NBS TECHNICAL NOTE 883

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Waterproofing Materials for Masonry

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Waterproofing Materials for Masonry

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Waterproofing Materials for Masonry

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ABSTRACT

The initial effectiveness and durability characteristics of fifty-five clear masonry waterproofing materials were evaluated using laboratory tests. This report contains the results of initial performance tests including water absorption, water vapor transmission, resistance to efflorescence and change in appearance. Durability tests, including periodic measurement of water absorption after exposures to accelerated weathering and outdoor exposures, were also conducted. Based on test results, performance criteria for clear waterproofing materials were developed. In addition, recommendations for the application of waterproofing materials were formulated. Finally, the report contains a summary of a survey concerning field experiences with waterproofing and a brief theoretical discussion of water flow.

Key words: Accelerated weathering; durability of waterproofing materials; masonry; performance criteria; waterproofing materials; water repellent materials.

1. INTRODUCTION

1.1 Background

Water damage to buildings or their contents is a serious problem. In the case of masonry buildings, water infiltration may be the result of the porosity of the masonry units and the mortar joint system, settlement or other cracks, open construction or expansion joints, defective flashings, roof leakage, etc. The two main methods of treatment to reduce or eliminate water infiltration are: a) reduction or elimination of the openings due to pores or cracks; and b) application of a water repellent treatment to the surface.

Because of its needs for waterproofing treatments for use on exterior masonry surfaces, the Department of Housing and Urban Development (HUD) requested the National Bureau of Standards (NBS) to perform studies on clear waterproofing materials for masonry surfaces and to develop performance criteria for the selection of such waterproofing materials.

While it is virtually impossible to completely exclude water from a building under all conditions, the proper use of waterproofing materials can minimize water infiltration. Waterproofing materials may be divided into two types, waterproofers and water repellents. In a general definition of terms, Maslow [1]* identified a waterproofing material as an impervious coating, e.g., coal tar, asphalt and some paints, which seals the surface to the infiltration of water and water vapor, while a water repellent is a material, e.g., aluminum stearate, and silicones, that penetrates the surface and permits the movement of water vapor but not the infiltration of water. In general, the clear waterproofing materials used above grade are water repellents. In this report, the single term "waterproofing" material is used to cover both materials that penetrate the surface and those that form a film on it.

Because of the higher relative humidity indoors at most times of the year, the usual direction of moisture movement through walls above grade is interior to exterior as illustrated in Figure 1 [2]. For this reason, and to prevent accumulation of moisture within the wall, the interior surface should be relatively impermeable, while the exterior surface should be permeable enough to permit transpiration of water vapor to the outside while resisting the inward passage of water. This applies even to waterproofed surfaces.

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* Figures in brackets indicate references.

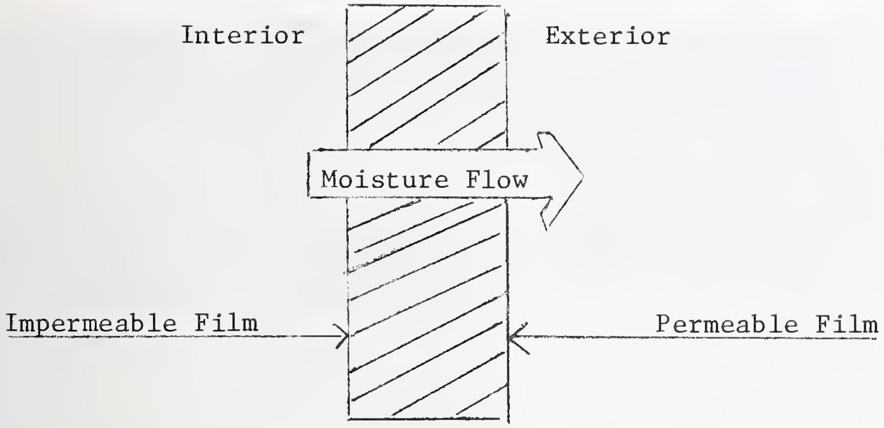

Figure 1. Masonry Wall Above Grade Showing the Usual Direction of Moisture Movement.

Where it is desirable to retain the original appearance of masonry after waterproofing, clear waterproofing materials are employed. Among clear waterproofing treatments which have been used historically are petroleum distillates and fatty substances (oils) dissolved in mineral spirits, aluminum stearate (with or without petroleum distillates), varnishes, inorganic salts, soluble soaps or glue dissolved in water [3, 4], molten paraffin [5], and emulsions and solutions of waxes and paraffins [6]. However, it appears that none of the waterproofing materials are fully satisfactory since new materials are continually being introduced in attempts to improve this type of treatment. For example, Litvin [7] included polyurethane, epoxy, acrylate, silicone and vinyl toluene resins, as well as the older type resins, in a comprehensive study of the soiling of clear coatings for exposed architectural concrete. Also, the older commercially available materials are continually being reformulated to improve their performance.

As a class, the clear materials tend to be less effective than opaque materials such as paints because, being usually of lower solids content than pigmented materials, they are less able to fill or bridge large cracks and openings. Also, they are usually less resistant to weathering. In spite of their limitations in performance, clear waterproofing treatments are of considerable value, particularly if proper care is exercised in their selection and application.

The demands made upon waterproofing agents for masonry walls depend upon the exposure conditions, the quality of the masonry units and the mason's workmanship, as well as the presence of cracks or other openings. Examples of some types of openings which may be present are shown in the portion of the house wall seen in Figure 2. Included are: open cracks between the mortar and brick due to loss of bond (Area C), bricks having cracks and voids (Areas D and E), incompletely filled joints (Area F), and possible settlement cracks (Areas C and F). Another example of

Figure 2. Section of a Clay Brick Wall Exhibiting Several Types of Openings.

Area C - open cracks between the mortar and brick due to loss of bond

Areas D, E - bricks having cracks and voids

Area F - incompletely filled joints

Area C and F - possible settlement cracks settlement cracks and incompletely filled joints is illustrated in Figure 3. The open cracks shown in this figure are larger than 0.05 cm (0.02 in) and Anderegg [6] has commented on the difficulty of sealing openings wider than this by any type of waterproofing treatment. It should also be noted that Fishburn et al. [5], Kanarowski [8], and Kruger and Loubser [9] have stated that workmanship involving the mortar joints affects the permeability of walls more than any other factor.

1.2 Objectives

The objectives of this study are:

1. To evaluate by laboratory methods the initial effectiveness and durability characteristics of commercially available, clear, waterproofing materials for masonry.

2. To survey field application and performance of the waterproofing treatments.

3. To study the methods of application of clear waterproofing materials and to prepare recommendations for their application.

4. To recommend performance criteria for clear waterproofing materials for masonry surfaces.

1.3 Approach

To evaluate the initial effectiveness and durability characteristics of waterproofing materials, small-scale laboratory tests which indicated the resistance of coated masonry specimens to the infiltration of water were carried out. These tests included water absorption, water vapor transmission, and resistances to efflorescence, wind-driven rain and hydrostatic pressure. Accelerated and outdoor weathering exposure tests were used to assay waterproofing performance over an extended time period. These tests were similar to the performance tests required for the quality assurance of other waterproofing materials, e.g., Fed. Spec. SS-W-110C [10], Fed. Spec. TT-C-555B [11]. The masonry materials used were clay brick and concrete block such as are frequently used in housing. The clear waterproofing materials covered most types which are commercially available.

The laboratory tests were designed to screen materials for effectiveness and durability and were not intended to exactly duplicate actual use conditions. In some respects, the laboratory tests were more severe than real life situations. However, these tests were useful for the comparison of the performance properties of different waterproofing materials and provided a basis for the development of preliminary performance criteria which are given in Appendix C of this report.

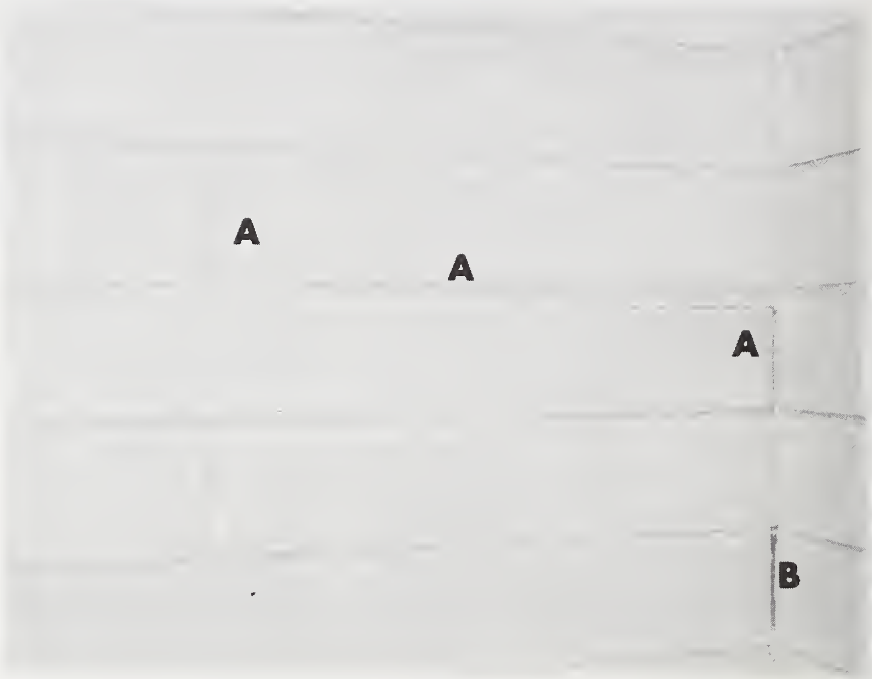

Figure 3. A Section of a Clay Brick Wall.

Area A - settlement crack

Area B - incompletely filled joint

A brief survey of field experience with waterproofing treatments was made by means of discussions with maintenance officials at HUD regional and area offices. The results which are commented upon in Section 4 are reported in Appendix A.

To study the methods of application, laboratory tests using brush, roller, air spray and airless spray application techniques were used. Based upon the laboratory results and on the survey of field application and performance, recommendations for waterproofing application are given in Section 5.

2. EXPERIMENTAL

2.1 Materials Selection

2.1.1 Waterproofing Materials

Fifty-five clear waterproofing materials were assembled for this study. The percent solids was determined by the procedure described in Fed. Test Method Std. No. 141a, Method 4041.1 [12]. The resin content of the solids was then identified as to generic type by infrared analysis. For materials with organic solvents, the procedure involved casting a film of the nonvolatile vehicle dissolved in acetone on a sodium chloride disc. A silver chloride disc was substituted when water-thinned materials were examined. The thickness of the sample was adjusted to give a background transmission between 85 and 95 percent. The identity of the nonvolatile vehicle was deduced by comparison with published spectra [13].

2.1.2 Masonry Units

Three kinds of masonry units representing types frequently used in the United States were chosen for this study. They were lightweight concrete block, dense aggregate concrete block and clay brick units. The concrete block units had two cores and nominal dimensions of 20 cm x 20 cm x 40 cm (8 in x 8 in x 16 in). The dry weights were approximately 14 kg (31 lb) and 22 kg (48 lb). Water absorption properties for the concrete block units were determined by test procedures as described in ASTM C 140-70 [14]; they are as follows: lightweight aggregate 12.9%, dense aggregate 4.5%. The brick units were commercially available good quality three core brick used in building construction. The nominal dimensions were 9 cm x 19 cm x 5 cm (3 1/2 in x 7 1/2 in x 2 in). The dry weight was about 1.7 kg (3 3/4 lb). Their properties as determined according to ASTM C 67-73 [15] are given below:

Net Solid Area %	Compressive Strength (Gross Area)		Percent Absorption		Saturation Coefficient	Initial Rate of Absorption g/30 in^2/min (g/193.5 cm^2/min)
	psi	MPa	24 h cold	5 h boil		
79.7	13085	90.02	7.1	9.1	0.76	21.1

Face slabs were prepared from these samples for the various test procedures. The lightweight block units were cut into specimens of two sizes having dimensions of about 9.5 cm x 19 cm x 4 cm (3 3/4 in x 7 1/2 in x 1 1/2 in) and 19 cm x 39.5 cm x 4 cm (7 1/2 in x 15 1/2 in x 1 1/2 in). The dense aggregate units were cut into slabs of about 19 cm x 39.5 cm x 4.5 cm (7 1/2 in x 15 1/2 in x 1 3/4 in). Since the brick units were cored and many tests involved the movement of water or salts, face slabs approximately 6 cm x 19 cm x 3 cm (2 1/4 in x 7 1/2 in x 1 1/4 in) were cut.

2.2 Screening Test Methods

2.2.1 Water Absorption

The water absorption of the untreated masonry materials was determined to establish a reference point. To compare the effectiveness of the waterproofing agents in protecting the masonry materials from water penetration, the water absorption test was repeated after application of the waterproofing materials. Lightweight block and brick slabs were used. It was found that the variation in water absorption of individual brick or concrete block slabs was large enough so that separate water absorption determinations for each test specimen were necessary. Water absorption of individual brick slabs was found to vary between 5.7 and 10.2 percent.

2.2.1.1 Untreated Masonry Materials

After a 24 hour immersion in water, the wet slabs were weighed (W_W). Then they were dried at 105°C to a constant weight, cooled, and reweighed (W_D). The difference in weights was the amount of water absorbed (W_A) by the untreated slab.

$$W_A = W_W - W_D$$

2.2.1.2 Waterproofed Masonry Materials

The test method for determination of the water absorption of a waterproofed slab was adapted from the procedure described in Fed. Spec. SS-W-110C, Water Repellent, Odorless, Silicone Base [10]. Instead of immersion of the substrate in the water repellent solution for ten seconds, the waterproofing material was brushed on four edges and the uncut face of the slab at a spreading rate of 2.45 m^2/ℓ (100 ft^2/gal) for lightweight aggregate block and 4.90 m^2/ℓ (200 ft^2/gal) for brick. Test specimens were prepared in triplicate for every waterproofing material. After a one week cure at ambient laboratory conditions (about 25°C and 35% relative humidity), the coated slabs were weighed (W_{CD}) then immersed, uncoated side up, into water. The test specimens were supported off the base of the container to permit circulation of the water. The water depth was maintained at 1.3 cm (1/2 in) during the test. At the end of 72 hrs, the slabs were reweighed (W_{CW}). The water absorption was the ratio of the water absorbed by the coated slab to the water absorbed by the original untreated slab.

$$\% \text{ Water Absorption} = \frac{W_{CW} - W_{CD}}{W_A} \times 100$$

The triplicate results were then averaged to give the average water absorption for each waterproofing material. After drying, reflectance measurements (45°) [16] were taken at three locations on the specimen using a photoelectric reflection meter.

2.2.2 Water Vapor Transmission

The water vapor transmission test determined the rate of movement of moisture from the interior of a saturated specimen out through the waterproofing material.

The brick slabs used for the water absorption test (Sec. 2.2.1.2) were completely submerged for 24 hours in water so that the top of the slab was 0.6 cm (1/4 in) below the water surface. The brick slabs were supported to permit free circulation of water around them. After 24 hours, the slabs were removed from the water and excess surface water removed by blotting with a damp cloth. The untreated face of the brick was then placed downward on a piece of aluminum foil slightly larger than the brick slab. The foil was sealed to the brick by pouring melted carnauba wax around its lower perimeter, then folding the foil up around it. The weight (W_B) of the brick slab was recorded, then the slabs were stored at ambient laboratory conditions (about 25°C and 35% relative humidity) with circulation of air. After seven days, the slabs were reweighed (W_E). The difference in the weights was the amount of moisture lost by transmission through the waterproofing coating. The water vapor transmission was defined as

$$\text{\% Water Vapor Tramission} = \frac{W_B - W_E}{W_A} \times 100$$

2.2.3 Resistance to Efflorescence

This test assessed the ability of a waterproofing coating to resist the passage of salts through it and permit the formation of efflorescence. The brick slabs from the water vapor transmission (Sec. 2.2.2) were used for this test. The aluminum foil was removed and the slabs were air dried to constant weight. The slabs were then placed with the uncoated face downward to a depth of 1.3 cm (1/2 in) in a 10% aqueous sodium sulfate solution for seven days. The liquid level was maintained constant throughout the test. The slabs were then removed, allowed to dry and the coated surfaces were examined for efflorescence. The coated face of the slab was rated visually on a scale of 1 to 4 as follows: 1 heavy efflorescence; 2 slight efflorescence; 3 no efflorescence on face but salt residues on edges; 4 no efflorescence.

2.2.4 Resistance to Humidity

The purpose of this test was to determine whether the waterproofing coatings were affected by continuous exposure to high humidity and condensation.

