NBSIR 84-2919

REVIEW OF TEST METHODS, PERFORMANCE REQUIREMENTS AND MATERIALS FOR CONSOLIDATING DEGRADED MASONRY SURFACES

Mary E. McKnight

Building Materials Division
Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
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Contract No.

October 1984

U. S. Department of Commerce
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U. S. DEPARTMENT OF COMMERCE, Malcolm Balrige, Secretary
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TABLE OF CONTENTS

TABLE OF CONTENTS

ABSTRACT

When a masonry surface with a weakened, deteriorated surface layer is to be coated, special preparation of the surface prior to maintenance coating is required. Two methods of surface preparation are usually used: 1) removal of the deteriorated surface layer and 2) consolidation of the deteriorated layer. Although the recommended procedure is to remove the degraded surface material, this procedure is not always possible. This report is concerned with the second approach, i.e., consolidation of the deteriorated surface layer. The literature was reviewed for test methods used to assess the performance of consolidating materials, the types of materials used, and the performance requirements needed for consolidating materials. Current test methods in use for evaluating consolidating ability, depth of penetration, water vapor permeability, thermal and chemical compatibility, appearance, recoatability and durability are described. Performance requirements found in the literature for these properties are cited. Consolidating materials fall into one of three classes: 1) inorganic materials, 2) alkoxysilanes, and 3) organic materials. However, none of these materials has been found to completely meet all the performance requirements sited. Recommendations for further work include characterization of mechanisms of degradation and developing improved accelerated tests and performance criteria.

Keywords: Consolidating materials; masonry; performance criteria; test methods

1. INTRODUCTION

Weathering of masonry surfaces, improper cleaning procedures, chemical attack and use of inappropriate coating systems can result in a deteriorated, weakened surface and loss of material [1,2]. When a weakened masonry surface is to be coated, special preparation is required because application of most coatings directly to a deteriorated surface may lead to failure. Two approaches for the preparation of a deteriorated surface are 1) removal of the deteriorated layer and 2) consolidation of this layer. Although the former approach is the preferred method according to the American Concrete Institute [3], it is not always feasible to blast or otherwise remove the degraded surface layer. Hence, consolidation of the surface may be desired. This report addresses the second approach. The objectives of this report are 1) to review test methods used for evaluation of consolidating materials, 2) to review generic types of materials which are presently used as consolidants, 3) to review reported performance requirements of consolidating materials, and 4) to recommend research needed to improve the selection and specification of consolidating materials.

2. PERFORMANCE TEST METHODS

Two ASTM standard practices [4,5] list recommended evaluation procedures for exterior coatings. However, it is implicitly implied in the practices that coatings will be applied to a sound, well-prepared surface. When the substrate is weakened or deteriorated, additional evaluation procedures are required. Many papers have been published on stone consolidants [6,7] and several international symposia dedicated to this subject have been held [8,9]. This large bank of information is also pertinent to the problem of maintaining other masonry surfaces. Included in the literature are details of performance tests which have been used to evaluate stone consolidating materials [6]. These tests relate to 1) consolidating ability, 2) penetration, 3) permeability of water vapor, 4) compatibility with the substrate and, 5) change in appearance. These test methods can also be used for assessing consolidants for other masonry materials. When the consolidating material is part of a coating system, compatibilty of intermediate or topcoat with the consolidated substrate also must be determined. These special test methods, as well as more detailed procedures for durability tests than described in the practices [4,5], are discussed below.

2.1 Consolidating Ability

Since the primary function of a consolidating material is to bond together the weak surface material of the substrate, a test which measures this ability is required. In one such test, granules of crushed material, similar to that of the substrate to be coated, which pass through a No. 30 (0.53 mm) but are retained on a No. 50 (0.29 mm) seive, are used to make test specimens [10]. The granules are throughly mixed with enough consolidating material to make a

moldable paste with no bleeding. The paste is placed in a plastic briquet mold as described in ASTM C190 [11] and allowed to cure according to the directions of the manufacturer of the consolidant. Tensile strength of the specimens are measured.

