PROPOSED TESTING PROTOCOLS FOR SURFACE APPLIED CONCRETE SEALERS

Requested by:

American Association of State Highway and Transportation Officials (AASHTO)

Standing Committee on Highways

Prepared by:

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<tr>
<td>NCHRP</td>
<td>National Cooperative Highway Research Program</td>
<td>Cover</td>
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<td>WJE</td>
<td>Wiss, Janney, Elstner Associates</td>
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<tr>
<td>AASHTO</td>
<td>American Association of State Highway and Transpiration Officials</td>
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<td>DOT</td>
<td>Department of Transportation</td>
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</tr>
<tr>
<td>MMA</td>
<td>Methyl Methacrylate</td>
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</tr>
<tr>
<td>UV</td>
<td>Ultraviolet</td>
<td>1</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile Organic Compound</td>
<td>2</td>
</tr>
<tr>
<td>QA</td>
<td>Quality Assurance</td>
<td>2</td>
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<tr>
<td>HMWM</td>
<td>High molecular Weight Methacrylate</td>
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<tr>
<td>ASTM</td>
<td>American Society of Testing and Materials</td>
<td>5</td>
</tr>
<tr>
<td>NTPEP</td>
<td>National Transportation Product Evaluation Program</td>
<td>10</td>
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<tr>
<td>QPL</td>
<td>Qualified Product List</td>
<td>11</td>
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<tr>
<td>RH</td>
<td>Relative Humidity</td>
<td>23</td>
</tr>
<tr>
<td>CMU</td>
<td>Concrete Masonry Units</td>
<td>24</td>
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<tr>
<td>RILEM</td>
<td>International Union of Laboratories and Experts in Construction Materials, Systems and Structures</td>
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<tr>
<td>SSP</td>
<td>Saturated Surface Dry</td>
<td>30</td>
</tr>
<tr>
<td>BPN</td>
<td>British Pendulum Tester Number</td>
<td>33</td>
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<tr>
<td>FTIR</td>
<td>Fourier Transform Infrared</td>
<td>38</td>
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<tr>
<td>ATR</td>
<td>Attenuated Total Reflectance</td>
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<td>VT</td>
<td>Vapor Transmission</td>
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<td>SL</td>
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<td>MSDS</td>
<td>Material Safety Data Sheet</td>
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<tr>
<td>CAS</td>
<td>Chemical Abstracts Service</td>
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<tr>
<td>HMIS</td>
<td>Hazardous Materials Identification System</td>
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<td>NFPA</td>
<td>National Fire Protection Association</td>
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<td>OSHA</td>
<td>Occupational Safety and Health Administration</td>
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</tr>
<tr>
<td>PEL</td>
<td>Permissible Exposure Limit</td>
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</tr>
<tr>
<td>ACGIH</td>
<td>American Conference of Governmental Industrial Hygienists</td>
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</tr>
<tr>
<td>TLV</td>
<td>Threshold Limit Value</td>
<td>54</td>
</tr>
<tr>
<td>TWA</td>
<td>Time Weighted Average</td>
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</tr>
<tr>
<td>QPL</td>
<td>Qualified Product List</td>
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<tr>
<td>AAR</td>
<td>Alkali-Aggregate Reaction</td>
<td>67</td>
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<tr>
<td>HRWRA</td>
<td>High range water reducing admixture</td>
<td>A-8</td>
</tr>
<tr>
<td>Wsw</td>
<td>Weight of Sealer Applied Wet</td>
<td>A-12</td>
</tr>
<tr>
<td>DRC</td>
<td>Drying Rate Coefficient</td>
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<tr>
<td>SAR</td>
<td>Saltwater Absorption Ratio</td>
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<tr>
<td>TC</td>
<td>Total Chloride</td>
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<tr>
<td>RCR</td>
<td>Relative Chloride Ratio</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<td>------------------------------------------</td>
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<tr>
<td>PPE</td>
<td>Personal Protective Equipment</td>
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<tr>
<td>SRC</td>
<td>Skid Resistance Coefficient</td>
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ABSTRACT

Maintenance of bridges is an ongoing concern for Departments of Transportation and the application of concrete sealers is a widely-used method for protecting bridge structures from moisture and deicers or saltwater. Concrete surface sealers are a low cost and easily applied method for protection of concrete structures against future deterioration and corrosion. NCHRP Synthesis 209, *Sealers for Portland Cement Concrete Highway Facilities*, systematically reviewed technical information available through 1993 and comprehensively described the state of the practice for concrete sealers. The study found hundreds of available sealer products, which had been evaluated with widely variable testing protocols. A need for standard testing protocols for product qualification, quality assurance, application quality control and field testing to assess the need for reapplication was identified and is the focus of this research.

A survey was sent to all US and Canadian Departments of Transportation and select international highway agencies to obtain information on what test methods are used to prequalify and evaluate the effectiveness of concrete sealers. A review of available literature and sealer manufacturer data was also used to develop sealer testing and evaluation criteria. Based on the understanding of performance requirements for sealer products and the review of current test methods and practices, recommended test protocols have been developed for each of the following areas: (1) concrete sealer product qualification, (2) sealer product quality assurance and field application quality control, and (3) field testing to assess sealer performance and the need for re-application.
EXECUTIVE SUMMARY

As the bridge inventory in the United States ages and Departments of Transportation (DOT’s) are faced with the challenge of extending the useful life of existing, as well as newly constructed, structures, strategies proven to be cost-effective and practical for preserving concrete structures from deterioration are needed. One such strategy employs the use of surface sealers, which serve to mitigate the onset and progression of concrete deterioration and embedded steel reinforcing corrosion. However, the vast array of sealers and product qualifications, along with competing performance claims, has resulted in uncertainties regarding the choice of appropriate sealers, their performance, and correct quality assurance testing protocols. Numerous testing methods have been employed by suppliers, researchers and highway agencies, and the reported data are often confusing or conflicting. Ultimately, this study seeks to provide clarity to the uncertainties associated with the current state of the practice relative to testing surface sealers through suggested changes to AASHTO M224Use of Protective Sealers for Portland Cement Concrete.

NCHRP Synthesis 209 Sealers for Portland Cement Concrete Highway Facilities (P. D. Cady 1994), systematically reviewed technical information available through 1993 and represented the state of the practice for concrete sealers. Concrete sealers were found to be widely used to reduce future deterioration and corrosion of bridges, but the lack of national standard testing procedures and specifications for concrete sealers hindered their understanding, use, and acceptance. A need for standard testing protocols for product qualification, quality assurance, application quality control and field testing to assess the need for reapplication was identified.

This research provides a review of existing testing methods and presents recommended testing protocols for product qualification, job-site quality assurance, application quality control and field testing. This was conducted through a literature review, discussions with sealer manufacturers, and a survey of highway agencies in the US and abroad. The literature review and DOT survey was conducted to update the state of the practice related to testing methodologies for concrete sealers. This review obtained information on what test methods are used by the agencies, material information, specifications, test data, qualified product lists, and project information. The survey also requested information on the experience and performance, both good and bad, of sealer products.

After compiling the useful information concerning the various testing methods, the advantages and disadvantages of the various methods were reviewed. Decisions were made on what is the best test method and what are the key performance and property requirements of the sealer products. This was done first by identifying what properties all concrete sealers must possess, described as the “universal” properties. Initial screening tests for these universal properties are recommended, as well as testing for specific applications as they apply. The universal properties of all concrete sealers include resistance to water penetration, resistance to chloride ion (deicer or seawater) penetration, effectiveness at various application temperatures, resistance to outdoor weathering and alkali found in concrete and vapor transmission properties. Other application-specific tests are presented that can be preformed for use on traffic-bearing deck surfaces (abrasion resistance, skid resistance, and curing time), freeze-thaw exposure resistance, reducing deicer scaling of poorly air entrained concrete, performance under adverse conditions, and other considerations such as color, appearance, and safety.

In addition to the sealer product prequalification testing that can be used to evaluate sealer products for inclusion on qualified product lists or specifications, recommended test protocols were also
developed for routine product quality assurance and jobsite application quality control as well as guidelines for field testing to assess sealer performance and the need for re-application.
Sealers on concrete highway structures are primarily used to reduce the penetration of chloride salts and moisture into the concrete and are most effective when applied early in the life of a structure. They can also be effective in reducing the rate of deterioration in chloride contaminated structures with ongoing corrosion. Sealers have the advantage over other repair techniques, such as overlays, of being applied easily and economically to the surface of both new and old concrete decks and structures.

Many state agencies use their own maintenance forces to apply sealers on a time-available basis, which makes sealers economically attractive. Procurement of sealer materials statewide under a blanket contract can result in a low material price. Through training maintenance forces can retain their application experience, and this has historically resulted in satisfactory sealer performance. Other state agencies issue contracts for deck sealing and use cores to determine coverage and sealer penetration performance, which in turn is used to determine pay quantities. However, some state agencies are not set up with laboratory or field personnel to evaluate sealer performance for this type of contract specification.

Significant progress has been made in the past 25 years in concrete protection using sealers. NCHRP Report No. 244 (Pfeifer and Scali 1981) was the first major study that evaluated various concrete sealer types under a standard test program. Weight gain and net chloride ion content ingress of standard coated and uncoated concrete cubes and slab specimens were evaluated. The performance of the materials varied from excellent through unsatisfactory. Effectiveness of the sealers is greatly influenced by their chemical formulations, as well as concrete quality, surface preparation, and application conditions.

Five categories of sealers were found to be effective in the NCHRP 244 study. These were polyurethanes, a methyl methacrylate (MMA), certain epoxy formulations, low molecular weight siloxane oligomers, and silanes. Many of the polyurethanes have the limitation that they can degrade when exposed to the ultraviolet (UV) rays of the sun. Epoxies, acrylics, and methacrylates are very effective sealers; however, at the viscosities normally used, they do not penetrate into the concrete, but leave a continuous film or coating on the surface. This can create skid resistance problems and coating wear issues on decks. Also, they are not highly vapor permeable so do not allow the deck to dry between rain or snow events. With the use of any type of sealer, surface preparation, including cleanliness and moisture content of the concrete surface, is extremely important. With those that do not penetrate but adhere to the surface, it is also important to provide some mechanical lock, or "tooth" for the material to adhere.

The sealers available today may be classified as either film forming (coatings) or penetrating (penetrants). Urethanes and epoxies are two of the most commonly used film forming sealers for concrete. Their penetrating ability is minimal, with most of the material remaining on the surface to form a thick barrier. The ability of these products to effectively penetrate concrete is restricted by the relatively large molecular structure of the material. The presence of solvents in the formulation, therefore, will not appreciably enhance penetration capabilities.

Common penetrating sealers are silanes, siloxane oligomers, and methyl methacrylate. The methyl methacrylate monomer is highly volatile and is rarely used as a sealer, especially due to restrictions of recent air pollution regulations. Silanes and siloxanes are both derived from the silicone family. When catalyzed by moisture within the concrete, these silicon-based materials react with the silica in concrete to form a hydrophobic siloxane resin treated layer of concrete along the surface that repels water without loss of vapor transmission properties. Unlike film forming sealers, the effectiveness of the penetrating sealers is not dependent on the continuity of an exposed surface film. However, the
effectiveness and durability of these materials rely heavily on achieving good penetration depths into the concrete surface. Alberta Department of Transportation and Utilities (Kotte, 1987; Carter, 1989) developed a test procedure in 1987 based on the NCHRP 244 procedure but that tested concrete samples before and after surface abrasion by sandblasting. This provided a means to evaluate the long-term effectiveness of penetrating sealers as the surface of the concrete is worn away from traffic exposure.

While it is reasonable to assume that each sealer should work equally well in all parts of the country, local conditions can affect sealer selection. Penetration of some formulations of silanes and the adhesion of some epoxy resins vary greatly depending on the moisture condition of the concrete. A sealer that works well in a dry climate may not work as well where high moisture conditions prevail. Also, different deicer chemicals are used in different states and this may affect a certain sealer’s performance, such as its ability to prevent deicer scaling. Sealer effectiveness is related to many factors including: the quality of concrete (porosity, water-cement ratio), age of concrete (days of curing), presence of cracking, condition and preparation of the concrete surface (moisture content, contamination, pretreatment), and application conditions (weather, wind, temperature, coverage rate, number of coats, recoat time). Trial applications in the field are often recommended to ensure that satisfactory performance can be achieved. Local air pollution laws limiting volatile organic compounds (VOC) must be considered when selecting a sealer. Highly volatile sealers are already prohibited in many states, and their use may be eliminated entirely in the near future.

NCHRP Synthesis 209 Sealers for Portland Cement Concrete Highway Facilities (P. D. Cady 1994) was completed in 1994. The study found sealing to be the lowest first-cost method for protection of concrete structures against future deterioration and corrosion, and potentially the lowest life-cycle cost procedure to extend the service life of concrete bridges. The study found hundreds of available sealer products, with widely variable testing protocols for product qualification, product quality assurance (QA), field application assurance, and field testing for assessment of sealer reapplication needs and product performance. The NCHRP Synthesis 209 recommended the development of a national standard testing specification for concrete sealers consisting of testing protocols that are aligned with the goals of this current study. A key attribute of the effort described in this document was to define variables involved in the testing that imitate expected field conditions covering the various levels of service, including geographic limitations, concrete substrate conditions, and exposure conditions that may be encountered (P. D. Cady 1994).

The goals of this study are to carry out the recommendations of NCHRP Synthesis 209 and develop testing protocols for surface-applied sealers for inclusion in AASHTO M224. Some state agencies have developed their own product evaluation and field application testing procedures, but usually only for a narrow range of products and for a narrow range of test conditions. This research reviewed existing testing methods and provides recommended testing protocols for product qualification, quality assurance, application quality control and field testing. Because the NCHRP Synthesis 209 systematically reviewed technical information available through 1993, much of this current effort focused on identifying current practice, new techniques, and products and systems developed since 1993.

Based on the need for standard testing protocols for sealer product qualification, product quality assurance, product application and field testing, NCHRP Project 20-7/Task 235 was conducted at the request of the AASHTO Highway Subcommittee on Maintenance. Recommended standard protocols have been developed based on review of the literature and the transportation agency survey results. The protocols provide a set of standard universal test methods for prequalification of sealers and recommend optional test methods suitable for specific application conditions. Some tests are very similar to tests that are been routinely used by agencies and other test procedures are new, having never been performed, and address specific testing or performance needs.
This report contains a large amount of technical information and has been organized into several chapters. Two draft test methods have been developed and are provided in the Appendix; Appendix A - Standard Method of Test for Protective Sealers for Portland Cement Concrete and Appendix B - Guideline for Quality Assurance, Job Site Quality Control, and Reapplication of Protective Sealers for Portland Cement Concrete. Chapter 4 provides the background and logic used to develop the Standard Method of Test for Protective Sealers for Portland Cement Concrete to be used to compare sealers and pre-qualify their use. Chapter 5 provides the background and logic used to develop the Guideline for Quality Assurance, Job Site Quality Control, and Reapplication of Protective Sealers for Portland Cement Concrete. Chapter 6 provides a report summary and suggestions for future work. Preceding these chapters are Chapter 2 that includes the agency survey responses and Chapter 3 that provides a list of the various test methods that are sometimes used to characterize sealers and measure performance. Readers interested in how other agencies evaluate and use sealers should read Chapter 2 but this information and the information in Chapter 3 is not essential if the reader is most interested in learning about the recommended testing procedures.
CHAPTER 2

SURVEY RESPONSES

INTRODUCTION

A survey was conducted to gather information about current practices in sealer testing, approval, and use. Surveys were sent to transportation professionals in every US state and Canadian province or territory, and also to the United Kingdom, Australia, and Germany.

The survey asked for feedback about the common types of sealers used, procedures for selecting sealers, surface preparation methods, and also about test methods. The bulk of the survey asked respondents about test methods used and feedback on potential tests, as well as comments on the testing processes in general. Respondents listed the test methods their agency uses for laboratory product qualification, routine product quality assurance, field application quality assurance, and field performance and re-application quality assurance. In addition, the respondents were asked to provide feedback on each of these processes. The following section summarizes the responses to the survey.

Total Responses
Thirty-three (33)

Responding Locations Using Sealers
Twenty-six(26): AR, CO, FL, IA, IL, ME, MO, MS, NH, NV, NY, OH, OR, RI, TX, VA, VT, WV, Alberta, British Columbia, Manitoba, Newfoundland, Prince Edward Island, Ontario, Quebec, Germany

Responding Locations Not Using Sealers
Seven (7): GA, KS, LA, ND, NJ, SC, WA

SEALER TYPES USED

All twenty-six responding agencies that use sealers report the use of penetrating sealers. Silane sealers are, by far, the most commonly cited penetrating sealers, and are used by 23 (70%) of respondents. Linseed oil and siloxane sealers are the second most commonly cited, and are used by 10 (30%) and 9 (27%) of responding agencies, respectively. The types of penetrating sealers used by respondents are presented below. Each respondent may have listed more than one type of sealer.

<table>
<thead>
<tr>
<th>Sealer Type</th>
<th>Number of Responses</th>
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<tbody>
<tr>
<td>Silane</td>
<td>23</td>
</tr>
<tr>
<td>Siloxane</td>
<td>9</td>
</tr>
<tr>
<td>Silane/Siloxane Blend</td>
<td>6</td>
</tr>
<tr>
<td>Silicone</td>
<td>1</td>
</tr>
<tr>
<td>Silicate</td>
<td>3</td>
</tr>
<tr>
<td>Linseed Oil</td>
<td>10</td>
</tr>
<tr>
<td>Stearates</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>1 (epoxy)</td>
</tr>
</tbody>
</table>

Table 1. Penetrating sealer usage (26 Responses Total)
Nineteen responding agencies (58%) report the use of a barrier-type sealer. Epoxy sealers are the most commonly cited, with 14 agencies (42%) reporting the use of these sealers. MMA sealers are used by 10 (30%) of agencies. The types of barrier-type sealers used by respondents are presented below.