After the water absorption had been determined on individual brick face slabs according to Section 2.2.1.1, the four sides and the uncut face were coated with a waterproofing material at a spreading rate of 4.90 m^2/ℓ (200 ft^2/gal). Duplicate specimens were prepared for each test material. After being allowed to cure one week at ambient laboratory conditions (about 25°C and 35% relative humidity), the coated face of the brick was exposed on a Cyclic Environmental Tester[1] [2] using a continuous condensation cycle and a 38 ± 2°C air temperature. Samples were removed and weighed at periodic intervals, and water absorption and reflectance measurements were taken after six and fourteen weeks.

2.2.5 Resistance to Accelerated Weathering

The accelerated weathering test is intended to simulate natural weathering. It was performed to determine if the effectiveness of waterproofing materials was changed by exposure to ultraviolet light.

Brick face slabs were used as the substrate for the waterproofing materials in this test. The water absorption of the individual brick slabs was measured as described in Section 2.2.1.1. The brick slabs were then coated at a spreading rate of 4.90 m^2/ℓ (200 ft^2/gal) on the four edges and the uncut face and allowed to cure one week at ambient laboratory conditions (about 25°C and 35% relative humidity). Duplicate test specimens were prepared. The uncoated face was protected by placing the slab, uncoated face down, on a piece of aluminum foil and sealing

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1/ Available from the Q-Panel Company, Cleveland, Ohio 44135.

2/ Certain commercial equipment, instruments or materials are identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

with melted carnauba wax. The test specimens were placed in a Weather-Ometer[1/], single enclosed carbon arc, exposed to a 102-18 cycle, i.e., 102 minutes light only, 18 minutes light and water spray. At 500 hour exposure intervals, the brick slabs were removed and water absorption measurements made. Reflectance measurements (45°) [16] were made after the slabs were dried to a constant weight.

2.2.6 Outdoor Exposures

The purpose of the outdoor exposures was to determine the effect of natural weathering. The water absorptions of the individual brick slabs were measured as described in Section 2.2.1.1. The brick slabs were coated at a spreading rate of 4.90 m^2/ℓ (200 ft^2/gal) on the four edges and the uncut face and allowed to cure one week at ambient laboratory conditions (about 25°C and 35% relative humidity). Duplicate test specimens were prepared for each test material. The test specimens were exposed in a horizontal position at the NBS outdoor exposure site in Gaithersburg, Maryland, from May to November of 1974. Before being exposed a water absorption test with a 6 hour rather than 72 hour immersion was performed on one brick slab of each waterproofing material. At one month intervals, reflectance measurements were made and the 6 hour water absorption test was repeated on the same brick specimen for each waterproofing material. (The 6 hour, rather than the usual 72 hour water immersion period was used in order to maximize outdoor exposure.) After six months, all the brick slabs were retrieved and dried to a constant weight before making reflectance measurements (45°) [16] and determining the 72 hour water absorption.

2.2.7 Resistance to Wind-Driven Rain

This test was intended to determine the ability of a waterproofing material to resist water penetration under pressures simulating a wind-driven rain of 160.9 km/h (100 mph). Since this is a severe test, the

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[1/] Available from the Atlas Electric Devices Co., Chicago, Ill. 60613.

dense aggregate block was chosen as the substrate for the preliminary tests. Measurements were made on dense aggregate face slabs (about 19 cm x 39.5 cm x 4.5 cm [7 1/2 in x 15 1/2 in x 1 3/4 in]) following the procedure described in Federal Specification TT-C-555B, Coating, Textured (For Interior and Exterior Masonry) [11].

The face slabs were coated with waterproofing materials in one and two coat applications at a spreading rate of 4.90 m^2/ℓ (200 ft^2/gal). The three waterproofing materials used in this test were selected to give a variation in both solids content and generic type of resin. The coated slabs remained on the wind-driven rain apparatus until failure occurred. Penetration of water through the slab to the uncoated side was termed failure.

Brick wallettes were constructed of one brick width with five mortar joints. Thus, the dimensions of the coated face were approximately 19 cm x 40 cm (7 1/2 in x 16 in). The mortar used conformed to type N of ASTM C 270-73 [17]. To simulate surface cracks in the mortar, half the wallettes had two metal shims, one each of 5 cm x 0.025 mm (2 in x 1 mil) and 5 cm x 0.1 mm (2 in x 4 mil), placed between the mortar and brick approximately 1 cm (1/2 in) in depth of penetration. The shims were removed before the mortar set. The specimens were prepared in triplicate with and without the shim cracks. All the wallettes were given 2 coats of waterproofing material [4.90 m^2/ℓ (200 ft^2/gal)], then permitted to cure for one week. The waterproofing materials used to coat the wallettes were: a silicone of 4.6% solids; an acrylate of 31.1% solids; and a modified silicone of 9.9% solids.

2.2.8 Exposure to Hydrostatic Pressure

The purpose of this test is the same as that of the wind-driven rain, i.e. to determine the ability of a waterproofing material to resist water penetration under pressures simulating a wind-driven rain of 160.9 km/h (100 mph).

A modification of a water permeability test on concrete masonry units described by Smith [18] was used to measure the water permeability of the coated brick wallettes. The wallettes were prepared as described in Section 2.2.7. The modification of the test involved construction of a wood frame 15.2 cm (6 in) high, and 15.2 cm (6 in) wide by 34.3 cm (13 1/2 in) long. A tank was formed by sealing the frame to the perimeter of the coated surface of the brick wallette with a caulking compound complying with Federal Specification TT-C-00598C [19]. Water was added to a 12.7 cm (5 in) height and the frame was covered with plastic to prevent evaporation of water. The loss of head of water with time and the visual examination of the mortar joints were used to estimate the effectiveness of the waterproofing treatment. Due to the results of the initial tests, after the hydrostatic pressure tests were completed, half of the wallettes had a third coat [2.45 m^2/ℓ (100 ft^2/gal)] of waterproofing material added and the test was repeated.

2.2.9 Methods of Application

The purpose of this investigation was to determine the relative effectiveness of the different application methods. The methods used for the waterproofing coatings were brush, roller, airless spray, and conventional air spray. The techniques used to apply the coatings by these methods were those described in Chapter 4, Painting Operations, of Paints and Protective Coatings [20]. The substrates utilized were brick, lightweight and dense concrete block. Application was to the vertical surfaces and the coating was applied until the surface was saturated or flooded. Two coats were applied 24 hours apart. After the coatings were dried, the brick and lightweight aggregate block test specimens were tested for water absorption.

3. RESULTS AND DISCUSSION

3.1 Materials

3.1.1 Waterproofing Materials

The waterproofing materials used in this study covered the range of commercially available materials. The inclusion or omission of a particular product should not be considered important since the purpose of this work was to establish criteria by which selection could be made in the future rather than to evaluate specific waterproofing materials. Information from the manufacturers about the spreading rates and recommended substrates for the waterproofing materials is contained in Table 1. If there was no information, a blank was left in the table.

All waterproofing materials were characterized by determining the percent solids and the type of binder or resin. Infrared analysis was used to identify the resins by generic type. The solids content and resin components of the waterproofing coatings are listed in Table 2, together with water absorption data which will be discussed in Section 3.2.1. In mixtures, the order of resins listed does not reflect their content in the material as no attempt was made to determine the percent of individual components.

Of the 55 samples received, six were two-package systems (Nos. 1, 5, 21, 29, 37, 54) and eleven were water-thinned (Nos. 1, 2, 3, 5, 11, 25, 37, 42, 45, 46, 55) and the remainder were solvent-thinned one-package materials. The major generic types found were as follows: silicones or modified silicones (sixteen); acrylates (ten); styrene acrylates and vinyl toluene acrylates (eight); urethanes (six); aluminum stearate mixtures (five); silicone and other resin mixtures (five); polyester (one); inorganic (one), as well as various resin combinations. In general, these major types are broad classifications. The silicone or modified silicone category includes methyl silicones, methyl siliconates, polymethyl silicic acid, and other modified silicones. The acrylates are composed of ethyl, butyl, and isobutyl acrylates plus the methacrylates.

3.1.2 Masonry Materials

The brick and block materials used in this study were selected because they represent a range of types of masonry units used in the southeastern United States. Although it was recognized that the effectiveness of a product on the waterproofing of joints is an important consideration, individual slabs were used for the screening tests. Preparation of many specimens with uniform mortar joints would have been difficult since workmanship plays such an important role. Brick slabs were used for most of the screening tests since, if a waterproofing material is not effective on brick, it is unlikely to be effective on the more porous material in a mortar joint or a concrete block.

3.2 Initial Screening Tests

Three screening tests were performed to determine which waterproofing materials were initially most effective. The primary consideration

Table 1

Information from Manufacturer's Literature or Label for Waterproofing Materials

Waterproofing Sample	Substrate (Recommended for Use On)	Spreading Rate (ft^2/gal)	Composition
1	Concrete block, brick, stucco, masonry, concrete	225 1st coat; 425 2nd coat; If add 2nd coat, 4 h between. Two coats recommended for optimum results	Water based epoxy, 28.5% solids (2 part)
2	Concrete, stucco, slate, stone, masonry, transite, cement, plaster	100-300	Acrylic resins water thinned
3	Concrete, stone		Silicone water thinned
4	Brick, concrete, flagstone, stucco, block	100-150; 2 coats recommended for very dense surfaces	5% silicone
5			Water thinned, 2 part
6			Silicone, vinyl toluene acrylate
7			Silicone, vinyl toluene acrylate
8			Silicone, vinyl toluene acrylate
9	Concrete, precast & poured Brick Stucco Plaster, stone, tile Limestone Dense concrete block	120-170 70-100 80-100 200-300 175-200 60 1st coat (4 to 5 h between) 80 2nd coat	4.7 - 5.7% solids

Table 1 (continued)

Water-proofing Sample	Substrate (Recommended for Use On)	Spreading Rate (ft^2/gal)		Composition
		1st coat	2nd coat	
10	Block, porous	40	80	7.5 - 9.0% solids
	Split face block	40-50	70-80	
	Mammoth block	60	100	
	Slump block	65-70		
	Concrete	130-150		
	Brick	100		
	Stucco	100		
	Stone, tile	200-300		
11	Leathers, vinyls, plastics			Water thinned
12	Concrete	1st coat	2nd coat	
	Smooth	200	225-250	Blend of polymeric resins, 10% solids
	Sandblasted	125-150	175-200	
		2 coats recommended		
	Exposed Aggregate			
	3/8 in	150-200		
	3/4 in	160-250		
	Brick			
	Common	150-200		
	Face	200-275		
13	Concrete block	150		6% silicones
	Hard brick	150		
	Soft brick	100		
	Lightweight block	75		
	Masonry	150		
	Stucco	100-150		
	Asbestos shingles	50		
14				
15	Masonry			20% poly-methyl methacrylate
	Stone			
16	Concrete block	75-200		5% silicones
	lightweight porous	70-75		
	Stucco			SS-W-00110
	Brick			
	hard fired	150-200		
	soft	100-125		
	Stone			
	Concrete			
	Asbestos shingles	(If add 2nd coat, 24 h between)		

Table 1 (continued)

Waterproofing Sample	Substrate (Recommended for Use On)	Spreading Rate (ft^2/gal)	Composition
17	Linoleum, tile, wood, concrete	150-200	Polypropylene glycol, aliphatic diisocyanate copolymer, 40% solids
18	Concrete		15.1% styrene acrylate; 32.8% solids
19	Stucco, brick, concrete, asbestos cement, normal porosity masonry, dense porosity masonry	75-125 if one coat only or 2 coats at 175-200 (4 h between) Saturate surface both cases	Silicone
20	Concrete, metal, wood	550-700*	Polyurethane, 33-36% solids
21	Stone	350-400	Hydrophilic acrylic, 6-9% solids (2 part)
	Brick		
	common	150-175	
	glazed, wirecut	350-400	
	Masonry	350	
	Concrete		
	precast	300-350	
	cast in place	250-300	
	Lightweight block	150	
22	Brick Concrete Stone	180-270; On porous surfaces 2 coats recommended (6 h between)	Poly oxo aluminum stearate
23	Brick, mortar, concrete, block, concrete	100-125; 2 coats recommended (6 h between)	Modified oil 15% solids
24	Dense concrete, dense brick, mortar, stucco, wood	65-100; 2 coats recommended (24 h between)	Mineral oil
25	Brick, concrete, stone, tile, terrazzo	250-2100; depending on porosity	30% mineral solids, water thinned

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* This application rate gives one mil thickness.

Table 1 (continued)

Waterproofing Sample	Substrate (Recommended for Use On)	Spreading Rate (ft^2/gal)	Composition
26	Concrete, brick, masonry, stucco	50-250	
27	Masonry, brick	150-200 If not painted over, 2 coats recommended (2 h between)	5% silicone
28	Terra-Cotta Dense brick Common brick Cement brick Concrete Concrete block Mortar Terrazzo	250-400 150-200 100-125 60-100 150-200 60-100 100-125 250-400 2 coats recommended for dense surfaces (12 h between)	5% silicone SS-W-00110A
29			2 part
30	Concrete, plaster, brick, mortar, stone, stucco, terrazzo	250-400	Modified polyester, 36% solids
31		300 2 coats recommended (1 h between)	15% solids
32		300 2 coats recommended (1 h between)	30% solids
33	Concrete		Vinyl acrylic modified with hydrophobic agents
34	Concrete		Vinyl acrylic resin
35	Concrete		Vinyl acrylic resin
36	Concrete		Silicone type resin with hydrophobic agents
37	Concrete, stone, brick, masonry block	75-100 1st coat 150-200 2nd coat 2 coats recommended for porous surfaces (6 h between)	Acrylic, polyethylene, and epoxy resins, water thinned, (2 part)

Table 1 (continued)

Water-proofing Sample	Substrate (Recommended for Use On)	Spreading Rate (ft^2/gal)	Composition
38	Masonry, concrete, cinder block walls		Butyrate resins
39	Exposed concrete, asbestos cement, cement based plasters, exposed aggregate concrete, jointing compounds		Polymethyl silicic acid, 18% solids
40	Brick, concrete, cinder block, mortar, stucco, stone		Polymethyl silicic acid, 50% solids
41	Concrete	100-200	
	Precast	200-400	
	Light, sandblasted	100-200	Several organic & inorganic solids
	Dense masonry brick	50-250*	
	Dense, smooth block	50 1st coat 75 2nd coat	
	Lightweight, slumpstone block	100-150	
	Common smooth brick	150-300	
	Common porous brick	100-200	
42	Masonry, brick, concrete, marble, painted surfaces	2 coats recommended (1/2 h between)	Water based copolymer, 26.5% solids
43	Concrete	150-200	Solids: chlorinated polymer 61.4%, synthetic polymer 37.4%
44	Concrete	2 coats recommended for porous materials	ASTM C-309, AASHO DES-M-148
45	Soil	Mixtures of 44-1 to 20-1 water to sample	Polysilioxane water thinned
46	Brick, concrete, drywall, masonite	1200-1800	Water based acrylic epoxy
47	Concrete		Blend of polymers, resins, hydrocarbon solvents; 10% solids
	Poured	250	
	Precast	275	
	Precast/Exp. Agg.	300	
	Concrete block	200	
	Cinder block	125	
	Mortar	250	

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* Voids larger than .020 in shall have sealer applied first.

