators. (Rome: ICCROM, 1988), pp. 73-95.

GRAIN SIZE DISTRIBUTION - SAMPLE 1

MECHANICAL METHOD

Weight of Dry sample + container	290.55
Weight of Container	232.30
Weight of dry sample	58.25

Total Weight of Sample	200.00 g.
Weight passed through sieves	56.25 g.
Weight Wet Sample	143.75 g.

SIEVE ANALYSIS AND GRAIN SHAPE				
Sieve No.	Diam. (mm)	Wt. Retained	% Retained	% Passing
8	2.36	2.73	1.365	98.64
16	1.18	3.69	1.845	98.64
30	0.600	6.08	3.040	96.79
50	0.300	10.77	5.385	93.75
100	0.150	12.26	6.130	88.37
200	0.075	29.37	14.685	82.24
Pan		2.26		67.55
TOTAL 67.16 (67.20 == OK)				

Table 1

GRAIN SIZE DISTRIBUTION - SAMPLE 1

HYDROMETER METHOD

Date	Time of Reading	Elaps. Time in min.	Temp °C	Actual Hydrom Reading R	Correct Hydrom Reading Rc	% Finer	Hydrom Correct For Meniscus	L From Table 4	$\frac{L}{t}$	K from Table 3	Diam. mm.
Nov. 30	11:45 am	0.50	19	59.0	55.7	40.816	58.0	7.3	14.6000	0.0136	0.05197
Nov. 30	11:46 am	1	19	56.0	52.7	38.618	55.0	7.3	7.3000	0.0136	0.03675
Nov. 30	11:47 am	2	19	54.0	50.7	37.152	53.0	7.8	3.9000	0.0136	0.02686
Nov. 30	11:49 am	4	19	51.0	47.7	34.954	50.0	8.1	2.0250	0.0136	0.01935
Nov. 30	11:51 am	5	19	48.0	44.7	32.756	47.0	8.6	1.7200	0.0136	0.01784
Nov. 30	11:53 am	6	19	47.0	43.7	32.023	46.0	8.8	1.4667	0.0136	0.01647
Nov. 30	11:55 am	10	19	45.0	41.7	30.557	44.0	9.1	0.9100	0.0136	0.01297
Nov. 30	12:05 pm	20	19	39.0	35.7	26.161	38.0	10.1	0.5050	0.0136	0.00966
Nov. 30	12:15 pm	30	19	37.5	34.2	25.061	36.5	10.3	0.3433	0.0136	0.00797
Nov. 30	12:45 pm	60	19	35.0	31.7	18.229	34.0	10.7	0.1783	0.0136	0.00574
Nov. 30	13:45 pm	120	19	24.0	20.7	15.169	23.0	12.5	0.1042	0.0136	0.00439
Nov. 30	15:45 pm	240	19	20.0	16.7	12.238	19.0	12.7	0.0529	0.0136	0.00313
Nov. 30	19:45 pm	480	19	18.5	15.2	11.138	17.5	13.4	0.0279	0.0136	0.00227
Dec. 1	11:45 am	1440	19	18.0	14.7	10.772	17.0	13.5	0.0094	0.0136	0.00132
Dec. 2	10:50 am	2880	18	17.0	13.5	9.893	16.0	13.7	0.0048	0.0138	0.00095

Table 2

GRAIN SIZE DISTRIBUTION - SAMPLE 2

MECHANICAL METHOD

Weight of Dry sample + container	311.24
Weight of Container	240.20
Weight of dry sample	62.58

Total Weight of Sample	200.00 g.
Weight passed through sieves	68.21 g.
Weight Wet Sample	131.79 g.

SIEVE ANALYSIS AND GRAIN SHAPE				
Sieve No.	Diam. (mm)	Wt. Retained	% Retained	% Passing
8	2.36	2.18	1.09	98.91
16	1.18	3.43	1.715	97.19
30	0.600	5.37	2.685	94.51
50	0.300	12.07	6.035	88.47
100	0.150	15.07	7.535	80.94
200	0.075	30.09	15.044	65.89
Pan		2.80		
TOTAL 71.01 (71.04 == OK)				

Table 3

GRAIN SIZE DISTRIBUTION - SAMPLE 2

HYDROMETER METHOD

Date	Time of Reading	Elaps. Time In min.	Temp °C	Actual Hydrom Reading R	Correct Hydrom Reading Rc	% Finer	Hydrom Correct For Meniscus	L From Table 4	$\frac{L}{t}$	K from Table 3	Diam. mm.
Nov. 30	11:55 am	0.50	19	58.0	54.7	41.090	57.0	7.0	14.0000	0.0136	0.05089
Nov. 30	11:56 am	1	19	56.0	52.7	39.588	55.0	7.3	7.3000	0.0136	0.03675
Nov. 30	11:57 am	2	19	54.0	50.7	38.086	53.0	7.6	3.8000	0.0136	0.02651
Nov. 30	11:59 am	4	19	50.0	46.7	35.081	49.0	8.3	2.0750	0.0136	0.01959
Nov. 30	12:01 pm	5	19	47.0	43.7	32.827	46.0	8.8	1.4667	0.0136	0.01647
Nov. 30	12:03 pm	6	19	45.0	41.7	31.325	44.0	9.1	1.1375	0.0136	0.01450
Nov. 30	12:05 pm	10	19	40.0	36.7	27.569	39.0	9.9	0.9900	0.0136	0.01353
Nov. 30	12:15 pm	20	19	39.0	35.7	26.818	38.0	10.1	0.5050	0.0136	0.00966
Nov. 30	12:25 pm	30	19	37.0	33.7	25.315	36.0	10.4	0.3467	0.0136	0.00801
Nov. 30	12:55 pm	60	19	33.0	29.7	22.310	32.0	11.1	0.1850	0.0136	0.00585
Nov. 30	13:55 pm	120	19	23.0	19.7	14.799	22.0	12.7	0.1058	0.0136	0.00442
Nov. 30	15:55 pm	240	19	19.0	15.7	11.794	18.0	13.3	0.0554	0.0136	0.00320
Nov. 30	19:55 pm	480	19	16.0	12.7	9.540	15.0	13.8	0.0288	0.0136	0.00231
Dec. 1	11:55 am	1440	19	15.5	12.0	9.014	14.5	14.1	0.0098	0.0136	0.00137
Dec. 2	11:00 am	2880	18	15.0	11.5	8.639	14.0	14.2	0.0049	0.0138	0.00097

Table 4

GRAIN SIZE DISTRIBUTION - SAMPLE 3

MECHANICAL METHOD

Weight of Dry sample + container	311.24
Weight of Container	240.20
Weight of dry sample	62.58

Total Weight of Sample	200.00 g.
Weight passed through sieves	68.21 g.
Weight Wet Sample	131.79 g.

SIEVE ANALYSIS AND GRAIN SHAPE				
Sieve No.	Diam. (mm)	Wt. Retained	% Retained	% Passing
8	2.36	2.18	1.090	98.91
16	1.18	3.43	1.715	97.19
30	0.600	5.37	2.685	94.51
50	0.300	12.07	6.035	88.47
100	0.150	15.07	7.535	80.94
200	0.075	30.09	15.044	65.89
Pan		2.26		67.55
TOTAL 71.01 (71.04 == OK)				

Table 5

GRAIN SIZE DISTRIBUTION - SAMPLE 3

HYDROMETER METHOD

Date	Time of Reading	Elaps. Time In min.	Temp °C	Actual Hydrom Reading R	Correct Hydrom Reading Rc	% Finer	Hydrom Correct For Meniscus	L From Table 4	$\frac{L}{t}$	K from Table 3	Diam. mm.
Nov. 30	12:05 pm	0.50	19	60.0	56.7	39.049	59.0	6.6	13.2000	0.0136	0.04941
Nov. 30	12:06 pm	1	19	57.0	53.7	36.983	56.0	7.1	7.1000	0.0136	0.03624
Nov. 30	12:07 pm	2	19	55.0	51.7	35.606	54.0	7.4	3.7000	0.0136	0.02616
Nov. 30	12:09 pm	4	19	53.0	45.7	31.473	52.0	7.8	1.9500	0.0136	0.01899
Nov. 30	12:11 pm	5	19	49.0	45.2	31.129	48.0	8.4	1.4000	0.0136	0.01609
Nov. 30	12:13 pm	6	19	48.5	45.2	31.129	47.5	8.7	1.0875	0.0136	0.01418
Nov. 30	12:15 pm	10	19	45.0	41.7	28.719	44.0	9.1	0.9100	0.0136	0.01297
Nov. 30	12:25 pm	20	19	41.0	37.7	25.964	40.0	9.7	0.4850	0.0136	0.00947
Nov. 30	12:35 pm	30	19	35.0	31.5	21.694	34.0	10.7	0.3567	0.0136	0.00812
Nov. 30	13:05 pm	60	19	32.0	28.5	19.628	31.0	11.2	0.1867	0.0136	0.00588
Nov. 30	14:05 pm	120	19	30.0	26.3	18.113	29.0	11.5	0.0958	0.0136	0.00421
Nov. 30	16:05 pm	240	19	29.5	26.2	18.044	28.5	11.7	0.0488	0.0136	0.00300
Nov. 30	20:05 pm	480	19	28.0	24.7	17.011	27.0	11.9	0.0248	0.0136	0.00214
Dec. 1	12:05 pm	1440	19	27.0	23.5	16.184	26.0	12.0	0.0083	0.0136	0.00126
Dec. 2	11:10 am	2880	18	25.0	21.5	14.807	24.0	12.4	0.0043	0.0138	0.00091

Table 6

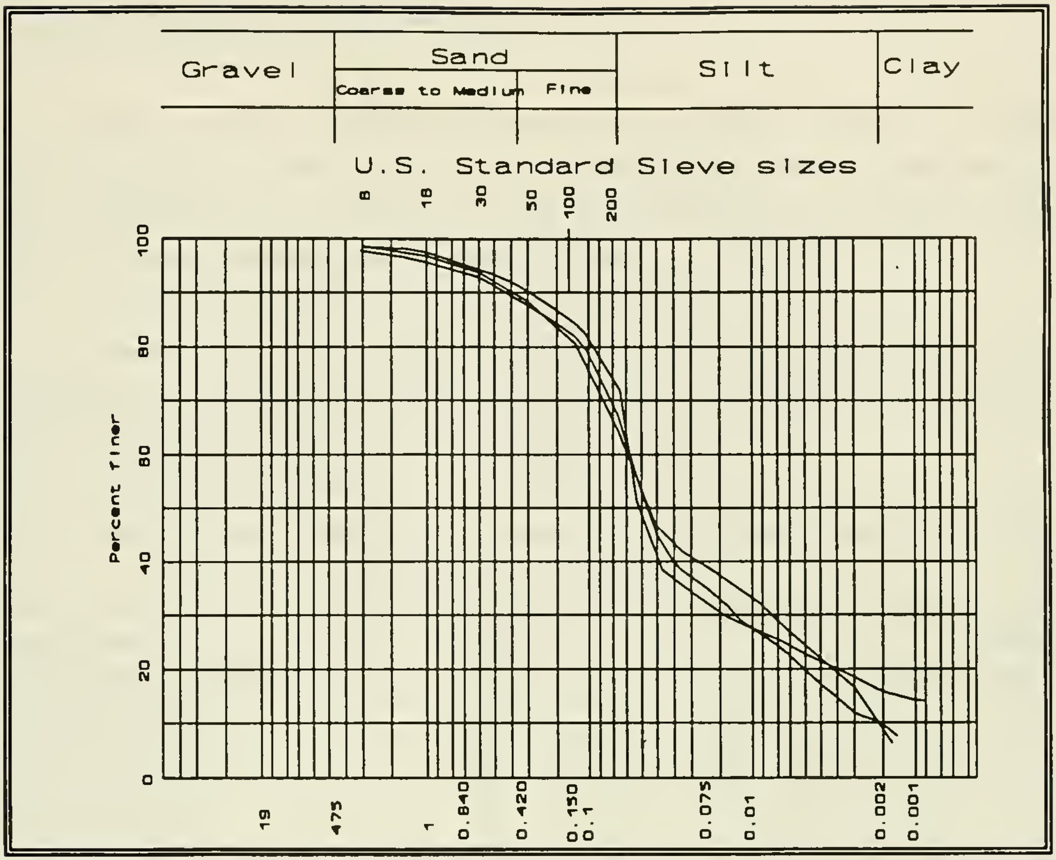

Figure 2

The results show that the soil is composed approximately of:

Gravel	2 %
Sand	26 %
Silt	54 %
Clay	18 %

4.1.2 Plastic Limit (ASTM D4318-84/BS 1377-75)

The plastic limit of a soil is defined as the water content, expressed as a percentage of the mass of the oven-dried soil, at the boundary between the plastic and semi-solid states. The water content at this limit is arbitrarily defined as the lowest water content at which the soil can be rolled into threads 3 mm. (1/8") in diameter without the threads breaking into pieces.[3]

The plastic limit of the soil was determined using the established procedures[4] which involved eliminating the water content in several operations and weighing the sample before and after treatment. The test was repeated three times and the data are reported in Table 7.

PLASTIC LIMIT OF SOILS

Sample number	**1**	**2**	**3**	**MEAN**
Wt. Wet Soil + Cont. M2)	49.83	47.49	50.04	
Wt. Dry Soil + Cont. (M3)	48.19	45.88	48.54	
Water Loss (M2 - M3)	1.63	1.61	1.50	
Wt. Container	39.54	37.27	40.53	
Wt. Dry Soil (M3 - M1)	8.65	8.61	8.01	
Plastic Limit **(M2 - M3) x 100** **(M3 - M1**	**18.84**	**18.69**	**18.72**	**18.75**

MEAN PLASTIC LIMIT 18.75%

Table 7

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[3] Jeanne Marie Teutonico, p. 96.

[4] Jeanne Marie Teutonico, pp. 96-99.

4.1.3 Liquid Limit (ASTM D4318-84/BS 1377-75)

The soil's water content is expressed as a percentage of the oven-dried soil at the boundary between the liquid and plastic states. At this boundary the water content is arbitrarily defined as the moment when two halves of a soil cake placed in a Casagrande device flow together for a distance of ½ inch (12.7mm) along the bottom of the groove separating the two halves, when the cup is dropped 25 times for a distance of 1 cm. (0.3937") at the rate of 2 drops/second.[5]

The liquid limit of the soil was determined by forming a groove in the Casagrande cup and adding water to the sample at a specific rate until a groove disappears. This procedure was repeated on three different samples and an average was calculated. Results are displayed in Table 8 and Figure 3.

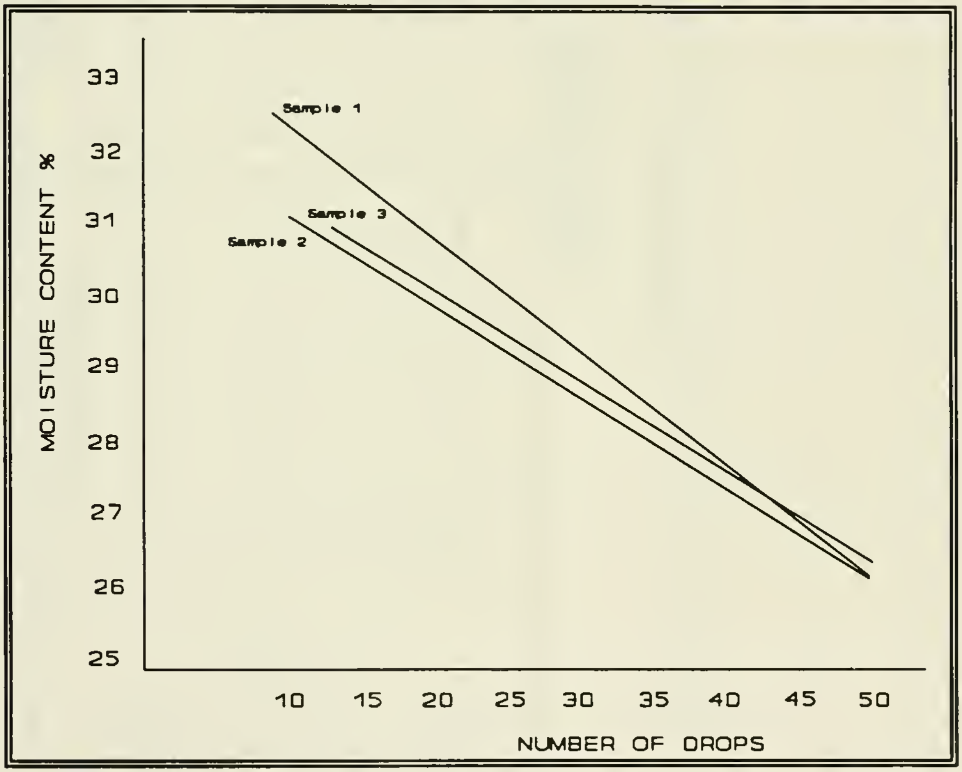

Figure 3

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[5] Jeanne Marie Teutonico, pp. 102-107.

LIQUID LIMIT OF SOILS

	SAMPLE NUMBER 1				SAMPLE NUMBER 2				SAMPLE NUMBER 3			
Container number	1	2	3	4	1	2	3	4	1	2	3	4
Number of Drops	50	35	24	7	50	28	22	10	50	30	23	12
Wt. Wet Soil + Cont. M2)	42.16	41.98	49.63	48.42	46.78	56.18	49.05	51.87	40.85	45.18	49.12	45.88
Wt. Dry Soil + Cont. (M3)	40.50	39.68	47.29	45.39	44.92	53.09	46.56	49.15	38.91	42.81	47.06	43.45
Water Loss (M2 - M3)	1.66	2.30	2.34	3.03	1.86	3.09	2.49	2.72	1.94	2.37	2.06	2.43
Wt. Container	34.20	31.55	39.40	36.08	37.86	42.43	38.20	40.40	31.55	34.40	40.10	35.60
Wt. Dry Soil (M3 - M1)	6.30	8.13	7.89	9.31	.06	10.66	8.36	8.75	7.36	8.41	6.96	7.85
Moisture Content % (M2 - M3) x 100 (M3 - M1	26.35	28.29	29.66	32.55	26.35	28.29	29.85	31.09	26.40	28.20	29.60	30.95

MEAN LIQUID LIMIT 29.27%
MEAN PLASTIC LIMIT 18.75%

PLASTICITY INDEX (29.27 - 18.75) = 10.52%

Table 8

4.1.4 X-Ray Diffraction Analysis

The X-Ray Diffraction analysis allows the phase identification of mineralogical components of the clay but requires sophisticated equipment and trained evaluation.[6] For this analysis a 100 gram. sample was examined using x-ray diffractometry to obtain an estimate of the relative abundance of the various minerals present in the bulk sample. The analysis was executed at the Materials Science Laboratory, University of Pennsylvania, and the results identified the following minerals in apparent order of abundance: *(See Table 9)*

X-RAY DIFFRACTION - RESULTS

EL	SAMPLE 1		SAMPLE 2		SAMPLE 3		%
	CPS	AT%	CPS	AT%	CPS	AT%	AT%
Si	738.5021	46.0	296.8938	45.6	688.123	64.7	52.1
Al	292.4949	22.6	110.0377	21.5	186.476	19.8	21.3
Fe	284.3350	16.3	146.2919	20.5	661.984	6.3	14.4
K	135.6576	5.4	53.6339	5.2	54.619	3.9	4.5
Ca	29.6945	1.2	36.0292	3.5	38.325	2.7	2.4
Mg	39.9943	1.7	6.0849	2.3	8.085	1.5	1.8
Ti	51.9141	2.2	10.2898	1.1	8.899	0.7	1.3
S	13.2948	0.8	2.0650	0.3	2.630	0.2	0.4

Table 9

Therefore it can be concluded that the clay used is composed by approximately 52.1% of Silicone, 21.3% of Aluminum, 14.4 % of Iron, and small percentages of potassium, calcium, magnesium, titanium and sulphur.

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[6] Clifton J.R.; Brown P.W.; and Robbins C.R. "Methods for Characterizing Adobe Building Materials", National Bureau of Standards - Technical note 977. (Washington D.C.: National Bureau of Standards, 1978).

4.1.5 Organic Material Content

Two standard tests were used for the detection of organic matter. The first test[7] consisted of stirring a mixture of soil with Sodium Hydroxide (NaOH diluted to 3%) with 100 gr. of dried crushed soil. After allowing the mix to stand for 24 hours and re-shaking it, the color of the surrounding water was observed. A neutral color resulted - meaning a low organic matter content.

The second test[8] - a quantitative analysis - was performed by heating 30 gram of oven-dried crushed soil sample with a flame in an open dish until all the carbonaceous material was oxidized by the air. The weight difference was calculated and the loss identified as approximate the organic matter content. Although imprecise; this test gives an approximate idea of the quantitative organic matter content of the soil. Results show that the clay analyzed has approximately 3.97% organic matter, which means that it is a very low organic matter content. *(See Table 10).*

ORGANIC MATERIAL CONTENT			
	W_1 (gr.)	W_2 (gr.)	% Organic Material Content
Sample 1	10.00	9.54	4.60
Sample 2	10.00	9.61	3.90
Sample 3	10.00	9.66	3.40
Average	10.00	9.60	3.97

Table 10

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[7] CRATerre. Soil Encyclopedia. Draft provided by Jeanne Marie Teutonico.

[8] Shugar /Shugar /Bauman /Bauman. Chemical Technician's Ready Reference Handbook. Second Edition, (U.S.A.: McGraw - Hill Book Company, 1973), pp. 576-577.

4.1.6 Soluble Salts Content - Qualitative and Quantitative Analysis

The procedure followed for the determination of the amount and composition of soluble salts consisted of dispersing a weighted dry sample in distilled water and collecting the filtrate. This operation was repeated at least four times in order to ensure complete washing.[9] All the soil was then oven-dried and weighed. The difference between the first and second weights was determined as the amount of soluble salts. Quantitative data so obtained may be compared to the mineral phase determination performed by X-ray diffraction.

Micro chemical spot tests were performed on the resulting distilled water solution following a series of techniques. 250 grams of soil were diluted in distilled water and filtered as specified above. The soil was then dried and weighed again in order to determine the amount of salts dissolved in water. Results are shown in Table 11. The percentage of soluble salts content of the soil was approximately 3.16%.

SOLUBLE SALTS CONTENT - QUANTITATIVE ANALYSIS			
	W_1 (gr.)	W_2 (gr.)	% Soluble Salts Content
Sample 1	250.00	242.50	3.000
Sample 2	250.00	238.95	4.420
Sample 3	250.00	244.89	2.044
Average	250.00	242.11	3.156

Table 11

For the qualitative analysis of salts, different chemical tests were executed following the guidelines displayed in "Soil Identification"[10]

The chemical tests executed to determine the presence of soluble salts in the soil, detected the

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[9] Giacomo Chiari. "Characterization of Adobe as Building Material: Preservation Techniques", Adobe: International Symposium and Training Workshop on the Conservation of Adobe. (Lima, Perú: UNDP/UNESCO, 1983), pp. 31-40.

[10] CRATerre, p. 10

presence of a very small amount of carbonates, while no reaction was achieved on the chemical tests for chlorides, nitrates or sulphates.

4.1.7 pH

pH is a value taken to represent the acidity or alkalinity of an aqueous solution, and is defined as the logarithm of the reciprocal of the Hydrogen-ion concentration of a solution.[11] In distilled water (neutral) the concentration of H+, is equal to $1/10^7$, corresponding to pH = 7.

The measurement of pH for adobe can be useful because acid solutions (low pH) promote flocculation of the clay minerals from suspensions, while a high pH can lead to the formation of a stable suspension of clay. The pH of the soil can also make it possible to determine the presence of soluble salts. If the soil is acidic, it is usually because some organic matter is present. If it is basic, it indicates the presence of carbonates, sulphates, chlorides or similar. For measuring the pH of the adobe blocks, the ASTM Test D 4972 - 89 "Standard Test Method for pH of Soils " was used. *(See Appendix B)*

pH indicator strips recorded a pH of 7.5 - slightly alkaline.

4.1.8 Color (Munsell Soil Standards)

The color evaluation of the soil was done with the Munsell Soil Color Chart. The soil color was compared to 199 different standard color chips that are arranged according to three variables: Hue, Value and Chroma.

The Hue notation indicates its relation to red, yellow, green, blue, and purple and is symbolized by letters. Value notation indicates the color lightness, and Chroma its strength - they are both symbolized by numbers.[12] The use of this standard procedure also allowed the detection of any color variations when consolidants were applied to the clay plasters.

The color of the soil, was matched to 5/10YR/3 (Brown).

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[11] Hawley, p. 893.

[12] Munsell Soil Color Charts - Munsell Color, 1988 Edition. (U.S.A.: Macbeth Division of Kollmargen Instrument Corporation, 1988).

CONCLUSIONS

The soil used for the testing program is a silty soil with 10 to 20% of clay and little gravel present. The large amount of silt creates a rather porous structure with less problems of adhesion than clayey soils, commonly used for construction in other parts of the world.[13]

Plasticity index

The plasticity index depends largely on the amount of clay present. The strength of the soil increases as the plasticity index increases. However, the tendency of a clay to expand when wet and shrink when dried also increases as the plasticity index increases.

According to the Geotechnical classification - USCS System - the soil examined is a fine soil,[14] with a low plasticity index and medium cohesive strength.

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[13] Pascal Odul, professor at CRATerre/EAG, personal communication.

[14] A Fine Soil - or Clay and Silt Soil - is defined when more than half the elements have a diameter less than 0.08 mm.

4.2 GENERAL TEST SPECIFICATIONS

4.2.1 Plaster Coatings

Based on a survey of traditional plasters used on earthen buildings, five different types were selected for the laboratory tests: clay plaster, lime plaster, gypsum plaster and two combinations with lime: a clay/lime plaster and a gypsum/lime plaster.

All plaster mixtures used the same ratios of binder and aggregate and two coats of plaster were applied to the reconstituted adobe block support. The first or "base" coat always measured 10 mm thick with a ratio of 1 part binder to 3 parts sand; and the second or "finish" coat measured 4 mm thick with a ratio of 1 part binder to 4 parts sand. Thickness and constituent ratios were based on standard practices found in the literature.

4.2.1.1 Products and Materials Used

- Clay Plaster

The material used for the clay plaster was obtained from the adobes used for the adobe support. *(See Chapter 4.1 Adobe Blocks)*. For the finish coat the same clay was sieved through a No.30 sieve in order to eliminate coarse particles.[15]

- Lime Plaster

The hydrated lime, used for all lime-based plasters, was "Type S Corson's Miracle Lime for Construction, Corson Lime Co., Plymouth Meeting, PA - USA". This lime meets ASTM specifications C-207 for Type S Lime. Before application, the lime was thoroughly dry mixed with sand and water was slowly added until the desired plasticity was achieved.

- Gypsum Plaster

A gypsum molding plaster was used in this mixture because it is a more finely ground form of calcined gypsum than gauging plaster and it is generally used without lime. The product employed was "Plaster of Paris" distributed by ServiStar, American Hardware Supply Co. Butler, PA 16001, meeting

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[15] A peruvian construction guidebook illustrates a clay plastering method, and specifies that only fine clay particles must be used for the final coat in order to avoid irregularities on the finish. The No. 30 sieve was chosen to meet these purposes. Pontificia Universidad Católica del Perú. "Nuevas casas resistentes de Adobe" Cartilla de difusión No. 2, Región de la Costa, p. 36.

the ASTM C-28-86 Standard Specifications for Gypsum Plasters Finish coat.

The gypsum plaster was dry mixed with sand and 1 pound of dry mixture was added to ½ pint of cold water and allowed to soak for 2 minutes. The setting time was within the time limits shown in Table 1 of the ASTM C472-90. *(See Appendix B).*

- Clay/Lime Plaster

This plaster was prepared with the same clay, lime and sand as specified above, mixed in the proportions 1 part clay, 1 part lime, and 6 (or 8) parts sand.

- Gypsum/Lime Plaster

The gypsum used for this plaster was a gauging plaster, which when combined with hydrated lime or lime putty, provides setting properties and increases dimensional stability during drying. The proportions used on the plaster, depending on the coat type, were 1 part clay, 1 part lime, and 6 (or 8) parts sand. The gypsum used on the test was "Champion Quality gauging plaster white - Quick set" manufactured by United States Gypsum Company - Chicago, IL 60606-4385; a subsidiary of USG Corporation, meeting the ASTM C-28-86 Standard Specifications for Gypsum Plasters for Gauging plaster for Finish coat, and approved by the board of standard and appeals for use in New York City, under calendar No. 800-39-SM.

- Sand

According to standard specifications -ASTM C 778-80a "Standard Specification for STANDARD SAND" the sand used on the Base Coat for all the tests was 20-30 mesh sand, U.S. Standard sand, predominantly graded to pass a No. 20 sieve and be retained on a No. 30 sieve.[16] The sand was obtained from The Morie Company, INC. 1201 N. High Street. Milville, NJ 08332.

For the second coat a finer sand was used, "White Sand", which contains sand/gravel CAS # 14808-60-7 and manufactured by Ace-Crete products, Inc. Bayville, New Jersey 08721. This sand meets

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[16] The Morie Laboratory report, indicates the following particle sizes:

Sieve	Cum %	% Rei	% Pass
#6	0.0	0.0	100.0
#12	0.0	0.0	100.0
#20	54.6	54.6	45.4
#30	96.3	41.8	3.7
#40	99.9	3.5	0.1
#50	100.0	0.0	0.0

the requirements of Applicable Freight classification Georgia Pacific, Hamlet, NC, USA.

4.2.1.2 Plaster Application

The plasters were applied in two coats with a different thickness for each coat,

Base coat: 10 mm thick min.
Finish coat: 4 mm thick min.

The base coat, 1 part binder to 3 parts 20-30 sand, was applied to a pre-moistened support surface with sufficient material and pressure to provide a good bond to the support. It was double backed immediately to 10 mm thickness, and straightened to a true surface without application of water (water might have caused blistering if applied at this time). The material was then allowed to take consistency and was textured with a float, thus leaving the surface sufficiently rough to provide a mechanical key for the finish coat. Before the application of the second coat, the plaster was cured for 72 hours.

The finish coat, 1 part binder to 4 parts white sand, was next applied by trowelling it with firm pressure, then doubling back and filling out to a true, even surface. After the plaster had become firm, it was trowelled with a minimum amount of water to a smooth finish, free of imperfections. Once the plaster was applied, it was cured for 28 days as specified for each plaster type. *(See below: Curing Period).*

4.2.1.3 Mold Preparation

For two of the tests, Adhesion and Vapor Transmission, it was necessary to prepare molds of two different shapes *(See specifications for each shape on the samples preparation).* The mixture used was the same as the base coat (1 part binder to 3 parts sand), using a water temperature of approximately 70 ± 2 °F.

The required amount of water was placed in a clean 2-qt. mixing bowl, mixing vigorously the binder, sand and water for 1 min. with a metal spoon or stiff-bladed spatula to produce a mortar of uniform consistency. The molds were coated with a thin film of mineral oil and placed on an oiled glass or metal plate. A layer of plaster about 1" thick was then placed into the mold and puddled several times across with a 1" wide spatula until all bubbles were removed. Molds were then filled to a point slightly above the tops by the same filling and puddling procedure used above. As soon as the plaster had set, the excess was cut off to a plane surface flush with the top of the mold using a stiff broad knife. The samples were then cured as specified for each type *(See Curing Period).*

- Lime Plasters:[17]

Molded samples were allowed to dry slowly by covering them with a damp cloth in a raised tent-like manner. After 24 hours, the cloth was removed and the samples allowed to cure for another 12 hours before removal from the mold. The samples were allowed to cure for a minimum of 28 days in a Moist Room provided by the Engineering Department at Drexel University[18] with a controlled temperature of 69 °F (20 °C) and a Relative Humidity of 65-70%. After removal from the Moist Room, the samples were left at room temperature for another 2 days (on each side for Vapor Transmission and Adhesion Tests).

4.2.1.4 Curing Period

The curing period for plasters was at least 28 days with variables depending on the plaster type:

- Clay Plasters:

The clay plasters were cured for a minimum of 28 days in controlled temperature of 73 °F (23 °C), and relative humidity not exceeding 50%. The consolidant was then applied and left at room temperature for another 14 days.

- Lime Plasters:

The samples were cured for a minimum of 28 days in a Moist Room with a controlled temperature of 69 °F (20 °C) and a Relative Humidity of 65-70%. After removal from the Moist Room, the samples were left at room temperature for another 2 days, or until completely dry. The consolidant was then applied and left at room temperature for another 14 days.

- Gypsum Plasters:

The gypsum plasters were placed in a Moist Cure Chamber built for this purpose at the Architectural Conservation Laboratory by sealing a fish tank and pumping in moisture regularly thus maintaining a constant high relative humidity (of 90 - 100%). For the Vapor Transmission and Adhesion Tests, the plasters were removed from their molds as soon as thoroughly hardened, but retained in the moist air for less than a total of 16 hrs. After the Moist Chamber period was completed, the plasters were cured for at least 28 days at room temperature (approx. 73°F), consolidants were applied after this period of time and the samples cured for another 14 days before testing.

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[17] These directions were followed on all plasters containing lime: pure lime plasters, clay/lime and gypsum/lime plasters.

[18] Thanks to Dr. Hamid and the professors working at the Drexel University Engineering Department for their generous assistance.

4.2.2 Consolidants

4.2.2.1 Products and Materials Used

- Natural Consolidant: Tuna Cactus Mucilage

The Tuna cactus is a variety of cactus plant (Opuntia Ficus Indica) which has been traditionally used both as an additive and as a consolidant on earthen constructions in many areas of South America, particularly in Peru[19]. The mucilages, sulfuric acid esters contained in the vesicular cells of the Tuna Cactus, are water insoluble, absorb and hold the water and thus develop viscous solutions. This gummy substance has conglomerating properties and inhibits and selects bacteria, promoting the consolidation of materials and avoiding the formation and proliferation of bacteria.

- Acrylic Resin: Acryloid B-67

Acryloid B-67 is an isobutyl methacrylate polymer, produced by Rohm and Haas Company, Independence Mall West, Philadelphia, PA 19105. Although the use of acrylic resins as consolidants for earthen constructions has not been generally pursued as consolidants on earthen surfaces due to their shallow depth of penetration and the undesirable surface change in color and gloss, this acrylic resin was included in the testing program because of its good results in previous uses as a stone and plasters consolidant.

The alkali-soluble acrylic Neocryl BT-520 was also tried, diluted in alcohol and water at 5 and 10% in order to compare its depth of penetration with the Acryloid B-67, and possible use on the tests. Although no change in color and a very slightly glossy surface were recorded, the very shallow depth of penetration achieved was not acceptable, and its use discarded.[20]

The selection of a proper solvent in order to achieve an acceptable depth of penetration and no glossy films on the surface was found to be very important to obtain a successful consolidation. It was proved that the depth of penetration was not as efficient when a too rapidly evaporating solvent was used with the acrylic resin, and to find the most suitable solvent that provided an acceptable depth of penetration for B-67 on clay plasters, different solvents - with different rates of evaporation - were tested. The solvents tested, were:

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[19] Thanks to Ana María Hoyle, who works on the experimental consolidation of the walls of Chan-Chan in Perú with Tuna Cactus Mucilage, for supplying the leaves used on the experiment.

[20] It was considered that this acrylic resin could be the solution for a non-toxic, readily available and inexpensive product for the application on clay plasters, but since the penetration of the emulsion was very shallow and not acceptable, it was decided not to include this alkali-soluble acrylic on the tests.

- **Naphtha,** a mineral spirit, when applied to a clay plaster, left a glossy surface after the fourth application, and changed dramatically in color (Munsell Soil Chart No. 3/10YR/3 - dark brown). The penetration achieved was very shallow (about 1/8").
- **Acetone,** achieved almost no penetration -- mainly due to its very fast evaporation rate. It left a glossy surface and darkened the color of the clay plaster (Munsell Soil Color No.4/10YR/2 - dark grayish brown).
- **Methyl Ethyl Ketone,** the solvent used on the ethyl silicate Conservare OH - Stone Strengthener, was also tried as a solvent for B-67, resulting in a very poor penetration and a change of color (Munsell Soil Chart No. 4/10YR/2 - dark grayish brown).
- **Diethylbenzene,** whereas the application of B-67 dissolved in Diethylbenzene changed the color of a clay plaster (Munsell Soil Chart No.4/10YR/2 - dark grayish brown), it did not leave a glossy surface and a full penetration was achieved.

It was therefore decided to use diethylbenzene as the solvent for the acrylic consolidant.

- Ethyl Silicate: Conservare OH - Stone Strengthener

Conservare OH, a ready to use commercial consolidant, contains ethyl silicate resin, methyl ethyl ketone and acetone *(See Material Safety Data Sheets, Appendix B)* - and is designed for consolidation treatment and stabilization of deteriorated masonry materials. It is not a hydrophobic consolidant and therefore treated surfaces can absorb water after treatment. Since water repellency is not a truly desirable property for an adobe consolidant, this is a suitable product for earthen constructions. Conservare OH is manufactured by ProSoCo, Inc. P.O. Box 1578, Kansas City, KS 66117, USA.

4.2.2.2 Application Procedures

All consolidants were sprayed until full penetration was achieved. To achieve full penetration and prevent surface crust formations, consolidants were applied in repeated applications -- the number of applications depending on the plaster type -- referred to as "cycles". It was necessary to wait 14 days between consolidation of the samples and the tests, to let the consolidant go through its hydrolysis process.

- Natural Consolidant: Tuna Cactus Mucilage

The interior content of the tuna leaf was removed and weighed, soaking 350 grams in 0.5 liters of water for 24 hours. After this period, the gum left was screened through a cheese-cloth and mixed with water at 10% by volume.

The solution was then spray applied to the samples in repeated cycles until full penetration was reached. Typical treatments involved 10 to 15 separate applications. The samples were then placed at room temperature for at least 14 days before testing.

- Acrylic Resin: Acryloid B-67

- Acryloid B-67 (5% solids)
- Diethylbenzene (solvent)

The solution was sprayed to the surface in repeated cycles every time it was completely absorbed by the plaster, until full penetration was reached. Typical treatments involved 19 - 21 applications. The samples were then placed at room temperature for at least 14 days before testing.

- Ethyl Silicate: Conservare OH - Stone Strengthener

The solution was sprayed in cycles, until full penetration on the plaster was achieved. A cycle consisted of three saturating applications at five minutes intervals, while typical treatments involved seven or eight cycles (21-24 separate applications). 30 minutes were allowed between each cycle, and additional cycles were applied until excess material remained visible on the surface for 30 minutes following the last application, or until full penetration was achieved.

The samples were placed in a sealed container for at least 14 days before testing, in order to avoid premature evaporation of the consolidant and to control cure.

4.3 EXPERIMENTAL DESIGN

A preliminary program of approach and method was structured in conjunction with Frank Matero, thesis advisor, and revised by Pascal Odul, CRATerre, and Alejandro Alva and Jeanne Marie Teutonico, ICCROM. The study of the behavior of plasters when applied to an earthen substrate and of consolidants, required an understanding of the plasters properties, such as adhesion, the bond between plaster and substrate; vapor transmission; and capillarity; as well as resistance to environmental factors such as abrasion and water resistance.

ASTM Tests were selected due to their standardization of procedures and consistent and confident results, and re-designed to meet the requirements of the plasters. *(See Appendix C)*

The ASTM tests selected were:

- ASTM C241-85 - "Standard Test Method for Abrasion resistance of Stone Subjected to Foot Traffic."

- ASTM C307-83 "Standard Method for Tensile Strength of Chemical Resistant Mortar, grouts, and Monolithic Surfacing."

- ASTM E96 - "Standard Test for Moisture Vapor Transmission of Dimension Stone."

In addition, a RILEM and a CRATerre tests were selected:

- CRATerre Drop Test

- RILEM Test Method No. II.4 - "Capillarity Test."

All tests data were documented photographically and recollected in standardized laboratory sheets *(See Appendix E)*

4.3.1 ABRASION RESISTANCE

Based on Test : ASTM C241 - 85
"Standard Test Method for Abrasion Resistance of Stone Subjected to Foot Traffic"

No. Specimens
@ Test : 1 (4 Consolidants)
@ Plaster type : 4 (5 Plasters)
TOTAL : 20

Specimens Reqd. : Plasters are applied to reconstituted adobes

TIME NEEDED
Cure adobe brick : 14 days
Cure 1st. Coat : 3 days
Cure 2nd. Coat : 28 days
Consolidation : 14 days
Test : 1 day
TOTAL : 60 DAYS

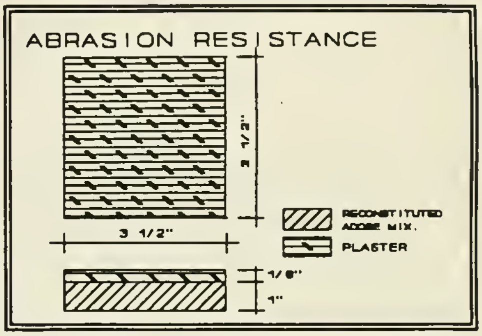

Figure 4

Following specifications by ASTM C241 - 85

Scope

To determine the abrasion resistance of traditional plasters applied to earthen blocks and their modification with different types of consolidants.

Referenced documents

ASTM Standards:
- ASTM C241 - 85 "Standard Test Method for Abrasion Resistance of Stone Subjected to Foot Traffic".

Other:
- Technique developed by Darrel Butterbaugh [17]

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[17] Morgan W. Phillips. "Acrylic Precipitation Consolidants" Science and Technology in the Service of Conservation. Preprints to the Contributions to the Washington Congress, 3-9 September 1982. (London, 1983.)

Significance and Use

This test method is useful in indicating the abrasion resistance between various traditional plasters used on earthen construction and the difference in resistance when different consolidants -- a natural product (cactus tuna), an acrylic resin solution (Acryloid B-67, 5% in Diethylbenzene) and an ethyl silicate (75% silicic acid ester Conservare OH) -- are applied.

Apparatus

- *Scales*, used in weighing materials for mixes conformed to the following requirements: the permissible variation at a load of 1000 g. shall be ± 1.0 g.; at a load of 1500 g., it shall be ±2.0 g.

- *Abrasive Unit*, S.S. White Model K, with Standard round nozzle operating pressure of 60 p.s.i./ standard round nozzle (0.046cm. interior diameter) powder flow "8", with "Micro-Grain Precision Abrasive Powder", Glass Beads No. MS-XL manufactured in USA by MDC Industries Inc., Philadelphia, Pennsylvania.

- *Shield*, a metal shield of galvanized steel 3 ½" square having three openings 1.3 cm. (½") diameter in the top left side corner. Suitable clamps were also provided to hold the shield fixed on the test specimen during the test.

- *Frame Support*, used to maintain the same distance between the air abrasive unit and the sample sandblasted.

Test Specimens

For this test, five types of plasters -- clay, lime, gypsum, clay/lime, and gypsum/lime -- were applied to reconstituted adobes of 3 ½" x 3 ½" x 1" *(See Fig. 4)* and tested following the specifications noted previously *(See General Tests Specifications)*. To these plasters the consolidants were applied. Three samples were prepared for each test period. *(See Chapter 4.2.1.2 - Plaster Application Procedures)*. In order to discern the difference of abrasion resistance when consolidants are applied, a test to the plasters without consolidant (control) was performed.

Preparation of Materials

- The plaster was applied to the adobe brick in two coats, the first coat 10 mm. thick, cured for 72 hours at room temperature, and the second coat 4 mm. thick, cured for a minimum of additional 28 days. *(See Chapter 4.2.1.4 - Curing Period)*.

- The consolidants were applied to three samples of each plaster type until full penetration of the plaster was achieved. The samples were then allowed to cure for an additional 14 days period.

- Once ready for the test, each specimen was placed vertically on the support designed for the test -- an "L" shaped plexiglass structure -- at a fixed distance from the nozzle of the microblasting unit to the sample surface.[18] The distance selected between sandblast nozzle and specimen was 2.5 cm.

Procedure

- Each sample was sandblasted in three different areas for one second on each area, using glass beads No. MS-XL, and a constant pressure of 80 psi.

- After sandblasting, the bore hole was measured by filling it level with the same abrasive used (very fine free-flowing glass beads), weighing this abrasive and converting the weight into volume.

- The estimate of abrasion resistance was obtained by measuring the size of the small holes produced by a metered blast of airborne abrasive.

Calculation

To convert the weight into volume, V (cm^3), per cavity in cubic centimeters,

$V = W/D$

V = Volume
W = Weight of glass beads in cavity
D = Specific Gravity of glass beads (= 2.5 $g./cm^3$)

Conditioning

See Chapter 4.1 - Adobe Blocks, and Chapter 4.2 - General Tests Specifications for adobe and plasters mixes and curing time.

Report *(See Data Table I: Appendix E)*

The following information was reported:

- Size of hole by weight of each specimen.
- Average of the tests on individual specimens expressed to two significant figures were reported as the abrasive resistance of the sample, (All results were included in data).
- Using the average weight results, the volume and surface were calculated for each consolidant and plaster type tested.
- The abrasion coefficient loss to the nearest 0.01 cm^3/cm^2 was calculated.

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[18] Specifications for Morgan W. Phillips' test were: Abrasive used S.S. White Model K. Abrasive Unit, standard round nozzle (0.046cm. int. diam.); working distance 3.8 cm.; operating pressure 120 p.s.i.; powder flow setting '5'; powder level 3.8-6.4 cm. from top of canister; abrasive S.S. No. 9 glass beads

4.3.2 ADHESION

Based on Test : ASTM C307-83
"Standard Method for Tensile Strength of Chemical Resistant Mortar, Grouts, and monolithic Surfacing"

No. Specimens
@ Test : 6 (4 Tests)
@ Plaster Type : 24 (5 Plasters)
TOTAL : 120

Specimens Reqd. :
- Adobe Mixture
- Plaster

TIME NEEDED
Adobe mix cure : 14 days
Plaster cure : 28 days
Consolidation : 14 days
TOTAL TIME : 49 DAYS

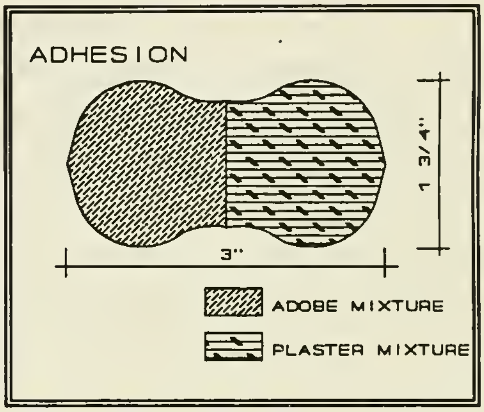

Figure 5

Following specifications by: ASTM C307 - 83 (Reapproved 1988)

Scope

To determine of the adhesive strength between a clay substrate and different plasters. The values stated in inch-pound units are to be regarded as the standard.

Referenced documents

ASTM Standards:

- ASTM C307 - 83 (Reapproved 1988) "Standard Method for Tensile Strength of Chemical-Resistant Mortar, Grouts, and Monolithic Surfacing"
- ASTM C904 - "Definition of terms relating to Chemical-Resistant Nonmetallic Materials."
- ASTM E4 - "Practice for Load Verification of Testing Machines."

Significance and Use

This test was used to provide information on the adhesive properties of various traditional plasters on an adobe substrate and changes on adhesive strength when different consolidants are applied.

Apparatus

- *Scales,* used in weighing materials for mixes, conforming to the following requirements. The permissible variation at a load of 1000 g. ± 1.0 g; at a load of 1500 g., it shall be ± 2.0 g.

- *Weights,* The permissible variations on weights used in weighing materials was as described in ASTM C307, Table 1.

- *Briquet Molds,* The mold for making test specimens was made of cast bronze and had sufficient material in the sides to prevent spreading during molding. Gang molds of the type shown in ASTM C307, were used *(See Fig. 5 for shape and size specifications).* The dimension of the briquet molds were: the width of the mold, between inside faces at waist line of briquet, 1 in. (25 mm.); with permissible variations of ± 0.01 in. (± 0.25 mm.); the thickness of the molds measured at the point of greatest thickness of either side of the mold at the waist line, 1 in. with permissible variations of +0.004 in. (±0.10 mm) and -0.002 in. (-0.05mm.). The briquet test specimens conformed to the dimensional requirements shown in ASTM C307.

- *Equipment for mixing Materials,* consisted of a container of suitable size made of non-corrosive metal, and a strong, sturdy spatula or trowel.

- *Testing Machine,* universal-type, in which the load is applied manually at a constant but adjustable rate of cross head movement. The machine used conformed to Practice E 4.

- *Tension Clips,* for holding the tension test specimens which was in accordance with ASTM C307.

Temperature and Humidity

The temperature in the vicinity of the mixing operation was reported as 71±°F. The relative humidity was approximately 40%.

Number of Test Specimens

Six specimens were prepared for each test period.

Preparation of Mixtures

- *Adobe Mixture,* The reconstituted samples were made from adobes produced in New Mexico, USA. *(See characteristics and properties of the Adobe Blocks in Chapter 4.1).* At least 500 g. of mixture was prepared for each set of tests by soaking the adobe blocks in water and letting them stand for 24 hours before re-molding.*(See Chapter 4.2.1.3 Mold Preparation for specifications).*

- *Plaster*, Five types of plasters were tested: clay, lime, gypsum, clay/lime and gypsum/lime. After curing for 28 days, three different consolidants were applied: a natural product (Tuna Cactus Mucilage), an ethyl silicate (75% silicic acid ester Conservare OH) and an acrylic resin solution (Acryloid B-67, 5% in Diethylbenzene). For each set of tests (6 samples) at least 500 g. of plaster were mixed in proper proportions. *(See Chapter 4.2 Plasters' General Specifications)*

Molding Test Specimens

Prior to filling, the molds were covered with a thin coat of silicon grease, to prevent sticking of the mixture to the metal of the mold. In the case of clay, water was enough to prevent adhesion of the material to the molds. The waist of the molds were divided by a small piece of paper as a separator and each half packed separately with the clay mixture -- which would function as the substrate -- so that it could be divided in two later. The pieces were cured for a minimum of 14 days and after cured, one half of the sample was placed back into the mold and the other half filled with the plaster mixture, letting it cure as specified by each plaster. *(See Chapter 4.2.1.4 Plaster's Curing Period)* Care was taken to prevent entrapment of air which would have caused void spaces. The excess of mixture was finally struck off evenly with a spatula.

The consolidants were applied by capillary rise until they had penetrated through all the plaster and reached the adobe mixture. *(See Fig. 6)*. The specimens were allowed to cure for an additional period of at least 14 additional days at 73 ± 4 °F (23 ± 2 °C).

Conditioning

See Chapter 4.1 - Adobe Blocks, and Chapter 4.2 - General Tests Specifications for adobe and plasters mixes and curing time.

Procedure

The specimens were tested at Soil Laboratory, Drexel University after the 14 days consolidation period. Height and width at waist of each test specimen was measured to the nearest 0.001".

The specimens were placed and centered carefully in the clips of the testing machine, and weight was added at the end of the testing device, pulling the specimens apart. The total weight used to separate plaster from substrate was recorded.

Report *(See Data Table II: Appendix E)*

The following information was reported:

- The average tensile strength in pounds per square inch (or MPa) of six specimens.
- The breaking point with respect to the interface between plaster and adobe mixture.

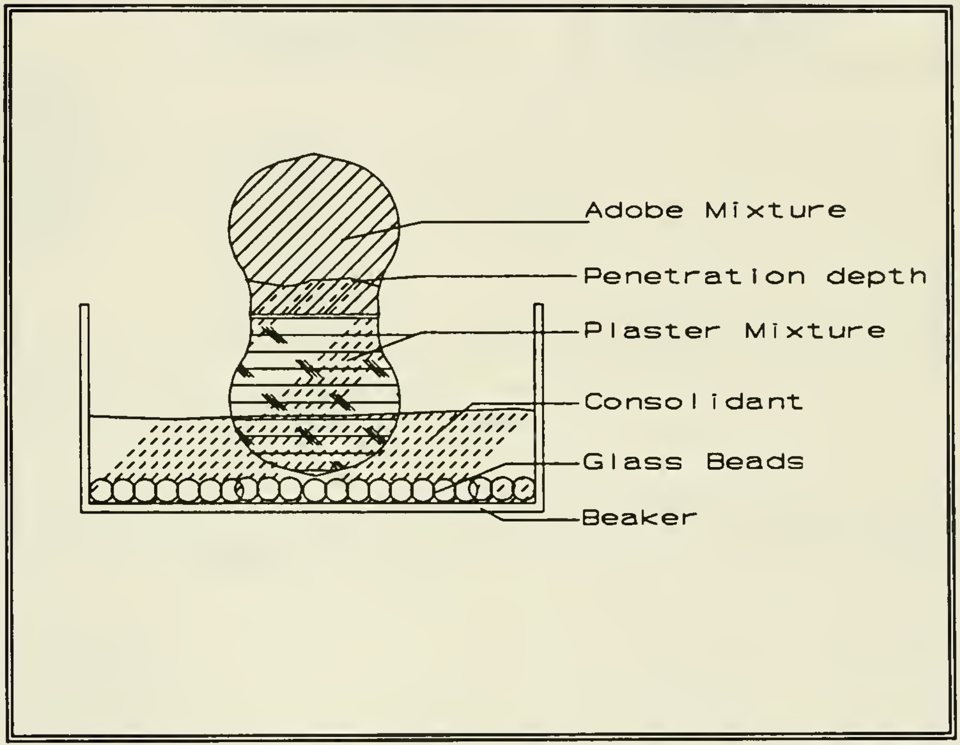

Figure 6

4.3.3 CAPILLARITY

Based on Test : **RILEM Test Method II.4**
"Capillarity Test"

No. Specimens
@ Test : **3 (4 Consolidants)**
@ Plaster type : **12 (5 Plasters)**
TOTAL : **60**

Specimens Reqd. : **Plasters are applied to**
reconstituted Adobes

TIME NEEDED
Cure adobe brick : **14 days**
Cure 1st. Coat : **3 days**
Cure 2nd. Coat : **28 days**
Consolidation : **14 days**
Test : **1 day**
TOTAL : **60 DAYS**

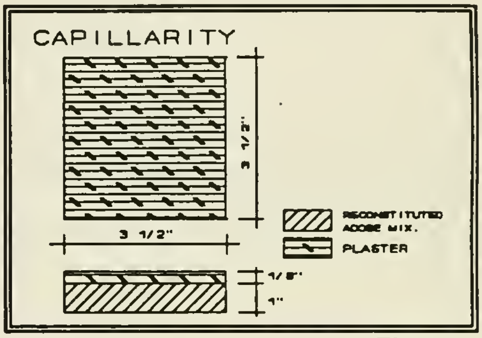

Figure 7

Following the specifications by RILEM Test Method II.4

Scope

To measure the quantity of water absorbed under normal atmospheric pressure by the surface of a masonry material over a definite period of time.