<table>
<thead>
<tr>
<th>Sealer Type</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthetic Gum Resins</td>
<td>0</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>2</td>
</tr>
<tr>
<td>Polyester</td>
<td>1</td>
</tr>
<tr>
<td>Epoxy (including 1 epoxy-urethane)</td>
<td>14</td>
</tr>
<tr>
<td>Acrylic</td>
<td>6</td>
</tr>
<tr>
<td>MMA (may include HMWM* crack repair sealers)</td>
<td>10</td>
</tr>
<tr>
<td>Other Barrier-Type Sealer</td>
<td>4 (asphalt seal coat, aliphatic urethanes, AASHTO M 224, mixed polymers)</td>
</tr>
</tbody>
</table>

*High molecular weight methacrylate resins used for sealing cracks

Many responding agencies use multiple types of sealers. In some cases, multiple types of sealers are approved by the agencies, and the use is determined on a case-by-case basis, while, in other cases, particular types of sealers are preferred for new construction or for rehabilitation.

**Sealer Product Selection**

Most agencies that use sealers look to qualified products lists, agency guidelines, or application or testing protocols prior to selecting a sealer system. Most agencies have their own guidelines or qualified products lists, although some agencies use another agency’s guidelines or qualified products lists. Few agencies use research studies or industry or association guidelines. Indicated below is how many agencies reported using each resource.

<table>
<thead>
<tr>
<th>Source</th>
<th>Number of Responses</th>
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<tr>
<td>Agency Guidelines</td>
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<td>Qualified Products Lists</td>
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<tr>
<td>Application or Testing Protocols</td>
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<td>Research Studies</td>
<td>5</td>
</tr>
<tr>
<td>Industry or Association Guidelines or Manuals</td>
<td>4</td>
</tr>
</tbody>
</table>

**TEST METHODS**

**Laboratory Product Qualification**

Water absorption, chloride penetration, and spectroanalysis are the most commonly used tests for laboratory product qualification. Presented below lists the number of agencies that perform each type of test during the laboratory product qualification process, and which test methods they use. Some locations, including New York, West Virginia, Texas, Rhode Island, New Hampshire, and Alberta have in-house test procedures for certain property measurements, but most agencies use ASTM standard tests.
### Table 4. Test methods used for laboratory product qualification

<table>
<thead>
<tr>
<th>Property</th>
<th>Number of Respondents Performing Tests</th>
<th>Test Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Absorption</td>
<td>14</td>
<td>• New York Method 717-01E&lt;br&gt;• Rhode Island Evaluation of Concrete Surface Sealers (Water Absorption)&lt;br&gt;• Tex-897-B&lt;br&gt;• ASTM D570&lt;br&gt;• Alberta BT001 (Waterproofing Performance)&lt;br&gt;• NCHRP 244&lt;br&gt;• New Hampshire Item 534&lt;br&gt;• Ontario Silane Sealer Testing Program (Water Absorption)&lt;br&gt;• ASTM C642</td>
</tr>
<tr>
<td>Chloride Penetration</td>
<td>12</td>
<td>• New Hampshire Item 534&lt;br&gt;• New York 717-01E&lt;br&gt;• AASHTO T259&lt;br&gt;• Rhode Island Evaluation of Concrete Surface Sealers (Chloride Intrusion Screening)&lt;br&gt;• NCHRP 244 Series II cube test&lt;br&gt;• NCHRP 244 Series IV - Southern Climate&lt;br&gt;• Ontario Silane Sealer Testing Program (15% NaCl Solution Absorption)&lt;br&gt;• AASHTO T260</td>
</tr>
<tr>
<td>Sealer Penetration</td>
<td>7</td>
<td>• Virginia VTM 101 (for crack sealers)&lt;br&gt;• NCHRP 244 Series IV - Southern Climate&lt;br&gt;• Ontario Silane Sealer Testing Program (Depth of Penetration)&lt;br&gt;• Tex-897-B&lt;br&gt;• Visual</td>
</tr>
<tr>
<td>Coating Thickness</td>
<td>4</td>
<td>None given</td>
</tr>
<tr>
<td>Freeze/Thaw</td>
<td>4</td>
<td>• Section 601.13.3.2 West Virginia’s 2003 Supplemental Specifications -- Concrete Protective Coating Materials (Freeze-Thaw Test)&lt;br&gt;• ASTM C666&lt;br&gt;• Rhode Island Evaluation of Concrete Surface Sealers (Freeze/Thaw Resistance)</td>
</tr>
<tr>
<td>Deicer Scaling Resistance</td>
<td>5</td>
<td>• Illinois Modified ASTM C672&lt;br&gt;• AASHTO T259&lt;br&gt;• ASTM C672&lt;br&gt;• ASTM B117&lt;br&gt;• Ontario Silane Sealer Testing Program (Salt Scaling Resistance)</td>
</tr>
<tr>
<td>Coating Bond to Concrete</td>
<td>5</td>
<td>• ASTM C882&lt;br&gt;• Visual&lt;br&gt;• ACI 503R - Adhesion Test</td>
</tr>
<tr>
<td>Water Vapor Transmittance</td>
<td>5</td>
<td>• New York 717-01E (Moisture Vapor Transmission)&lt;br&gt;• Rhode Island Evaluation of Concrete Surface Sealers (Water Vapor Transmission)&lt;br&gt;• Alberta BT001 (Water Vapour Transmission Performance)&lt;br&gt;• Ontario Silane Sealer Testing Program (Water Vapour Transmission)</td>
</tr>
<tr>
<td>Alkali Resistance</td>
<td>2</td>
<td>• Alberta BT002</td>
</tr>
<tr>
<td>Property</td>
<td>Number of Respondents Performing Tests</td>
<td>Test Methods</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>----------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Carbon Dioxide Transmittance</td>
<td>0</td>
<td>• Illinois Modified ASTM C672</td>
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<td></td>
<td></td>
<td>• ASTM C672</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM C882</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rhode Island Evaluation of Concrete Surface Sealers Tests</td>
</tr>
<tr>
<td>Concrete Test Sample Surface Condition</td>
<td>6</td>
<td>• ASTM C672</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM C882</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rhode Island Evaluation of Concrete Surface Sealers Tests</td>
</tr>
<tr>
<td>Concrete Test Sample Moisture Condition</td>
<td>5</td>
<td>• ASTM C672</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM C882</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rhode Island Evaluation of Concrete Surface Sealers Tests</td>
</tr>
<tr>
<td>Concrete Carbonation</td>
<td>0</td>
<td>• ASTM C672</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM C882</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT001</td>
</tr>
<tr>
<td>Concrete Temperature</td>
<td>9</td>
<td>• AASHTO M233</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• AASHTO M224</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D2369</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM C882</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D5095</td>
</tr>
<tr>
<td>Percent Solids</td>
<td>9</td>
<td>• AASHTO M233</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• AASHTO M224</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D2369</td>
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<tr>
<td></td>
<td></td>
<td>• ASTM C882</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT001</td>
</tr>
<tr>
<td>Percent Volatiles</td>
<td>7</td>
<td>• EPA 24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D5095</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT001</td>
</tr>
<tr>
<td>Spectroanalysis</td>
<td>10</td>
<td>• Illinois/Instrument Method</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• IR trace</td>
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<tr>
<td></td>
<td></td>
<td>• FTIR fingerprinting</td>
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<tr>
<td></td>
<td></td>
<td>• Tex-888-B</td>
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<tr>
<td></td>
<td></td>
<td>• Alberta BT008</td>
</tr>
<tr>
<td>Viscosity</td>
<td>8</td>
<td>• Brookfield VT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D2393</td>
</tr>
<tr>
<td>pH</td>
<td>2</td>
<td>• ASTM D1293</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>3</td>
<td>• AASHTO M233</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D163</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• AASHTO M224</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM E100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D1475</td>
</tr>
<tr>
<td>Coating Shrinkage</td>
<td>1</td>
<td>• ASTM D2566</td>
</tr>
<tr>
<td>Coating Tensile Strength and Elongation</td>
<td>4</td>
<td>• ASTM C307</td>
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<tr>
<td></td>
<td></td>
<td>• ASTM D412</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D638</td>
</tr>
<tr>
<td>Application Rate</td>
<td>7</td>
<td>• New York 717-01E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT001</td>
</tr>
<tr>
<td>Property</td>
<td>Number of Respondents Performing Tests</td>
<td>Test Methods</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
<td>• ASTM D260 (for linseed oil)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM C307</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM C672</td>
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<tr>
<td></td>
<td></td>
<td>• ASTM D638</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Gas Chromatogram</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM C884</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D822</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM C1202</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Visual</td>
</tr>
</tbody>
</table>

**Routine Product Quality Assurance**

Spectroanalysis is the most common routine product quality assurance test used by the respondents, followed by percent solids. A couple of respondents use gas chromatography, in addition to spectroanalysis, for chemical identification of the constituents of a sealer material. The following lists the test methods used for routine product quality assurance.

**Table 5. Test methods used for routine product quality assurance**

<table>
<thead>
<tr>
<th>Property</th>
<th>Number of Respondents Performing Tests</th>
<th>Test Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Solids</td>
<td>5</td>
<td>• 105 °C to constant mass (similar to ASTM D 1644 Method A)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D 5095</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT001</td>
</tr>
<tr>
<td>Percent Volatiles</td>
<td>3</td>
<td>• AASHTO M233</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• AASHTO M224</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D2369</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D5095</td>
</tr>
<tr>
<td>Spectroanalysis</td>
<td>8</td>
<td>• Fingerprinting (methods undefined)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Tex-888-B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT008</td>
</tr>
<tr>
<td>Viscosity</td>
<td>1</td>
<td>None provided</td>
</tr>
<tr>
<td>pH</td>
<td>1</td>
<td>• ASTM D1293</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2</td>
<td>• AASHTO M233</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D163</td>
</tr>
<tr>
<td></td>
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<td>• AASHTO M224</td>
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<td>• ASTM E100</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
<td>• ASTM D56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Visual</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Gas Chromatograph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT008</td>
</tr>
</tbody>
</table>

**Field Application Quality Assurance**

Application rate, concrete temperature, concrete surface condition, and concrete moisture condition were the most commonly reported field application quality assurance tests. Despite the common use of tests, few standard test methods or requirements were reported. Many respondents use visual
evaluation, which is generally not performed according to a written test method, to assess field application. Some respondents did not list any testing methodology, indicating that standard test methods may not be available. The following lists the test methods used for field application quality assurance.

### Table 6. Test methods used for field application quality assurance

<table>
<thead>
<tr>
<th>Property</th>
<th>Number of Respondents Performing Tests</th>
<th>Test Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Surface Condition</td>
<td>8</td>
<td>• Visual</td>
</tr>
<tr>
<td>Concrete Moisture Condition</td>
<td>7</td>
<td>• Visual</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• James moisture meter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ASTM D4263</td>
</tr>
<tr>
<td>Application Rate</td>
<td>12</td>
<td>• Measure volume used per surface area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Wet film thickness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Visual</td>
</tr>
<tr>
<td>Core Sampling</td>
<td>4</td>
<td>• ASTM C42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Chloride content (no method given)</td>
</tr>
<tr>
<td>Sealer Penetration Depth</td>
<td>1</td>
<td>• Visual</td>
</tr>
<tr>
<td>Field Chloride Penetration Resistance</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Surface Electrical Resistance</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Concrete Carbonation</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Concrete Temperature</td>
<td>9</td>
<td>• Visual check of thermometer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Surface thermometer</td>
</tr>
<tr>
<td>Surface Absorption</td>
<td>3</td>
<td>• Visual</td>
</tr>
<tr>
<td>Water Permeability</td>
<td>2</td>
<td>• Visual</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Alberta BT005</td>
</tr>
<tr>
<td>Air Permeability</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Skid Resistance</td>
<td>4</td>
<td>• ASTM E 274</td>
</tr>
<tr>
<td>Bond Strength</td>
<td>2</td>
<td>• Visual</td>
</tr>
<tr>
<td>Mock-Ups</td>
<td>4</td>
<td>• Virginia VTM 41 and VTM 92</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>None provided</td>
</tr>
</tbody>
</table>

### Field Performance and Re-Application Testing

Application rate and concrete temperature were the most commonly cited field performance and re-application quality assurance tests. However, no standard test methods were listed for either property, likely indicating, as with the field application quality assurance; there are no suitable standard test methods available. A few agencies perform core sampling, but no agencies reported the use of field chloride penetration resistance or surface electrical resistance tests. It is not clear how the agencies determine if a sealed surface has deteriorated to the point of requiring re-application. The following lists the test methods used for evaluating the field performance of applied sealers.
Table 7. Test methods used for field performance and re-application quality assurance

<table>
<thead>
<tr>
<th>Property</th>
<th>Number of Respondents Performing Tests</th>
<th>Test Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Surface Condition</td>
<td>4</td>
<td>• Visual</td>
</tr>
<tr>
<td>Concrete Moisture Condition</td>
<td>3</td>
<td>• Visual • ASTM D4263</td>
</tr>
<tr>
<td>Application Rate</td>
<td>8</td>
<td>• Measure volume used per surface area • Wet film thickness</td>
</tr>
<tr>
<td>Core Sampling</td>
<td>3</td>
<td>• ASTM C42 • Alberta BT005</td>
</tr>
<tr>
<td>Sealer Penetration Depth</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Field Chloride Penetration Resistance</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Surface Electrical Resistance</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Concrete Carbonation</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Concrete Temperature</td>
<td>6</td>
<td>• Visual check of thermometer • Surface thermometer</td>
</tr>
<tr>
<td>Surface Absorption</td>
<td>3</td>
<td>• Visual</td>
</tr>
<tr>
<td>Water Permeability</td>
<td>1</td>
<td>• Alberta BT005</td>
</tr>
<tr>
<td>Air Permeability</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Skid Resistance</td>
<td>3</td>
<td>• ASTM E274</td>
</tr>
<tr>
<td>Bond Strength</td>
<td>2</td>
<td>• Virginia VTM 41 and VTM 92</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>• Air quality test desired</td>
</tr>
</tbody>
</table>

RESPONDENTS COMMENTS ON TESTING METHODS AND PROCEDURES

Laboratory Product Qualification

Many respondents think that a pre-defined set of standard test methods would aid in the laboratory product qualification process. Several agencies would like to see test methods that simulate field conditions better, as well as longer-term testing and performance assessments. The respondents’ suggestions for improving the laboratory product qualification process are provided below.

Table 8. Suggestions for improving the laboratory product qualification process

<table>
<thead>
<tr>
<th>Location</th>
<th>Suggestions for improving the laboratory product qualification process</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>• Uniformity in qualification properties between states would be helpful.</td>
</tr>
<tr>
<td>CO</td>
<td>• Better testing procedures that simulate field conditions with de-icing chemical exposures need to occur.</td>
</tr>
<tr>
<td>IL</td>
<td>• Need laboratory tests to simulate field performance.</td>
</tr>
<tr>
<td></td>
<td>• Evaluating salt ponded samples (for 6 months) by checking chloride ion penetration.</td>
</tr>
<tr>
<td>MO</td>
<td>• All labs need to adhere directly to the test methods used or clearly state if they varied from them and document any modifications.</td>
</tr>
<tr>
<td></td>
<td>• AASHTO NTPEP needs to accelerate plans to test penetrating sealers.</td>
</tr>
<tr>
<td></td>
<td>• The states need new qualified products for continuing rehabilitation of old structures and preventative maintenance of new ones.</td>
</tr>
<tr>
<td>Location</td>
<td>Suggestions for improving the laboratory product qualification process</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| NH       | • Standardized testing protocols and performance specifications.  
|          | o Should identify which properties are most relevant and indicative of sealer performance.  
|          | o Currently, NH only tests absorption, chloride penetration and penetration of sealer into the concrete. |
| NY       | • One of the improvements that our agency has utilized is accepting silane sealers based on chemical fingerprinting to identify specific molecules and percent active ingredients.  
|          | o This has enabled us to shorten the length of time to approve such products.  
|          | o We have found in partnering with industry that there only four (4) silane molecules being utilized for penetrating sealers.  
|          | o There are only a few suppliers of the base silanes.  
|          | o Therefore, by looking at the chemistry and proportioning of the products, it is easier to identify which products will be acceptable for use.  
|          | o Alberta DOT uses a similar protocol as part of their approval process with much success.  
|          | • Unfortunately, the performance-based lab prequalification tests have given erroneous results in some incidences, especially when testing for chloride intrusion which can be skewed with certain aggregate sources. |
| OH       | • More information on long-term performance is desired. |
| OR       | • For the Barrier-type sealers, we have been investigating whether using vapor pressure tests would be worthwhile. This may help the resin penetrate into cracks.  
|          | • A test for cure time would be good. The product should give plenty of time to penetrate the crack, yet not remain open for more than an hour or so.  
|          | • Movement of the crack during cure of the barrier type sealer is an unknown.  
|          | • An investigation on performance of barrier sealers with damp cracks would be interesting. |
| RI       | • Major concern with penetrants is the effective depth of penetration.  
|          | o Concern is that freeze/thaw scaling eliminates protection.  
|          | o Unable to determine depth with available laboratory equipment for silanes and siloxanes. |
| TX       | • We need to consider adding a few tests to the program. |
| VA       | • Limited resources and experience compel reliance on the manufacturer. |
| VT       | • Chloride penetration, scaling resistance, moisture retention, moisture vapor movement through the sealer, and sealer penetration would be some of the important tests I would like to see. |
| WV       | • Create an ASTM or AASHTO standard for each type of material. That way, a uniform series of tests could be established.  
|          | o This would reduce costs for product manufacturers since it could eliminate different testing programs for each state.  
|          | o It would also make it easier for the DOT’s since it would just require a reference to the ASTM or AASHTO spec instead of having to develop a specific testing program. |
| Quebec   | • By the publication of an ASTM method of evaluation.  
|          | • By the publication of a guide presenting the performance and limitations of the sealers. |

**Routine Product Quality Assurance**

Many respondents are interested in chemical fingerprinting tests for the routine product quality assurance process. Most have little time to devote to routine quality assurance testing. The respondents’ suggestions for improving routine product quality assurance testing are presented below.