Table 1 (continued)

Waterproofing Sample	Substrate (Recommended for Use On)	Spreading Rate (ft^2/gal)		Composition
47 cont.	Brick			
	Face	400		
	Common	250		
	Stone	175-300		
	Plaster & stucco	325		
	Wood	200-400		
48				Silicone SS-W-0110
49	Cement, masonry, brick, stucco, stone, asbestos shingles	150		5% silicone SS-W-110B
50	Concrete, brick, stone			Polyurethane 53% solids
51				
52	Porous lightweight block	75-150, 2 coats (24 h between) recommended for very coarse or porous surfaces		Acrylic, 40% solids
53	Porous brick, concrete masonry	100-150		Silicones and methyl methacrylate 15% solids
54	Metal, wood, stone, masonry, stucco, concrete			Fluoro copoly urea (2 part)
		1st coat	2nd coat	
55	Soft brick	100-250	150-350	Water based modified acrylic polyvinyl acetate 51% solids
	Hard brick	100-350	150-350	
	Clay block	75-150	100-200	
	Dense block	75-200	100-300	
	Smooth lightweight block	50-100	75-150	
	Split lightweight block	40-80	70-110	
	Slump block	50-120	75-160	
	Rough concrete	400	400	
	Smooth concrete	800	400	
		2 coats required (2 h between)		

Table 2

Water Absorption of Coated Lightweight Block Slabs
(Brush Application at Spreading Rate of 2.45 m^2/ℓ (100 ft /gal))

Waterproofing Sample	Percent Water Absorption* 1 coat	Percent Water Absorption* 2 coats	Resin Components	Percent Solids
1	92.5	19.5	silicone or modified silicone, epoxy	27.2
2	91.5	81.5	acrylate	18.5
3	89.5	80.9	silicone or modified silicone	4.7
4	92.6	10.9	silicone or modified silicone	3.7
5	90.9	75.7	urethane	35.9
6	93.7	66.3	vinyl toluene acrylate	19.9
7	80.9	54.4	vinyl toluene acrylate	13.2
8	92.3	51.9	vinyl toluene acrylate	21.2
9	94.1	55.2	acrylate, aluminum stearate, oil	4.8
10	82.6	45.9	acrylate, aluminum stearate, oil	6.8
11	90.8	68.5	urethane	33.5
12	89.3	9.2	silicone or modified silicone, oil	6.2
13	68.9	26.0	silicone or modified silicone	4.6
14	59.3	7.2	silicone or modified silicone	33.1
15	92.6	71.8	acrylate	17.7
16	74.7	27.3	silicone or modified silicone	5.1
17	71.4	27.9	urethane	39.7
18	92.0	76.2	styrene acrylate	30.3
19	72.3	33.3	silicone or modified silicone	4.3
20	40.9	28.1	urethane	33.6
21	75.6	59.1	acrylate	10.1
22	93.2	**	aluminum stearate	4.9

Table 2 (continued)

Waterproofing Sample	Percent Water Absorption*		Resin Components	Percent Solids
	1 coat	2 coats		
23	100.3	35.7	oil, aluminum stearate	15.5
24	89.4	19.4	silicone or modified silicone, aluminum stearate, oil	5.6
25	92.8	56.7	inorganic	25.8
26	92.6	60.0	silicone or modified silicone	9.0
27	59.6	32.6	silicone or modified silicone	4.6
28	74.0	20.6	silicone or modified silicone	1.4
29	72.2	7.3	polyester	78.1
30	85.8	59.4	acrylate	37.0
31	71.1	45.3	acrylate	16.4
32	90.5	74.5	acrylate	30.8
33	94.1	45.8	vinyl toluene acrylate	6.6
34	84.2	49.1	vinyl toluene acrylate	8.0
35	94.7	66.6	vinyl toluene acrylate	12.1
36	79.4	53.9	silicone or modified silicone	3.4
37	92.1	78.7	acrylate, hydrocarbon	20.8
38	85.2	36.9	acrylate	31.1
39	42.0	33.4	silicone or modified silicone	18.2
40	40.9	28.0	silicone or modified silicone	56.5
41	90.7	61.7	aluminum stearate mixture	10.0
42	62.3	51.7	acrylate	26.1
43	58.5	47.3	styrene acrylate, chlorinated hycrocarbon	17.7
44	79.7	70.1	styrene acrylate	18.1
45	93.7	75.6	silicone or modified silicone	49.3
46	96.4	82.7	acrylate	33.1
47	77.4	41.2	silicone or modified silicone	9.9
48	22.3	9.7	silicone or modified silicone	53.0

Table 2. (continued)

Waterproofing Sample	Percent Water Absorption*		Resin Components	Percent Solids
	1 coat	2 coats		
49	79.1	17.0	silicone or modified silicone	4.7
50	87.2	18.1	urethane	33.9
51	79.4	91.2	silicone or modified silicone, vinyl toluene acrylate, oil	30.0
52	74.0	13.5	vinyl toluene acrylate, silicone or modified silicone	43.2
53	54.0	41.7	acrylate	13.1
54	94.6	75.0	urethane	8.3
55	93.6	83.5	vinyl acetate, acrylate	51.3

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* The percent water absorption is the ratio of the water absorbed by the coated test specimen to the water absorbed by the test specimen before it was coated.

** Insufficient material to apply the second coat.

was whether the materials would keep the water out as determined by the water absorption test. Water vapor transmission and resistance to efflorescence measurements were also made.

3.2.1 Water Absorption

Initially, it was intended to perform the water absorption screening tests on lightweight aggregate block slabs in accordance with the procedure outlined in the Federal Specification for silicone waterproofing materials, SS-W-110C. The method calls for the test specimens to be totally immersed for ten seconds in the waterproofing solution under test. However, modification of the test method was necessary because immersion of the substrate in waterproofing materials of different viscosities gave widely different application rates. In addition, the spreading rates (the areas covered by unit volumes of coating material) resulting from immersion were usually many times greater than the manufacturers' recommended application rates. Thus, to ensure a constant spreading rate which approximated actual applications, the waterproofing materials were applied by brush at selected spreading rates. A single spreading rate for each substrate also contributed to consistency of the experiment.

The waterproofing product was brushed on the four edges and the uncut face of the slab. Coating the sixth side was omitted because this would seal the test specimen and complicate interpretation of the results. The lightweight aggregate slabs were coated at a spreading rate of 2.45 m^2/ℓ(100 ft^2/gal). Due to the lower porosity of the brick, the higher solids materials were not absorbed as readily into the brick as the lightweight block. Consequently, they dripped off when applied to the brick slabs at a spreading rate of 2.45 m^2/ℓ (100 ft^2/gal). Instead 4.90 m^2/ℓ (200 ft^2/ gal) was used for brick. These spreading rates were chosen after examining the range of the manufacturers' recommended spreading rates and are well within the range of recommendations listed in Table 1. For example, of the fifty-five materials, twenty-four had no label instructions for application on any substrate, seven had higher than a 4.90 m^2/ℓ (200 ft^2/gal) spreading rate for brick, twelve had lower rates of application, and twelve were close to 4.90 m^2/ℓ (200 ft^2/gal).

The water absorption was measured on the lightweight aggregate block slabs having one coat of waterproofing material. Results of this 72 hour test were disappointing. These results are tabulated in Table 2. Only three samples had water absorption averages as low as 40%, and these were all high solids materials; they were No. 20, 33.6% urethane resin; No. 40, 56.5% modified silicone resin; and No. 48, 53.0% silicone resin. Some of the waterproofing products seemed to protect the block slabs for about a day, but then permitted water to enter. Also, results on the lightweight block slabs were inconsistent. Even among the more successful samples, there were very few cases where the water absorption of all 3 replicates was similar. With some products, the water absorption of one or two slabs was much lower than the remaining slab. These initial results for coatings on lightweight concrete block gave little differentiation between coatings. It was therefore decided to perform water absorption tests on brick face slabs to seek a more definitive ranking of the coatings. Later, the lightweight block slabs were given a second coat of the waterproofing agent at the same spreading rate, and water absorption measurements were repeated. As expected, the second coat generally reduced water absorption appreciably; in one case, No. 12, the change was from 89.3% to 9.2% (see Table 2).

The results of the water absorption tests run on brick face slabs [one coat at 4.90 m^2/ℓ (200 ft^2/gal)] are tabulated in Table 3. They showed better differentiation between samples. Thirty-six samples out of the total of fifty-five had average water absorption percentages of 40 percent or lower on brick as compared to only three for the coated lightweight concrete block. Also, the materials which had 5 percent silicone resin (Nos. 4, 13, 16, 19, 27, 28, 36 and 49) and which were stated to, or would be expected to, conform to Fed. Spec. SS-W-110C varied in percent water absorption from 6.8 to 96.4 (6.8, 8.3, 22.0, 25.7, 27.4, 54.2, 68.0, 96.4) and in ranking between seventh and fifty-third. From the water absorption results on both the brick and block slabs, it was evident that there was a large variation in effectiveness in protecting the substrate against water absorption. It should be noted that the water absorption results on brick and lightweight block with two coats ranked the waterproofing materials differently.

Table 3

Water Absorption, Water Vapor Transmission, and Efflorescence Tests on Coated Brick Substrate*

Waterproofing Sample	Percent Solids	Percent Water Absorption**	Percent Water Vapor Transmission	Efflorescence Rating***
1	27.2	67.0	24.4	4
2	18.5	100.3	81.9	3
3	4.7	19.6	45.3	4
4	3.7	25.7	25.3	4
5	35.9	91.1	39.3	2
6	19.9	22.8	23.9	2
7	13.2	63.9	38.0	4
8	21.2	7.5	18.4	4
9	4.8	50.7	45.5	4
10	6.8	7.1	27.8	3
11	33.5	68.2	29.2	4
12	6.2	6.5	21.5	3
13	4.6	27.4	28.8	4
14	33.1	66.3	17.7	4
15	17.7	71.7	58.3	2
16	5.1	22.0	18.7	4
17	39.7	11.2	14.5	3
18	30.3	29.2	31.8	2
19	4.3	68.0	36.1	4
20	33.6	10.3	16.1	3
21	10.1	95.8	76.7	4
22	4.9	6.0	29.2	2
23	15.5	36.4	55.0	2
24	5.6	15.9	37.5	4
25	25.8	48.3	52.2	3
26	9.0	73.4	34.8	3
27	4.6	8.3	27.3	3
28	1.4	96.4	68.0	3
29	78.1	13.4	9.1	4
30	37.0	12.3	24.8	4
31	16.4	7.6	25.8	3
32	30.8	6.1	20.2	2
33	6.6	9.4	45.8	3
34	8.0	31.2	57.7	4
35	12.1	30.2	47.7	3
36	3.4	54.2	78.6	4
37	20.8	93.7	55.9	2
38	31.1	9.9	19.6	4
39	18.2	5.0	28.8	4
40	56.5	8.6	8.3	4
41	10.0	45.0	51.6	3
42	26.1	41.6	74.7	1
43	17.7	13.1	58.1	2
44	18.1	13.3	48.8	3
45	49.3	17.6	46.3	4

Table 3 (continued)

Waterproofing Sample	Percent Solids	Percent Water Absorption**	Percent Water Vapor Transmission	Efflorescence Rating***
46	33.1	46.6	66.0	1
47	9.9	5.6	29.8	3
48	53.0	7.0	10.7	4
49	4.7	6.8	28.8	4
50	33.9	9.2	13.2	4
51	30.0	11.3	30.4	4
52	43.2	5.5	15.2	4
53	13.1	7.2	29.9	4
54	8.3	108.5	85.1	3
55	51.3	35.5	38.9	2
Untreated brick			83.4	1

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* Spreading Rate = 4.90 m^2/ℓ (200 ft^2/gal)

** The percent water absorption is the ratio of water absorbed by the coated test specimen to the water absorbed by the test specimen before it was coated.

*** 1 heavy efflorescence on coated surface
2 slight efflorescence on coated surface
3 no efflorescence on coated surface but salt residues on edges
4 no efflorescence on coated surface

In the course of the water absorption test, some random observations were made. Waterproofing materials, 1, 29, 42, 46 and 55 turned white where the material was exposed to water. The whiteness occurred even after the samples had been aged one week before testing. It would not have been expected that the resin would be affected by the presence of water. Beads of white material were evident above the immersed areas on the sides of No. 45, and No. 37 seemed to be flaking off in some of the non-immersed areas. Even after the water absorption test, No. 48 was not tack free.

3.2.2 Water Vapor Transmission

A waterproofing material applied to the exterior surface of a building should be permeable enough to permit transpiration of accumulated moisture to the outside. At the same time, the exterior surface should be resistant to the inward passage of liquid water. Water vapor transmission measurements were made on the coated brick slabs and the averages of the three determinations are contained in Table 3. Fourteen waterproofing materials had an average moisture loss of greater than 50%. The materials having 5% silicone resin had losses of 25.3, 28.8, 18.7, 36.1, 27.3, 68.0, 78.6 and 28.8 percent.

3.2.3 Resistance to Efflorescence

Results of the efflorescence tests are also tabulated in Table 3. Only two materials permitted the formation of heavy efflorescence on the coated surface while ten others developed slight efflorescence. On a number of test specimens, it seemed as if capillary action up the sides had permitted some salts to accumulate on the sides at the upper edges, although there was no evidence of efflorescence through the coated surface. Figures 4 and 5 illustrate the observed differences in resistance to efflorescence. Of the twelve waterproofing materials that permitted efflorescence to form, nine of the coatings contained acrylate, styrene acrylate, or vinyl toluene acrylate resins, while two others had aluminum stearate resins. All silicones and modified silicones resisted the formation of efflorescence.

3.2.4 Appearance

Reflectance measurements were taken of the 55 waterproofing products on brick, lightweight aggregate block and dense aggregate block. Changes in the reflectance value caused by application of the waterproofing materials are tabulated in Table 4. The visual effects of typical coatings on dense and lightweight aggregate block are illustrated in Figure 6. The horizontal strip across the middle of each block is an uncoated area for comparison. Often there is a noticeable change in reflectance and also in gloss. Waterproofing materials 1, 5, 17, 18, 20, 29, 30, 32, 37, 38, 40, 42, 46, 51, 52 and 55 had a glossy appearance on all three substrates. It is possible that where there are appreciable differences in reflectance between original substrate and coated substrate, non-uniform application of a coating would produce an unsightly result. There may be instances where differences in reflectance and in

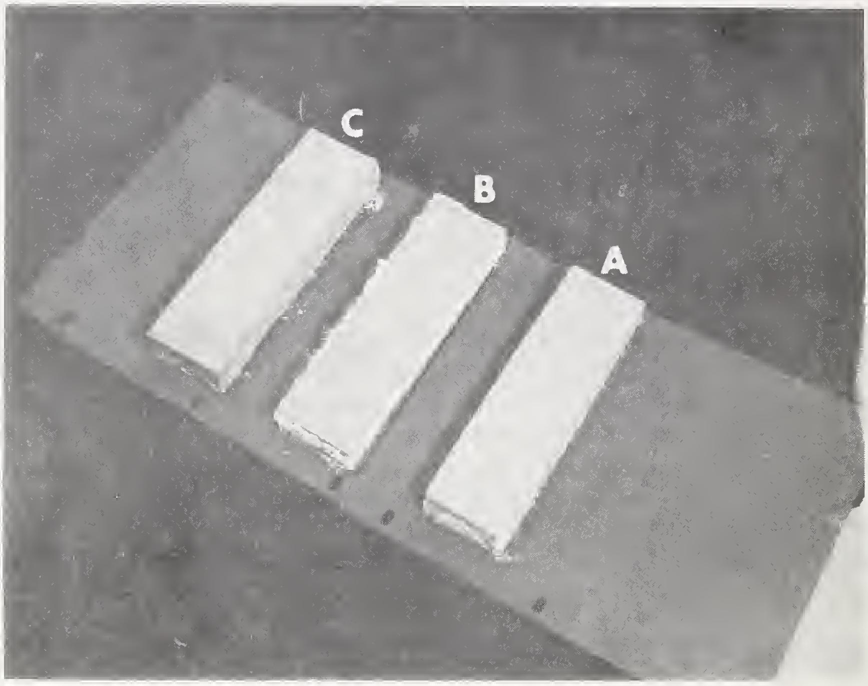

Figure 4. Waterproofed Brick Samples from Efflorescence Test.

A - no evidence of efflorescence, rating 4.

B - no efflorescence on upper surface but accumulation of salts on sides at upper edges, rating 3.

C - slight efflorescence on upper surface, rating 2.

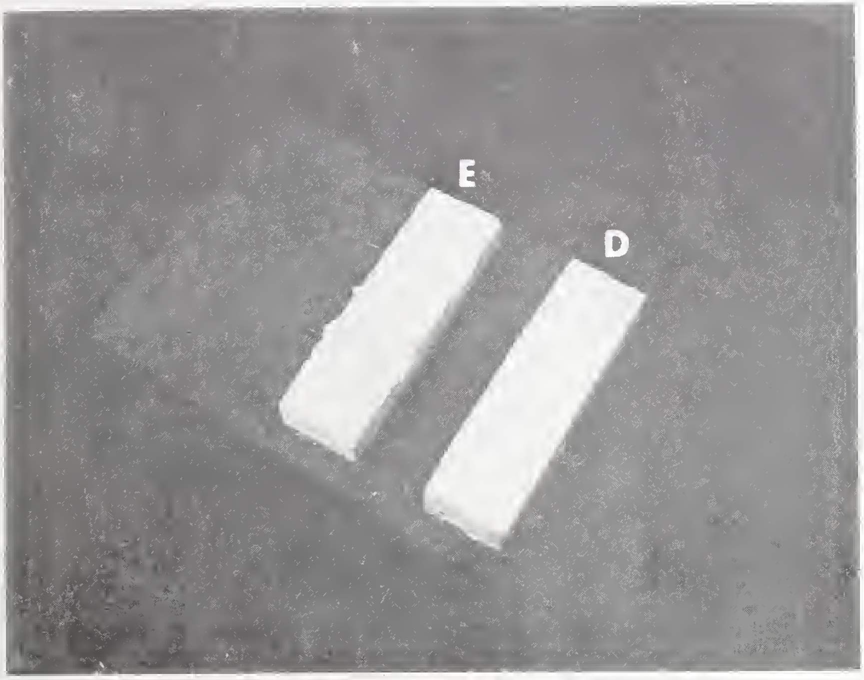

Figure 5. Brick Samples from Efflorescence Test.