2.2 Depth of Penetration

In order for the consolidating materials to bind weakened surface material together, the consolidant must penetrate through the weakened layer to sound substrate material. One test method developed to determine the depth of penetration [9] uses a 150 mm cube of substrate material to which a a 140 mm diameter glass cylinder is attached. All the exposed surface of the cube, except the side opposite the cylinder, is coated with molten wax and allowed to cool. A 500 ml aliquot of consolidant is added to the cylinder and the assembly is allowed to stand for one hour. The cylinder is then emptied and covered and the consolidating material allowed to migrate for 24 hours. The specimen is then fractured by knife edges along the plane parallel to the direction of consolidant flow in a compression machine. Maximum depth of penetration of the consolidant is measured. In another test, the consolidating material is applied at the rate recommended for maintenance, the test specimen is fractured and the depth of penetration is measured [12].

2.3 Water Vapor Permeability

Large changes in the water vapor permeability of masonry substrates caused by the application of coatings are reported to be associated with accelerated degradation [6]. Changes in the permeability of consolidated materials, as compared with untreated materials, can be determined using the method described in ASTM E96 [13]. Samples are sealed above either a 0 percent or 100 percent

relative humidity environment and placed in a constant 50 percent relative humidity environment at a specified temperature. The amount of water taken up or lost is determined as a function of time.

2.4 Compatibility

2.4.1 Thermal

In this test procedure, thermal expansions of specimens of substrate treated with the consolidant are compared with thermal expansion of untreated specimens. A method to measure thermal expansion of consolidated stone using an interferometer is available [14]. Specimens are dried at 105 C to constant weight and then completely immersed in the consolidant for 4 hours. Viscous materials are diluted with an appropriate solvent to increase their ability to penetrate the specimens. Treated specimens are broken and the cross section examined to be certain that the consolidants have penetrated to the center of the specimens.

2.4.2 Chemical

Since most masonry substrates are alkaline, consolidating materials must be alkali resistant. ASTM D1308 [15] describes a spot test procedure to evaluate chemical resistance. Sodium hydroxide solutions having concentrations by weight of about 0.5 percent are often used to evaluate alkali resistance of coatings [16,17]. Since the laboratory test may not correlate with field exposure durability, field tests are also performed.

2.5 Change in Appearance

When the consolidated surface is not to be topcoated, changes in color, gloss and reflectance of the consolidated surface are important. To determine

these changes, color [18], reflectance [19] and gloss [20] of untreated substrate material are measured. The substrate is coated with the consolidant and the consolidant allowed to cure. Color, reflectance and gloss of the consolidated material are measured and the values compared with those obtained before coating. Changes in texture between untreated and treated masonry surfaces can also be important even if a topcoat is applied. No standard methods are available to assess change in texture. Evaluation of texture should include such properties as smoothness and porosity.

2.6 Coatability

When a consolidant is used as part of a coating system, it is essential that good interfacial adhesion be obtained and that it remain so after weathering. Adhesion of a coating applied to a consolidated surface can be measured qualitatively using a tape test according to ASTM method D3359 [21] and after immersion in distilled water (Fed. St. Test Method 141, Method 6301 [22]). To obtain more quantitative numbers, tensile adhesion can be measured using a pneumatic adhesion tester [23].

2.7 Durability

Although there is guidance on evaluation of performance of coatings in durability tests in the ASTM Standard Practices [4,5], additional information is needed to completely specify the testing procedure. Evaluation of consolidated specimens (complete with the topcoats, if any) in accelerated laboratory tests should be accompanied with exterior field testing. Laboratory tests should include 1) exposure in an accelerated weathering machine with moisture and 2) exposure to freeze-thaw cycles. Acid rain tests should also be conducted if the structure will be exposed to acid rain conditions. An acid rain test,

used in evaluation of consolidating materials, has been described [10]. In this test, specimens are exposed to water, acidified with CO_2, NO_x, or SO_2, which drip on the surface of the treated substrate. The amount of material that is dissolved is measured. Field tests should be carried out in several different climate zones. Changes in appearance, adhesion and water vapor transmission, as a result of either field or laboratory testing should be determined as described in sections 2.3, 2.5 and 2.6.

3. CONSOLIDATING MATERIALS

Several types of materials have been used as consolidants. These materials can be classified into one of the following types: inorganic, aloxysilanes, and organic polymers.