**Table 9. Suggestions for improving routine product quality assurance**

<table>
<thead>
<tr>
<th>Location</th>
<th>Suggestions for improving routine product quality assurance</th>
</tr>
</thead>
</table>
| AR       | • The quality assurance tests are used in an attempt to verify that the manufacturer/supplier has not changed their product since the initial approval for inclusion on the qualified product list (QPL).  
|          | • Additional tests, such as specific gravity, and published allowed variances would be helpful. |
**Location Suggestions for improving routine product quality assurance**

<table>
<thead>
<tr>
<th>Location</th>
<th>Suggestions for improving routine product quality assurance</th>
</tr>
</thead>
</table>
| MO       | • Pull off tests are needed for protective coatings on non-wearing surfaces, such as bent caps to ensure good surface prep and bond.  
          | • A good penetration test for testing sealers in the lab and field are needed.  
          | • A good, repeatable way to test crack sealers needs to be developed. |
| NH       | • NH does not currently perform any additional testing of products after they have been qualified for listing on our Qualified Products List.  
          | • Fingerprinting of products would allow for assurance that product is the same as originally qualified.  
          | • Retesting of products would allow for assurance that product is the same as originally qualified.  
          | • Retesting of products every few years might be feasible.  
          | • Staffing limitations would not allow for extensive quality assurance testing. |
| NY       | • By utilizing chemical fingerprinting, it is fairly easy and time efficient to monitor the consistency of products.  
          | • This, of course, is only applicable with the silane based penetrating sealers.  
          | • If coating sealers could have a chemical fingerprint as a "litmus" for projected field performance, it would be easier to monitor these types of products on a more routine basis. |
| OH       | • IR fingerprinting is a good test. It should be used on failures to check products, if not used on everything. |
| RI       | • Would like to see better methods to fingerprint sealers to verify that they meet the specifications of what was approved (quantification currently is difficult), and for multi-component products, that a proper mix ratio has been obtained. |
| TX       | • More tests need to be run. TxDOT does very little QA testing due to sheer volume of work. |
| VA       | • Limited resources and experience compel reliance on the manufacturer. |
| VT       | • Can it be done by chemical analysis? |
| WV       | • Annual re-qualification based on a reduced number of core lab tests. |

**Field Application Quality Assurance**

Respondents commented on the lack of standard procedures for field application quality assurance. The currently used field application quality assurance processes vary from location to location, from testing moisture at the concrete surface, to confirming that the product used is on the approved list (by comparing the product label with the approved list).

Surface preparation, penetration and/or bonding of the sealer, temperature, application rates, concrete moisture condition, curing time tests have been indicated as useful. Field tests would be most suitable if they are simple, inexpensive to carry out, and non-destructive. Some respondents are interested in test methods that do not require coring of the substrate. The respondents’ suggestions for improving the field application quality assurance testing are presented below.

**Table 10. Suggestions for improving sealer field application assurance**

<table>
<thead>
<tr>
<th>Location</th>
<th>Suggestions for improving sealer field application assurance</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL</td>
<td>• Uniform constructions guidelines are needed.</td>
</tr>
</tbody>
</table>
| MO       | • Good surface preparation needs to be tested and good penetration or bonding of the coating.  
          | • Follow the specifications and manufacturer's recommendations for temperature of application.  
          | • Check application rates periodically.  
          | • Pull off tests to check adequate curing time and bonding if a surface coating. |
| NH       | • Any field application testing would have to be simple and use a minimal amount of inexpensive equipment.  
          | • The majority of NH's usage is on vertical surfaces so field testing would have to be suitable for that application. |
**Location Suggestions for improving sealer field application assurance**

<table>
<thead>
<tr>
<th>Location</th>
<th>Suggestions for improving sealer field application assurance</th>
</tr>
</thead>
</table>
| NY       | • NYSDOT current process for field application quality assurance only looks to see that the container label of the applied sealer matches the product as it appears on the approved list.  
• The Engineer in charge also compares the quantities used to the original estimates to insure standardized coverage rates have been followed. |
| OH       | • Require installers to re-do installations with a longer-term warranty if it doesn't last.  
• There needs to be some sort of long-term performance criteria and require some sort of warranty. |
| TX       | • We will have to start testing sealer application (penetration) but need to come up with a non-destructive test (not coring) |
| VA       | • Limited resources and experience compel reliance on the manufacturer. |
| VT       | • Moisture tests of concrete surfaces, a maximum amount of moisture limit |
| WV       | • More training of DOT Inspectors.  
• Also more specifics on test methods and allowable tolerances (application rates, thicknesses, etc.) in the specs. |
| Alberta  | • Regular field audits and inspections.  
• Review of Bridge Sealing Data Sheets while the sealing contract is in progress to identify any potential problems prior to the contractor demobilizing. |

**Field Performance and Re-Application Quality Assurance**

Respondents suggested that improvements in simple field tests are necessary, primarily for chloride intrusion and water permeability. Several stated that non-destructive tests are preferable to destructive tests. Guidelines on applicable tests and applications are desired. The respondents’ suggestions for improving the field performance and re-application process are presented below.

**Table 11. Sealer field performance and re-application evaluation testing suggestions**

<table>
<thead>
<tr>
<th>Location</th>
<th>Sealer field performance and re-application evaluation testing suggestions</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL</td>
<td>• Doing research on this.</td>
</tr>
</tbody>
</table>
| MO       | • Before and long after application (2-3 yrs.) chloride penetration tests should be done on field locations.  
• A good non-destructive test such as a reliable and simple air or water permeability test should be investigated. |
| NH       | • As with field application QA testing, this testing would have to be simple and utilize inexpensive equipment. |
| NY       | • Currently we do not have a field performance and re-application evaluation process.  
• Older bridge decks (those not sealed at the time of construction) have been treated by our maintenance forces on a 3 to 5 year rotation schedule.  
• Re-application has been dependent upon the condition of the deck and whether the silane is absorbing into the concrete. Visual observation of "beading" or the lack of absorption to the concrete would make the deck a poor candidate for re-application. |
| RI       | • Rapid non-destructive or minimally destructive tests for permeability and chloride resistance would be useful. |
| TX       | • TxDOT does not perform any testing to determine sealer re-application needs.  
• Most decisions are based on judgment and experience.  
• Our system is too large (50,000+ bridges) to do much testing.  
• Sealer performance is not a critical issue for more than 2/3 of the state as they don't use de-icing chemicals. |
| VA       | • Limited resources and experience compel reliance on the manufacturer. |
| WV       | • Warranties.               |
| Alberta  | • Establish a regular field performance evaluation program as part of our regular sealing programs. |
| Quebec   | • Publication of a simple test that can be conducted in situ to determine the need for re-application. |
SURFACE PREPARATION METHODS

The methods of surface preparation used vary widely. Many agencies specify that manufacturer’s recommendations be followed when preparing the surface. Others specify that the surface should be clean, free of grease, dust, or other contaminants without specifying a particular preparation method. The surface preparation required varies depending on the sealer to be applied; different preparation methods are required for different types of sealers.

Many respondents indicated that they follow manufacturer’s instruction prior to installing a sealer for new and pre-existing concrete. For new concrete, the age at application is a concern, and several agencies require the concrete to be at least 28-days old. Others agencies allow application of the sealer after 7 days, or when a specified moisture content is achieved. Many require that any applied curing compound be completely removed prior to sealer application.

Air sweeping and water blasting are the most commonly cited methods for surface preparation prior to using a penetrating sealer, with 11 responding agencies (34%) using each. Other methods are also used and are presented below.

Table 12. Concrete surface preparation method prior to using penetrating sealer
(23 total responses).

<table>
<thead>
<tr>
<th>Preparation Method</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Prep</td>
<td>3</td>
</tr>
<tr>
<td>Air sweep</td>
<td>11</td>
</tr>
<tr>
<td>Broom</td>
<td>3</td>
</tr>
<tr>
<td>Sandblast</td>
<td>8</td>
</tr>
<tr>
<td>Shot Blast</td>
<td>6</td>
</tr>
<tr>
<td>Hydro-demolition</td>
<td>1</td>
</tr>
<tr>
<td>Water/grit blast</td>
<td>2</td>
</tr>
<tr>
<td>Water blast</td>
<td>11</td>
</tr>
<tr>
<td>Milling</td>
<td>0</td>
</tr>
<tr>
<td>Crack Routing</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>4 (steam, wire brush, acid etch)</td>
</tr>
</tbody>
</table>

Sandblasting is the most commonly cited surface preparation method prior to applying a barrier-type sealer, with 9 (28%) responses. Other methods, such as air sweeping, are also used. Presented below indicates what preparation methods are used for barrier-type sealers.

Table 13. Concrete surface preparation method prior to using barrier-type sealer
(19 total responses).

<table>
<thead>
<tr>
<th>Preparation Method</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Prep</td>
<td>2</td>
</tr>
<tr>
<td>Air sweep</td>
<td>7</td>
</tr>
<tr>
<td>Broom</td>
<td>3</td>
</tr>
<tr>
<td>Sandblast</td>
<td>9</td>
</tr>
<tr>
<td>Shot Blast</td>
<td>5</td>
</tr>
<tr>
<td>Hydro-demolition</td>
<td>2</td>
</tr>
<tr>
<td>Water/grit blast</td>
<td>4</td>
</tr>
</tbody>
</table>
The following provides survey comments on precautions to be used for applying sealers.

### Table 14. Special precautions when using sealers on new concrete

<table>
<thead>
<tr>
<th>Location</th>
<th>Special precautions when using sealers on new concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>- Surfaces are thoroughly cleaned, removing all traces of curing compound, laitance, dirt, dust, salt, oil, asphalt or other foreign materials, but shall not cause undue damage to the surface, remove or alter the existing surface finish or texture, or expose the coarse aggregate.</td>
</tr>
<tr>
<td>CO</td>
<td>- Concrete cure must meet manufacturer requirements.</td>
</tr>
</tbody>
</table>
| FL       | - Only use sealers in new construction when cracks appear.  
|          | - Always apply special precautions as per manufacturer recommendations. Specifications contain wording on that regard for methacrylate. |
| IL       | - No, various sealers are allowed. |
| MO       | - New decks must have curing mats removed a minimum 48 hours to dry and surface must be clean before application of concrete sealer (Linseed oil).  
|          | - Penetrating sealers applied to surfaces only above 35 degrees Fahrenheit.  
|          | - Protective coatings - concrete must be cured a minimum 28 days. |
| NV       | - For all sealers, curing compound must be removed. |
| OH       | - The period of drying for new concrete or repairs is 10 days.  
|          | - No moisture testing is performed. |
| OR       | - We would follow the manufacturer's recommendations for proper prep and installation, but the age of the concrete would be a concern. |
| RI       | - Generally we require that the concrete cure sufficiently and that the laitance formation is effectively complete prior. |
| TX       | - For Silane, must wait 14 days after placing deck and at least one day after removal of curing mats.  
|          | - Curing compound must be removed. |
| VA       | - Remove curing compound if applied. |
| VT       | - Make sure any curing compounds are completely removed  
|          | - No standing water on surface  
|          | - Protect any paved surfaces. |
| WV       | - The product manufacturer's recommendations shall be followed. |
| Alberta  | - Type 1c - Low V.O.C. Penetrating Sealers For Low Water/Cement Ratio Traffic Bearing Surfaces, Outdoor Exposure Where Deck Relative Moisture Content is 80%, i.e. Minimum 3 days of continuous drying since last heavy rain |
| Manitoba | - MIT allows the application of silane on concrete that is between 7 & 14 days old. |
| Newfoundland | - 40% silane by weight. New concrete and/or restoration work should be allowed to reach full 28 day cure prior to application. |
| Ontario  | - No special precautions. Intend to use silane sealers routinely on new construction. |
| Quebec   | - For Silane: Application on new concrete after a minimum of 28 days. |
| Germany  | - Surface protection systems are only applied as an exception in case of extremely impaired structural elements (e.g. column bases, tunnel portals, bridge caps (a German specialty)).  
|          | - Penetrating sealers should not be applied on moist soil. |
Respondent’s Experiences with Sealers

The survey respondents had varied experiences with sealer application. Some agencies report good results with the use of sealers, while others no longer use sealers, preferring to work with high performance concrete. Several agencies cited problems with surface preparation prior to sealer application. The respondent from Alberta mentioned the use of site data forms as encouraging proper application. The respondents’ comments regarding experiences with sealer application are presented below.

Table 15. Experiences with Sealer Application

<table>
<thead>
<tr>
<th>Location</th>
<th>Experiences with Sealer Application</th>
</tr>
</thead>
</table>
| AR       | • Boiled Linseed Oil (Class 1 Sealer) is the only sealer commonly used.  
          • The silane/oxysiloxane (Class 2 Sealer) and the high molecular weight methacrylate resin sealers are typically only used when a problem is encountered during construction (e.g. excessive deck cracking, high water/cement ratio concrete, high air content concrete). |
| CO       | • Sealers generally have only moderate value. Penetration depths at best only 1/2 inch. |
| FL       | • FDOT no longer uses concrete sealers as a preventive measure. Resistance to chloride penetration is provided to the concrete by using high performance concretes. Sealers are used as a reactive measure when cracks develop or surface defects are present. |
| IA       | • Silane and siloxane based sealers have not tested well. |
| IL       | • Skid resistance is concern for barrier type coatings. |
| MO       | • Have not found anything which tests better than Linseed Oil for scaling resistance and initial chloride resistance. If applied too heavy it may take a long Time-to-Cure to re-open to traffic.  
          • Penetrating sealers cure more quickly and application is easier so maintenance operations are moving towards more use. |
| NH       | • Concrete sections are often completed just prior to winter weather and require protection for anti-icing chemicals. Because of this, silane is often placed in less than optimal (cold) conditions. Some manufacturers claim their product can be placed at temperatures down to 20 °F. It would be good to be able to verify performance under these conditions. |
| NY       | • NYSDOT has been using sealers for over 20 years with a great deal of success. With new bridge decks there has been an appreciable decline in the amount of scaling typically seen after the first few winters of service.  
          • Silane based penetrating sealers have been an important part of our belt and suspenders approach for extending service life of bridge decks. Depending on atmospheric conditions and active silane molecules being utilized, drying time can vary greatly adding to lengthened lane closure times.  
          • With higher solids content, coverage rates have increased which has led to more sensitivity to windy conditions.  
          • Late season applications have also led to some issues with ambient temperature restrictions. |
| OH       | • Have had some problems with poor surface prep for barrier sealers. Installers don't always follow application instructions.  
          • When applying a MMA crack filler, the surface needs to be dry, but it is difficult to get the crack to dry. |
| OR       | • Our biggest problem has been the wide variety of Barrier Type sealers. All of them seem pretty good on the surface, but with viscosity variations from 100 to 300 cps it is difficult to evaluate them. Some of them set up too fast to even test, i.e. urethanes. Do they work, or do they plug up at the top of the crack? |
| RI       | • Limited experience with field application, because currently only one film former is approved (water-based epoxy).  
          • Insuring proper mixing with correct ratio is critical for curing (severe discoloration within months if ratio during application is not maintained).  
          • Penetrant sealers have limited usage, due to concerns about effects on freeze/thaw performance and effective penetration depths. |
<table>
<thead>
<tr>
<th>Location</th>
<th>Experiences with Sealer Application</th>
</tr>
</thead>
</table>
| TX            | • We seem to be neutral regarding sealer application and are attempting to determine if they are truly effective.  
• We used to core to determine depth of penetration but decided it was better not to core just to measure penetration.  
• We’ve had issues with the cleaning requirements for silane.                                                                                                           |
| VA            | • Problems with mixing two part epoxies.                                                                                                                                                                                              |
| VT            | • We just began using it extensively in 2005 so we don’t have a lot of field time on the products yet.  
• I am not aware of any agency research projects at this time in relation to long term monitoring.  
• I have done some testing using the rapid chloride test AASHTO T 277 and have found that specimens treated with a silane product do have lower coulomb values when compared with untreated specimens. |
| WV            | • Good, as long as there is a good contractor doing the application and surface preparation is sufficient.                                                                                                                       |
| Alberta       | • The large majority of our experiences have been positive with sealer application. The use of site data forms and record management has helped ensure the product and application rates are closely adhered to.  
• The few negative experiences we’ve had in the Province have been related to inexperienced Contractor personal not interpreting site data correctly (moisture), quality of site prep, or rushing to catch up on due to inclement weather etc. |
| Prince Edward Island | • Good experience. Typically used on bridge decks for temporary (i.e. overwintering) application until waterproofing membrane and asphalt are placed.  
• Used on Traffic Barriers as well.                                                                                                                                            |
| Quebec        | • Solvent-based material damage bituminous surface.  
• Change in the concrete color after the application of the sealer                                                                                                               |
| Germany       | • Effective and durable if required application quality is guaranteed                                                                                                                                                                |

The responding agencies experiences with sealer performance were varied. Some agencies have good experience with sealers, while others no longer routinely apply sealers to concrete surfaces. Some agencies cited concerns with effectiveness of penetrating sealers. The respondents’ comments regarding experiences with sealer performance are presented below.