D - waterproofed sample with heavy efflorescence, rating 1.

E - uncoated brick with no waterproofing applied, heavy effloresceece, rating 1.

Table 4

The Effects of Waterproofing Materials on the Appearance of Masonry*

Waterproofing Sample	Brick	Lightweight Aggregate Block	Dense Aggregate Block
1	5.9	8.9	24.9
2	2.4	2.5	6.6
3	2.1	5.5	2.6
4	1.5	3.4	.7
5	4.9	7.5	26.4
6	5.8	10.7	14.9
7	4.4	9.2	11.1
8	5.6	7.7	16.7
9	1.9	4.4	3.4
10	2.9	4.3	6.7
11	5.9	11.1	26.2
12	3.4	3.9	1.7
13	2.9	3.7	.2
14	5.6	9.6	24.7
15	.8	7.0	8.4
16	3.1	4.4	1.4
17	7.4	8.2	14.9
18	6.0	13.3	25.4
19	1.3	4.6	.7
20	6.6	11.9	16.9
21	2.9	5.1	12.9
22	2.8	4.7	13.1
23	3.4	15.8	11.4
24	2.2	5.0	8.2
25	3.2	7.5	17.9
26	4.2	3.4	6.9
27	3.3	1.0	8.6
28	3.0	.8	9.7
29	8.6	13.8	27.1
30	6.6	10.0	25.6
31	5.3	8.3	11.2
32	5.3	9.7	16.1
33	1.4	5.6	5.9
34	4.1	6.6	4.2
35	3.7	8.7	11.7
36	-3.4	-1.8	.4
37	4.9	10.5	10.4
38	6.3	10.8	15.4
39	4.7	7.0	13.2
40	6.7	15.1	25.6
41	5.5	10.8	8.4
42	2.3	6.7	7.1
43	5.8	4.6	10.6
44	6.8	8.5	20.6
45	4.5	11.7	18.9

Table 4 (continued)

Waterproofing Sample	Brick	Lightweight Aggregate Block	Dense Aggregate Block
46	2.8	6.2	7.6
47	2.1	6.5	3.6
48	8.9	15.0	23.4
49	1.5	7.3	4.2
50	7.1	16.0	1.6
51	5.6	3.9	18.9
52	3.9	10.2	22.6
53	3.9	3.9	11.9
54	1.7	9.6	-.3
55	2.1	4.9	2.8

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* The values in the table represent the differences between the 45° reflectance of the specimens before and after waterproofing. Each value represents an average of measurements taken in three locations on the test specimens. The reflectance values for the untreated masonry materials were: brick 19.5, lightweight aggregate block 37.9, dense aggregate block 42.4.

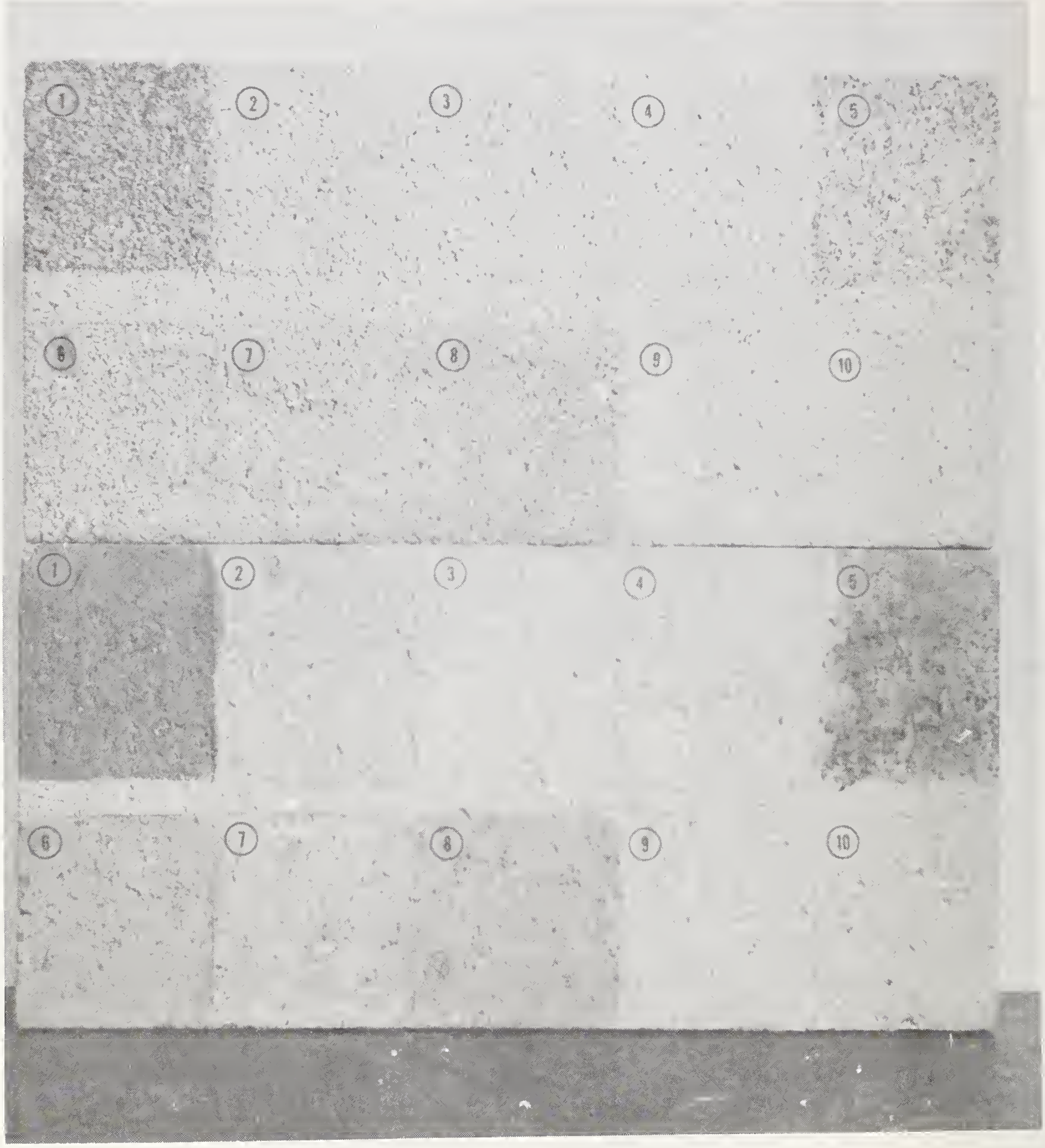

Figure 6. Masonry units illustrating changes in appearance caused by waterproofing materials Nos. 1-10. The upper unit is a lightweight aggregate block while the lower unit is a dense aggregate block. The horizontal strip across the middle of each block is an uncoated area for comparison.

gloss may not be too objectionable, but it would be recommended to coat a small test area prior to coating any large surface area.

3.3 Second Phase Screening Tests

While the initial performance of any waterproofing material is important, its ability to protect the substrate over an extended time period is equally important. The waterproofing coating is expected to protect the building and contents from water damage, and the coated surfaces themselves should not introduce a potential maintenance problem. The objective of the second phase was to measure durability characteristics of selected coatings that showed good initial performance. The selection of the fifteen waterproofing coatings for the second phase of the test was based primarily on the water absorption tests on brick, i.e., all were less than 20%. Consideration was also given to the inclusion of as many different generic types of waterproofing materials as possible. For example, No. 3 was included because it was a water-thinned, modified silicone.

Other factors involved in the selection were resistance to efflorescence, water vapor transmission, appearance, handling properties, and solids content. For example, one sample was very caustic, one coating had a limited pot life of approximately 30 minutes, and some samples became whitish on exposure to moisture. All of these were excluded. Some manufacturers produced several products by varying resin content or solvent. In other cases, similar resins were used by more than one manufacturer as evidenced by similarity of the infrared spectra. The resins of the following waterproofing materials were judged to be similar: Nos. 6, 7, 8, 33, 34, 35; Nos. 9, 10; Nos. 13, 48, 49; Nos. 20, 50; Nos. 27, 40; Nos. 30, 38, 53; Nos. 31, 32; Nos. 43, 44. In such cases, only one example of each resin type was included.

In general, the two-part systems and the water-thinned systems did not perform well enough to be included in the second phase of the study. Only the first fifty samples were considered for inclusion in the additional tests since the last five were received too late to complete their initial screening prior to the start of the second phase. The fifteen waterproofing materials selected are listed in Table 5.

The resin types contained in these fifteen consisted of five silicones or modified silicones, two urethanes, two acrylates, one vinyl toluene acrylate, one aluminum stearate and four resin mixtures. It should be emphasized that each of these resins was distinct, although they may have been of the same generic type.

Although there are many important durability characteristics in materials, three tests, resistance to humidity, accelerated weathering, and outdoor exposure, were chosen to evaluate the performance of the fifteen coatings during the second phase of testing.

Table 5

15 Waterproofing Materials for the Second Phase of Testing

Waterproofing Sample	Resin Components	Percent Solids	Percent Water Absorption* Brick**	Percent Water Absorption* Lightweight Aggregate Block**
3	silicone or modified silicone	4.7	19.6	80.9
10	acrylate, aluminum stearate, oil	6.8	7.1	45.9
12	silicone or modified silicone, oil	6.2	6.5	9.2
17	urethane	39.7	11.2	27.9
20	urethane	33.6	10.3	28.1
22	aluminum stearate	4.9	6.0	93.2
24	silicone or modified silicone, aluminum stearate, oil	5.6	15.9	19.4
27	silicone or modified silicone	4.6	8.3	32.6
31	acrylate	16.4	7.6	45.3
33	vinyl toluene acrylate	6.6	9.4	45.8
38	acrylate	31.1	9.9	36.9
39	silicone or modified silicone	18.2	5.0	33.4
43	styrene acrylate, chlorinated hydrocarbon	17.7	13.1	47.3
47	silicone or modified silicone	9.9	5.6	41.2
49	silicone or modified silicone	4.7	6.8	17.0

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* The percent water absorption is the ratio of the water absorbed by the coated test specimen to the water absorbed by the test specimen before it was coated.

** Brick slabs - one coat at 4.90 m^2/ℓ (200 ft^2/gal)
Lightweight aggregate block slabs - 2 coats each at 2.45 m^2/ℓ (100/ft^2/gal).

3.3.1 Resistance to Humidity

This test was intended to evaluate the effects of exposing the coatings to 100% relative humidity with condensation on the coated surface at all times. The results of exposure of coated brick slabs in the Cyclic Environmental Tester are listed in Table 6. It is of interest that for all but four samples the water absorption decreased between the original values and the six week exposures. A possible explanation is that there is some post cure of the resins which improved their performance. By fourteen weeks exposure, Nos. 3, 33, 38 and 43 had appreciable increases in water absorption. No. 3 was a water-thinned product, while Nos. 33, 38 and 43 had vinyl toluene acrylate, acrylate, and styrene acrylate mixture, respectively, as resins.

3.3.2 Resistance to Accelerated Weathering

The water absorption results after exposure of the coated brick slabs in the Weather-Ometer for 500, 1000, 1500, 2000 and 2500 hours are tabulated in Table 7. The original water absorption values are listed for comparison. Again, an apparent post-cure phenomenon occurred between the original values and those at 500 hours exposure. As can be seen, after 2500 hours, Nos. 17, 20, 22, 31, 33, 38 and 43 have had appreciable increases in water absorption. In addition, Nos. 3, 10 and 39 have risen slightly above the original values.

These results on the water absorption vs. exposure of the fifteen samples are also illustrated in Figures 7 and 8. The purpose is three-fold: to illustrate an apparent post-cure phenomenon, to show the similarities between silicone-containing waterproofing materials and to point out the wider range of performance properties (water absorption) of the other types of waterproofing materials. These figures also illustrate the generally superior performance of the silicone-containing waterproofing materials under these conditions. The products that formed a film on the surface (Nos. 17, 20, 31, 38 and 43) were apparently more affected by the ultraviolet radiation as evidenced by the greater changes in water absorption. One high solids material, No. 39, was the exception to this generality, but it also was a modified silicone and would be expected to perform as the other silicone-containing waterproofing materials.

When reflectance measurements were taken, a general slight fading trend was noted, but the changes did not relate to water absorption results.

Table 6

Water Absorption After Exposure to High Humidity with Condensation*

Waterproofing Sample	Percent Water Absorption**		
	Original	6 Weeks	14 Weeks
3	19.6	29.7	39.6
10	7.1	4.3	1.7
12	6.5	2.4	.4
17	11.2	5.1	7.1
20	10.3	4.6	1.1
22	6.0	4.7	7.2
24	15.9	4.1	1.9
27	8.3	2.9	1.8
31	7.6	5.2	8.4
33	9.4	30.1	50.5
38	9.9	9.2	15.7
39	5.0	6.3	3.2
43	13.1	57.6	67.4
47	5.6	3.7	3.4
49	6.8	2.6	1.6

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* The test specimens consisted of brick slabs having one application of waterproofing material at 4.90 m^2/ℓ (200 ft^2/gal).

** The percent water absorption is the ratio of the water absorbed by the coated test specimen to the water absorbed by the test specimen before it was coated.

Table 7

Water Absorption After Exposure in Weather-Ometer*

Waterproofing Sample	Percent Water Absorption**					
	Original	500 h	1000 h	1500 h	2000 h	2500 h
3	19.6	11.6	13.6	16.7	14.6	20.3
10	7.1	3.5	10.7	10.9	13.2	11.0
12	6.5	5.7	9.7	5.4	6.0	4.8
17	11.2	5.8	12.0	21.4	41.1	62.3
20	10.3	6.3	11.1	17.7	11.2	17.5
22	6.0	6.2	59.1	54.5	53.7	66.7
24	15.9	3.8	8.4	6.6	4.8	4.7
27	8.3	5.8	9.0	5.8	4.9	4.1
31	7.6	7.4	43.1	23.8	20.6	51.0
33	9.4	32.8	93.5	104.9	98.6	100.2
38	9.9	4.4	9.9	7.4	10.2	18.5
39	5.0	5.4	11.3	10.5	8.6	9.9
43	13.1	17.0	86.7	90.7	68.5	101.1
47	5.6	4.3	7.3	7.4	7.0	6.7
49	6.8	4.0	6.5	7.6	4.5	5.2

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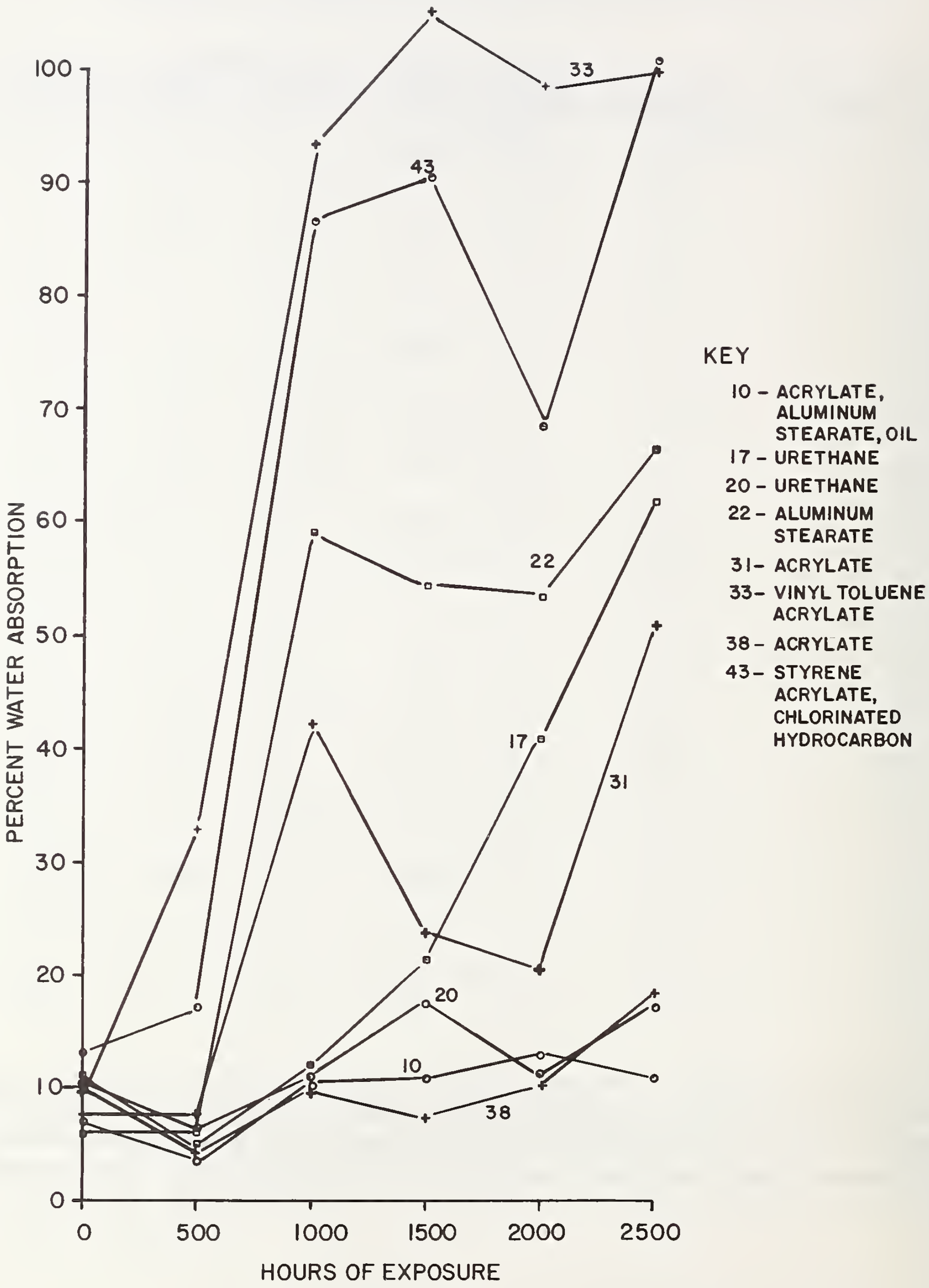
* The test specimens consisted of brick slabs having one application of waterproofing material at 4.90 m^2/ℓ (200 ft^2/gal).