3.1 Inorganic Materials

Inorganic materials, such as calcium hydroxide and barium sulfate, were used extensively during the 19th century as stone consolidants and are still being used occasionally [6]. However, in general, these materials have not been very successful in consolidating stone and some acceleration of stone decay as a result of their use has been noted [6]. This accelerated deterioration is thought to be due to a hard crust that develops on the surface and to changes in molecular structure that occur as a result of their use. Soluble alkali silicates have also been used for consolidation of stone but poor performance has often been reported [6]. However, soluble alkali silicates are now being considered for consolidation of degraded concrete or stucco.

3.2 Alkoxysilanes

Alkoxysilanes are reported to be good candidates for stone consolidating materials because of their ability to penetrate the surface effectively before polymerizing and because the film formed has little effect on the flow of water vapor, on the frost resistance of the stone, and on the porosity of stone [28]. In experimental studies, silane consolidants were found to effectively penetrate test specimens [12,24]. However, in one study, two alkoxysilanes failed to form moldable specimens in the consolidation test described in section 2.1 [10]. Alkoxysilanes which are applied in the polymerized state are often called silicones and their use as water-repellents is well known [25,26].

3.3 Organic Materials

Two types of organic materials have been used to consolidate stone. In one type, the monomer or an oligomer is applied directly to the surface and polymerization takes place after application. In the other, the monomer is polymerized before application. Methylmethacrylate monomer has been used to consolidate several masonry materials and, where effective penetration was achieved, the durability and mechanical properties of concrete were shown to be improved [29]. Moldable specimens of limestone and sandstone were also reported to be formed using a methylmethacrylate consolidant [10]. However, incomplete impregnation may result in the formation of a distinct, undesirable interface between treated and untreated material. Experiments are on-going to determine the durability of treated brick in a mild coastal environment [24].

Polymeric materials which have been used as consolidants include acrylics, vinyls, silicones, epoxies and urethanes. These materials are known for their ability to form protective continuous films and are used to protect steel, wood and the like. But for consolidation of masonry materials, the mechanism of film formation for organic materials should be such that resinous material is not deposited on the surface as the solvent evaporates. For if the polymer is deposited on the surface, a distinct layer will be produced. Such a layer may be quite resistant to the flow of water, and possess different thermal and water absorption properties than the bulk substrate. This could cause excessive shear stresses near the surface, resulting in spalling of the substrate [28]. In one study [10], two epoxy consolidants penetrated a sandstone specimen 2 to 3 mm and, in another study [7], an acrylic epoxy was found to reduce the permeability of water vapor by 30 percent. However, the ability of epoxy consolidants to consolidate ground stone has been demonstrated. The consolidated stone was

resistant to erosion in the acid rain test (sec 2.7) [10]. An acrylic resin was found to penetrate sandstone to a depth of about 15 mm, consolidate ground stone and provide effective protection in the acid rain test [10]. Thermal expansion of stone consolidated with organic polymers was found to be quite variable [10]. For example, the coefficient of thermal expansion for sandstone treated with an epoxy decreased by 15 percent; while for limestone treated with a silane, the coefficient of thermal expansion increased by 43 percent as compared with untreated material.

4. PERFORMANCE REQUIREMENTS

The performance requirements of consolidating materials that are related to the tests described in section 2 are reviewed in this section. Other requirements relating to such characteristics as application properties and storage stability are not included. These types of requirements are well established and are found in most Federal paint specifications.

4.1 Consolidating Ability

The primary function of consolidating materials is to reinforce a weak surface and protect it from further degradation. One means of assessing consolidating ability is to measure both tensile and compressive strength of the consolidated surface material. A proposed performance requirement is that the strength of the consolidated surface material, when prepared as described in section 2.1, be similar to, but less than, that of the bulk material of the substrate [6]. No numerical values defining "similar" were found in the literature.

4.2 Depth of Penetration

The ability of a consolidant to penetrate the surface depends upon the porosity of the surface to be consolidated, as well as the physical and chemical properties of both the substrate and the consolidating material. A high degree of penetration may result in gradual changes taking place in the thermal and chemical properties from the consolidated surface to the bulk material [20]. Penetration of a weathered porous surface to a depth of at least 25 mm has been suggested as a performance requirement [31].