**Table 16. Experiences with sealer performance**

<table>
<thead>
<tr>
<th>Location</th>
<th>Experiences with sealer performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>• We have a task force studying several different products for determination of value gained.</td>
</tr>
</tbody>
</table>
| FL           | • For the most, the overall experience is positive.  
• We no longer use sealers because high performance concretes are more efficient in preventing chloride penetration and do not require re-application.  
• Negative side includes the difficulties associated with reapplication (especially in tidal zones).                                                                 |
| IL           | • No concern but research is evaluating various products.                                                                                                                                                                           |
| ME           | • For silane/siloxane sealers: used twice on different projects, temporary.  
• On one project the concrete deck was sealed for one winter, cored in the spring and salt levels were found to be high in the top 2”. Used material with solids content that was too low (?).  
• On the other project, a product with a higher solids content was used and salt was found to have penetrated but only to 1/2” depth which will be ground off in the spring of 2008 when a high-performance membrane and microsurface material will be applied. |
| MO           | • Penetrating sealers in field and lab tests do not hold up to chloride penetration tests as well.  
• Cannot get penetrating sealers to work to fill large cracks.                                                                                                                                                                     |
| NY           | • Our agency’s experience in regards to sealer performance has mostly been a positive one.  
• When good construction practices have been followed we have seen excellent performance with sealers.                                                                                                                                 |
<table>
<thead>
<tr>
<th>Location</th>
<th>Experiences with sealer performance</th>
</tr>
</thead>
</table>
| OH       | • The depth of penetration of penetrating sealers really depends on the quality of the concrete.  
  o Manufacturers have claims for good penetration depth on concrete with w/c = 0.5.  
  o Ohio is lucky if they get 1/16 inch penetration with concrete with w/c<0.5. |
| OR       | • We don't use the penetrating sealers much anymore. We have tried them on a few bridges, but still use them for remedial work on thin cover applications where the contractor makes a minor mistake in forming.  
  • We generally depend on high quality concrete and either coated or stainless bar for routine protection. |
| RI       | • Film former is believed to provide effective chloride protection for five to seven years.  
  o Sealer flakes away after 10-15 years.  
  o Discolors noticeably after about one year (UV effect on epoxy). |
| TX       | • Hard to determine. We conducted a research project over 15 years ago and it determined that there was very little difference between a deck treated with various sealers and one left untreated. The problem with the study was that it was only 3 years long and could not assess long-term performance. |
| VA       | • Good experience with epoxy overlays.  
  • Penetrating sealers on old decks do not last due to concrete patch failures.  
  • Limited use of sealers on new decks. Emphasis is on quality concrete rather than sealers or coatings. |
| WV       | • Mixed. Some work better than others. |
| Alberta  | • Alberta Transportation has been using concrete sealers since the mid 80's and developed testing specifications using in-house staff.  
  o AT's annual concrete bridge deck testing program provides an opportunity to determine what rehabilitation and maintenance activities are effective in extending service life and performance of our concrete decks and curbs.  
  o Half cell testing is the primary method used to track the performance of our deck and curbs.  
  • The use of concrete sealers has been effective in several regions of the province and significantly extended the service life of the deck/curbs. |
CHAPTER 3

TEST METHODS FOR SEALER PERFORMANCE AND CHARACTERIZATION

LITERATURE REVIEW

Sealers on portland cement concrete are primarily used to reduce the penetration of chloride salts and moisture into the concrete. They can be effective in reducing the rate of deterioration in concrete structures with ongoing moisture-driven deterioration mechanisms, most typically corrosion of the reinforcing steel, but also scaling, freezing and thawing deterioration, and alkali silica reaction. Sealers have the advantage of being applied easily and economically to the surface of both new and old concrete.

In 1994, NCHRP Synthesis 209 Sealers for Portland Cement Concrete Highway Facilities (P. D. Cady 1994) was published reviewing the state of the art in sealer use and evaluation procedures. This literature review is intended to supplement that comprehensive synthesis, providing a brief summary of that work and work on sealer evaluations conducted since that time.

NCHRP Synthesis 209 (P. D. Cady 1994) discussed the types of sealers available for use on portland cement concrete and the current practice and performance of these sealers based on a survey of highway agencies and a literature review. Procedures for evaluating and testing sealers were reviewed and recommendations were made regarding the need for standard testing procedures.

The study found sealing to be the lowest first cost method for protection of concrete structures against future deterioration and corrosion, and potentially the lowest life-cycle cost method, depending on performance. The study found hundreds of available sealer products and classified them into the following general groups (P. D. Cady 1994):

- Silanes, Siloxanes, Siliconates
- Epoxies
- Gum Resins and Mineral Gums
- Linseed Oil
- Stearates
- Acrylics
- Silicates and Fluorosilicates
- Urethanes and Polyurethanes
- Polyesters
- Chlorinated Rubber
- Silicones
- Vinyls
- Blends and Combination Systems

The chemistry and mechanism by which the concrete is protected by each sealer is discussed in this report, so will not be repeated here.

The approaches employed by the construction industry for evaluating sealers and their performance were reviewed, and it was found that widely variable testing protocols are employed (P. D. Cady 1994). The bulk of performance evaluation included the following general categories:

- Absorption
- Water vapor transmission
- Chloride penetration
Freezing and thawing and scaling resistance
Reinforcement corrosion
Accelerated weathering
Carbonation

Most testing of sealers has been conducted in the laboratory. Field testing is conducted less often, rarely reported and test results do not always provide results consistent with laboratory studies.

To support evaluation and the rational use of sealers, NCHRP Synthesis 209 recommended the development of a national standard testing specification for concrete sealers falling into four categories: 1) product qualification, 2) product quality assurance, 3) field application quality assurance, and 4) field testing for assessment of sealer reapplication needs and product performance (P. D. Cady 1994) forms the basis of the objectives of the current work.

Sealer performance depends not only on the sealer properties, but also on the field exposure, concrete substrate, concrete service, environment, and presence of existing sealers. Selection of the best sealer depends on each of these conditions at the job site. Further, Synthesis 209 recommended that sealer selection be based on life cycle cost analysis based on corrosion-related deterioration service life prediction and chloride diffusion modeling (P. D. Cady 1994). However, a complete understanding of anticipated performance is needed to accurately model performance.

With a small number of exceptions, few studies have been conducted examining test methods for sealers since the publication of Synthesis 209. Two of those studies that compared or developed new test methods were initiated with the objective of identifying the best performing sealer in a given environment and the test method evaluation was conducted as a side task. The notable studies includes work conducted on behalf of the Oklahoma (Bush 1998), Wisconsin (Pincheria and Dorshorst 2005), and Missouri (Wenzlick 2007) Departments of Transportation.

Bush (Bush 1998) compared the results of standard testing procedures specified by the Oklahoma Department of Transportation, including water absorption (ASTM C642), chloride ion intrusion (AASTHTO T259) and visible depth of silane penetration (OHD-L34), with the results of testing conducted according to methods modeled after, but not identical to, the procedures reported in NCHRP Report 244 Series II (Pfeifer and Scali 1981). The comparison was done using a single sealer (silane) on concrete mixtures with different water-cement ratios. Bush concluded that the penetration depth of the sealer was influenced by the moisture content of sample, which is different for the two procedures being compared (Bush 1998). The trend in decreasing effect on the absorption with lower water-cement ratio was not consistent with both test procedures and the measured absorption values differed widely because of difference in the moisture content of samples at the start of test. Finally, the chloride levels were similar despite differences in the test procedures. Bush concluded that different tests evaluating the same performance do not necessarily produce similar results (Bush 1998).

Testing conducted at the University of Wisconsin-Madison (Pincheria and Dorshorst 2005) evaluated 23 products (deck sealers and crack sealants) for the Wisconsin Department of Transportation relative to their expected performance when exposed to deicing salts and freezing and thawing. The deck sealers were tested on prisms ponded with chloride solutions with and without exposure to 90 freezing and thawing cycles. The penetration depth was also determined using a dye-based method. The crack sealants were evaluated on prisms that were cracked using a splitting tensile procedure, then reassembled and bonded at a specified crack width using the crack sealant. Four crack widths were used: 1/32, 1/16, 1/8, and 1/5 in. The performance of the crack sealants were evaluated in terms of penetration and bond strength and durability. The penetration and filling ability of the sealants was observed visually, while the bond strength and durability was evaluated using a similar splitting tensile test procedure to that used to
crack the prisms. The bond strength was tested with and without exposure to 300 freezing and thawing cycles. Based on this test program, recommendations regarding the performance of the tested products, which were grouped into three performance categories, were made. The authors suggest that, since a significant effect was observed, freezing and thawing should be included in future studies of sealer performance. They also suggest that a large number of samples be taken during chloride penetration testing due to the large scatter observed in this test. Finally, they recommended field performance evaluations in the form of chloride penetration testing be conducted in the future to provide a basis for evaluating sealer performance in place (Pincheria and Dorshorst 2005).

A major focus of the work conducted for Missouri Department of Transportation (Wenzlick 2007) was the effectiveness of sealers for use treating cracked bridge decks. The use of linseed oil is standard practice in Missouri, but the performance of various alternative sealers was evaluated to see if they may be more effective. The performance of sealers on cracked concrete was studied using a draft Ohio Department of Transportation test (Cracking Sealing Test, AASHTO T259 Modified). This test was conducted on beams broken in three-point bending, then reassembled and ponded with water. The times for water to move through the cracks were monitored before and after the samples were sealed. It was concluded that this test was not effective (Wenzlick 2007). This is likely because the crack width was not well-controlled. Wenzlick concluded cracks bigger than 0.30 to 0.64 mm were not easily sealed by penetrating sealers (Wenzlick 2007). He does not recommend scaling testing or the test of cracked beams, but does suggest that that chloride ponding (AASHTO T259) and absorption (ASTM C642) testing be used as the basis for selecting sealers (Wenzlick 2007).

TEST METHOD SUMMARIES

Introduction

The following section summarizes test methods relevant for testing concrete sealers. Many of these tests were identified from the DOT survey. Many are ASTM standard methods (ASTM Standards, available in Annual Book of ASTM Standards or at www.astm.org) but others are state or province methods used by the agency that developed them. Some, in particular Alberta’s test methods, which are specified in Alberta Infrastructure and Transportation, Technical Standards Branch B388-January 2009 Specification For Concrete Sealers, are used by more than one agency. Other test methods were identified during literature searches, searches of manufacturer’s product literature, or from the research team’s experience. The source of each method is identified as follows: (A) indicates that the method is used by at least one transportation agency, and was listed in a response to the survey; (S) indicates that a sealer supplier or manufacturer uses the test method, and (L) indicates that the method was obtained from the literature search.

The methods are categorized by whether they are used to characterize the sealers, or whether they test the performance of sealers. Within each broad category, the methods are further categorized by the properties being tested.

PERFORMANCE TEST METHODS

Water Absorption

New York 717-01E Protective Sealers for Structural Concrete (Water Absorption) (A)

Concrete of a specified mix is cast into 4 by 8 inch cylinders and cured for 28 days. The surfaces are sandblasted and conditioned for a further 14 days. All surfaced are coated with sealer. The sealed
cylinders are placed in a 50% humidity, 21°C environment for six days, and then weighed. The cylinders are weighed every 24 hours until the masses of the cylinder are constant to 0.5%. The cylinders are then immersed in 15% sodium chloride solution for 21 days, and then the surfaces are dried. The percent absorption is measured gravimetrically.

Rhode Island Evaluation of Concrete Surface Sealers (Water Absorption)(A)

The sealer is applied to concrete block specimens (3 to 5 inches square by 11 to 16 inches long). The sealed specimens and an uncoated control set are placed in a tank and covered with water. The specimens are removed, surfaces dried, and weighed once daily for 2 weeks. Sealer performance as weight gain is determined gravimetrically.

Tex-897-B Determining the Water Repellency and Depth of Penetration of Penetrating Concrete Treatments (Water Repellency)(A)

Concrete blocks (6 by 6 by 1 inch) are fabricating using a Texas standard bridge mix, and cured for at least 45 days in a fog room. After curing, the specimens are brushed and rinsed with tap water to remove laitance and stored in a 50% humidity environment until the weight equilibrates so that the weight change is less than 0.1% in a day (generally about 1 week). The specimens are waterproofed on the edges by coating with epoxy, and returned to storage in 50% humidity until the sealer is applied. The sealer is applied to the exposed surfaces at the desired application rate, and cured for 7 days in a 50% humidity environment. After curing, the specimens are weighed, and immersed in a 10% solution of table salt for 28 days. After soaking, the specimens are rinsed with tap water, surfaces dried, and weighed.

ASTM D570 Standard Test Method for Water Absorption of Plastics(A)

Plastic (not concrete) specimens are immersed in room temperature or boiling distilled water for specified durations. Water absorption is measured gravimetrically.

Alberta BT001-July 00 Test Procedure for Measuring the Vapour Transmission, Waterproofing and Hiding Power of Concrete Sealers (Waterproofing Performance)(A)

Cubes are fabricated of concrete of an appropriate mix according to BT010. The moisture content of the cubes is measured by removing 3 cubes from the moist curing room, weighing, drying at 95°C for 7 days, weighing, and calculating the difference. These cubes are discarded. Prior to applying sealers to test cubes, the cubes are equilibrated in a 50% humidity environment until the desired moisture content (depending on the type of sealer to be tested) is obtained. Three cubes are selected for sealing and three cubes are selected to be used as unsealed controls. Sealer is applied in the manner specified for each sealer type, and total sealer uptake is measured gravimetrically. Cubes are weighed then immerses in tap water for 120 hours (5 days). The surfaces are dried and the cubes weighed within 60 seconds of removal. Waterproofing performance is reported based on a comparison of the average weight gain of sealed cubes and control cubes. For Type 1 sealers, the test is repeated after abrading the faces of the cubes.

Ontario Silane Sealer Testing Program (Water Absorption)(A)

A 6 inch by 12 inch cylinder is cast and cured for 14 days in a moist room. The cylinder is then cut into 2 inch thick disks, and cured at room temperature in air for 14 days. Sealers are applied to all sides of the disks. Two sealed concrete disks and two uncoated control disks are immersed in water for 21 days. Water absorption is determined gravimetrically.
**ASTM C642 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete (A)**

Concrete specimens (at least 350 cubic cm [21 cubic inches]) are dried in an oven to constant weight. The specimens are immersed in water until constant mass is reached, and then immersed in boiling water for a specified amount of time and weighed after drying. Absorption is determined gravimetrically.

**New Hampshire Item 534 - Water Repellents (Procedure based on NCHRP Report 244, Series 1) (A)**

Mortar cubes (2 inch on a side) are fabricated, cured in lime water for 7 days, and air dried for 21 days. After drying, the cubes are brushed with a wire brush. A glass container and gratings, and tongs are weighed, and then one cube is placed in the container and the system is weighed again. The cube is removed and sealer placed in the container, weighed, and the cube is immersed for 2 minutes, and then removed, placed on a grating, and excess sealer is allowed to drip back into the container. The contents of the container are weighed and the sealer application amount is determined by weight. The cubes are then air dried for 14 days, and immersed in a solution of 15% sodium chloride. The weight of each cube (surface dry) is recorded at 1, 7, 14 and 21 days of immersion.

**NCHRP 244 Concrete Sealers for Protection of Bridge Structures (A)**

This report lists two water absorption test methods, Series I and Series II, which are described below.

**NCHRP 244 Concrete Sealers for Protection of Bridge Structures - Series I (S)**

Concrete cubes (4 inches on a side) are cast and cured in lime saturated water for 7 days. The cubes are sandblasted at 7 days of age and replaced in the plastic bags until 21 days of age. They are then air dried for 21 days at 50% relative humidity (RH). At 28 days of age, samples are separated into two groups: The first half receive two coats of sealer, followed by a 14-day curing period. They are then immersed in 15% sodium chloride. The other group of cubes receives two coats of boiled linseed oil, then are exposed to UV radiation through 35 days of age and sandblasted to represent an aged treated concrete surface. The sealers are applied and cured for 14 days, then immersed in 15% sodium chloride for 21 days. After the 21-day soak in sodium chloride solution, the cube is broken in half. Half of the cube is ground and the acid-soluble chloride ion concentration measured. Weight change during drying, weight change during soaking, and chloride ion content are compared to uncoated controls.

**NCHRP 244 Concrete Sealers for Protection of Bridge Structures - Series II (S)**

Concrete cubes (4 inches on a side) are cast and moist cured by placing in plastic bags at 73°F. The cubes are sandblasted at 7 days of age and replaced in the plastic bags until 21 days of age. They are then air dried at 50% RH and 73°F for 1, 5, and 21 days. Sealer is applied after the specified drying period. After sealer application, the cubes are air dried for a total of 31 days of drying. During all drying processes, cubes are weighed every 7 days. At the age of 52 days, the cubes are immersed in a solution of 15% sodium chloride for 21 days. Saturated surface dry weight is measured at 3, 6, 9, 12, 15, 18, and 21 days. After the 21-day soak in sodium chloride solution, the cube is broken in half. Half of the cube is ground and the acid-soluble chloride ion concentration measured. Weight change during drying, weight change during soaking, and chloride ion content are compared to uncoated controls.
Federal Specification SSW 110 Water Repellent, Colorless, Silicone Resin Base

This specification was cancelled in 1996, but references a number of tested properties, including water repellence, weathering, and breathing. For the water repellence test, mortar cubes are dried at 80ºC, and then submerged in 1/4-in. of water for 24 hours. The weight change during testing is determined. These cubes are dried at 80ºC back to the original weight, sealed, and then cured for 48 hours. The cubes are re-submerged in 1/4-in. of water for 72 hours. The new weight change is measured. The weathering test involves exposure in a weatherometer for 300 hours in accordance with Fed. Test Method Std. No. 141, method 6151. This federal test method described an open arc ultraviolet apparatus, but has since been cancelled. The breathing test involves samples of common brick capable of absorbing 10-20% of their dry weight. The samples are treated on all sides but one, and then the untreated side is submerged in water until saturated (determined by constant weight). The untreated side is then sealed with wax paper and the specimen weight loss measured in a 50% RH environment for 7 days.


This standard provides brick and tile test methods, and includes absorption and rate of absorption tests. For the initial absorption test, samples are dried in oven, then saturated in room temperature or boiling water. The saturation coefficient is the ratio of weight gain after 24-hr boil to weight gain after 5-hr boil. In the rate of absorption test, samples are oven dried, and then a face is submerged 1/8 in. for 1 min. The rate of absorption is calculated based on weight gain.

ASTM C140 Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units

This standard gives test methods for Concrete Masonry Units (CMU) and similar products, including an absorption test. In that test, the samples are saturated over 24-hours of immersion, and then oven dried.

ASTM G53 Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials (Withdrawn 2000)

This practice outlines the operating procedures for a UV and condensation test cabinet, but is not a test method. It has since been replaced by ASTM G154 Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials.

ASTM E514 Standard Test Method for Water Penetration and Leakage Through Masonry

This test is intended to simulate wind-driven rain and evaluates the resistance to water penetration of a masonry assembly at least 12 ft² in size. Observations of the amount of water penetrating the assembly are recorded. The results are highly dependent on the quality of assembly and testing apparatus.