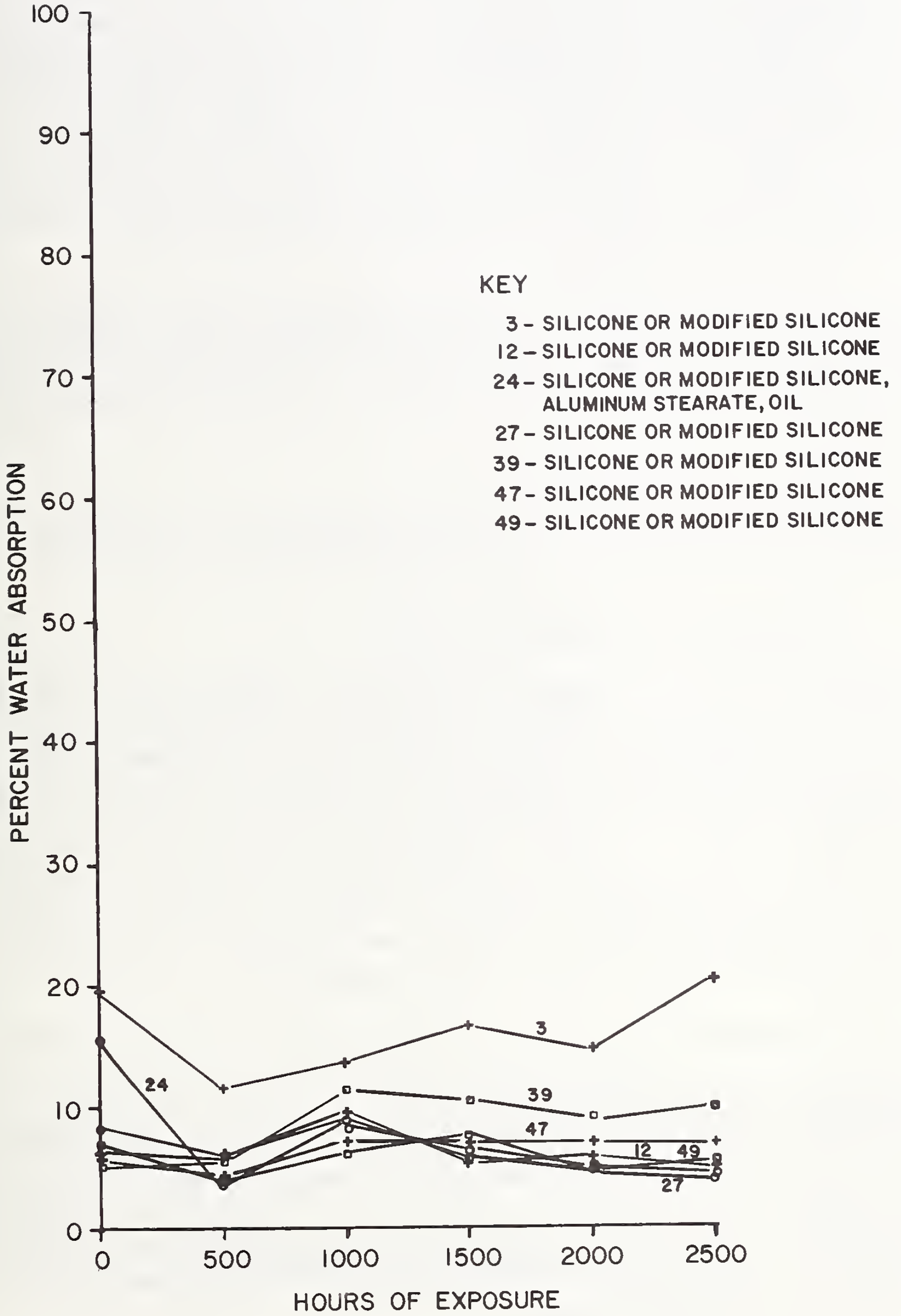
** The percent water absorption is the ratio of the water absorbed by the coated test specimen to the water absorbed by the test specimen before it was coated.

Figure 7 - Accelerated Weathering Exposure of Waterproofing Materials Containing No Silicone Resins



These are the materials from the second phase of testing which contain no silicone resins. (The products with silicone resins are in figure 8.) The test specimens were brick slabs with one coat of waterproofing material applied at 4.90 m^2/ℓ (200 ft^2/gal).

Figure 8 - Accelerated Weathering Exposure of Waterproofing Materials Containing Silicone Resins



These are the materials from the second phase of testing which contain silicone or modified silicone resins. (The products with no silicone are in figure 7.) The test specimens were brick slabs with one coat of waterproofing material applied at 4.90 m^2/ℓ (200 ft^2/gal).

3.3.3 Outdoor Exposure

The 72 hour water absorption was measured on the specimens which had been exposed to natural weathering for six months. These results are contained in Table 8. Similar trends were also observed during the six hour water absorption tests which were performed at one month intervals to monitor changes in the materials. Waterproofing materials Nos. 17, 20, 22, 33, 38 and 43 all showed appreciable increases in water absorption from the original values. Although the water absorption of No. 3 did not rise above the original, it was high when compared to the other products. Reflectance measurements were taken, but as with the accelerated weathering exposures, only a general slight fading trend was noted. Uncoated brick also changed slightly in 5 months exposure.

The outdoor and Weather-Ometer exposures compare favorably. The fact that there was a good correlation between outdoor and Weather-Ometer exposures justifies the inclusion of an accelerated aging test in the performance criteria for these clear waterproofing coatings.

3.4 Mortar Joint Evaluations

The purpose of these tests was to evaluate the effectiveness of different types of products in waterproofing mortar joints.

3.4.1 Resistance to Wind-Driven Rain

This test was a laboratory simulation of wind-driven rain which is one of the main causes of above grade water infiltration into buildings. Since the wind-driven rain test is severe, dense aggregate block slabs rather than lightweight aggregate block slabs were chosen as the substrate for preliminary tests. The slabs were coated with three waterproofing materials (Nos. 10, 31 and 49) which were chosen to have a variation in solids content and resin type. No. 10 was an acrylate, aluminum stearate, oil mixture of 6.8% solids, while No. 31 was an acrylate having a relatively high solids content of 16.4%. No. 49 was a 4.7% silicone conforming to SS-W-110B and was useful for comparison.

The resistance to wind-driven rain of all the test specimens which had a single coat of waterproofing material at 4.90 m^2/ℓ (200 ft^2/gal) was poor, i.e., pinhole leaks were observed within 15 minutes and, within an hour, 1/4 to 1/2 of the back surface was wet. Application of a second coat at 4.90 m^2/ℓ (200 ft^2/gal), improved the resistance to wind-driven rain, but water still penetrated to the back surface of all the specimens after five hours.

After the preliminary tests on dense aggregate block slabs were completed, brick wallettes were coated with three waterproofing materials. These three materials used in the evaluation on the mortar joints were

Table 8

Water Absorption After Exposure Outdoors*

Waterproofing Sample	Percent Water Absorption** Original	6 months
3	19.6	17.1
10	7.1	6.5
12	6.5	4.6
17	11.2	53.3
20	10.3	49.6
22	6.0	11.8
24	15.9	3.9
27	8.3	4.1
31	7.6	8.6
33	9.4	99.8
38	9.9	17.4
39	5.0	6.1
43	13.1	98.9
47	5.6	4.7
49	6.8	5.8

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* The test specimens consisted of brick slabs having one application of waterproofing material at 4.90 m^2/ℓ (200 ft^2/gal). They were exposed from May to November 1974 at the NBS exposure site in Gaithersburg, Maryland.

** The percent water absorption is the ratio of the water absorbed by the test specimen before it was coated.

selected on the basis of their good performance after 1500 hours in the Weather-Ometer and represented a range in solids content and resin type. Availability of the quantity needed for the applications was also a factor. The waterproofing materials used were: No. 27, a 4.6% silicone; No. 38, a 31.1% acrylate; and No. 47, a 9.9% modified silicone.

Due to the irregular surface at the joints, the wallettes could not be sealed successfully on the wind-driven rain apparatus. Since this testing involved determining the protection a waterproofing material affords at the brick-mortar interface, the wind-driven rain test was considered impractical for this purpose.

3.4.2 Exposure to Hydrostatic Pressure

This test was set up as an alternative to the wind-driven rain test. It was designed to measure the water permeability of a coating exposed to water at a pressure of 1245.5 Pascals or 12.7 cm (5 in) of water which is equivalent to a wind of 160.9 km/h (100 mph) [21], as in the wind-driven rain test. It was more convenient than the wind-driven rain test because the specimens were tested in a horizontal position and could be more easily sealed to the test apparatus, and because the specimens could be tested individually rather than in groups of three.

The loss of water with time and the visual examination of the mortar joints were used to judge the effectiveness of the waterproofing materials. Visual examination of the mortar joints showed that water leakage occurred through about half of the joints. After 3 days, few of the wallettes had any water remaining in the tank. All wallettes coated with No. 27 permitted all of the water to pass through. One of the test specimens coated with No. 38 had water remaining, while four of the wallettes coated with No. 47 retained some water.

When this test was completed on the wallettes having one coat of waterproofing material, half of the wallettes were dried and an additional coat at 2.45 m^2/ℓ (100 ft^2/gal) was applied. After a one week cure period, the test was repeated. Although there was improvement with the addition of the third coat of waterproofing material, some water did penetrate all wallettes even after only six hours. After 24 hours exposure, wallettes coated with No. 27 had 2.5 cm (1 in), 8 cm (3 1/8 in), and 10 cm (4 in) of water remaining; wallettes coated with No. 38 had 8.3 cm (3 1/4 in), 11 cm (4 1/4 in), and 12.7 cm (5 in) of water remaining; and wallettes coated with No. 47 had 7.6 cm (3 in), 11 cm (4 1/4 in), and 12.7 cm (5 in) of water remaining. It appears that well-filled mortar joints can be waterproofed if a sufficient quantity of a good waterproofing material is applied. However, it must be pointed out that the sealing of the surface may result in a low water vapor transmission which could introduce new problems. This might include the concentration of soluble salts in the walls which may crystallize underneath the surface treated with the waterproofing material and cause the masonry surface to spall off.

The use of this test did not answer the question of how to test mortar joints when evaluating a coating. The 12.7 cm (5 in) head of water is equivalent to about a 160 km/h (100 mph) wind and is too extreme. In areas that are subjected to hurricane force winds, sealing the joints to these pressures is imperative. However, in other regions it should not be necessary. Modifying this test to use hydrostatic pressures which correlate with more normal wind velocities could make it useful in evaluating the resistance of coatings to wind-driven rain.

3.5 Methods of Application

These tests were carried out to determine the relative effectiveness of four different methods of application of waterproofing agents to masonry surfaces. The methods used were brush, roller, conventional air spray and airless spray. Two waterproofing materials were used, they were No. 6, 19.9% solids and No. 24, 5.6% solids. They were selected because of their different solids content. The application rate was not specified, rather the waterproofing materials were applied until the surface was saturated or flooded. Two coats were applied 24 hours apart. After a one week cure the waterproofing effectiveness was judged by submitting brick slabs and lightweight aggregate concrete slabs to a 72 hour water absorption test. These test results are listed in Table 9. In general, brush and roller were more effective than spray application.

Table 9

Water Absorption on Masonry Substrates Having Waterproofing Materials Applied by Different Application Procedures*

Application Method	Percent Water Absorption** No. 6, 20% solids Brick	Lightweight Aggregate Concrete Block	No. 24, 6% solids Brick	Lightweight Aggregate Concrete Block
Brush	7.0	34.8	4.7	11.2
Roll	5.1	42.8	5.9	14.0
Airless Spray***	53.3	42.2	12.5	67.7
Air Spray***	18.8	79.8	30.4	81.4

* Two flood coats of waterproofing material were applied 24 hours apart.

** The percent water absorption is the ratio of the water absorbed by the coated test specimen to the water absorbed by the test specimen before it was coated.

*** Cobwebbing (a spider web effect caused by premature drying) was encountered with the 20% solids material.

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4. FIELD SURVEY

A number of maintenance officials in HUD area and regional offices were surveyed with respect to their experiences in the field application and performance of waterproofing treatments. Several points were evident from these discussions which are reported in Appendix A. Apparently, the eastern and southeastern areas of the United States have more serious waterproofing problems than other regions. Since some water may enter through paths other than through the walls, the cause of water infiltration should always be determined prior to waterproofing. Most successful waterproofing treatments involve the application of more than one coat of material. Best results seem to be attained by hiring an experienced commercial firm for the application of the waterproofing material, and requiring a guarantee of their work.

5. RECOMMENDATIONS FOR THE SELECTION AND APPLICATION OF CLEAR WATERPROOFING MATERIALS FOR MASONRY

Based on the literature, the test results reported here, and the field experiences of HUD area and regional engineers, the following recommendations concerning the selection and application of clear waterproofing materials for masonry may be made:

1. The cause of the water infiltration problem should be determined. The building should be inspected to identify repairs or improvements which may be necessary before applying a waterproofing material.

2. Prior to application of any waterproofing product, all mortar joints should be sealed, and, unless a manufacturer specifically guarantees that his material will bridge such imperfections, cracks greater than 0.05 cm (0.02 in) in either the joints or the masonry units should be filled.

3. If it is impractical to repoint or fill large cracks, the use of surface fillers and pigmented coatings should be considered.

4. Waterproofing materials which meet the performance criteria given in Appendix C should be used. In general, solvent-based materials are more likely to meet the criteria than two-part materials or water-thinned products.

5. The surface should be prepared in accord with the manufacturer's recommendations. The surface on which the waterproofing material is to be applied should be clean and dry. Dirt, grease, asphalt, stains, efflorescence, or other loose material should be removed from the surfaces by approved methods prior to application of the waterproofing material.

6. The method of application should be in accord with the manufacturer's recommendations. Laboratory tests found that brush and roller application usually give better results than spray application, with the airless spray being more effective than air spray. However, in the field, airless spray has been found to be a very effective method of application.

7. A minimum of two coats of the waterproofing product should be applied at spreading rates recommended by the manufacturer for the specific substrate and method of application.

8. Where appearance is critical, a test panel should be coated prior to general application of any coating to determine if the appearance of the coated material is acceptable to the buyer.