Referenced documents

RILEM[19] Test:
- RILEM Test Method No. II.4 "Capillarity Test"

Other:
- Frances Gale, "Measurement of Water Absorption" Association for Preservation Technology. Vol XXI No. 3/4 1989, pp.8-9.

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[19] RILEM (Reunion Internationale des Laboratories D'Essais et de Recherches sur les Materiaux et les Constructions) with headquarters in Paris, France.

Significance and Use

The primary purpose of this method is to provide a simple means of measuring the rate at which water moves through porous materials such as masonry. The test can be performed at the site or in the laboratory and can be used to measure vertical or horizontal supports. This test was used to determine the degree of protection afforded by a consolidation treatment.

The variables presented in this test, were five traditional plasters: clay, lime, gypsum, clay/lime, and gypsum/lime, to which three consolidants were applied: a natural product (Tuna Cactus Mucilage), an acrylic resin solution (Acryloid B-67, 5% in Diethylbenzene), and an ethyl silicate (75% silicic acid ester Conservare OH).

Apparatus

- *RILEM Tube,* Test apparatus is available in two forms: one designed for application to vertical surfaces and measures horizontal transport of water or its resistance to wind-driven rain penetration; and a second form designed for application to horizontal surfaces and measures vertical transport. The open, upper end of the pipe has an area of 5.7 cm2. The vertical tube is graduated from 0 to 4 cm3 with each gradation representing an increment of 0.1 cm3.
- *Other* equipment consisted of devices for handling the specimen and measuring time, water quantities, temperature, and humidity.

Temperature

The air in the laboratory was maintained at a temperature of not less than 75 ± 15 °F (24 ± 9.5 °C) and a relative humidity of not less than 30% nor more than 70%. The water applied to the specimen was fresh and potable and its temperature maintained above the dew point in the testing room.

Test Specimens

For this test, five types of plasters -- clay, lime, gypsum, clay/lime, and gypsum/lime -- were applied to reconstituted adobes of 3 ½" x 3 ½" x 1" *(See Fig. 7)* and tested following the specifications noted previously *(See General Tests Specifications)*. To these plasters the three consolidants were applied. Three samples were prepared for each test period. *(See Chapter 4.2.1.2 - Plaster Application Procedures).* In order to discern the difference of abrasion resistance when consolidants are applied, a test to the plasters without consolidant (control) was performed.

Preparation of Materials

- The plaster was applied to the adobe brick in two coats, the first coat 10 mm. thick, cured for 72 hours at room temperature, and the second coat 4 mm. thick, cured for a minimum of additional 28 days. *(See Chapter 4.2.1.4 - Curing Period).* The consolidants were applied to three samples of each plaster type until full penetration of the plaster was achieved. The samples were then allowed to cure for an additional 14 days period.

Procedure

- The pipe-like apparatus was affixed to the sample with a bead of window putty and exerting manual pressure on the cylinder to ensure adhesion.
- Water was added through the upper open end of the pipe until the column reached the 0 gradation mark and the quantity of water absorbed by the material during a specified period of time was read directly from the graduated tube.
- The volume of water absorbed was recorded every minute the first five minutes (when considered necessary) and afterwards every 5 minutes the first 15 minutes and then every 15 minutes for one hour.

NOTE: During the procedure, a tight seal with the clay samples was not possible because water would disperse the clay molecules, breaking the seal between the Rilem Tube Test and the clay plaster. Therefore, a different test was used for clay plasters, consisting of placing a drop of water on the finished surface and recording the time elapsed until the drop completely penetrated the plaster.

Conditioning

See Chapter 4.1 - Adobe Blocks, and Chapter 4.2 - General Test Specifications for adobe and plasters mixes and curing time.

Report *(See Data Tables III-XX: Appendix E)*

The following information was reported:

- pH and temperature of the water.
- Period of time water is applied.
- Volume of water absorbed in cubic centimeters as a function of time in minutes.

4.3.4 VAPOR TRANSMISSION

Based on Test : ASTM E96-80
"Standard Test Methods for Water Vapor Transmission of Materials"

No. Specimens
@ Test : 3 (4 Tests)
@ Plaster type : 12 (5 Plasters)
TOTAL : 60

Specimens Reqd. : Plaster

TIME NEEDED
Plaster cure : 28 days
Dry @ surface : 2 x 2 days
Consolidation : 14 days
Test data : at least 10-14 days
TOTAL TIME : 53 DAYS (min.)

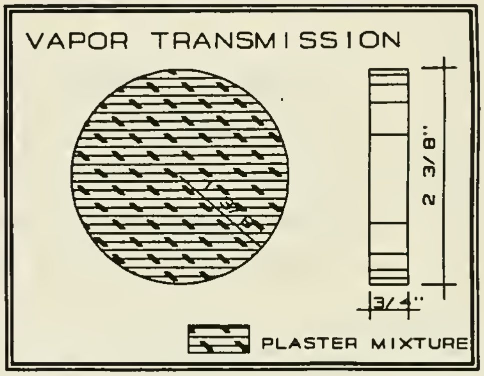

Figure 8

Following specifications by: ASTM E96 - 80

Scope

To determine the water vapor transmission (WVT) of plaster products where the passage of water vapor may be of importance. The methods are limited to specimens not over ¼ in. (32 mm.) in thickness. From the two methods provided by ASTM E96 for the measurement of permeance, the Water Method was selected because it approaches actual conditions found outside and has been successfully used on mortars and paints.[20] In the Water Method the dish contains distilled water and the change in weigh determines the rate of vapor movement through the specimen from the water to the controlled atmosphere.

Referenced documents

ASTM Standards:
- ASTM E96 - 80 "Standard Test Methods for Water Vapor Transmission of Materials."
- ASTM C270 -87 "Standard specification for Mortar Unit Masonry"

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[20] Judith Jacob and Norman Weiss. "Laboratory Measurement of Water Vapor Transmission rates of Masonry Mortars and Paints" Association of Preservation Technology 3/4. Vol. XXI,(December 1989): 20-27.

Significance and Use

The purpose of this test was to obtain, by means of simple apparatus, reliable values of water vapor transfer through permeable and semi-permeable materials expressed in suitable units.

Apparatus

- *Scales*, used in weighing materials for mixes conformed the following requirements: the permissible variation at a load of 1000 g. shall be ± 1.0 g.; at a load of 1500 g., it shall be ± 2.0 g.

- *Molds*, The molds used for this test were rings made of rigid plastic with an interior diameter of 2 3/4" and 3/4" high.[21] These dimensions assured sufficient rigidity to prevent the disks from breaking upon removal of the molds. The disks were also thin enough to yield noticeable weight changes on daily basis.

- *Test Dish*, Tri-cornered polypropylene 250 ml. beakers were used as test dishes. These beakers have a top-most inner diameter of 3 ¼"; thus preventing the samples from being too close to the water. In the case of the clay specimens the separation between water and specimens was very small due to the shrinkage of the material, but they were carefully manipulated in order to avoid wetting them once they were in the test dish.

- *Desiccating Chamber*, Designed and assembled at The Architectural Conservation Laboratory at the University of Pennsylvania consisted of a glass box (36"x 12") with a capacity of 24 dish assemblies. It was filled at the bottom with desiccant[22], and covered with a glass sheet to prevent humidity changes within the chamber.

Temperature and Humidity

The Relative Humidity was maintained at 10 ± 5% [23] in the desiccating chamber and controlled on a daily basis. The desiccators were changed as often as needed - depending on the external weather and amount of samples in the chamber - in order to maintain the same relative humidity throughout the duration of the test. It was not possible to control the temperature in the chamber. However, it was measured daily and fluctuated between 50 and 75 °F.

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[21] Norman Weiss and Judith Jacob, p. 26.

[22] The desiccant used for the Desiccating Chamber was Drierite $CaSO_4$ - Anhydrous Hammond - Size 8 mesh, manufactured in USA by W.A. Hammond Drierite Co., Xenia, Ohio.

[23] Norman Weiss and Judith Jacobs maintain in the test a temperature on 22-25 °C, and a RH of less than 10%

Test Specimens

Five types of plasters - clay, lime, gypsum, clay/lime, and gypsum/lime - were prepared according to the specifications noted previously *(See Chapter 4.2 - General Test Specifications)*. The consolidants - a natural product (Tuna Cactus Mucilage), an acrylic resin solution (Acryloid B-67, 5% in Diethylbenzene), and an ethyl silicate (75% silicic acid ester Conservare OH) - were sprayed in order to discern the difference in vapor transmission when consolidants are applied.

Preparation of Materials

- After preparation of the plaster mix it was poured into molds. At least 20 samples of each plaster type were prepared in order to choose the best samples for the test *(See Chapter 4.2.1.3 - Mold Preparation)*. After making sure no voids were present the excess was screeded. The specimens were labeled on their edges before initiating the curing period.

- The plasters were cured for at least 28 days *(See Chapter 4.2.1.4 - Curing Period)*.

- After curing the samples were allowed to dry for 48 hours on each side, and the laitence removed to expose the pore structure that characterizes each plaster mix. The laitence was removed by brushing both the top and bottom surfaces with a stainless steel wire brush.

- The consolidants were then applied with a spray bottle to three samples of each plaster type until full penetration was achieved and the number of applications performed was recorded. The plasters remained in the laboratory at room temperature for another 14 days for complete penetration of the consolidant into the plaster.

- Once ready for testing the samples were re-weighed and electrical tape was wrapped around the edge of each sample disk in order to avoid any vapor transmission through the sides of the samples. Re-labeling was also necessary. Each of the samples was then placed on top of a beaker containing 100 ml. distilled water. A sample of each plaster type without consolidant was placed in an empty beaker to be used as a "blank".[24]

- After placing the taped disks in the rims of the containers, an impermeable seal was insured by melting wax around the interface between the electrical tape and the beaker. Molten paraffin was used for this test. Once fit the samples were placed in the desiccating chamber and the chamber was covered with the glass top.

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[24] The "blank" sample reported the lapse of time needed by the plasters to reach their equilibrium: it indicated when no more water was evaporating from the sample itself but coming out from the beaker. Initially collected data was therefore not useful until the "blanks" were judged to reach the equilibrium. The period of time necessary to reach the equilibrium, varied significantly from one plaster to another.

Test Data

The dish assembly, a sample and container unit, was placed in the desiccating chamber. Daily weighing of the assembly measured the amount of water that evaporated through the sample; the measurements were then used to calculate the rate of water vapor transmission.

Conditioning

See Chapter 4.1 - Adobe Blocks, and Chapter 4.2 - General Test Specifications for adobes and plasters mixes and curing time.

Procedure

- The samples were weighed every 24 hours (± 20 min.) for at least 10 days once the "blank" had reached equilibrium. The samples were relocated within the chamber thus avoiding the constant placement of any group in a section that was less conductive to vapor transmission.

Analysis of Results, Calculations

The results of the rate of water vapor transmission may be determined either graphically or numerically. For purposes of this test the analysis was determined graphically.

Graphic Analysis

- The weight was plotted against the elapsed time and resulted in an inscribed curve which tended to become straight. Judgment here was required and numerous points were helpful. When a straight line fitted the plot of at least six properly spaced points, with due allowance for scale sensitivity, a nominally steady state was determined to exist and the slope of the straight line was denominated the rate of water vapor transmission.[25]
- The average daily weight loss was also plotted against elapsed time (i.e., the average of the weight losses of the three dish assemblies of each type). This graph illustrated that the samples behaved synchronously, although the results might have been erratic.
- The average daily weight loss data was transformed into a set of accumulative data. The y-axis value for each day as the sum of the average daily weight losses to that point, divided by the number of days elapsed. These values were plotted as a function of time.
- The Water Vapor Transmission (WVT) was finally calculated in grams of water transmitted through a unit square meter of mortar surface per hour.

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[25] On the test prepared by Weiss and Jacobs, the first graphic resulted not being a straight line as described by the ASTM Test. Therefore, two more graphics were prepared.

Report *(See Data Tables XXI-XL: Appendix E)*

The following information was reported:

- Weight of plasters cured as disks before and after consolidation.
- Both daily temperature and RH values.
- Weight of dish assembly every 24 hours. A minimum of ten data points was required for the interpretation of the test results.
- Permeability of each specimen and the average permeability of all specimens tested.
- The plots indicating the section of the curve used to calculate permeability.

4.3.5 WATER RESISTANCE

Based on Test : CRATerre Drop Test

No. Specimens
@ Test : 3 (4 Tests)
@ Plaster type : 12 (5 Plasters)
TOTAL : 60

Specimens Reqd. : Plasters are applied to reconstituted Adobe Blocks

TIME NEEDED
Cure adobe brick : 14 days
Cure 1st. Coat : 3 days
Cure 2nd. Coat : 28 days
Consolidation : 14 days
Test : 1 day
TOTAL : 60 DAYS

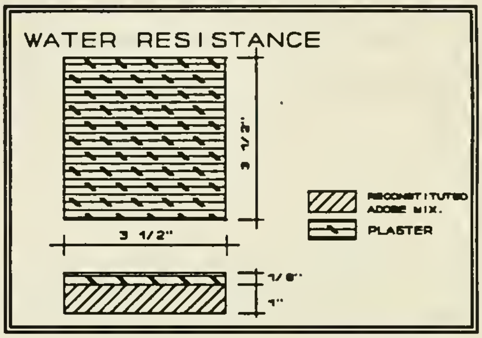

Figure 9

Following specifications: CRATerre-Drop Test

Scope

To determine the resistance to leakage of unit masonry subjected to a constant impact of a droplet. The test consists of submitting the face of a prepared sample to the impact of a droplet at a rate of one drop per second for a period of one hour or until the specimen is penetrated. The repeated observation of the samples allowed the examination of the water resistance of the plasters in two ways: aggressive penetration by the constant hit of a drop of water on one point, and penetration of plaster absorption.

Referenced documents

CRATerre:
- Douline, A., "Batiments en vouter et compoler en adobe, Niger" memoire de CEAA-Terre, CRATerre-EAG, Grenoble, France 1990

ASTM Standards:
- ASTM E514 - 7

EBS (Experimental Building Station):
- Accelerated Erosion Test

Significance and Use

The primary purpose of this method is to obtain information to aid in the evaluation of water resistance of adobe blocks with a combination of different variables in order to determine their effectiveness. The variables presented in this test, were five traditional plasters: clay, lime, gypsum, clay/lime, and gypsum/lime, to which three consolidants were applied: a natural consolidant (Tuna Cactus Mucilage), an acrylic resin solution (B-67, 5% dilution in Diethylbenzene), and an ethyl silicate (75% silicic acid ester Conservare OH).

Apparatus

- *Dropping instrument,* adjusted to dispense one drop of water every second. Utilized as dropping instruments were plastic bottles with a dispenser on the bottom and a regulator device attached to it.

- *Support for the sample,* The support for the sample was a 3 ½" x 3 ½" wooden frame. The frame was hollow in the center in order to observe if the brick collapsed when water was released at one drop per second. The sample was placed 2.50 meters below the droplet. *(See Fig. 10)*

- *Other* equipment consisted of devices for handling the specimen and measuring time, water quantities, temperature and humidity.

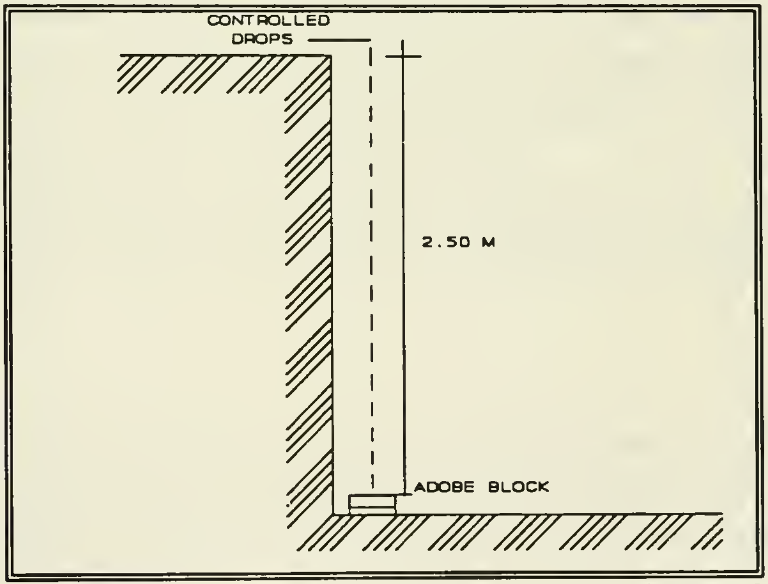

Figure 10

Temperature

- The air in the laboratory was maintained at a temperature of not less than 75 ± 15 °F (24 ± 9.5 °C) and a relative humidity of not less than 30% nor more than 70%. It was very important to ensure that no influential air movement surrounded the experiment thus insuring that the droplet would fall on the same spot at all times.
- The water applied to the specimen was fresh and potable and its temperature was maintained above the dew point in the testing room.

Test Specimens

For this test, five types of plasters - clay, lime, gypsum, clay/lime, and gypsum/lime - were tested following the specifications noted before *(See General Test Specifications)*. To these plasters the three consolidants were applied. The plasters were applied to reconstituted adobes of 3 ½" x 3 ½" x 1" *(See Fig. 9)*; three samples were prepared for each test period. *(See Chapter 4.2.1.2 - Plaster application)*.

Preparation of Materials

- The plaster was applied to the adobe brick in two coats, being the first 10 mm. thick, cured for 72 hours at room temperature, and the second coat 4 mm. thick, cured for a minimum of additional 28 days. *(See Chapter 4.2.1.4 - Curing Period)*
- The consolidants were applied to three samples of each plaster type until full penetration on the plaster was achieved. The samples were then allowed to cure for an additional 14 days period.
- Once ready for the test, each specimen was placed on a square frame so that its center is unsupported thus allowing observation of possible adobe collapse.
- The dropping device was placed and adjusted 2.50 meters above the sample so that water was applied to the center of the specimen's exposed face, and water application was adjusted at 1 drop per second.

Procedure

The exposed face of the specimen was subjected to a constant impact of a water drop at a rate of 1 drop per second for one hour on clay plasters and two hours for all other plasters. The test was interrupted at regular intervals in order to record both depth and width of erosion - when measurable - as well as width of absorption.

The maximum depth of erosion in one hour was measured in centimeters. This value divided by 60 resulted in the rate of erosion in cm./min. If the drop bored a hole through the plaster in less than one hour, the rate of erosion was obtained by dividing the thickness of the specimen by the time taken for full penetration to occur. When no erosion occurred, only the rate of absorption was recorded.

Conditioning

See Chapter 4.1 - Adobe Blocks, and Chapter 4.2 - General Test Specifications for adobes and plasters mixes and curing time.

Report *(See Data Tables XLI-XLVII: Appendix E)*

The following information was reported,

- Ph and temperature of the water.
- Time period of water application.
- Depth and width of erosion of the specimen at 5', 10', 15', 30', 60' (for clays) and 120' (for all other plasters) to determine the erosion rate in cm./min.
- Width and depth of absorption of the brick at same elapsed time to determine the absorption rate in cm./min.
- Time for brick to collapse (if occurred).

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Results tables and graphics are inserted in this chapter, while the data information is appended in Appendix E.

5.1 TEST CONCLUSIONS

5.1.1 Abrasion Resistance

The abrasion resistance test measures the degree of cohesive strength imparted to the plasters through consolidation. The abrasion resistance coefficient was measured in cm^3/cm^2 as the volume of material lost when the plaster was submitted to a constant aggregate blasting for one-minute interval.

Besides a separation between lime plaster and clay substrate on some samples -- resulting from the wet environment to which they were exposed during the curing period in a moist room (see adhesion test below) -- no further complications were encountered in conjunction with this test. The fact that some plasters had separated from the substrate was not a restraint in this case, since the test was executed only on the plaster surface. All data are presented in Table I: Abrasion Data, appended in Appendix E. The results of the test are displayed in Table 12. Untreated Lime plasters displayed the best abrasion resistance (0.12 cm^3/cm^2), followed by clay plasters (0.16 cm^3/cm^2) and gypsum plasters (0.18 cm^3/cm^2). The clay/lime plaster displayed a very poor abrasion resistance (0.32 cm^3/cm^2), and the gypsum/lime plaster produced the lowest abrasion resistance (0.49 cm^3/cm^2). *(See Table 12)*

Clay plaster consolidated with Tuna cactus mucilage improved resistance to abrasion only by 6.25%, and by 68% when consolidated with Acryloid B-67 . The best abrasion resistance improvement was accomplished with Conservare OH, which enhanced the clay plaster's resistance by 87%.

Lime plasters consolidated with Tuna cactus mucilage improved resistance to abrasion by 16% and the same improvement of 87.5% was achieved when either Acryloid B-67 or Conservare OH was applied to them.

Gypsum plasters consolidated with Tuna cactus mucilage improved resistance to abrasion by 50%, and improved by 94% when either Acryloid B-67 or Conservare OH was applied.

Clay/lime plasters, which showed a very poor abrasion resistance when tested without consolidant, were improved by 56% with the Tuna cactus mucilage -- by far the best results for all five plasters treated with the mucilage; by 81% when Acryloid B-67 was applied, and by 97% when Conservare OH was applied. Conservare OH resulted in the most significant improvement of the clay/lime plaster when compared with the degree of improvement recorded for all other consolidated plasters, and the lowest abrasion coefficient (0.01 cm^3/cm^2) for all the plasters tested.

Gypsum/lime plasters consolidated with Tuna cactus mucilage improved resistance to abrasion by 37% and by 85% when consolidated with Conservare OH. Acryloid B-67 proved to perform better on gypsum/lime plasters, improving their resistance by 89%, the highest abrasion resistance achieved with Acryloid B-67 when compared with the degree of improvement recorded for all other consolidated plasters.

In conclusion, the abrasion coefficient on all plasters was improved when any of the above consolidants was applied. Conservare OH proved to be the best consolidant for plasters containing clay, while Acryloid B-67 and Conservare OH conferred identical results on pure gypsum and pure lime plasters. Plasters prepared with gypsum and lime (1:1) were most improved with Acryloid B-67.

ABRASION RESISTANCE - RESULTS

PLASTER TYPE		WEIGHT (gr)	VOLUME (cm^3)	SURFACE ABRASION DIAM. (cm)	ABRASION COEFFICIENT (cm^3/cm^3)	RATING*
CLAY	AR-N	0.52	0.208	1.30	**0.16**	D
	AR-T	0.49	0.196	1.30	**0.15**	D
	AR-A	0.16	0.064	0.80	**0.05**	B
	AR-E	0.06	0.024	0.55	**0.02**	A
LIME	AR-N	0.39	0.156	1.10	**0.12**	D
	AR-T	0.33	0.132	1.30	**0.10**	D
	AR-A	0.07	0.028	0.50	**0.02**	A+
	AR-E	0.08	0.032	0.40	**0.02**	A+
GYPSUM	AR-N	0.61	0.244	1.30	**0.18**	D
	AR-T	0.31	0.124	1.30	**0.09**	C
	AR-A	0.04	0.016	0.45	**0.01**	A
	AR-E	0.04	0.016	0.40	**0.01**	A+
CLAY LIME	AR-N	1.06	0.42	1.50	**0.32**	D
	AR-T	0.48	0.192	1.00	**0.14**	C
	AR-A	0.20	0.080	0.60	**0.06**	B
	AR-E	0.03	0.012	0.50	**0.01**	A
GYPSUM LIME	AR-N	1.63	0.652	2.00	**0.49**	D
	AR-T	1.04	0.416	1.60	**0.31**	D
	AR-A	0.18	0.072	0.55	**0.05**	B
	AR-E	0.22	0.088	0.70	**0.07**	B

Table 12

***RATING:**

A	**Excellent**	- (less than 0.05 cm^3/cm^2)
B	**Good**	- (0.05 - 0.09 cm^3/cm^2)
C	**Fair**	- (0.10 - 0.14 cm^3/cm^2)
D	**Poor**	- (more than 0.15 cm^3/cm^2)

ABRASION RESISTANCE - RESULTS

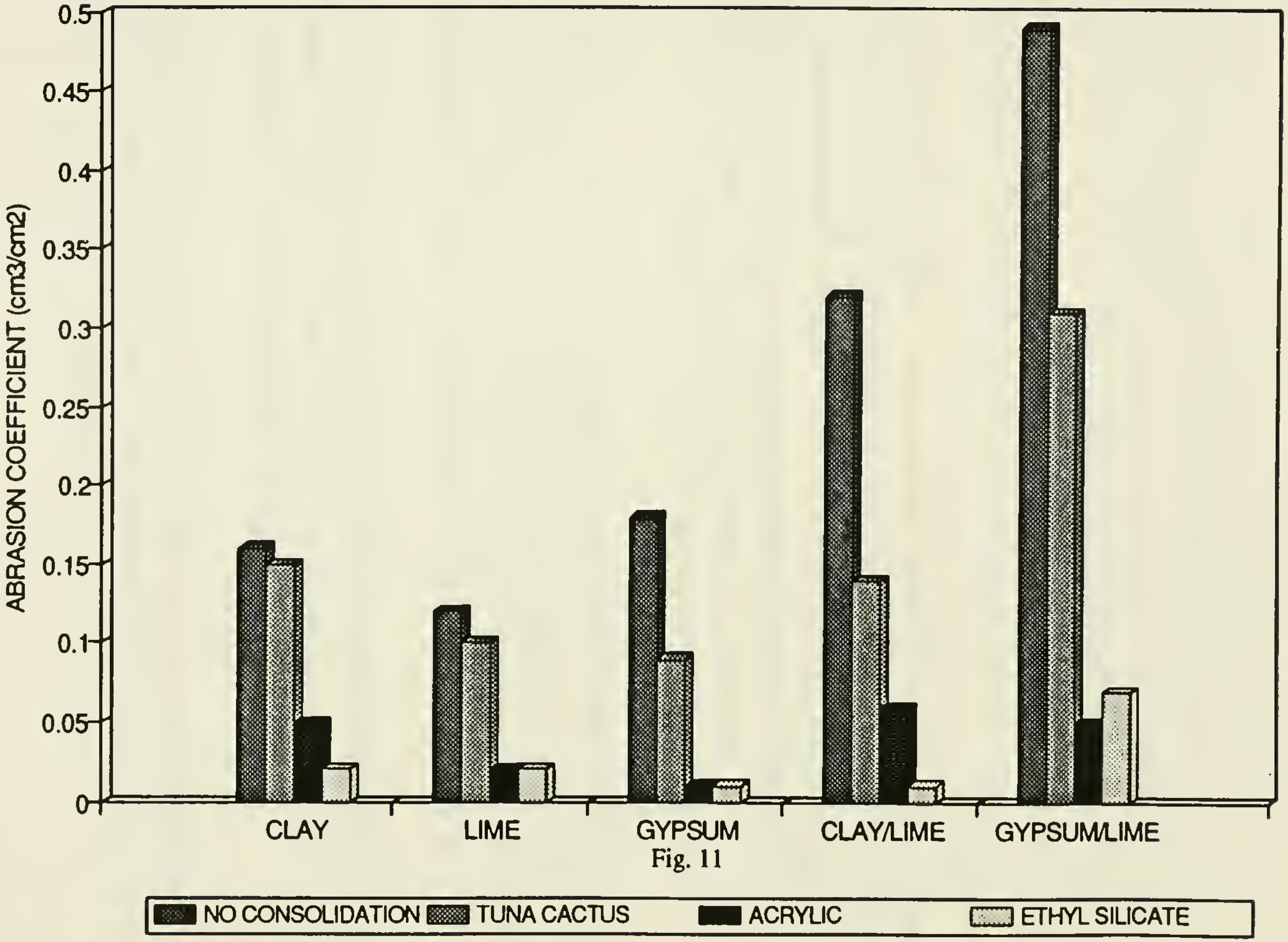

Fig. 11

5.1.2 Adhesion

The adhesion test indicates the strength at the interface between two elements (bond between plaster and substrate) and is measured in lb./sq.in. This test was performed at the Engineering Laboratory, Drexel University, using a Briquet Testing Machine.[1]

Some of the problems encountered during the execution of this test were that many of the plasters containing lime, after curing in the wet chamber for 28 days, separated from the clay substrate and had to be re-adhered. The re-adhesion was achieved by re-wetting the interface so that the clay would become plastic again, able to adhere to the plaster. After this the specimens were dried for an additional period of 7 days before the application of the consolidant. No difference between re-attached and non-re-attached samples was registered.

Also, the specimens that were faulty or gave strengths resulting in too high or too low numbers after the test -- differing by more than 20% from the average value of all specimens made from the same sample -- were not considered in determining the tensile strength, and are marked with an (*) on Table II: Adhesion Data *(See Appendix E)*. The factors that might have altered their adhesion strength are: straw between the two materials -- giving them extra-strength -- or poor adhesion due to poor preparation of the samples. The breaking point was also recorded, and is presented on Fig. 20.

The samples were first tested without consolidant in order to later compare the results with the treated samples. Clay plasters adhered best to the clay substrate (24.83 lb/sq.in.) followed by lime (8.46 lb./sq.in.) and clay/lime plasters (6.21 lb./sq.in.). Gypsum plasters recorded the lowest tensile strength between plaster and substrate, being only 3.39 lb./sq.in. All results are displayed on Table 13.

The tensile strength of clay plasters was reduced by 36% when Tuna cactus mucilage was applied, and increased by 59% when Acryloid B-67 was applied. The most effective consolidant for clay plasters was Conservare OH, which increased the tensile strength by 79%.

The tensile strength of lime plasters was reduced by 20% when Tuna cactus mucilage was applied, and increased by 85% with Acryloid B-67. The most effective consolidant for lime plasters was Conservare OH, which increased the tensile strength by 106%.

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[1] Thanks to Dr. Hamid and professor Jesus .... for their assistance on the execution of the test.

On gypsum plasters all consolidants showed improvement. Tuna cactus mucilage improved the tensile strength by 33%, Acryloid B-67 by 83%, and Conservare OH by 182%.

On clay and lime (1:1) plasters all consolidants showed improvement. Tuna cactus mucilage improved the tensile strength by 36% and Acryloid B-67 by 63%. Conservare OH showed the best tensile strength improvement when applied on clay/lime plasters, a 254% improvement than without consolidant.

The tensile strength of gypsum and lime (1:1) plasters was reduced by 40% when Tuna cactus mucilage was applied, but was increased by 30% with Acryloid B-67, and by 40% with Conservare OH.

In conclusion, Conservare OH proved to be the best treatment for improving the adhesion between plasters and clay substrate, improving the tensile strength in all plaster types. The acrylic solution Acryloid B-67 also improved adhesion between plasters and clay, but only by about 40% less than treatments with Conservare OH. Tuna cactus mucilage was not effective, and in most cases (clay and lime plasters) it reduced normal adhesion strength.

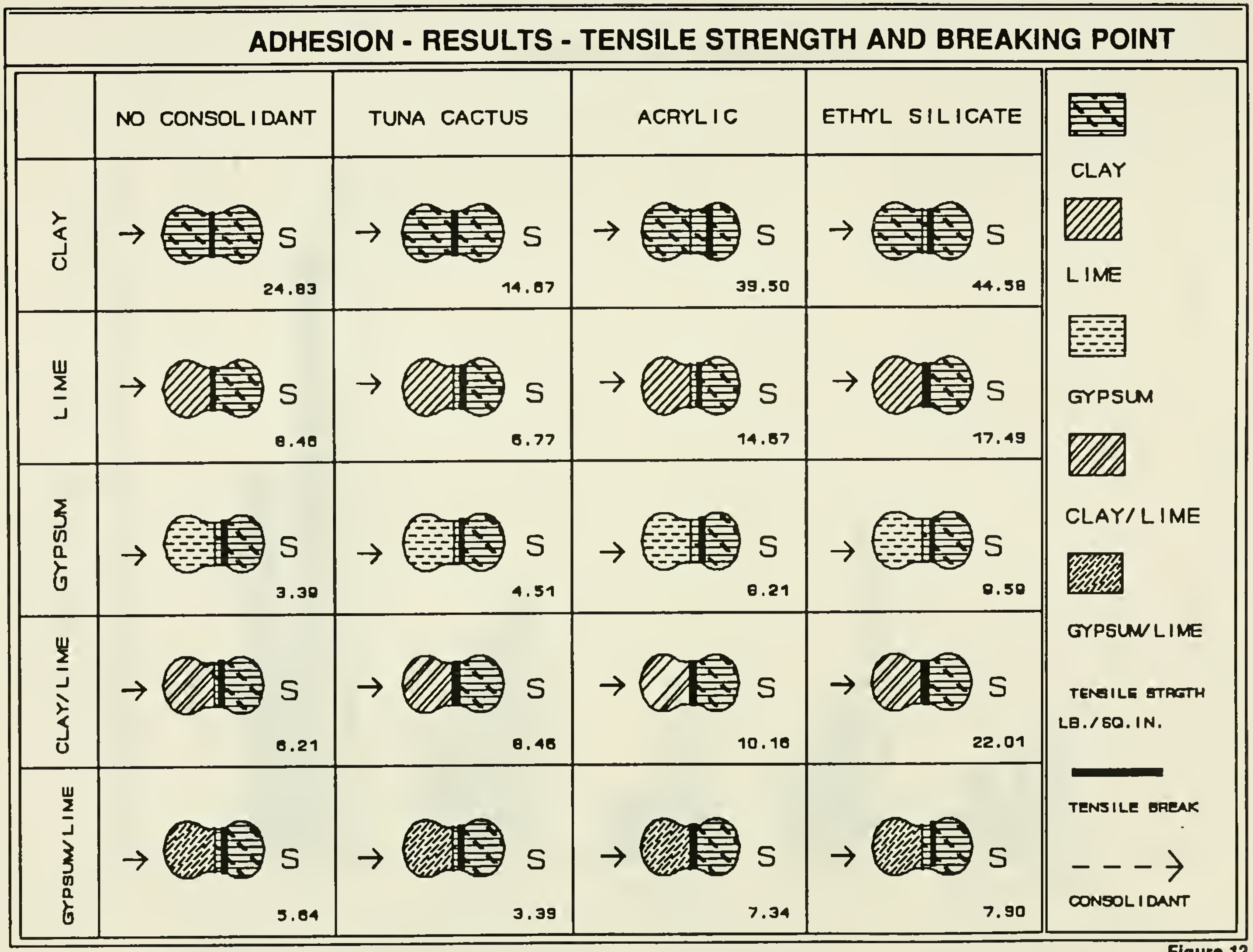
ADHESION - RESULTS

PLASTER TYPE		WEIGHT (gr)	WEIGHT (lb)	TENSILE STRENGTH (lb/sq.in.)	TENSILE STRENGTH (gr/cm²)	RATING*
CLAY	AD-N	200.70	0.44	24.83	1,745.35	A
	AD-T	119.92	0.26	14.67	1,031.18	A
	AD-A	315.94	0.70	39.50	2,776.53	A
	AD-E	357.51	0.79	44.58	3,133.82	A+
LIME	AD-N	69.30	0.15	8.46	594.67	B
	AD-T	55.01	0.12	6.77	475.88	C
	AD-A	120.03	0.26	14.67	1,031.18	A
	AD-E	139.88	0.31	17.49	1,229.41	A
GYPSUM	AD-N	27.18	0.06	3.39	238.29	D
	AD-T	36.54	0.08	4.51	317.02	D
	AD-A	51.46	0.11	6.21	436.51	C
	AD-E	75.97	0.17	9.59	674.10	B
CLAY LIME	AD-N	51.49	0.11	6.21	436.51	C
	AD-T	69.78	0.15	8.46	594.67	B
	AD-A	83.51	0.18	10.16	714.17	B
	AD-E	176.85	0.39	22.01	1,547.13	A
GYPSUM LIME	AD-N	46.15	0.10	5.64	396.45	C
	AD-T	28.17	0.06	3.39	238.29	D
	AD-A	57.28	0.13	7.34	515.94	C
	AD-E	64.57	0.14	7.90	555.31	B

Table 13

***RATING:**

A Excellent - (more than 15 lb/sq.in.)
B Good - (7 - 25 lb/sq.in.)
C Fair - (5 - 7 lb/sq.in.)
D Poor - (less than 5 lb/sq.in)



ADHESION - RESULTS - TENSILE STRENGTH AND BREAKING POINT

	NO CONSOLIDANT	TUNA CACTUS	ACRYLIC	ETHYL SILICATE
CLAY	→ S 24.83	→ S 14.67	→ S 39.50	→ S 44.58
LIME	→ S 8.46	→ S 6.77	→ S 14.67	→ S 17.49
GYPSUM	→ S 3.39	→ S 4.51	→ S 8.21	→ S 9.59
CLAY/LIME	→ S 6.21	→ S 8.46	→ S 10.16	→ S 22.01
GYPSUM/LIME	→ S 5.64	→ S 3.39	→ S 7.34	→ S 7.90

Figure 12

ADHESION - RESULTS

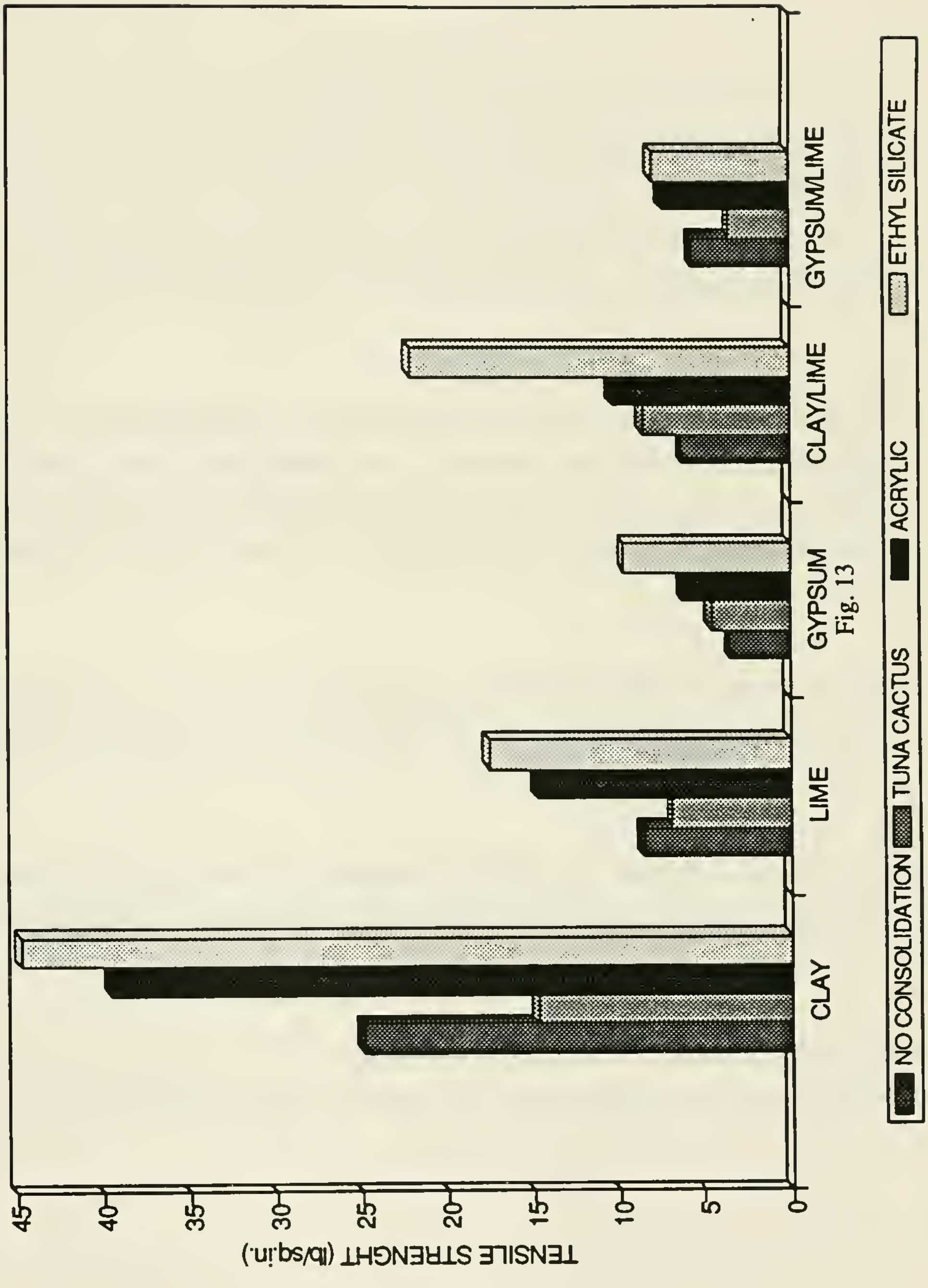


Fig. 13

5.1.3 Capillarity

The capillarity test measures the capillary conduction -- the quantity of water absorbed by the plasters' surfaces -- over a specific period of time. Vertical water transport was measured using RILEM tube tests for one hour in order to record the degree of protection afforded by the plasters when different consolidants were applied.

The only problem encountered on the performance of this test, was that the clay plasters without consolidant and with Tuna cactus mucilage could not retain the tube test for a long time due to the instability of the tube to adhere to the surface. On these plasters another method was used to measure the absorption rate. *(See chapter 4.2.4.3 - Capillarity).* All the test data was recorded on Tables III - XX: Capillarity Data, displayed on Appendix E. The results of the test are presented on Table 14.

The test was first performed on untreated samples in order to later compare the results with samples treated with the three different consolidants. On untreated plasters the highest absorption rate was achieved by clay plasters (2.90 cm^3 min), followed by gypsum (2.75 cm^3/min), gypsum/lime (1.83 cm^3/min), and lime (1.80 cm^3/min). The lowest absorption rate was achieved by clay/lime plasters (0.073 cm^3/min).

Clay plasters decreased their rate of absorption by 9% when consolidated with Tuna cactus mucilage, by 97% when consolidated with Conservare OH, and by 99% when consolidated with Acryloid B-67.

Lime plasters decreased their rate of absorption by 11% when consolidated with Tuna cactus mucilage, by 73.6% when consolidated with Conservare OH, and by 99.7% when consolidated with Acryloid B-67.

Gypsum plasters decreased their rate of absorption by 60% when consolidated with Tuna cactus mucilage, by 98.8% when consolidated with Conservare OH, and by 99.93% when consolidated with Acryloid B-67.

Clay and lime plasters (1:1) decreased their rate of absorption by 50% when consolidated with Conservare OH, by 66% with Tuna cactus mucilage, the highest decrease in absorption achieved on plasters consolidated with Tuna cactus mucilage; and by 100% when consolidated with Acryloid B-67.

Gypsum and lime (1:1) plasters increased their absorption rate by 31% when Tuna cactus mucilage was applied. This was the only condition when the rate of absorption increased after consolidation. Gypsum/lime plasters decreased their rate of absorption by 32% when Conservare OH was applied, and by 99.95 when Acryloid B-67 was applied.

In conclusion, all consolidants (except Tuna cactus mucilage on gypsum/lime plaster) decreased the absorption rate of the plasters. Tuna cactus mucilage imparted the least change in absorption rate on all plasters, except for the clay/lime plaster, where Conservare OH's improvement percentage was higher than Tuna cactus mucilage. Acryloid B-67 imparted the highest change in absorption rates on all the plasters.

A decrease in absorption rate is not always a desirable property on plasters because although it means that the surface is absorbing less water, the water absorption capacity of the porous building material is decreased restricting further treatments and therefore unsatisfactory where aqueous cleaning or re-consolidation is necessary. As explained in Chapter 3, water repellency is not a truly desirable property for an adobe treatment.

CAPILLARITY - RESULTS

PLASTER TYPE		ABSORPTION RATE (cm^3/min.)	RATING*
CLAY	CA-N	2.90	A+
	CA-T	2.65	A
	CA-A	0.016	C
	CA-E	0.085	B
LIME	CA-N	1.800	A
	CA-T	1.600	A
	CA-A	0.005	D
	CA-E	0.475	B
GYPSUM	CA-N	2.750	A
	CA-T	1.100	A
	CA-A	0.002	D
	CA-E	0.033	C
CLAY LIME	CA-N	0.073	B
	CA-T	0.025	C
	CA-A	NO ABS.	E
	CA-E	0.036	C
GYPSUM LIME	CA-N	1.83	A
	CA-T	2.400	A
	CA-A	0.001	D
	CA-E	1.250	A

Table 14

*RATING:

A **Excellent** - VERY HIGH (more than 1 cm^3/min.)
B **Good** - HIGH (0.050 - 1.00 cm^3/min.)
C **Fair** - MEDIUM (0.010 - 0.050 cm^3/min.)
D **Poor** - LOW (less than 0.009 cm^3/min.)
E **No Absorption**

CAPILLARITY - RESULTS

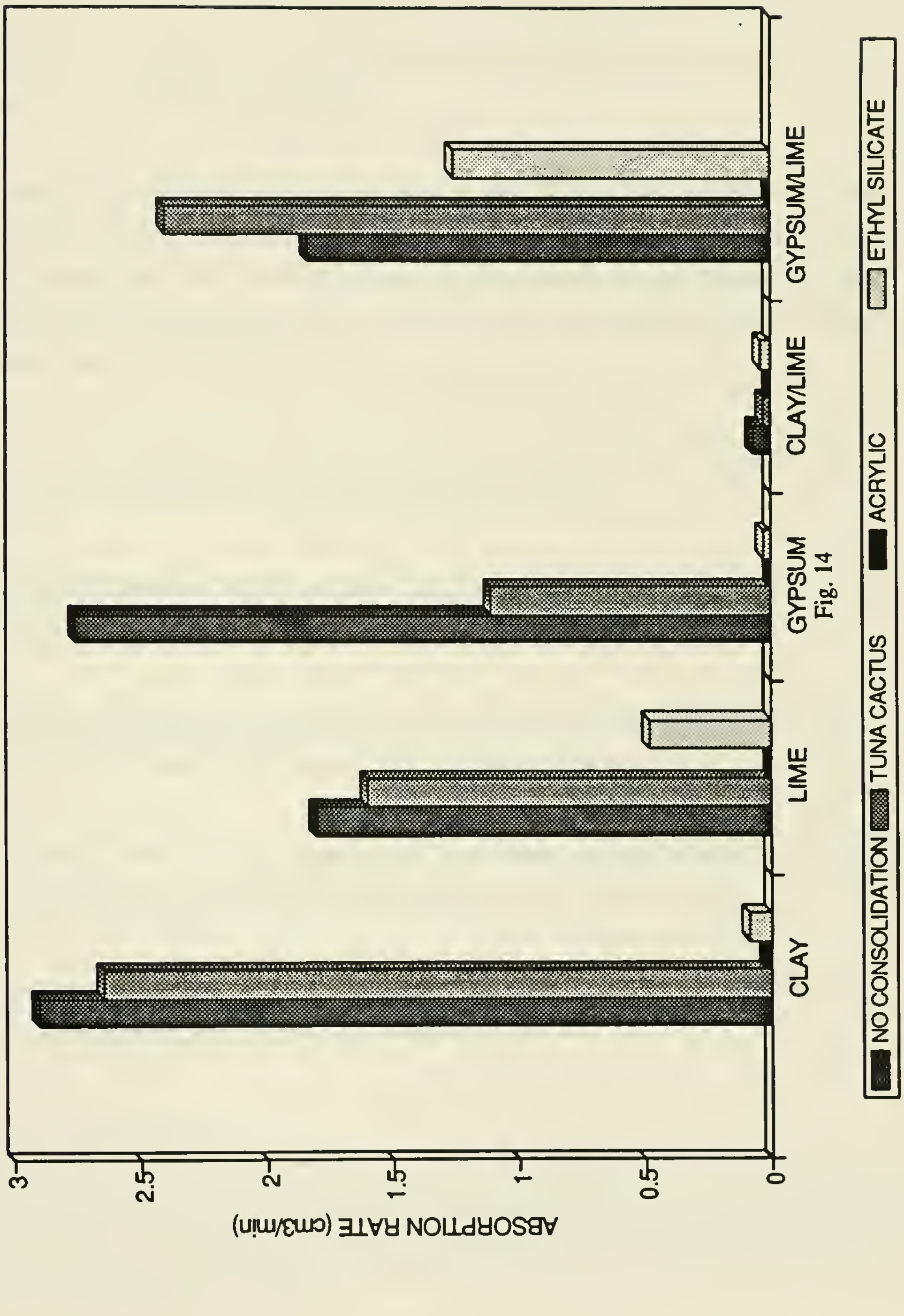


Fig. 14

5.1.4 Vapor Transmission

The vapor transmission test was performed in order to measure with simple apparatus, the passage of water vapor through porous building materials (WVT), in this case, the five different plasters used throughout the experiments. The test was conducted for 28 days, and although the samples did not completely stabilize after that period of time, reliable values were obtained, *(See Tables XXI - XLI: Vapor Transmission Test - Data and Vapor Transmission Test - Individual Results, Appendix E)*[2] and all samples appear to have behaved synchronously.

All plaster types were tested without consolidant in order to compare results with the treated samples. The higher water vapor transmission (WVT) was achieved by the clay plaster (10.7 g./m^2hr), followed by the gypsum plaster (9.6 g./m^2hr.). Lime and clay/lime plasters displayed the same water vapor transmission when untreated (6.6 g./m^2hr.), and the lowest water vapor transmission was displayed by the gypsum/lime plaster (6.5 g./m^2hr). *(See Results in Table 16).*

Clay plasters consolidated with Tuna cactus mucilage increased the WVT by 1.8%, and decreased by 40% with Acryloid B-67, and by 44% with Conservare OH.

Lime plasters consolidated with Tuna cactus mucilage decreased the WVT by 6%, by 10% with Acryloid B-67, and by 22% with Conservare OH.

Gypsum plasters consolidated with Tuna cactus mucilage increased the WVT by 1%, and decreased by 21.8% with Conservare OH, and by 23% with Acryloid B-67.

Clay and lime plasters (1:1) consolidated with Tuna cactus mucilage increased the WVT by 1.5%, and decreased by 17% with Acryloid B-67, and by 30% with Conservare OH.

Gypsum and lime plasters (1:1) consolidated with Acryloid B-67 decreased the WVT by 1.5, by 3% with Tuna cactus mucilage, and by 23% with Conservare OH.

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[2] The tables presented on the appendix E were collected over a period of 28 days. The data was collected in two parts responding only to space provided by the spread sheet. Two different tables were designed for this test: the first table -- Vapor Transmission Test - Data - (plaster name) -- displays the weight of the dish assembly, and below in a shadowed row, the average of the three samples' weight difference. The second table -- Vapor Transmission-Individual Results-(plaster name) -- displays each one of the samples' weight difference, and below it, on the shadowed row, the average of the three samples' weight difference is repeated.

In conclusion it was observed that Tuna cactus mucilage altered the Water Vapor Transmission the least of all the plasters, followed by Acryloid B-67, although only on plasters containing lime and/or clay. Plasters containing clay increased their WVT just by 1 - 2%, when Tuna cactus mucilage was applied. Clay plasters also exhibited the highest difference between treated and untreated conditions in WVT when synthetic consolidants were applied. Finally, plasters containing lime exhibited the highest decrease in WVT when consolidated with Tuna cactus mucilage.