ITM 605 Moisture Permeability of Epoxy Sealer Films, Indiana Department of Transportation Office of Materials Management

Samples cut from fireclay brick samples are dried at 49ºC (120ºF) and immersed in epoxy sealer. The samples are air dried for 2-3 hours at room temperature and then oven dried at 43ºC (110ºF). The samples are cooled to room temperature and then submerged in boiling water for 2 hours. The percent increase in weight is the reported result.
Sealed concrete cores, generally 3-inch diameter by 2- to 3-inches long, are dried to constant weight. A material to waterproof the sides of the cores is applied (faces left exposed). The specimens are placed, sealed face down, on glass rods, in a water bath. Water does not cover the other face. After 24 and 48 hours, the core is removed, wiped dry, and weighed. Percent absorption is determined gravimetrically.

EN 13580:2002 Products and systems for the protection and repair of concrete structures - Test methods - Water absorption and resistance to alkali for hydrophobic impregnations

For this combined absorption/alkali resistance test, nine 4-in. cubes are prepared and wet cured for 28 days. Six cubes are air dried for 7 days. Three of these are treated with sealer, while three are left untreated. The six samples are then submerged in water. The untreated samples are removed for weighing after 1 hour, and the treated samples are removed for weighing after 24 hours. The rate of increase calculated in units of weight per square root of time for each condition is calculated and the ratio of these rates is reported as the “absorption ratio”. Subsequent to this test, the treated samples are submerged in 0.1 N potassium hydroxide solution (5.6 g/l) for 21 days. The samples are air-dried to the original weight before the first absorption test and another absorption test is then conducted to determine the “absorption ratio” after alkali exposure.

Test No. II.4 Water Absorption under low pressure (pipe method) from “Recommended Tests to Measure the Deterioration of Stone and to Assess the Effectiveness of Treatment Methods” Materials and Structures, Vol. 13, No. 75, May-June 1980, pp. 201-205. (L)

This test, sometimes known as the “RILEM tube test”, is applicable to field testing and rapidly determines the amount of water absorbed by a surface under low pressure. A water reservoir, supporting a column of water 3.9 or 4.3 in. (9.8 or 11 cm) in height, is sealed to the surface of the concrete. The amount of water absorbed by the concrete after 5, 10, 15, 30 or 60 minutes is measured based on the drop in column height. This test can be conducted on both horizontal and vertical surfaces. The ease of testing and test results are sensitive to the surface roughness.


This test is similar in concept to the previously mentioned Test No. II.4. In this test, the water reservoir supports a column of water 15.7 in. (40 cm) in height. The drop in column height is measured over 10 minutes. These modifications produce a more severe test, since greater pressures are produced by the greater column height.

Chloride Penetration

New Hampshire Item 534 - Water Repellents (Procedure based on NCHRP Report 244, Series 1) (A)

Testing is conducted as described above in the Water Absorption section. After 21 days, the cubes are removed and allowed to air dry for 14 days, then cut in half. Half of each cube is pulverized and
the chloride content is tested using an acid digestion potentiometric technique. The other half is
immersed in water and the depth of penetration of the sealer is measured after 24 hours. Absorption of
sodium chloride solution is measured gravimetrically and compared to uncoated cubes.

_AASHTO T260 Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials
(A)_

Specimens of concrete are pulverized. For acid-soluble chloride ion content, specimens are
digested in acid, and for water-soluble chloride ion content, the specimens are extracted with water. For
the water-soluble procedure, the chloride ion content is determined potentiometrically or with an ion-
selective electrode. For the acid-soluble procedure, the chloride ion content is determined
potentiometrically, with an ion-selective electrode or by atomic absorption spectroscopy.

_AASHTO T259 Resistance of Concrete to Chloride Ion Penetration (A)_

Concrete slabs (12 by 12 by 3 inches) are fabricated, cured, and the sealer is applied. For
specimens to be exposed to vehicular traffic, the surface is abraded. Slabs are ponded with sodium
chloride solution, and exposed for a specified amount of time. After the sodium chloride solution is
removed, samples are taken at specified depths and tested for chloride ion content according to AASHTO
T260. Chloride content from exposed specimens is compared to baseline values from unexposed
specimens.

_New York 717-01E Protective Sealers for Structural Concrete (Chloride Penetration(A)_

Concrete specimens are fabricated and tested according to New York 717-01E Protective Sealers
for Structural Concrete (Water Absorption). Powder samples at 25, 50, and 75 mm depths are obtained
from these cylinders. Chloride ion is determined according to NY 502-05C. Total absorbed chloride is
determined by subtracting total chloride from baseline chloride.

_New York 502-05C Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw
Materials (A)_

Chloride is determined by AASHTO T260, procedure B (acid digestion and chloride
measurement by atomic absorption).

_Rhode Island Evaluation of Concrete Surface Sealers (Chloride Intrusion Screening) (A)_

Sealed concrete specimens (3 by 3 by 14 inches) are partially immersed, along with uncoated
control specimens, into a saturated solution of highway deicing salt. A specimen is removed and tested
every ten days. A section of concrete is drilled from each of 3 sides and tested for chloride content. The
average chloride content for each sealer type is calculated over a 24-week test period. Sealers which
reduce chloride absorption by 55% or more are considered candidates for further testing.

_NCHRP 244 Concrete Sealers for Protection of Bridge Structures - Series I and II(A)_

See the discussion under the heading “Water Absorption”.

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NCHRP 244 Concrete Sealers for Protection of Bridge Structures - Series IV - Southern Climate (A)

Reinforced concrete slabs (12 by 12 by 5 inches) are cast and then cured under plastic for 21 days. After initial cure, the top surfaces are lightly sandblasted to remove laitance, and then the slabs are stored in the laboratory for 5 additional days. At 28 days, the sides of the slabs are coated with an epoxy. The top surface of the slabs are coated with sealer, and allowed to dry for 16 days. The Southern Climate test slabs are then exposed to a weekly cycle consisting of ponding with one-half inch of 15% sodium chloride solution for 100 hours, then the solution is drained, the slab is rinsed with tap water, and the slabs are placed in a chamber at 100°F and exposed to ultraviolet light for 68 hours. This exposure cycle is repeated for a total exposure of 24 weeks. The specimens are inspected visually and tested for corrosion potentials with a copper-copper sulfate reference cell periodically during the exposure. After the exposure is complete, a hole is drilled to approximately 1/4 inch depth, and the powder removed. The slab is further drilled to a depth of 1-1/4 inch, the powder collected and combined with the powder from five similar holes drilled in the slab. The acid-soluble chloride concentration is measured.

Ontario Silane Sealer Testing Program (15% NaCl Solution Absorption) (A)

A 6 inch by 12 inch cylinder is cast and cured for 14 days in a moist room. The cylinder is then cut into 2 inch thick disks, and cured at room temperature in air for 14 days. Sealers are applied to all sides of the disks. Two sealed concrete disks and two uncoated control disks are immersed in 15% sodium chloride solution for 21 days. Sodium chloride solution absorption is determined gravimetrically. After testing, one disk is crushed and tested according to a testing procedure LS 417.

LS 417 Method of Test for Determination of Total Chloride Ion in Concrete - (Acid Soluble) (A)

Sections of concrete are ground, digested in nitric acid. The chloride ion content is determined potentiometrically.

NCHRP 244 Concrete Sealers for Protection of Bridge Structures - Series IV - Northern Climate (S)

Concrete slabs are prepared and cured in the same manner as the Southern Climate samples. The Northern Climate test slabs are exposed to the following daily cycle for 5 workdays each week: 1) 15-hour (or more) freeze, 2) 2-hour thaw at room temperature, 3) 3-hour exposure to UV and infrared heat at 100°F, 4) 3-hr soak in 15% sodium chloride and 0.02 M sulfuric acid solution, and 5) rinse with fresh water. This is continued for 24 weeks. These slabs are evaluated in a similar manner to the Southern Climate samples.

ASTM C1202 Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration (S)

Nominally 4-in. diameter by 2-in. thick pucks of concrete are mounted between chambers containing solutions of sodium chloride and sodium hydroxide. A 60V potential difference is applied across the sample and the total charge passed in 6 hours is measured. The electrical conductance of the test sample is intended to provide a rapid indication of its resistance to the penetration of chloride ions.
ASTM C1152 Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete

Pulverized concrete is digested in acid. The chloride content is determined potentiometrically.

Freeze/Thaw

Section 601.13.3.2 West Virginia’s 2003 Supplemental Specifications -- Concrete Protective Coating Materials (Freeze-Thaw Test)

Three 4 by 4 by 6 inch concrete specimens are cast and cured in a moist room for 14 days. The specimens are then dried in room air for 24 hours. Sealer is applied at 50 ± 10 sq. ft./gal on all sides of the specimens, and let dry for 24 hours. After sealer application, the specimens are immersed in water at room temperature for 3 hours, then placed at 5°F for one hour, followed by thawing in room temperature air for one hour. Immersion, freezing, and thawing are repeated for 50 cycles. At the end of the test, the specimens are examined for visible effects. Specimens should not have any visible effects.

Rhode Island Evaluation of Concrete Surface Sealers (Freeze/Thaw Resistance)

Conduct tests according to ASTM C666, Procedure A.

ASTM C666 Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

Concrete prisms (3 to 5 inches square by 11 to 16 inches long) are repeatedly frozen and thawed. For Procedure A, freezing and thawing is carried out in water. For procedure B, freezing is carried out in air, and thawing in water. Periodically, specimens are evaluated visually and with relative dynamic modulus of elasticity.

Deicer Scaling Resistance

Illinois Modified ASTM C672 Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

Concrete specimens (7 by 12 by 3 inches) are fabricated from materials meeting Illinois Specifications for Road and Bridge Construction. After moist curing for seven days, and drying until the concrete meets the moisture requirements of the sealer, sealers are applied to the surface. The freezing cycle takes place with a water pond, then, while frozen, sodium chloride deicing salt is placed on the frozen surface, and the specimens are re-frozen. After thawing, the specimens are rinsed, and the process is begun again. The specimens are subject to a total of 60 freeze/thaw salt application cycles. Specimens are examined visually and rated according to criteria in the method.

ASTM C672 Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

Concrete specimens (at least 3 inches high by 72 square inches surface area), with applicable sealer, are subjected to repeated freezing and thawing while the surface is exposed to calcium chloride or other deicer solution. The tested specimens are examined visually and given a rating.
ASTM B117 Standard Practice For Operating Salt Spray (Fog) Apparatus (A)

Provides the conditions used for running a salt spray apparatus. A spray of sodium chloride is used solution to create a corrosive atmosphere.

Ontario Silane Sealer Testing Program (Salt Scaling Resistance) (A)

Conduct testing according to Ontario Ministry of Transportation Test Method LS 412. The MTO LS-412 procedure is similar to ASTM C672, with the exception that the test solution is sodium chloride. This test also provides an alternate method for evaluating scaling performance consisting of periodic collection and measurement of the mass of the debris on the surface of the test slabs.

LS 412 Method of Test for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals (A)

Concrete slabs (300 by 300 by 75 mm, or 12 by 12 by 3 inches) are cast, moist cured for 14 days and air dried at 50% RH and 23°C for 14 days. The specimens are ponded with a 3% sodium chloride solution, and subject to repeated freezing and thawing. After every 5 cycles, the salt solution is removed, along with any loose concrete, and the specimen is washed with salt solution. The residue of concrete removed from the specimen is dried and weighed. The specimen is returned to the freezing and thawing for a total of 50 cycles. Mass loss and visual evaluation at every 5 cycles is reported.

Water Vapor Transmission Resistance

New York 717-01E Protective Sealers for Structural Concrete (Moisture Vapor Transmission) (A)

Concrete specimens are cast and tested according to New York 717-01E Protective Sealers for Structural Concrete (Water Absorption). The specimens are then placed in a 50% relative humidity, 21°C environment for 21 days, and weighed. The moisture vapor transmission is determined gravimetrically.

Rhode Island Evaluation of Concrete Surface Sealers (Water Vapor Transmission) (A)

Specimens are first tested according to the Rhode Island Evaluation of Concrete Surface Sealers Water Absorption test. After completion of the water absorption test, the specimens are dried in air for two weeks. The specimens are weighed on a daily basis. Performance is related to average weight loss during drying.

Alberta BT001-July 00 Test Procedure for Measuring the Vapour Transmission, Waterproofing and Hiding Power of Concrete Sealers (Vapour Transmission Performance) (A)

Cubes are fabricated of concrete of an appropriate mix according to BT010. The moisture content of the cubes is measured by removing 3 cubes from the moist curing room, weighing, drying at 95°C for 7 days, weighing, and calculating the difference. These cubes are discarded. Prior to applying sealers to test cubes, the cubes are equilibrated in a 50% humidity environment until the desired moisture content (depending on the type of sealer to be tested) is obtained. Three cubes are selected for sealing and three cubes are selected to be used as unsealed controls. Sealer is applied in the manner specified for each type, and total sealer uptake is measured gravimetrically. Sealed and unsealed control cubes are dried in a 50%
RH, 23°C environment for 15 days, and then weighed. The cubes are returned to the controlled environment and weighed after an additional 10 days. Vapor transmission is measured gravimetrically.

Ontario Silane Sealer Testing Program (Water Vapour Transmission)\(^{(A)}\)

Specimens are fabricated and tested according to Ontario Silane Sealer Testing Program (Water Absorption). The disks are then dried at room temperature for 21 days. The water vapor transmission is determined gravimetrically.


This method provides a procedure for conducting vapor transmission tests suited to coating films. The tested material is sealed over a cup filled with water or desiccant, and the pan is placed in a controlled environment. This test can be evaluated based on measurement of water weight loss or desiccant weight gain. These measurements are used to determine the rate of water vapor movement.

ASTM E96 Standard Test Methods for Water Vapor Transmission of Materials\(^{(S)}\)

This method provides a procedure for conducting vapor transmission tests on a number of materials, though the methods are the responsibility of the ASTM Committee on Thermal Insulation. The tested material is sealed over a pan filled with water or desiccant, and the pan is placed in a controlled environment. The weight loss of the water or weight increase of the desiccant is measured to determine the rate of water vapor movement.

NCHRP 244 Concrete Sealers for Protection of Bridge Structures - Series I, Series II, and Series IV (S)

See the discussion under the heading “Water Absorption”.

OHD-L-35 Method of Test for Moisture Vapor Permeability of Treated Concrete. (Inactive)\(^{(S)}\)

This method, which was made inactive in 2003, involves curing concrete blocks for 7 days before drying them at 110°C (230°F) and weighing them. The blocks are allowed to cool, then placed in water for 48 hours. The blocks are weighed, then coated and dried again at 110°C (230°F), after which they are re-weighed. The ratio of the weight lost during the second drying, and the weight gained during the water immersion is calculated as the percent moisture loss.

EN 13579:2002 Products and systems for the protection and repair of concrete structures - Test methods - Drying test for hydrophobic impregnations (L)

Nine 4-in. cubes are prepared and wet cured for 28 days. Three cubes are oven dried to estimate the saturated surface dry (SSD) moisture content of the cubes. The remaining six cubes are air dried until the moisture content is 5.0±0.5%. Three are treated with sealer, while three are left untreated. The six samples are then placed in an environmental chamber set at 40±5% RH and 86±3.6°F (30±2°C). The untreated samples are removed for weighing after 6 and 18 hours, and the treated samples are removed for weighing after 24 and 48 hours. The rate of decrease in weight between measurements for each condition is calculated and the ratio of these rates is reported as the “drying rate coefficient”.
Alkali Resistance

Alberta BT002-July 00 Test Procedure for Alkaline Resistance of Penetrating Sealers for Bridge Concrete (A)

Concrete specimens are fabricated and tested according to Alberta BT001-July 00 Test Procedure for Measuring the Vapour Transmission, Waterproofing and Hiding Power of Concrete Sealers. These tests are conducted on Type 1 sealers (penetrating sealers) only. Cubes are oven-dried at 60°C until the weight after abrasion is reached. The cubes are then immersed in a 0.1N potassium hydroxide solution for 21 days. The cubes surfaces are dried and weighed, and then dried further at 60°C until the previously measured weight is obtained. Cubes are then immersed in tap water for 120 hours (5 days), surfaces dried, and weighed. The waterproofing performance after the alkaline solution exposure is determined gravimetrically.

EN 13580:2002 Products and systems for the protection and repair of concrete structures - Test methods - Water absorption and resistance to alkali for hydrophobic impregnations (L)

See discussion under section titled “Water absorption”.

Concrete Test Sample Surface Condition

Alberta BT010-July00 Test Procedure for Casting and Storing Concrete Test Specimens for use in Approval Testing of Sealers (A)

Two mix designs are provided, depending on the type of sealer to be tested. The types of sealers are classified in Alberta B388-January 2009 Specification for Concrete Sealers. All Type 1 sealers are penetrating sealers. Type 1a sealers are for use where concrete is sheltered and relatively dry. Type 1b sealers are for use outdoors where a higher moisture content is expected. Type 1c sealers are for application in outdoor conditions on low water-cement ratio (0.30-0.45) concrete, where the relative moisture content is high. Type 2 sealers are clear, film forming sealers for use on non-traffic bearing elements and are classified depending on whether the sealers is a one-component (Type 2a) or two-component system (Type 2b). Type 3 sealers are colored, film forming sealers for use on elements highly exposed to view. For testing, a 0.5 water-cement ratio (w/c) mix is specified for Type 1a, 1b, 2a, 2b and 3 sealers, while 0.35 w/c mix is specified for Type 1c sealers. Cubes are cast from the mix, of a specified size, depending on the mix so cubes can later be differentiated by type. Cubes with 0.5 w/c are 100 mm (about 4 inches) on a side. Cubes with a 0.35 w/c are 95mm by 100mm by 100mm (3.75 by 4 by 4 inches). The screeded face is marked with a pen. Cubes with 0.5 w/c are cured for a minimum of 42 days in a moist room. Cubes with 0.35 w/c are cured for a minimum of 5 days in a moist room. The cubes are dried in laboratory air for 24 hours and then sand blasted on all faces. The specimens with 0.35 w/cm may be kept in a moist room for up to 182 days from casting. The specimens with 0.5 w/cm may be kept in storage in a moist room indefinitely.