4.3 Water Vapor Permeability

Consolidating materials are usually designed to restrict the flow of liquid water but to allow the flow of water vapor. However, if water vapor transmission is greatly retarded, moisture may accumulate behind the consolidated surface. Then as water vapor slowly passes through the consolidated layer, soluble salts will be carried toward the surface. Resulting crystal formation could lead to spalling of the substrate or blistering of coating films or both. It has been suggested that vapor transmission of a consolidated surface should be no less than 50 percent of an untreated surface [7].

4.4 Compatibility

4.4.1 Thermal

To minimize shear stresses, the coefficient of thermal expansion of the consolidated layer should be similar to that of the bulk substrate. Recommended performance requirements for thermal properties were not found in the literature.

4.4.2 Chemical

Chemical compatibility of the consolidant with the substrate is required for good durability. No data relating performance in accelerated chemical exposure tests to in-service performance were found. Minimum suggested performance requirements for in-service tests should require no deterioration after several years exposure in moist, warm climates.

4.5 Change in Appearance

The effect of consolidating materials on the appearance of masonry substrates has been reported to include changes in color and reflectance, formation of a white substance in the pores and a smoothing of the overall appearance [6].

The importance of these effects on the overall appearance of the material is best left to the decision of the maintenance engineer. Changes in color of 1 to 2 Hunter color units [18] are usually apparent visually. Changes in reflectance, gloss and texture may also be undesirable. Changes in reflectance of less than 10 percent [19] and of 85 degree gloss of less than 10 percent [20] are normally not detected visually. Since there are no visual standards for characterizing texture, only qualitative requirements can be specified at present.

4.6 Coatability

When a consolidating material is being used as part of a coating system, the intermediate or topcoat must be compatible with the consolidated surface. Both initial adhesion of the intermediate or topcoat to the consolidated surface and adhesion after weathering must be adequate. Initial values of tensile adhesion of an acrylic latex to untreated concrete surfaces have been reported to range from 1 to 5 MPa depending on the method of casting and the surface pretreatment [32]. An estimate of acceptable adhesion of 0.8 MPa for architectural paints and 1.2 MPa for floor paints has been reported [32]. When qualitative tests are used, such as a tape test, there should be no intercoat adhesion failure observed.

4.7 Durability

For any environment, the durability of the consolidated surface will depend on both the durability of the consolidating material and the consolidated surface. As for other coatings, durability of the consolidating materials will depend on their resistance to degradation by ultraviolet radiation, temperature cycling, moisture and pollutants. Many factors will affect the durability

of the consolidated surface itself. These include depth of penetration of the consolidant, compatibility of the consolidating material with the substrate and porosity. Pore size and pore size distribution have been reported to have an effect on the durability of the surface [30]. (Frost and salt crystallization damage increase as the proportion of small pores and cracks increases. Thus, partially filling pores and cracks with consolidating materials could be harmful.)

Exposures of 1000 hours in an accelerated weathering machine, of 1000 hours in the acid rain environment, or of 1000 cycles in the freeze-thaw test or of a combination of the tests have been reported [7,10]. Suggested interim performance requirements for coating systems are that color changes as a results of such exposures be less than 1 Hunter unit and that no loss of surface integrity be observed. But, because of the often observed poor correlation of accelerated durability tests with field tests, field testing of materials should also be carried out.

5. RECOMMENDATIONS

From this study, it is obvious that there is a need for further evaluation of consolidating materials in both the laboratory and the field. There is very little assessible data on the service life of consolidating materials and little comparable laboratory data. Standard test methods are not available to measure many of the key performance properties. Work to relate some laboratory measured properties with service life is just beginning; hence, only a few performance criteria have been established. Therefore, the following recommendations for further work are made:

Initiate field tests of consolidating materials from each generic class over degraded concrete, stucco or other masonry surfaces. Test specimens should include both those topcoated and not topcoated.

Perform the laboratory tests described in section 2 on materials exposed in field tests to develop new or improved performance criteria.

Characterize the mechanisms of degradation observed in both the field and laboratory tests.

Using the information obtained in the mechanistic research, develop new test methods, as needed, to characterize the performance properties of candidate materials.

Work to develop voluntary consensus standards so that performance data can be compared more easily among laboratories. This would improve the knowledge base so that coating selections could be made more effectively.

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