9. The weather conditions on the day of application should fall into the range recommended by the manufacturer.

10. Where possible, waterproofing should be done by a commercial firm whose specialty is waterproofing and who is willing to bond or guarantee the work. In any case, experienced personnel should do the work and, if possible, a manufacturer's representative should be present during the application.

6. SUMMARY AND CONCLUSIONS

The fifty-five waterproofing materials obtained for the study were representative of those produced for waterproofing in above ground application. The resins used for these materials were identified by infrared analysis and included the following generic types: silicones or modified silicones; acrylates; styrene acrylates, vinyl toluene acrylates; urethanes; aluminum stearate mixtures; silicone and other resin mixtures; polyesters; inorganic; as well as various resin combinations.

A screening process, based upon initial performance of the coatings on masonry substrates, was used to limit the number of waterproofing materials to fifteen for the second phase of the testing. The tests included water absorption, water vapor transmission, resistance to efflorescence, appearance and handling properties. The second phase screening was designed to evaluate the durability characteristics of the fifteen coatings that showed good initial performance. The durability tests performed were: resistance to humidity, accelerated weathering and outdoor exposure.

These performance tests were used to develop recommended performance criteria for the selection of clear waterproofing materials for use on masonry surfaces. The criteria are listed in Appendix C. Table 10 tabulates the results of the screening tests related to the performance criteria for the fifteen waterproofing materials.

The ability of a waterproofing material to protect the substrate over an extended period of time is most important. Consequently, the results of the Weather-Ometer and outdoor exposures are especially significant. After 2500 hours in the Weather-Ometer and six months exterior exposure, sample Nos. 10, 12, 24, 27, 39, 47 and 49 have continued to show good performance. No. 39 is no longer available in this country, although it performed well in these tests. It may be noted that, of the materials that met all the performance criteria, most materials contained silicone resins, but only two were analogous to the silicone water repellent as described in Fed. Spec. SS-W-110C. Also, of the waterproofing materials used in this study, twenty-one contained silicone resins. This indicates that the presence of silicone resins is not always a guarantee of good waterproofing performance.

Table 10

Results of Screening Tests Related to the Performance Criteria

		Appearance					
Waterproofing Samples	Total Solids, %	Reflectance Differences, Lightweight Aggregate Concrete Block	% Water Absorption*	% Water Vapor Transmission	Resistance to Efflorescence Rating	% Water Absorption* After Accelerated Weathering Exposure (1500 hrs)	% Water Absorption* After Continuous Condensation Exposure (14 weeks)
3	4.7	5.5	19.6	45.3	4	16.7	29.7
10	6.8	4.3	7.1	27.8	3	10.9	4.3
12	6.2	3.9	6.5	21.5	3	5.4	2.4
17	39.7	8.2	11.2	14.5	3	21.4	5.1
20	33.6	11.9	10.3	16.1	3	17.7	4.6
22	4.9	4.7	6.0	29.2	2	54.5	4.7
24	5.6	5.0	15.9	37.5	4	6.6	4.1
27	4.6	1.0	8.3	27.3	3	5.8	2.9
31	16.4	8.3	7.6	25.8	3	23.8	5.2
33	6.6	5.6	9.4	45.8	3	104.9	30.1
38	31.1	10.8	9.9	19.6	4	7.4	9.2
39	18.2	7.0	5.0	28.8	4	10.5	6.3
43	17.7	4.6	13.1	58.1	2	90.7	57.6
47	9.9	6.5	5.6	29.8	3	7.4	3.7
49	4.7	7.3	6.8	28.8	4	7.6	2.6
Proposed Performance Criteria		10 maximum	20 maximum	20 minimum	3 minimum	15 maximum	15 maximum

* The percent water absorption is the ratio of water absorbed by the coated test specimen to the water absorbed by the test specimen before it was coated.

While the second phase of this study was limited to testing fifteen materials, other products contained similar resins (see Section 3.3). Although Nos. 9, 13, 40 and 48 were not tested, they have resins similar to some of the waterproofing materials mentioned above that have shown good performance. Similar performance may be expected from these, provided that the percent solids content is at least equal to the waterproofing material above having an equivalent resin. It should be noted that Nos. 40 and 48 are intended to be diluted rather than used at the concentration provided for this study.

The final testing included the performance characteristics of selected waterproofing materials on exposure to laboratory simulation of wind-driven rain of 160.9 km/h (100 mph). Although two and three coat applications of waterproofing materials were applied, some of the mortar joints in the brick wallettes continued to leak. Modification of the test, exposing the test specimens to hydrostatic pressure to more closely relate it to normal wind velocities, could make this a more useful test for the evaluation of coatings to wind-driven rain.

On the basis of the tests performed, it appeared that the Weather-Ometer results, which related closely to the results of outdoor exposure at the NBS site can predict failures of the waterproofing materials. However, this test uses single unit test specimens, e.g. a single brick slab, while the major waterproofing problem is involved with the overall masonry system. This system includes cracks and voids in the masonry substrate, open cracks between mortar and masonry due to loss of bond, incompletely filled mortar joints, settlement cracks, and the porosity of the particular materials. The results of tests performed to measure the ability of certain materials to waterproof mortar joints were inconclusive. More work should be done on the development of suitable methods to evaluate water penetration. In addition to modification of existing tests, another approach to investigating the properties of waterproofing agents could be through a study of the effects of waterproofing materials on material properties pertaining to liquid penetration. This could include measurement of contact angles, breakthrough pressures, and pore size distribution. Such an approach is outlined in Appendix D. Characterization of performance in this manner could be the starting point to development of test methods of a more basic and general type.

The methods of application of waterproofing materials were studied. A list of recommended practices for application was prepared based upon literature survey, the test results reported, and the survey of field application and performance experience of HUD area and regional maintenance officials.

7. ACKNOWLEDGMENTS

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APPENDIX A

FIELD SURVEY OF APPLICATION AND PERFORMANCE OF WATERPROOFING MATERIALS

A1. Background

HUD maintenance engineers in seventeen regional and area offices throughout the country were contacted to obtain information about maintenance and application problems encountered in the field. The information gathered is summarized in this Appendix. A survey form similar to the one in Appendix B could be used in establishing a data bank which, if coordinated with HUD headquarters, could serve as a record of performance and provide data on durability.

A2. Geographical

Some HUD personnel listed water infiltration as a major continuing maintenance problem, while others had difficulty in recalling more than one or two specific instances. In general, it appears that is a more serious problem in the east and southeast than in other regions of the country. Some areas reported dampness on the interior of a building but this was due to condensation in areas of high relative humidity rather than from water leaks from the outside.

A3. Major Problem Areas

Waterproofing problems appear to occur primarily above grade in both low and high rise apartment buildings. Waterproofing below grade was not considered to be a large problem.

The problems mentioned fell into several categories. A number related to the original construction of the building. These ranged from design deficiencies to problems resulting from poor workmanship. An example of design deficiency is cracks caused by normal building movements as in a large prestressed concrete building erected with no expansion joints to allow for thermal movement. In this case, water infiltration is difficult to halt because, if the cracks are patched, subsequent movements of the structure may cause the cracks to reopen or cause new cracks to occur. A similar deficiency exists when expansion joints are omitted from large concrete slabs intended for floors and roofs. Movement of the concrete may cause cracks to form in the exterior mortar joints. Another example is a structure in which the loads on exterior brick walls which support the floors cause cracking in the walls.

Contrary to expectation, hollow core walls were cited by several as being more prone to water infiltration than the older type of solid brick or masonry construction. Sometimes there was concern that the walls might not have been constructed properly. In such cases, it was considered wise to consult an architect with specific experience with the type of construction involved. Application of a waterproofing material may not solve the problem.

Other leakage problems cited were related to water entering through roofs or in the area of existing openings such as doors and windows. These problems can usually be eliminated by proper roof flashing or careful application of a good caulking around the doors and windows.

It does not seem that waterproofing problems are confined to buildings of any particular age. Some officials mentioned that their waterproofing problems were primarily limited to buildings twenty or more years old, while others had major concerns with structures less than five years old.

A4. Materials

The type of building material which seemed to be most frequently involved in problem areas was brick. However, prestressed concrete, cinder block, concrete block, split block and stucco were also mentioned. This may reflect the frequency of use of these particular materials in the areas having waterproofing problems. In addition, mortar joints were almost universally cited as a contributing problem if not the major one. Joints in the end walls were cited several times as having waterproofing problems.

There are several reasons for water infiltration. Some of the materials are naturally more porous than others. Certain materials deteriorate with age and weathering and become more porous, e.g. lime-sand mortar. In addition, cracks may form and permit the passage of water through the material. Also, deterioration with age may cause looseness of joints or damage to building materials. Extreme conditions such as high winds or hurricanes, or abrasion by wind-driven sand, may accelerate changes in the surface of the material.

A5. Treatments

Several solutions to problems caused by cracks were mentioned. With mortar joints, depending on the size of the crack, the mortar may be tuck-pointed. Others merely repair with new mortar or caulking. In certain cases of hairline cracks, a waterproofing material is applied directly to the surface. This should only be done if the manufacturer says the material can bridge cracks of the size present and can provide evidence of its ability to do so. Otherwise cracks should be repaired first.

Since it is often difficult to identify the specific joints that leak in a wall, it is generally necessary to repair all joints on the entire wall or in the particular area. Although it cannot be used with clear waterproofing products, one novel solution to joint crack problems was reported. It involves painting the joint or crack then immediately placing a 9 cm (3 1/2 in) wide fiber glass strip in the wet paint over the joint. Later, another coat of paint is applied over the entire wall. This solution is reported to cost less than half the cost of replacing the mortar and has continued to be effective for more than 5 years. However, this treatment involves the use of pigmented coatings and would not be used with clear waterproofing materials. Nevertheless, some find the use of color coatings makes the buildings more attractive and provides individuality to buildings in large projects.

A6. Selection of Waterproofing Materials

Once a waterproofing problem has been found, the choice of waterproofing material is important. Most officials related unhappy experiences with materials which were totally inadequate. Those with serious waterproofing problems agreed that finding a waterproofing product which would last more than a couple years was difficult. As a result, when they found a process or product which filled their needs, they used it exclusively.

A7. Service Life

Service life with waterproofing materials varied. Silicones have long been known as waterproofing products, yet many reported they were able to get only 2 to 3 years of service from one coat of silicone. Consequently, they switched to other materials which provided a longer service life. Due to high labor costs, most officials prefer as few coats as possible and would put on one heavy coat rather than two thinner coats. Some individuals were satisfied with silicone performance and reported five years and more of service. It was pointed out that a 5% silicone should not be thinned (as is often done on site by applicators), that two or more coats are necessary, and that warm temperatures during application are important. Failure to follow this advice could shorten the life expectancy for silicone materials.

A8. Application

Many who had gone to products other than silicone carefully described the application procedure. Usually, it consisted of careful surface preparation followed by a multiple coat application of the waterproofing material under closely supervised conditions. It was pointed out that waterproofing integrity was best assured when temperatures of 10°C (50°F) or above are observed during application. In addition, all waterproofing materials should be manually stirred before and during application.

In most cases waterproofing jobs were contracted out to commercial firms with specialized experience. When possible, a guarantee for minimum expected performance was obtained. While the ultimate in waterproofing is permanent protection, a service life of at least 10 years is desirable. When HUD maintenance personnel applied the waterproofing materials, generally they were either experienced or had a manufacturer's representative present to advise. In any case, for optimum results, it was felt that the manufacturer's recommendations must be followed strictly and, if possible, a manufacturer's representative should be present during the application. When possible, waterproofing should be accomplished by a recognized, local, firm that guarantees and certifies its work.

Only minor problems involving incompatibility of new and old waterproofing products have been encountered. One way to handle this is to delay application by permitting the existing product to weather off. If time does not permit this, a pressurized detergent wash followed by high pressure water (3.45 MPa (500 psi)) has been effective in removing coatings from masonry. With certain products, it may not be possible to get good adhesion on any building material that has been previously coated. These could be applied to new construction only.

Conventional air spray seemed to be the most common application method utilized with waterproofers. Brushes were also frequently employed, depending on the substrate, but this was a more labor intensive application method. Airless spray and roller application were used far less often. Fertilizer spray pumps for small jobs are efficient and have been quite productive. On two story buildings, telescopic poles have been used to apply materials.

A9. Summary

The comments from the HUD maintenance engineers emphasized several important points. These were:

1. Certain parts of the United States, particularly the east and southeast, tended to have more serious and frequent water infiltration problems.

2. Application of a waterproofing material did not solve all water infiltration problems. The building should first be inspected to determine the cause of the problem. Certain repairs or modifications may be needed before applying a waterproofing material. Poor design of a building may permit water leakage which cannot be corrected with conventional waterproofing products.

3. Successful waterproofing procedures usually involved careful surface preparation followed by the application of several coats of material. Problems with silicones may have been due to lack of care in surface preparation.

4. Commercial firms which guaranteed their work usually gave good results.

APPENDIX B

PROPOSED WATERPROOFING SURVEY FOR CLEAR WATERPROOFING AGENTS

Name ______________

Title _____________

Number of units
responsible for ___

1. What type of waterproofing problems do you have?

Above grade ______________ Below grade ____________

2. What are the results of waterproofing problems, e.g. interior damage? ____

3. In what type of construction do you have problems?

High rise _____________ Single family detached _____________

Low rise ______________ Single family attached _____________

4. What type of building materials are leaking?

Wood ____________ Concrete _______________

Stone ___________ Cinder block: dense _______ porous ________

Brick ___________ Mortar joints _____________

Other ___________

5. Are the leaks localized in one wall or at one level? _______________

6. What direction do the leaking walls face? __________________________

7. Does the water enter only under certain weather conditions or at certain times of the year? ______________________________

8. Do you have problems with cracks? __________ How big? _______

9. Do you know their cause? _______________

10. What products have you used to waterproof?

Brand Name ___________ Others ____________

11. Are these clear? ___________

12. How did you choose these products? _________________________

13. What are the most effective clear products?

Brand Names ________________

14. What are the least effective clear products?

Brand Names ________________

15. Do you use different waterproofers on different substrates? _____

16. How often do you have to repeat the treatment? ___________ yrs.

17. What problems do you encounter in waterproofing application? ____

____

18. Problems of compatibility of different products? ________________

19. Is the wall prepared in any way before application of the waterproofing material? ____

20. What method of application is used:

Air spray _______ Brush __________ Other ___________

Airless spray ______ Roller __________

21. How many coats? ___________ How long between coats? ____________

22. Do you observe any special precautions during application? _______

____

23. Do you use different application methods with different products?

____

24. Do you have any special application techniques which you use or know of? ____

25. Is your waterproofing done by your own maintenance crews or by employees of a commercial waterproofing company? ________________

____

26. Do you require a guarantee? ______________________

If so, what does it include? _____________________________________

27. How much money do you spend on waterproofing (cost/year)?

Labor _______________ Materials ___________ Labor & Materials _________

APPENDIX C

RECOMMENDED TENTATIVE PERFORMANCE CRITERIA FOR THE SELECTION OF CLEAR WATERPROOFING MATERIALS FOR USE ON MASONRY SURFACES

C1. Introduction

Tentative performance criteria for the selection of clear waterproofing materials for use on masonry surfaces have been developed. These criteria are based on results of tests conducted on fifty-five clear waterproofing materials. The tests and criteria are intended to be used in evaluating the performance of clear waterproofing materials and they may be more severe than real life situations. The criteria selected were chosen to reflect performance characteristics which these waterproofing materials would be expected to show in service; they include appearance, application, water repellence, water vapor transmission, resistance to efflorescence, and resistance to accelerated weathering.

A description of the substrate materials, test methods, and conditions of application are included along with the performance criteria in this Appendix since some people may choose to use these as guidelines for purchase specifications.

The brick used in the development of these criteria were commercially available good quality brick for building construction. Since the brick to be used was cored, face slabs approximately 6 cm x 19 cm x 3 cm (2 1/4 in x 7 1/2 in x 1 1/4 in) were cut for test specimens. Due to the variation in water absorption of individual brick slabs, separate water absorption determinations for each test specimen before coating were necessary. The brick slabs had an average water absorption after 24 hour submersion of 7.1% based on the dry weight of the brick. However, individual slabs were found to vary between 5.7 and 10.2 percent.

These criteria were developed using a one coat application of waterproofing material on brick face slabs at a spreading rate of 4.90 m^2/ℓ (200 ft^2/gal). The four edges and the uncut face of the test specimen were coated with waterproofing material for the tests. This spreading rate was chosen after examining the range of the manufacturers' recommended spreading rates. It should be noted that this spreading rate was intended for testing purposes and should not be interpreted as a recommendation for a spreading rate for field applications.