Concrete Moisture Condition

ASTM D4263 Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method (A)

A plastic sheet of specified dimensions is affixed to a concrete surface, taping all of the edges. The plastic is removed after the specified time, and the sheet visually inspected for moisture.
James Moisture Meter (A)

This is a proprietary instrument used to measure moisture in solid materials based on electrical resistivity.


This test measures the electrical resistance between two strips of conductive paint applied to the concrete surface after the surface is wetted for 5 minutes. The test can be used to evaluate sealer effectiveness by comparing the results from a sealed surface with a similar measurement on uncoated sections of the same concrete.

ASTM F2170 Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes (L)

Holes are drilled into concrete to the desired depth and humidity probes with liners are inserted into the hole. After equilibration of the humidity inside the liners, the relative humidity of the concrete is measured.

Core Sampling

ASTM C42 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete (A)

Cores of specified diameter are removed from hardened concrete. Dry coring is recommended so the moisture condition of the cores can be preserved until testing. However, ASTM C42 allows wet coring followed immediately by wiping excess water off the cores, allowing the surface to dry and conditioning in plastic bags. As necessary, the length of the core can be altered.

Alberta BT005-July 00 Test Procedure for Measuring the Waterproofing Performance of Core Samples Taken from Sealed Concrete Surfaces (A)

The non-sealed face of the cores is cut to achieve a total core length of 50 mm. The cores are dried at 70°C to constant weight. The sides of the cored specimens are sealed with wax, and the specimens are weighed.

For non-penetrating sealers, the cores are immersed with sealed end down in 5mm tap water, and then placed on supports to allow water to access the sealed end of the core. The cores are removed after 24 hours, the surfaces are dried and the cores weighed. If the mass increases by less than 2g, the non-sealed end is immersed for 24 hours, the surface dried, and weighed. If the mass increases by more than 2g, the specimen is oven dried until within 2g of pre-immersion mass before the non-sealed end is immersed.

For penetrating sealers, the cores are immersed sealed end down on pins, removed after 24 hours, surfaces dried, and weighed. If the mass gain is less than 2g, the sealed surface is sandblasted to remove 5.5g of cement paste and the immersion and weighing is repeated with the sealed-side down. If the mass
gain is more than 2g, the cores are dried to within 2g of the pre-immersion weight prior to the sandblasting step. The non-sealed end is immersed for 24 hours, then the surfaces dried and the specimen weighed. Waterproofing performance is determined gravimetrically.

**OHD L-39 Method of Test for Water Immersion Test for Determining Percent Moisture Absorption of Core Taken from Portland Cement Concrete to which Water Repellent Solution has been Applied (L)**

A 4-in. diameter core is retrieved from the treated concrete structure no sooner than 5 days after sealer is applied. The core is oven dried, and then the sides and bottom are sealed with paraffin wax. The core is water-saturated according to ASTM C642 Section 5.2, which states the core will be immersed in water until constant mass is reached. The gain in weight during the immersion is determined.

**Skid Resistance**


A standard tire is placed on a rig that is towed behind a vehicle. When moving at a constant specified velocity, water is applied to the paved surface, and the tire is locked. The forces on the wheel are measured with transducers. Skid resistance is measured by a calculation of the forces on the wheel.

**AASHTO T278 Standard Method of Test for Surface Frictional Properties Using the British Pendulum Tester (L)**

A pendulum with a rubber slider is adjusted so that the rubber slider contacts the surface to be tested. The pendulum and slider is raised and swung down onto the surface. The degree of skid resistance is measured in British Pendulum Tester Number (BPN) units.

**Bond Strength**

**Virginia VTM 41 Bond Strength of Epoxy Resin Systems or Grouts Used With Concrete – (Physical Lab) (A)**

Testing is conducted in a manner similar to ASTM C882.

**Virginia VTM 92 Testing Epoxy Concrete Overlays for Surface Preparation and Adhesion - (Physical Lab) (A)**

Test patches are placed on typical 1.5 by 3 foot areas of the bridge deck. These areas are prepared with the same methods to be used for the entire surface. A small sample of the epoxy components are mixed and tested for gel time, by measuring the amount of time it takes for the mixed epoxy to gel. A 1/2-quart quantity of the epoxy is measured, mixed, and placed over each test patch, using the same methods as full-scale placement. Aggregate is placed on the test patch, the epoxy is allowed to cure and excess aggregate is swept or vacuumed away. Afterward, a 1-quart epoxy batch is measured, mixed, and placed at each test patch, aggregate is broadcast, and the system is allowed to cure. After curing, the test patch is cored to a depth of about 3/8 inch into the concrete. A pipe cap is bonded to the cored disk with an epoxy adhesive. Three areas per test patch are tested in tension. The type of failure is rated according to a 5-ranking system outlined in the test method.
**CA Test 551 Method of Test for Determining Suitability of Materials for Overlayment and Repair of Portland Cement Concrete Pavement and Structures, Caltrans (S)**

This test involves producing prisms 3x3x12-in. in size consisting half of mortar and half repair materials. The bond is then tested by applying a flexural load the sample. This is not applicable to most sealer materials.


Coatings are tested in tension with one of five types of portable adhesion testers. A dolly is adhered to the surface, and then pulled perpendicular to the surface until failure. The plane of failure (at the adhesive/dolly interface, within the adhesive, within the coating, etc.) and pull-off strength are noted. Results obtained with the different types of equipment are not directly comparable to results obtained by other equipment.

**Other**

**EN 1504 Part 2 Products and systems for the protection and repair of concrete structures -- Definitions, requirements, quality control and evaluation of conformity, Surface protection systems for concrete (A)**

This document outlines three classes of products: hydrophobic impregnants, impregnants, and coatings. The document outlines important properties for each class, and refers to test methods to evaluate the properties. Tolerances for material identification characteristics and properties as well as performance requirements for each class of sealer are provided.

**ASTM D260 Standard Specification for Boiled Linseed Oil (A)**

This specification provides a table with requirements for Type I and Type II boiled linseed oils.

**ASTM C884 Standard Test Method for Thermal Compatibility Between Concrete and an Epoxy-Resin Overlay (A)**

Epoxy resin mortar is applied to a test concrete slab. The sample is thermally cycled between specified temperatures. After exposure, the sample is examined for cracks or debonding.

**ASTM D822 Standard Practice for Filtered Open-Flame Carbon-Arc Exposures of Paint and Related Coatings (A)**

A practice for operating equipment for simulated ultraviolet weathering of materials.

**ASTM C1202 Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride ion Penetration (A)**

See the discussion under the heading “Chloride Penetration.”
ASTM D2805 Standard Test Method for Hiding Power of Paints by Reflectometry (L)

Paint is carefully and uniformly applied at specified wet film thicknesses to substrates with a black and white pattern. Reflectance is measured and hiding power is determined by calculated from the data. This test is more precise than other test methods, but does not simulate real-world conditions in the manner in which the paint is applied.


A paint sample is brushed in a controlled manner over a standard black and white chart. The hiding power is compared to another paint, either at the same or different loading rates.


A paint is sprayed in a controlled manner over a standard chart. The hiding power is determined by measuring the dry film thickness at which the pattern on the standard chart is no longer visible.

ASTM D7089 Standard Practice for Determination of the Effectiveness of Anti-Graffiti Coating for Use on Concrete, Masonry and Natural Stone Surfaces by Pressure Washing (L)

Concrete specimens are fabricated in triplicate and coated with the anti-graffiti sealers. After curing, the surfaces are marked with spray paint and markers in multiple colors. After the paint and marker has been allowed to cure, the surfaces are exposed to a series of cleaning procedures of increasing severity to determine the cleanability of the surface. If re-cleanability testing is desired, the specimens are marked again and subjected to further cleaning procedures.

CHARACTERIZATION TESTS

Sealer Penetration

VTM 101 Determination of Penetration of Gravity Filled Polymer Crack Sealers – (Physical Lab) (A)

MX-45 filter sand is placed in a paper cup and vibrated to consolidate. A specified amount of pre-mixed polymer crack sealer is placed in the paper cup on top of the consolidated sand and left to sit for 24 hours. The paper cup is then removed, and any loose sand is removed from the polymer/sand composite. The percent polymer penetration is related to the ratio of the mass of the polymer/sand composite to mass of the original sand and polymer.

Ontario Silane Sealer Testing Program (Depth of Penetration)(A)

A 6 inch by 12 inch cylinder is cast and cured for 14 days in a moist room. The cylinder is then cut into 2 inch thick disks, and cured at room temperature in air for 14 days. Sealers are applied to all sides of the disks. One disk is cut in to quadrants and immersed in water for one minute. After removal from the water, the depth of sealer penetration is measured twice on each sawcut side. Measurements are taken to the nearest 0.5mm. All 16 readings are averaged.

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Concrete specimens are cast and tested according to Tex-897-B Determining the Water Repellency and Depth of Penetration of Penetrating Concrete Treatments (Water Repellency). After testing, one of three triplicate specimens is tested for depth of penetration. This specimen is dried in air for 1 day, broken in half, and the fractured edge is placed in water to darken the areas unexposed to sealer. The depth of penetration is measured at the exposed edges.

NCHRP 244 Concrete Sealers for Protection of Bridge Structures - Series IV - Southern Climate

See the discussion under the heading “Chloride Penetration”.

OHD L-40 Method of Core Test for Determining the Depth of Penetration of Penetrating Water Repellent Treatment Solution into Portland Cement Concrete

A 4-in. diameter core is taken from the structure in which sealer performance is being evaluated. The core is split longitudinally and the top of the core is immersed in a penetrant die (sulfonazo III sodium salt). The area where the dye is not able to stain the concrete is measured and used to estimate the average depth of penetration.

Bond to Concrete

ASTM C882 Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear

This test method provides a means for evaluating bonding systems for concrete. The bond strength is determined on samples fabricated by bonding two sections of mortar cylinder with slanted faces. The test is performed by applying a compressive force to the cylinder, creating a shear force along the bonding system. This is only applicable to coatings with high build thicknesses.

ACI 503R - Use of Epoxy Compounds with Concrete - Field Test for Surface Soundness and Adhesion

A patch of concrete is prepared and the epoxy sealer is applied, using the same methods as to be employed by for the field application. A core is drilled through the sealer and just into the underlying substrate. A pipe cap is adhered to the cored area, and the system is tested in tension. The load at failure is recorded, along with the type of failure.

Coating Thickness

ASTM D6132 Standard Test Method for nondestructive Measurements of Dry Film Thickness of Applied Organic Coatings using an Ultrasonic Gage

This method describes the use of an ultrasonic thickness gage to measure thickness of organic coatings on substrates, including concrete. For rough substrates, multiple readings are required.
The coating is cut or drilled as a specified angle, to expose all coating layers to the substrate. A value for thickness is measured through a microscope with a scaled reticle. These measured values are converted to actual coating thickness depending on the angle of the cut or drill hole.

**Concrete Temperature**

*Tex-829-B Measuring Pavement Temperature (A)*

A surface thermometer is placed on the concrete surface, and read after the thermometer has been in contact for five minutes. The thermometer reading is repeated every 2 minutes until the temperature is consistent.

*Alberta BT010-July00 Test Procedure for Casting and Storing Concrete Test Specimens for use in Approval Testing of Sealers (A)*

See the discussion under the heading “Deicer Scaling Resistance.”

*Alberta BT001-July 00 Test Procedure for Measuring the Vapour Transmission, Waterproofing and Hiding Power of Concrete Sealers (Waterproofing Performance) (A)*

See the discussion under the heading “Water Absorption.”

**Percent Solids**

*AASHTO M233 Boiled Linseed Oil Mixture for Treatment of Portland Cement Concrete (A)*

Tests percent solids by ASTM D1644, Method A.

*ASTM D1644 Standard Test Method for Nonvolatile Content of Varnishes (A)*

A measured amount of material is placed in a dish. The dish is heated at constant temperature for a specified amount of time. The nonvolatile content is determined gravimetrically.

*ASTM D2369 Standard Test Method for Volatile Content of Coatings (A)*

A specified amount of coating liquid is placed in an aluminum dish with appropriate solvent. The material is heated in an oven for a specified amount of time. The percent volatile content is determined gravimetrically.

*Alberta BT001-July 00 Test Procedure for Measuring the Vapour Transmission, Waterproofing and Hiding Power of Concrete Sealers (Solids Content) (A)*

For Type 1 sealers, ASTM D5095 is used. For Type 2 and 3 sealers, a quantity of sealer equivalent to the uptake for one cube is placed in an aluminum pan with equivalent surface area to a cube, and weighed. The pan and sealer is placed in a conditioning chamber at 50% RH and 23°C for 14 days, and weighed. The non-volatile content is measured gravimetrically.
ASTM D5095 Standard Test Method for Determination of the Nonvolatile Content in Silanes, Siloxanes and Silane-Siloxane Blends Used in Masonry Water Repellent Treatments (A)

A specimen of the water repellent is mixed with a catalyst of pre-determined nonvolatile content. The mixture is allowed to sit for a specified amount of time, and then heated in an oven for a specified amount of time. Nonvolatile content is determined gravimetrically.

For product approval, the non-volatile content can be measured by placing the weighed aluminum pan with sealer in an oven at a higher temperature until constant weight. Constant weight is determined by cooling the sample in a desiccator, and noting a weight difference of less than 2% of the weight loss. Non-volatile content is determined gravimetrically.

EPA 24 Surface Coatings - Volatile Matter Content (A)

Use ASTM D 2369.

Spectroanalysis and Gas Chromatography

Illinois/Instrument Method (A)

Fourier Transform Infrared (FTIR) spectra of all sealers are collected.

Tex-888-B Obtaining the Infrared Spectrum of Organic Materials (A)

The sealer is prepared by casting a film of 15% or lower solids content onto an appropriate salt plate, by pressing a film of liquid between two salt plates, by filling a sample cell with liquid, or by pressing dried material into a salt pellet. The infrared spectrum of the sample is run over the desired wavenumber range. The major peaks should show transmittance between 5 and 25%, although this may be adjusted to show other peaks of interest.

Tex-877-B Obtaining Infrared Spectra by Internal Reflection Spectroscopy (Not listed in survey but provided by TxDOT) (A)

For powdered solids, if necessary, the sample is ground with a mortar and pestle. An appropriate solvent is used to convert the sample to a slurry or paste. The slurry is applied to the crystal on the internal reflectance accessory or attenuated total reflectance accessory of the infrared spectrophotometer. The FTIR spectrum is read after evaporation of the solvent. For non-powdered solids, the material is placed in intimate contact with the crystal of the accessory. The FTIR spectrum is then read. For liquids, the liquid is placed in intimate contact with the crystal of the accessory. The FTIR spectrum is then read.

BT008-February 2004 Test Procedure for Finger Printing Sealers Using Infrared Spectroscopy and Gas Chromatographic Separation (A)

Method A-Infrared Spectra: The sample is run, from 4000 to 400 wavenumbers, as a thin film between potassium bromide or silver chloride plates.

Method B-Gas Chromatography: 0.1 microliter of sample is injected into the specified column with a helium carrier gas at 0.8mL/min flow rate, under a specified temperature program, for a total run time of 35 minutes.
ASTM E1252 Standard Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis (L)

Provides guidance on the collection of infrared spectra. Discussions of sample preparation techniques for liquids, solids, and gasses are included.

ASTM E260 Standard Practice for Packed Column Gas Chromatography (L)

Provides guidance on equipment use, stationary phases, carrier gasses, and methods of qualitative and quantitative analysis.

ASTM E573 Standard Practice for Internal Reflection Spectroscopy (L)

This method provides guidance on sampling for internal reflection spectroscopy, including guidance on attenuated total reflectance (ATR) spectroscopy, a commonly used internal reflection technique. Also provides guidance on comparing internal reflection spectra to transmission spectra.

**Viscosity**

*Brookfield (A)*

Brookfield viscometers are proprietary instruments used to measure viscosity.

ASTM D2393 Standard Test Method for Viscosity of Epoxy Resins and Related Components (Withdrawn--No replacement)(A)

Components are brought to temperature in a water bath. If a multi-component mixture, components are mixed immediately prior to viscosity measurement. Viscosity is measured with a Brookfield RVF or similar viscometer.

**pH**

*ASTM D1293 Standard Test Methods for pH of Water (A)*

A laboratory pH meter is calibrated with two standards that bracket the anticipated pH of the sample. The pH of the sample is measured with the calibrated meter.

**Specific Gravity**

*ASTM D1475 Standard Test Method for Density of Liquid Coatings, Inks, and Related Products (A)*

Density is measured at a specified temperature by use of a calibrated pycnometer or weight-per-gallon cup.
ASTM E100 Standard Specification for ASTM Hydrometers (A)

Specifications for hydrometers, which are used to measure specific gravity by placing the appropriate hydrometer in the homogenized liquid and reading the specific gravity on the hydrometer stem.

AASHTO M233 Boiled Linseed Oil Mixture for Treatment of Portland Cement Concrete (A)

Test specific gravity by ASTM D1963.


This method was withdrawn in 2004.

ASTM D891 Standard Test Methods for Specific Gravity, Apparent, of Liquid Industrial Chemicals (L)

Specific gravity is measured with a hydrometer or pycnometer. The hydrometer method involves suspending a calibrated hydrometer in a cylinder filled with the liquid. The pycnometer is a container of determined volume that is filled with the liquid and then weighed.

Coating Shrinkage

ASTM D2566 Standard Test Method for Linear Shrinkage of Cured Thermosetting Casting Resins During Cure (A)

The resin is cast into a mold of specified size and length. After curing, the resin specimen is removed and replaced in the mold. The shrinkage relative to the mold is measured.

Coating Tensile Strength and Elongation

ASTM C307 Standard Test Method for Tensile Strength of Chemical Resistant Mortar, Grouts, and Monolithic Surfacing (A)

The materials are mixed and placed in a mold of specified dimensions. The samples are tested in tension after a specified curing period.

ASTM D412 Standard Test Methods for Vulcanized Rubbers and Thermoplastic Elastomers - Tension (A)

Specimens are cut from a sheet of the material to be tested. The material is tested in tension until failure. Elongation is measured by benchmarking the specimen and recording elongation at rupture.