VAPOR TRANSMISSION TEST - ACUMULATIVE RESULTS

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
VT-CL-N	1.07	1.04	0.96	0.96	0.96	0.97	0.98	0.97	1.02	1.00	1.00	1.01	1.01	1.02	1.01	1.00	0.98	0.98	0.97	0.96
VT-CL-T	1.15	1.10	1.00	1.00	0.99	1.01	1.02	1.01	1.05	1.03	1.04	1.04	1.05	1.06	1.05	1.03	1.02	1.00	0.99	0.98
VT-CL-A	0.69	0.68	0.65	0.62	0.60	0.60	0.61	0.60	0.61	0.60	0.59	0.60	0.61	0.60	0.60	0.59	0.59	0.58	0.58	0.57
VT-CL-E	0.50	0.51	0.48	0.49	0.49	0.50	0.52	0.51	0.55	0.54	0.55	0.55	0.56	0.57	0.56	0.56	0.55	0.54	0.54	0.53
VT-LI-N	0.70	0.71	0.69	0.68	0.66	0.64	0.63	0.63	0.62	0.60	0.61	0.60	0.60	0.60	0.59	0.59	0.60	0.60	0.60	0.59
VT-LI-T	0.64	0.67	0.64	0.64	0.62	0.61	0.60	0.60	0.59	0.58	0.57	0.57	0.57	0.56	0.58	0.56	0.57	0.57	0.56	0.56
VT-LI-A	0.61	0.62	0.60	0.60	0.58	0.56	0.58	0.58	0.55	0.54	0.54	0.54	0.54	0.53	0.53	0.53	0.54	0.54	0.53	0.53
VT-LI-E	0.54	0.55	0.53	0.52	0.50	0.50	0.50	0.49	0.48	0.48	0.48	0.47	0.47	0.47	0.47	0.47	0.47	0.46	0.46	0.46
VT-GY-N	0.90	0.86	0.83	0.83	0.82	0.83	0.84	0.84	0.84	0.85	0.86	0.86	0.86	0.86	0.88	0.87	0.87	0.87	0.87	
VT-GY-T	0.96	0.91	0.86	0.86	0.84	0.85	0.88	0.86	0.86	0.86	0.87	0.87	0.86	0.67	0.87	0.87	0.88	0.88	0.88	
VT-GY-A	0.70	0.69	0.65	0.66	0.66	0.66	0.66	00 66	0.66	0.66	0.66	0.66	0.66	0.66	0.67	0.67	0.67	0.67	0.67	
VT-GY-E	0.71	0.70	0.67	0.68	0.68	0.68	0.67	0.67	0.68	0.68	0.68	0.67	0.67	0.67	0.68	0.68	0.68	0.68	0.68	
VT-CM-N	0.68	0.65	0.60	0.59	0.58	0.59	0.60	0.60	0.61	0.61	0.61	0.62	0.62	0.62	0.61	0.61	0.61	0.60	0.60	
VT-CM-T	0.63	0.63	0.59	0.58	0.59	0.61	0.61	0.61	0.62	0.62	0.62	0.63	0.62	0.63	0.62	0.62	0.62	0.61	0.61	
VT-CM-A	0.57	0.56	0.53	0.52	0.51	0.52	0.52	0.51	0.51	0.51	0.51	0.51	0.50	0.51	0.50	0.50	0.50	0.50	0.50	
VT-CM-E	0.49	0.48	0.45	0.43	0.43	0.44	0.43	0.43	0.43	0.42	0.42	0.42	0.43	0.43	0.43	0.43	0.43	0.42	0.42	
VT-GM-N	0.74	0.68	0.64	0.64	0.62	0.63	0.61	0.61	0.61	0.60	0.60	0.59	0.59	0.59	0.60	0.60	0.60	0.59	0.59	
VT-GM-T	0.69	0.63	0.59	0.60	0.59	0.60	0.59	0.59	0.58	0.58	0.57	0.58	0.57	0.57	0.57	0.57	0.57	0.57	0.57	
VT-GM-A	0.71	0.65	0.61	0.61	0.61	0.59	0.60	0.60	0.59	0.59	0.59	0.59	0.59	0.58	0.58	0.59	0.59	0.59	0.58	
VT-GM-E	0.58	0.51	0.48	0.48	0.47	0.48	0.47	0.47	0.47	0.47	0.47	0.46	0.46	0.45	0.45	0.46	0.46	0.45	0.45	

Table 15

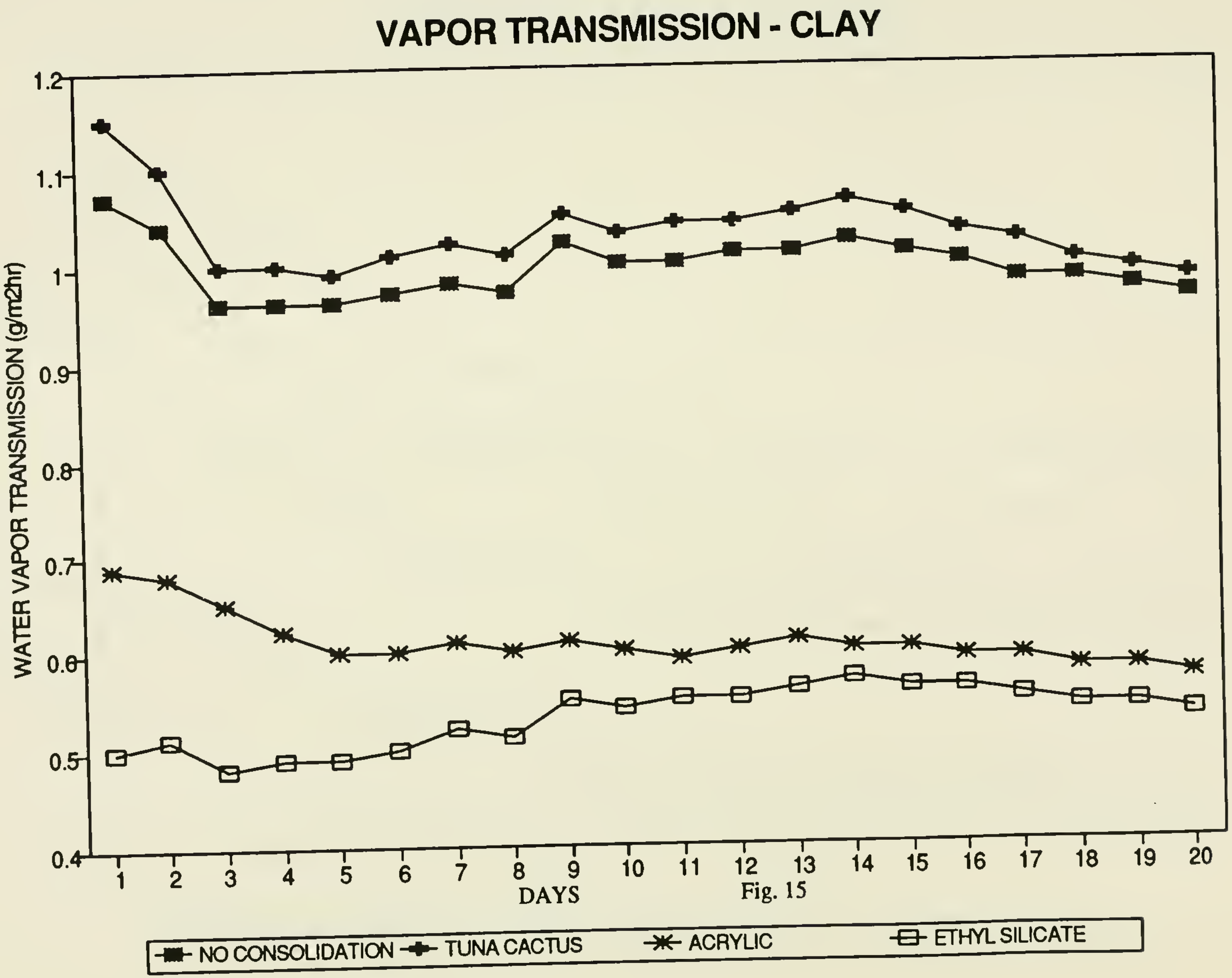

VAPOR TRANSMISSION - CLAY
WATER VAPOR TRANSMISSION (g/m2hr)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
DAYS
NO CONSOLIDATION
TUNA CACTUS
ACRYLIC
ETHYL SILICATE

Fig. 15

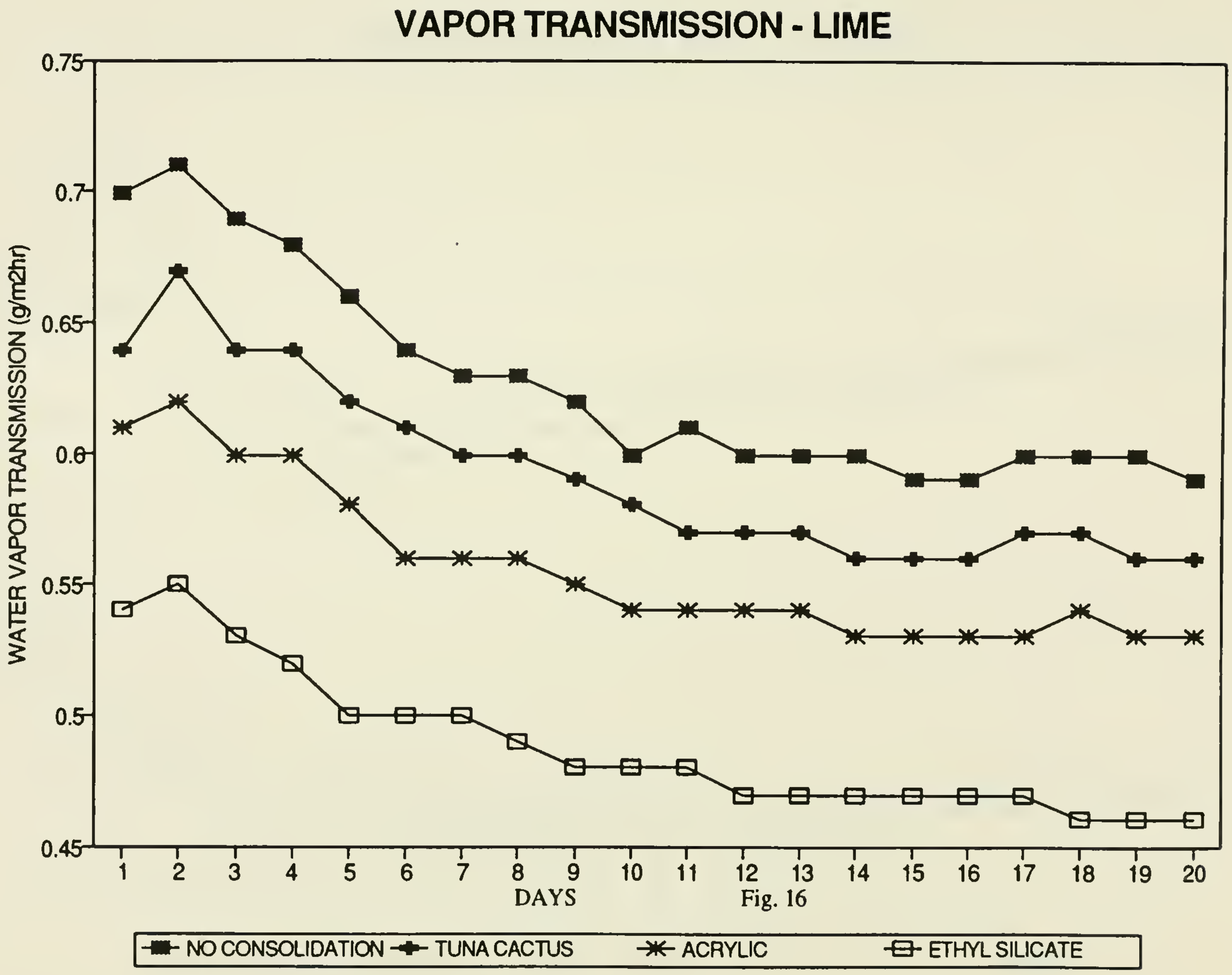

VAPOR TRANSMISSION - LIME
WATER VAPOR TRANSMISSION (g/m2hr)
0.75
0.7
0.65
0.6
0.55
0.5
0.45
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
DAYS
NO CONSOLIDATION
TUNA CACTUS
ACRYLIC
ETHYL SILICATE

Fig. 16

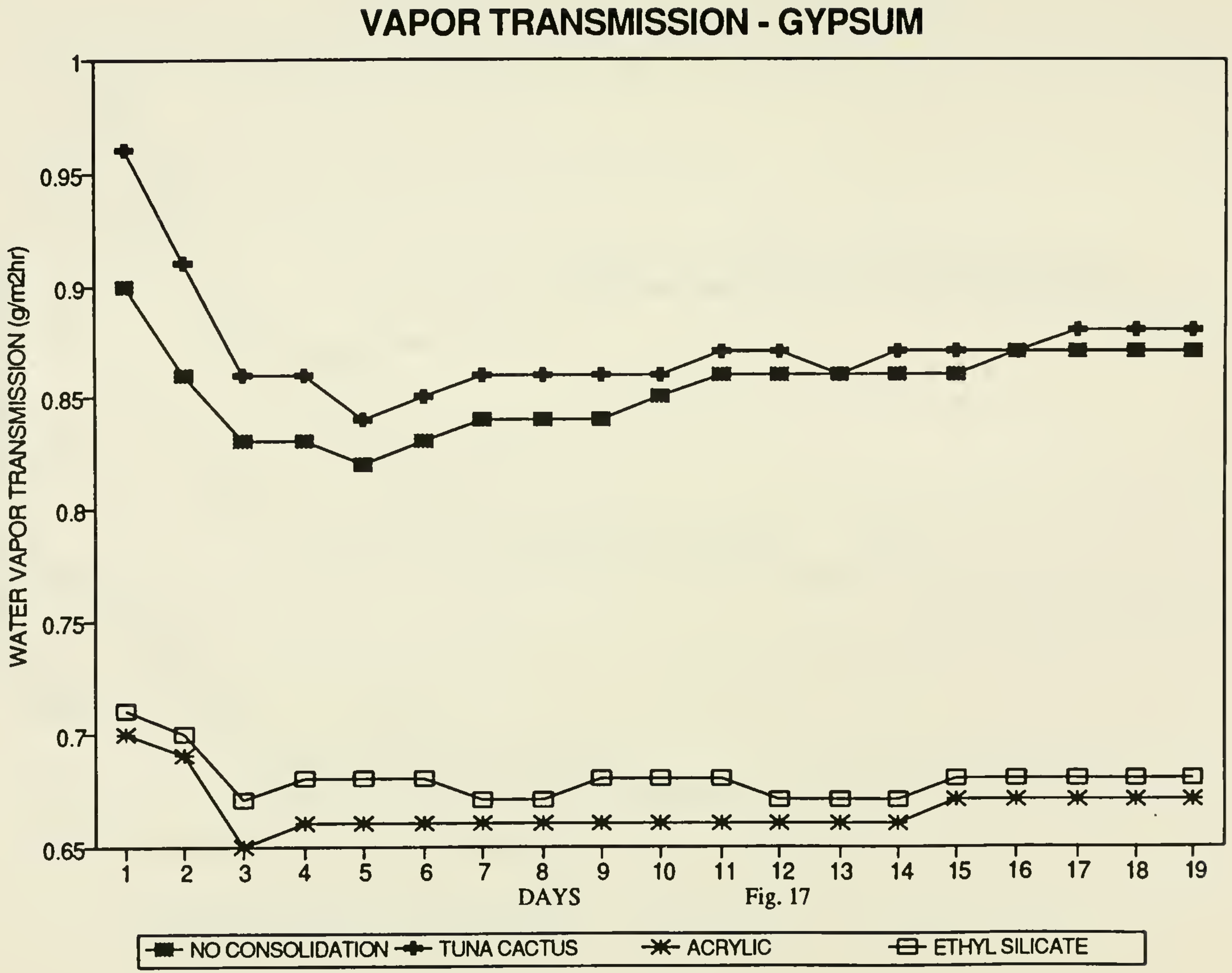

VAPOR TRANSMISSION - GYPSUM
WATER VAPOR TRANSMISSION (g/m2hr)
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
DAYS
NO CONSOLIDATION
TUNA CACTUS
ACRYLIC
ETHYL SILICATE

Fig. 17

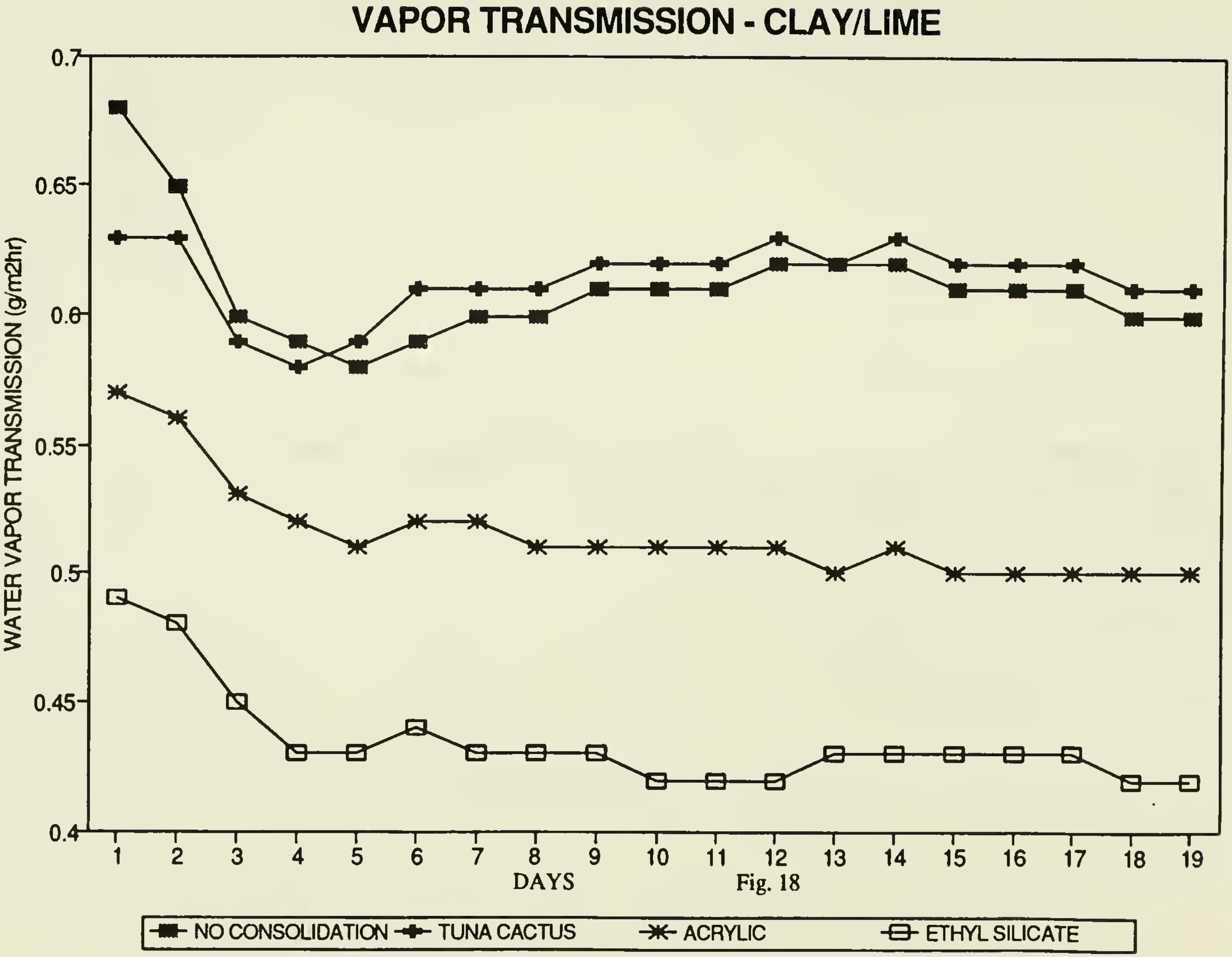
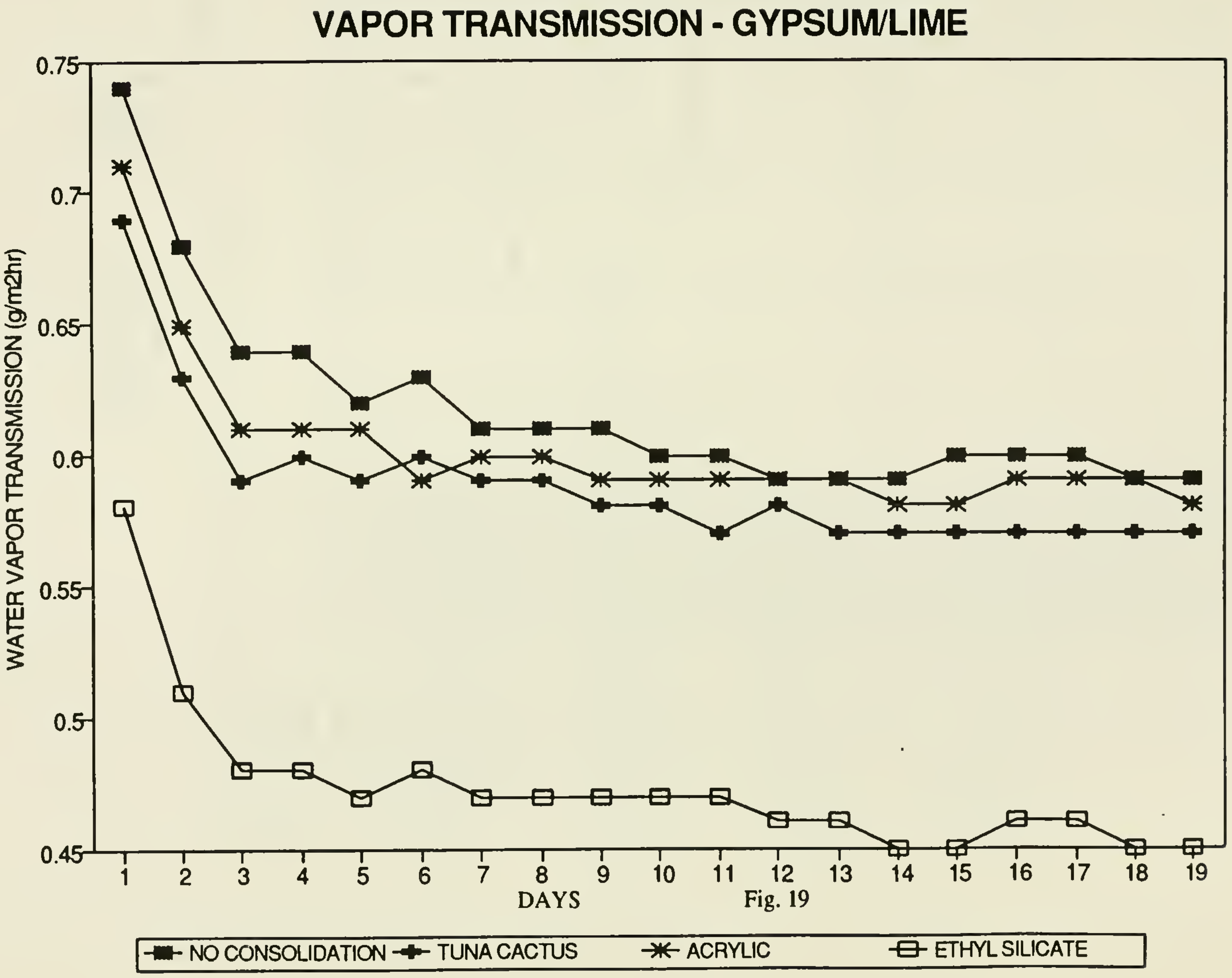

VAPOR TRANSMISSION - CLAY/LIME
WATER VAPOR TRANSMISSION (g/m2hr)
0.7
0.65
0.6
0.55
0.5
0.45
0.4
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
DAYS
NO CONSOLIDATION
TUNA CACTUS
ACRYLIC
ETHYL SILICATE

Fig. 18


VAPOR TRANSMISSION - GYPSUM/LIME
WATER VAPOR TRANSMISSION (g/m2hr)
0.75
0.7
0.65
0.6
0.55
0.5
0.45
1
2
3
4
5
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16
17
18
19
DAYS
NO CONSOLIDATION
TUNA CACTUS
ACRYLIC
ETHYL SILICATE

Fig. 19

VAPOR TRANSMISSION - RESULTS

PLASTER TYPE		VAPOR TRANSMISSION RATE (g.)	WATER VAPOR TRANSMISSION (g./m^{2}hr.)	RATING*
CLAY	VT-N	0.97	10.7	A+
	VT-T	0.99	10.9	A+
	VT-A	0.58	6.4	B
	VT-E	0.54	6.0	C
LIME	VT-N	0.60	6.6	B
	VT-T	0.56	6.2	B
	VT-A	0.53	5.9	C
	VT-E	0.46	5.1	C
GYPSUM	VT-N	0.87	9.6	A
	VT-T	0.88	9.7	A
	VT-A	0.67	7.4	B
	VT-E	0.68	7.5	B
CLAY LIME	VT-N	0.60	6.6	B
	VT-T	0.61	6.7	B
	VT-A	0.50	5.5	C
	VT-E	0.42	4.6	D
GYPSUM LIME	VT-N	0.59	6.5	B
	VT-T	0.57	6.3	B
	VT-A	0.58	6.4	B
	VT-E	0.45	5.0	C

Table 16

*RATING:

A	Excellent	- (more than 9.5 g./m^{2}hr.)
B	Good	- (6.1 - 9.4 g./m^{2}hr.)
C	Fair	- (5.1 - 6.0 g./m^{2}hr.)
D	Poor	- (less than 5.0 g./m^{2}hr.)

VAPOR TRANSMISSION - RESULTS

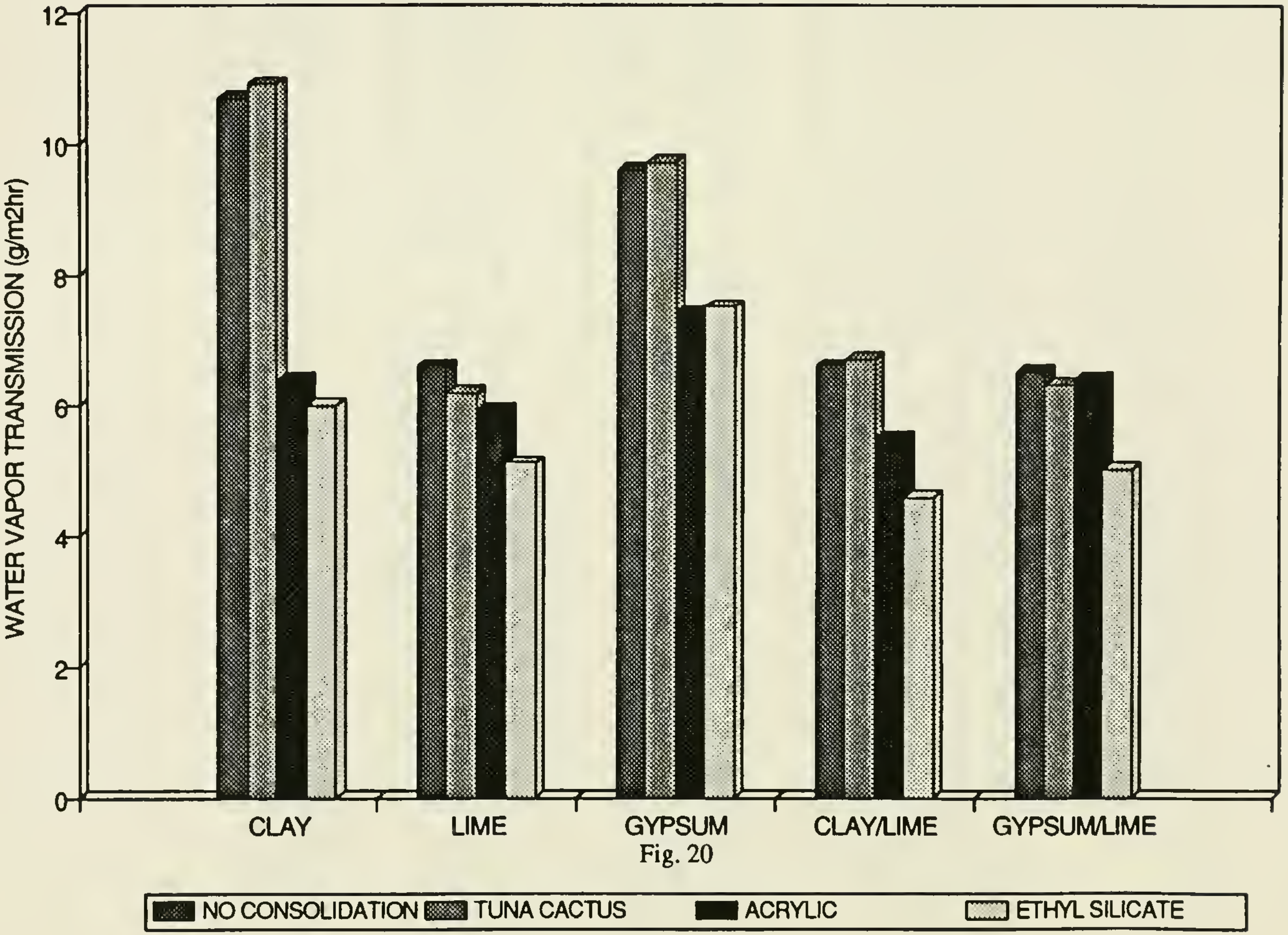

Fig. 20

5.1.5 Water Resistance

The drop test subjected the samples to the impact of a droplet of water over a specific period of time. In order to accomplish an accurate reading, all plasters except clay plasters were submitted to the test for two hours. Clay plasters were submitted to the test for only one hour, the standard time, due to their high reactivity with water.

Several measurements were recorded for this test, *(See Tables XLII to LXI on Appendix E)* but for tabulation procedures, only the width (diameter) of erosion (cm/min) was used as the water resistance indicator factor. The data results are displayed on Table 17.

Tests were first performed on samples without consolidant in order to later compare the results with treated samples. Non-consolidated plasters containing lime were more resistant than the other plasters to the water. No erosion was recorded on lime and clay/lime plasters while a width of erosion rate of 0.013 cm/min was recorded for the gypsum/lime plaster. The gypsum plasters registered an erosion rate of 0.049 cm/min, and clay plasters registered 0.076 cm/min, the poorest erosion rate.

Clay plasters consolidated with Acryloid B-67 increased their water resistance by only 11%, and the surface cracked and spalled on the sides, losing water repellency properties. When consolidated with Tuna cactus mucilage, clay plasters increased their water resistance by 24%, and when consolidated with Conservare OH no erosion was recorded.

Lime plasters did not erode when submitted to the drop test, however an absorption of 0.120 cm/min was recorded on non-consolidated and Tuna cactus mucilage consolidated lime plasters. The width of absorption decreased by 72% when Conservare OH was applied.

Gypsum plasters increased their water resistance by 10% when Tuna cactus mucilage was applied, and no erosion was recorded with either Acryloid B-67 or Conservare OH. No absorption was recorded with Acryloid B-67 applied to the gypsum plasters.

Clay and lime plasters (1:1) did not erode when submitted to the drop test, while an absorption of 0.067 cm/min was achieved on the non-consolidated sample. Both Tuna cactus mucilage and Conservare OH consolidants improved the absorption rate (less absorption) by 50%. No absorption was recorded when Acryloid B-67 was applied to clay/lime plasters.

Gypsum and lime plasters (1:1) decreased the water resistance rate by 238% when Tuna cactus mucilage was applied. This was the only case when water resistance rate decreased after consolidation. No erosion was recorded on gypsum/lime plasters consolidated with either Acryloid B-67 or Conservare OH. No absorption was recorded when Acryloid B-67 was applied.

In conclusion, plasters containing lime achieved the highest water resistance -- with and without consolidant. Plasters consolidated with Acryloid B-67 did not absorbed water, but the substrate -- which was not treated by the consolidants -- eventually became wet by the water overflowing the surface, and deteriorated in the same way as any other plaster; sometimes the adobe substrate even collapsed faster. Therefore Acryloid B-67 did not seem appropriate for a good water resistance on clay plasters.

WATER RESISTANCE - RESULTS

PLASTER TYPE		WIDTH OF EROSION (cm/min)	DEPTH OF EROSION (cm./min)	WIDTH OF ABSORPTION (cm./min)	RATING*
CLAY	WR-N	0.076	0.040	0.06	D
	WR-T	0.058	0.027	0.032	C
	WR-A	0.067	0.035	NO ABS.	D
	WR-E	NO EROSION	NO EROSION	0.013	A
LIME	WR-N	NO EROSION	NO EROSION	0.120	A
	WR-T	NO EROSION	NO EROSION	0.120	A
	WR-A	NO EROSION	NO EROSION	NO ABS.	A
	WR-E	NO EROSION	NO EROSION	0.033	A
GYPSUM	WR-N	0.049	0.046	0.160	C
	WR-T	0.044	0.045	0.120	C
	WR-A	NO EROSION	NO EROSION	NO ABS.	A
	WR-E	NO EROSION	NO EROSION	0.002	A
CLAY LIME	WR-N	NO EROSION	NO EROSION	0.067	A
	WR-T	NO EROSION	NO EROSION	0.033	A
	WR-A	NO EROSION	NO EROSION	NO ABS.	A
	WR-E	NO EROSION	NO EROSION	0.033	A
GYPSUM LIME	WR-N	0.013	0.005	0.058	B
	WR-T	0.044	0.005	0.033	C
	WR-A	NO EROSION	NO EROSION	NO ABS.	A
	WR-E	NO EROSION	NO EROSION	0.020	A

Table 17

*RATING:

A Excellent - (no erosion)
B Good - (0.010 - 0.040 cm/min.)
C Fair - (0.041 - 0.060 cm/min.)
D Poor - (more than 0.060 cm/min.)
E No Absorption

WATER RESISTANCE - RESULTS

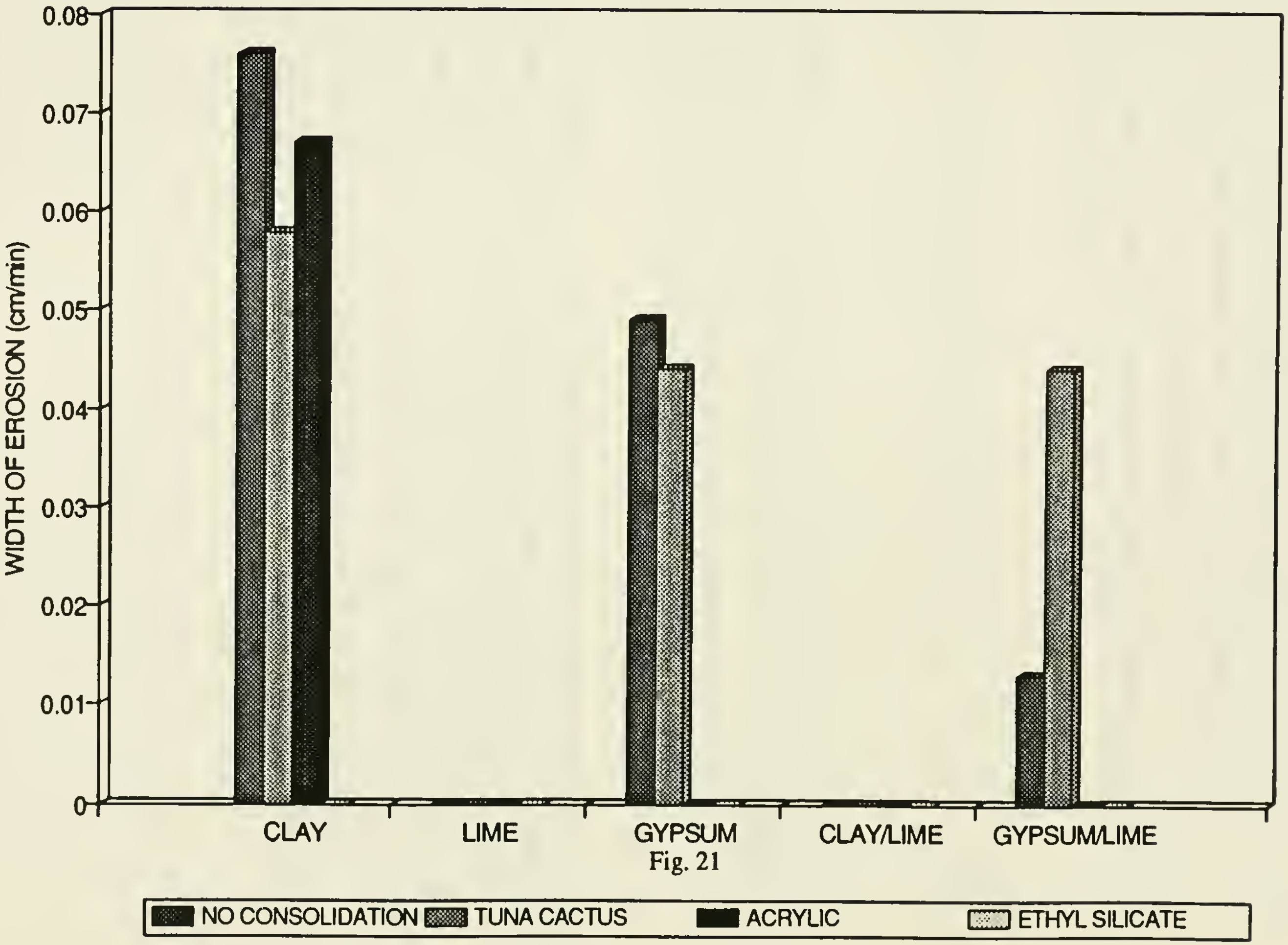

Fig. 21

5.2 GENERAL CONCLUSIONS

Although all tests were performed on unweathered materials, it can be assumed that the results obtained are translatable to weathered materials. Each plaster type was graded and ranked according to its performance in each of the tests. A comprehensive method was developed with the data resulting from the tests in order to reinforce their interpretation. Results were summarized qualitatively: from A+ which was given only to the best performing plaster/consolidant sample for any given test to E, the worst performing, depending on the different results obtained.[3] Results of all tests by plaster type are displayed in Table 19: Tests Conclusions. General conclusions about the performance of the treated and untreated plasters are summarized below:

Clay Plasters

Clay plasters achieved the best bond between plaster and substrate, by the reason of being the same material.

When consolidated, Conservare OH proved to be the most efficient consolidant for clay plasters, although it resulted in a 6.18% weight increase and a slight color change. This consolidant achieved the best tensile strength, water resistance and abrasion resistance for this plaster type. Capillarity rate was good, and vapor transmission decreased 43%.

Tuna cactus mucilage improved most of the properties tested on clay plasters, although not as dramatically as Conservare OH. All properties inherent to the material (adhesion, vapor transmission and capillarity) were either improved or remained the same with this consolidant, although water and abrasion resistance improved very little. A weight increase of only 0.13% was recorded and no color change resulted. Consequently, it can be concluded that the application of Tuna cactus mucilage does not cause deterioration of clay plasters and it could be used as a consolidant providing limited improvements in weathering. Also important is its availability and low cost for large applications in regions where the plant is found.

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[3] The categories are explained at the bottom of each Results' Table

Acryloid B-67 on clay plasters changed the color *(see Chapter 4)* and increased the weight by 0.82%. This consolidant enhanced only the abrasion resistance and adhesion properties of the clay plaster and reduced vapor transmission rate and capillarity. The water resistance of clay plasters consolidated with Acryloid B-67 was improved by 11%, however the ingress of liquid water into micro-cracks resulting from the treatment deteriorated the material beneath. In conclusion, while a 5% solution of Acryloid B-67 in diethylbenzene does improve the abrasion resistance and thus cohesive strength of this particular clay plaster, it can result in secondary erosion at the interface of treated and untreated material when water is introduced.

Lime Plasters

Lime plasters conferred the best abrasion resistance and water resistance of all plasters and good adhesion between plaster and substrate, being the second best (65% less adhesive strength than clay plasters). Working properties were poor and they required a long time to cure. On consolidated samples, both Conservare OH and Acryloid B-67 appear to be good consolidants for lime plasters on earthen supports because they improved the abrasion and water resistance -- Conservare OH resulted in a slightly higher capillarity rate. Although vapor transmission and capillarity decreased when these consolidants were applied, the lime plaster's color did not change and weight increased by 0.51% with Acryloid B-67 and by 6.37% with Conservare OH.

Tuna cactus mucilage did not significantly improve the lime plasters and in fact it decreased the bond strength between the lime plaster and the clay substrate. Weight increase was not significant (0.9%).

Gypsum Plaster

Gypsum plasters achieved a good capillarity rate and vapor transmission, being the second best after clay plasters (only 5% decrease in capillarity and 10% decrease in vapor transmission). Water resistance was slightly better than with clay plasters, but abrasion resistance was worse than clay and lime plasters. Working properties were poor and bond strength between plaster and substrate was the worst of all systems.

When consolidated, both Conservare OH and Acryloid B-67 improved the gypsum plasters' properties -- Conservare OH resulting in a slightly higher capillarity rate and adhesive strength. Weight gain was 0.55% with Acryloid B-67 and 12.40% with Conservare OH.

Tuna cactus mucilage significantly improved only the abrasion resistance of gypsum plasters, and did not adversely change other properties tested. Weight gain was 0.05%

Clay/lime Plaster

Untreated clay/lime plasters showed good bond strength with the substrate, although 75% less than the clay plasters, as well as a stronger cohesive strength and water resistance than all other plasters. Capillarity rate was the lowest achieved for all plasters, and vapor transmission was 61.7% less than clay. This plaster also displayed the best working properties of all the plasters.

Conservare OH proved to be a very good consolidant for clay/lime plasters, improving adhesion, water and abrasion resistance. Vapor transmission and capillarity rates decreased by 30% and 50% respectively when this consolidant was applied, but no color change was recorded, and the weight increased 6.40%.

Tuna cactus mucilage improved adhesion strength, water and abrasion resistance, and decreased capillarity rate and vapor transmission. No color change was recorded on clay/lime plasters treated with Tuna cactus, and the weight increased 0.13%.

Acryloid B-67 did not improve significantly the properties of clay/lime plasters. Although the weight increased only 0.15%, no capillarity rate could be measured; presumably due to pore filling at the surface. It is not recommended to use this consolidant when treating any clay - based plasters.

Gypsum/lime Plasters

Untreated gypsum/lime plasters displayed the worst vapor transmission and abrasion resistance of all the systems, poor water resistance, and a capillarity rate 37% less than that of clay. Working properties were poor and required plasters a long time to cure.

When treated, both Conservare OH and Acryloid B-67 were equally effective on improving water and abrasion resistance on gypsum/lime plasters. These plasters increased by 0.76% in weight when Acryloid B-67 was applied, and by 7.66% with Conservare OH.

Tuna cactus proved not to be effective on these plasters, although they were not adversely affected. Weight gain was 0.06%

In conclusion, the plaster-clay substrate system that displayed the most compatible properties before consolidation was clay plaster on clay substrate. Clay plasters conferred good protection to the substrate, the second best abrasion resistance, (lime plasters were the best), identical vapor transmission to that of the substrate; and the highest bonding strength (clay on clay). Obviously, due to the water-sensitivity of clays, the water resistance coefficient was the worst achieved of all the systems.

The most incompatible plaster on clay substrates appeared to be the gypsum/lime plaster. Although it conferred a better water resistance than clay and gypsum plasters, it displayed the lowest water vapor transmission (60.7% less than clay), one of the poorest bond strengths between plaster and substrate (the lowest achieved by the gypsum plaster) and the worst abrasion resistance.

After consolidation, not all consolidants improved to the same degree. While all consolidants tested achieved full depth of penetration after a variable number of applications (depending on the plaster and consolidant), different plasters on clay support improved different properties such as water resistance, abrasion resistance (mechanical attack), and vapor transmission. Also, all consolidants improved the abrasion and water resistance of plasters (except for tuna cactus mucilage on gypsum/lime plasters).

CONSOLIDANTS PROPERTIES

CONSOLIDANT	COST	TOXICITY	CURE TIME	BIO-DETERIORATION	PREPARATION
TUNA CACTUS MUCILAGE	LOW	NONE	1 day	NONE	CUSTOM
Acryloid B-67 5% in Diethylbenzene	$15 per gallon	Slightly toxic	1 day	NONE	COMMERCIAL
CONSERVARE OH	$60 per gallon	TOXIC	14-28 days	NONE	COMMERCIAL

Table 18

Tuna cactus mucilage treatments changed the plasters' properties the least: water vapor transmission was not altered significantly (1-7%) and capillarity changed in a range of 10-40%, thus allowing further treatments. Plasters treated with Tuna cactus mucilage did not change in color and their weight increased only in about 0.092%. General advantages of this consolidant are low cost, availability, no toxicity and low biodeterioration. General disadvantages custom formulation and short pot life.

Acryloid B-67 treatments evidenced the largest decrease in capillarity rate (100%) on all plasters, and vapor transmission alteration was in a range of 2-40%. Color changed significantly on clay based plasters and the weight increased an average of 0.55%. Acryloid B-67 on clay plasters promoted cracking of the clay plaster and they cannot be recommended on clays. General advantages are low toxicity (in Diethylbenzene), low cost and low biodeterioration. General disadvantages are custom formulation.

Conservare OH treatments evidenced the largest decrease in water vapor transmission of all systems (43-22%) and capillarity results varied significantly from plaster to plaster, clay/lime plaster being the least altered and clay plaster the most altered. Color was only slightly changed on clay based plasters while no color change was recorded on all other plasters. Weight gain was on an average of 7.80%, a very high number compared to other treatments. This could be a drawback when consolidating fragile surfaces since Conservare OH does not confer adhesive properties to the treated material, and the added weight might accelerate the collapse of already detached plasters. Pre-stabilization would therefore be necessary first. The hydrolysis process also takes a long time (from 14 to 28 days). General advantages of this consolidant are low biodeterioration and good availability as a ready-to-use commercial product. General disadvantages are high toxicity, high cost, and long cure time.

TESTS CONCLUSIONS

PLASTER TYPE		ADHESION	VAPOR TRANSMISSION	WATER RESISTANCE	ABRASION RESISTANCE	CAPILLARITY
CLAY	WR-N	A	A+	D	D	A+
	WR-T	A	A+	C	D	A
	WR-A	A	B	D	B	C
	WR-E	A+	C	A	A	B
LIME	WR-N	B	B	A	D	A
	WR-T	C	B	A	D	A
	WR-A	A	C	A	A	D
	WR-E	A	C	A	A	B
GYPSUM	WR-N	D	A	C	D	A
	WR-T	D	A	C	C	A
	WR-A	C	B	A+	A	D
	WR-E	B	B	A+	A	C
CLAY LIME	WR-N	C	B	A	D	B
	WR-T	B	B	A	C	C
	WR-A	B	C	A	B	E
	WR-E	A	D	A+	A	C
GYPSUM LIME	WR-N	C	B	B	D	A
	WR-T	D	B	C	D	A
	WR-A	C	B	A	B	D
	WR-E	B	C	A	B	A

Table 19

*RATING:

A	Excellent
B	Good
C	Fair
D	Poor
E	No Absorption

5.3 RECOMMENDATIONS

This study has examined five different plasters traditionally used on earthen structures. The earthen substrate selected was a naturally - occurring clay currently used in the Southwest of the United States (New Mexico). In order to expand on the project model established and the results obtained, the following recommendations are offered:

- SEM analysis should be performed before and after treatments in order to better understand the processes of each consolidation treatment applied.

- More laboratory research should be performed using different variables such as other clay types, other consolidants or the same consolidants prepared under different conditions,[4] or with samples aged for one year in outdoor situations.

- Design and execution of a field testing program should be implemented using the results of the study in order to compare laboratory results with actual field conditions.

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[4] Another method for preparing the Tuna cactus mucilage, allows it to stand for one week before application.*(See chapter 2: natural amendments)*. This or other methods should be tried in order to compare their efficiency.

CHAPTER 6: GLOSSARY

Additive: A non-specific term applied to any substance added to a base material in low concentrations for a definite purpose.
Additives can be divided in two groups:

1. Those which have a secondary function (antioxidants, inhibitors, thickeners, etc.)
2. Those that are essential to the existence of the end product (emulsifiers, leavening agents, etc.)

Adhesive: A Substance which applied on the surface of a weakened material, restores the adhesive and cohesive strength of the finish layer.

Asphalt: Semi-solid mixture of several hydrocarbons of complex nature. It is amorphous, has a low specific gravity, and has a black or brownish or reddish black color, and pitchy luster.
Any of the natural bitumens and asphalts (brown or black) or the artificial pitches, except those produced by destructive distillation. Asphalt is also obtained from the residue of petroleum, coal tar, lignite and tar.[1]

Binder: Non-volatile, total solids or film-forming ingredients in a protective coating which serve to bind or cement the pigment particles together in the course of application. Such materials are usually oils, varnishes and/or plasticizers.[2]

Bitumastic: A protective coating used primarily for waterproofing. It is made from especially refined coal tar pitch and fillers.[3]

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[1] Jefferey R. Stewart, p. 11

[2] Ibid, p. 15

[3] Ibid, p. 15

Bitumen: Naturally occurring residue of the evaporation of petroleum. Mineral pitch, asphalt or semi-solid tar from petroleum.[4]

Casoid: A synthetic plastic resin made from a casein base.[5]

Chalk: A natural white calcium carbonate.[6] Soft friable limestone of marine origin earthy in texture and white, gray or buff in color, found widely distributed in Europe and America chiefly in the Cretaceous system, and composed for the most part of the minute shells of Foraminifera.

Clays: Mineralogically, clays have specific chemical formulas and crystalline formations which are determined primarily by the parent material, time and geologic activity. Most clays are a varied mixture of quartz grains, decomposed rock products, and undecomposed rock debris. The three most common types of clays are aluminosilicates with varying impurities: kaolinites, illites and sectites.

Clay minerals are "natural aluminosilicates layered in plate-like structures of linked aluminum silicate tetrahedra contained within layers of magnesium or aluminum hydroxide"[7]

Coal tar: Softens at lower temperatures than bitumen and oxidizes more easily. Its uses are similar to bitumen, except for heavy duty uses in road construction.

Collagen: An insoluble fibrous protein that occurs in vertebrates as the chief constituent of the fibrils of connective tissue, characterized by swelling in water solutions. It is converted to gelatin and glue on prolonged heating with water an to leather on tanning.[8]

Consolidant: A substance introduced into the fabric of a weakened material in order to re-establish the bonds between adjacent grains, restoring its cohesive strength.

Emulsion: A fluid consisting of a microscopically heterogeneous mixture of two phases, both of which are liquid at ordinary temperatures. In other words, an emulsion is a preparation in which the small particles of a liquid remain in suspension in an additional liquid with which it is not ordinarily miscible.[9]

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[4] Ibid, p. 15

[5] Ibid, p. 22

[6] Ibid, p. 23

[7] Pamela French, "Problems of in Situ Conservation of Mudbrick and Plaster", In Situ: Archaeological Conservation, (Marina del Rey, U.S.A.: The Getty Conservation Institute, 1987), p. 48.

[8] Webster's Third New International Dictionary, p. 443.

[9] Jefferey R. Stewart, p. 37

Glue: A hard protein substance that absorbs water to form a jelly or a viscous solution with strong adhesive properties that is obtained like gelatin by cooking down materials as bones, yielding collagen and is usually considered to contain gelatin along with other products.[10]

Gum: Natural gums are hydrophilic polysaccharides composed of monosaccharide units joined by glycosidic bonds. They are gelatinous when moist but harden on drying,[11] and are exuded by trees and shrubs in tropical areas or as phycocolloids (algae) or extracted from them by solvents. Gum is a carbohydrate high polymer that is insoluble in alcohol and other organic solvents, but generally soluble or dispersible in water. Natural gums are used as protective colloids and emulsifying agents in food products, and as sizing for textiles.[12]

Lime: a general term which includes the various chemical and physical forms of quicklime, hydrated lime, and hydraulic lime. It may be high-calcium, magnesian, or dolomitic.[13]

Mucilage: a gelatinous substance that contains protein, polysaccharides and usually uronides[14] that is obtained by extraction by either hot or cold water[15] from the seeds coats, roots or other parts of plants. Similar to plant gums generally insoluble in alcohol but some are partly soluble in water and partly soluble in alcohol. Although when water insoluble, mucilages can absorb and hold it, developing viscous solutions.

Pargetting: (pergetting, pergening, parging, parge-work) was in use as early as 1450 to denote a plastic covering for walls and ceilings. The term more commonly referred to ornamental work, but it was also applied to plain work.[16]

Pitch: A term applied to pyragenous residues obtained in the distillation of organic materials; usually confined to tars obtained from resinous woods. Of dark color, viscous to solid consistency; comparatively non-volatile, fusible; composed principally of hydrocarbons; sometimes associated with carbonaceous matter, the non-carbonaceous constituents being largely soluble in carbon disulfide, yielding water-soluble sulfonation products.[17]

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[10] Webster's Third New International Dictionary, p. 968.

[11] Ibid., p. 1011.

[12] Hawley's Condensed Chemical Dictionary, p. 581.

[13] ASTM C51-90 "Standard Terminology relating to Lime and Limestone" (as used by the industry). Annual Book of American Standards for Testing Materials Vol 04.01, Cement, Lime and Gypsum (Philadelphia, U.S.A.: ASTM, 1990), p. 47.

[14] Webster's Third New International Dictionary, p. 1534.

[15] Hawley's Condensed Chemical Dictionary, p. 800.

[16] John and Nicola Ashrust, Mortars, Plasters and Renders, p. 81.

[17] Herbert Abraham, p. 46.

Plaster: (plaister) Plaster is a substance made of water and some absorbent matter, such as chalk or lime well purified with which walls are overlaid of figures cast.[18]

Quicklime: Obtained by roasting limestone, seashells and some marbles to a red glow, resulting in calcium oxide. This powdery substance was then screened to remove lumps (which could later "pop" or spall when mixed with water). The powder was then mixed with water, a process called "slaking" or hydrating. This mixing was often done on site, and the chemical reaction would release a lot of heat, expanding the mass 2 or 3 times its original volume. After slaking for 24 hours, it was considered ready for use. At this point the chemical change redefines the mix to calcium hydroxide. Lime "putty" is simply a screen paste of a slaked lime.

Resin: vegetable-derived hard brittle solid to soft semisolid amorphous mixture of carboxylic acids, essential oils, and terpenes[19], that are usually transparent or translucid and yellowish to brown in color with a characteristic luster, that are formed especially in plant secretions and are obtained as extracts from plants that contain usually resin acids. Their esters are soluble in ether and other organic solvents but not in water. Resins are electrical non-conductors and used chiefly in varnishes, printing inks and medicine.[20]

Sap: A watery solution of organic products of metabolism that circulates through the vascular system, carries raw materials to the pherispheral chlorophyll, bearing cells. It is a major commercial source of sugar in sugarcane, various palms, and the sugar maple.[21]

Stucco: The word Stucco was used to denote ornamental plasterwork and finely finished material. Since the 19th century, the term stucco has been favored in the USA when referring to plaster on the exterior walls, being the corresponding interior application referred to as plaster or plastering. However, on the West Coast, only the final coat is referred to as stucco, and this textured or colored coat may be used in interior locations as well.[22]

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[18] Encyclopedia Londinensis or Universal Dictionary of Arts, Sciences and Literature. Compiled, digested and arranged by John Wilkes of Millard House. Encyclopedia Office: London, 1825. Volume XX, p. 625.

[19] Hawley's Condensed Chemical Dictionary, p. 1004.

[20] Webster's Third New International Dictionary, p. 1932.

[21] Webster's Third New International Dictionary, p. 2013.

[22] John and Nicola Ashurst, Mortars, Plasters and Renders, p. 81.

Tar: A term applied to pyrogenous condensates obtained in the destructive or dry distillation of organic materials such as wood, peat, lignite, coal, bituminous shales, or other vegetable or mineral materials.[23] It is of dark color, liquid consistency; having characteristic odors; comparatively volatile at high temperatures; composed principally of hydrocarbons sometimes associated with carbonaceous matter, the non-carbonaceous constituents being largely soluble in carbon disulfide, yielding water-soluble sulfonation products.[24]

Whiting: Calcium carbonate prepared as powder by grinding chalk, limestone, or a synthetic product and used as a pigment and extender, in putty and in rubber compounding and paper coating.

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[23] Jefferey R. Stewart, p. 101.