These criteria may also be applied when examining waterproofing materials according to the individual manufacturer's recommended rates of application. Manufacturer's recommendations vary in spreading rate for different masonry substrates, as well as in the number of coats to be applied. If either the rate of application, the number of coats or the substrate materials differ from those used in the development of these criteria, the criteria may not be directly applicable. In such a case, the performance criteria would have to be modified in certain performance tests. Any variances in the performance requirements should be agreed upon between purchaser and the manufacturer. This should include agreement on the rate of application for testing (including number of coats) and the method of application as well as the substrate material. The designated rate, method and substrate should then be used in all tests.

To permit all waterproofing materials to cure equally before being tested, all test specimens were cured for one week at normal laboratory conditions (about 25°C and 35% relative humidity) after coating.

C2. Performance Criteria

C2.1 Effect on Appearance of Masonry Surfaces

Requirement

When applied using the designated rate and method to the clean, dry, masonry surface to be waterproofed, the material should present a uniform appearance and should not change the reflectance of the substrate appreciably.

Criterion

When applied using the designated rate and method, the reflectance of the coated masonry should not differ by more than 10 units from that of the uncoated masonry substrate when examined by directional reflectance measurements as described in Fed. Test Method Std. No. 141a, Method 6121 [1]. The uncoated masonry substrate should have a directional reflectance of at least 35.

Commentary

Materials with a resin content higher than 35 percent tended to form a noticeable glossy film on the surface. While the reflectance requirement is included to ensure that the original appearance of the masonry substrate is maintained, there may be instances where agreement between purchaser and supplier may eliminate this requirement, e.g., the masonry substrate is dark and reflectance differences would be minimal, or the darker appearance, if uniform, may be esthetically acceptable.

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[1] 45-Degree, 0-Degree Directional Reflectance, Method 6121, Fed. Test Method Std. No. 141a, Paint, Varnish, Lacquer and Related Materials; Methods of Inspection, Sampling, and Testing, Superintendent of Documents, U. S. Government Printing Office, Washington, D.C. 20402 (1965).

C2.2 Application Properties

Requirement

The waterproofing material should have good flow, leveling, and spreading characteristics. The coating should be capable of being applied by the designated method. The coated surface should be capable of being recoated within 24 hours.

Criteria

The waterproofing material when applied using the designated rate and method, should dry to a uniform, smooth appearance with no conspicuous laps or film on the surface, and no brush, spray, or other similar characteristic marks.

Commentary

A clear waterproofing material is designed for use where the original appearance of the masonry is to be retained. Conspicuous laps or film of waterproofing material on the surface will change the uniformity of appearance. Where more than a one coat application is desired, it is necessary that the coating be absorbed into the surface readily. This was a problem with some of the water-thinned materials, making it extremely difficult to apply a uniform second coat. While the manufacturer is given wide latitude in the manufacture of the waterproofing material, it should be noted that the two-package catalyzed systems or aqueous resin dispersions were generally found to be unsuitable because of limited pot life, gloss imparted to the surface, or the assumption of a whitish opaque appearance on extended exposure to water.

C2.3 Storage Stability

Requirement

The waterproofing material should be stable in storage.

Criterion

After a 30-day storage in a three-quarters filled, closed container, the waterproofing material should show no signs of separation or settling that cannot be readily remixed to a homogeneous stage.

Commentary

The success of a waterproofing treatment depends upon uniform application to the substrate. If the nonvolatile vehicles have separated from solution so that they cannot be remixed, this will not be possible and the material should not be used.

C2.4 Resistance to Water Penetration

Requirement

The waterproofing material should produce a surface which is resistant to water penetration.

Criterion

The brick test specimen, having 5 sides coated using the designated rate and method, should have a water absorption of less than 20% by comparison to the untreated test specimen.

The coated slabs shall be weighed then immersed, uncoated side up, into 1.3 cm (1/2 in) of water. The slabs should be supported off the base of the container to permit movement of water. At the end of 72 hours, the slabs shall be reweighed. The water absorption is the ratio of the amount of water absorbed by the coated slab to the amount absorbed by the original untreated slab. The appearance of the coated brick should not change noticeably during immersion. After drying, the reflectance of the exposed brick should not differ by more than 5 units from that of the coated unexposed brick when examined by directional reflectance measurements as described in Fed. Test Method Std. No. 141a, Method 6121 [1].

Commentary

The degree to which a waterproofing material prevents the infiltration of water is very important. Of the 55 materials tested, 27 materials passed this requirement.

C2.5 Water Vapor Transmission

Requirement

The waterproofing material should be sufficiently permeable to water vapor when applied using the designated rate and method, to prevent accumulation of moisture in the wall.

Criterion

The brick test specimen (coated using the designated rate and method) should have a moisture loss of not less than 20% when tested in the following manner.

The test specimens shall be submerged for 24 hours in water. The slabs shall then be removed and the excess surface water removed by blotting. The untreated face of the brick slab shall be placed downward on a piece of aluminum foil slightly larger than the slab. The foil shall be sealed to the brick slab. The weight of this test specimen shall be recorded prior to placing it in a room at a temperature of 20-24°C and a relative humidity of 50 ± 5 percent with a free circulation of air. After seven days, the test specimens shall be reweighed. The difference in the weights is the amount of moisture lost by transmission through the waterproofing coating. The water vapor transmission is the ratio of this value to the amount of water absorbed by the original untreated test specimen.

Commentary

Due to the relative humidity within a building, the usual direction of moisture movement through masonry walls above grade is interior to exterior. Thus, the waterproofing coating should have at least a small permeability to the flow of moisture if accumulation of moisture in the wall is to be avoided. Of the 55 materials tested, only 11 materials did not meet this requirement; these were generally, materials of high resin content.

C2.6 Resistance to Efflorescence

Requirement

The waterproofing material should be resistant to the formation of efflorescence.

Criterion

The brick test specimen (coated using the designated rate and method) should show no visible signs of efflorescence on the coated surface when tested in the following manner. The test specimen shall be placed with the uncoated face downward in 1.3 cm (1/2 in) of a 10% aqueous sodium sulfate solution. The brick slab should be supported off the base of the container to permit movement of the liquid. After seven days, the specimens should then be removed, allowed to dry, and examined for efflorescence.

Commentary

The resistance to efflorescence test is designed to simulate the movement of water soluble salts in masonry. Of the 55 materials tested, only 12 materials had moderate or heavy efflorescence as examined visually. If salts are present in the walls, they may crystallize beneath the surface treated with waterproofing material and cause the masonry surface to spall off. For this reason, the resistance to efflorescence may be an optional criterion.

C2.7 Accelerated Weathering

Requirement

The waterproofing material should maintain a surface resistant to water penetration after long exposure to accelerated weathering.

Criterion

The brick test specimen (coated using the designated rate and method) shall be exposed for 1,500 hours in a Weather-Ometer, single enclosed carbon arc, to a 102-18 cycle, i.e. 102 minutes light only, 18 minutes light and water spray. The exposed brick specimens should have a water absorption of less than 15% and reflectance difference of not more than 5 units when tested as described in the criterion of C2.4.

Commentary

The degree to which a waterproofing material prevents and maintains the prevention of water infiltration when exposed to weathering is important. Since outdoor weathering takes too long, an accelerated test is needed. Of the 15 materials tested in the accelerated weathering test described above, 8 materials had a water absorption of less than 15%. Also, the same 15 materials exposed outdoors at the NBS weathering site for 6 months had similar water absorption results.

C2.8 Continuous Condensation Exposure

Requirement

The waterproofing material should maintain a waterproofed surface after exposure to continuous condensation.

Criterion

The coated face of the brick test specimens shall be exposed for six weeks on a Cyclic Environmental Tester to a continuous condensation cycle, 38 ± 2°C air temperature. The exposed brick specimens should have a water absorption of less than 15% and a reflectance difference of not more than 5 units when tested as described in the criterion of C2.4.

Commentary

The ability of a waterproofing material to continue to prevent water infiltration when the coated surface is exposed to condensation is important. While this test may be more than a real life situation, 12 of the 15 materials met this criteria.

APPENDIX D

THEORETICAL CONSIDERATIONS OF WATER FLOW THROUGH A PORE IN A WALL

D1. Background

A masonry wall consists of masonry units, brick or concrete block, with a layer of mortar between adjacent units (Figure D1). In general, the units and the mortar are porous on the microscopic scale. There may be larger visible openings (cracks, flaws) between the mortar and the units or within the mortar, particularly if the workmanship is not of the highest quality.

Although the pores and cracks which are the paths for the flow of water through a wall are of irregular shapes, some insights into factors affecting water penetration can be gained by considering a model in which the paths consist of parallel tubes perpendicular to the face of the wall. The flow of water through the wall under various conditions can then be described in terms of the total volume of pores and the distribution of pore diameters. To develop this model, it is first necessary to consider water flow through a single pore.

D2. The Breakthrough Pressure

The pressure difference required to force water to advance through a pore depends on the surface tension (σ) of the water, the diameter (d) of the pore, and the advancing contact angle (θ) between water and the surface of the pore (Figure D2). This pressure, which may be termed the breakthrough pressure (P_b) is given by:

$$P_b = \frac{-4\ \sigma \cos\ \theta}{d} \qquad (1)\ [1]$$

Since P_b is negative when θ is less than 90°, water will migrate spontaneously through the pore under these conditions and an opposing pressure would have to be applied to prevent its passage. On the other

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Reference

[1] Schwartz, A. M., Capillarity Theory and Practice, (Proc. Fifth Annual State of Art Symposium on the Physics and Chemistry of Interfaces, Washington, D.C. June 11-12, 1968), Book, Chemistry and Physics of Interfaces - II, Ed. Gushee, D. E., pp. 1-13 (American Chemical Society Publications, Washington, D. C., 1971).

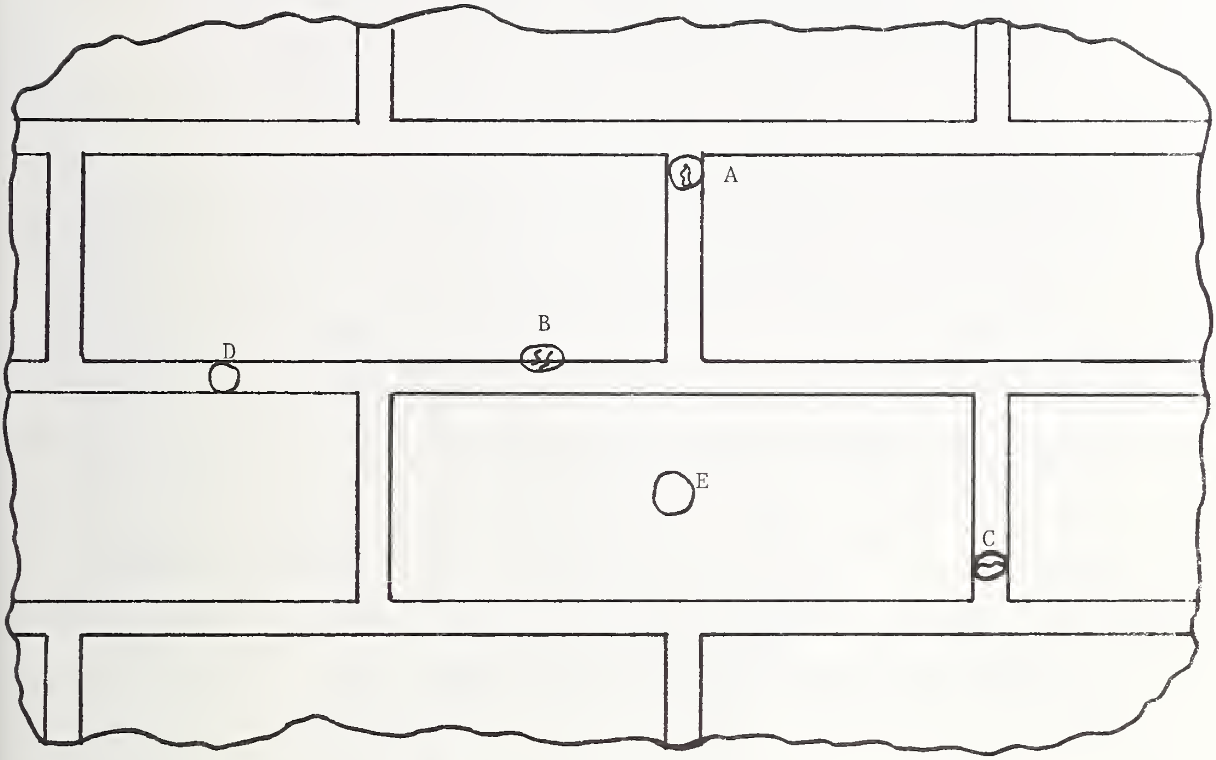

Figure D1. Model of a Masonry Wall

Paths for passage of water through a masonry and mortar wall:

A	incompletely filled mortar joints
B	hairline cracks between mortar and masonry unit
C	cracks through mortar
D	mortar
E	the masonry unit

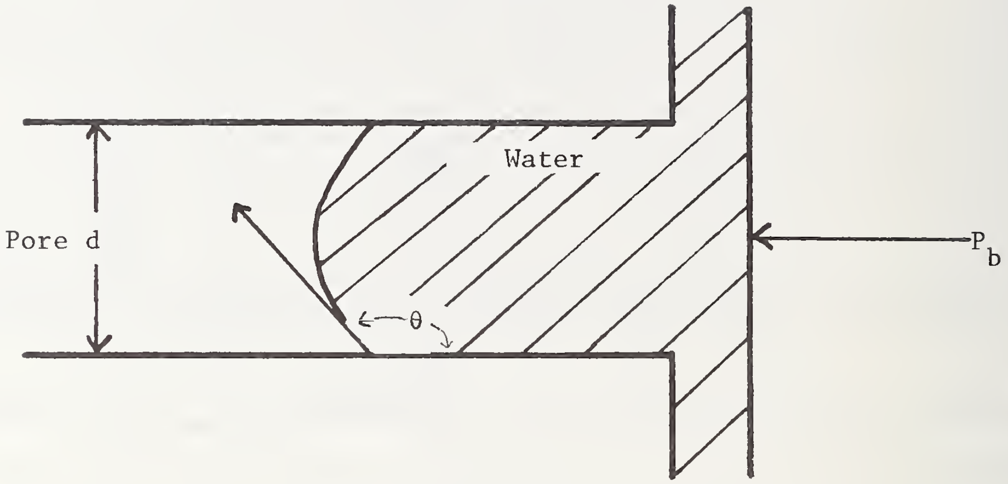

Figure D2. Model of a Pore

The breakthrough pressure, P_b, needed to force water through a cylindrical pore depends on the pore diameter, d, and on the advancing contact angle, θ, between the water and the pore wall.

hand, a positive pressure would be required to force the water through the pore if θ was greater than 90°. (Certain waterproofing agents, i.e. water repellent materials, function by increasing the contact angle θ from less than, to greater than, 90°).

The smaller the pore diameter, the greater the breakthrough pressure. This can be seen from the curves in Figure D3 in which P_b is plotted for various pore diameters and for five values of θ. These curves were calculated from equation 1. They show that, if θ is 120°, only pores with diameters less than about 0.05 cm (0.02 in) will have breakthrough pressures greater than 300 Pa (which is equivalent to the pressure of an 80.5 km/h (50 mph) wind-driven rain). Thus, it is unlikely that pores with diameters greater than 0.05 cm (0.02 in) can be adequately waterproofed against an 80.5 km/h (50 mph) wind-driven rain by waterproofing materials whose sole function is to increase the contact angle. If larger pores are present, waterproofing can only be achieved by materials which are able to, at least partially, fill the pores. Calculations for the breakthrough pressures and wind forces are contained in Appendix E.

D3. Rate of Flow

The rate of flow of water through a cylindrical pore depends on the pore diameter d (cm), the applied pressure P (Pascals), the length ℓ (cm) of the pore, and the viscosity η (Pascal seconds) of the water. The rate of flow Q (cm^3/s) is given by

$$Q = \frac{\pi P d^4}{128 \eta \ell} \qquad (2)\ [2]$$

Because of the high power of d in the numerator of equation 2, the rate of flow at a given pressure increases rapidly with pore diameter. In addition, the rate of flow over an area increases as the number of

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Reference

[2] Dalla Valle, J. M., Characteristics of Packings, Chapt. 6, Micromeritics, The Technology of Fine Particles, pp. 100-129, (Pitman Publishing Corporation, New York, New York, 1943).