ASTM D638 Standard Test Method for Tensile Properties of Plastics (A)

Samples of specified dimensions are cut from film or sheets of the material. The specimens are tested in tension until rupture. Poisson’s ratio may also be measured.
Other

*ASTM D93 Standard Test Methods for Flash-Point by Pensky-Martens Closed Cup Tester(A)*

This standard gives a method of measurement of flash point to determine flammability of a petroleum product.

*ASTM D56 Standard Test Method for Flash Point by Tag Closed Cup Tester(A)*

This standard gives a method of measurement of flash point to determine flammability of petroleum products.
CHAPTER 4

STANDARD METHOD OF TEST FOR PROTECTIVE SEALERS FOR PORTLAND CEMENT CONCRETE - RECOMMENDED TESTING PROCEDURES FOR SEALER PREQUALIFICATION

The methods used by transportation agencies to evaluate sealers vary widely in many aspects including sample size, concrete quality, sample conditioning, test method and duration, and other criteria. The intent of the proposed Method of Test, discussed in this chapter and the Guideline, discussed in the next chapter, is to establish test methods that can be universally applied but that will also provide comparable results to previously used tests, such that the history of data already generated is not made obsolete. The intent is to combine and improve on the existing methods, without inventing wholly new evaluation techniques unless necessary. Furthermore, the new test methods should not be overly complex or difficult to execute. A proposed AASHTO Draft method Standard Method of Test for Protective Sealers for Portland Cement Concrete is shown in Appendix A.

Some agencies have a single list of approved sealers and other agencies have more than one approved list of sealers, each for a specific application or exposure. It is useful to define the universal properties of all sealers and to do initial screening tests for these universal properties. Other application-specific tests can then be preformed and approved lists can be generated for each special application.

The universal properties (U) of all sealers used for concrete highway structures include:

- Resistance to water penetration
- Resistance to chloride ion (deicer or seawater) penetration
- Permits vapor transmission
- Resistance to outdoor weathering and alkali found in concrete
- Reasonable curing times

Properties related to specific applications include:

Traffic-bearing deck surfaces (T)

- Abrasion resistance
- Skid resistance
- Time-to-Cure

Improvement in concrete durability

- Freeze-thaw resistance
- Scaling resistance

Effectiveness at various application temperatures and when applied to wet (SSD) concrete for

- Resistance to water penetration
- Resistance to chloride ion (deicer or seawater) penetration
- Permits vapor transmission
- Resistance to outdoor weathering and alkali found in concrete
- Reasonable curing times
Other considerations

- Color and appearance
- Safety
- Economy
- Special situations and adverse conditions
- Effectiveness on cracked concrete

**UNIVERSAL PROPERTIES**

Universal properties are those that govern performance important to all sealer applications and should be evaluated as part of any sealer testing program.

**Water Absorption, Alkali Resistance, Chloride Penetration, and Vapor Transmission**

NCHRP Report 244 set the standard protocol for screening candidate sealer materials based on absorption and vapor transmission properties. Most agencies have specified a variation of the NCHRP 244 Series II and Series IV test procedures that include saltwater immersion and a measurement of the vapor transmission or moisture loss during drying.

**Test Sample Preparation and Treatment**

One major challenge is to select a standard specimen size and a standard concrete mix with which to evaluate the sealer effectiveness. Concrete absorptions vary widely nationally as materials vary, and this variability could affect test results. However, the sealers must perform on a variety of concretes made with different aggregate types and other constituent materials. Therefore, testing sealers on local or regional concrete mixtures is reasonable and the need for using a standard mix or a standard aggregate is not considered essential to the test. To assist standardization, recommended mix design parameters have been presented in the test method so results can be compared. Further, the use of a standard sand, such as Ottawa sand, and a standard cement or cement chemistry may further improve the universality of the test.

Individual state agencies will need to assess test results provided to them to determine if the concrete used in the test is adequately similar to the concrete within their jurisdiction. The test concrete mixtures currently specified to screen sealer performance by different agencies typically contain only moderate amounts of cement, and a water-cement ratio (w/c) between 0.44 and 0.50. Fly ash or other supplementary cementitious additives are not used. For the proposed test, a moderately high w/c (0.50) concrete mix design is recommended. This is similar to the mix used in the original NCHRP 244 study and for which represents most historic data. This mix is typical of what might be expected for most existing structures built before the mid 1990’s. Modern concretes often have lower w/c making them less permeable. Since penetrating sealers may not be as effective on these more dense concretes, provisions for testing alternate concrete mixtures are also provided for in the test.

The specimen size must be such that it is large enough to include coarse aggregate but small enough that accurate weight measurements can be achieved with normal laboratory balances. It is also an advantage if the specimen is symmetrical in that more than one face can be tested or examined. While some agencies use prisms or cylinders, most have adopted the 4-inch cube used in the NCHRP 244 study. It is recommended that the 4-inch concrete cube be used as the basis for standard testing, for several reasons. Most sealers have already been evaluated using this specimen size and the NCHRP 244 Series II technique. Some agencies have substituted 4 by 8-in. cylinders however, the symmetry of a 4-inch cube
eases the sandblasting surface preparation and makes evaluation of sealer penetration depth easier. The cube also provides more surface area to weight ratio than a cylinder. Form release agents or oils are not used on forms since the oil can adversely affect the penetration or bond of the sealer or coating.

Sample conditioning prior to sealer treatment varies by different agencies. The NCHRP 244 and Alberta BT010 Test Procedure for Casting and Storing of Concrete Test Specimens for Use in Approval Testing of Sealers methods lightly sandblast the cube surfaces before treatment while the European EN 13579 test does not. NCHRP 244 Series II testing examined the effect of varying the drying time of the cubes prior to sealer application from 1, 5 or 21 days. The best sealers were not sensitive to the drying time prior to sealing, while some less effective sealers were somewhat affected. While the NCHRP 244 study used very limited wet curing and conditioned the cubes using fixed time periods in 50% RH, the Alberta BT001 Test Procedure for Measuring the Vapour Transmission, Waterproofing and Hiding Power of Concrete Sealers procedure dries wet-cured cube samples to a fixed moisture content (70% measured by weight) relative to wet cured samples. The EN 13579 procedure also conditions wet cured samples to an equivalent moisture content, specifying 5 ± 0.5%. While more time consuming, drying the cubes to a standard moisture content prior to sealer treatment should result in more consistent test results than by using just a fixed drying time. Further, Alberta requires that the drying must be accomplished within set time periods (14 to 21 days) so a certain moisture gradient within the cubes is achieved. Three cubes are selected for sealing that are closest to the target relative moisture after drying within the same time period for testing. Cubes cannot be stored in the adjusted moisture content for later sealing. The intent of this drying process is to obtain a moisture gradient condition in which the cube surface is drier than the interior of the cube and that simulates normal field conditions when the sealers are applied.

Alberta allows unlimited storage time for cube samples unless they are low water-cement ratio samples that are limited to 182 days (6 months). As cubes age they become less permeable and this could affect the relative results. The proposed test procedure limits the age of all cubes to greater than 42 days but less than 182 days of age prior to treatment, unless the testing is being done specifically to evaluate the effect of the sealer on newly placed or aged concrete.

Sealer application for penetrating sealers is done by immersing the entire cube in the sealer solution for no more than 2 minutes according the method given in Alberta BT001 and by immersing each face of the cube independently according the method outlined in EN 13579. Sealer application in NCHRP 244 was done according to the manufacturer’s recommendations, and usually sealers were applied by brush. When a second coat was required to achieve the recommended application rate, it was done after 24 hours. Alberta BT001 allows a maximum of three immersions for penetrating (Type 1) sealers and maximum of two coats for film forming sealers with the intent of achieving the manufacturer’s recommended coverage rate. A maximum of four hours is allowed between immersions or coats. The EN 13579 standard suggests a 120 ± 5 sec immersion time for each face but this can be adjusted if the manufacturer’s suggested coverage rate is not achieved. Complete immersion of the cubes in the penetrating sealer avoids arguments over whether all surfaces were covered properly. This may be better than what is normally obtained in the field; however, for a screening test, it is appropriate to be conservative and ensure that the sealer has the best opportunity for success. Coating materials must be applied by brush or small roller and care must be taken to completely cover all surfaces and corners.

The application rate of the sealer merits consideration. Usually a manufacturer has a range of recommended application rates, since different surface conditions and concretes will absorb or require different amounts of sealer or coating. It is fair to assume that if the sealer performs well at the minimum recommended application rate that it will also perform well at higher application rates. However, the opposite may not be true. Therefore, the sealer should be tested at the minimum recommended application rate. Ultimately, each agency can decide on what application rate is applicable and the rate actually tested may depend somewhat on how the cubes are conditioned. Immersion of the cubes in
penetrating sealers will provide a certain sealer absorption that must be reported but may not be directly in-line with the manufacturer’s minimum application rate. It is important that the test results be reported in terms of the application rate used in the prequalification tests and agencies can then specify that the tested rate will be the minimum applied rate in the field or they may conservatively specify a higher rate.

**Moisture Vapor Transmission Test**

NCHRP 244 measured the moisture loss in the cubes over 21 days at 50% RH after the cubes had been tested for absorption by immersion in saltwater for 21 days. The Alberta and EN 13579 standards measure the vapor transmission before the water immersion tests are performed on the recently coated cube samples. These samples are then used for the immersion tests. The advantage in measuring vapor transmission first is that all cubes are starting at the same moisture condition so values can be compared directly. NCHRP 244 and Alberta BT001 use a 50% RH environment at 23°C, while EN 13579 uses 40% RH and 30°C to promote drying during the vapor transmission test. Alberta BT001 measures the vapor transmission over a 10-day period after 5 days of conditioning. The EN 13579 standard weighs the control cubes over an 18-hour period and the treated cubes over a 24-hour period after the cubes are conditioned to less than their untreated weight. The initial 5 days of conditioning in the Alberta BT001 test allows the volatile compounds to escape from the coating or sealer and the associated weight loss is not counted in the water vapor transmission determination. While the measurements at 5 and 15 days have been a standard for Alberta, if a five-day standard work week is assumed, these measurement times limit when the cubes can be coated to Wednesday or Thursday to avoid testing on a weekend. This is problematic, since the time that the cubes are coated with the sealer depends on the drying condition of the cubes and the cubes cannot be held at a certain moisture condition, since a non-standard moisture gradient will result. Sealing and vapor transmission testing needs to be initiated as soon as the cubes reach the desired moisture content. Based on review of these standards and to ease testing, it is recommended that the vapor transmission testing be performed before water immersion tests so all samples are at the same initial moisture condition and that the drying period for measuring the vapor loss is 14 days. Review of the data from the 21-day test in NCHRP 244 report show that results collected at 14 days are sufficient to differentiate sealer performance and is better than at earlier ages.

**Waterproofing Performance by Immersion Test, Chloride Penetration and Alkali Resistance**

The Alberta BT001 and EN 13579 standards allow cubes tested for vapor transmission to be used for moisture absorption. EN 13579 requires that the cubes are placed in a chamber over a saturated solution of potassium sulfate (that provides a RH of 97%) until the immersion testing per EN 13580. Specimens are treated in a fume hood, cured for 48 hours then placed over the saturated solution of potassium sulfate. After 14 days, cubes are immersed in demineralized water in individual beakers. Treated cubes are immersed for 24 hours and untreated cubes for 1 hour and the absorption ratio is calculated. Cubes are then placed in a potassium hydroxide (alkali) solution for 21 days, and the absorption test is repeated after the cubes are dried to their pre-immersion weight.

After the vapor transmission test, Alberta BT001 requires that the treated cubes be oven dried at 60°C to match the average control sample relative moisture content. The samples are then immersed in plain water for 120 hours (5 days) and weight gain is recorded. If subject to abrasion, the cubes are then sandblasted to remove about 12 grams per face, and the test is repeated.

The cubes in the Alberta BT001 tests are conditioned to a pre-determined moisture content before testing for absorption. When setting target weights to achieve uniform moisture contents for each sample, the applied sealer weight must be known and subtracted from the original cube weight. Alberta BT001
determines the weight of the hardened sealer adhering to the test cubes at the end of the 15-day drying period based on the following assumptions:

- **a)** All sealer evaporation takes place during the initial 5-day drying period.
- **b)** The concurrent water loss in the test cubes is equal to the water loss in the control cubes during the same 5-day drying period, multiplied by the vapor transmission ratio (VT).
- **c)** It follows that the balance of test cube losses during the initial 5-day drying period is made up of sealer loss due to evaporation (SL), and
- **d)** It also follows that the weight of sealer adhering to sealed cubes at the end of the total 15-day drying period is equal to the total sealer weight applied to the cube, minus evaporated sealer.

An alternate and more straightforward method to estimate the sealer weight applied to cubes is proposed that calculates the remaining weight of the sealer based on its measured percent solids. Assuming that all volatiles are lost after the 14-day drying period, the remaining sealer weight should be the initial weight of sealer weight applied to the cubes (weight measured immediately after application) multiplied by the percent solids (non-volatile) content.

NCHRP 244 immersed the sampled for 21 days in saltwater, and the testing did not include abrasion. In this NCHRP 244 research, the untreated control cubes quickly approached saturation after about 3 to 7 days. The sealed cubes continued to gain weight over the 21-day period, but the first 3 to 7 days of performance foretold the performance over the rest of the 21 days. Therefore, good separation of the coated and uncoated sample’s performance typically occurred after about 3 to 7 days of immersion. The proposed test method suggests immersion in saltwater for 7 days.

Alkali resistance is measured by both Alberta BT002 and the EN13580 procedures, but was not measured in the NCHRP 244 study. Alberta’s highway agency believes that this testing is important since after they introduced the test, several products that were on their approved list failed and had to be dropped. Both the Alberta BT002 and EN13580 procedure immerses the cubes in a dilute potassium hydroxide solution for 21 days after the first water immersion test. The cubes are then dried to their weight prior to the first immersion test and the water absorption test is repeated.

For water absorption testing, Alberta BT001 uses tap water and the EN 13580 test uses demineralized water (conductivity < 50μS). The NCHRP 244 procedure used saltwater to simulate northern or marine exposures. Since sealers as primarily used to protect northern and marine structures, saltwater is suggested in the proposed test. The added advantage of using saltwater is that the chloride ion penetration in the cubes can also be tested and compared. An extra set of cubes is suggested in the proposed method for continued ponding in saltwater to 21 days and determination of the chloride content and depth of sealer penetration or coating thickness. After 21 days of saltwater immersion, the cubes are rinsed with tap water, weighed, broken in half, and one half is tested for acid-soluble chloride content. The proposed sampling procedure further cuts the cube halves at least 20 mm (3/4 in.) from the edges of the cube so that the test sample represents a one-dimensional diffusion unaffected by the corners. A sampling profile of 6-12, 15-22, 25-32, and 35-42 mm (1/4 to 1/2, 5/8 to 7/8, 1 to 1-1/4, and 1-3/8 to 1-5/8 in.) is recommended. The relative chloride content as a percent of the control samples at each depth is calculated.

### Depth of Sealer Penetration

Oklahoma (OHD L-40) has a published method for determining the depth of sealer penetration. The method oven dries the samples to a constant weight and treats the fractured core surface with Sulfonazo dye. The samples are photographed and the photographs are used to determine the depth of penetration. While this method may provide good results, a faster and more straightforward means of determining the depth of sealer penetration is proposed.
The test cubes are broken in half using a compressive load on approximate 10-mm (3/8-in.) diameter steel rods centered on the top and bottom cube faces. The cubes are fractured in two generally equal halves. One half of the sealed cube is tested for depth of sealer penetration or coating thickness. First the cube is dried and then the fractured sample face is immersed or sprayed with a dye solution [red food coloring or Sulfonazo III sodium salt dye]. The use of a water-soluble dye helps identify the area of hydrophobic paste that represents the sealer penetration depth. The Sulfonazo dye was developed many years ago to stain concrete surfaces. However, this dye is expensive and a solution of food dye works similarly.

The dye-treated surface is allowed to air dry and the depth of sealer penetration is measured with the assistance of a microscope or magnifier. The depth of sealer penetration or coating thickness is measured to the nearest 1-mm (0.04-in.) at 10-mm (0.4-in.) intervals within the center 50 mm (2 in.) of each exposed face (6 readings per cube face). The locations of the measurements may need to be adjusted if the reading is affected by the presence of coarse aggregate particles. If this occurs, the measurement location should be adjusted slightly or these measurements should not be included in the reported readings. The readings are averaged and the minimum and maximum depths of penetration are reported. It may not be necessary to dye-impregnate cubes with barrier coatings that are non-penetrating. These thicker coating materials can be measured directly if it is known that no penetration has occurred.

**Weathering and Saltwater Resistance**

Weathering resistance is evaluated using slab specimens subjected to cyclic ponding with saltwater and drying by heat and exposure to ultraviolet light. This test was first developed as the NCHRP 244 Concrete Sealers for Protection of Bridge Structures - Series IV - Southern Climate Test. A modification of this test was used in the NCHRP 244 study to evaluate the effectiveness of sealers on cracked concrete. The effect of weathering is measured as a percent reduction in the chloride ion penetration on treated slabs compared to untreated control slabs. The effectiveness of each candidate sealer is expressed as the percent by which chloride absorption is reduced as compared to uncoated concrete. For the proposed testing an additional coated slab is cast, but not exposed, to allow comparison of the treated surface at the end of the test and for skid resistance testing, if the sealer is being approved for traffic-bearing surfaces.

Weathering tests were done as part of the NCHRP 244 program but are not specified by Alberta’s highway agency or the European standard. Alberta staff considers this important but rely on water immersion testing to select sealers, since reasonable correlation between the immersion tests and weathering tests were found in the NCHRP 244 study. The intent of weathering testing is to determine if the sealer remains effective after cyclic wetting and drying and exposure to ultraviolet radiation. The weathering test performed in NCHRP 244 included both northern exposure tests and southern exposure tests on uncracked and cracked concrete. The conclusion of the NCHRP 244 report recommends using accelerated test methods that include alternate wetting and drying cycles and appropriate ultraviolet light exposures, since both types of exposure appear to create realistic environments that important to coating performance.