[24] Herbert Abraham, p. 82.

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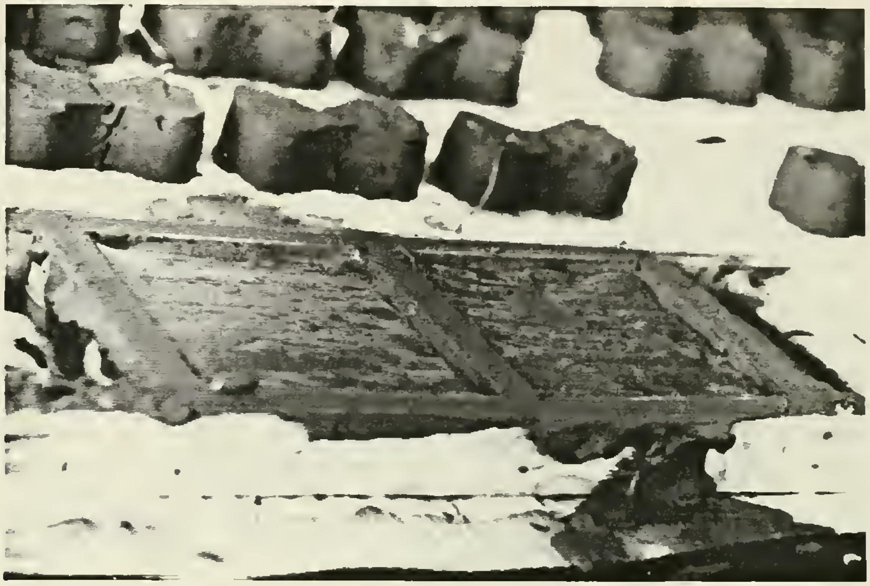
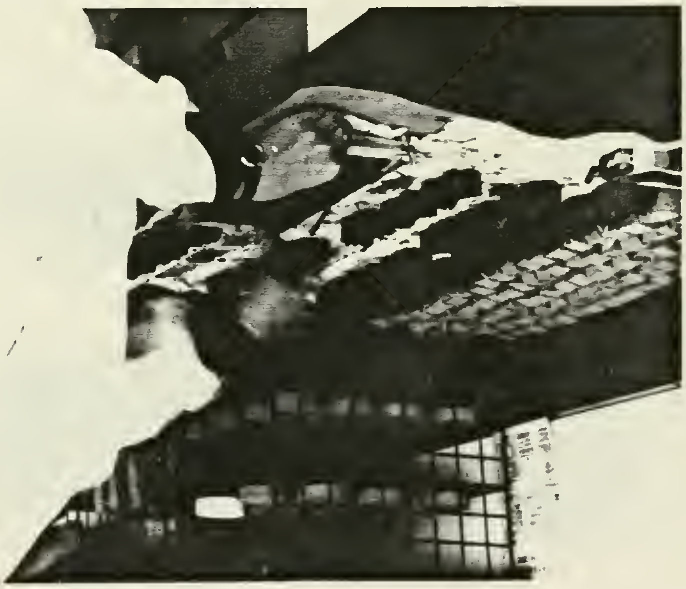
CHAPTER 8: PHOTOGRAPHS

SAMPLES PREPARATION - PHOTOGRAPHS



3½ x 3½ adobe block moldings. Preparation of samples for abrasion resistance, water resistance and capillarity tests.

No. 1



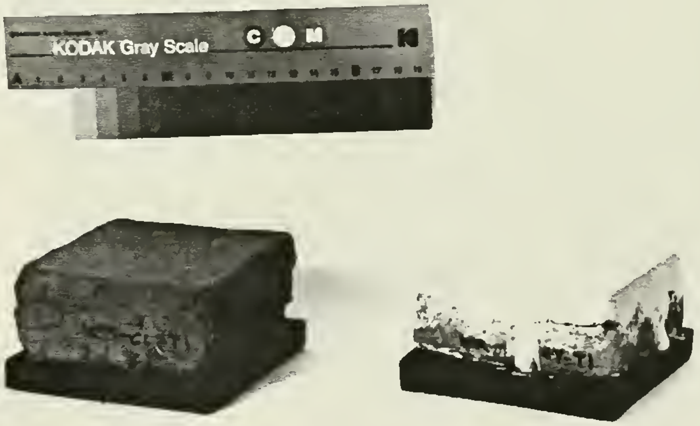
Adobe blocks moldings.

No. 2

SAMPLES PREPARATION - PHOTOGRAPHS

Lime plaster application on adobe blocks, first coat.

No.
3



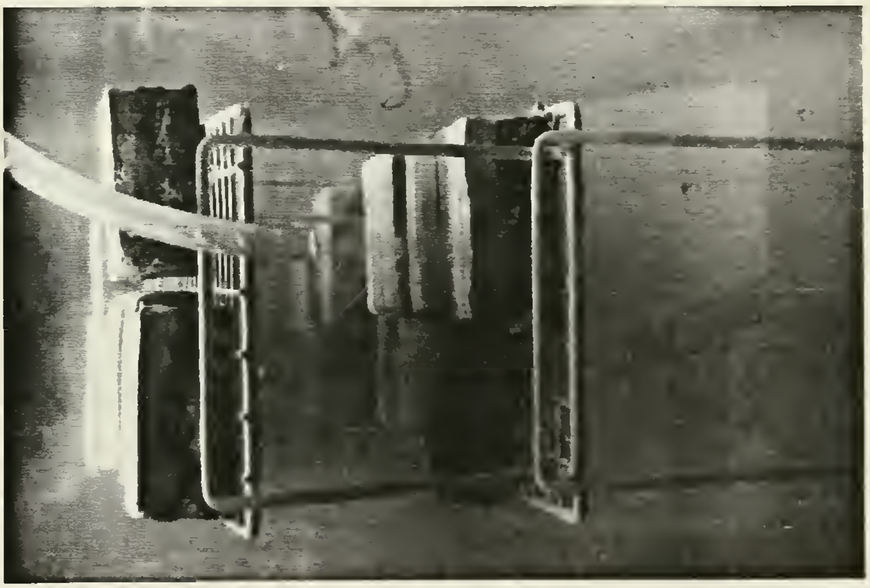
Clay and Gypsum plastered samples

No.
4

SAMPLES PREPARATION - PHOTOGRAPHS

Briquet molds - Adhesion samples preparation.

No. 5



Curing of gypsum plastered adobe blocks in the moist chamber, at 80% Relative Humidity.

No. 6

CONSOLIDATION OF SAMPLES - PHOTOGRAPHS

Consolidants used on tests: Conservare OH, Tuna cactus mucilage, and B-67 resin at 5% on Diethylbenzene; and spray bottle used for application

No. 7

Consolidants application to the adhesion tests samples was achieved by capillary rise.

No. 8

SAMPLES CURING - PHOTOGRAPHS

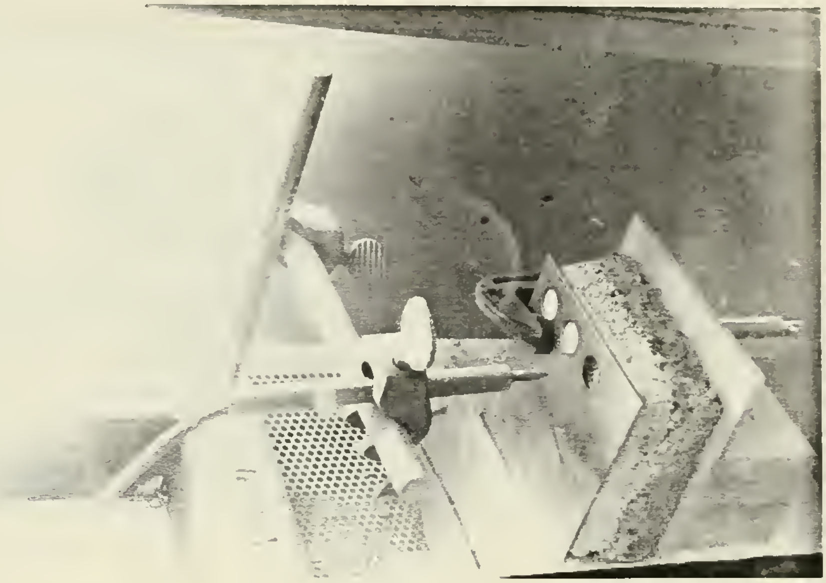
The plastered adobe blocks were cured for 14 days after application of consolidants. Note the plastic bags used on Conservare OH treated samples.

No. 9

Vapor transmission samples after application of consolidant were wrapped with electric tape and re-labeled.

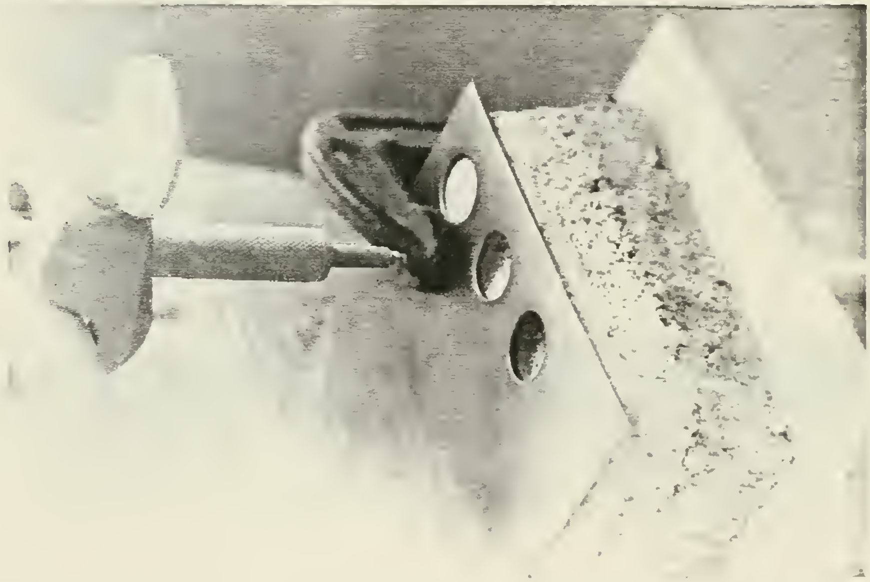
No. 10

ABRASION RESISTANCE TEST - PHOTOGRAPHS



Each sample was sandblasted in three different areas for one second on each area, using glass beads No. MS-XL.

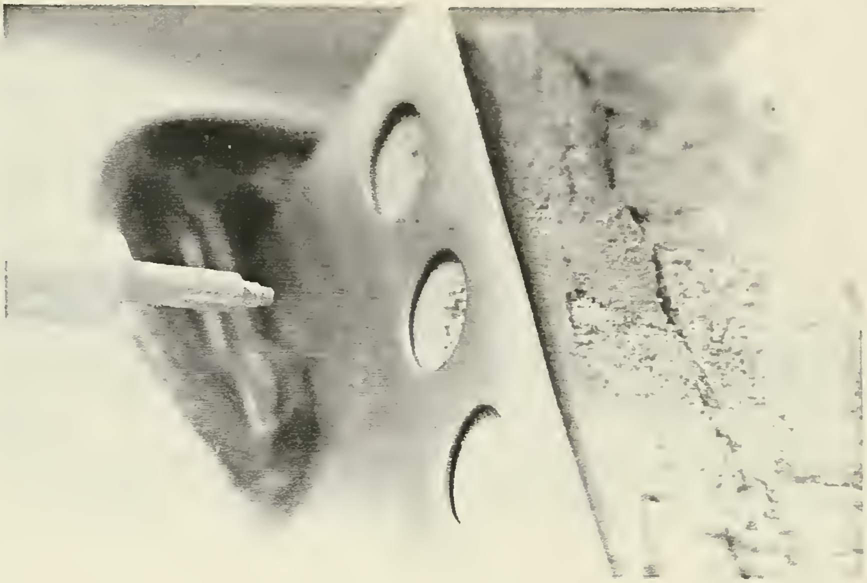
No. 11



The pressure was maintained constant at 80 psi. A metal shield was designed for this purpose.

No. 12

ABRASION RESISTANCE TEST - PHOTOGRAPHS



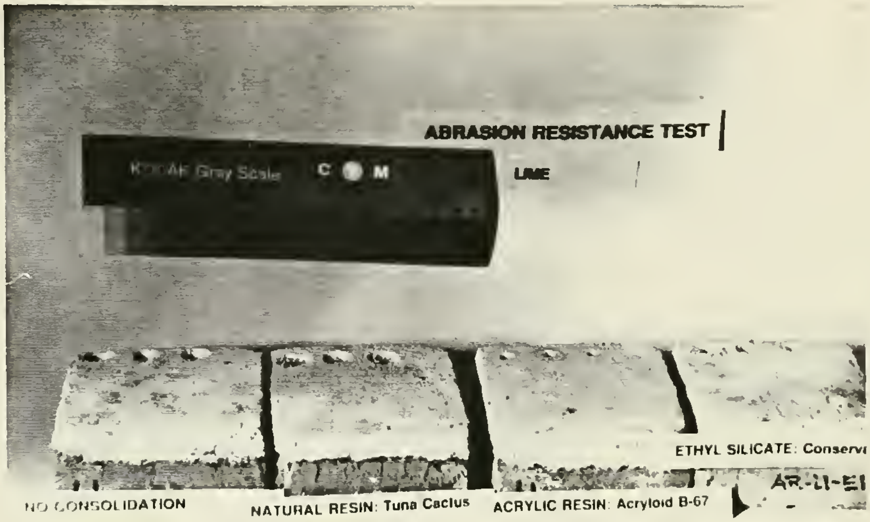
Abrasion Resistance Test

No. 13

Abrasion Resistance Test Results - Clay Plaster

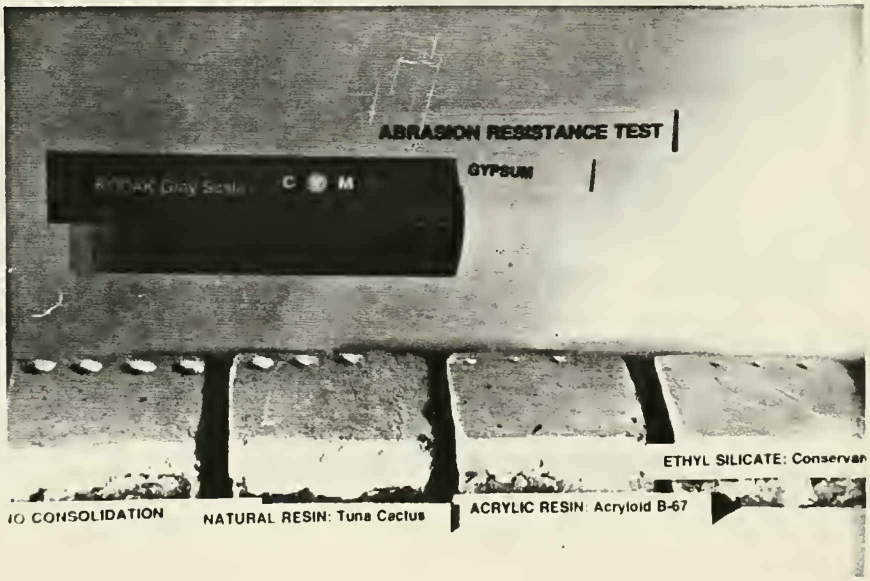
No. 14

ABRASION RESISTANCE TEST - PHOTOGRAPHS



Abrasion Resistance Test Results - Lime Plaster

No. 15



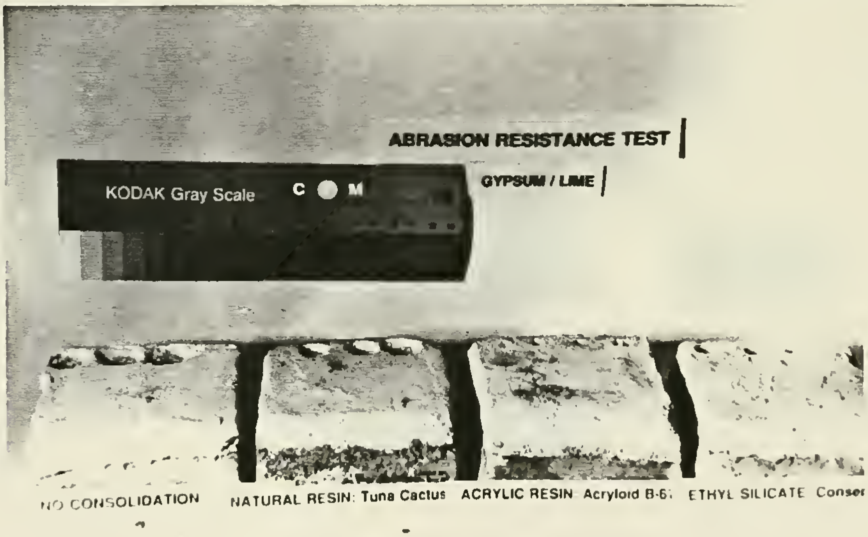
Abrasion Resistance Test Results - Gypsum Plaster

No. 16

ABRASION RESISTANCE TEST - PHOTOGRAPHS

Abrasion Resistance Test Results - Clay / Lime Plaster

No. 17



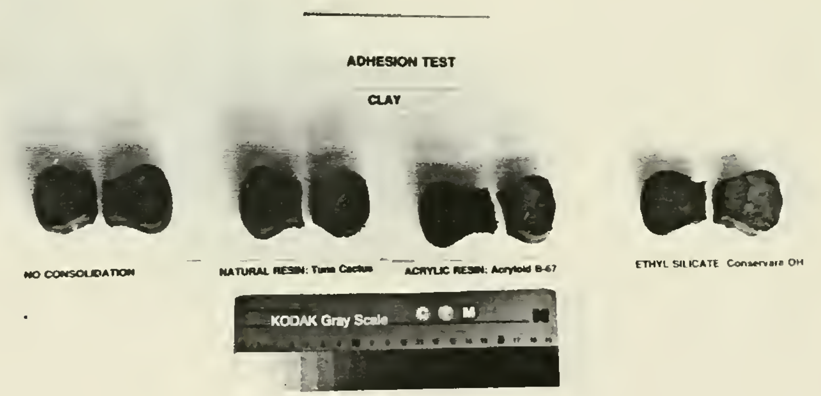
Abrasion Resistance Test Results - Gypsum / Lime Plaster

No. 18

ADHESION TEST - PHOTOGRAPHS

The sample's substrate cured for a period of 14 days, and after that the plaster was added and cured for 28 more days.

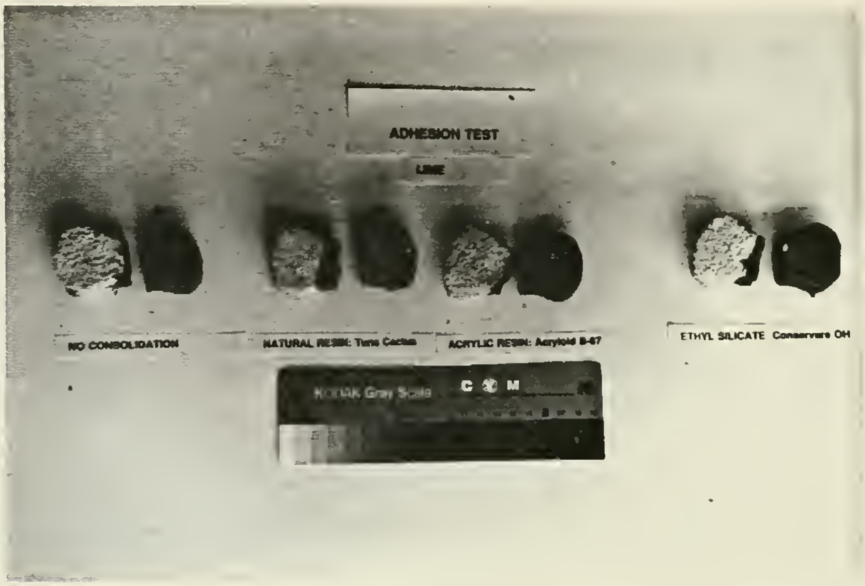
No.
19



Adhesion Test Results - Clay Plaster

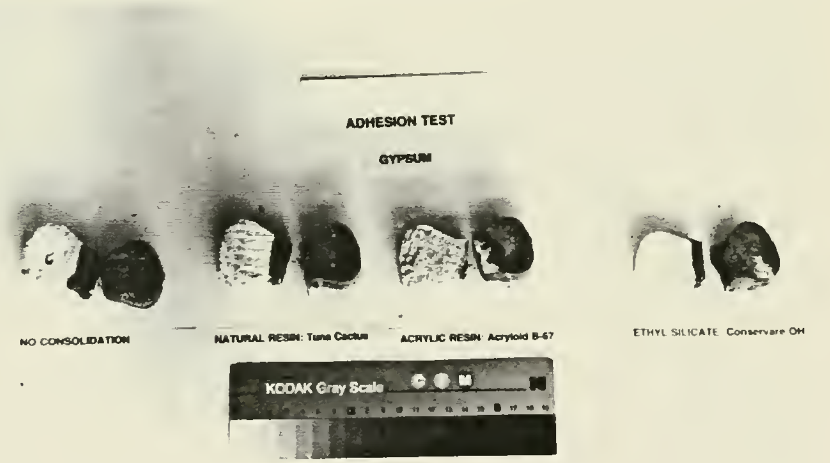
No.
20

ADHESION TEST - PHOTOGRAPHS



Adhesion Test Results - Lime Plaster

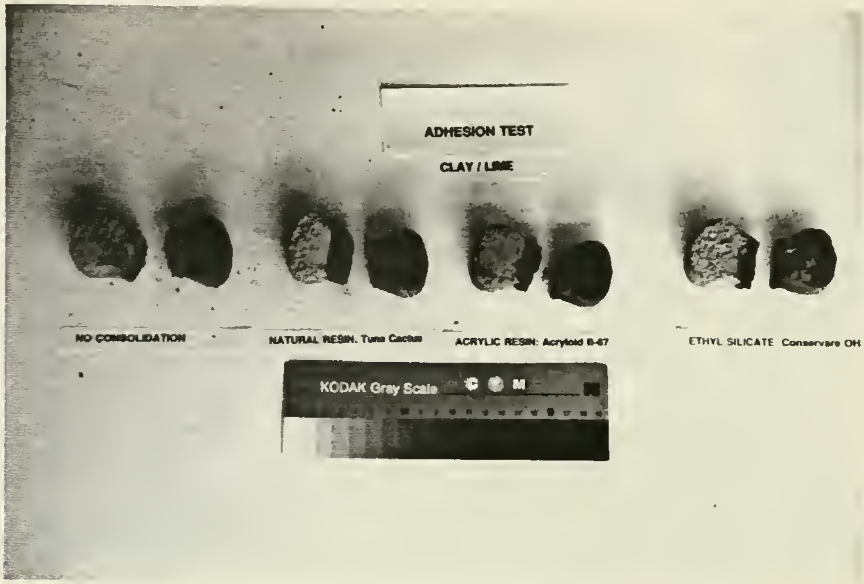
No. 21



Adhesion Test Results - Gypsum Plaster

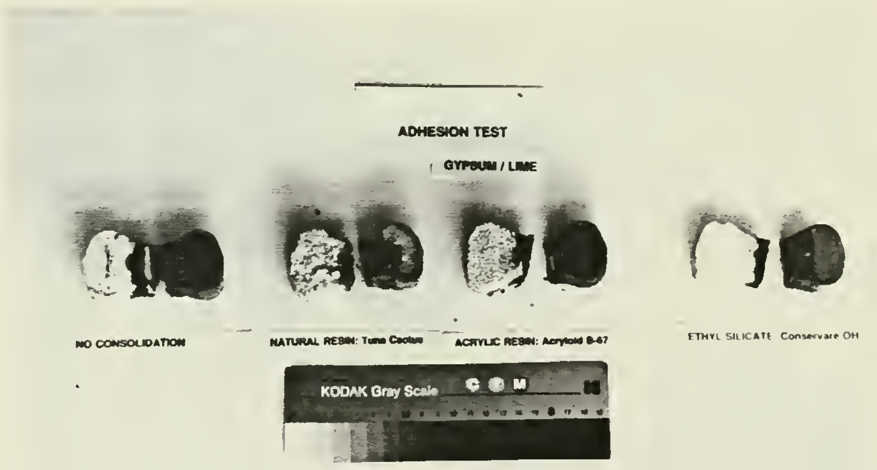
No. 22

ADHESION TEST - PHOTOGRAPHS



Adhesion Test Results - Clay / Lime Plaster

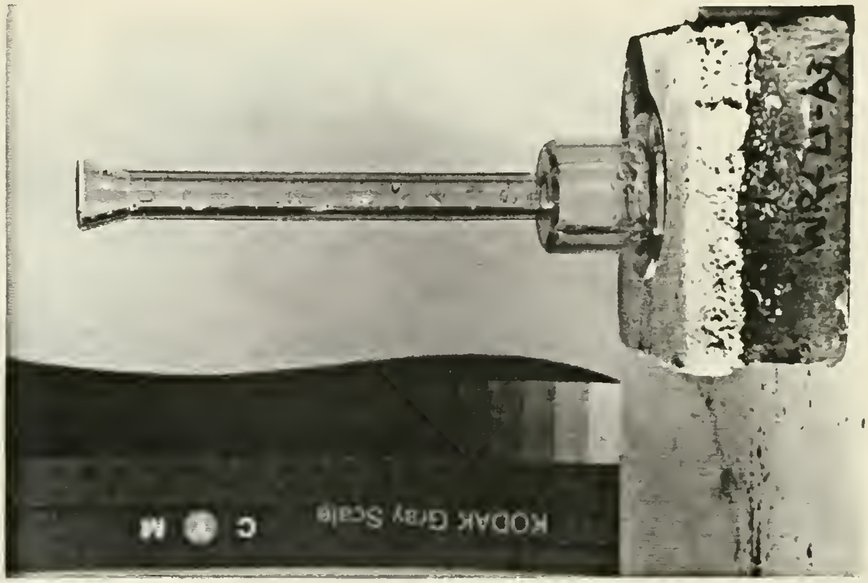
No. 23



Adhesion Test Results - Gypsum / Lime Plaster

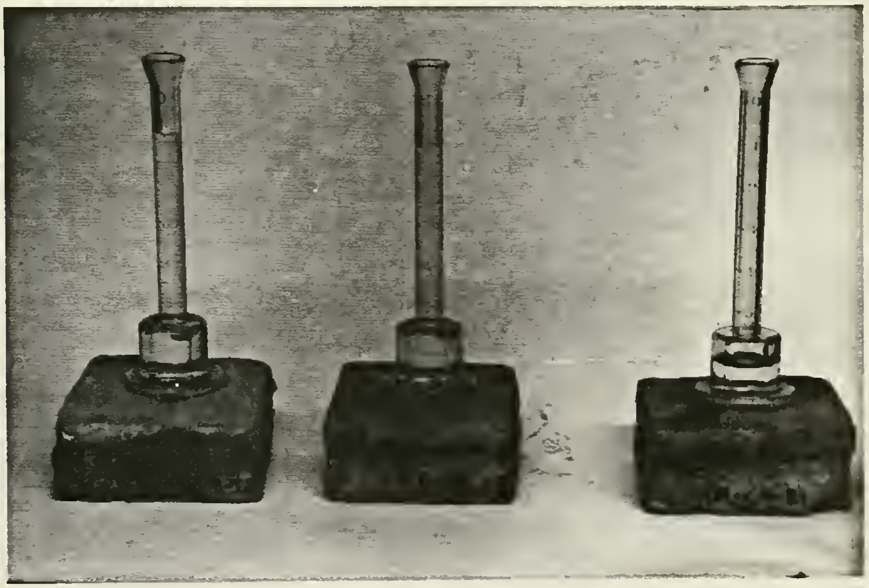
No. 24

CAPILLARITY TEST - PHOTOGRAPHS



Capillarity Test on Lime plaster treated with B-67

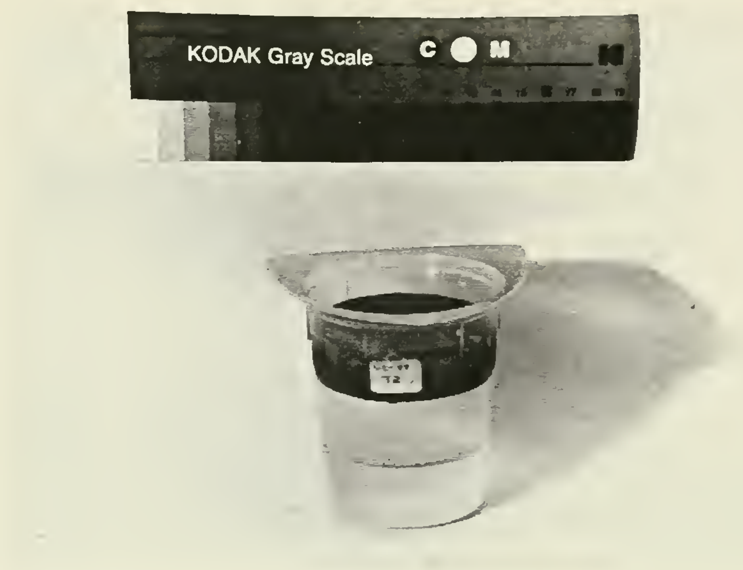
No. 25



Capillarity Test on Clay/Lime plasters treated with Tuna Cactus mucilage and Conservare OH.

No. 26

VAPOR TRANSMISSION TEST - PHOTOGRAPHS



Dish Assembly

No.
27

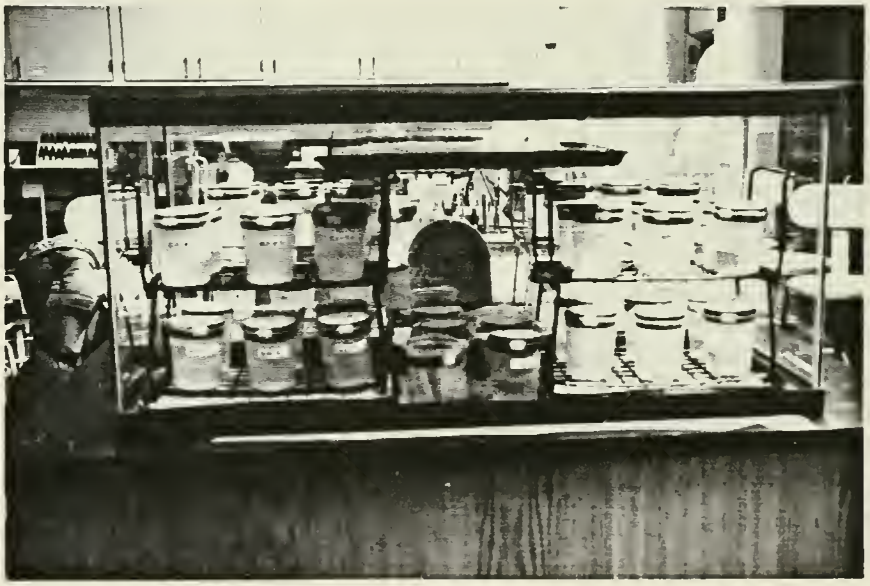
Dish assemblies with clay plaster samples on dry chamber, at 15% Relative Humidity.

No.
28

VAPOR TRANSMISSION TEST - PHOTOGRAPHS

Dry chamber with Gypsum, Clay/lime and Gypsum/lime samples

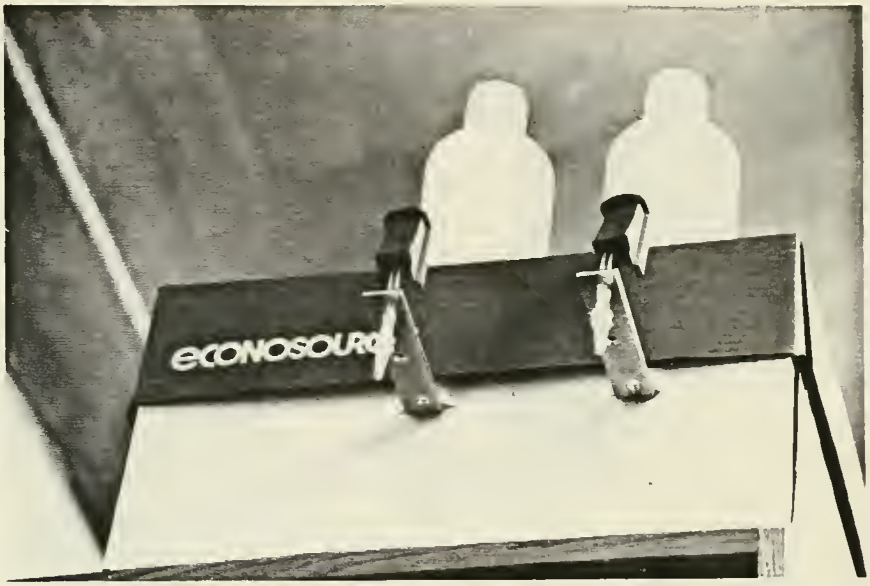
No. 29



Dry chamber

No. 30

WATER RESISTANCE TEST - PHOTOGRAPHS



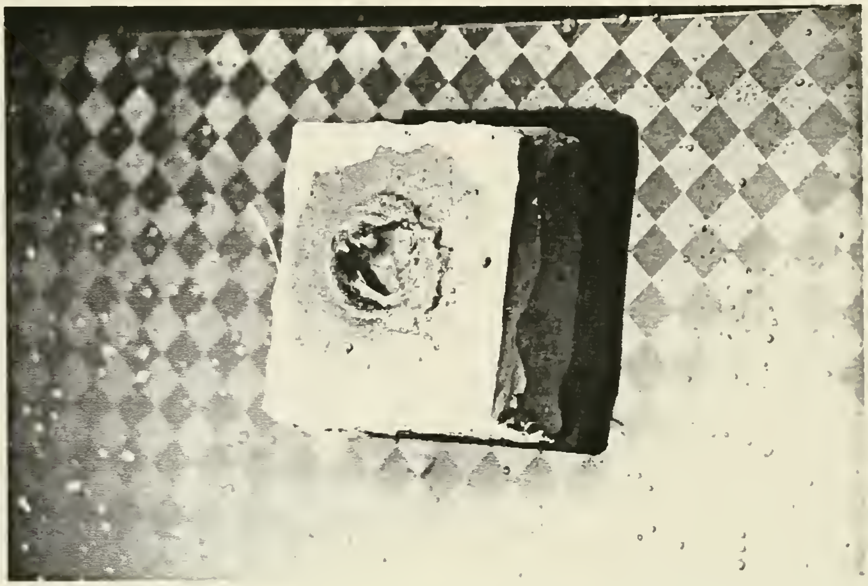
Water dropper device, adjusted to liberate one drop per second

No. 31

No consolidated clay sample after 10 seconds of test perform

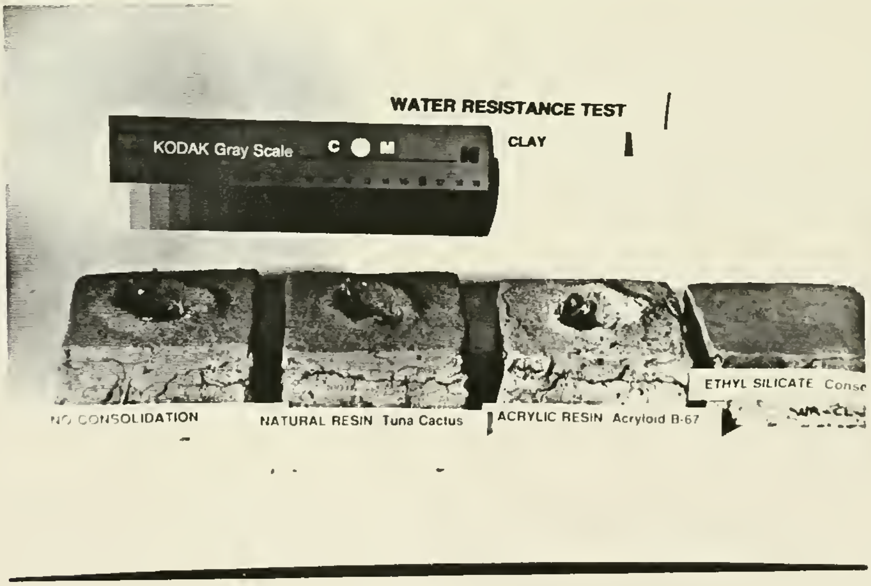
No. 32

WATER RESISTANCE TEST - PHOTOGRAPHS



No consolidated clay sample after 30 minutes of test perform.

No. 33



Water Resistance Test Results - Clay Plaster

No. 34

APPENDIX A: TRADITIONAL MIXTURES

CLAY PLASTERS

Costa Rican Traditional Earth Plaster by Rolf Ruge, architect; as described to Joe Tibbets in San Jose, Costa Rica in 1986. [1]

> *The first coat is applied over the adobes and consists of pulverized cowdung mixed with a finer sand/clay soil. The dung provides the fiber to prevent cracking. Mix to typical plaster consistency.*
>
> *The second coat is a fine river sand, mixed with a little clay with some calcium carbonate (Cal). In some localities, Jugo de tuna or prickly pear pulp has been added, which serves as stabilizer.*

Egyptian Exterior Mud plaster - stabilized described by Hassan Fathy, architect, as reported to Joe Vaughan, architect, Abiquiu, NM, 1980.

> *- 10 parts sand*
> *- 1 part red clay*
> *- 1 part earth (mainly recycled adobe)*
>
> *For one batch in a 10cu. ft. mixer (above ingredients will be repeated to capacity) add 6 no. 10 cans of asphalt emulsion, diluted in adequate water to make the mix."*

LIME PLASTERS

Jerome Iowa[2], in describes a traditional lime plaster recipe:

> *- Slake 44 pounds of hydrated lime in 6 gallons of water for at least 24 hours. If any lumps remain, screen them out.*
>
> *- Into one part of this lime paste, add 3 parts of fine sand. Mix thoroughly, adding only enough water to form a workable, putty-like consistency. Apply to wall with trowel."*[3]

---

[1] Joseph M. Tibbets. The Earthbuilders' Encyclopedia. Southwest Solaradobe School. (Phoenix, Arizona: Messenger Graphics, 1989), p. 56.

[2] Jerome Iowa, p. 73.

[3] Ibid, p. 100.

GYPSUM PLASTERS

Egyptian interior finish [4]

Have Gypsum mixed with water, and stir continously until it loses its setting power.

Add 1/10 gum arabic to the Gypsum st the consistency of sour milk (as in thin yogurt or buttermilk). Apply to earth wall with a brush. Use over a 2 coat mud plaster base as a finish coat . (powdered tempera could possibly be added for color).

CLAY AND LIME PLASTERS

South African Lime/Earth plaster[5]

- *6 parts red earth*
- *2 parts sand*
- *1 part hydrated lime*

The mix is prepared like regular adobe muds, and when reaching the correct consistency is applied with a trowel rather thin to the dampened wall. It will dry and crack, after which the applicator rubs the wall down with a sacking pad. The pad is covered with the same mix wetted to a thin cream consistency.

This is essential a clay/lime mix, made less cayey with the addition of sand. Lime and clay react well together, providing a relatively durable coating. Hydrated lime will tend to neutralize acid soils and stabilize clays.

---

[4] This recipe was reported by Hassan Fathy, architect, to Joe Vaughan, architect, Abiquiu, NM 1980, and appears in The Earthbuilders' Encyclopedia.

[5] Rammed Earth Walls for Buildings. USDA Farmers' Bulletin No. 1500 (Washington D.C.: USDA, 1926). p. 12.

PAINTS

Cement-based paint[6]

1 part calcium stearate (powdered)
2 parts calcium chloride (powdered)
50 parts Portland Cement
25 parts clean, fine sand

Mix these ingredients together to obtain a uniform mixture. Then add 50 parts water and mix a hoe until a creamy mixture is obtained.

Pour the mixture through a fly screen to remove lumps and large particles. Use white portland cement in the mixture if a white coating is desired. For other colors, add 3-4 parts of a powdered, oxide pigment. Only the second coat needs to be colored.

Limewash Recipes

A casein whitewash that is reportedly quite durable and "will not chalk or rub". Very weather resistant, and its origins date back to 1921, when it was promoted by the U.S. National Lime Association:[7]

- *50 lbs hydrated lime (with 7 gallons water)*
- *5 lbs. casein (with 2 gallons hot water)*
- *3 lbs. TSP (trisodium phosphate) (with one gallon water)*
- *3 pints formaldehyde*

Procedure for outside walls: Soak the 5 lbs. casein in 2 gallons of hot water until the casein is thoroughly soft-this takes about 2 hours. Dissolve the 3 lbs. of TSP in one gallon of water. Add this solution to the casein solution, making sure that all ingredients are dissolved. When the casein-TSP mix is completely cool, stir in 8 gallons of cool lime paste. The lime paste is achieved by slaking 50 pounds of hydrated lime in 6 gallons of water overnight.

Just before using dissolve 3 pints of formaldehyde in 3 gallons clear water. Slowly add this to the casein-lime solution.

Stir constantly and vigorously, for if you add the formaldehyde all at once, the casein will jell and ruin the whitewash. Mix only enough for one day's painting at a time, for it doesn't keep.

---

[6] Wolfskill; Dunlap and Gallaway, p. 8.

[7] Taken from Building with adobe and stabilized earth blocks. USDA leaflet 535. (Washington D.C.: USDA, 1965), p. 2.

Weather Resistant Lime Whitewash[8]

Mix the following ingredients:
- 62 lbs. (one bushel) quicklime (slacked with 12 gallons of hot water)
- one lb. Sulphate of Zinc & 2 lbs. of table salt dissolved in 2 gallons of boiling water.
-2 gallons of skimmed milk.

"One Year Whitewash"[9]

- *1 1/2 gallons unslaked lime (quicklime)*
- *3 1/2 gallons of water*
- *1/2 pound of melted tallow*

Boil the water in a large can, add the lime, and stir well. Then add the melted tallow to the boiling mixture and stir again. Apply the mixture with a large brush. If it is difficult to spread, add a little water. Considered a temporary protection, lasting about a year in most climates.

Government formula whitewash[10]

- *1/2 bushel of Quicklime*
- *1 peck of salt*
- *3 lbs. Ground rice*
- *1/2 lbs. Powdered Spanish Whiting*
- *1 lb. clear glue*

Slake the quicklime with boiling water, keeping it covered until slaked. Then strain it and add the salt, dissolved in warm water. Boil the rice in water to a thin paste in one pot. In an adjacent pot, dissolve the Spanish Whiting and glue in warm water. Mix all together and let stand for several days, keeping the mix warm in a kettle or portable furnace, then apply as hot as possibble .

Note: One ounce of Alum added to each gallon of whitewash increases its adhesion to the earth wall. One pint of molasses per 5 gallons of whitewash renders the lime more soluable and causes it to more deeply penetrate the masonry.

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[8] Elbert Hubbell, Earth Brick Construction. (Washington D.C.: U.S. Office of Indian Affairs, 1943), p. 9.

[9] Wolfskill, Dunlap and Gallaway, p. 6.

[10] Rammed Earth Walls for Buildings, p. 12.

Whitewash[11]

> *The basis of most limewash recipes is the mixing of a quantity of tallow, which may be from 2 to 10 lb., into a bushel of quicklime to form an insoluble calcium soap. The tallow should be placed in the center of the quicklime and the whole should be slaked together. If the quicklime is slow in slaking, it should be covered with sacking, and hot water should be used.*
>
> *The addition of pigments may necessitate an increase in tallow, but a useful mean to remember is 5 lb. tallow to a bushel of quicklime.... Pigments are useful in giving opacity to the limewash, which would otherwise be transparent and wet with rain. A small quantity of carbon black making a pale grey wash is sufficient for this purpose.* [12]

Traditional English Lime Whitewash[13]

- *1 bushel quicklime (62 lbs.)*
- *20 lbs. beef tallow*
- *Dry color as needed*

Place the quicklime in a barrel with the tallow and color. Slake with hot water, covering with a sackcloth to keep in the steam (from the reaction). When the lime is slaked, the tallow will have disappeared, having formed a chemical compound with the lime. Thin to an easy flowing consistency with water, strain, and apply directly to the earth wall.

"Factory" Whitewash (interiors), for walls, Ceilings, Posts, etc., [14]

(a) 62 lb. (1 bushel) quicklime, slake with 15 gallons water. Keep barrel covered till steam ceases to arise. Stir occasionally to prevent scorching.
(b) 2 1/2 lb. rye-flour; beat up in 1/2 gallon of cold water, then add 2 gallons boiling water.
(c) 2 1/2 lb. common rock-salt, dissolve in 2 1/2 gallons of hot water.

Mix (b) and (c), then pour into (a), and stir until all is well mixed. This is the whitewash used in the large implement factories, and recommended by insure companies. The above formula gives a product of perfect brush consistency.

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[11] Clough Williams-Ellis and John and Elizabeth Eastwick-Field, p. 105.

[12] Ibid, pp. 105-106.

[13] USDA Farmers' Bulletin no. 1500, p. 8.

[14] Three typical recipes, taken from "White paints and Painting" Scott

"Weatherproof" Whitewash (exteriors) for Buildings, Fences, etc.

(a) 62 lb. (1 bushel) quicklime, slake with 12 gallons of hot water.
(b) 2 lb. common table salt, 1 lb. sulphate of zinc, dissolved in a gallon of boiling water.
(c) 2 gallons skimmed milk.
Pour (b) into (a), then add the milk (c), and mix thoroughly.

"Light House" Whitewash: (recipe of English origins for along the sea-coast, or for more humid (rainy) locations, where wind-driven moisture could be a factor)

(a) 62 lb. (1 bushel) quicklime, slake with 12 gallons of hot water.
(b) 12 gallons rock-salt, dissolve in 6 gallons of boiling water.
(c) 6 lb. Portland cement
Pour (b) into (a), and then add (c).

Note: Alum added to a lime whitewash prevents it rubbing off. An ounce to the gallon is sufficient. Flour paste answers the same purpose, but needs zinc sulphate as a preventive.

Bitumen cut-back.[15]

Take 40 kg. (80 lbs.) of 80/100 bitumen and melt it on gentle fire. To this, add 10 kg. (20 lbs.) of Kerosene Oil and 0.5 kg. (1 lb.) of paraffin wax and mix well to obtain a homogeneous mixture

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[15] HUDCO- Housing and Urban Development Corporation, p.36

APPENDIX B: MATERIAL SAFETY DATA SHEETS

99-175-002

Material Safety Data Sheet

ProSoCo, Inc.

I PRODUCT IDENTIFICATION

MANUFACTURER'S NAME AND ADDRESS:
ProSoCo, Inc.
P.O. Box 171677
Kansas City, Kansas 66117

EMERGENCY TELEPHONE NUMBER: 913/281-2700

PRODUCT TRADE NAME: Conservare® OH Stone Strengthener (MA)

II HAZARDOUS INGREDIENTS

CHEMICAL NAME	(COMMON NAME)	CAS NO.	NFPA CODE	ACGIH TLV/TWA	OSHA PEL/TWA
2-Propanone	(Acetone)	67-64-1	1,3,0,-	750	1,000
2-Butanone	(Methyl Ethyl Ketone)	78-93-3	1,3,0,-	200	200
Tetraethylorthosilicate	(Ethyl Silicate)	78-10-4	2,2,0,-	10	100

Percent content of hazardous ingredients withheld as trade secret pursuant to Massachusetts regulations.

III PHYSICAL DATA

	BOILING POINT (°F)	VAPOR PRESSURE (mm Hg)	VAPOR DENSITY (Air=1)	EVAPORATION RATE (n=Butyl Acetate)
2-Propanone	133	182 (68°F)	2.0	7.7
2-Butanone	175	75 (68°F)	2.5	3.8
Tetraethylorthosilicate	302.6	1.0 (68°F)	Unknown	Unknown

	SPECIFIC GRAVITY	% VOLATILE BY VOLUME	SOLUBILITY IN WATER	APPEARANCE AND ODOR
Conservare® OH Stone Strengthener (MA)	0.935	Approx. 75.0	Negligible	Clear liquid, sweet ketone odor

IV FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (METHOD): 29°F (T.O.C.)

FLAMMABLE LIMITS: Lower: 1.8 Upper: 13.0

EXTINGUISHING MEDIA: Carbon dioxide, dry chemical, alcohol-resistant foam, or water fog. Do not use direct water stream. Avoid accumulation of water as product will float.

SPECIAL FIRE FIGHTING PROCEDURES:
Do not enter confined fire space without proper protective equipment, including a NIOSH/MSHA approved self-contained breathing apparatus. Cool fire exposed containers, surrounding equipment and structures with water.

UNUSUAL FIRE AND EXPLOSION HAZARDS:
Vapors are heavier than air and may accumulate in low areas or areas inadequately ventilated. Vapors may also travel along the ground to be ignited at location distant from handling site; flash back of flame to handling site may occur.

Never use welding or cutting torch on or near drum (even empty) because product (even just residue) can ignite explosively.

FLAMMABLE!!! Keep container tightly closed. Isolate from oxidizers, heat, and open flame. Closed containers may explode if exposed to extreme heat. Applying to hot surfaces requires special precautions.

V HEALTH HAZARD DATA

PRIMARY ROUTES OF EXPOSURE: Inhalation, skin, eyes.

CARCINOGEN INFORMATION: Not listed (OSHA, IARC, NTP).

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: No applicable information found.

EFFECTS OF OVEREXPOSURE:
Highly irritating to eyes. Moderately irritating to skin. High concentrations may produce anesthetic or narcotic effect.

EYE CONTACT: Liquid is highly irritating to the eyes. Vapors are also irritating. Possible moderate corneal injury.

SKIN CONTACT: Liquid is moderately irritating to the skin. Repeated, prolonged contact can result in defatting to the skin which may lead to dermatitis.

INHALATION: Breathing high vapor concentrations or prolonged breathing of lower concentrations can cause nose and throat irritation and may cause headache, dizziness and loss of consciousness.

NOTE: Minor embryotoxic/fetotoxic effects have been observed in laboratory rats exposed to over 1,000 ppm of MEK for most of the gestation period by the inhalation route (5 times the OSHA-PEL/TWA).

INGESTION: Liquid ingestion may result in vomiting; aspiration of liquid into the lungs must be avoided as liquid contact with the lungs can result in chemical pneumonitis and pulmonary edema/hemorrhage.

EMERGENCY AND FIRST AID PROCEDURES:

EYE CONTACT: If in eyes, flush with large amounts of water, lifting upper and lower lids occasionally. If persistent irritation occurs, get medical attention. Get medical attention.

SKIN CONTACT: Wash with soap and water. Remove contaminated clothing and do not reuse until laundered. If persistent irritation occurs, get medical attention.

INHALATION: Remove victim to fresh air and provide oxygen if breathing is difficult. Give artificial respiration if not breathing. Get medical attention.

INGESTION: Do not give liquids if victim is unconscious or very drowsy. Otherwise, give no more than two glasses of water and induce vomiting by giving 30cc (two tablespoons) syrup of Ipecac. If Ipecac is unavailable, give two glasses of water and induce vomiting by touching finger to back of victim's throat. Keep victims head below hips while vomiting. Get medical attention.

VI REACTIVITY DATA

STABILITY: Stable.

CONDITIONS TO AVOID:
Oxidizing materials, nitric plus acetic acid, and nitric plus sulfuric acid.

INCOMPATIBILITY (MATERIALS TO AVOID): Oxidizing materials.

HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS:
Carbon monoxide and unidentified organics may be formed during combustion.

VII SPILL OR LEAK PROCEDURES

SPILL, LEAK AND WASTE DISPOSAL PROCEDURES:

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED:

Large Spills: Eliminate potential sources of ignition. Wear appropriate respirator and other protective clothing. Shut off source of leak only if safe to do so. Dike and contain. Remove with explosion proof equipment. Soak up residue with a noncombustible absorbent such as clay or vermiculite; place in drums for proper disposal. Flush area with water to remove trace residue; dispose of flush solutions in drums.

Small Spills: Soak up with a noncombustible absorbent and place in drums for disposal. Flush area with water to remove trace residue; collect flush solutions for disposal.

Handling equipment must be grounded to prevent sparking.

WASTE DISPOSAL METHODS:
Dispose of in a facility approved under RCRA regulations for hazardous waste. Containers must be leak proof and properly labeled.

VIII SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION:
If Threshold Limit Value (TLV) of the product or any component is exceeded, a NIOSH/MSHA jointly approved air supplied respirator is advised in absence of proper environmental control. OSHA regulations also permit other NIOSH/MSHA respirators under specified conditions. (See your safety equipment supplier.) Engineering or administrative controls should be implemented to reduce exposure.

VENTILATION: Provide sufficient general and/or local exhaust ventilation to maintain exposure below TLV(s).

Use explosion proof ventilation as required to control vapor concentrations below the TLV.

PROTECTIVE CLOTHING: Wear protective clothing as required to prevent skin contact.

PROTECTIVE GLOVES: Wear solvent resistant gloves, such as nitrile rubber.

EYE PROTECTION:

Chemical splash goggles in compliance with OSHA regulations are advised; however, OSHA regulations also permit other type safety glasses. (Consult your safety equipment supplier.)

OTHER PROTECTIVE EQUIPMENT:

Solvent resistant boots and headgear. Safety shower and eyewash.

IX SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE:

Store away from oxidizing materials in a cool, dry place with adequate ventilation. Keep away from heat and open flames. Keep containers tightly sealed. Wash up with soap and water before eating, drinking, smoking or using toilet facilities. Launder contaminated clothing before reuse. Containers of this material may be hazardous when emptied since emptied containers retain product residues (vapor, liquid, and/or solid). All hazard precautions given in the Data sheet must be observed.

Ground equipment to prevent accumulation of static charge. Containers must be bonded and grounded when pouring or transferring materials.

OTHER PRECAUTIONS:

Environmental Hazards - This product is considered an "oil" under the Clean Water Act. Keep out of surface water and watercourses or sewers entering or leading to surface waters.