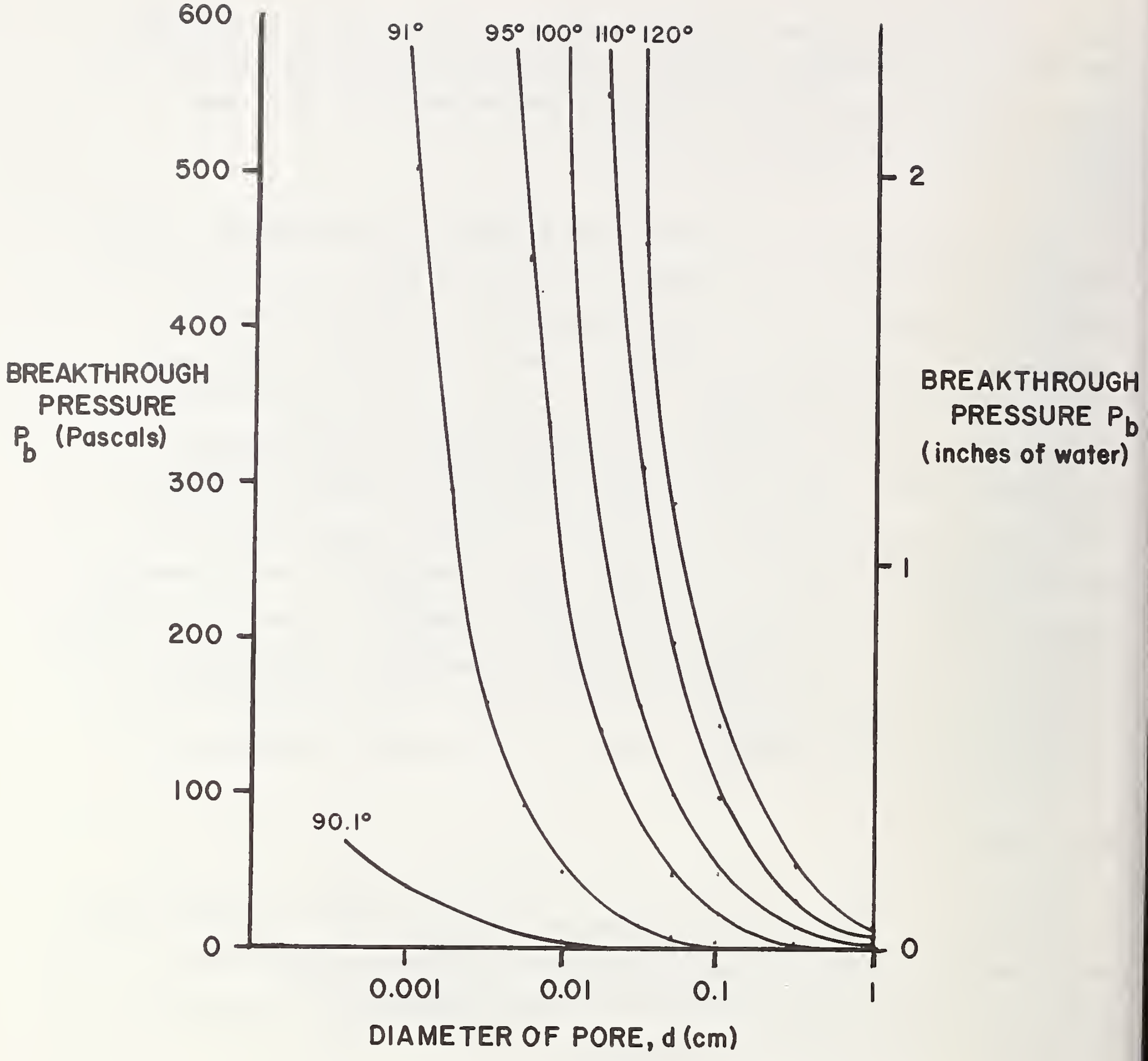

Figure D3. The breakthrough pressure, P_b, for water in cylindrical pores of diameter, d, and its dependence on the contact angle, θ. Pores with diameter greater than about 0.03 cm (.01 in) will always have breakthrough pressures less than 500 Pascals (2 in water or 64.4 mph wind) and could not be satisfactorily waterproofed against wind driven rain with a material acting as water repellent even if θ was as high as 120°.

capillaries increase. The number of pores per unit area $(cm^2) = \frac{4\varepsilon}{\pi d^2}$ where is the porosity and d is the diameter (cm) of the pore. The rate of flow, $Q \frac{cm^3}{s}$ through a one cm^2 area is $Q/cm^2 = \frac{Pd^2\varepsilon}{32\ \ell n}$

The results of calculations of the rate of flow, Q, through an array of parallel pores of the same diameter uniformly distributed over the whole area of a wall of thickness 10 cm (4 in) are given in Figure D4 for various total porosities, ; the pressure used in the calculation is 498.2 Pa (2 in) of water. Appendix E contains these calculations. Here, it can be seen that, for a given porosity, the greatest rate of flow is for the wall with the largest pores. This illustrates why materials with larger pores (e.g. concrete block) are more permeable than materials with smaller pores (e.g. clay brick), and why large pores (e.g. cracks or imperfections in a masonry unit or mortar, or at their interface) may give a disproportionately large contribution to the flow of water through a wall.

D4. General Considerations

While the pores in a wall are certainly not an array of parallel tubes as in the model discussed above, useful deductions can be made from such a model. Thus it may be deduced that:

1. Other factors being equal, the rate of flow of water under a given pressure will be low if the pore diameters are all small.

2. A small volume of large pores may allow the passage of more water than a much larger volume of small pores.

3. Waterproofing materials that act as water repellents may be effective in preventing flow of water from wind-driven rain through small pores (e.g. less than about 0.05 cm (0.02 in) but they are much less likely to be effective in preventing flow through large pores (e.g. greater than about 0.1 cm (0.04 in).

4. To prevent flow through large pores, it is probably necessary to use a waterproofing material which will effectively reduce the sizes of, or block, the pore openings, and possibly, also act as a water repellent.

5. If dimensional changes which cause cracking take place in the wall, a waterproofing material must not crack if it is to remain effective.

These deductions draw attention to the fact that openings (e.g. greater than about 0.05 cm (0.02 in) in a wall are those which are most important and most difficult to deal with in waterproofing against wind-driven rain. These include incompletely filled mortar joints, hairline cracks between mortar and masonry units, larger cracks due to thermal or moisture movement or settlement and, possibly, flaws in the masonry units.

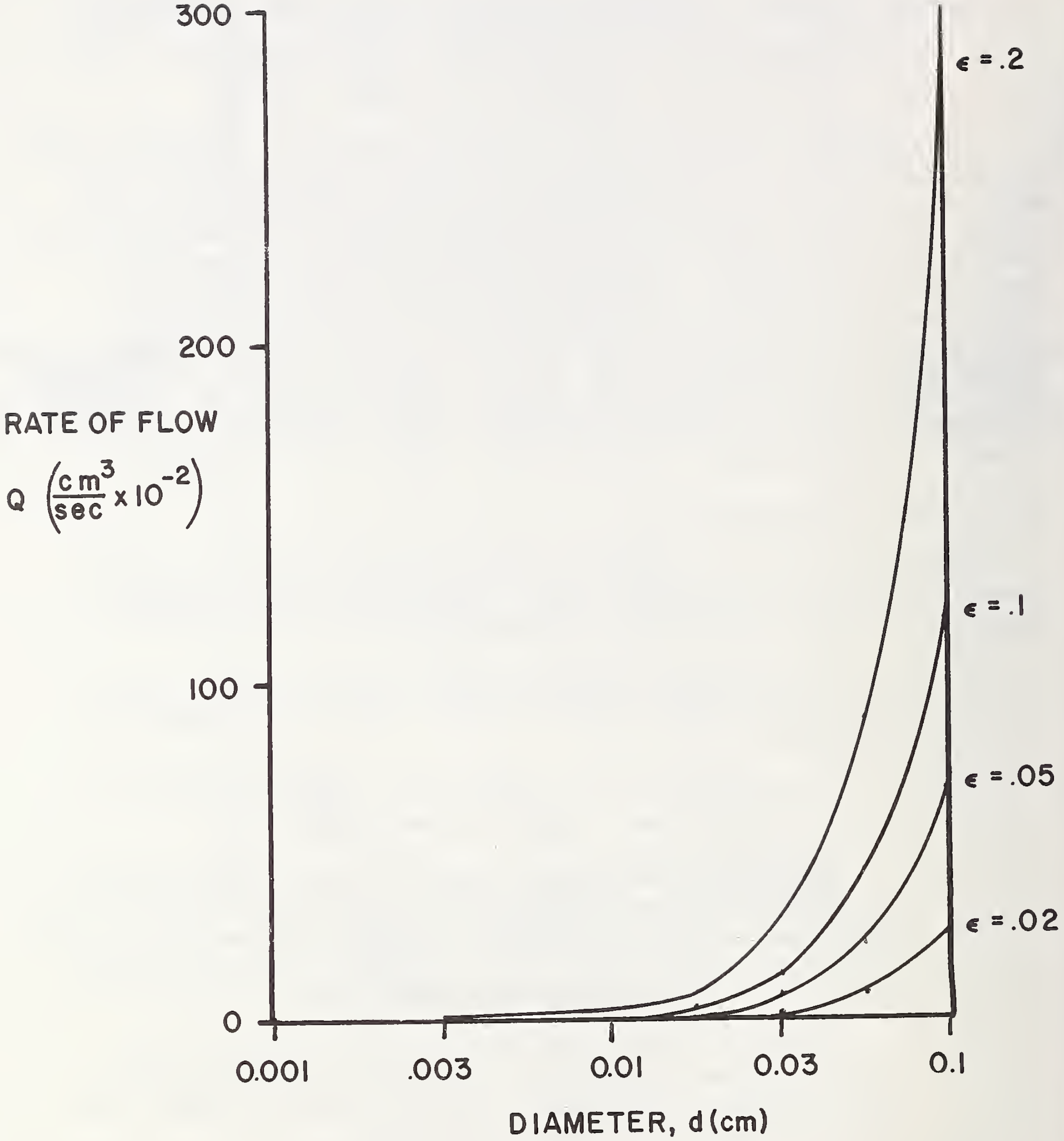

Figure D4. Rate of flow of water through a one cm^2 area of a 10 cm thick wall of porosity ε at pressure of 498.2 Pa. The flow is attributable to parallel tubes of diameter, d, perpendicular to the wall surface under a pressure of 498.2 Pa which is equivalent to 2 in of water or a 103.6 km/h (64.4 mph) wind. For any value of ε, the rate of flow increases as the square of the pore size. The pores of clay brick are generally in the 0.001 cm diameter range while hairline cracks and larger visible openings will generally be between about 0.01 and 0.1 cm.

APPENDIX E

CALCULATIONS FOR THEORETICAL CONSIDERATION OF WATER FLOW THROUGH A PORE

Wind Force Equivalents

(1) $P_v = 0.000482\ V_w^2$ [1]

P_v = wind velocity head, inches water gage

V_w = wind velocity, miles per hour

Based on air density of 1.2 kg/m^3 (0.075 lb/ft^3)

$$1 \text{ in water} = 2.54 \text{ cm} = 2.54 \text{ g/cm}^2 \times 98.07 \frac{\text{Pa}}{(\text{g/cm}^2)} = 249.1 \text{ Pa}$$

1 in water = 249.1 Pa
2 in water = 498.2 Pa
3 in water = 747.3 Pa
4 in water = 996.4 Pa
5 in water = 1245.5 Pa

1 mi = 1.609 km
1 mph = 1.609 km/h

from (1) above

when V_w		then P_v	
mph	km/h	in	Pa
10	16.1	0.05	12.0
20	32.2	0.19	48.0
25	40.2	0.30	75.0
30	48.2	0.43	108.1
40	64.4	0.77	192.1
50	80.5	1.21	300.2
60	95.6	1.74	432.2
70	112.7	2.36	588.3
80	128.7	3.08	768.4
90	144.8	3.90	972.5
100	160.9	4.82	1200.6

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[1] Infiltration and Natural Ventilation, Chpt. 19, ASHRAE Handbook of Fundamentals, pp. 333-346, (American Society of Heating and Refrigerating, and Air-Conditioning Engineers, Inc., New York, New York, 1972).

Breakthrough Pressure of Water Through a Pore

(2) $P_b = \frac{-4\ \sigma \cos\ \theta}{d}$ [2]

σ = surface tension of water
= 7.2×10^{-4} N/cm

θ = contact angle between water and surface of pore

d = diameter (cm) of pore

from equation (2) above

	P_b in Pascals				
d (cm)	$\theta = 120°$	$\theta = 110°$	$\theta = 100°$	$\theta = 95°$	$\theta = 91°$
1.0	14.4	9.9	5.0	2.5	.5
0.32	45.4	31.1	15.8	7.9	1.6
0.1	144	98.5	50.0	25.1	5
0.5	287	197	99.8	50.1	10
0.03	455	311	158	79.4	15.9
0.01	1440	985	500	251	50.3
0.003	4554	3115	1581	794	159
0.001	14400	9850	5001	2510	503

---

[2] Schwartz, A. M., Capillarity Theory and Practice, (Proc. Fifth Annual State of Art Symposium on the Physics and Chemistry of Interfaces, Washington, D.C., June 11-12, 1968), Book, Chemistry and Physics of Interfaces - II, Ed. Gushee, D. E., pp. 1-13 (American Chemical Society Publications, Washington, D.C. 1971).

Diameter Equivalents

d (cm)	d (in)
1.0	0.39
0.32	0.13
0.1	0.04
0.5	0.02
0.03	0.01
0.01	0.004
0.003	0.001
0.001	0.0004

Flow Through Capillaries

Water Flow Through a Tube:

$$V = \frac{\pi P d^4 t}{128 \ell \eta} \quad (3)$$ [3]

V = volume delivered (cm^3)
P = pressure (Pa)
d = diameter of tube (cm)
t = time (s)
ℓ = length of tube (cm)
η = viscosity of liquid (Pa·s)

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[3] Dalla Valle, J., Characteristics of Packings, Chpt. 6, Micromeritics the Technology of Fine Particles, pp. 100-129, (Pitman Publishing Corporation, New York, New York, 1943).

(4) $\text{No. of capillaries/cm}^2 = \frac{4\varepsilon}{\pi d^2}$ [3]

ε = porosity
d = diameter of capillary (cm)

(5) $$\text{Volume delivered/cm}^2 = \frac{\pi P\ d^4\ t}{128\ \ell\ \eta} \times \frac{4\varepsilon}{\pi d^2} = \frac{P\ d^2\ \varepsilon t}{32\ \ell\ \eta}$$

For water at 15°C, $\eta = 1.1 \times 10^{-3}$ Pa•s

For a 10 cm long capillary, P = 498.2 Pa (2 in water) = 64.4 mph wind from equation (5) above

	V (cm^3/s) through a 1 cm^2 area			
	ε			
d (cm)	0.2	0.1	0.05	0.002
1.0	$2.8 \times 10^{+2}$	$1.4 \times 10^{+2}$	$7.1 \times 10^{+1}$	$2.8 \times 10^{+1}$
0.1	2.8	1.4	7.1×10^{-1}	2.8×10^{-1}
0.06	8.95×10^{-1}	4.5×10^{-1}	2.2×10^{-1}	8.95×10^{-2}
0.03	2.8×10^{-1}	1.4×10^{-1}	7.1×10^{-2}	2.8×10^{-2}
0.02	8.95×10^{-2}	4.5×10^{-2}	2.2×10^{-2}	8.95×10^{-3}
0.01	2.83×10^{-2}	1.4×10^{-2}	7.1×10^{-3}	2.8×10^{-3}
0.003	2.8×10^{-3}	1.4×10^{-3}	7.1×10^{-4}	2.8×10^{-4}
0.001	2.8×10^{-4}	1.4×10^{-4}	7.1×10^{-5}	2.8×10^{-5}

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The initial effectiveness and durability characteristics of fifty-five clear masonry waterproofing materials were evaluated using laboratory tests. This report contains the results of initial performance tests including water absorption, water vapor transmission, resistance to efflorescence and change in appearance. Durability tests, including periodic measurement of water absorption after exposures to accelerated weathering and outdoor exposures, were also conducted. Based on test results, performance criteria for clear waterproofing materials were developed. In addition, recommendations for the application of waterproofing materials were formulated. Finally, the report contains a summary of a survey concerning field experiences with waterproofing and a brief theoretical discussion of water flow.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Accelerated weathering; durability of waterproofing materials; masonry; performance criteria; waterproofing materials; water repellent materials.

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