'ISCLAIMER: The information contained on the Material Safety Data Sheet has been compiled from data considered accurate. This data is believed to be reliable, but it must be pointed out that values for certain properties are known to vary from source to source. ProSoCo, Inc. expressly disclaims any warranty express or implied as well as any liability for any injury or loss arising from the use of this information or the materials described. This data is not to be construed as absolutely complete since additional data may be desirable when particular conditions or circumstances exist. It is the responsibility of the user to determine the best precautions necessary for the safe handling and use of this product for his unique application. This data relates only to the specific material designated and is not to be used in combination with any other material. Many federal and state regulations pertain directly or indirectly to the product's end use and disposal of containers and unused material. It is the purchaser's responsibility to familiarize himself with all applicable regulations.

DATE OF PREPARATION August 15, 1988

DATE: 03/02/91
PO NBR: N/A
ACCT: 00089101
INDEX: 0008000000
CAT NO: [illegible]
SHEET: R-0123.900

MATERIAL SAFETY DATA SHEET

EASTMAN KODAK COMPANY
343 State Street
Rochester, New York 14650

For Emergency Health, Safety, and Environmental Information, call 716 722-5151
For other purposes, call the Marketing and Distribution Center in your area.

Date of Preparation: 3/7/83 Form Approved by U.S. Department of Labor

SECTION I. IDENTIFICATION

- Product Name: Diethylbenzene (Techn.)
- Size(s): CAT 113 [illegible] - bulk; CAT 113 [illegible] - 1 kg; CAT 113 3381 - [illegible] kg
- Synonym(s): Mixture of m-Diethylbenzene and p-Diethylbenzene
- Formula: $(C_2H_5)_2C_6H_4$
- Kodak Laboratory Chemicals Catalog Number(s): T1981
- Kodak Accession Number: 901981
- Kodak Hazard Rating Codes: H: [illegible] S: 2 F: 2 C: 0

SECTION II. PRODUCT AND COMPONENT HAZARD DATA

A.

COMPONENT(S):	Weight Percent	TLV(R)	Kodak Accession No.	CAS Reg. No.
Diethylbenzene (Techn.)	approx 100	—	901981	[illegible]

B. PRECAUTIONARY LABEL STATEMENT(S):

WARNING!
CAUSES SKIN AND EYE IRRITATION
HARMFUL IF INHALED
COMBUSTIBLE
Avoid contact with eyes, skin, and clothing.
Avoid breathing vapor.
Keep away from heat and flame.
First Aid: In case of contact, immediately flush eyes or skin with plenty of water for at least 15 minutes. If inhaled, remove to fresh air. In case of eye contact, get medical attention.

SECTION III. PHYSICAL DATA

- Appearance and Odor: Clear liquid
- Melting Point: Not Available
- Boiling Point: 178 C (352 F) @ 760 mmHg
- Vapor Pressure: 1 mmHg @ 20 C
- Evaporation Rate (n-butyl acetate = 1): Not Available
- Vapor Density (Air = 1): 4.64
- Volatile Fraction by Weight: approx 100
- Specific Gravity (H_2O = 1): 0.868
- Solubility in Water (by Weight): Negligible

SECTION IV. FIRE AND EXPLOSION HAZARD DATA

- Flash Point: 53 C (128 F) Setaflash closed cup
- Autoignition Temperature: 430 C (806 F)
- Flammable Limits in Air (% by volume in air):
  Lower: approx 0.8 at 57 C;
  Upper: approx 5.0 at 85 C
- Extinguishing Media: Water spray; Dry chemical; CO2, Foam
- Special Fire Fighting Procedures:
  Wear self-contained breathing apparatus and protective clothing to prevent contact with skin and eyes.
- Unusual Fire and Explosion Hazards: None Known

SECTION V. REACTIVITY DATA

- Stability: Stable
- Incompatibility: Strong oxidizers
- Hazardous Decomposition Products
  As with any other organic material, combustion will produce carbon dioxide and probably carbon monoxide.
- Hazardous Polymerization: Will not occur.

SECTION VI. TOXICITY AND HEALTH HAZARD DATA

A. EXPOSURE LIMITS Not established

B. EXPOSURE EFFECTS

Inhalation	High concentrations may cause narcosis
Eyes	Causes eye irritation.
Skin	Causes irritation

C. FIRST AID

Inhalation	Remove from exposure, treat symptomatically, and get medical attention if symptoms persist
Eyes	Immediately flush eyes with plenty of water for at least 15 minutes and get medical attention
Skin	Immediately flush skin with plenty of water for at least 15 minutes and get medical attention if symptoms are present after washing.

D. TOXICITY DATA

Test	Species	Result	Classification(3)
Acute Oral LD50	Rat	1200 mg/kg(1)	Slightly toxic
LC50 (Inhalation)	Mouse	GT 5500 ppm(1)	
Skin Irritation	Rabbit	Moderate(1)	
Eye Irritation	Rabbit	Transient irritation(2)	

Other: Rats, rabbits, guinea pigs, and monkeys were exposed to concentrations of 400 to 2200 ppm, 7 to 8 hours/day, 5 days/week for as long as 6 months. The guinea pigs, rabbits, and monkeys were not affected. The rats showed a slight increase in kidney and liver weights.(1)

Ethylbenzene, a structurally related chemical to diethylbenzene, is irritating and may cause central nervous system effects. Therefore, diethylbenzene may also produce central nervous system effects as well as irritation.

SECTION VII. PERSONAL PROTECTION AND CONTROLS

A. RESPIRATORY PROTECTION:

An appropriate NIOSH-approved respirator for organic vapors should be worn if needed.

B. VENTILATION:

Local Exhaust: Recommended

Mechanical (General): Recommend at least ten air changes per hour for good general room ventilation.

C. SKIN AND EYE PROTECTION:

Protective gloves should be worn.
Safety glasses should be worn.

SECTION VIII. SPECIAL STORAGE AND HANDLING PRECAUTIONS

Material is classified as a combustible liquid. Keep away from heat and flame.
Keep from contact with oxidizing materials

SECTION IX. SPILL, LEAK, AND DISPOSAL PROCEDURES

Remove all sources of ignition.
Absorb material in vermiculite or other suitable absorbant and place in impervious container.
Package appropriately for safe feed to an incinerator.
Dispose in an approved incinerator or contract with licensed chemical waste disposal agency.
Discharge, treatment, or disposal may be subject to federal, state, or local laws.

SECTION X. ENVIRONMENTAL EFFECTS DATA

This chemical has not been tested for environmental effects.

SECTION XI. TRANSPORTATION

For transportation information regarding this product, please phone the Eastman Kodak Distribution Center nearest you: Rochester, NY (716) 254-1300; Oak Brook, IL (312) 654-5300; Chamblee, GA (404) 455-0123; Dallas, TX (214) 241-1611; Whittier, CA (213) 945-1255; Honolulu, HI (808) 833-1661.

SECTION XII. REFERENCES

1. Patty, F.A., Editor, Industrial Hygiene and Toxicology, Vol. II, 3rd Revised Edition, Interscience Publishers, 1981.

2. Grant, W., Toxicology of the Eye, Charles C. Thomas Publisher, 1974.

3. Hodge, H.C. and Sterner, J.H., American Industrial Hygiene Association Quarterly, 10, 93 (1949)

R-0123.900
J113-5565*
J113-5571*
J113-5581*
JT1931*
82-0757

*** END OF DOCUMENT *** SHEET NBR: R-0123.900 CAT NBR EK1135571 *** END OF DOCUMENT ***

APPENDIX C: ASTM TESTS

REFERENCES

[illegible] K., and Heuze, F. E., "Measurement of [illegible] in Boreholes," *Proceedings of the 10th U.S.* [illegible] *Mechanics*, University of Texas, Austin, TX, [illegible]

[illegible] Effects in the Determination of Rock Mass [illegible]," *Rock Mechanics*, Vol 12, 1980, pp.

[illegible] B., "The NX-Borehole Jack: A Lesson [illegible] *International Journal of Rock Mechanics and* [illegible] April 1985, pp. 105–112

[illegible] An Analysis of the Goodman Jack," *Proceed-* [illegible] *Symposium on Rock Mechanics*, University of [illegible] 1976, pp. 4-D1-1–4-D1-8

[illegible] Diameter as a Factor in Borehole Jack [illegible] *of the 22nd U.S. Symposium on Rock* [illegible] Cambridge, MA, 1981, pp. 422-427

(6) Shuri, F. S., Feves, M. L., Peterson, G. L., Foster, K. M., and Kienle, C. F., *Field and In Situ Rock Mechanics Testing Manual*, ONWI-310, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH, 1981.

(7) Swolfs, H. S., and Kibler, J. D., "A Note on the Goodman Jack," *Rock Mechanics*, Vol 15/2, 1982, pp. 57–66

(8) Patrick, W. C., Yow, J. L., Jr., and Axelrod, M. C., "Observations of Borehole Deformation Modulus Values Before and After Extensive Heating of a Granite Rock Mass," *Proceedings of the 26th U.S. Symposium on Rock Mechanics*, Balkema, A. A., Rotterdam, 1985, pp. 851–858

(9) Heuze, F. E., and Salem, A., "Rock Deformability Measured In Situ Problems and Solutions," *Proceedings International Symposium on Field Measurements in Rock Mechanics*, Zurich, Balkema, A. A., Rotterdam, 1977, pp. 375–387.

(10) Meyer, T. O., and McVey, J. R., *NX-Borehole Jack Modulus Determinations in Homogeneous, Isotropic, Elastic Materials*, U.S. Bureau of Mines, RI 7855, Washington, DC, 1974

Designation: D 4972 – 89

Standard Test Method for pH of Soils[1]

This standard is issued under the fixed designation D 4972; 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.

1. Scope

1.1 This test method covers the measurement of the pH of soils for uses other than for corrosion testing. Such measurements are used in the agricultural, environmental, and the natural resources fields. This measurement determines the degree of acidity or alkalinity in soil materials suspended in water and a 0.01 *M* calcium chloride solution. Measurement in both liquids are necessary to fully define the soil's pH. This variable is useful in determining the solubility of soil minerals, the mobility of ions in the soil, and assessing the viability of the soil-plant environment. A more detailed discussion of the usefulness of this parameter is not warranted here, however, it can be found in many discussions of the subject. A few such discussions are given as Refs (1)[2] through (6) at the end of the text.

1.2 The values given in SI units are regarded as standard.

1.3 *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 670 Practice for Preparing Precision and Bias Statements for Test Methods of Construction Materials[3]

G 51 Test Method for pH of Soil for Use In Corrosion Testing[4]

3. Summary of Test Method

3.1 Measurement of the pH of soils in both suspensions of water and a calcium chloride solution are made with either a potentiometer using a pH sensitive electrode system (Method A), or pH sensitive paper (Method B). The potentiometer is calibrated with buffer solutions of known pH. The pH sensitive paper is a less accurate measurement and should only be used for a rough estimate of the soil pH. The electrode must be used for this measurement unless the pH sensitive paper is specified.

4. Significance and Use

4.1 The pH of the soil is a useful variable in determining the solubility of soil minerals, the mobility of ions in the soil and assessing the viability of the soil-plant environment.

4.2 pH measurements are made in both water and a calcium chloride solution, because the calcium displaces some of the exchangeable aluminum. The low ionic strength counters the dilution effect on the exchange equilibrium by setting the salt concentration of the solution closer to that expected in the soil solution. The pH values obtained in the solution of calcium chloride are slightly lower than those measured in water due to the release of more aluminum ions which then hydrolyses. Therefore, both measurements are required to fully define the character of the soil's pH.

4.3 For the purpose of this test method the test soil must be sieved through a No. 10 sieve (2 mm sieve mesh openings). Measurements on soils or soil fractions having particle sizes larger than 2 mm by this test method may be invalid. If soil or soil fractions with particles larger than 2 mm are used, it must be stated in the report since the results may be significantly different.

4.4 All water used for this test method must be distilled and deionized.

5. Interferences

5.1 This test method as measured by a pH probe has possible interferences due to a suspension effect or sedimentation potential. Users interested in a detailed discussion of the mechanism of this effect can find it in Refs (5) and (6).

5.2 This effect is the main reason Test Method G 51 can not be used for general measurement of pH outside of that for corrosion analysis. Test Method G 51 measures pH (an aqueous parameter) without adding any aqueous phase to the soil. This results in excessive soil particle-pH probe contact that over-estimates the activity of the hydrogen ions in solution and is therefore unacceptable for general soil analysis.

5.3 The suspension effect can be mitigated by careful attention to 9.1.

6. Apparatus

6.1 *Method A, pH Meter*—Potentiometer equipped with glass-calomel electrode system. Follow the manufacturer's instructions for the pH meter used. A silver/silver chloride electrode system or similar is also acceptable.

6.2 *Method B, pH Paper*—pH paper sensitive to a pH range from 1 to 12, with resolution to the nearest 0.2 pH unit.

7. Reagents

7.1 *Purity of Reagents*—Reagent grade chemicals should be used in all tests. Unless otherwise indicated, it is intended that all reagents should conform to the specifications of the

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[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.06 on Physico-Chemical Properties of Soils and Rocks.

Current edition approved Nov. 10, 1989. Published December 1989.

[2] The boldface numbers in parentheses refer to a list of references at the end of the test method.

[3] *Annual Book of ASTM Standards*, Vols 04.01, 04.02, 04.03, and 04.08.

[4] *Annual Book of ASTM Standards*, Vol 03.02.

[illegible] of Reagents of the American Chemical Society, where such specifications are available.[4] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

[illegible] Water should be distilled, deionized [illegible] free of carbon dioxide. The pH of [illegible] checked prior to testing the soil. Should [illegible] of 6.5 to 7.5, it should be discarded [illegible] for the test.

[illegible] *Phthalate Buffer Solution* (0.05 *M*)— [illegible] 105°C of potassium phthalate [illegible]. The pH of this solution should be [illegible] the solution against evaporation and [illegible] with molds. Replace the solution [illegible]. The effect of temperature is:

pH
4.0

[illegible] the pH of the solution does not change [illegible] temperature from 5 to 37°C.

[illegible] *Solution* (1.0 *M*)—Dissolve [illegible] in a 1-L volumetric flask, [illegible] and mix. Dilute 15 mL of [illegible] in a volumetric flask.

[illegible] *Solution* (0.01 *M*)—Dilute 20.0 mL [illegible] solution to 2 L with water. The pH of [illegible] 5 and 7.

[illegible] (0.025 *M*)—Dissolve 3.40 g [illegible] HPO_4 in water and dilute to 1 [illegible]. The pH of this solution [illegible] temperature is as follows:

pH
7.0
6.9
6.9
6.8
6.8

pH Meter

[illegible] pH meter using the acid potassium phthalate buffer solutions. Adjustment of the [illegible] the manufacturer's direction.

[illegible] with the pH electrode. [illegible] partially settled suspension to [illegible].

[illegible] air dried soil that has [illegible] 10 sieve (2 mm holes) to remove [illegible]. No drying the soil is necessary to [illegible] control the amount of water [illegible].

[illegible]—For both methods, weigh out [illegible] soil. Place the soil into a glass [illegible] approximately 10 mL of distilled water. Mix thoroughly and let stand for 1 h.

9.4 *Method A*—Read pH on pH meter.

9.5 *Method B*—Read pH on pH paper.

9.6 *pH in 0.01 M Calcium Chloride Solution*—For both methods weigh out approximately 10 g of air dried soil. Place the soil into a glass container and add approximately 10 mL of the 0.01 *M* $CaCl_2$ solution. Mix thoroughly and let stand for 1 h.

9.7 *Method A*—Read pH on pH meter.

9.8 *Method B*—Read pH on pH paper.

9.9 The mixture should be at approximately room temperature (15 to 25°C) at the time of pH measurement.

10. Report

10.1 Report the pH of the soil to the first decimal place. Specify which of the pH measurements is in water and which is in the calcium chloride solution. Also specify whether the determinations were made with Method A or Method B. If size fractions other than sieved through the No. 10 sieve are used, it must be stated in the report since the results may be significantly different.

11. Precision and Bias

11.1 *Precision*

11.1.1 *Within-Laboratory Precision*—The within laboratory standard deviations for Method A are 0.031 (pH units) for the water mixture and 0.139[6] (pH units) for the calcium chloride mixture. Therefore, results of two properly conducted tests in the same or different laboratories should not differ by more than 0.065[6] (pH units) for the water mixture and 0.389 pH units for the calcium chloride mixture. The within-laboratory standard deviations for Method B are 0.189 (pH units) for the water mixture and 0.212[6] (pH units) for the calcium chloride mixture. Therefore, results of two properly conducted tests in the same or different laboratories should not differ by more than 0.53[6] (pH units) for the water mixture and 0.60 pH units for the calcium chloride mixture.

11.1.1.1 The precision of Method A presented was determined by the National Technical Center of the United States Department of Agriculture. In their evaluation they used 17 replicates for the water mixture and 32 replicates in testing the calcium chloride mixture.

11.1.1.2 The precision of Method B presented was determined by the United States Army Environmental Hygiene Agency. In their evaluation they used 25 replicates in testing each mixture.

11.1.2 *Between-Laboratory Precision*—The between-laboratory standard deviation has not been determined for either method. Subcommittee D18.06 is actively seeking data to evaluate the between laboratory precision of this test method.

11.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

12. Keywords

12.1 soil, pH, acidity, alkalinity, reaction

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[4] [illegible] Society Specifications, [illegible] on the testing of reagents not [illegible] of Chemicals and Standards, [illegible] New York, NY, and the United

[6] These data satisfy the 1S and D2S requirements outlined in Practice C 670.

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(1) Garrels, R. M., and Christ, C. L., *Solutions, Minerals, and Equilibria*, Freeman Cooper, San Francisco, CA, 1965.

(2) Greenland, D. J., and Hayes, M. H. B., *The Chemistry of Soil Processes*, Wiley, NY, 1981.

(3) Sposito, G., *The Thermodynamics of Soil Solutions*, Clarendon, Oxford, 1981.

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Designation: C 472 – 90

Standard Test Methods for Physical Testing of Gypsum, Gypsum Plasters and Gypsum Concrete[1]

This standard is issued under the fixed designation C 472; 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.

These test methods have 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 approved by the Department of Defense.

1. Scope

1.1 These test methods cover the physical testing of gypsum, gypsum plasters, and gypsum concrete.

1.2 The test methods appear in the following sections:

	Sections
Precautions for Physical Tests	4
Reagents and Materials	5
Free Water	6 to 9
Fineness	10 to 14
Normal Consistency of Plaster	15 to 19
Normal Consistency of Gypsum Concrete	20 to 24
Time of Setting	25 to 29
Time of Setting (Alternate Temperature Rise Method)	30 to 35
Compressive Strength	36 to 41
Density	42 to 46

1.3 *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.* For a specific precautionary statement, see X1.2.1.

2. Referenced Documents

2.1 *ASTM Standards:*

C 11 Definitions of Terms Relating to Gypsum and Related Building Materials and Systems[2]

C 778 Specification for Standard Sand[2]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[3]

3. Terminology

3.1 *Definitions:*

3.1.1 For useful definitions refer to Definitions of Terms C 11.

4. Precautions for Physical Tests

4.1 Gypsum products are peculiar in that their properties are very greatly affected by the small amounts of impurities that may be introduced by careless laboratory manipulation. In order to obtain concordant results, it is, therefore, absolutely essential to observe the following precautions:

4.1.1 All apparatus shall be kept thoroughly clean. Especially, all traces of set plaster shall be removed. For mixing pastes and mortars, a 500-mL rubber dental bowl is a convenience.

4.1.2 Care must be used when drying gypsum, gypsum plasters, or gypsum concrete. Exceeding the specified drying temperatures may calcine the specimens, which will cause inaccurate test results.

5. Reagents and Materials

5.1 Distilled or deionized water, free of chlorides and sulfates, shall be used for mixing gypsum plasters and gypsum concrete.

5.2 Standard sand shall be used exclusively and shall meet the requirements of 20–30 sand in Specification C 778.

FREE WATER

6. Significance and Use

6.1 This test method determines the free water contained in gypsum, gypsum plasters, and gypsum concrete samples, and prepares the sample for subsequent testing.

7. Apparatus

7.1 *Balance*, capable of weighing at least 1 lb (454 g) at a precision of 0.002 lb (0.1 g).

7.2 *Drying Oven*, set at 110 ± 5°F (43.3 ± 2.8°C).

7.3 *Desiccator*, containing calcium chloride or equivalent desiccant.

8. Procedure

8.1 Weigh a sample of not less than 1 lb (0.45 kg) of the material as received and spread it out in a thin layer in a suitable vessel. Place in an oven and dry at 110 ± 5°F (43.3 ± 2.8°C) for 2 h; then cool in an atmosphere free from moisture and weigh again. The loss of weight corresponds to the free water and shall be calculated as a percentage of the sample as received.

8.2 Retain the dried sample in an airtight container until used for the fineness test (Sections 10 to 14).

9. Precision and Bias

9.1 The precision and bias of the free water test method have not been determined.

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[1] These test methods are under the jurisdiction of ASTM Committee C-11 on Gypsum and Related Building Materials and Systems and are the direct responsibility of Subcommittee C11.01 on Specifications and Test Methods for Gypsum ....

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

[3] *Annual Book of ASTM Standards*, Vols 04.01 and 14.02.

as specified in 31.4. The movable temperature sensor, in this case, shall be positioned 25 to 33 % of the distance up from the bottom and between the inner and outer cup. Alternately, the cup containing the test mixture may be positioned over a spring-loaded sensor to ensure close contact with the bottom of the cup.

31.4 *Insulated Block or Beaker*, with walls and bottom having a thermal resistance of at least R6 (6 (h·ft²·°F)/Btu) (1.1 (m²·K)/W), and a centered cavity into which the sample cup fits snugly.

NOTE 4—An insulating block may be constructed from a block of expanded polystyrene which, after carving a cavity into which the sample cup fits snugly, has walls and bottom at least 1.5 in. (38 mm) thick. An insulating beaker may be made by stuffing glass fiber or mineral wool insulation at least 2 in. (50.8 mm) thick around the sample container and within the walls of a beaker. The insulated block or beaker should have an insulated cover of the same insulating material through which the temperature probe can extend into the test material.

32. Test Conditions

32.1 Tests shall be made in a room or cabinet maintained at a temperature of 70 ± 2°F (21.1 ± 1.1°C). Materials and mixing water used for the test shall be at 70 ± 2°F (21.1 ± 1.1°C).

NOTE 5—If a constant-temperature cabinet is not available, a constant-temperature water bath may be fitted with a cover which will admit the body of the cup holder but not its rim, so that the cup holder is in contact with the water in the bath.

33. Procedure

33.1 *Gypsum Concrete and All Gypsum Plasters, Except Gypsum Neat Plaster*—Start the timing of the test at the moment of contact of the dry material with the water. Mix approximately 200 g of the sample to make a paste of normal consistency. Place the paste in a clean dry sample to about ¾ in. (19 mm) from the top. Place the filled cup in an empty cup in the insulated block or beaker and adjust the sensing element as required in 31.3. Cover the cup with a watch glass or plastic film or cover the surface of the paste with mineral oil to a depth of approximately ¼ in. (6 mm).

33.2 *Gypsum Neat Plaster*—Prepare the plaster as required in 27.2 and test as required in 33.1.

34. Report

34.1 Report the time of setting as the elapsed time in minutes from the time when the sample was first added to the water to the time when set is complete.

35. Precision and Bias

35.1 The precision and bias for the time of setting, alternate temperature rise test method, have not been determined.

COMPRESSIVE STRENGTH

36. Significance and Use

36.1 This test method is used to determine the compressive strength of gypsum plaster and gypsum concrete and is used to determine compliance with applicable specifications. The correlation between this test method and service performance has not been determined.

37. Apparatus

37.1 *Specimen Molds*—Molds for making test specimens shall be 2-in. (50.8 mm) split cube molds made of noncorrodible material and shall be sufficiently rigid to prevent spreading during molding. The molds shall have no more than three cube compartments and shall be separable into not more than two parts. When assembled, the parts of the molds shall be held firmly together, and dimensions shall conform to the following requirements: Interior faces shall be plane surfaces with a maximum variation of 0.001 in. (0.03 mm) for new molds and 0.002 in. (0.05 mm) for old molds; distance between opposite faces, and height of the molds, measured separately for each cube compartment, shall be 2 ± 0.005 in. (50.8 ± 0.13 mm) for new molds or 2 ± 0.020 in. (50.8 ± 0.51 mm) for old molds; angle between adjacent interior faces and between interior faces and top and bottom planes of the mold shall be 90 ± 0.5°, measured at points slightly removed from the intersection of the faces.

37.2 *Testing Machine*, either the hydraulic or the screw type, with sufficient opening between the upper bearing surface and the lower bearing surface of the machine to permit the use of verifying apparatus. The load applied to the test specimen shall be indicated with an accuracy of ±1.0 %. The load indicating device shall have a means of indicating maximum load. 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 free to tilt in any direction. A hardened metal bearing block shall be used beneath the specimen to minimize wear of the lower platen of the machine. The lower bearing block shall have concentric circles at ⅛-in. intervals centered on the block to facilitate accurate centering of the test specimen. The bearing block surfaces intended for contact with the specimen shall have a Rockwell hardness number not less than 60 HRC. These surfaces shall not depart from plane surfaces by more than 0.0005 in. (0.013 mm) when the blocks are new and shall be maintained within a permissible variation of 0.001 in. (0.025 mm).

37.3 *Drying Oven*, a mechanical convection oven maintained at a temperature of 100 ± 10°F (37.8 ± 5.5°C) and a relative humidity not to exceed 50 %.

37.4 *Desiccator*, that can be tightly sealed and of such a size as to hold at least one set of 6 cubes, containing magnesium perchlorate or calcium chloride.

38. Test Specimens

38.1 Mix sufficient sample at normal consistency to produce not less than 34 fluid oz (1000 mL) of mixed mortar and cast into six specimen molds (see 37.1). Neat gypsum plaster shall be premixed dry with two parts by weight of standard sand (see 5.2). For the quantity of water, see Sections 15 to 24, except that no retarder shall be added. The temperature of the water shall be 70 ± 2°F. Place the required amount of water in a clean 2-qt (2-L) mixing bowl. For all gypsum plasters except gypsum concrete, add the required amount of dried plaster and allow to soak for 2 min. Mix vigorously for 1 min with a metal spoon or stiff-blade spatula to produce a mortar of uniform consistency. For gypsum concrete, soak for 1 min, and stir vigorously (about

Standard Test Method for Abrasion Resistance of Concrete by Sandblasting[1]

This test method 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 This test method covers determination of the abrasion resistance characteristics of concrete by subjecting it to the impingement of air-driven silica sand. It is intended for use as a basis for the development of informed judgment.

1.2 The values stated in SI units are to be regarded as the standard except where inch-pound units are given first followed by SI units in parentheses.

1.3 *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.*

NOTE—Other procedures are available for measuring abrasion resistance of concrete surfaces in addition to subjecting it to air driven silica sand. Consideration should be given to other methods of testing as outlined in C 779 and C 944. The test method most closely representing service conditions should be used.

2. Referenced Documents

2.1 *ASTM Standards*

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2,3]

C 778 Specification for Standard Sand[3]

C 779 Test Method for Abrasion Resistance of Horizontal Concrete Surfaces[2]

C 944 Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method[2]

E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials[4]

3. Significance and Use

3.1 This test method covers the laboratory evaluation of the relative resistance of concrete surfaces to abrasion. This procedure simulates the action of waterborne abrasives and abrasives under traffic on concrete surfaces. It performs a cutting action which tends to abrade more severely the less resistant components of the concrete. Adjustments in the pressure used and the type of abrasive permit a variation in the severity of abrasion which may be used to similate other types of wear.

TABLE 1 Permissible Variations on Weights

Weight, g	Permissible Variations on Weights in Use, g
1000	± 0.50
800	± 0.35
300	± 0.30
250	± 0.25
300	± 0.20

4. Apparatus

4.1 *Scales*—The scale shall have a capacity of 5000 g or more. The permissible variation at a load of 5000 g (11 lb) shall be ±5 g (0.2 oz).

4.2 *Weights*—The permissible variations on weights used in weighing shall be as prescribed in Table 1. The permissible variations on new weights shall be one half of the values given in Table 1.

4.3 *Sand Blast Apparatus*—The sand blast apparatus shall consist of an injector-type gun. The gun shall have a high-velocity air jet fed by a suitably controlled rate of flow for the abrasive material. The nozzle shown in Fig. 1 shall consist of cold-rolled bar stock, 1½ in. (38 mm) long, or hardened tool steel HRC 48 ± 2 as determined by Test Method E 18, drilled to 0.250 ± 0.001 in. (6.35 ± 0.02 mm) through the center. The walls of the nozzle shall have a 45° bevel on the inside at the upper end. A compressed air supply of approximately 100 psi (690 kPa) shall be available and equipped with a pressure-control device. Provision shall be made to collect the spent abrasive and dust. Suitable jigs and clamps shall be provided to hold the test specimen in a fixed position with relation to the discharge end of the nozzle. For laboratory wear testing of concrete specimens a commercial sand blast cabinet may be selected similar to that shown in Fig. 2.[5]

4.4 *Shield*—The metal shield shall be made from 14 to 20 gage (1.90 to 0.91 mm) galvanized steel or similar stock at least 6 in. (152 mm) square or in diameter if circular having an opening 1.13 ± 0.01 in. (28.70 ± 0.25 mm) in diameter in the center. Opening 1.13 in. (28.7 mm) in diameter is equivalent to 1 in.^{2} or 6.45 cm^2. Suitable clamps shall be provided to hold the shield fixed on the test specimen during the test.

4.5 *Abrasive*—The abrasive shall conform to C 778 and be graded to pass a 850-μm (No. 20) sieve and retained on a 600-μm (No. 30) sieve.

5. Preparation of Specimens

5.1 Immerse the specimens in water for 24 h and then surface dry with a damp cloth to obtain a saturated, surface-dry condition at the time of test.

6. Calibration of Apparatus

6.1 Adjust the air pressure to 414 ± 1 kPa (60 ± 1 psi) and collect the abrasive for a period of 1 min. Adjust the rate of flow of abrasive to 600 ± 25 g/min.

NOTE Caution—The abrasive shall be regraded or replaced after every 60-min operating time in order to maintain a uniform grading.

A cold-rolled steel nozzle should be replaced every 60 min of operating time. A hardened tool steel nozzle should be changed as required to maintain the original uniform flow and blast pattern.

7. Procedure

7.1 Place the specimen with the surface to be tested normal to the nozzle axis and at a distance of 3 ± 0.1 in. (76 ± 2.5 mm) from the end. Clamp the specimen, with shield attached, firmly in place. Expose the surface to the blast for a period of 1 min. Repeat this on at least eight different spots on the surface. Determine the abraded volume by filling the abrasion cavities with an oil base modeling clay. Press the clay into the cavities manually with a moderate amount of finger pressure and level flush with a straight edge. Weigh the clay supply before and after the cavities are filled instead of removing the clay from the filled cavities. Repeat filling with clay at least once on each specimen to ensure reproducible results.

8. Calculation

8.1 Calculate the weight of clay, W_c, as follows

$$W_c = W_i - W_f$$

where

W_i = weight, initial supply, and

W_f = weight, final supply.

8.2 Calculate the specific gravity of clay, D, as follows

$$D = B/(B - C)$$

where:

B = weight of clay in air, g, and

C = weight of clay in water, g.

8.3 Calculate the volume of clay, V, per cavity in cubic centimetres, as follows

$$V = W/D$$

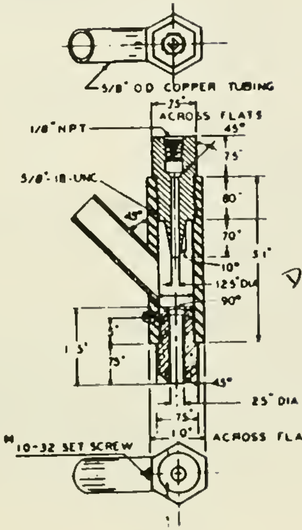

FIG. 1 Gun Nozzle Assembly

D = 2.42-2.50

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[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.03.13 on Methods of Testing Concrete for Resistance to Abrasion.

Current edition approved April 28, 1989. Published June 1989. Originally published as C 418 – 58 T. Last previous edition C 418 – 81.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

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

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

[5] A sand blast cabinet is available from CLEMCO Industries, 2177 Jerrold Ave., San Francisco, CA 94124.

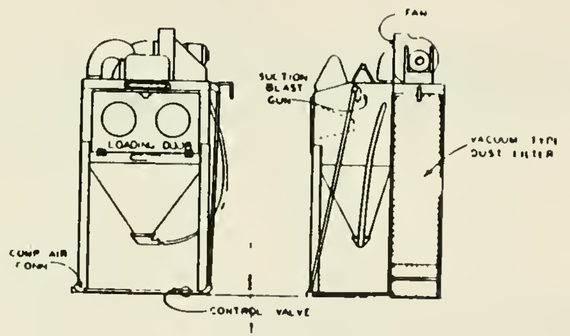

FIG. 8 Sand Blast Cabinet

where:

W = weight of clay in cavity, and

D = specific gravity of clay

8.4 Calculate the abrasion coefficient loss on a volumetric basis, expressed in cubic centimetres per square centimetre, in order to compensate for variable densities of specimens, as follows:

$$A_c = V/A$$

where

A_c = abrasion coefficient, cubic centimetres per square centimetre, and

A = area of surface abraded, square centimetres

9. Report

9.1 Report the following information:

9.2 Report the abrasion coefficient loss to the nearest 0.01 cm^3/cm^2.

10. Precision and Bias

10.1 On a limited sampling (Note 2), the single-operator coefficient of variation has been found to be 9.1 %.[*] Therefore, results of two properly conducted tests by the same operator on the same material using the same equipment should not differ by more than 25.8 %[*] of their average.

10.2 On a limited sampling (Note 2), the multi-operator coefficient of variation has been found to be 10.3 %.[*] Therefore, results of two properly conducted tests by two operators on the same material using the same equipment should not differ from each other by more than 29.1 %[*] of their average.

NOTE 2—The data, on file at ASTM Headquarters, and expected to be published involve two operators performing the tests on samples made from the same batch and repeated on another day. Two concrete mixtures having different expected abrasion resistance were also used. The tests were conducted in one laboratory using the same equipment. As more laboratories become more equipped and capable of performing the test, a more detailed interlaboratory test program will be conducted.

10.3 Since there is no acceptable reference material suitable for determining bias for the procedure in this test method, no statement of bias is being made.

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[*] These numbers represent, respectively, the (1S %) and (D2S %) limits as described in Practice C 670 for Preparing Precision and Bias Statements for Test Methods for Construction Materials.

American Association State
Highway and Transportation Officials Standard
AASHTO No.: T 132

Standard Test Method for Tensile Strength of Hydraulic Cement Mortars[1]

The committee responsible for this standard has voted its withdrawal. In the absence of substantial reasons that it should be continued the Society will approve withdrawal from publication in October 1991.

1. Scope

1.1 This test method covers the determination of the tensile strength of hydraulic cement mortars employing the briquet specimen. It is primarily for use by those interested in research on methods for determining tensile strength of hydraulic cement.

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 whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 150 Specification for Portland Cement[2]

C 184 Test Method for Fineness of Hydraulic Cement by the 150-µm (No. 100) and 75-µm (No. 200) Sieves[2]

C 187 Test Method for Normal Consistency of Hydraulic Cement[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 778 Specification for Standard Sand[2]

C 1005 Specification for Weights and Weighing Devices for Use in the Physical Testing of Hydraulic Cements[2]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[3]

3. Significance and Use

3.1 Researchers in the field of hydraulic cement have recognized the need for improved tensile strength. This test method allows for the determination of tensile strength of a hydraulic cement mortar by casting and testing briquet specimens. It is recommended that the tester be familiar with this test method in order to obtain the best possible accuracy and precision.

3.2 Table 2 contains minimum tensile strength values which were stated limits in Specification C 150 - 68.[2] The user of this test method may be interested in comparing research results with these values when briquets composed of 1 part cement to 3 parts standard sand have been made. These values may not be appropriate for comparison when different proportions, or proportions involving other than standard sand, have been used.

4. Apparatus

4.1 *Weights and Weighing Devices*—The weights and weighing devices shall conform to the requirements of Specification C 1005. The weighing device shall be evaluated for precision and accuracy at a total load of 1000 g or at 2000 g, as applicable.

4.2 *Sieves*—Square-hole, woven wire cloth, No. 20 (850-µm) and No. 30 (600-µm) sieves conforming to Specification E 11 shall be used.

4.3 *Glass Graduates*—Glass graduates of suitable capacities (preferably large enough to measure the mixing water in a single operation) shall be made to deliver the indicated volume at 68°F (20°C). The permissible variation shall be ±1.0 mL. These graduates shall be subdivided to at least 1 mL, except that the graduation lines may be omitted for the lowest 5 mL for 100 and 150-mL graduates and for the lowest 10 mL for a 200-mL graduate. The main graduation lines shall be circles and shall be numbered. The least graduations shall extend at least one seventh of the way around the cylinder, and intermediate graduations shall extend at least one fifth of the way around.

4.4 *Briquet Molds*—The molds for making test specimens shall be made of metal not attacked by the cement mortar, and shall have sufficient material in the sides to prevent spreading during molding. Gang molds, when used, shall be of the type shown in Fig. 1. The dimensions of the briquet molds shall conform to the following requirements: width of mold, between inside faces, at waist line of briquet, 1 in. (25 mm) with permissible variations of ±0.01 in. (0.25 mm) for molds in use and ±0.005 in. (0.13 mm) for new molds; thickness of molds measured at the point of greatest thickness on either side of the mold at the waist line, 1 in. with permissible variations of +0.004 in. (0.10 mm) and −0.002 in. (0.05 mm) for new molds and −0.02 in. (0.5 mm) for molds in use. The briquet test specimens shall conform to the dimensional requirements shown in Fig. 2.

4.5 *Trowel*—The trowel shall be of a convenient size and have a steel blade 4 to 6 in. (100 to 150 mm) long.

4.6 *Testing Machine*—The testing machine shall be capable of applying the load continuously at a rate of 600 ± 25 lbf (2.67 ± 0.11 kN)/min, with provision for adjustments of the rate of loading. The requirements for accuracy of the testing machine shall be as follows. The error for loads of not less than 100 lbf (445 N) shall not exceed ±1.0 % for a new machine, or ±1.5 % for a used machine. The testing machine shall be calibrated frequently in order to determine its accuracy.

Note 1—For instructions relating to the manner and frequency of calibration of the testing machine, see Section 40 of the Manual of Cement Testing.[3]

4.7 *Clips*—The clips for holding the tension test specimens shall be in accordance with Fig. 3.

5. Standard Sand

5.1 The sand used for making test specimens (see 8.1) shall be natural silica sand conforming to the requirements for 20–30 standard sand as described in Specification C 778.

6. Temperature and Humidity

6.1 The temperature of the air in the vicinity of the mixing slab, the dry materials, molds, and base plates shall be maintained between 68 and 81.5°F (20 and 27.5°C). The temperature of the mixing water, moist closet or moist room, and water in the briquet storage tank shall not vary from 73.4°F (23°C) by more than ±3°F (1.7°C).

6.2 The relative humidity of the laboratory shall not be less than 50 %. The moist closet or moist room shall be so constructed as to provide storage facilities for test specimens at a relative humidity of not less than 95 %.

7. Number of Briquets

7.1 Three or more briquets shall be made for each period of test specified.

8. Procedure

8.1 *Proportioning, Consistency, and Mixing of Mortars*:

8.1.1 The proportions of the standard mortar shall be 1 part cement to 3 parts standard sand by weight. The quantities of dry materials to be mixed at one time in the batch of mortar shall be not less than 1000 g nor more than 1200 g for making six briquets and not less than 1500 g nor more than 1800 g for making nine briquets. The percentage of water used in the standard mortar shall depend upon the percentage of water required to produce a neat cement paste of normal consistency from the same sample of cement and shall be as indicated in Table 1, the values being in percentage of the combined dry weights of the cement and standard sand. Determine the percentage of water required to produce a neat cement paste of normal consistency in accordance with Test Method C 187.

Note 2—Other proportions involving the use of graded sand, silica flour, or other similar materials may also be used to develop meaningful research information.

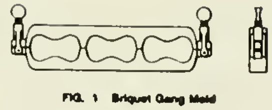
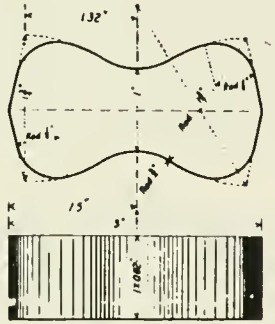


FIG. 1 Briquet Gang Mold



NOTE—1 in. = 25.4 mm

FIG. 2 Briquet Specimen for Tensile Strength Test

TABLE 1 Percentage of Water for Standard Mortars

Water for Neat Cement Paste of Normal Consistency, %	Water for Mortar of One Part Cement to Three Parts Standard Sand, %[A]
15	9.0
16	9.2
17	9.3
18	9.5
19	9.7
20	9.8
21	10.0
22	10.2
23	10.3
24	10.5
25	10.7
26	10.8
27	11.0
28	11.2
29	11.3
30	11.5

[A] When the proportions of cement to sand are other than one to three by weight, the amount of mixing water shall be calculated from the following formula upon which Table 1 is based:

$$y = \frac{2}{3}\left[\frac{P}{(n+1)}\right] + K$$

where

y = water required for the sand mortar, %,
P = water required for neat cement paste of normal consistency, %,
n = number of parts of sand to one of cement by weight, and
K = a constant which for the standard sand has the value 6.5.

TABLE 2 Tensile Strength[A]

	Cement Type				
	I	II	III	IV	V
1 day in moist air, psi (kPa)			275 (1896)		
1 day in moist air, 2 days in water, psi (kPa)	150 (1034)	125 (862)	375 (2586)		
1 day in moist air, 6 days in water, psi (kPa)	275 (1896)	250 (1724)		175 (1207)	250 (1724)
1 day in moist air, 27 days in water, psi (kPa)	350 (2413)	325 (2241)		300 (2068)	325 (2241)

[A] Taken from Specification C 150 - 58 without change.

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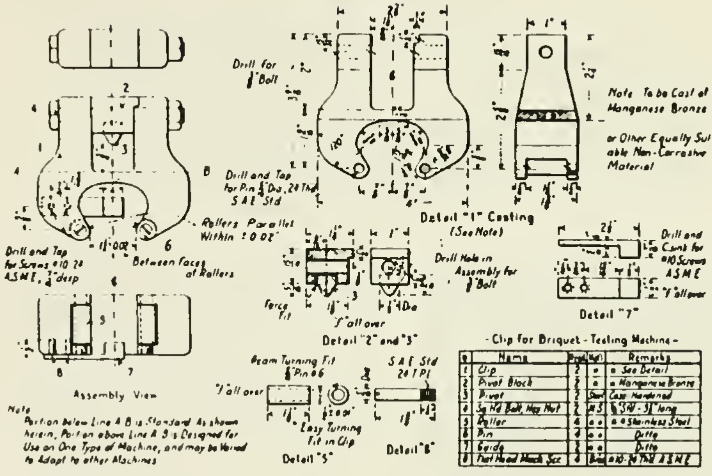
[1] This test method is under the jurisdiction of ASTM Committee C-1 on Cement and is the direct responsibility of Subcommittee C01.27 on Strength.

Current edition approved June 28, 1985. Published August 1985. Originally published as C 190 - 44 T. Last previous edition C 190 - 82.

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

[3] *Annual Book of ASTM Standards*, Vol 14.02.



NOTE—1 in. = 25.4 mm

FIG. 3 Clips for Briquet Testing Machine

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8.1.2 Weigh the dry materials, place them upon a smooth nonabsorbent surface, thoroughly mix dry, and form a crater in the center. Pour the proper percentage of clean water into the crater, and turn the material on the outer edge into the crater within 30 s by the aid of a trowel. After an additional interval of 30 s for the absorption of the water, during which interval lightly trowel the dry mortar around the outside of the cone over the remaining mortar to reduce the evaporation losses and to promote absorption, complete the operation by continuous, vigorous mixing, squeezing, and kneading with the hands for 1½ min. During the operation of mixing, protect the hands with snug-fitting rubber gloves.

8.2 *Molding Test Specimens*

8.2.1 Before being filled, thinly cover the molds with a film of mineral oil. Immediately following completion of mixing the mortar, and with the molds resting on unoiled glass or metal plates, fill the molds heaping full without compacting. Then press the mortar in firmly with the thumbs, applying the force 12 times to each briquet, at points to include the entire surface. The force shall be such that the simultaneous application of both thumbs will register a force of 15 to 20 lbf (67 to 89 N). Maintain each application of the thumbs not longer than sufficient to attain the specified force. Then heap the mortar above the mold and smooth it off with a trowel. Draw the trowel over the mold in such a manner as to exert a force of not more than 4 lbf (17.8 N). Cover the mold with a plane glass or metal plate oiled with mineral oil, and turn over the mold and plates (held together with the hands) rotating the mold about its longitudinal axis. Remove the top plate and repeat the operation of heaping, thumbing, and smoothing off. Use no ramming or tamping, nor any troweling in excess of that required to smooth off the specimen.

8.3 *Storage of Test Specimens*

8.3.1 Keep all test specimens, immediately after molding, in the molds on the base plates in the moist closet or moist room for from 20 to 24 h with their upper surfaces exposed to the moist air but protected from dripping water. If removed from the molds before 24 h, keep them on the shelves of the moist closet or moist room until they are 24 h old, then immerse the specimens, except those for the 24-h test, in saturated lime water in storage tanks constructed of noncorroding materials. Keep the storage water clean by changing as required.

8.4 *Determination of Tensile Strength*

8.4.1 Test the briquet specimens immediately after their removal from the moist closet for 24-h specimens, and from storage water for all other specimens. Break all test specimens for a given test age within the permissible tolerance prescribed in the following table:

Test Age	Permissible Tolerance
24 h	±½ h
3 days	±1 h
7 days	±3 h
28 days	±12 h

If more than one specimen at a time is removed from the moist closet for the 24-h tests, cover these briquets with a damp cloth until time of testing. If more than one specimen at a time is removed from the storage water for testing, place these briquets in a pan of water at a temperature of 73.4 ± 3°F (23 ± 1.7°C) and of sufficient depth to completely immerse each briquet until time of testing.

8.4.2 Wipe each briquet to a surface-dry condition, and remove any loose sand grains or incrustations from the surfaces that will be in contact with the clips of the testing machine. The bearing surfaces of the clips shall be clean and free of sand, and the roller bearings shall be well oiled and maintained so as to ensure freedom of turning. Keep the stirrups supporting the clips free of accumulations, and keep the pivots in proper adjustment so that the clips may swing freely on the pivots without binding in the stirrups. Carefully center the briquets in the clips and apply the load continuously at the rate of 600 ± 25 lbf (2.67 ± 0.11 kN)/min.

9. Faulty Briquets and Retests

9.1 Briquets that are manifestly faulty, or that give strengths differing by more than 15 % from the average value of all test briquets made from the same sample and tested at the same period, shall not be considered in determining the tensile strength (Note 3). After discarding briquets or strength values, if less than two strength values are left for determining the tensile strength at any given period, a retest shall be made.

NOTE 3—Reliable strength results depend upon careful observance of all of the specified requirements and procedures. Erratic results at a given test period indicate that some of the requirements and procedures have not been carefully observed, for example, those covering the testing of the briquets, as prescribed in 8.4.2.

10. Calculation

10.1 Record the total maximum load indicated by the testing machine and calculate the tensile strength in pounds-force per square inch or kilopascals. If the cross-sectional area of a briquet varies more than 2.0 % from the nominal, use the actual area for the calculation of the tensile strength. The tensile strength of all acceptable test briquets (see Section 9) made from the same sample and tested at the same period shall be averaged and reported to the nearest 5 psi (34.5 kPa).

11. Precision and Bias

11.1 The following precision statements are applicable when a test result is the average of tensile strength tests of three briquettes molded from a single batch of mortar tested at the same age. It is applicable to mortar made with Type I, IA, II, or III cement tested at 3 or 7 days (1 and 3 days for Type III cement) (Note 4).

NOTE 4—The appropriate limits are likely somewhat smaller at 1 day and larger at ages greater than 7 days.

11.1.1 *Multilaboratory Precision*—The multilaboratory standard deviation has been found to be 32 psi (220.6 kPa). Therefore the results of properly conducted tests of a single batch by two different laboratories should not differ from each other by more than 90 psi (620.5 kPa) (Note 5).

NOTE 5—These numbers represent, respectively, the (1S) and (D2S) limits as described in Practice C 670.

11.1.2 *Single-Laboratory Precision*—The single-laboratory standard deviation has been found to be 21 psi (144.7 kPa). Therefore the results of two properly conducted tests of single batches of mortar made with the same materials either on the same day or within the same week should not differ from each other by more than 59 psi (406.7 kPa) (Note 5).

For additional useful information on details of cement test methods, reference may be made to the "Manual of Cement Testing," *Annual Book of ASTM Standards*, **Vol 04.01.**

Standard Test Method for
Tensile Strength of Chemical-Resistant Mortar, Grouts, and Monolithic Surfacings[1]

This standard is issued under the fixed designation C 307; 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 test method 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.

ε1 Note—Section 1.2 was added editorially in April 1988.

1. Scope

1.1 This test method covers the determination of tensile strength of chemical-resistant mortars, grouts, and monolithic surfacings.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *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 904 Definitions of Terms Relating to Chemical-Resistant Nonmetallic Materials[2]

E 4 Practice for Load Verification of Testing Machines[3]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this Test Method, see Definitions C 904.

4. Significance and Use

4.1 It is recognized that chemical-resistant mortars, grouts, and monolithic surfacings are not usually under tension when in service, however, such data is useful for purposes of determining the rate of cure and other properties.

5. Apparatus

5.1 *Scales* used in weighing materials for mixes shall conform to the following requirements: The permissible variation at a load of 1000 g shall be ±1.0 g, at a load of 1500 g it shall be ±2.0 g.

5.2 *Weights*—The permissible variations on weights used in weighing materials shall be as described in Table 1.

5.3 *Briquet Molds*—The molds for making test specimen shall be made of metal not attacked by the materials and shall have sufficient material in the sides to preven spreading during molding. Gang molds, when used, shall b of the type shown in Fig. 1. The dimensions of the briqu molds shall be the width of the mold, between inside faces, a waist line of briquet, 1 in. (25 mm) with permissib variations of ±0.01 in. (±0.25 mm); the thickness of th molds measured at the point of greatest thickness of eith side of the mold at the waist line, 1 in. with permissib variations of +0.004 in. (±0.10 mm) and −0.002 in. (−0.0 mm). The briquet test specimens shall conform to th dimensional requirements shown in Fig. 2.

5.4 *Equipment for Mixing Materials*, consisting of container of suitable size, preferably made of noncorrodib metal, or a porcelain enameled pan, and a strong, sturd spatula or trowel.

5.5 *Equipment for Melting Sulfur Mortar*, consisting of container of suitable size, preferably made of noncorrodib metal, and a heater for melting the sulfur mortar. Al required is a laboratory mixer capable of operating at a spe sufficient to lift the aggregate but without beating air into th melt.

5.6 *Testing Machine*, universal-type, in which the load applied hydraulically, mechanically, or electromechanicall at a constant but adjustable rate of crosshead moveme The machine shall conform to Practice E 4.

5.7 *Tension Clips*, for holding the tension test specime shall be in accordance with Fig. 3.

6. Temperature

6.1 The temperature in the vicinity of the mixing ope tion shall be 73 ± 4°F (23 ± 2°C), unless otherwise specifi by the manufacturer. The actual temperature shall b reported.

7. Test Specimens

7.1 The briquet test specimens shall conform to th dimensional requirements shown in Fig. 2. Six specime shall be prepared for each test period.

8. Preparation of Mortar, Grout, and Monolithic Surfaci

8.1 *Resin Mortar, Grout, and Monolithic Surfacings*:

TABLE 1 Permissible Variations on Weights

Weight, g	Permissible Variations on Weights in Use, plus or minus, g
1000	0.50
900	0.45
750	0.40
500	0.35
300	0.30
250	0.25
200	0.20
100	0.15
50	0.10
20	0.05
10	0.04
5	0.03
2	0.02
1	0.01

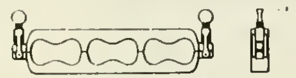

FIG. 1 Briquet Gang Mold

8.1.1 Mix the materials in the proper proportions and in the manner specified by the manufacturer of the materials. If the proportions specified are by volume, weigh the materials and report the corresponding proportions by weight. Record the time required for mixing.

8.1.2 Mix at least 1000 g of mortar, from which the six briquet test specimens are prepared, assuming that the mortar density is not greater than 2.0. Larger batches will be required if the density of the mortar appreciably exceeds 2.0 g/cm³.

8.2 *Sulfur Mortar*—If the sulfur mortar is furnished in the form of ingots or lumps, use at least one entire piece and a minimum of 1000 g for the sample. Melt the sample within 1 h and hold the temperature at 265 to 290°F (130 to 143°C) for at least 15 min while stirring with a laboratory-type mixer. Cast all test specimens from this sample.

8.3 *Silicate and Silica Materials*—Follow the same procedure described in 8.1.

9. Molding Test Specimens

9.1 *Resin Mortars, Grouts, and Monolithic Surfacings*:

9.1.1 Prior to filling, give the molds a thin coat of suitable material, such as silicon grease, to prevent sticking of the mortar to the metal of the mold. Various materials may be used, provided they do not interfere with the setting of the mortar and do not materially change the dimensions of the mold.

9.1.2 Fill molds with the mortar prepared in accordance with 8.1, taking care to prevent entrapment of air which could cause void spaces. Strike the mortar off evenly with a spatula.

9.2 *Sulfur Mortars*—Cover the waist of the mold with a small lubricated plate. Pour the molten sulfur mortar into both sides of the mold and puddle it to completely fill the space under the plate. Allow the plate, placed across the center of the mold, to remain in place for at least 15 min after the briquet has been poured.

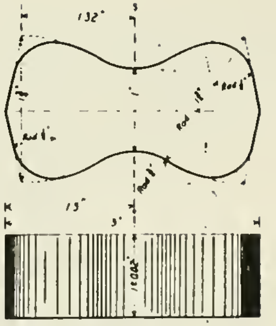

FIG. 2 Briquet Specimens for Tensile Strength Test

9.3 *Silicate and Silica Materials*—Follow the same procedure described in 9.1.

10. Conditioning

10.1 *Resin Mortars, Grouts, and Monolithic Surfacings*—Allow the test specimens to remain in their respective molds for a period of 18 to 24 h after molding. Age the specimens for a period of at least 6 additional days at 73 ± 4°F (23 ± 2°C).

10.2 *Sulfur Mortars*—Allow the test specimens to cool until all of the mortar has completely solidified. After removal from the molds, remove all rough edges from the surface of the briquet that will come in contact with tension testing apparatus. Age the specimens for a total of 48 h (after pouring) at 73 ± 4°F (23 ± 2°C).

10.3 *Silicate and Silica Materials*:

10.3.1 *Silicate Materials*—After removal from the mold, acid treat the specimens in strict accordance with the manufacturer's recommendations. Record the method of acid treatment. If not required, so record. Age the specimens for a period of 7 days in air at 73 ± 4°F (23 ± 2°C) and at a relative humidity not exceeding 80%, the seven days to include the time in the mold.

10.3.2 *Silica Materials*—Age the cast specimens for a period of seven days in air at 73 ± 4°F (23 ± 2°C), the 7 days to include time in the mold.

10.4 Age the specimens, supported in such a manner that air circulates on all sides, at a temperature of 73 ± 4°F (23 ± 2°C) and at a maximum relative humidity of 80% until tested. Protect all specimens from contact with water until tested.

11. Procedure

11.1 *Resin Mortar, Grouts, and Monolithic Surfacings*—Test the specimens on the seventh day after casting. If desired, the conditioning time may be changed to establish the age-strength relationship. Report the age of the specimens.

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[1] This test method is under the jurisdiction of ASTM Committee C-3 on Chemical-Resistant Nonmetallic Materials and is the direct responsibility of Subcommittee C03.01 on Test Methods.

Current edition approved Sept. 30, 1983. Published February 1984. Originally published as C 307 – 53 T. Last previous edition C 307 – 77.

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

[3] Annual Book of ASTM Standards, Vol 03.01.

150 complete circular strokes per minute) with a large spoon for 3 min Setting time of the mortar, as determined by Sections 24, 25, and 29, shall be within the time limits shown in Table 1. If setting time is in excess of the maximum limit, the cubes shall be discarded, and the next mix shall be adjusted by adding freshly ground gypsum accelerator to the plaster, except for Keene's cement, to which molding plaster shall be added to reduce setting time within the limits shown. The amount of gypsum accelerator or molding plaster used to accelerate the setting time shall not exceed 1 % of the weight of the plaster or Keene's cement

38.2 Coat the molds with a thin film of mineral oil or other mold release agent and place on an oiled glass or metal plate Place a layer of mortar about 1 in (25 mm) in depth in each mold and puddle ten times across the mold between each pair of opposite faces with a 1 in (25 mm) wide spatula to remove air bubbles Fill the molds to a point slightly above the tops of the molds, by the same filling and puddling procedure used for the first layer Also fill the conical mold for the Vicat apparatus described in 26.1 and 26.2 and determine the time of setting (see Section 27) As soon as the mortar or paste has set, cut off the excess to a plane surface flush with the top of the mold, using a stiff broad knife or similar implement Place the filled molds in moist air (90 to 100 % relative humidity) The cubes may be removed from the molds as soon as thoroughly hardened, but must be retained in the moist air not less than a total of 16 h Place the cubes in an oven as specified in 37.1 Dry the cubes to constant weight as determined by weighing once each day, but do not dry longer than 7 days Then place the cubes in a desiccator as described in 37.4 for a minimum of 16 h before testing Test the cubes immediately on removal from the desiccator

TABLE 1 Setting-Time Limits for Mortar

Kind of Material	Setting Time, min	
		max
Molding plaster	[illegible]	140
Keene's cement		
Standard	40	120
Quick set	20	40
Gypsum concrete	20	40
Ready mixed plaster	90	120
Neat plaster (with 2 parts sand)	120	150
Wood fibered plaster	90	120
Bond plaster	120	150
Gauging plaster		
Slow set	40	120
Quick set	20	40
Veneer plaster	30	90

39. Procedure

39.1 As soon as the cube specimens have been dried (Section 38), determine their compressive strengths. Position the cubes in the testing machine so that the load is applied on surfaces formed by faces of the molds, not on top and bottom Apply the load continuously and without shock, at a constant rate within the range 15 to 40 psi (103 to 276 kPa)/s During application of the first half of the maximum load a higher rate of loading shall be permitted.

40. Report

40.1 Report the average compressive strength as the compressive strength of the material, except that if the strengths of one or two of the cubes vary more than 15 % from the average of the six, discard them and report the compressive strength as the average of the remaining specimens In case the compressive strengths of three or more cubes vary more than 15 % from the average, discard the results and repeat the test

41. Precision and Bias

41.1 The precision and bias for the compressive strength test method have not been determined.

DENSITY

42. Significance and Use

42.1 This test method is used to determine the density of cast gypsum concrete and is used to determine compliance with the specification for gypsum concrete The correlation between this test method and service performance has not been determined

43. Apparatus

43.1 *Balance*, capable of weighing at least 1500 g (3.3 lb) to the nearest gram (0.002 lb)

44. Procedure

44.1 Determine the density of gypsum concrete by weighing the six cubes in grams to the nearest gram or in pounds to the nearest 0.002 lb after drying and cooling, as described in 38.2, and before determining the compressive strength

45. Report

45.1 Report the density in pounds per cubic foot calculated by multiplying the total weight of the six cubes in grams by 0.0794 or the total weight in pounds by 36.0

46. Precision and Bias

46.1 The precision and bias for the density test method have not been determined

APPENDIX

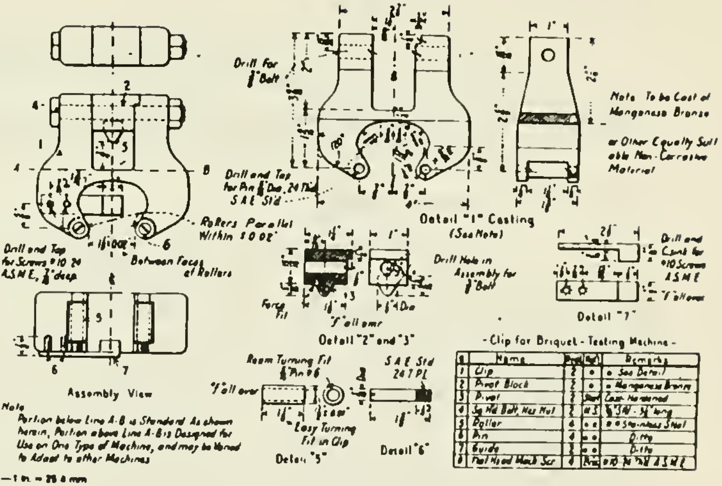
(Nonmandatory Information)

X1. ALCOHOL WASH METHOD OF SIEVING GYPSUM AND GYPSUM PRODUCTS

X1.1 It is impracticable to sieve dry gypsum through a No 325 (45-μm) sieve, and water cannot be used as a washing agent without introducing errors due to hydration or solution

X1.2 Use isopropyl alcohol (99 %) as the washing agent (see X1.2.1). Place the alcohol in a vessel 1 to 2 in. (25.4 to 50.8 mm) larger in diameter than the sieve, to a depth above 2 in Place 50 ± 0.01 g of the sample on a No. 325 (45-μm) sieve or, if desired, a coarser sieve up to and including the No. 100 (150-μm) sieve Lower the sieve into the alcohol until the sample is wetted throughout. Lift the sieve out of the alcohol, with a swirling motion, permitting the alcohol to drain through the sample back into the vessel Repeat this operation at least eight times, until the alcohol passes freely through the sieve and the sample is essentially free from fines. Wash the residue retained on the sieve with about 100 mL of clear alcohol, and then blot the bottom of the sieve with a soft, dry, lint-free cloth. Dry the sieve with the residue at 100 to 125°F (38 to 53°C) Shake the sieve on mechanical shaker (Ro-Tap or equivalent) for 2 min ± 1 Weigh the material retained on the sieve Multiply by 2 weight of material retained after shaking in order to ob percentage of the original sample If desired, to per simultaneous determinations of coarser fractions, the resi after drying and before shaking may be transferred to a se of coarser sieves up to and including the No. 100, nested sequential order above the No 325 sieve The alcohol m be reused after decanting or filtering, provided its stren does not fall below 95 %

X1.2.1 Caution—When using isopropyl alcohol, keep away, provide good ventilation, and avoid excessive inha tion of vapor



NOTE—1 in. = 25.4 mm

FIG. 3 Clips for Briquet Testing Machines

11.2 *Sulfur Mortars*—Test the specimens after 48 h of conditioning. Report the age of the specimens.

11.3 *Silicate and Silica Material*, in accordance with 11.1.

11.4 Measure height of test specimen to nearest 0.001 in.; width at waist (1 in.) to ±0.05 in.; and length (3 in.) to ± 0.05 in. Place the specimens and center them carefully in the clips of the testing machine. Pull the specimens at a rate of 0.20 to 0.25 in./min (5 to 6.4 mm/min) of crosshead movement (speed of movement when the machine is running without a load).

12. Report

12.1 Report the following information:

12.1.1 Manufacturer's name of material and generic

12.1.2 Mixing ratio by weight,

12.1.3 Conditioning procedure, and

12.1.4 The average tensile strength in pounds per sq inch (or MPa) of six specimens.

13. Precision and Bias

13.1 *Repeatability*—Duplicate results by the same o ator shall be considered suspect if they differ by more 15 % of the mean value of the two results.

TABLE 1 *Continued*

Distribution cycle 11	Rail, TOFC and COFC					
Test type	Handling	Vehicle stacking	Rail switching	Stacked vibration	Loose-load vibration	Handling
Element	A or B	D	H	E	F	A or B
Distribution cycle 12	Air (intercity) and motor freight (local), over 100 lb, unitized or palletized					
Test type	Handling	Vehicle stacking	Stacked vibration	Vehicle vibration	Handling	
Element	A or B	D	E	O	A or B	
Distribution cycle 13	Air (intercity) and motor freight (local), single package up to 100 lb (45.4 kg)					
Sequence	1	2	3	4	5	
Test type	Manual handling	Vehicle stacking	Loose-load vibration	Vehicle vibration	Manual handling	
Element	A	D	F	O	A	
Distribution cycle 14	Warehousing (partial cycle to be added to other cycles as needed)					
Test type	Handling	Warehouse stacking				
Element	A or B	C				

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.

Designation: E 96 - 80

Standard Test Methods for
WATER VAPOR TRANSMISSION OF MATERIALS[1]

This standard is issued under the fixed designation E 96; 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.

1. Scope

1.1 These methods cover the determination of water vapor transmission (WVT) of materials through which the passage of water vapor may be of importance, such as paper, plastic films, other sheet materials, fiberboards, gypsum and plaster products, wood products, and plastics. The methods are limited to specimens not over 1¼ in. (32 mm) in thickness except as provided in Section 9. Two basic methods, the Desiccant Method and the Water Method, are provided for the measurement of permeance, and two variations include service conditions with one side wetted and service conditions with low humidity on one side and high humidity on the other. Agreement should not be expected between results obtained by different methods. That method should be selected which more nearly approaches the conditions of use.

1.2 The values stated in inch-pound units are to be regarded as the standard. Metric inch-pound conversion factors for WVT, permeance, and permeability are stated in Table 1. All conversions of mm Hg to Pa are made at a temperature of 0°C.

2. Applicable Documents

2.1 *ASTM Standards:*

C 168 Definitions of Terms Relating to Thermal Insulating Materials[2]

C 677 Recommended Practice for Use of a Standard Reference Sheet for the Measurement of the Time-Averaged Vapor Pressure in a Controlled Humidity Space[2]

D 449 Specification for Asphalt in Dampproofing and Waterproofing[3]

D 2301 Specification for Vinyl Chloride Plastic Pressure-Sensitive Electrical Insulating Tape[4]

3. Summary of Methods

3.1 In the Desiccant Method the test specimen is sealed to the open mouth of a test dish containing a desiccant, and the assembly placed in a controlled atmosphere. Periodic weighings determine the rate of water vapor movement through the specimen into the desiccant.

3.2 In the Water Method, the dish contains distilled water, and the weighings determine the rate of vapor movement through the specimen from the water to the controlled atmosphere. The vapor pressure difference is nominally the same in both methods except in the variation, with extremes of humidity on opposite sides.

4. Significance and Use

4.1 The purpose of these tests is to obtain, by means of simple apparatus, reliable values of water vapor transfer through permeable and semipermeable materials, expressed in suitable units. These values are for use in design, manufacture, and marketing. A permeance value obtained under one set of test conditions may not indicate the value under a different set of conditions. For this reason, the test conditions should be selected that most closely approach

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[1] These methods are under the jurisdiction of ASTM Committee C-16 on Thermal Insulation and are the direct responsibility of Subcommittee C16.33 on Thermal Insulation Finishes and Vapor Transmission.

Current edition approved Oct. 31, 1980. Published February 1981. Originally published as E 96 – 53 T. Last previous edition E 96 – 66 (1972).

[2] *1982 Annual Book of ASTM Standards*, Part 18.

[3] *1983 Annual Book of ASTM Standards*, Vol 04.04.

[4] *1982 Annual Book of ASTM Standards*, Part 40.

the conditions of use. While any set of conditions may be used and those conditions reported, standard conditions that have been useful are shown in Appendix X1.

5. Terminology

5.1 Definitions of terms used in this standard will be found in Definitions C 168, from which the following are quoted.

"*water vapor permeability*—the time rate of water vapor transmission through unit area of flat material of unit thickness induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions."

NOTE—Permeability is a property of a material, but the permeability of a body that performs like a material may be used. Permeability is the arithmetic product of permeance and thickness.

"*water vapor permeance*—the time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions."

NOTE—Permeance is a performance evaluation and not a property of a material.

"*water vapor transmission rate*—the steady water vapor flow in unit time through unit area of a body, normal to specific parallel surfaces, under specific conditions of temperature and humidity at each surface."

6. Apparatus

6.1 *Test Dish*—The test dish shall be of any noncorroding material, impermeable to water or water vapor. It may be of any shape. Light weight is desirable. A large, shallow dish is preferred, but its size and weight are limited when an analytical balance is chosen to detect small weight changes. The mouth of the dish shall be as large as practical and at least 4.65 in.^{2} (3000 mm^2). The desiccant or water area shall be not less than the mouth area except if a grid is used, as provided in 12.1, its effective area shall not exceed 10 % of the mouth area. An external flange or ledge around the mouth, to which the specimen may be attached, is useful when shrinking or warping occurs. When the specimen area is larger than the mouth area, this overlay upon the ledge is a source of error, particularly for thick specimens. This overlay material should be masked as described in 10.1 so that the mouth area defines the test area. The overlay material results in a positive error, indicating excessive water vapor transmission. The magnitude of the error is a complex function of the thickness, ledge width, mouth area, and possibly the permeability. The error is discussed by Joy and Wilson.[4] This type of error should be limited to about 10 to 12 %. For a thick specimen the ledge should not exceed ¾ in. (19 mm) for a 10-in. (254-mm) or larger mouth (square or circular) or ⅛ in. (mm) for a 5-in. (127-mm) mouth (square or circular). For a 3-in. (76-mm) mouth (square or circular) the ledge should not exceed 0.11 in. (2.8 mm) wide. An allowable ledge may be interpolated for intermediate sizes or calculated according to Joy and Wilson.[4] A rim around the ledge (Fig. X2.1) may be useful. If a rim is provided, it shall be not more than ¼ in. (mm) higher than the specimen as attached. Different depths may be used for the Desiccant Method and Water Method, but a ¾-in. (19 mm) depth (below the mouth) is satisfactory for either method.

6.2 *Test Chamber*—The room or cabinet where the assembled test dishes are to be placed shall have a controlled temperature and relative humidity. The temperature chosen shall be between 70 and 90°F (21 and 32°C), and shall be maintained constant within 1°F (0.6°C). A temperature of 90°F (32°C) is recommended (Note 1). The relative humidity shall be maintained at 50 ± 2 %, except where extremes of humidities are desired, when the conditions shall be 100 ± 1°F (38 ± 0.6°C) and 90 ± 2 % relative humidity. Both temperature and relative humidity shall be measured frequently, or preferably recorded continuously. Air shall be continuously circulated throughout the chamber, with a velocity sufficient to maintain uniform conditions at all test locations. Its velocity over the specimen, in feet per minute, shall be (numerically) not less than ten times the permeance of the specimen, in perms, but at least 50 ft/min, or in centimetres per second not less than 7.7 times the permeance, in metric perms, but at least 250 cm/s.

NOTE 1—Simple temperature control by heating [illegible] is usually made possible at 90°F (32°C). However, it is very desirable to enter the controlled space, and a comfortable temperature is more satisfactory for that arrangement. Temperatures of 73.4°F (23°C) and 80°F (26.7°C) are in use and are satisfactory for this purpose. With cyclic control, the average test temperature may be obtained from a sensitive thermometer in a mass of dry sand. The temperature of the chamber walls facing a specimen over water should not be cooler than the water to avoid condensation on the test specimen.

6.3 *Balance and Weights*—The balance shall be sensitive to a change smaller than 1 % of the weight change during the period when a steady state is considered to exist. The weights used shall be accurate to 1 % of the weight change during the steady-state period. For example: A 1-perm (5.7×10^{-11} kg·Pa^{-1}·s^{-1}·m^{-2}) specimen 10 in. (254 mm) square at 80°F (26.7°C) passes 8.6 grains or 0.56 g/day. In 18 days of steady state, the transfer is 10 g. For this usage, the balance must have a sensitivity of 1 % of 10 g or 0.1 g and the weights must be accurate to 0.1 g. If, however, the balance has a sensitivity of 0.2 g or the weights are no better than 0.2 g, the requirements of this paragraph can be met by continuing the steady state for 36 days. An analytical balance that is much more sensitive will permit more rapid results on specimens below 1 perm (5.7×10^{-11} kg·Pa^{-1}·s^{-1}·m^{-2}) when the assembled dish is not excessively heavy. A light wire sling may be substituted for the usual pan to accommodate a larger and heavier load.

7. Materials

7.1 *Desiccant and Water:*

7.1.1 For the Desiccant Method, anhydrous calcium chloride in the form of small lumps that will pass a No. 8 (2.36-mm) sieve, and free of fines that will pass a No. 30 (600-μm) sieve, shall be used (Note 2). It shall be dried at 400°F (200°C) before use.

NOTE 2—If CaCl$_2$ will react chemically on the specimen, an adsorbing desiccant such as silica gel, activated at 400°F (200°C), may be used; but the moisture gain by this desiccant during the test must be limited to 4 %.

7.1.2 For the Water Method, distilled water shall be used in the test dish.

7.2 *Sealant*—The sealant used for attaching the specimen to the dish, in order to be suitable for this purpose, must be highly resistant to the passage of water vapor (and water). It must not lose weight to, or gain weight from, the atmosphere in an amount, over the required period of time, that would affect the test result by more than 2 %. It must not affect the vapor pressure in a water-filled dish. Molten asphalt or wax is required for permeance tests below 4 perms (2.3×10^{-10} kg·Pa^{-1}·s^{-1}·m^{-2}). Sealing methods are discussed in Appendix X2.

8. Sampling

8.1 The material shall be sampled in accordance with standard methods of sampling applicable to the material under test. The sample shall be of uniform thickness. If the material is of nonsymmetrical construction, the two faces shall be designated by distinguishing marks (for example, on a one-side-coated sample, "I" for the coated side and "II" for the uncoated side).

9. Test Specimens

9.1 Test specimens shall be representative of the material tested. When a product is designed for use in only one position, three specimens shall be tested by the same method with the vapor flow in the designated direction. When the sides of a product are indistinguishable, three specimens shall be tested by the same method. When the sides of a product are different and either side may face the vapor source, four specimens shall be tested by the same method, two being tested with the vapor flow in each direction and so reported.

9.2 A slab, produced and used as a laminate (such as a foamed plastic with natural "skins") may be tested in the thickness of use. Alternatively, it may be sliced into two or more sheets, each being separately tested and so reported as provided in 9.4, provided also, that the "overlay upon the cup ledge" (6.1) of any laminate shall not exceed ⅛ in. (3 mm).

9.3 When the material as used has a pitted or textured surface, the tested thickness shall be that of use. When it is homogeneous, however, a thinner slice of the slab may be tested as provided in 9.4.

9.4 In either case (9.2 or 9.3), the tested overall thickness, if less than that of use, shall be at least five times the sum of the maximum pit depths in both its faces, and its tested permeance shall be not greater than 5 perms (3.3

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[4] Joy, F. A., and Wilson, H. G., "Standardization of a Dish Method for Measuring Water Vapor Transmission," National Research Council of Canada, Research Paper 2, January 1966, p. 263.

metric perms;

9.5 The overall thickness of each specimen shall be measured at the center of each quadrant to the nearest 0.002 in. (0.05 mm) and the results averaged.

Note 3—The time required for testing a thick specimen of low permeability is long, in many cases increasing as the square of the thickness. When testing a low-permeance material that may be expected to lose or gain weight throughout the test (because of evaporation or oxidation), it may be advisable to provide an additional specimen or "dummy" tested exactly like the others except that no desiccant or water is put in the dish. For thick hygroscopic specimens of low permeability, the time required to reach the steady state may be as long as 60 days. Other materials may reach it quickly.

10. Attachment of Specimen to Test Dish

10.1 Attach the specimen to the dish by sealing (and clamping if desired) in such a manner that the dish mouth defines the area of the specimen exposed to the vapor pressure in the dish. If necessary, mask the specimen top surface, exposed to conditioned air so that its exposure duplicates the mouth shape and size and is directly above it. A template is recommended for locating the mask. Thoroughly seal the edges of the specimen to prevent the passage of vapor into, or out of, or around the specimen edges or any portion thereof. The same assurance must apply to any part of the specimen faces outside their defined areas. Suggested methods of attachment are described in Appendix X2.

Note 4—In order to minimize the risk of condensation on the interior surface of the sample when it is placed in the chamber, the temperature of the water prior to preparation of the test specimen should be within ±2°F (±1.1°C) of the test condition.

11. Procedure for Desiccant Method

11.1 Fill the test dish with desiccant within ¼ in. (6 mm) of the specimen. Leave enough space so that shaking of the dish, which must be done at each weighing, will mix the desiccant.

11.2 Attach the specimen to the dish (see 10.1) and place it in the controlled chamber, specimen up, weighing it at once. (This weight may be helpful to an understanding of the initial moisture in the specimen.)

11.3 Weigh the dish assembly periodically, often enough to provide eight or ten data points during the test. A data point is the weight at a particular time. The time that the weighing is made should be recorded to a precision of approximately 1 % of the time span between successive weighing. Thus, if weighings are made every hour, record the time to the nearest 30 s; if recordings are made every day, a time to the nearest 15 min would be allowed. At first the weight may change rapidly; later a steady state will be reached where the rate of change is substantially constant. Weighings should be accomplished without removal of the test dishes from the controlled atmosphere, but if removal is prescribed necessary, the time the specimens are kept at different conditions, temperature or relative humidity, or both, should be kept to a minimum. Analyze the results as prescribed in 13.1.

11.4 Terminate the test or change the desiccant before the water added to the desiccant exceeds 10 % of its starting weight (Notes 1 and 4). This limit cannot be exactly determined and judgement is required. The desiccant gain may be more or less than the dish weight-gain when the moisture content of the specimen has changed.

Note 5—The WVT of some materials (especially wood) may depend on the ambient relative humidity immediately before the test. An apparent hysteresis results in higher WVT if the prior relative humidity was above the test condition and vice versa. It is therefore recommended that specimens of wood and paper products be conditioned to constant weight in a 50 % relative humidity atmosphere before they are tested. Some specimens may be advantageously preconditioned to minimize the moisture that the specimen will give up to the desiccant. This applies when the specimen is likely to have high moisture content or when it is coated on the top (vapor source) side.

12. Procedure for Water Method

12.1 Fill the test dish with distilled water to a level ¾ ± ¼ in. (19 ± 6 mm) from the specimen. The air space thus allowed has a small vapor resistance, but it is necessary in order to reduce the risk of water touching the specimen when the dish is handled. Such contact invalidates a test on some materials such as paper, wood, or other hygroscopic materials. The water depth shall be not less than ⅛ in. (3 mm) to ensure coverage of the dish bottom throughout the test. However, if the dish is of glass, its bottom must be visibly covered at all times but no specific depth is required. Water surges may be reduced in placing a grid of light noncorroding material in the dish to break the water surface. This grid shall be at least ¼ in. (6 mm) below the specimen, and it shall not reduce the water surface by more than 10 % (Note 5).

Note 6—For the Water Method, baking the empty dish and promptly coating its mouth with sealant before assembly is recommended. The water may be added most conveniently after the specimen is attached, through a small sealable hole in the dish above the water line.

12.2 Attach the specimen to the dish (see 10.1). Some specimens are likely to warp and break the seal during the test. The risk is reduced by preconditioning the specimen, and by clamping it to the dish ledge (if one is provided).

12.3 Weigh the dish assembly and place it in the controlled chamber on a true horizontal surface. Follow the procedure given in 11.3. If the test specimen cannot tolerate condensation on the surface, the dish assembly shall not be exposed to a temperature that differs by more than 5°F (2.8°C) from the control atmosphere to minimize the risk of condensation on the specimen. Analyze the results as prescribed in 13.1.

12.4 Where water is expected to be in contact with the barrier in service, proceed as in 11.3 except place the dish in an inverted position. The dish must be sufficiently level so that water covers the inner surface of the specimen despite any distortion of the specimen due to the weight of the water. With highly permeable specimens it is especially important to locate the test dish so that air circulates over the exposed surface at the specified velocity. The test dishes may be placed on the balance in the upright position for weighing, but the period during which the wetted surface of the specimen is not covered with water must be kept to a minimum.

13. Analysis of Results, Calculations

13.1 The results of the rate of water vapor transmission may be determined either graphically or numerically.

13.1.1 *Graphic Analysis*—Plot the weight against elapsed time, and inscribe a curve which tends to become straight. Judgment here is required and numerous points are helpful. When a straight line adequately fits the plot of at least six properly spaced points, with due allowance for scale sensitivity, a nominally steady state exists (Note 3), and the slope of the straight line is the rate of water vapor transmission.

13.1.2 *Numerical Analysis*—A mathematical least squares regression analysis of the weight as a function of time will give the rate of water vapor transmission. An uncertainty, or standard deviation of this rate, can also be calculated to define the confidence band. For very low permeability materials, this method can be used to determine the results after 30 to 60 days when using an analytical balance, with a sensitivity of ±1 mg, even if the weight change does not meet the 100 times the sensitivity requirement of 6.3. Specimens analyzed in this manner must be clearly identified in the report.

13.2 Calculate the water vapor transmission, WVT, and permeance as follows.

13.2.1 *Water Vapor Transmission*:

$$\text{WVT} = G/tA = (G/t)/A$$

where:

In inch-pound units:

G = weight change, grains (from the straight line),

t = time during which G occurred, h,

G/t = slope of the straight line, grains/h,

A = test area (cup mouth area), ft², and

WVT = rate of water vapor transmission, grains/h·ft²

In metric units:

G = weight change (from the straight line), g,

t = time, h,

G/t = slope of the straight line, g·h⁻¹·m⁻²,

A = test area (cup mouth area), m², and

WVT = rate of water vapor transmission, g·h⁻¹·m⁻².

13.2.2 *Permeance*:

$$\text{Permeance} = \text{WVT}/\Delta p = \text{WVT}/S(R_1 - R_2)$$

where:

In inch-pound units:

Δp = vapor pressure difference, in. Hg,

S = saturation vapor pressure at test temperature, in. Hg,

R_1 = relative humidity at the source expressed as a fraction (the test chamber for desiccant method; in the dish for water method), and

R_2 = relative humidity at the vapor sink expressed as a fraction

In metric units

Δp = vapor pressure difference, mm Hg (1.333×10^2 Pa),

S = saturation vapor pressure at test temperature, mm Hg (1.333×10^2 Pa),

R_1 = relative humidity at the source expressed as a fraction (the test chamber for desiccant method, in the dish for water method), and

R_2 = relative humidity at the vapor sink expressed as a fraction.

13.2.3 In the controlled chamber the relative humidity and temperature are the average values actually measured during the test and (unless continuously recorded) these measurements shall be made as frequently as the weight measurements. In the dish the relative humidity is nominally 0 % for the desiccant and 100 % for the water. These values are usually within 3 % relative humidity of the actual relative humidity for specimens below 4 perms (2.3×10^{-10} kg·Pa^{-1}·s^{-1}·m^{-1}) when the required conditions are maintained (no more than 10 % moisture in $CaCl_2$ and no more than 1 in. (25 mm) air sp. c above water).

13.3 Only when the test specimen is homogeneous (not laminated) and not less than ½ in. (12.5 mm) thick, calculate its average permeability (perm in.) (metric perm-cm) as follows:

Average permeability = permeance × thickness

NOTE 7 *Example*—In a desiccant test that ran 288 h (12 days) on an exposed area of 100 in.² (0.0645 m²) it was found that the rate of gain was substantially constant after 48 h and during the subsequent 240 h, the weight gain was 12 g. The controlled chamber conditions were measured at 89.0°F (31.7°C) and 49 % relative humidity.

Required: WVT and permeance

Calculation (inch pound units):

G/t = $(12 \times 15.43)/240 = 0.771$ grains/h (15.43 is conversion from grains to grams),

A = $100/144 = 0.694$ ft²,

S = 1.378 in. Hg (from tables),

R_1 = 49 % (in chamber),

R_2 = 0 % (vapor sink), and

WVT = $0.771/0.694 = 1.11$ grains/ft²·h.

Permeance = $WVT/(1.378 \times 0.49) = 1.64$ perms

Calculation (metric units):

G/t = $12/10 = 1.2$ g/24 h = 0.05 g h^{-1},

A = 0.0645 m²,

S = 35 mm Hg (from tables),

R_1 = 49 % (in chamber),

R_2 = 0 % (vapor sink), and

WVT = $1.2/0.0645 = 0.775$ g/(h·m²)·0.775 g·h^{-1}·m^{-2}.

Permeance = $WVT/(35 \times 0.49) = 9.4 \times 10$ kg·Pa^{-1}·S^{-1}·m^{-1}

13.4 Metric units and conversion factors are given in Table 1.

14. Report

14.1 The report shall include the following:

14.1.1 Identification of the material tested including its thickness.

14.1.2 Test method used (desiccant or water).

14.1.3 Test temperature.

14.1.4 Relative humidity in the test chamber.

14.1.5 Permeance of each specimen in perms (to two significant figures).

14.1.6 The side of each specimen on which the higher vapor pressure was applied (The sides shall be distinguished as "side A" and "side B" when there is no obvious difference between them. When there is an obvious difference, this difference shall also be stated, such as "side A waxed" and "side B unwaxed").

14.1.7 The average permeance of all specimens tested in each position.

14.1.8 The permeability of each specimen (as limited by 13.3), and the average permeability of all specimens tested.

14.1.9 Include a portion of the plot indicating the section of the curve used to calculate permeability.

14.1.10 State design of cup and type or composition of sealant.

15. Precision and Accuracy

15.1 Results obtained by any one procedure on several specimens from the same sample may differ as much as 10 % from their average. Two significant figures in water vapor transmission or permeance will, therefore, usually suffice to characterize the sample. Nevertheless careful attention to all aspects of the procedure is required in order to obtain test results of able precision. Possible errors resulting from tolerances are shown in Table 2. Accuracy of methods and apparatus may be [illegible] aed by using Recommended Practice C 677.

TABLE 1 Metric Units and Conversion Factors[A,B]

Multiply	by	To Obtain (for the same test condition)
	WVT	
g/(h·m²)	0.00249	grains/(h·ft²)
grains/(h·ft²)	0.696	g/(h·m²)
	PERMEANCE	
ng·Pa^{-1}·s^{-1}·m^{-2}	0.0174	1 perm
1 perm	57.45	ng·Pa^{-1}·s^{-1}·m^{-2}
	PERMEABILITY	
ng·Pa^{-1}·s^{-1}·m^{-1}	0.686	1 perm inch
1 perm inch	1.459	ng·Pa^{-1}·s^{-1}·m^{-1}

[A] These units are used in the construction trade. Other units may be used in other standards.

[B] All conversions of mm Hg to Pa are made at a temperature of 0°C.

TABLE 2 Errors Resulting from the Tolerances

Section		Notes	Possible Error, % Dry cup	Possible Error, % Wet cup
6.1	Cup ledge	A	+12	+12
7.2	Sealant gain or loss		±2	±2
6.2	Chamber temperature	B	±3	±3
6.2	Chamber relative humidity	B	±4	±4
6.3	Balance sensitivity	B	±1	±1
6.3	Accuracy of weights	B	±1	±1
11, 12	Air in dish	C	−1	−3
11.4	10 % water in $CaCl_2$		−6	

[A] This error applies to a homogeneous specimen 1⅛ in. (32 mm) thick. The error is smaller for a thin specimen and is limited to 10 % for a laminate by the ⅛ in. (3 mm) overlay provided in 9.2.

[B] These errors are eliminated by correct measurements and calculations based thereon.

[C] This error applied to a 4 perm (2.6-metric perm) specimen, and is smaller for lower permeance.

APPENDIXES

X1. STANDARD TEST CONDITIONS

X1.1 Standard test conditions that have been useful are:

X1.1.1 *Procedure A*—Desiccant Method at 73.4°F (23°C).

X1.1.2 *Procedure B*—Water Method at 73.4°F (23°C).

X1.1.3 *Procedure BW*—Inverted Water Method at 73.4°F (23°C).

X1.1.4 *Procedure C*—Desiccant Method at 90°F (32.2°C).

X1.1.5 *Procedure D*—Water Method at 90°F (32.2°C).

X1.1.6 *Procedure E*—Desiccant Method at 100°F (37.8°C).

X2. CUP DESIGN AND SEALING METHODS

X2.1 An ideal sealing material has the following properties:

X2.1.1 Impermeability to water in either vapor or liquid form.

X2.1.2 No gain or loss of weight from or to the test chamber (evaporation, oxidation, hygroscopicity, and water solubility being undersirable).

X2.1.3 Good adhesion to any specimen and to the dish (even when wet).

X2.1.4 Complete conformity to a rough surface.

X2.1.5 Compatibility with the specimen and no excessive penetration into it.

X2.1.6 Strength or pliability (or both).

X2.1.7 Easy handleability (including desirable viscosity and thermal of molten sealant).

X2.1.8 Satisfactory sealants possess these properties in varying degrees and the choice is a compromise, with more tolerance in items at the beginning of this list for the sake of those at the latter part of the list when the requirements of 7.2 are met (Note A2). Molten asphalt or wax is required for permeance tests below 4 perms (2.6 metric perms). Tests to determine sealant behavior should include:

X2.1.8.1 An impervious specimen (metal) normally sealed to the dish and so tested, and

X2.1.8.2 The seal normally assembled to an empty dish with no specimen and so tested.

X2.2 The following materials are recommended for general use when the test specimen will not be affected by the temperature of the sealant.

X2.2.1 Asphalt, 180 to 200°F (82 to 93°C) softening point, meeting the requirements of Specification

D 449, Type C. Apply by pouring.

X2.2.2 Beeswax and rosin (equal weights). A temperature of 275°F (135°C) is desirable for brush application. Pour at lower temperature.

X2.2.3 Microcrystalline wax[8] (60 %), mixed with refined crystalline paraffin wax (40 %).

X2.3 The materials listed in X2.3.1 are recommended for particular uses such as those shown in Figure X2.1. The suggested procedure described in X2.3.2 applies to an 11-3/8-in. (289-mm) square specimen if its permeance exceeds 4 perms (2.6 metric perms) (limited by evaporation of sealants).

X2.3.1 *Materials*:

X2.3.1.1 Aluminum foil, 0.005 in. (0.125 mm) minimum thickness.

X2.3.1.2 Tape, meeting the requirements of Specification D 2301, vinyl chloride plastic pressure-sensitive, electrical insulating tape.

X2.3.1.3 Cement, contact bond, preferably rubber base.

X2.3.2 *Procedure*:

X2.3.2.1 *Step 1*—Seal aluminum foil around edges of specimen, leaving a 100-in.² (0.0654-m²) exposed test area on each side. Use contact bond cement as directed by the manufacturer.

X2.3.2.2 *Step 2*—Spread sealant on inside of rim and ledge. Place desiccant (dry), or water and surge control material (wet) in pan. Press specimen in place. Avoid squeezing compound into the test area.

X2.3.2.3 *Step 3*—Coat outside of rim and bottom of ledge with contact bond cement, and place foil strips from edge of template, around rim, and bottom of ledge.

X2.4 A method of using hot asphalt, as applied to a 10-in. (254-mm) square mouth dish with ledge and rim, is as follows:

X2.4.1 *Apparatus*:

X2.4.1.1 *Template*—A square frame of brass or steel, 3/16 in. (5 mm) thick and 3/4 in. (19 mm) deep. The 3/16-in. (5-mm) thickness is tapered to zero at the bottom of the frame where it will touch the test specimen and maintain a 10-in. (254-mm) square test area.

X2.4.1.2 *Sealant*—Asphalt (see X2.2.1) used at the proper pouring consistency of 375 to 450°F (179 to 232°C).

X2.4.1.3 *Melting Pot* for the asphalt, electrically heated, with one dimension greater than 11-3/8 in. (289 mm).

X2.4.1.4 *Small Ladle* for pouring.

X2.4.2 *Procedure*—Mark the 11-3/8-in. (289 mm) square specimen with a line at an equal distance from each edge, so that the area enclosed by the lines is as nearly as possible a 10-in. (254-mm) square. The template may be used for marking. Dip each edge of the specimen in molten asphalt up to the line, so that the test area is defined and all edges are coated with a heavy layer of asphalt. Place the specimen over the pan containing water or desiccant. Lightly oil the template or coat with petroleum jelly on its outer side, and place on the specimen. Pour molten asphalt into the space between the template and the rim of the pan. After the asphalt has cooled for a few minutes, the template should be easily removable.

X2.5 Hot wax may be applied like asphalt. It may also be applied (freely) with a small brush. Its lower working temperature may be advantageous when a specimen contains moisture.

X2.6 Several designs for dishes with supporting rings and flanges are shown in Fig. X2.2. Various modifications of these designs may be made provided that the principle of prevention of edge leakage by means of a complete seal is retained. The dishes may be constructed of any rigid, impermeable, corrosion-resistant material, provided that they can be accommodated on the available analytical balance. A lightweight metal, such as aluminum or one of its alloys, is generally used for larger-size dishes. In some cases when an aluminum dish is employed and moisture is allowed to condense on its surface, there may be appreciable oxidation of the aluminum with a resulting gain in weight. Any gain in weight will ordinarily depend on the previous history of the dish and the cleanness of the surface. An empty dish carried through the test procedure as a control will help to determine whether any error may be expected from this cause. When aluminum dishes are used for the water methods, a pressure may develop inside the assembly during a test due to corrosion. This can cause seal failure or otherwise affect the results. Where this is a problem, it can be overcome by providing inside the dish a protective coating of baked-on epoxy resin or similar material. Dishes with flanges or rings that project from the inner walls of the dish are to be avoided, as such projections influence the diffusion of the water vapor. The depth of the dish for the water procedures is such that there is a 0.80 ± 0.20 in. (20 ± 5-mm) distance between the water surface and the under surface of the specimen, with a water depth of about 0.20 in. (5 mm).

X2.6.1 For the desiccant-in-dish procedures, the dishes need not be as deep as those required for the water-in-dish procedures. The desiccant is within 5/16 in. (8 mm) of the under surface, and a minimum depth of only 1/2 in. (12 mm) of desiccant is required.

X2.6.2 The dishes shown in Fig. X2.2 require a molten seal.

X2.6.3 A template such as is shown in Fig. X2.2 is usually used for defining the test area and effecting the wax seal. It consists of a circular metal disk 1/8 in. (3.18 mm) or more in thickness with the edge beveled to an angle of about 45°. The diameter of the bottom (smaller) face of the template is approximately equal to, but not greater than, the diameter of the effective opening of the dish in contact with the specimen. Small guides may be attached to the template to center it automatically on the test specimen. A small hole through the template to admit air, and petrolatum applied to the beveled edge of the template facilitate its removal after sealing the test specimen to the dish. In use, the template is placed over the test specimen and when it is carefully centered with the dish opening, molten wax is flowed into the annular space surrounding the beveled edge of the template. As soon as the wax has solidified, the template is removed from the sheet with a twisting motion. The outside flange of the dish should be high enough to extend over the top of the specimen, thus allowing the wax to completely envelop the edge.

X2.6.4 Gasketed types of seals are also in use on appropriately designed dishes. These simplify the mounting of the specimen, but must be used with caution, since the possibility of edge leakage is greater with gasketed seals than with wax seals. Gasketed seals are not permitted for the measurement of permeance less than 0.044 perms (2.5 ng·Pa⁻¹·s⁻¹·m²). As a further precaution when gasketed seals are used instead of preferred sealants, a blank test run is suggested using glass or metal as a dummy specimen.

X2.6.5 A suitable weighing cover consists of a circular disk of aluminum 1/32 to 3/32 in. (0.8 to 2.4 mm) in thickness provided with a suitable knob in the center for lifting. The cover fits over the test specimen when assembled and makes contact with the inside beveled surface of the wax seal at, or just above, the plane of the specimen. The cover is free of sharp edges which might remove the wax and is numbered or otherwise identified to facilitate its exclusive use with the same dish.

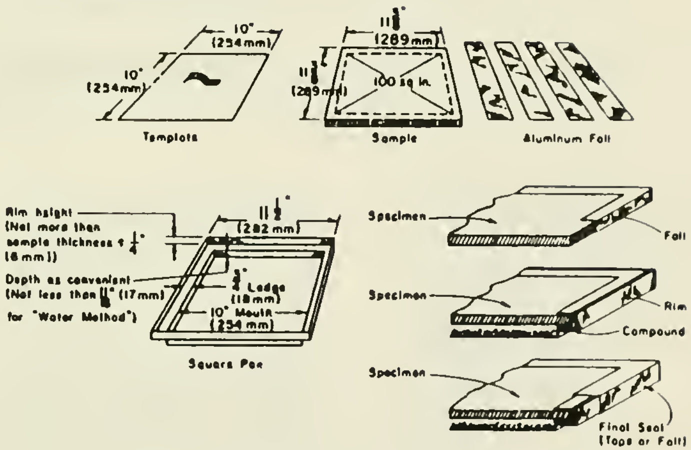

FIG. X2.1 Apparatus for Water Vapor Transmission Tests of Large Thick Specimens

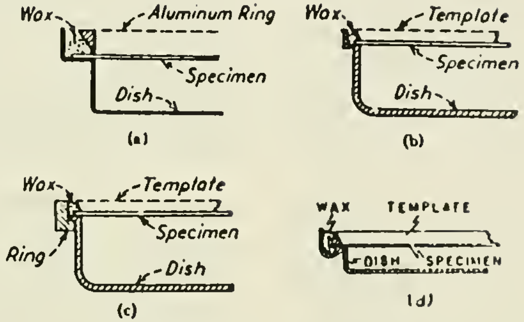

FIG. X2.2 Several Types of Dishes for Water Vapor Transmission Tests of Materials in Sheet Form

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[8] Grade Nos 2305 or 2310 of the Mobil Oil Corp., or the equivalent, have been found satisfactory for this purpose.

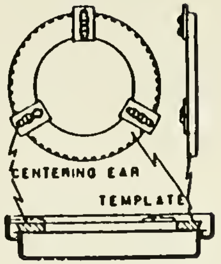

FIG. X2.3 Template Suitable for Use in Making the Wax Seals on Test Dishes

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Designation: E 97 – 82

Standard Test Method for
DIRECTIONAL REFLECTANCE FACTOR, 45-deg 0-deg, OF OPAQUE SPECIMENS BY BROAD-BAND FILTER REFLECTOMETRY[1]

This standard is issued under the fixed designation E 97; 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 method has been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.

1. Scope

1.1 This method covers the determination of the 45-deg, 0-deg directional reflectance factor of nonfluorescent opaque specimens by means of filter photometers. To obtain similar results from spectrophotometers, see Recommended Practice E 308.

NOTE 1—The values stated in inch-pound units are to be regarded as the standard.

NOTE 2—This method has been developed for determining (1) the daylight luminous reflectance factor of paint, opaque white porcelain enamels, and ceramic whitewares, and (2) the blue-light reflectance factor (sometimes called "brightness") of uncolored papers and pulps in sheet form. The method may also be used for determining the reflectance factor of other opaque specimens.

NOTE 3—The blue-light reflectance factor of paper provides a measure of freedom from yellowness such as results in pulp and paper from the presence of lignin and other so-called impurities left by incomplete bleaching.

NOTE 4—Blue-light reflectance factor by this method differs slightly, both spectrally and geometrically from the TAPPI Standards T 217 and T 452. The TAPPI methods are considered to be standard for the pulp and paper industry when brightness measurements are to be made.

2. Applicable Documents

2.1 *ASTM Standards:*

C 347 Test for Reflectivity and Coefficient of Scatter of White Porcelain Enamels[2]

D 523 Test for Specular Gloss[3, 5]

D 585 Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard or Related Products[4]

D 823 Producing Films of Uniform Thickness of Paint, Varnish, Lacquer, and Related Products on Test Panels[3]

E 179 Recommended Practice for Selection of Geometric Conditions for Measurement of Reflectance and Transmittance[5]

E 284 Definitions of Terms Relating to Appearance of Materials[5]

E 308 Recommended Practice for Spectrophotometry and Description of Color in CIE 1931 System[3, 5]

2.2 *TAPPI Standards*[6]

T 217 Brightness of Pulp

T 452 Brightness of Paper and Paper Board

3. Significance and Use

3.1 Measurements of reflectance factor provide a measure of the amount of incident radiation reflecting diffusely under the geometric conditions of this method. High values indicate low absorption. When the response of the detector conforms to the sensitivity of the average human eye (Y-tristimulus filter), the result is designated luminous reflectance. For near white specimens, the reflectance value for blue

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[1] This method is under the jurisdiction of ASTM Committee E-12 on Appearance of Materials and is the direct responsibility of Subcommittee E12.03 on Geometric Practices.

Current edition approved Oct. 29, 1982. Published December 1982. Originally published as E 97 – 53 T. Last previous edition E 97 – 77.

[2] *1982 Annual Book of ASTM Standards*, Part 17.

[3] *1983 Annual Book of ASTM Standards*, Vol 06.01.

[4] *1982 Annual Book of ASTM Standards*, Part 20.

[5] *1982 Annual Book of ASTM Standards*, Part 46.

[6] Available from Technical Association of the Pulp and Paper Industry, One Dunwoody Park, Atlanta, Ga. 30341.

APPENDIX D: SAMPLE LABELING SYSTEM PROGRAM

SAMPLE LABELING SYSTEM PROGRAM

AD - CL - N1

TEST NAME
PLASTER TYPE
CONSOLIDANT TYPE
SAMPLE NUMBER

TESTS NAMES

AD - ADHESION
AR - ABRASION RESISTANCE
CA - CAPILLARITY
VT - VAPOR TRANSMISSION
WR - WATER RESISTANCE

PLASTER TYPES

CL - CLAY
LI - LIME
GY - GYPSUM
CM - CLAY AND LIME
GM - GYPSUM AND LIME

CONSOLIDATION TREATMENTS

N - NO CONSOLIDATION
T - TUNA CACTUS MUCILAGE
E - ETHYL SILICATE: SILICIC ACID ESTER (CONSERVARE OH)
A - ACRYLIC SOLUTION (5% ACRYLOID B-67 IN DIETHYLBENZENE)

SAMPLES TESTING

TEST	NAME	SAMPLE SHAPE AND SIZE	AMOUNT
ASTM C307-83	ADHESION	Braquet Gang Mold 3"x1.32"x1"	6
ASTM E96-80	VAPOR TRANSMISSION	Test Dish 4.65 in2 x 3/4"	4
DROP TEST	WATER RESISTANCE	Adobe Brick Support 4" x 4" x 1 1/2" Plastered with five different types of plaster	3
ASTM C241-82	ABRASION RESISTANCE		3
RILEM TUBE TEST	CAPILLARITY		3

ABRASION RESISTANCE - SAMPLE TESTING PROGRAM

	Consolidant Applied	Number of Samples			Average
		1	2	3	
CLAY	No Consolidant	AR-CL-N1	AR-CL-N2	AR-CL-N3	AR-CL-N
	Tuna Cactus	AR-CL-T1	AR-CL-T2	AR-CL-T3	AR-CL-T
	Acrylic Emulsion	AR-CL-A1	AR-CL-A2	AR-CL-A3	AR-CL-A
	Ethyl Silicate	AR-CL-E1	AR-CL-E2	AR-CL-E3	AR-CL-E
LIME	No Consolidant	AR-LI-N1	AR-LI-N2	AR-LI-N3	AR-LI-N
	Tuna Cactus	AR-LI-T1	AR-LI-T2	AR-LI-T3	AR-LI-T
	Acrylic Emulsion	AR-LI-A1	AR-LI-A2	AR-LI-A3	AR-LI-A
	Ethyl Silicate	AR-LI-E1	AR-LI-E2	AR-LI-E3	AR-LI-E
GYPSUM	No Consolidant	AR-GY-N1	AR-GY-N2	AR-GY-N3	AR-GY-N
	Tuna Cactus	AR-GY-T1	AR-GY-T2	AR-GY-T3	AR-GY-T
	Acrylic Emulsion	AR-GY-A1	AR-GY-A2	AR-GY-A3	AR-GY-A
	Ethyl Silicate	AR-GY-E1	AR-GY-E2	AR-GY-E3	AR-GY-E
CLAY LIME	No Consolidant	AR-CM-N1	AR-CM-N2	AR-CM-N3	AR-CM-N
	Tuna Cactus	AR-CM-T1	AR-CM-T2	AR-CM-T3	AR-CM-T
	Acrylic Emulsion	AR-CM-A1	AR-CM-A2	AR-CM-A3	AR-CM-A
	Ethyl Silicate	AR-CM-E1	AR-CM-E2	AR-CM-E3	AR-CM-E
GYPSUM LIME	No Consolidant	AR-GM-N1	AR-GM-N2	AR-GM-N3	AR-GM-N
	Tuna Cactus	AR-GM-T1	AR-GM-T2	AR-GM-T3	AR-GM-T
	Acrylic Emulsion	AR-GM-A1	AR-GM-A2	AR-GM-A3	AR-GM-A
	Ethyl Silicate	AR-GM-E1	AR-GM-E2	AR-GM-E3	AR-GM-E

Table A

ADHESION - SAMPLE TESTING PROGRAM

	Consolidant Applied	Number of Samples						Avg.
		1	2	3	4	5	6	
CLAY	No Consolidant	AD-CL-N1	AD-CL-N2	AD-CL-N3	AD-CL-N4	AD-CL-N5	AD-CL-N6	AD-CL-N
	Tuna Cactus	AD-CL-T1	AD-CL-T2	AD-CL-T3	AD-CL-T4	AD-CL-T5	AD-CL-T6	AD-CL-T
	Acrylic Emulsion	AD-CL-A1	AD-CL-A2	AD-CL-A3	AD-CL-A4	AD-CL-A5	AD-CL-A6	AD-CL-A
	Ethyl Silicate	AD-CL-E1	AD-CL-E2	AD-CL-E3	AD-CL-E4	AD-CL-E5	AD-CL-E6	AD-CL-E
LIME	No Consolidant	AD-LI-N1	AD-LI-N2	AD-LI-N3	AD-LI-N4	AD-LI-N5	AD-LI-N6	AD-LI-N
	Tuna Cactus	AD-LI-T1	AD-LI-T2	AD-LI-T3	AD-LI-T4	AD-LI-T5	AD-LI-T6	AD-LI-T
	Acrylic Emulsion	AD-LI-A1	AD-LI-A2	AD-LI-A3	AD-LI-A4	AD-LI-A5	AD-LI-A6	AD-LI-A
	Ethyl Silicate	AD-LI-E1	AD-LI-E2	AD-LI-E3	AD-LI-E4	AD-LI-E5	AD-LI-E6	AD-LI-E
GYPSUM	No Consolidant	AD-GY-N1	AD-GY-N2	AD-GY-N3	AD-GY-N4	AD-GY-N5	AD-GY-N6	AD-GY-N
	Tuna Cactus	AD-GY-T1	AD-GY-T2	AD-GY-T3	AD-GY-T4	AD-GY-T5	AD-GY-T6	AD-GY-T
	Acrylic Emulsion	AD-GY-A1	AD-GY-A2	AD-GY-A3	AD-GY-A4	AD-GY-A5	AD-GY-A6	AD-GY-A
	Ethyl Silicate	AD-GY-E1	AD-GY-E2	AD-GY-E3	AD-GY-E4	AD-GY-E5	AD-GY-E6	AD-GY-E
CLAY LIME	No Consolidant	AD-CM-N1	AD-CM-N2	AD-CM-N3	AD-CM-N4	AD-CM-N5	AD-CM-N6	AD-CM-N
	Tuna Cactus	AD-CM-T1	AD-CM-T2	AD-CM-T3	AD-CM-T4	AD-CM-T5	AD-CM-T6	AD-CM-T
	Acrylic Emulsion	AD-CM-A1	AD-CM-A2	AD-CM-A3	AD-CM-A4	AD-CM-A5	AD-CM-A6	AD-CM-A
	Ethyl Silicate	AD-CM-E1	AD-CM-E2	AD-CM-E3	AD-CM-E4	AD-CM-E5	AD-CM-E6	AD-CM-E
GYPSUM LIME	No Consolidant	AD-GM.N1	AD-GM-N2	AD-GM-N3	AD-GM-N4	AD-GM-N5	AD-GM-N6	AD-GM-N
	Tuna Cactus	AD-GM-T1	AD-GM-T2	AD-GM-T3	AD-GM-T4	AD-GM-T5	AD-GM-T6	AD-GM-T
	Acrylic Emulsion	AD-GM-A1	AD-GM-A2	AD-GM-A3	AD-GM-A4	AD-GM-A5	AD-GM-A6	AD-GM-A
	Ethyl Silicate	AD-GM-E1	AD-GM-E2	AD-GM-E3	AD-GM-E4	AD-GM-E5	AD-GM-E6	AD-GM-E

Table B

CAPILLARITY - SAMPLE TESTING PROGRAM

	Consolidant Applied	Number of Samples			Average
		1	2	3	
CLAY	No Consolidant	CA-CL-N1	CA-CL-N2	CA-CL-N3	CA-CL-N
	Tuna Cactus	CA-CL-T1	CA-CL-T2	CA-CL-T3	CA-CL-T
	Acrylic Emulsion	CA-CL-A1	CA-CL-A2	CA-CL-A3	CA-CL-A
	Ethyl Silicate	CA-CL-E1	CA-CL-E2	CA-CL-E3	CA-CL-E
LIME	No Consolidant	CA-LI-N1	CA-LI-N2	CA-LI-N3	CA-LI-N
	Tuna Cactus	CA-LI-T1	CA-LI-T2	CA-LI-T3	CA-LI-T
	Acrylic Emulsion	CA-LI-A1	CA-LI-A2	CA-LI-A3	CA-LI-A
	Ethyl Silicate	CA-LI-E1	CA-LI-E2	CA-LI-E3	CA-LI-E
GYPSUM	No Consolidant	CA-GY-N1	CA-GY-N2	CA-GY-N3	CA-GY-N
	Tuna Cactus	CA-GY-T1	CA-GY-T2	CA-GY-T3	CA-GY-T
	Acrylic Emulsion	CA-GY-A1	CA-GY-A2	CA-GY-A3	CA-GY-A
	Ethyl Silicate	CA-GY-E1	CA-GY-E2	CA-GY-E3	CA-GY-E
CLAY LIME	No Consolidant	CA-CM-N1	CA-CM-N2	CA-CM-N3	CA-CM-N
	Tuna Cactus	CA-CM-T1	CA-CM-T2	CA-CM-T3	CA-CM-T
	Acrylic Emulsion	CA-CM-A1	CA-CM-A2	CA-CM-A3	CA-CM-A
	Ethyl Silicate	CA-CM-E1	CA-CM-E2	CA-CM-E3	CA-CM-E
GYPSUM LIME	No Consolidant	CA-GM-N1	CA-GM-N2	CA-GM-N3	CA-GM-N
	Tuna Cactus	CA-GM-T1	CA-GM-T2	CA-GM-T3	CA-GM-T
	Acrylic Emulsion	CA-GM-A1	CA-GM-A2	CA-GM-A3	CA-GM-A
	Ethyl Silicate	CA-GM-E1	CA-GM-E2	CA-GM-E3	CA-GM-E

Table C

VAPOR TRANSMISSION - SAMPLE TESTING PROGRAM

	Consolidant Applied	Number of Samples			Average
		1	2	3	
CLAY	No Consolidant	VT-CL-N1	VT-CL-N2	VT-CL-N3	VT-CL-N
	Tuna Cactus	VT-CL-T1	VT-CL-T2	VT-CL-T3	VT-CL-T
	Acrylic Emulsion	VT-CL-A1	VT-CL-A2	VT-CL-A3	VT-CL-A
	Ethyl Silicate	VT-CL-E1	VT-CL-E2	VT-CL-E3	VT-CL-E
LIME	No Consolidant	VT-LI-N1	VT-LI-N2	VT-LI-N3	VT-LI-N
	Tuna Cactus	VT-LI-T1	VT-LI-T2	VT-LI-T3	VT-LI-T
	Acrylic Emulsion	VT-LI-A1	VT-LI-A2	VT-LI-A3	VT-LI-A
	Ethyl Silicate	VT-LI-E1	VT-LI-E2	VT-LI-E3	VT-LI-E
GYPSUM	No Consolidant	VT-GY-N1	VT-GY-N2	VT-GY-N3	VT-GY-N
	Tuna Cactus	VT-GY-T1	VT-GY-T2	VT-GY-T3	VT-GY-T
	Acrylic Emulsion	VT-GY-A1	VT-GY-A2	VT-GY-A3	VT-GY-A
	Ethyl Silicate	VT-GY-E1	VT-GY-E2	VT-GY-E3	VT-GY-E
CLAY LIME	No Consolidant	VT-CM-N1	VT-CM-N2	VT-CM-N3	VT-CM-N
	Tuna Cactus	VT-CM-T1	VT-CM-T2	VT-CM-T3	VT-CM-T
	Acrylic Emulsion	VT-CM-A1	VT-CM-A2	VT-CM-A3	VT-CM-A
	Ethyl Silicate	VT-CM-E1	VT-CM-E2	VT-CM-E3	VT-CM-E
GYPSUM LIME	No Consolidant	VT-GM-N1	VT-GM-N2	VT-GM-N3	VT-GM-N
	Tuna Cactus	VT-GM-T1	VT-GM-T2	VT-GM-T3	VT-GM-T
	Acrylic Emulsion	VT-GM-A1	VT-GM-A2	VT-GM-A3	VT-GM-A
	Ethyl Silicate	VT-GM-E1	VT-GM-E2	VT-GM-E3	VT-GM-E

Table D

WATER RESISTANCE - SAMPLE TESTING PROGRAM

	Consolidant Applied	Number of Samples			Average
		1	2	3	
CLAY	No Consolidant	WR-CL-N1	WR-CL-N2	WR-CL-N3	WR-CL-N
	Tuna Cactus	WR-CL-T1	WR-CL-T2	WR-CL-T3	WR-CL-T
	Acrylic Emulsion	WR-CL-A1	WR-CL-A2	WR-CL-A3	WR-CL-A
	Ethyl Silicate	WR-CL-E1	WR-CL-E2	WR-CL-E3	WR-CL-E
LIME	No Consolidant	WR-LI-N1	WR-LI-N2	WR-LI-N3	WR-LI-N
	Tuna Cactus	WR-LI-T1	WR-LI-T2	WR-LI-T3	WR-LI-T
	Acrylic Emulsion	WR-LI-A1	WR-LI-A2	WR-LI-A3	WR-LI-A
	Ethyl Silicate	WR-LI-E1	WR-LI-E2	WR-LI-E3	WR-LI-E
GYPSUM	No Consolidant	WR-GY-N1	WR-GY-N2	WR-GY-N3	WR-GY-N
	Tuna Cactus	WR-GY-T1	WR-GY-T2	WR-GY-T3	WR-GY-T
	Acrylic Emulsion	WR-GY-A1	WR-GY-A2	WR-GY-A3	WR-GY-A
	Ethyl Silicate	WR-GY-E1	WR-GY-E2	WR-GY-E3	WR-GY-E
CLAY LIME	No Consolidant	WR-CM-N1	WR-CM-N2	WR-CM-N3	WR-CM-N
	Tuna Cactus	WR-CM-T1	WR-CM-T2	WR-CM-T3	WR-CM-T
	Acrylic Emulsion	WR-CM-A1	WR-CM-A2	WR-CM-A3	WR-CM-A
	Ethyl Silicate	WR-CM-E1	WR-CM-E2	WR-CM-E3	WR-CM-E
GYPSUM LIME	No Consolidant	WR-GM-N1	WR-GM-N2	WR-GM-N3	WR-GM-N
	Tuna Cactus	WR-GM-T1	WR-GM-T2	WR-GM-T3	WR-GM-T
	Acrylic Emulsion	WR-GM-A1	WR-GM-A2	WR-GM-A3	WR-GM-A
	Ethyl Silicate	WR-GM-E1	WR-GM-E2	WR-GM-E3	WR-GM-E

Table E

APPENDIX E: TEST DATA TABLES

ABRASION RESISTANCE - DATA

PLASTER TYPE	CLAY	LIME	GYPSUM	CLAY/ LIME	GYPSUM/ LIME
AR-N1	0.51	0.39	0.61	1.15	1.61
AR-N2	0.52	0.38	0.55	0.98	1.58
AR-N3	0.52	0.40	0.67	1.06	1.63
AR-N	0.52	0.39	0.61	1.06	1.63
AR-T1	0.50	0.35	0.33	0.52	1.06
AR-T2	0.46	0.28	0.27	0.44	0.90
AR-T3	0.50	0.36	0.33	0.48	1.17
AR-T	0.49	0.33	0.31	0.48	1.04
AR-A1	0.14	0.10	0.05	0.14	0.18
AR-A2	0.14	0.06	0.03	0.24	0.17
AR-A3	0.20	0.05	0.05	0.23	0.19
AR-A	0.16	0.07	0.04	0.20	0.18
AR-E1	0.07	0.11	0.03	0.03	0.24
AR-E2	0.06	0.07	0.03	0.03	0.23
AR-E3	0.06	0.05	0.05	0.04	0.20
AR-E	0.06	0.08	0.04	0.03	0.22

Table I

ADHESION - DATA

	NO CONSOLIDANT	TUNA	ACRYLIC	ETHYL SILICATE
CL-1	194.93	25.48*	307.87	214.55*
CL-2	89.34*	113.34	136.14*	528.10*
CL-3	182.27	144.68	351.17	442.10
CL-4	239.86	101.30	219.78*	325.33
CL-5	15.42*	120.37	372.05	343.82
CL-6	185.76	16.53*	232.68	318.77
CL	200.7050	119.9225	315.9425	357.5050
LI-1	32.79*	137.42*	125.42	103.67
LI-2	99.01	30.97*	120.37	199.84
LI-3	64.78	63.71	68.35*	64.36*
LI-4	52.06	41.25	44.66*	98.55
LI-5	28.64*	54.33	128.07	157.47
LI-6	61.35	60.76	106.25	77.46*
LI	69.3000	55.0125	120.0275	139.8825
GY-1	32.79	36.53	88.04*	59.38
GY-2	10.96*	40.81	62.31	64.09
GY-3	28.77	64.53*	48.83	73.42
GY-4	156.52*	43.23	53.37	69.08
GY-5	19.99	25.61	42.35	94.57
GY-6	6.24*	18.50*	50.43	95.30
GY	27.1833	36.5450	51.4580	75.9733
CM-1	49.45	100.32*	56.61*	81.54*
CM-2	36.90	64.88	80.36	138.98
CM-3	81.80	86.09	89.45	92.57*
CM-4	47.55	78.15	135.08*	217.67
CM-5	48.88	66.35	78.56	224.24
CM-6	44.36	53.44	85.67	126.51
CM	51.4900	69.7820	83.5100	176.8500
GM-1	42.36	26.54	58.36	58.77
GM-2	117.51*	21.36	83.90*	63.42
GM-3	41.35	33.28	90.96*	85.95*
GM-4	47.66	30.67	54.87	72.33
GM-5	44.55	76.73*	54.86	60.05
GM-6	39.85	29.02	61.05	68.30
GM	43.1540	28.1740	57.2850	64.5740

Table II

CAPILLARITY - DATA - CLAY - ACRYLIC				
TIME ELAPSED	**CA-CL-A1**	**CA-CL-A2**	**CA-CL-A3**	**CA-CL-A**
1'	No absorption	No absorption	No absorption	No absorption
2'	No absorption	0.15	No absorption	No absorption
3'	No absorption	0.20	0.05	0.08
4'	No absorption	0.22	0.10	0.10
5'	0.10	0.23	0.15	0.16
10'	0.20	0.25	0.20	0.22
15'	0.30	0.275	0.30	0.29
30'	0.45	0.50	0.45	0.46
45'	0.70	0.80	0.75	0.75
60'	0.95	1.00	0.95	0.96

Table III

CAPILLARITY - DATA - CLAY - ETHYL SILICATE				
TIME ELAPSED	**CA-CL-E1**	**CA-CL-E2**	**CA-CL-E3**	**CA-CL-E**
1'	2.00*	1.00	0.75	0.88
2'	4.10	1.25	1.00	1.13
3'	5.20	1.50	1.25	1.38
4'	5.50	1.75	1.50	1.63
5'	below meter	1.80	1.70	1.75
10'	All water absorbed	2.10	2.00	2.05
15'	--	2.60	2.50	2.55
30'	--	3.75	3.60	3.68
45'	--	4.80	4.70	4.75
60'	--	5.15	5.00	5.08

Table IV

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* Water is expanding through cracks on the surface and wetting the adobe substrate

CAPILLARITY - DATA - LIME - NO CONSOLIDANT

TIME ELAPSED	CA-LI-N1	CA-LI-N2	CA-LI-N3	CA-LI-N
1'	3.50	2.00	2.50	2.66
2'	5.00	3.75	4.10	4.28
3'	below meter	5.10	5.50	5.50
4'	below meter	below meter	below meter	below meter
5'	below meter	below meter	below meter	below meter
10'	below meter	below meter	below meter	below meter
15'	below meter	below meter	below meter	below meter
30'	20' All water absorbed	22' All water absorbed	20' All water absorbed	21' All water absorbed
45'	--	--	--	--
60'	--	--	--	--

Table V

CAPILLARITY - DATA - LIME - TUNA

TIME ELAPSED	CA-LI-T1	CA-LI-T2	CA-LI-T3	CA-LI-T
1'	2.00	2.50	2.10	2.20
2'	3.20	4.00	3.50	3.56
3'	5.00	5.00	4.50	4.83
4'	below meter	below meter	below meter	below meter
5'	below meter	below meter	below meter	below meter
10'	below meter	below meter	below meter	below meter
15'	below meter	below meter	below meter	below meter
30'	20' All water absorbed	28' All water absorbed	35' all water absorbed	31' All water absorbed
45'	--	--	--	--
60'	--	--	--	--

Table VI

CAPILLARITY - DATA - LIME - ACRYLIC EMULSION

TIME ELAPSED	CA-LI-A1	CA-LI-A2	CA-LI-A3	CA-LI-A
1'	No absorption	No absorption	No absorption	No absorption
2'	No absorption	No absorption	No absorption	No absorption
3'	No absorption	No absorption	No absorption	No absorption
4'	No absorption	No absorption	No absorption	No absorption
5'	No absorption	No absorption	0.05	No absorption
10'	No absorption	0.10	0.05	0.05
15'	0.025	0.15	0.05	0.08
30'	0.05	0.40	0.05	0.16
45'	0.075	0.50	0.10	0.23
60'	0.10	0.60	0.12	0.27

Table VII

CAPILLARITY - DATA - LIME - ETHYL SILICATE

TIME ELAPSED	CA-LI-E1	CA-LI-E2	CA-LI-E3	CA-LI-E
1'	0.05	1.00	0.05	0.37
2'	1.25	2.25	1.50	1.67
3'	1.75	3.10	2.00	2.28
4'	2.25	3.90	2.75	2.97
5'	2.70	4.50	3.75	3.65
10'	4.00	5.50	4.75	4.75
15'	4.75	below meter	5.50	below meter
30'	5.50	below meter	below meter	below meter
45'	below meter	below meter	below meter	below meter
60'	below meter	below meter	below meter	below meter

Table VIII

CAPILLARITY - DATA - GYPSUM - NO CONSOLIDANT

TIME ELAPSED	CA-GY-N1	CA-GY-N2	CA-GY-N3	CA-GY-N
1'	4.00	3.25	3.70	3.65
2'	5.50	5.50	5.50	5.50
3'	below meter	below meter	below meter	below meter
4'	below meter	below meter	below meter	below meter
5'	All water absorbed	below meter	below meter	below meter
10'	--	All water absorbed	12' All water absorbed	All water absorbed
15'	--	--	--	--
30'	--	--	--	--
45'	--	--	--	--
60'	--	--	--	--

Table IX

CAPILLARITY - DATA - GYPSUM - TUNA

TIME ELAPSED	CA-GY-T1	CA-GY-T2	CA-GY-T3	CA-GY-T
1'	1.20	1.25	1.50	1.32
2'	3.00	2.10	3.75	2.95
3'	4.00	3.10	5.50	4.20
4'	5.00	3.70	below meter	4.90
5'	5.50	4.50	below meter	5.50
10'	below meter	below meter	below meter	below meter
15'	below meter	below meter	13' All water absorbed	below meter
30'	All water absorbed	20' All water absorbed	--	All water absorbed
45'	--	--	--	--
60'	--	--	--	--

Table X

CAPILLARITY - DATA - GYPSUM - ACRYLIC EMULSION

TIME ELAPSED	CA-GY-A1	CA-GY-A2	CA-GY-A3	CA-GY-A
1'	No absorption	No absorption	No absorption	No absorption
2'	No absorption	No absorption	No absorption	No absorption
3'	No absorption	No absorption	No absorption	No absorption
4'	No absorption	No absorption	No absorption	No absorption
5'	No absorption	No absorption	No absorption	No absorption
10'	No absorption	No absorption	No absorption	No absorption
15'	No absorption	No absorption	No absorption	No absorption
30'	No absorption	0.05	0.02	0.02
45'	0.05	0.05	0.06	0.05
60'	0.10	0.10	0.08	0.09

Table XI

CAPILLARITY - DATA - GYPSUM - ETHYL SILICATE

TIME ELAPSED	CA-GY-E1	CA-GY-E2	CA-GY-E3	CA-GY-E
1'	0.05	0.05	No absorption	0.03
2'	0.10	0.08	0.05	0.08
3'	0.12	0.12	0.08	0.11
4'	0.15	0.25	0.15	0.18
5'	0.20	0.50	0.25	0.32
10'	0.30	0.80	0.35	0.48
15'	0.45	1.10	0.50	0.68
30'	0.60	2.00	0.70	1.10
45'	0.90	2.95	1.00	1.62
60'	1.05	3.75	1.10	1.97

Table XII

CAPILLARITY - DATA - CLAY / LIME - NO CONSOLIDANT

TIME ELAPSED	CA-CM-N1	CA-CM-N2	CA-CM-N3	CA-CM-N
1'	No absorption	0.05	No absorption	0.17
2'	0.10	0.75	0.45	0.43
3'	0.10	1.00	0.75	0.62
4'	0.15	1.25	1.05	0.82
5'	0.15	1.50	1.50	1.05
10'	0.15	2.40	2.45	1.67
15'	0.15	3.50	3.50	2.38
30'	0.20	5.50	5.50	3.73
45'	0.25	below meter	below meter	4.00
60'	0.30	below meter	below meter	4.35

Table XIII

CAPILLARITY - DATA - CLAY / LIME - TUNA

TIME ELAPSED	CA-CM-T1	CA-CM-T2	CA-CM-T3	CA-CM-T
1'	No absorption	No absorption	No absorption	No absorption
2'	No absorption	0.025	No absorption	0.01
3'	No absorption	0.05	No absorption	0.02
4'	No absorption	0.075	0.025	0.03
5'	No absorption	0.10	0.075	0.06
10'	0.05	0.15	0.10	0.10
15'	0.10	0.25	0.15	0.16
30'	0.25	0.75	0.50	0.50
45'	0.30	1.60	1.00	0.63
60'	0.40	2.25	1.85	1.50

Table XIV

CAPILLARITY - DATA - CLAY / LIME - ACRYLIC EMULSION

TIME ELAPSED	CA-CM-A1	CA-CM-A2	CA-CM-A3	CA-CM-A
1'	No absorption	No absorption	No absorption	No absorption
2'	No absorption	No absorption	No absorption	No absorption
3'	No absorption	No absorption	No absorption	No absorption
4'	No absorption	No absorption	No absorption	No absorption
5'	No absorption	No absorption	No absorption	No absorption
10'	No absorption	No absorption	No absorption	No absorption
15'	No absorption	No absorption	No absorption	No absorption
30'	No absorption	No absorption	No absorption	No absorption
45'	No absorption	No absorption	No absorption	No absorption
60'	No absorption	No absorption	No absorption	No absorption

Table XV

CAPILLARITY - DATA - CLAY / LIME - ETHYL SILICATE

TIME ELAPSED	CA-CM-E1	CA-CM-E2	CA-CM-E3	CA-CM-E
1'	0.50	No absorption	No absorption	0.16
2'	0.75	No absorption	No absorption	0.25
3'	1.00	No absorption	No absorption	0.33
4'	1.30	No absorption	No absorption	0.43
5'	1.50	0.05	No absorption	0.51
10'	2.75	0.05	No absorption	0.93
15'	3.60	0.075	0.05	1.22
30'	5.00	0.10	0.10	1.73
45'	5.50	0.15	0.15	1.90
60'	below meter	0.25	0.15	2.13

Table XVI

CAPILLARITY - DATA - GYPSUM / LIME - NO CONSOLIDANT

TIME ELAPSED	CA-GM-N1	CA-GM-N2	CA-GM-N3	CA-GM-N
1’	2.40	3.50	3.50	3.13
2’	4.00	4.50	4.50	4.33
3’	5.50	5.50	5.50	5.50
4’	below meter	below meter	below meter	below meter
5’	below meter	below meter	below meter	below meter
10’	below meter	below meter	below meter	below meter
15’	below meter	below meter	below meter	below meter
30’	21' All water absorbed	17' All water absorbed	20' All water absorbed	19' All water absorbed
45’	--	--	--	--
60’	--	--	--	--

Table XVII

CAPILLARITY - DATA - GYPSUM / LIME - TUNA

TIME ELAPSED	CA-GM-T1	CA-GM-T2	CA-GM-T3	CA-GM-T
1’	3.50	3.00	3.00	3.16
2’	4.50	5.00	5.00	4.80
3’	below meter	below meter	below meter	below meter
4’	below meter	below meter	below meter	below meter
5’	below meter	below meter	below meter	below meter
10’	All water absorbed	below meter	12' All water absorbed	13' All water absorbed
15’	--	18' All water absorbed	--	--
30’	--	--	--	--
45’	--	--	--	--
60’	--	--	--	--

Table XVIII

CAPILLARITY - DATA - GYPSUM / LIME - ACRYLIC EMULSION				
TIME ELAPSED	**CA-GM-A1**	**CA-GM-A2**	**CA-GM-A3**	**CA-GM-A**
1'	No absorption	No absorption	No absorption	No absorption
2'	No absorption	No absorption	No absorption	No absorption
3'	No absorption	No absorption	No absorption	No absorption
4'	No absorption	No absorption	No absorption	No absorption
5'	No absorption	No absorption	No absorption	No absorption
10'	No absorption	No absorption	No absorption	No absorption
15'	No absorption	No absorption	No absorption	No absorption
30'	No absorption	0.01	No absorption	No absorption
45'	No absorption	0.03	0.01	0.01
60'	0.01	0.05	0.03	0.03

Table XIX

CAPILLARITY - DATA - GYPSUM / LIME - ETHYL SILICATE				
TIME ELAPSED	**CA-GM-E1**	**CA-GM-E2**	**CA-GM-E3**	**CA-GM-E**
1'	2.10	1.75	1.75	1.86
2'	3.40	3.00	3.00	3.10
3'	4.10	4.00	4.00	4.03
4'	5.00	5.00	5.00	5.00
5'	5.00	below meter	below meter	below meter
10'	below meter	below meter	below meter	below meter
15'	below meter	below meter	below meter	below meter
30'	below meter	below meter	below meter	below meter
45'	below meter	below meter	below meter	below meter
60'	below meter	below meter	below meter	below meter

Table XX

VAPOR TRANSMISSION TEST - DATA - CLAY (Part 1)

Day	1	2	3	4	5	6	7	8	1	2	3	4	5	6
Temp°F	65.2	60.3	58.4	57.3	62.3	69.7	70.3	69.9	74.3	64.7	64.9	70.2	69.9	69.6
R.U.	40%	7%	7%	8%	15%	8%	8%	9%	10%	8%	10%	11%	10.5%	10%
Blank	128.04	127.45	127.24	127.11	126.96	126.82	126.70	126.58	126.53	126.46	126.42	126.40	126.36	126.30
VT-Blank		0.59	0.21	0.13	0.15	0.14	0.12	0.12	0.05	0.07	0.04	0.02	0.04	0.06
VT-CL-N1	227.01	226.24	225.70	225.20	224.50	223.56	222.53	221.71	220.68	219.73	218.93	218.02	217.11	216.12
VT-CL-N2	231.59	230.73	230.01	229.13	228.38	227.33	226.16	225.21	224.09	223.00	222.13	221.12	220.14	219.01
VT-CL-N3	221.91	221.16	220.62	220.05	219.32	218.35	217.30	216.45	215.40	214.44	213.65	212.71	211.79	210.81
VT-CL-N		0.79	0.60	0.65	0.73	0.99	1.08	0.87	1.07	1.00	0.82	0.95	0.94	1.03
VT-CL-T1	225.21	224.36	223.69	222.47	221.16	220.35	219.70	218.56	217.29	216.16	215.28	214.18	213.16	212.02
VT-CL-T2	236.80	236.12	235.65	234.98	234.47	233.61	232.65	231.85	230.89	229.93	229.26	228.38	227.54	226.57
VT-CL-T3	228.33	227.58	226.90	225.89	225.18	224.22	223.00	221.98	220.75	219.72	218.83	217.79	216.78	215.68
VT-CL-T		0.76	0.61	0.97	0.84	0.88	0.94	0.99	1.15	1.04	0.81	1.01	0.96	1.07
VT-CL-A1	240.12	239.92	239.55	239.15	238.69	238.06	237.36	236.65	235.94	235.26	234.71	234.20	233.65	233.07
VT-CL-A2	234.57	234.30	233.84	233.41	232.88	232.27	231.32	230.68	230.01	229.35	228.72	228.17	227.65	227.04
VT-CL-A3	238.78	238.56	238.23	237.83	237.40	236.79	236.07	235.33	234.63	233.97	233.41	232.88	232.32	231.77
VT-CL-A		0.23	0.39	0.41	0.47	0.62	0.79	0.70	0.69	0.67	0.58	0.53	0.54	0.58
VT-CL-E1	234.24	233.78	233.53	233.24	232.93	232.59	232.05	231.58	231.01	230.47	230.03	229.44	228.91	228.33
VT-CL-E2	244.30	243.74	243.52	243.23	242.97	242.61	242.18	241.74	241.29	240.78	240.41	239.90	239.41	238.85
VT-CL-E3	246.14	245.57	245.36	245.06	244.79	244.43	243.97	243.58	243.09	242.58	242.21	241.67	241.21	240.67
VT-CL-E		0.53	0.23	0.29	0.28	0.35	0.48	0.43	0.50	0.52	0.39	0.55	0.49	0.56

Table XXI

VAPOR TRANSMISSION - INDIVIDUAL RESULTS - CLAY (Part 1)

Day	1	2	3	4	5	6	7	8	1	2	3	4	5	6
Temp °F	65.2	60.3	58.4	57.3	62.3	69.7	70.3	69.9	74.3	64.7	64.9	70.2	69.9	29.6
R.U.	40%	7%	7%	8%	15%	8%	8%	9%	10%	8%	10%	11%	10.5%	10%
VT-Blank		0.59	0.21	0.13	0.15	0.14	0.12	0.12	0.05	0.07	0.04	0.02	0.04	0.06
VT-CL-N1		0.77	0.54	0.50	0.70	0.94	1.03	0.82	1.03	0.95	0.80	0.91	0.91	0.99
VT-CL-N2		0.86	0.72	0.88	0.75	1.05	1.17	0.95	1.12	1.09	0.87	1.01	0.98	1.13
VT-CL-N3		0.75	0.54	0.57	0.73	0.97	1.05	0.85	1.05	0.96	0.79	0.94	0.92	0.98
VT-CL-N		0.79	0.60	0.65	0.73	0.99	1.08	0.87	1.07	1.00	0.82	0.95	0.94	1.03
VT-CL-T1		0.85	0.67	1.22	1.31	0.81	0.65	1.14	1.27	1.13	0.88	1.10	1.02	1.14
VT-CL-T2		0.68	0.47	0.67	0.51	0.86	0.96	0.80	0.96	0.96	0.67	0.88	0.84	0.97
VT-CL-T3		0.75	0.68	1.01	0.71	0.96	1.22	1.02	1.23	1.03	0.89	1.04	1.01	1.10
VT-CL-T		0.76	0.61	0.97	0.84	0.88	0.94	0.99	1.15	1.04	0.81	1.01	0.96	1.07
VT-CL-A1		0.20	0.37	0.40	0.46	0.63	0.70	0.71	0.71	0.68	0.55	0.51	0.55	0.58
VT-CL-A2		0.27	0.46	0.43	0.53	0.61	0.95	0.64	0.67	0.66	0.63	0.55	0.52	0.61
VT-CL-A3		0.22	0.33	0.40	0.43	0.61	0.72	0.74	0.70	0.66	0.56	0.53	0.56	0.55
VT-CL-A		0.23	0.39	0.41	0.47	0.62	0.79	0.70	0.69	0.67	0.58	0.53	0.54	0.58
VT-CL-E1		0.46	0.25	0.29	0.31	0.34	0.54	0.47	0.57	0.54	0.44	0.59	0.53	0.58
VT-CL-E2		0.56	0.22	0.29	0.26	0.36	0.43	0.44	0.45	0.51	0.37	0.51	0.49	0.56
VT-CL-E3		0.57	0.21	0.30	0.27	0.36	0.46	0.39	0.49	0.51	0.37	0.54	0.46	0.54
VT-CL-E		0.53	0.23	0.29	0.28	0.35	0.48	0.43	0.50	0.52	0.39	0.55	0.49	0.56

Table XXII

VAPOR TRANSMISSION TEST - DATA - CLAY (Part 2)

Day	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Temp°F	70.3	72.2	71.9	70.9	73.8	72.6	73.3	70.5	68.7	63.4	59.1	60.7	64.4	62.1
R.U.	10%	10%	11%	11%	12%	11%	12%	12%	11%	11%	12%	11%	12%	11%
Blank	126.23	126.25	126.22	126.22	126.20	126.19	126.19	126.16	126.15	126.16	126.16	126.16	126.16	126.16
VT-Blank	0.07	-0.02	0.03	0.00	0.02	0.01	0.00	0.03	0.01	-0.01	0.00	0.00	0.00	0.00
VT-CL-N1	215.05	214.24	212.82	212.09	211.08	210.05	208.97	207.76	207.00	206.23	205.46	204.73	203.98	203.26
VT-CL-N2	217.84	216.91	215.36	214.55	213.41	212.30	211.14	209.86	208.98	208.12	207.31	206.40	205.64	204.94
VT-CL-N3	209.85	208.94	207.52	206.78	205.74	204.76	203.69	202.55	201.72	200.95	200.25	199.13	198.36	197.7
VT-CL-N	1.07	0.88	1.46	0.76	1.06	1.04	1.10	1.21	0.82	0.80	0.76	0.92	0.76	0.69
VT-CL-T1	210.86	209.85	208.29	207.39	206.23	205.10	203.92	202.63	201.73	200.91	200.04	199.22	198.36	197.7
VT-CL-T2	225.61	224.77	223.44	222.76	221.77	220.83	219.79	218.71	217.95	217.18	216.50	215.71	215.04	214.42
VT-CL-T3	214.58	213.63	212.08	211.22	210.03	208.94	207.76	206.48	205.61	204.81	204.00	203.17	202.36	201.71
VT-CL-T	1.07	0.93	1.48	0.81	1.11	1.05	1.13	1.22	0.84	0.80	0.79	0.81	0.78	0.64
VT-CL-A1	232.46	232.02	231.40	230.86	230.29	229.71	229.19	228.57	227.97	227.41	226.91	226.34	225.84	225.36
VT-CL-A2	226.47	225.85	225.12	224.59	224.03	223.41	222.83	222.22	221.63	221.07	220.55	219.99	219.45	218.95
VT-CL-A3	231.17	230.62	229.93	229.41	228.88	228.28	227.76	227.16	226.60	226.08	225.60	225.02	224.47	223.98
VT-CL-A	0.59	0.54	0.68	0.53	0.55	0.60	0.54	0.61	0.58	0.55	0.50	0.57	0.53	0.49
VT-CL-E1	227.70	227.18	226.29	225.83	225.18	224.59	223.89	223.20	222.71	222.24	221.82	221.36	220.86	220.52
VT-CL-E2	238.20	237.77	236.94	236.51	235.94	235.30	234.72	234.04	233.53	233.14	232.71	232.24	231.83	231.44
VT-CL-E3	240.02	239.57	238.73	238.33	237.73	237.15	236.53	235.85	235.38	234.96	234.53	234.07	233.66	233.28
VT-CL-E	0.64	0.47	0.85	0.43	0.61	0.60	0.63	0.68	0.49	0.43	0.43	0.46	0.44	0.37

Table XXIII

VAPOR TRANSMISSION - INDIVIDUAL RESULTS - CLAY (Part 2)

Day	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Temp°F	70.3	72.2	71.9	70.9	73.8	72.6	73.3	70.5	68.7	63.4	59.1	60.7	64.4	62.1
R.U.	10%	10%	11%	11%	12%	11%	12%	12%	11%	11%	12%	11%	12%	11%
VT-Blank	0.07	-0.02	0.03	0.00	0.02	0.01	0.00	0.03	0.01	-0.01	0.00	0.00	0.00	0.00
VT-CL-N1	1.07	0.81	1.42	0.73	1.01	1.03	1.08	1.21	0.76	0.77	0.77	0.73	0.75	0.72
VT-CL-N2	1.17	0.93	1.55	0.81	1.14	1.11	1.16	1.28	0.88	0.86	0.81	0.91	0.76	0.70
VT-CL-N3	0.96	0.91	1.42	0.74	1.04	0.98	1.07	1.14	0.83	0.77	0.70	1.12	0.77	0.66
VT-CL-N	1.07	0.88	1.46	0.76	1.06	1.04	1.10	1.21	0.82	0.80	0.76	0.92	0.76	0.69
VT-CL-T1	1.16	1.01	1.56	0.90	1.16	1.13	1.18	1.29	0.90	0.82	0.87	0.82	0.86	0.66
VT-CL-T2	0.96	0.84	1.33	0.68	0.99	0.94	1.04	1.08	0.76	0.77	0.68	0.79	0.67	0.62
VT-CL-T3	1.10	0.95	1.55	0.86	1.19	1.09	1.18	1.28	0.87	0.80	0.81	0.83	0.81	0.65
VT-CL-T	1.07	0.93	1.48	0.81	1.11	1.05	1.13	1.22	0.84	0.80	0.79	0.81	0.78	0.64
VT-CL-A1	0.61	0.44	0.62	0.54	0.57	0.58	0.52	0.62	0.60	0.56	0.50	0.57	0.50	0.48
VT-CL-A2	0.57	0.62	0.73	0.53	0.56	0.62	0.58	0.61	0.59	0.56	0.52	0.56	0.54	0.50
VT-CL-A3	0.60	0.55	0.69	0.52	0.53	0.60	0.52	0.60	0.56	0.52	0.48	0.58	0.55	0.49
VT-CL-A	0.59	0.54	0.68	0.53	0.55	0.60	0.54	0.61	0.58	0.55	0.50	0.57	0.53	0.49
VT-CL-E1	0.63	0.52	0.89	0.46	0.65	0.59	0.70	0.69	0.49	0.47	0.42	0.46	0.50	0.34
VT-CL-E2	0.65	0.43	0.83	0.43	0.57	0.64	0.58	0.68	0.51	0.39	0.43	0.47	0.41	0.39
VT-CL-E3	0.65	0.45	0.84	0.40	0.60	0.58	0.62	0.68	0.47	0.42	0.43	0.46	0.41	0.38
VT-CL-E	0.64	0.47	0.85	0.43	0.61	0.60	0.63	0.68	0.49	0.43	0.43	0.46	0.44	0.37

Table XXIV

VAPOR TRANSMISSION TEST - DATA - LIME (Part 1)

Day	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Temp°F	68.7	64.2	64.9	68.5	71.3	73.1	74.0	69.2	64.3	62.6	62.4	61.6	61.9	64.9
R.U.	42%	16%	17%	17%	17%	20%	20%	20%	20%	25%	20%	20%	20%	20%
Blank	148.56	148.52	148.53	148.53	148.54	148.56	148.51	148.52	148.55	148.55	148.52	148.52	148.54	148.52
VT-Blank		0.04	-0.01	0.00	-0.01	-0.02	0.05	-0.01	-0.03	0.00	0.03	0.00	-0.02	0.02
VT-LI-N1	248.28	247.84	247.14	246.59	246.04	245.38	244.39	243.73	243.07	242.46	241.87	241.31	240.79	240.23
VT-LI-N2	246.25	245.81	245.17	244.70	244.15	243.46	242.70	241.98	241.23	240.54	239.85	239.30	238.75	238.14
VT-LI-N3	243.13	242.63	241.85	241.12	240.67	239.94	238.85	238.12	237.39	236.72	236.06	235.46	234.88	234.27
VT-LI-N		0.46	0.71	0.58	0.52	0.69	0.95	0.70	0.71	0.66	0.65	0.57	0.55	0.59
VT-LI-T1	251.85	251.41	250.73	250.15	249.65	249.03	247.98	247.36	246.67	246.09	245.47	244.95	244.41	243.85
VT-LI-T2	243.32	242.85	242.09	241.40	240.90	240.23	239.13	238.46	237.70	237.07	236.39	235.81	235.24	234.64
VT-LI-T3	251.64	251.19	250.51	249.97	249.47	248.87	247.85	247.23	246.57	246.01	245.40	244.88	244.34	243.83
VT-LI-T		0.45	0.71	0.60	0.50	0.63	1.06	0.64	0.70	0.59	0.64	0.54	0.55	0.56
VT-LI-A1	250.32	249.93	249.24	248.73	248.23	247.61	246.66	246.05	245.43	244.85	244.29	243.76	243.26	242.73
VT-LI-A2	249.86	249.45	248.80	248.31	247.81	247.20	246.30	245.70	245.10	244.54	244.01	243.53	243.05	242.53
VT-LI-A3	247.11	246.65	245.97	245.41	244.91	244.30	243.27	242.66	241.98	241.40	240.78	240.30	239.78	239.25
VT-LI-A		0.42	0.67	0.52	0.50	0.61	0.96	0.61	0.63	0.57	0.57	0.50	0.50	0.53
VT-LI-E1	257.79	257.32	256.64	256.12	255.63	255.02	254.16	253.63	253.09	252.57	252.08	251.65	251.17	250.70
VT-LI-E2	256.86	256.35	255.67	255.14	254.65	254.05	253.17	252.63	252.08	251.56	251.08	250.66	250.20	249.75
VT-LI-E3	257.42	256.90	256.21	255.69	255.19	254.59	253.70	253.16	252.59	252.10	251.66	251.20	250.67	250.18
VT-LI-E		0.50	0.68	0.52	0.49	0.60	0.88	0.54	0.55	0.51	0.47	0.44	0.49	0.47

Table XXV

VAPOR TRANSMISSION - INDIVIDUAL RESULTS - LIME (Part 1)

Day	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Temp °F	68.7	64.2	64.9	68.5	71.3	73.1	74.0	69.2	64.3	62.6	62.4	61.6	61.9	64.9
R.U.	42%	16%	17%	17%	17%	20%	20%	20%	20%	25%	20%	20%	20%	20%
VT-Blank		0.04	-0.01	0.00	-0.01	-0.02	0.05	-0.01	-0.03	0.00	0.03	0.00	-0.02	0.02
VT-LI-N1		0.44	0.70	0.55	0.55	0.66	0.99	0.66	0.66	0.61	0.59	0.56	0.52	0.56
VT-LI-N2		0.44	0.64	0.47	0.55	0.69	0.76	0.72	0.75	0.69	0.69	0.55	0.55	0.61
VT-LI-N3		0.50	0.78	0.73	0.45	0.73	1.09	0.73	0.73	0.67	0.66	0.60	0.58	0.61
VT-LI-N		0.46	0.71	0.58	0.52	0.69	0.95	0.70	0.71	0.66	0.65	0.57	0.55	0.59
VT-LI-T1		0.44	0.68	0.58	0.50	0.62	1.05	0.62	0.69	0.58	0.62	0.52	0.54	0.56
VT-LI-T2		0.47	0.76	0.69	0.50	0.67	1.10	0.67	0.76	0.63	0.68	0.58	0.57	0.60
VT-LI-T3		0.45	0.68	0.54	0.50	0.60	1.02	0.62	0.66	0.56	0.61	0.52	0.54	0.51
VT-LI-T		0.45	0.71	0.60	0.50	0.63	1.06	0.64	0.70	0.59	0.64	0.54	0.55	0.56
VT-LI-A1		0.39	0.69	0.51	0.50	0.62	0.95	0.61	0.62	0.58	0.56	0.53	0.50	0.53
VT-LI-A2		0.41	0.65	0.49	0.50	0.61	0.90	0.60	0.60	0.56	0.53	0.48	0.48	0.52
VT-LI-A3		0.46	0.68	0.56	0.50	0.61	1.03	0.61	0.68	0.58	0.62	0.48	0.52	0.53
VT-LI-A		0.42	0.67	0.52	0.50	0.61	0.96	0.61	0.63	0.57	0.57	0.50	0.50	0.53
VT-LI-E1		0.47	0.68	0.52	0.49	0.61	0.86	0.53	0.54	0.52	0.49	0.43	0.48	0.47
VT-LI-E2		0.51	0.68	0.53	0.49	0.60	0.88	0.54	0.55	0.52	0.48	0.42	0.46	0.45
VT-LI-E3		0.52	0.69	0.52	0.50	0.60	0.89	0.54	0.57	0.49	0.44	0.46	0.53	0.49
VT-LI-E		0.50	0.68	0.52	0.49	0.60	0.88	0.54	0.56	0.51	0.47	0.44	0.49	0.47

Table XXVI

VAPOR TRANSMISSION TEST - DATA - LIME (Part 2)

Day	8	9	10	11	12	13	14	15	16	17	18	19	20	
Temp°F	69.3	72.4	75.4	75.1	74.6	75.1	71.0	68.8	68.7	72.4	71.5	71.7	69.3	
R.U.	22%	19%	19%	20%	22%	23%	20%	20%	20%	19%	19%	20%	20%	
Blank	148.52	148.51	148.48	148.50	148.50	148.51	148.44	148.43	148.45	148.46	148.44	148.44	148.44	
VT-Blank	0.00	0.01	0.03	-0.02	0.00	-0.01	0.07	0.01	-0.02	-0.01	0.02	0.00	0.00	
VT-LI-N1	239.65	239.13	238.62	238.04	237.54	236.94	236.32	235.81	235.27	234.66	234.12	233.57	233.03	
VT-LI-N2	237.54	237.00	236.48	235.88	235.36	234.76	234.15	233.65	233.07	232.42	231.77	231.18	230.62	
VT-LI-N3	233.65	233.09	232.56	231.94	231.40	230.77	230.16	229.61	229.05	228.42	227.81	227.21	226.63	
VT-LI-N	0.60	0.54	0.52	0.60	0.52	0.61	0.61	0.52	0.56	0.63	0.60	0.58	0.56	
VT-LI-T1	243.31	242.82	242.34	241.79	241.30	240.77	240.24	239.74	239.20	238.61	238.09	237.56	237.04	
VT-LI-T2	234.05	233.49	232.98	232.38	231.88	231.30	230.73	230.16	229.56	228.94	228.32	227.74	227.18	
VT-LI-T3	243.30	242.85	242.37	241.84	241.36	240.85	240.30	239.75	239.18	238.59	238.05	237.51	236.97	
VT-LI-T	0.55	0.50	0.49	0.56	0.49	0.54	0.55	0.54	0.57	0.60	0.56	0.55	0.54	
VT-LI-A1	242.15	241.66	241.20	240.68	240.22	239.72	239.19	238.68	238.16	237.57	237.05	236.57	236.05	
VT-LI-A2	241.99	241.49	241.04	240.53	240.07	239.57	239.06	238.53	237.99	237.43	236.91	236.41	235.95	
VT-LI-A3	238.64	238.15	237.68	237.15	236.67	236.11	235.56	235.05	234.46	233.88	233.34	232.80	232.28	
VT-LI-A	0.58	0.49	0.46	0.52	0.47	0.52	0.53	0.52	0.55	0.58	0.53	0.51	0.50	
VT-LI-E1	250.30	249.85	249.44	248.97	248.51	248.05	247.53	247.10	246.64	246.19	245.74	245.35	244.95	
VT-LI-E2	249.30	248.92	248.43	247.97	247.53	247.06	246.57	246.11	245.64	245.19	244.77	244.38	243.99	
VT-LI-E3	249.92	249.49	249.10	248.65	248.23	247.78	247.35	246.89	246.41	245.99	245.60	245.18	244.77	
VT-LI-E	0.44	0.42	0.43	0.46	0.44	0.46	0.48	0.45	0.47	0.44	0.42	0.40	0.40	

Table XXVII

VAPOR TRANSMISSION - INDIVIDUAL RESULTS - LIME (Part 2)

Day	8	9	10	11	12	13	14	15	16	17	18	19	20	
Temp°F	69.3	72.4	75.4	75.1	74.6	75.1	71.0	68.8	68.7	72.4	71.5	71.7	69.3	
R.U.	22%	19%	19%	20%	22%	23%	20%	20%	20%	19%	19%	20%	20%	
VT-Blank	0.00	0.01	0.03	-0.02	0.00	-0.01	0.07	0.01	-0.02	-0.01	0.02	0.00	0.00	
VT-LI-N1	0.58	0.52	0.51	0.58	0.50	0.60	0.62	0.51	0.54	0.61	0.54	0.55	0.54	
VT-LI-N2	0.60	0.54	0.52	0.60	0.52	0.60	0.61	0.50	0.58	0.65	0.65	0.59	0.56	
VT-LI-N3	0.62	0.56	0.53	0.62	0.54	0.63	0.61	0.55	0.56	0.63	0.61	0.60	0.58	
VT-LI-N	0.60	0.54	0.52	0.60	0.52	0.61	0.61	0.52	0.56	0.63	0.60	0.58	0.56	
VT-LI-T1	0.54	0.49	0.48	0.55	0.49	0.53	0.53	0.50	0.54	0.59	0.52	0.53	0.52	
VT-LI-T2	0.59	0.56	0.51	0.60	0.50	0.58	0.57	0.57	0.60	0.62	0.62	0.58	0.56	
VT-LI-T3	0.62	0.45	0.48	0.53	0.48	0.51	0.55	0.55	0.57	0.59	0.54	0.54	0.54	
VT-LI-T	0.55	0.50	0.49	0.56	0.49	0.54	0.55	0.54	0.57	0.60	0.56	0.55	0.54	
VT-LI-A1	0.58	0.49	0.46	0.52	0.46	0.50	0.53	0.51	0.52	0.59	0.52	0.48	0.52	
VT-LI-A2	0.54	0.50	0.45	0.51	0.46	0.50	0.51	0.53	0.54	0.56	0.52	0.50	0.46	
VT-LI-A3	0.61	0.49	0.47	0.53	0.48	0.56	0.55	0.51	0.59	0.58	0.54	0.54	0.52	
VT-LI-A	0.58	0.49	0.46	0.52	0.47	0.52	0.53	0.52	0.55	0.58	0.53	0.51	0.50	
VT-LI-E1	0.60	0.45	0.41	0.47	0.46	0.46	0.52	0.43	0.46	0.45	0.45	0.39	0.40	
VT-LI-E2	0.45	0.38	0.49	0.46	0.44	0.47	0.49	0.46	0.47	0.45	0.42	0.39	0.39	
VT-LI-E3	0.56	0.43	0.39	0.45	0.42	0.45	0.43	0.46	0.48	0.42	0.39	0.42	0.41	
VT-LI-E	0.44	0.42	0.43	0.46	0.44	0.46	0.48	0.45	0.47	0.44	0.42	0.40	0.40	

Table XXVIII

VAPOR TRANSMISSION TEST - DATA - GYPSUM (Part 1)

Day	1	2	3	4	5	6	7	8	9	1	2	3	4	5
Temp°F	68.7	64.2	64.9	68.5	71.3	73.1	74.0	69.2	64.3	62.6	62.4	61.6	61.9	64.9
R.U.	42%	16%	17%	17%	17%	20%	20%	20%	20%	25%	20%	20%	20%	20%
Blank	134.85	134.89	134.91	134.89	134.87	134.87	134.90	134.87	134.87	134.89	134.91	134.89	134.88	134.89
VT-Blank		-0.04	-0.02	0.02	0.02	0.00	-0.03	0.03	0.00	-0.02	-0.02	0.02	0.01	-0.01
VT-GY-N1	224.37	223.66	222.65	222.54	221.16	220.13	218.99	217.93	216.84	215.89	215.06	214.27	213.44	212.63
VT-GY-N2	225.99	225.36	224.37	223.65	222.88	221.87	220.81	219.70	218.63	217.71	216.93	216.14	215.31	214.53
VT-GY-N3	225.74	225.12	224.21	223.82	222.65	221.69	220.54	219.58	218.47	217.63	216.77	216.06	215.23	214.44
VT-GY-N		0.65	0.97	0.41	1.11	1.00	1.12	1.04	1.09	0.90	0.82	0.76	0.83	0.79
VT-GY-T1	218.90	218.25	217.17	216.35	215.56	214.47	213.29	212.08	210.92	209.90	209.05	208.24	207.35	206.54
VT-GY-T2	224.23	223.54	222.55	221.70	220.92	219.87	218.72	217.55	216.42	215.42	214.53	213.75	212.85	212.05
VT-GY-T3	228.95	228.31	227.41	226.65	225.89	224.93	223.81	222.82	221.71	220.85	220.03	219.34	218.52	217.78
VT-GY-T		0.66	0.99	0.81	0.78	1.03	1.15	1.12	1.13	0.96	0.85	0.76	0.87	0.78
VT-GY-A1	225.69	225.15	224.25	223.56	222.92	222.07	221.04	220.20	219.21	218.46	217.71	217.06	216.33	215.65
VT-GY-A2	245.87	245.37	244.62	244.11	243.62	243.01	242.39	241.72	241.06	240.52	240.03	239.55	239.03	238.50
VT-GY-A3	228.22	227.61	226.79	226.13	225.38	224.51	223.45	222.56	221.51	220.71	219.93	219.28	218.51	217.78
VT-GY-A		0.55	0.82	0.62	0.63	0.78	0.90	0.80	0.90	0.70	0.67	0.59	0.67	0.65
VT-GY-E1	230.78	230.11	229.23	228.67	228.03	227.27	226.46	225.62	224.80	224.10	223.46	222.85	222.20	221.56
VT-GY-E2	223.29	222.71	221.88	221.15	220.49	219.63	218.59	217.75	216.73	215.97	215.22	214.54	213.79	213.08
VT-GY-E3	235.27	234.53	233.65	233.00	232.44	231.67	230.79	230.03	229.15	228.47	227.79	227.21	226.53	225.88
VT-GY-E		0.66	0.86	0.65	0.62	0.80	0.91	0.81	0.91	0.71	0.69	0.62	0.69	0.67

Table XXIX

VAPOR TRANSMISSION - INDIVIDUAL RESULTS - GYPSUM (Part 1)

Day	1	2	3	4	5	6	7	8	9	1	2	3	4	5
Temp °F	68.7	64.2	64.9	68.5	71.3	73.1	74.0	69.2	64.3	62.6	62.4	61.6	61.9	64.9
R.U.	42%	16%	17%	17%	17%	20%	20%	20%	20%	25%	20%	20%	20%	20%
VT-Blank		-0.04	-0.02	0.02	0.02	0.00	-0.03	0.03	0.00	-0.02	-0.02	0.02	0.01	-0.01
VT-GY-N1		0.71	1.01	0.11	1.38	1.03	1.14	1.06	1.09	0.95	0.83	0.79	0.83	0.81
VT-GY-N2		0.63	0.99	0.72	0.77	1.01	1.06	1.11	1.07	0.92	0.78	0.79	0.83	0.78
VT-GY-N3		0.62	0.91	0.39	1.17	0.96	1.15	0.96	1.11	0.84	0.86	0.71	0.83	0.79
VT-GY-N		0.65	0.97	0.41	1.11	1.00	1.12	1.04	1.09	0.90	0.82	0.76	0.83	0.79
VT-GY-T1		0.65	1.08	0.82	0.79	1.09	1.18	1.21	1.16	1.02	0.85	0.81	0.89	0.81
VT-GY-T2		0.69	0.99	0.85	0.78	1.05	1.15	1.17	1.13	1.00	0.89	0.78	0.90	0.80
VT-GY-T3		0.64	0.90	0.76	0.76	0.96	1.12	0.99	1.11	0.86	0.82	0.69	0.82	0.74
VT-GY-T		0.66	0.99	0.81	0.78	1.03	1.15	1.12	1.13	0.96	0.85	0.76	0.87	0.78
VT-GY-A1		0.54	0.90	0.69	0.64	0.85	1.03	0.84	0.99	0.75	0.75	0.65	0.73	0.68
VT-GY-A2		0.50	0.75	0.51	0.49	0.61	0.62	0.67	0.66	0.54	0.49	0.48	0.52	0.53
VT-GY-A3		0.61	0.82	0.66	0.75	0.87	1.06	0.89	1.05	0.80	0.78	0.65	0.77	0.73
VT-GY-A		0.55	0.82	0.62	0.63	0.78	0.90	0.80	0.90	0.70	0.67	0.59	0.67	0.65
VT-GY-E1		0.67	0.88	0.56	0.64	0.76	0.81	0.84	0.82	0.70	0.64	0.61	0.65	0.64
VT-GY-E2		0.58	0.83	0.73	0.66	0.86	1.04	0.84	1.02	0.76	0.75	0.68	0.75	0.71
VT-GY-E3		0.74	0.88	0.65	0.56	0.77	0.88	0.76	0.88	0.68	0.68	0.58	0.68	0.65
VT-GY-E		0.66	0.86	0.65	0.62	0.80	0.91	0.81	0.91	0.71	0.69	0.62	0.69	0.67

Table XXX

VAPOR TRANSMISSION TEST - DATA - GYPSUM (Part 2)

Day	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temp°F	69.3	72.4	75.4	75.1	74.6	75.1	71.0	68.8	68.7	72.4	71.5	71.7	69.3	68.9
R.U.	22%	19%	19%	20%	22%	23%	20%	20%	20%	19%	19%	20%	20%	20%
Blank	134.87	134.86	134.84	134.85	134.85	134.87	134.84	134.82	134.83	134.85	134.84	134.84	134.84	134.83
VT-Blank	0.02	0.01	0.02	-0.01	0.00	-0.02	0.03	0.02	-0.01	-0.02	0.01	0.00	0.00	0.01
VT-GY-N1	211.75	210.84	209.95	209.02	208.10	207.18	206.30	205.47	204.61	203.64	202.74	201.81	200.92	200.03
VT-GY-N2	213.68	212.82	211.97	211.08	210.20	209.26	208.36	207.49	206.63	205.70	204.81	203.88	202.99	202.12
VT-GY-N3	213.60	212.71	211.90	211.02	210.15	209.25	208.33	207.48	206.59	205.67	204.75	203.85	202.96	202.11
VT-GY-N	0.86	0.89	0.85	0.90	0.89	0.92	0.90	0.85	0.87	0.94	0.90	0.92	0.89	0.87
VT-GY-T1	205.62	204.77	203.90	202.92	202.04	201.07	200.14	199.29	198.40	197.44	196.52	195.60	194.75	193.83
VT-GY-T2	211.17	210.36	209.51	208.55	207.69	206.77	205.88	205.07	204.20	203.26	202.32	201.43	200.49	199.62
VT-GY-T3	216.94	216.14	215.28	214.37	213.56	212.66	211.77	210.94	210.07	209.15	208.25	207.36	206.45	205.57
VT-GY-T	0.88	0.82	0.86	0.95	0.85	0.93	0.90	0.83	0.88	0.94	0.92	0.90	0.90	0.89
VT-GY-A1	214.90	214.25	213.58	212.86	212.23	211.53	210.86	210.21	209.51	208.79	208.14	207.42	206.77	206.14
VT-GY-A2	237.99	237.39	236.79	236.09	235.49	234.83	234.21	233.59	232.93	232.23	231.58	230.92	230.26	229.63
VT-GY-A3	217.03	216.36	215.68	214.95	214.31	213.60	212.92	212.24	211.52	210.78	210.04	209.32	208.62	207.93
VT-GY-A	0.67	0.64	0.65	0.72	0.62	0.69	0.66	0.65	0.69	0.72	0.68	0.70	0.67	0.65
VT-GY-E1	220.91	220.27	219.64	218.92	218.29	217.61	216.98	216.34	215.65	214.94	214.26	213.57	212.89	212.25
VT-GY-E2	212.34	211.66	210.98	210.23	209.58	208.88	208.21	207.57	206.87	206.10	205.36	204.61	203.91	203.22
VT-GY-E3	225.20	224.57	223.90	223.18	222.55	221.86	221.22	220.61	219.93	219.21	218.51	217.82	217.13	216.48
VT-GY-E	0.69	0.65	0.66	0.73	0.64	0.69	0.65	0.63	0.69	0.73	0.71	0.71	0.69	0.66

Table XXXI

VAPOR TRANSMISSION - INDIVIDUAL RESULTS - GYPSUM (Part 2)

Day	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temp°F	69.3	72.4	75.4	75.1	74.6	75.1	71.0	68.8	68.7	72.4	71.5	71.7	69.3	68.9
R.U.	22%	19%	19%	20%	22%	23%	20%	20%	20%	19%	19%	20%	20%	20%
VT-Blank	0.03	0.01	0.02	-0.01	0.00	-0.02	0.03	0.02	-0.01	-0.02	0.01	0.00	0.00	0.01
VT-GY-N1	0.88	0.91	0.89	0.93	0.92	0.92	0.88	0.83	0.86	0.97	0.90	0.93	0.89	0.89
VT-GY-N2	0.85	0.86	0.85	0.89	0.88	0.94	0.90	0.87	0.86	0.93	0.89	0.93	0.89	0.87
VT-GY-N3	0.84	0.89	0.81	0.88	0.87	0.90	0.92	0.85	0.89	0.92	0.92	0.90	0.89	0.85
VT-GY-N	0.86	0.89	0.85	0.90	0.89	0.92	0.90	0.85	0.87	0.94	0.90	0.92	0.89	0.87
VT-GY-T1	0.92	0.85	0.87	0.98	0.88	0.97	0.93	0.85	0.89	0.96	0.92	0.92	0.85	0.92
VT-GY-T2	0.88	0.81	0.85	0.96	0.86	0.92	0.89	0.81	0.87	0.94	0.94	0.89	0.94	0.87
VT-GY-T3	0.84	0.80	0.86	0.91	0.81	0.90	0.89	0.83	0.87	0.92	0.90	0.89	0.91	0.88
VT-GY-T	0.88	0.82	0.86	0.95	0.85	0.93	0.90	0.83	0.88	0.94	0.92	0.90	0.90	0.89
VT-GY-A1	0.75	0.65	0.67	0.72	0.63	0.70	0.67	0.65	0.70	0.72	0.65	0.72	0.65	0.63
VT-GY-A2	0.51	0.60	0.60	0.70	0.60	0.66	0.62	0.62	0.66	0.70	0.65	0.66	0.66	0.63
VT-GY-A3	0.75	0.67	0.68	0.73	0.64	0.71	0.68	0.68	0.72	0.74	0.74	0.72	0.70	0.69
VT-GY-A	0.67	0.64	0.65	0.72	0.62	0.69	0.66	0.65	0.69	0.72	0.68	0.70	0.67	0.65
VT-GY-E1	0.65	0.64	0.63	0.72	0.63	0.68	0.63	0.64	0.69	0.71	0.68	0.69	0.68	0.64
VT-GY-E2	0.74	0.68	0.68	0.75	0.65	0.70	0.67	0.64	0.70	0.77	0.74	0.75	0.70	0.69
VT-GY-E3	0.68	0.63	0.67	0.72	0.63	0.69	0.64	0.61	0.68	0.72	0.70	0.69	0.69	0.65
VT-GY-E	0.69	0.65	0.68	0.73	0.64	0.69	0.65	0.63	0.69	0.73	0.71	0.71	0.69	0.66

Table XXXII

VAPOR TRANSMISSION TEST - DATA - CLAY / LIME (Part 1)

Day	1	2	3	4	5	6	7	8	9	1	2	3	4	5
Temp°F	68.7	64.2	64.9	68.5	71.3	73.1	74.0	69.2	64.3	62.6	62.4	61.6	61.9	64.9
R.U.	42%	16%	17%	17%	17%	20%	20%	20%	20%	25%	20%	20%	20%	20%
Blank	141.72	141.49	141.44	141.49	141.49	141.47	141.48	141.46	141.53	141.52	141.48	141.47	141.50	141.48
VT-Blank		0.23	0.05	-0.05	0.00	0.02	-0.01	0.02	-0.07	0.01	0.04	0.01	-0.03	0.02
VT-CM-N1	257.62	257.17	256.47	255.90	255.40	254.81	253.80	253.18	252.58	251.98	251.41	250.93	250.40	249.89
VT-CM-N2	247.68	247.17	246.34	245.75	245.11	244.39	243.24	242.47	241.79	241.08	240.43	239.86	239.20	238.67
VT-CM-N3	255.80	255.42	254.83	254.40	253.87	253.24	252.55	251.87	250.85	250.12	249.52	249.03	248.50	247.94
VT-CM-N		0.45	0.71	0.53	0.56	0.65	0.95	0.69	0.77	0.68	0.61	0.51	0.57	0.53
VT-CM-T1	246.90	245.97	245.18	244.59	243.91	243.25	242.07	241.37	240.63	239.99	239.34	238.82	238.22	237.61
VT-CM-T2	254.29	253.84	253.09	252.49	251.94	251.29	250.25	249.60	248.97	248.36	247.77	247.27	246.80	246.18
VT-CM-T3	248.82	248.30	247.53	246.95	246.32	245.63	244.52	243.79	243.11	242.46	241.85	241.30	240.76	240.14
VT-CM-T		0.63	0.77	0.59	0.62	0.67	1.11	0.69	0.68	0.63	0.62	0.52	0.54	0.62
VT-CM-A1	244.31	243.86	243.09	242.57	241.92	241.23	240.18	239.47	238.82	238.19	237.56	237.04	236.48	235.89
VT-CM-A2	253.30	252.89	252.26	251.70	251.18	250.60	249.68	249.07	248.49	247.95	247.46	247.00	246.49	246.13
VT-CM-A3	251.08	250.64	250.01	249.48	248.99	248.43	247.53	246.91	246.37	245.82	245.31	244.85	244.44	243.91
VT-CM-A		0.43	0.68	0.54	0.55	0.61	0.96	0.65	0.59	0.57	0.54	0.48	0.49	0.49
VT-CM-E1	255.85	255.46	254.92	254.43	253.97	253.46	252.80	252.13	251.64	251.19	250.75	250.40	250.07	249.62
VT-CM-E2	262.93	262.55	261.98	261.48	261.02	260.52	259.82	259.14	258.63	258.08	257.56	257.16	256.76	256.31
VT-CM-E3	253.31	252.88	252.29	251.76	251.26	250.71	250.03	249.34	248.86	248.39	247.93	247.55	247.17	246.71
VT-CM-E		0.40	0.57	0.51	0.47	0.52	0.68	0.68	0.49	0.49	0.47	0.38	0.37	0.45

Table XXXIII

VAPOR TRANSMISSION - INDIVIDUAL RESULTS - CLAY / LIME (Part 1)

Day	1	2	3	4	5	6	7	8	9	1	2	3	4	5
Temp °F	68.7	64.2	64.9	68.5	71.3	73.1	74.0	69.2	64.3	62.6	62.4	61.6	61.9	64.9
R.U.	42%	16%	17%	17%	17%	20%	20%	20%	20%	25%	20%	20%	20%	20%
VT-Blank		0.23	0.05	-0.05	0.00	0.02	-0.01	0.02	-0.07	0.01	0.04	0.01	-0.03	0.02
VT-CM-N1		0.45	0.70	0.57	0.50	0.59	1.01	0.62	0.60	0.60	0.57	0.48	0.53	0.51
VT-CM-N2		0.51	0.83	0.59	0.64	0.72	1.15	0.77	0.68	0.71	0.65	0.57	0.66	0.53
VT-CM-N3		0.38	0.59	0.43	0.53	0.63	0.69	0.68	1.02	0.73	0.60	0.49	0.53	0.56
VT-CM-N		0.45	0.71	0.53	0.56	0.65	0.95	0.69	0.77	0.68	0.61	0.51	0.57	0.53
VT-CM-T1		0.93	0.79	0.59	0.68	0.66	1.18	0.70	0.74	0.64	0.65	0.52	0.60	0.61
VT-CM-T2		0.45	0.75	0.60	0.55	0.65	1.04	0.65	0.63	0.61	0.59	0.50	0.47	0.62
VT-CM-T3		0.52	0.77	0.58	0.63	0.69	1.11	0.73	0.68	0.65	0.61	0.55	0.54	0.62
VT-CM-T		0.63	0.77	0.59	0.62	0.67	1.11	0.69	0.68	0.63	0.62	0.52	0.54	0.62
VT-CM-A1		0.45	0.77	0.52	0.65	0.69	1.05	0.71	0.65	0.63	0.63	0.52	0.56	0.59
VT-CM-A2		0.41	0.63	0.56	0.52	0.58	0.92	0.61	0.58	0.54	0.49	0.46	0.51	0.36
VT-CM-A3		0.44	0.63	0.53	0.49	0.56	0.90	0.62	0.54	0.55	0.51	0.46	0.41	0.53
VT-CM-A		0.43	0.68	0.54	0.55	0.61	0.96	0.65	0.59	0.57	0.54	0.48	0.49	0.49
VT-CM-E1		0.39	0.54	0.49	0.46	0.51	0.66	0.67	0.49	0.45	0.44	0.35	0.33	0.45
VT-CM-E2		0.38	0.57	0.50	0.46	0.50	0.70	0.68	0.51	0.55	0.52	0.40	0.40	0.45
VT-CM-E3		0.43	0.59	0.53	0.50	0.55	0.68	0.69	0.48	0.47	0.46	0.38	0.38	0.46
VT-CM-E		0.40	0.57	0.51	0.47	0.52	0.68	0.68	0.49	0.49	0.47	0.38	0.37	0.45

Table XXXIV

VAPOR TRANSMISSION TEST - DATA - CLAY / LIME (Part 2)

Day	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temp°F	69.3	72.4	75.4	75.1	74.6	75.1	71.0	68.8	68.7	72.4	71.5	71.7	69.3	68.9
R.U.	22%	19%	19%	20%	22%	23%	20%	29%	20%	19%	19%	20%	20%	20%
Blank	141.48	141.45	141.44	141.45	141.46	141.47	141.44	141.43	141.44	141.41	141.42	141.42	141.41	141.41
VT-Blank	0.00	0.03	0.01	-0.01	-0.01	-0.01	0.03	0.01	-0.01	0.03	-0.01	0.00	0.01	0.00
VT-CM-N1	249.27	248.68	248.08	247.45	246.85	246.24	245.60	245.04	244.45	243.94	243.38	242.81	242.33	241.82
VT-CM-N2	237.95	237.28	236.61	235.93	235.25	234.55	233.83	233.17	232.54	232.02	231.45	230.86	230.30	229.78
VT-CM-N3	247.30	246.70	246.11	245.47	244.86	244.21	243.55	242.98	242.37	241.81	241.23	240.65	240.16	239.60
VT-CM-N	0.66	0.62	0.62	0.65	0.63	0.65	0.67	0.60	0.61	0.53	0.57	0.58	0.51	0.53
VT-CM-T1	236.87	236.23	235.56	234.91	234.27	233.61	232.93	232.26	231.62	231.04	230.49	229.84	229.33	228.80
VT-CM-T2	245.54	244.93	244.30	243.69	243.05	242.42	241.78	241.24	240.60	240.07	239.52	238.91	238.39	237.83
VT-CM-T3	239.42	238.78	238.13	237.46	236.80	236.14	235.50	234.88	234.21	233.67	233.09	232.46	231.90	231.34
VT-CM-T	0.70	0.63	0.65	0.64	0.65	0.65	0.65	0.61	0.65	0.55	0.56	0.63	0.53	0.55
VT-CM-A1	235.30	234.76	234.21	233.64	233.09	232.51	232.06	231.50	230.92	230.45	229.96	229.40	228.86	228.33
VT-CM-A2	245.52	245.07	244.63	244.16	243.69	243.18	242.73	242.32	241.79	241.35	240.91	240.41	239.90	239.40
VT-CM-A3	243.43	242.95	242.47	241.98	241.50	241.00	240.55	240.14	239.63	239.19	238.74	238.24	237.76	237.27
VT-CM-A	0.56	0.49	0.49	0.51	0.50	0.53	0.45	0.46	0.54	0.45	0.46	0.52	0.51	0.51
VT-CM-E1	249.16	248.76	248.36	247.95	247.56	247.14	246.71	246.30	245.89	245.52	245.19	244.85	244.50	244.08
VT-CM-E2	255.81	255.39	254.95	254.51	254.09	253.63	253.15	252.71	252.25	251.84	251.38	250.92	250.48	250.06
VT-CM-E3	246.24	245.80	245.38	244.94	244.52	244.10	243.65	243.25	242.77	242.38	241.97	241.54	241.16	240.80
VT-CM-E	0.48	0.42	0.42	0.43	0.41	0.43	0.45	0.42	0.45	0.39	0.40	0.41	0.39	0.40

Table XXXV

VAPOR TRANSMISSION - INDIVIDUAL RESULTS - CLAY / LIME (Part 2)

Day	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temp°F	69.3	72.4	75.4	75.1	74.6	75.1	71.0	68.8	68.7	72.4	71.5	71.7	69.3	68.9
R.U.	22%	19%	19%	20%	22%	23%	20%	29%	20%	19%	19%	20%	20%	20%
VT-Blank	0.00	0.03	0.01	-0.01	-0.01	-0.01	0.03	0.01	-0.01	0.03	-0.01	0.00	0.01	0.00
VT-CM-N1	0.62	0.59	0.60	0.63	0.60	0.61	0.64	0.56	0.59	0.51	0.56	0.57	0.48	0.51
VT-CM-N2	0.72	0.67	0.67	0.68	0.68	0.70	0.72	0.66	0.63	0.52	0.57	0.59	0.56	0.52
VT-CM-N3	0.64	0.60	0.59	0.64	0.61	0.65	0.66	0.57	0.61	0.56	0.58	0.58	0.49	0.56
VT-CM-N	0.66	0.62	0.62	0.65	0.63	0.65	0.67	0.60	0.61	0.53	0.57	0.58	0.51	0.53
VT-CM-T1	0.74	0.64	0.67	0.65	0.64	0.66	0.68	0.67	0.64	0.58	0.55	0.65	0.51	0.53
VT-CM-T2	0.64	0.61	0.63	0.61	0.64	0.63	0.64	0.54	0.64	0.53	0.55	0.61	0.52	0.56
VT-CM-T3	0.72	0.64	0.65	0.67	0.66	0.66	0.64	0.62	0.67	0.54	0.58	0.63	0.56	0.56
VT-CM-T	0.70	0.63	0.65	0.64	0.65	0.65	0.65	0.61	0.65	0.55	0.56	0.63	0.53	0.55
VT-CM-A1	0.59	0.54	0.55	0.57	0.55	0.58	0.45	0.56	0.58	0.47	0.49	0.56	0.54	0.53
VT-CM-A2	0.61	0.45	0.44	0.47	0.47	0.51	0.45	0.41	0.53	0.44	0.44	0.50	0.51	0.50
VT-CM-A3	0.48	0.48	0.48	0.49	0.48	0.50	0.45	0.41	0.51	0.44	0.45	0.50	0.48	0.49
VT-CM-A	0.56	0.49	0.49	0.51	0.50	0.53	0.45	0.46	0.54	0.45	0.46	0.52	0.51	0.51
VT-CM-E1	0.46	0.40	0.40	0.41	0.39	0.42	0.43	0.41	0.41	0.37	0.33	0.34	0.35	0.42
VT-CM-E2	0.50	0.42	0.44	0.44	0.42	0.46	0.48	0.44	0.46	0.41	0.46	0.46	0.44	0.42
VT-CM-E3	0.47	0.44	0.42	0.44	0.42	0.42	0.45	0.40	0.48	0.39	0.41	0.43	0.38	0.36
VT-CM-E	0.48	0.42	0.42	0.43	0.41	0.43	0.45	0.42	0.45	0.39	0.40	0.41	0.39	0.40

Table XXXVI

VAPOR TRANSMISSION TEST - DATA - GYPSUM / LIME (Part 1)

Day	1	2	3	4	5	6	7	8	9	1	2	3	4	5
Tamp°F	68.7	64.2	64.9	68.5	71.3	73.1	74.0	69.2	64.3	62.6	62.4	61.6	61.9	64.9
R.U.	42%	16%	17%	17%	17%	20%	20%	20%	20%	25%	20%	20%	20%	20%
Blank	144.67	144.62	144.62	144.62	144.62	144.59	144.63	144.55	144.58	144.57	144.57	144.58	144.57	144.55
VT-Blank		0.05	0.00	0.00	0.00	0.03	-0.04	0.08	-0.03	0.01	0.00	-0.01	0.01	0.02
VT-GM-N1	241.26	240.89	240.19	239.65	239.22	238.41	237.74	236.91	236.21	235.48	234.90	234.36	233.76	233.22
VT-GM-N2	236.69	236.22	235.45	235.88	234.34	233.48	232.75	231.80	231.03	230.24	229.59	229.01	228.33	227.74
VT-GM-N3	240.01	239.63	238.92	238.38	237.88	237.13	236.44	235.62	234.87	234.18	233.56	233.01	232.37	231.84
VT-GM-N		0.41	0.73	0.22	0.82	0.81	0.70	0.87	0.74	0.74	0.62	0.56	0.64	0.55
VT-GM-T1	237.00	236.63	235.98	235.43	234.94	234.20	233.54	232.75	232.03	231.36	230.77	230.27	229.68	229.14
VT-GM-T2	237.80	237.40	236.70	236.15	235.66	234.84	234.16	233.25	232.56	231.79	231.20	230.64	230.04	229.47
VT-GM-T3	245.12	244.77	244.14	243.67	243.26	242.54	241.92	241.20	240.50	239.86	239.32	238.84	238.26	237.78
VT-GM-T		0.37	0.66	0.52	0.46	0.76	0.65	0.81	0.70	0.69	0.57	0.51	0.59	0.53
VT-GM-A1	240.14	239.76	239.06	238.42	237.92	237.25	236.44	235.73	234.91	234.21	233.60	233.08	232.45	231.94
VT-GM-A2	242.83	242.48	241.77	241.27	240.81	240.04	239.39	238.64	237.91	237.24	236.67	236.15	235.55	235.05
VT-GM-A3	239.44	239.05	238.36	237.85	237.29	236.53	235.85	235.00	234.31	233.55	232.95	232.40	231.77	231.24
VT-GM-A		0.37	0.70	0.55	0.51	0.73	0.71	0.77	0.75	0.71	0.59	0.53	0.62	0.51
VT-GM-E1	248.08	247.69	247.09	246.62	246.21	245.49	244.94	244.28	243.78	243.22	242.81	242.40	241.96	241.53
VT-GM-E2	243.14	242.70	242.06	241.54	241.10	240.37	239.77	239.02	238.48	237.88	237.46	237.02	236.54	236.10
VT-GM-E3	237.05	236.60	235.95	235.43	234.95	234.23	233.59	232.84	232.22	231.64	231.15	230.70	230.21	229.73
VT-GM-E		0.43	0.63	0.50	0.44	0.72	0.60	0.72	0.55	0.58	0.44	0.43	0.47	0.45

Table XXXVII

VAPOR TRANSMISSION - INDIVIDUAL RESULTS - GYPSUM / LIME (Part 1)

Day	1	2	3	4	5	6	7	8	9	1	2	3	4	5
Temp °F	68.7	64.2	64.9	68.5	71.3	73.1	74.0	69.2	64.3	62.6	62.4	61.6	61.9	64.9
R.U.	42%	16%	17%	17%	17%	20%	20%	20%	20%	25%	20%	20%	20%	20%
VT-Blank		0.05	0.00	0.00	0.00	0.03	-0.04	0.08	-0.03	0.01	0.00	-0.01	0.01	0.02
VT-GM-N1		0.37	0.70	0.54	0.43	0.81	0.67	0.83	0.70	0.73	0.58	0.54	0.60	0.54
VT-GM-N2		0.47	0.77	-0.43	1.54	0.86	0.73	0.95	0.77	0.79	0.65	0.58	0.68	0.59
VT-GM-N3		0.38	0.71	0.54	0.50	0.75	0.69	0.82	0.75	0.69	0.62	0.55	0.64	0.53
VT-GM-N		0.41	0.73	0.22	0.82	0.81	0.70	0.87	0.74	0.74	0.62	0.56	0.64	0.55
VT-GM-T1		0.37	0.65	0.55	0.49	0.74	0.66	0.79	0.72	0.67	0.59	0.50	0.59	0.54
VT-GM-T2		0.40	0.70	0.55	0.49	0.82	0.68	0.91	0.69	0.77	0.59	0.56	0.60	0.57
VT-GM-T3		0.35	0.63	0.47	0.41	0.72	0.62	0.72	0.70	0.64	0.54	0.48	0.58	0.48
VT-GM-T		0.37	0.66	0.52	0.46	0.76	0.65	0.81	0.70	0.69	0.57	0.51	0.59	0.53
VT-GM-A1		0.38	0.70	0.64	0.50	0.67	0.81	0.71	0.82	0.70	0.61	0.52	0.63	0.51
VT-GM-A2		0.35	0.71	0.50	0.46	0.77	0.65	0.75	0.73	0.67	0.57	0.52	0.60	0.50
VT-GM-A3		0.39	0.69	0.51	0.56	0.76	0.68	0.85	0.69	0.76	0.60	0.55	0.63	0.53
VT-GM-A		0.37	0.70	0.55	0.51	0.73	0.71	0.77	0.75	0.71	0.59	0.53	0.62	0.51
VT-GM-E1		0.39	0.60	0.47	0.41	0.72	0.55	0.66	0.50	0.56	0.41	0.41	0.44	0.43
VT-GM-E2		0.44	0.64	0.52	0.44	0.73	0.60	0.75	0.54	0.60	0.42	0.44	0.48	0.44
VT-GM-E3		0.45	0.65	0.52	0.48	0.72	0.64	0.75	0.62	0.58	0.49	0.45	0.49	0.48
VT-GM-E		0.43	0.63	0.50	0.44	0.72	0.60	0.72	0.55	0.58	0.44	0.43	0.47	0.45

Table XXXVIII

VAPOR TRANSMISSION TEST - DATA - GYPSUM / LIME (Part 2)

Day	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temp°F	69.3	72.4	75.4	75.1	74.6	75.1	71.0	68.8	68.7	72.4	71.5	71.7	69.3	68.9
R.U.	22%	19%	19%	20%	22%	23%	20%	20%	20%	19%	19%	20%	20%	20%
Blank	144.54	144.54	144.53	144.53	144.55	144.55	144.53	144.55	144.54	144.55	144.55	144.54	144.53	144.54
VT-Blank	-0.01	0.00	0.01	0.00	-0.02	0.00	0.02	-0.02	0.01	-0.01	0.00	0.01	0.01	-0.01
VT-GM-N1	232.61	232.09	231.48	230.86	230.26	229.73	229.17	228.61	228.09	227.49	226.87	226.29	225.77	225.23
VT-GM-N2	227.08	226.54	226.00	225.45	224.92	224.34	223.77	223.18	222.55	221.89	221.23	220.62	220.05	219.47
VT-GM-N3	231.15	230.65	230.06	229.43	228.85	228.31	227.73	227.14	226.58	225.95	225.33	224.75	224.19	223.65
VT-GM-N	0.65	0.52	0.58	0.60	0.57	0.55	0.57	0.58	0.57	0.63	0.63	0.59	0.55	0.55
VT-GM-T1	228.53	228.02	227.48	226.94	226.44	225.86	225.32	224.73	224.18	223.55	222.95	222.35	221.77	221.21
VT-GM-T2	228.83	228.30	227.72	227.13	226.56	226.05	225.52	224.89	224.27	223.68	223.04	222.47	221.89	221.30
VT-GM-T3	237.17	236.67	236.11	235.50	234.92	234.42	233.87	233.23	232.66	232.08	231.49	230.92	230.38	229.85
VT-GM-T	0.62	0.51	0.56	0.58	0.55	0.53	0.54	0.62	0.58	0.60	0.61	0.58	0.57	0.56
VT-GM-A1	231.25	230.69	230.15	229.57	229.01	228.44	227.85	227.23	226.71	226.11	225.46	224.88	224.26	223.65
VT-GM-A2	234.39	233.86	233.31	232.71	232.14	231.59	231.02	230.43	229.85	229.29	228.68	228.10	227.53	226.98
VT-GM-A3	230.56	230.03	229.47	228.85	228.27	227.70	227.11	226.52	226.00	225.48	224.88	224.24	223.66	223.11
VT-GM-A	0.68	0.54	0.55	0.60	0.57	0.56	0.58	0.60	0.54	0.56	0.62	0.60	0.59	0.57
VT-GM-E1	241.11	240.68	240.23	239.75	239.33	238.90	238.47	238.04	237.68	237.31	236.87	236.45	236.05	235.61
VT-GM-E2	235.57	235.14	234.69	234.22	233.79	233.34	232.88	232.44	232.02	231.57	231.07	230.62	230.17	229.74
VT-GM-E3	229.23	228.77	228.29	227.80	227.30	226.83	226.34	225.89	225.53	225.15	224.65	224.16	223.69	223.21
VT-GM-E	0.48	0.44	0.46	0.48	0.45	0.45	0.46	0.44	0.38	0.40	0.48	0.45	0.44	0.45

Table IXL

VAPOR TRANSMISSION - INDIVIDUAL RESULTS - GYPSUM / LIME (Part 2)

Day	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temp°F	69.3	72.4	75.4	75.1	74.6	75.1	71.0	68.8	68.7	72.4	71.5	71.7	69.3	68.9
R.U.	22%	19%	19%	20%	22%	23%	20%	20%	20%	19%	19%	20%	20%	20%
VT-Blank	-0.01	0.00	0.01	0.00	-0.02	0.00	0.02	-0.02	0.01	-0.01	0.00	0.01	0.01	-0.01
VT-GM-N1	0.61	0.52	0.61	0.62	0.60	0.53	0.56	0.56	0.52	0.60	0.62	0.58	0.52	0.54
VT-GM-N2	0.66	0.54	0.54	0.55	0.53	0.58	0.57	0.59	0.63	0.66	0.66	0.61	0.57	0.58
VT-GM-N3	0.69	0.50	0.59	0.63	0.58	0.54	0.58	0.59	0.56	0.63	0.62	0.58	0.56	0.54
VT-GM-N	0.65	0.52	0.58	0.60	0.57	0.55	0.57	0.58	0.57	0.63	0.63	0.59	0.55	0.55
VT-GM-T1	0.61	0.51	0.54	0.54	0.50	0.58	0.54	0.59	0.55	0.63	0.60	0.60	0.58	0.56
VT-GM-T2	0.64	0.53	0.58	0.59	0.57	0.51	0.53	0.63	0.62	0.59	0.64	0.57	0.58	0.59
VT-GM-T3	0.61	0.50	0.56	0.61	0.58	0.50	0.55	0.64	0.57	0.58	0.59	0.57	0.54	0.53
VT-GM-T	0.62	0.51	0.56	0.58	0.55	0.53	0.54	0.62	0.58	0.60	0.61	0.58	0.57	0.56
VT-GM-A1	0.69	0.56	0.54	0.58	0.56	0.57	0.59	0.62	0.52	0.60	0.65	0.58	0.62	0.61
VT-GM-A2	0.66	0.53	0.55	0.60	0.57	0.55	0.57	0.59	0.58	0.56	0.61	0.58	0.57	0.55
VT-GM-A3	0.68	0.53	0.56	0.62	0.58	0.57	0.59	0.59	0.52	0.52	0.60	0.64	0.58	0.55
VT-GM-A	0.68	0.54	0.55	0.60	0.57	0.56	0.58	0.60	0.54	0.56	0.62	0.60	0.59	0.57
VT-GM-E1	0.42	0.43	0.45	0.48	0.42	0.43	0.43	0.43	0.36	0.37	0.44	0.42	0.40	0.44
VT-GM-E2	0.53	0.43	0.45	0.47	0.43	0.45	0.46	0.44	0.42	0.45	0.50	0.45	0.45	0.43
VT-GM-E3	0.50	0.46	0.48	0.49	0.50	0.47	0.49	0.45	0.36	0.38	0.50	0.49	0.47	0.48
VT-GM-E	0.48	0.44	0.46	0.48	0.45	0.45	0.46	0.44	0.38	0.40	0.48	0.45	0.44	0.45

Table XL

WATER RESISTANCE - DATA - CLAY - NO CONSOLIDANT

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CL-N1	5	2.30	0.60	7.5 cm. diam. wet on surface
	10	2.80	1.00	8.2 cm. diam wet on surface
	15	2.90	1.50	all surface wet
	30	4.30	2.05	2 cm. deep wet
	45	4.50	2.40	2.5 cm. deep wet
	60	5.00	2.40	3.6 cm. deep wet
AR-CL-N2	5	2.50	0.80	6 cm. diam. wet on surface
	10	2.85	1.40	7.5 cm. diam. wet on surface
	15	3.10	2.00	8.2 cm diam. wet on surface
	30	3.85	2.35	1.5 cm. deep wet
	45	4.35	2.60	2.4 cm. deep wet
	60	4.50	2.90	3.45 cm. deep wet
AR-CL-N3	5	2.50	0.80	7 cm. diam. wet on surface
	10	2.80	1.30	8.5 cm. diam. wet on surface
	15	3.50	1.45	all surface wet
	30	3.85	1.70	1.7 cm deep wet
	45	3.95	1.80	2.5 cm. deep wet
	60	4.10	1.95	all brick wet

WATER RESISTANCE - AVERAGE - CLAY - NO CONSOLIDANT

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CL-N	5	2.43	0.73	7.5 cm. diam. wet on surface
	10	2.82	1.23	8 cm. diam. wet on surface
	15	3.17	1.65	all surface wet
	30	4.00	2.03	1.7 cm. deep wet
	45	4.27	2.27	2.45 cm. deep wet
	60	4.53	2.42	3.60 cm. deep wet

Table XLI

WATER RESISTANCE - DATA - CLAY - TUNA CACTUS

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CL-T1	5	2.50	0.70	6.5 cm. diam. wet on surface
	10	2.75	1.00	7.8 cm. diam. wet on surface
	15	2.90	1.30	8.5 cm. diam. wet on surface
	30	3.00	1.45	all surface wet
	45	3.20	1.50	4 mm. deep wet
	60	3.50	1.60	1.70 cm. deep wet
AR-CL-T2	5	2.10	0.80	3.60 cm. diam. wet on surface
	10	2.25	1.00	6 cm. diam. wet on surface
	15	2.40	1.40	7 cm. diam. wet on surface
	30	2.80	1.40	0.5 cm. diam. wet on surface
	45	3.20	1.45	0.5 cm deep wet
	60	3.50	1.50	1.6 cm. diam wet
AR-CL-T3	5	2.30	0.20	6.5 cm. diam. wet on surface
	10	2.55	0.40	7.35 cm. diam. wet on surface
	15	2.70	0.50	8.4 cm. diam. wet on surface
	30	3.10	1.00	1.2 cm. deep wet
	45	3.30	1.30	2.10 cm. deep wet
	60	3.40	1.70	2.4 cm. deep wet

WATER RESISTANCE - AVERAGE - CLAY - TUNA CACTUS

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CL-T	5	2.30	0.57	5.50 cm. diam wet on surface
	10	2.52	0.80	7.05 cm. diam. wet on surface
	15	2.67	1.07	7.90 cm. diam. wet on surface
	30	2.97	1.28	all surface is wet
	45	3.23	1.42	1 cm. deep wet
	60	3.47	1.60	1.9 cm. deep wet

Table XLII

WATER RESISTANCE - DATA - CLAY - ACRYLIC

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CL-A1	5	1.60	0.80	No water absorption
	10	2.70	1.20	No water absorption
	15	3.30	1.60	No water absorption
	30	3.50	1.90	All surface wet, borders are cracking
	45	3.60	2.30	All brick is wet, no water absorption
	60	3.80	2.50	All brick is wet, no water absorption
AR-CL-A2	5	1.00	0.50	No water absorption
	10	3.10	1.15	No water absorption
	15	3.30	1.30	No water absorption
	30	4.00	1.50	water on most of surface, cracks on
	45	4.00	1.65	All brick is wet, no water absorption
	60	4.10	1.75	All brick is wet, no water absorption
AR-CL-A3	5	1.40	0.70	No water absorption
	10	2.80	1.20	No water absorption
	15	3.25	1.50	No water absorption
	30	3.50	1.68	All surface wet, plaster cracks on borders
	45	3.80	1.85	All brick wet, no water absorption
	60	4.00	2.00	All brick wet, no water absorption

WATER RESISTANCE - AVERAGE - CLAY - ACRYLIC

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CL-A	5	1.33	0.67	No water absorption
	10	2.87	1.18	No water absorption
	15	3.28	1.47	No water absorption
	30	3.67	1.69	All surface wet, plaster cracks on borders
	45	3.80	1.93	All brick wet, no water absorption
	60	3.97	2.08	All brick wet, no water absorption

Table XLIII

WATER RESISTANCE - DATA - CLAY - ETHYL SILICATE

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CL-E1	5	--	--	5 cm. diam. wet on surface
	10	--	--	7.5 cm diam. wet on surface
	15	--	--	All surface wet
	30	--	--	All surface wet, 1mm. deep absorbed
	45	--	--	All surface wet, 2mm. deep absorbed
	60	NO EROSION		5 mm. deep absorbed
AR-CL-E2	5	--	--	4.5 cm. diam. wet on surface
	10	--	--	7.5 cm. diam. wet on surface
	15	--	--	water is running through a crack
	30	--	--	water penetrates to adobe through crack
	45	--	--	5 mm. deep water absorption
	60	NO EROSION		10 mm. deep water absorption
AR-CL-E3	5	--	--	5 cm. diam. wet on surface
	10	--	--	6.5 cm. diam. wet on surface
	15	--	--	All surface wet
	30	--	--	3 mm. deep water absorbed
	45	--	--	5 mm. deep water absorbed
	60	NO EROSION		7.5 mm. deep water absorbed

WATER RESISTANCE - AVERAGE - CLAY - ETHYL SILICATE

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CL-E	5	--	--	5 cm. diam. wet on surface
	10	--	--	7 cm. diam. wet on surface
	15	--	--	All surface wet
	30	--	--	2 mm. deep water absorbed
	45	--	--	3 mm. deep water absorbed
	60	NO EROSION		6.5 mm. deep water absorbed

Table XLIV

WATER RESISTANCE - DATA - LIME - NO CONSOLIDANT

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-LI-N1	5	--	--	8 cm. diam. wet on surface
	10	--	--	1 cm. deep wet
	15	--	--	1.5 cm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick collapsed on bottom center
AR-LI-N2	5	--	--	8 cm. diam. wet on surface
	10	--	--	1 cm. deep wet
	15	--	--	1.5 cm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick collapsed on bottom center
AR-LI-N3	5	--	--	8.5 cm. diam. wet on surface
	10	--	--	1.3 cm. deep wet
	15	--	--	1.8 cm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick collapsed on bottom center

WATER RESISTANCE - AVERAGE - LIME - NO CONSOLIDANT

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-LI-N	5	--	--	8 cm. diam. wet on surface
	10	--	--	1 cm. deep wet
	15	--	--	1.5 cm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick collapsed on bottom center

Table XLV

WATER RESISTANCE - DATA - LIME - TUNA CACTUS

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-LI-T1	5	--	--	8 cm. diam. wet on surface
	10	--	--	0.7 cm. deep wet
	15	--	--	2.9 cm. deep wet
	30	--	--	all brick wet
	60	--	--	(@ 90 min.) brick saturated
	120	NO EROSION		brick collapsed on bottom center
AR-LI-T2	5	--	--	8 cm. diam. wet on surface
	10	--	--	0.6 cm. deep wet
	15	--	--	1.3 cm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick collapsed on bottom center
AR-LI-T3	5	2.50	0.30	all surface wet
	10	3.00	0.30	all surface wet
	15	3.50	0.40	2 cm. deep wet
	30	3.70	0.50	all brick wet
	60	4.00	0.50	brick saturated
	120	4.50	0.60	brick collapsed on bottom center

WATER RESISTANCE - AVERAGE - LIME - TUNA CACTUS

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-LI-T	5	--	--	8 cm. diam. wet on surface
	10	--	--	1 cm. deep wet
	15	--	--	1.5 cm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick collapsed on bottom center

Table XLVI

WATER RESISTANCE - DATA - LIME - ACRYLIC

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-LI-A1	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		water overflows surface area and is absorbed by brick, causing collapse.*
AR-LI-A2	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		brick collapsed on bottom center*
AR-LI-A3	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		brick collapsed on bottom center*

WATER RESISTANCE - AVERAGE - LIME - ACRYLIC

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-LI-A	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		brick collapsed on bottom center

Table XLVII

WATER RESISTANCE - DATA - LIME - ETHYL SILICATE

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-LI-E1	5	--	--	5 cm. diam. wet on surface
	10	--	--	all plaster surface wet
	15	--	--	0.3 cm. deep plaster wet
	30	--	--	0.8 cm. deep wet
	60	--	--	all brick wet
	120	NO EROSION		all brick wet - no collapse on bottom
AR-LI-E2	5	--	--	8 cm. diam. wet on surface
	10	--	--	all plaster surface wet
	15	--	--	0.8 cm. deep plaster wet
	30	--	--	1.3 cm. deep wet
	60	--	--	all brick wet
	120	NO EROSION		brick wet - collapsed on bottom center
AR-LI-E3	5	--	--	6 cm. diam. wet on surface
	10	--	--	all plaster surface wet
	15	--	--	0.5 cm. deep plaster wet
	30	--	--	1 cm. deep wet
	60	--	--	all brick wet
	120	NO EROSION		all brick wet - no collapse on bottom

WATER RESISTANCE - AVERAGE - LIME - ETHYL SILICATE

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-LI-E	5	--	--	6 cm. diam. wet on surface
	10	--	--	all plaster surface wet
	15	--	--	0.5 cm. deep plaster wet
	30	--	--	1 cm. deep wet
	60	--	--	all brick wet
	120	NO EROSION		all brick wet - no collapse on bottom

Table XLVIII

WATER RESISTANCE - DATA - GYPSUM - NO CONSOLIDANT

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GY-N1	5	0.50	1.50	5 cm. diam. wet on surface
	10	0.80	2.15	all surface wet
	15	1.90	2.25	2 cm. deep wet
	30	2.80	2.45	all brick wet
	60	3.10	2.65	brick saturated: water flows out of brick
	120	3.60	collapsed	brick collapsed on bottom center
AR-GY-N2	5	0.50	1.50	5.50 cm. diam. wet on surface
	10	1.00	2.20	all surface wet
	15	2.00	2.35	2.50 cm. deep wet
	30	2.75	2.60	all brick wet
	60	3.05	2.80	brick saturated: water flows out of brick
	120	3.50	collapsed	brick collapsed on bottom center
AR-GY-N3	5	0.50	1.40	5 cm. diam. wet on surface
	10	0.70	2.10	all surface wet
	15	1.80	2.30	2.5 cm. deep wet
	30	2.15	2.55	all brick wet
	60	2.60	2.75	brick saturated: water flows out of brick
	120	3.50	collapsed	brick collapsed on bottom center

WATER RESISTANCE - AVERAGE - GYPSUM - NO CONSOLIDANT

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GY-N	5	0.50	1.47	5.3 cm. diam. wet on surface
	10	0.83	2.15	all surface wet
	15	1.90	2.30	2.4 cm. deep wet
	30	2.57	2.53	all brick wet
	60	2.92	2.73	brick saturated: water flows out of brick
	120	3.53	collapsed	brick collapsed on bottom center

Table IL

WATER RESISTANCE - DATA - GYPSUM - TUNA CACTUS

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GY-T1	5	2.00	1.50	all surface wet
	10	2.10	2.10	All plaster wet, has been perforated and drops fall directly on the brick.*
	15	2.50	2.10	brick wet on borders - 1mm. deep
	30	2.70	2.35	3 mm. deep wet
	60	2.80	2.40	1 cm. deep wet
	120	3.40	2.70	3.85 cm. wet
AR-GY-T2	5	1.70	0.70	all surface wet
	10	1.90	1.50	all plaster wet
	15	2.00	1.90	all plaster perforated*
	30	2.30	2.40	brick wet on borders - 1mm. deep
	60	2.50	3.00	2mm. deep wet
	120	3.00	3.10	5mm. deep wet
AR-GY-T3	5	1.70	0.90	all surface wet
	10	1.90	1.80	all plaster wet
	15	2.05	1.95	all plaster perforated*
	30	2.40	2.50	brick wet on borders - 1mm. deep
	60	2.60	2.75	2mm. deep wet
	120	3.10	3.10	5mm. deep wet

WATER RESISTANCE - AVERAGE - GYPSUM - TUNA CACTUS

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GY-T	5	1.80	1.03	all surface wet
	10	1.97	1.80	all plaster wet
	15	2.18	1.98	all plaster perforated*
	30	2.47	2.42	brick wet on borders - 1mm. deep
	60	2.63	2.72	2mm. deep wet
	120	3.17	2.97	5mm. deep wet

WATER RESISTANCE - DATA - GYPSUM - ACRYLIC

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GY-A1	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	water overflows surface area and is absorbed by brick, causing collapse
	120	NO EROSION		
AR-GY-A2	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	water overflows surface area and is absorbed by brick, causing collapse
	120	NO EROSION		
AR-GY-A3	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	water overflows surface area and is absorbed by brick, causing collapse
	120	NO EROSION		

WATER RESISTANCE - AVERAGE - GYPSUM - ACRYLIC

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GY-A	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	water overflows surface area and is absorbed by brick, causing collapse
	120	NO EROSION		

Table LI

WATER RESISTANCE - DATA - GYPSUM - ETHYL SILICATE

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GY-E1	5	--	--	all surface wet
	10	--	--	all surface wet, 3 mm. deep absorbed
	15	--	--	7 mm. deep absorbed
	30	--	--	1 cm. deep absorbed
	60	--	--	1.2 cm. deep absorbed
	120	NO EROSION		all brick wet - no collapse on bottom center
AR-GY-E2	5	--	--	all surface wet
	10	--	--	all surface wet, 2 mm. deep absorbed
	15	--	--	5 mm. deep absorbed
	30	--	--	9 mm. deep absorbed
	60	--	--	1 cm. deep absorbed
	120	NO EROSION		all brick wet - no collapse on bottom center
AR-GY-E3	5	--	--	all surface wet
	10	--	--	all surface wet, 4 mm. deep absorbed
	15	--	--	7 mm. deep absorbed
	30	--	--	1 cm. deep absorbed
	60	--	--	1.5 cm. deep absorbed
	120	NO EROSION		all brick wet - no collapse on bottom center

WATER RESISTANCE - AVERAGE - GYPSUM - ETHYL SILICATE

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GY-E	5	--	--	all surface wet
	10	--	--	all surface wet, 3 mm. deep absorbed
	15	--	--	7 mm. deep absorbed
	30	--	--	1 cm. deep absorbed
	60	--	--	1.2 cm. deep absorbed
	120	NO EROSION		all brick wet - no collapse on bottom center

Table LII

WATER RESISTANCE - DATA - CLAY / LIME - NO CONSOLIDANT

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CM-N1	5	--	--	6 cm. diam. wet on surface
	10	--	--	all surface and plaster wet
	15	--	--	8 mm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick saturated - no collapse on bottom
AR-CM-N2	5	--	--	7.5 cm. diam. wet on surface
	10	--	--	all surface and plaster wet
	15	--	--	1.3 cm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick saturated - no collapse on bottom
AR-CM-N3	5	--	--	7 cm. diam. wet on surface
	10	--	--	all surface and plaster wet
	15	--	--	9 mm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick saturated - no collapse on bottom

WATER RESISTANCE - AVERAGE - CLAY / LIME - NO CONSOLIDANT

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CM-N	5	--	--	7 cm. diam. wet on surface
	10	--	--	all surface and plaster wet
	15	--	--	1 cm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick saturated - no collapse on bottom

Table LIII

WATER RESISTANCE - DATA - CLAY / LIME - TUNA CACTUS

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CM-T1	5	--	--	7.5 cm. diam. wet
	10	--	--	all surface and plaster wet
	15	--	--	3 mm. brick wet
	30	--	--	3.7 cm. deep wet
	60	--	--	brick saturated
	120	NO EROSION		brick saturated - no collapse
AR-CM-T2	5	--	--	all surface wet
	10	--	--	all surface and plaster wet
	15	--	--	5 mm. brick wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick saturated - no collapse
AR-CM-T3	5	--	--	all surface wet
	10	--	--	all surface and plaster wet
	15	--	--	8 mm. brick wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick saturated - no collapse

WATER RESISTANCE - AVERAGE - CLAY / LIME - TUNA CACTUS

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CM-T	5	--	--	all surface wet
	10	--	--	all surface and plaster wet
	15	--	--	5 mm. brick wet
	30	--	--	all brick wet
	60	--	--	brick saturated
	120	NO EROSION		brick saturated - no collapse

Table LIV

WATER RESISTANCE - DATA - CLAY / LIME - ACRYLIC

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CM-A1	5	--	--	No water absorption
	10	--	--	No water absorption, surface is saturating
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption, water overflows
	120	NO EROSION		water overflows surface area and is absorbed by brick, causing collapse.*
AR-CM-A2	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		brick collapsed on bottom center*
AR-CM-A3	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		brick collapsed on bottom center*

WATER RESISTANCE - AVERAGE - CLAY / LIME - ACRYLIC

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CM-A	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		brick collapsed on bottom center*

Table LV

WATER RESISTANCE - DATA - CLAY / LIME - ETHYL SILICATE

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CM-E1	5	--	--	7 cm. diam. wet on surface
	10	--	--	all plaster wet
	15	--	--	8 mm. deep wet
	30	--	--	1.2 cm. deep wet
	60	--	--	2.8 cm. deep wet
	120	NO EROSION		all brick wet - no collapse on bottom
AR-CM-E2	5	--	--	6.3 cm. diam. wet on surface
	10	--	--	all plaster wet
	15	--	--	6 mm. deep wet
	30	--	--	1.2 cm. deep wet
	60	--	--	2.7 cm. deep wet
	120	NO EROSION		all brick wet - no collapse on bottom
AR-CM-E3	5	--	--	5 cm. diam. wet on surface
	10	--	--	all plaster wet
	15	--	--	2 mm. deep wet
	30	--	--	7 mm. deep wet
	60	--	--	1.4 cm. deep wet
	120	NO EROSION		all brick wet - no collapse on bottom

WATER RESISTANCE - AVERAGE - CLAY / LIME - ETHYL SILICATE

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-CM-E	5	--	--	6 cm. diam. wet on surface
	10	--	--	all plaster wet
	15	--	--	5 mm. deep wet
	30	--	--	1 cm. deep wet
	60	--	--	2 cm. deep wet
	120	NO EROSION		all brick wet - no collapse on bottom

Table LVI

WATER RESISTANCE - DATA - GYPSUM/LIME - NO CONSOLIDANT

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GM-N1	5	--	--	7 cm. diam. wet on surface
	10	--	--	7.5 cm. diam. wet on surface
	15	--	--	all surface wet - 5 mm plaster wet
	30	--	--	1.5 cm. deep wet
	60	--	--	3.50 cm. deep wet
	120	NO EROSION		brick saturated - collapsed on center
AR-GM-N2	5	--	--	all surface wet
	10	--	--	all surface wet - 7 mm plaster wet
	15	--	--	1.5 cm. deep wet
	30	--	--	all brick wet
	60	--	--	brick saturated - water overflows
	120	NO EROSION		brick saturated - collapsed on center
AR-GM-N3	5	1.00	0.50	6.5 cm. diam. wet on surface
	10	3.50	0.60	8 cm. diam. wet on surface
	15	1.50	0.70	all surface wet - 7 mm plaster wet
	30	2.00	0.85	1.8 cm. deep wet
	60	2.30	0.90	all brick wet
	120	3.00	0.90	brick saturated - collapsed on center

WATER RESISTANCE - AVERAGE - GYPSUM/LIME - NO

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GM-N	5	0.33	0.17	7 cm. diam. wet on surface
	10	1.17	0.20	7.5 cm. diam. wet on surface
	15	0.50	0.23	all surface wet - 5 mm plaster wet
	30	0.67	0.28	1.5 cm. deep wet
	60	0.77	0.30	3.50 cm. deep wet
	120	1.00	0.30	brick saturated - collapsed on center

Table LVII

WATER RESISTANCE - DATA - GYPSUM/LIME - TUNA CACTUS

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GM-T1	5	1.00	0.30	4 cm. diam. wet on surface
	10	3.50	0.30	all surface wet
	15	3.70	0.40	1 mm. brick wet - all plaster wet
	30	3.70	0.40	1 cm. deep of sample wet
	60	4.00	0.50	all brick wet
	120	4.50	0.50	all brick wet - no collapse
AR-GM-T2	5	--	--	7.5 cm. diam. wet
	10	--	--	all plaster wet
	15	--	--	all plaster - 5 mm brick wet
	30	--	--	1.5 cm. deep of sample wet
	60	--	--	some portions of brick are still dry - corners
	120	NO EROSION		(@ 72 min) water overflows - brick
AR-GM-T3	5	--	--	6.5 cm. diam. wet
	10	--	--	all plaster wet
	15	--	--	all plaster - 5 mm. brick wet
	30	1.50	0.20	8 mm. brick wet
	60	4.00	0.40	all brick wet
	120	4.50	0.40 -finish	all brick wet - no collapse

WATER RESISTANCE - AVERAGE - GYPSUM/LIME - TUNA CACTUS

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GM-T	5	0.33	0.10	6 cm. diam. wet on surface
	10	1.17	0.10	all surface wet
	15	1.23	0.13	4 mm. brick wet - all plaster wet
	30	1.73	0.20	1 cm. deep of sample wet
	60	2.67	0.30	all brick wet
	120	3.00	0.30	all brick wet - no collapse

Table LVIII

WATER RESISTANCE - DATA - GYPSUM/LIME - ACRYLIC

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GM-A1	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		All brick wet - collapse on bottom center
AR-GM-A2	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		All brick wet - collapse on bottom center
AR-GM-A3	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		All brick wet - collapse on bottom center

WATER RESISTANCE - AVERAGE - GYPSUM/LIME - ACRYLIC

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GM-A	5	--	--	No water absorption
	10	--	--	No water absorption
	15	--	--	No water absorption
	30	--	--	No water absorption
	60	--	--	No water absorption
	120	NO EROSION		All brick wet - collapse on bottom center

Table LIX

WATER RESISTANCE - DATA - GYPSUM/LIME - ETHYL SILICATE

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GM-E1	5	--	--	7.5 cm. diam. wet
	10	--	--	all surface wet
	15	--	--	all plaster wet - 2 mm. deep
	30	--	--	8 mm. deep wet
	60	--	--	2.2 cm. deep wet
	120	NO EROSION		all brick wet - no collapse
AR-GM-E2	5	--	--	7 cm. diam. wet
	10	--	--	7.5 cm. diam. wet
	15	--	--	all plaster wet - 5 mm. deep
	30	--	--	1 cm. deep wet
	60	--	--	1.2 cm. deep wet
	120	NO EROSION		1.5 cm. deep wet
AR-GM-E3	5	--	--	6.5 cm. diam. wet
	10	--	--	7 cm. diam. wet
	15	--	--	all plaster wet
	30	--	--	6 mm. deep wet
	60	--	--	1 cm. deep wet
	120	NO EROSION		1.1 cm. deep wet

WATER RESISTANCE - AVERAGE - GYPSUM/LIME - ETHYL SILICATE

	TIME ELAPS min.	WIDTH OF EROSION cm.	DEPTH OF EROSION cm.	WIDTH OF ABSORPTION
AR-GM-E	5	--	--	7 cm. diam. wet
	10	--	--	7.8 cm. diam. wet
	15	--	--	all plaster wet - 6 mm. deep
	30	--	--	1.1 cm. deep wet
	60	--	--	1.2 cm. deep wet
	120	NO EROSION		1.5 cm. deep wet

Table LX