A review of sealer manufacturers’ literature revealed that most sealers have been tested for compliance to NCHRP 244 Series IV southern exposure tests and only some have been tested using the northern exposure tests that include cyclic freezing. Since not all sealers are used on structures subjected to cyclic freezing and since the southern exposure test has been more universally used, a method modeled after the southern exposure test is proposed for inclusion in the standard procedure. Further, the primary protection mechanism for concrete exposed to cyclic freezing is proper air-entrainment and not the application of sealers. Therefore, sealer testing to reduce cyclic freezing damage is proposed as a special application test for deicer scaling and not as a Universal test.
The NCHRP 244 Series IV southern exposure tests cured the test slabs, 300 by 300 by 76 mm (12 by 12 by 3 in.), in plastic for 21 days. After initial cure, the test surfaces (bottom as cast) are lightly sandblasted to remove laitance, and then the slabs are stored in the laboratory for 5 additional days. At 28 days, the sides of the slabs are coated with an epoxy. The top surface of the slabs are coated with sealer, and allowed to dry for 16 days. The test slabs are then ponded with 12 mm (0.5 in.) of 15% sodium chloride solution for 100 hours. The solution is drained, the slab is rinsed with tap water, and the slabs are placed in a chamber at 100°F and exposed to ultraviolet light for 68 hours. This exposure cycle is repeated for a total exposure of 24 weeks, nearly 6 months.

Based on comments received in our survey, most agencies want quick tests and consider a 6-month test to be undesirable for a prequalification screening test. Some agencies, such as Alberta, would like to have an accelerated weathering test, but have not adopted a test since the likely duration is too long. Therefore, the proposed test includes a modified weekly cycling procedure that should not produce results significantly altered from that achieved with the NCHRP 244 Series IV southern exposure test and that includes the same amount of UV exposure. Test data show that chloride from saltwater is rapidly absorbed into dry concrete during the first 24 hours of ponding, then the rate of chloride penetration slows and is controlled by diffusion after the concrete voids are filled with water and the concrete becomes saturated. Therefore, reducing the ponding cycle from 100 hours (4 days) to 24 hours (1 day) should not greatly affect the final chloride values as compared to the controls. Two cycles per week can be achieved by doing this and using alternating UV exposure testing times of 48 and 72 hours to accommodate weekend periods, reducing the total testing time from 24 to 14 weeks.

The lamps used in the NCHRP 244 Series IV test have a peak emission at 368 nm, within the UV A range. Light is emitted from approximately 350 to 400 nm. Little light is irradiated at wavelengths lower than 350 nm. In contrast, lamps used for UV A exposure testing according to ASTM G154 Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials, have a peak emission at 340 nm, an a nearly Gaussian emittance in the range of 300 - 400 nm. The UV A-340 lamps used in ASTM G154 testing are intended to simulate daylight exposure. The effect of using lamps with the emittance profile of the F40BL lamps, as compared to using lamps with a more standardized UV A-340 emittance is unknown. However, since the NCHRP 244 Series IV tests have been demonstrated to be useful in evaluating surface applied sealers, lamps with the same profile are specified in the draft test method.

Sealer Characterization Test Methods

Infrared Spectroscopy

Infrared spectroscopy is a commonly available technique for chemical analysis of organic compounds and some inorganic compounds. It provides a spectrum showing peaks that correspond to a vibrational mode related to chemical bonds within the material. Each peak has a position measured by wavelength or, more commonly, wavenumber (reciprocal of wavelength). The intensity of the peak depends, in part, on the concentration, but peaks of greater intensity are not necessarily indicative of greater concentration. Infrared spectra are used to determine the molecules present in a system. Each molecule gives rise to a particular set of peaks, and by matching the spectrum with a library of known materials, the composition can be determined. Comparison of spectra run under identical conditions can be used to determine if changes to a certain materials formulation were made. However, care should be exercised when interpreting spectra because variations in sample collection conditions can lead to changes in peak intensity and sometimes slight shifts in peak position. Measuring the infrared spectra of a sealer material provides a “fingerprint” of that material and changes to the spectra indicate that the
sealer formulation has been modified in some way, or that the sealer may have aged beyond the allowable
shelf life. It is recommended that material supplied for prequalification testing be analyzed using infrared
spectroscopy and that this spectrum be kept on file for comparison with spectra obtained from materials
supplied to field projects in the future. If significant changes to the spectra are found, the sealer
manufacturer should be contacted to determine what caused these changes, and retesting for some or all
of the prequalification tests may be warranted. While being very useful for material identification, the
significance of spectral changes can be difficult to interpret for staff without significant experience using
this technique.

Spectra can be obtained in transmission or internal reflection mode. Spectra obtained in one mode
cannot necessarily be directly compared to spectra obtained in other modes. Be aware that internal
reflection spectra provide data from only the near-surface region, and the spectra may not be identical in
peak position and peak intensity to transmission spectra of the same material. Materials that contain a
solid filler or pigment may be analyzed directly by internal reflection, and the spectrum will indicate the
complete sample being analyzed (including pigment or filler). Spectra obtained of the entire sample
should not be compared with spectra obtained of the liquid phase separated from the solid. For materials
that contain both a solid and a liquid component, it is recommended that spectra be obtained of the
composite material with an internal reflection technique and of the separated liquid phase by an internal
reflection or transmission technique.

Gas Chromatography

Gas chromatography (GC) is another method to “fingerprint” organic materials and provides
additional information not obtained by infrared spectroscopy. It separates components in the mixture, and
provides a chromatogram showing peaks in a plot of intensity versus retention time. Each peak
corresponds to a compound or related group of compounds. Intensity or area of the peak correlates to the
concentration. The retention time depends on the composition of the compound and the conditions of the
separation. For a given set of run conditions (stationary phase, carrier gas flow rate, etc.), a given
molecule will always have the same retention time, and, if the concentration is the same, the intensity and
area under the peak should be the same.

GC needs to be coupled with another analytical technique, often mass spectrometry, to identify
the composition of unknowns. GC separates components of a mixture, and can be used to evaluate the
uniformity of different lots of a material, when run under the same conditions. The identity of the
molecule leading to a particular peak can be determined based on a standard analyzed under the same
conditions. When analyzed under the same conditions, the gas chromatogram is very useful to evaluate
the consistency of formulation. Either infrared spectroscopy or GC can be used to check if significant
changes in formulations of sealers have occurred, however, using both techniques provides the best
characterization of a particular sealer formulation.

Percent Solids

Percent solids values are a good indicator of uniformity in formulation from lot to lot of a
particular material. If the concentration of active ingredients is changed, the percent solids values will
reflect this change. However, changes in pigments, fillers, and thickeners will also affect the percent
solids. Therefore, if the content or composition of pigments, fillers, or thickeners is altered, this may
disguise any changes in the amount of active ingredient. The percent solids determination is used to
determine the weight of sealer applied to test samples and for monitoring job-supplied materials for
consistency or formula changes. However, for material quality control monitoring, this method should be
used in combination with a method of chemical fingerprinting, such as infrared spectroscopy or GC.
Specific Gravity

Specific gravity measurements are suitable for determining if changes in solvent, active solids concentration, or fillers or thickeners may have been made compared to the original material tested for prequalification. Changes in concentration will affect specific gravity, depending on whether the active ingredient has a greater density than the solvent or carrier. Changes in solvent concentration or composition will also affect the specific gravity, because the specific gravity will change with concentration, and similar solvents or carriers can have significant differences in specific gravity. Changes to the formulation of the active ingredient (for example, length of alkyl chain in a silane) may or may not change the overall specific gravity and may not be detected in these tests. However, these types of changes should be detected in chemical fingerprinting tests, which should be performed concurrently.

Specific gravity of a liquid is easily measured by hydrometer or by pycnometer. Measurements made using a pycnometer are more accurate, but take longer. Measurements made using a hydrometer are generally adequately accurate and significantly quicker.

Refractive Index

In the United Kingdom, refractive index is used for job-site quality assurance of silane sealers. Refractive index is a function of the silane monomer and solvent. Changes in refractive index indicate a change in formulation, but the specific changes in formulation cannot be determined by refractive index alone. A portable refractometer can be used to measure refractive indices of sealer specimens during the prequalification and routine and job site quality assurance processes.

SEALERS FOR TRAFFIC-BEARING SURFACES (T)

Sealers applied to deck surfaces must perform when subject to abrasion and not adversely affect deck skid resistance. Since most sealers are placed during short lane closures they must also cure rapidly and not track onto adjacent roadways where skid problems on ramps or asphalt concrete (AC) pavements can occur.

Effect of Surface Abrasion

The most commonly used test to measure the effect of abrasion on sealer effectiveness is the Alberta BT001. Many sealers have been tested using this method, and this method forms the basis for the procedures proposed for adoption. After immersion tests are conducted, the samples are dried to their pre-immersion weights and the surfaces of the cubes are sandblasted to remove 12 ± 1 g of material per face (cumulative weight loss for the six sides of 72 g ± 2 g). The cubes are then retested for water immersion and the waterproofing performance after abrasion is calculated as the average weight gain after abrasion divided by the average weight gain of control set, as a percent.

Only penetrating sealers are used on deck surfaces in Alberta. Most agencies do not allow coating-type sealers to be used on traffic-bearing surfaces, and no test procedures have been developed to determine the affect of surface abrasion on the effectiveness of non-penetrating coatings. A modification of Alberta BT001 has been developed and proposed that would allow for comparison of the performance of non-penetrating coating systems when subjected to abrasion. The amount of sand required to blast the untreated control cubes is measured, and the same amount of sand and blasting procedures are used to abrade each face of the coated cube samples.
Skid Resistance

None of the agencies use standard laboratory tests to check the skid resistance of treated surfaces. A new proposed test procedure has been developed that includes testing of the slabs using the pendulum skid tester per AASHTO T278 Standard Method of Test for Surface Frictional Properties Using the British Pendulum Tester. This test is recommended for newly sealed slabs, to estimate the skid resistance when a treated area is opened to traffic, and for after the test slabs have been subjected to the accelerated weather test, which includes saltwater ponding and UV exposure.

Ideally, field trials should be included for any sealer being used for travel surfaces. A field trial can be installed and tested using either AASHTO T278 or ASTM E274 Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire. The skid resistance of the treated and untreated areas should be tested before traffic is allowed on the treated surface and again after several months of traffic and weathering exposure.

Special attention should be given to non-penetrating sealers used on traffic-bearing surfaces. Some materials, especially polymers, can polish with time or lose surface-applied grit. Therefore, periodic field testing of these materials may be required to ensure that they do not lose skid resistance with time.

Time-to-Cure

None of the agencies use standard laboratory tests to check the time required for curing before traffic can be allowed on the treated surface. A new test procedure has been proposed for monitoring the drying time by measuring gel time, tack-free time and final set time of treated cube samples. Holes are drilled into the cube samples to simulate large and small voids that are typical of tined and grooved bridge deck surfaces.

The intent is to measure the time to traffic at both maximum and minimum application temperatures. It is recommended, unless otherwise specified, to use the manufacturer’s minimum recommended temperatures minus 3°C (5°F) and maximum recommended temperature plus 3°C (5°F). The proposed curing environment and air velocities are similar to what is specified in ASTM C1315.

FREEZE-THAW AND DEICER SCALING

Usually concrete is well-protected from cyclic freezing damage by adequate air entrainment. It is not appropriate to require all sealers to be effective in preventing scaling or cyclic freezing damage of non-air entrained concrete. Sealers are primarily used to protect concrete from water and deicers or salts. If the sealers are used in a cyclic freezing environment they must remain effective in that environment. Therefore, two types of tests are needed, depending on the expected result: 1) The sealer must remain effective at preventing water and chloride ingress after cyclic freezing exposures of properly air-entrained concrete, and 2) If the sealer is used to protect poorly air-entrained concrete from cyclic freezing damage, the test must be performed on poorly air-entrained concrete.

Effect of Cyclic Freeze-Thaw Exposure on Sealed, Air-Entrained Concrete

AASHTO T161 Resistance of Concrete to Rapid Freezing and Thawing, Procedure A provides rapid freezing and thawing in water. Procedure B provides rapid freezing in air and thawing in water. Since most transportation structures are outdoors, they often remain wet during freezing; Procedure A most closely simulates this process.
The Rhode Island DOT (RIDOT) tests sealers for cyclic freezing resistance using treated concrete prisms tested in accordance to ASTM C666, Procedure A. Periodically, RIDOT uses a visual rating scale to assess the sample condition and each sample face is rated between 0 and 5.

The proposed test method is similar to the RIDOT test procedures, except the cube samples from the immersion testing are used for cyclic freezing testing instead of separate prisms, saving additional sample preparations. Further, the cubes are retested for saltwater immersion after the cyclic freezing test to evaluate the effect of the cyclic freezing on the sealer or coating performance. The expectation is that concrete deterioration would not occur during the cyclic freezing, since the concrete is air-entrained. However, if the cyclic freezing degraded the sealed surfaces of the samples, the reduction in sealer effectiveness would be measured during the subsequent immersion testing.

The disadvantage of using cube samples is that the Relative Dynamic Modulus of Elasticity cannot be measured on cubes, beams are needed. As an alternate, standard prism samples (3 by 3 by 12 in prisms are recommended to keep the sample weight down) can be cast, treated, and tested in accordance with AASHTO T161 and the proposed test procedures. Prism samples can be visually graded and weight loss can be measured, but also the Relative Dynamic Modulus of Elasticity can be measured periodically during the test and compared to untreated control prisms.

The second aspect of cyclic freezing deterioration where sealer may provide benefits is when sealers are used to extend the service life of poorly air-entrained concrete. This property is best measured using the scaling resistance test discussed in the next section.

**Deicer Scaling Resistance (Non-air-entrained concrete)**

Illinois DOT measures the scaling resistance of sealed concrete using a modified version of ASTM C672 *Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals*. Ontario’s highway agency also tests sealers for deicer resistance using a similar test procedure (Test Method LS-412). Slabs ponded with 3% sodium chloride solution are frozen and thawed daily for 50 cycles. The surface is rated and the mass loss after each 5 cycles is measured. Comparing treated and untreated surfaces using the ASTM C672 method is a good way to compare the effect of the sealer on deicer scaling. ASTM C672 uses a solution of calcium chloride (4g CaCl/100ml) and the IDOT and Ontario methods specify a 3% solution of sodium chloride. IDOT further modifies the testing procedure by using air-entrained concrete (5.0 to 8.0%) unless testing non-air-entrained concrete is required, and water is placed on the slabs, frozen for 16 hours and then sodium chloride is applied to the surface of the ice, and they are kept frozen for another 5 hours. They are then removed from the freezer, rinsed and allowed to thaw and drain for about 3 hours before the cycle is repeated to a total of 60 cycles. This method requires more labor than the standard ASTM C672 that just adds the salt solution prior to freezing. Since deicers usually are applied before ice builds up on the surface of the roadway and sometimes deicer solutions are applied directly to the bare roadways, the proposed test method involves placing the salt solution directly on the sealed surface as the samples are frozen.

The type of deicer may have an effect on certain sealers. While ASTM C672 uses calcium chloride, most states use a rock salt mainly composed of sodium chloride. However, other states allow liquid deicers such as magnesium chloride that could affect sealed concrete differently. The proposed test recommends that sodium chloride be used as a standard salt solution, but that state agencies should require testing for the deicer most commonly being used on their roads.
ADVERSE CONDITIONS

Effect of Wet (SSD) Concrete Surface Condition at Time of Sealing

If the sealer is likely to be applied to wet concrete surfaces, it should be tested and pre-approved using tests where the sealer is applied to saturated concrete. The Moisture Vapor Transmission, Waterproofing Performance by Saltwater Immersion Test, and Time-to-Cure tests are repeated with the sealer applied to saturated surface dry (SSD) specimens. The sealers are applied to moist-cured cubes within 1 hour of removing them from the moist curing in a SSD condition.

Performance at Temperature Extremes

If the sealer is to be applied at temperature extremes, it should be tested and prequalified at the expected temperatures. This test can be used as a Universal test to bracket the range of acceptable application temperatures. The Moisture Vapor Transmission, Waterproofing Performance by Saltwater Immersion, and Time-to-Cure tests are repeated with the sealer applied and cured at the extreme temperatures. A minimum of 48 hours prior to treatment with the sealer, the cubes and sealer materials are conditioned in a chamber to the temperatures to be tested. Unless otherwise desired, it is recommended that the test temperatures are at least the manufacturer’s minimum recommended temperatures minus 3°C (5°F) and maximum recommended temperature plus 3°C (5°F). Typical temperature ranges recommended for sealers include 4°C (40°F) and 40°C (105°F).

OTHER CONSIDERATIONS

Color and Appearance

Aesthetic appearance is important for some sealer applications. In these cases, color and appearance of the sealer should be included as part of the prequalification and routine and job site quality assurance tests. Aesthetic approval can be subjective, and agency policies for approval should be maintained. Several ways of measuring color exist. Instrumental methods for measuring color in a variety of coordinate systems are available, instrumental methods to measure gloss and reflection are also available. These instrumental methods are preferred over non-instrumental methods because they reduce the effect of factors such as ambient lighting and the experience of the observer, by often providing an integral light source and a standard observer. Other color analysis methods involve the comparison of a standard color card to the specimen of interest. These methods are less expensive and easier to implement than the instrumental methods, but results can vary depending on ambient lighting conditions and the observer. Some sealers are used as anti-graffiti coatings. These anti-graffiti coatings are intended to either repel the ink or paint, or to provide an easy-to-clean surface so that the graffiti can be removed.

Safety

Safety is a concern when handling many sealer systems. The persons involved with laboratory testing and field application should familiarize themselves with the hazards of the particular system prior to potential exposure. The hazards vary from skin sensitization to allergic reaction, inhalation hazards, and fire hazards. Users should read the material safety data sheet (MSDS) for all systems prior to use. A MSDS should be available to all persons who may become exposed. The particular format of a MSDS varies, but includes mandatory information, as required by 29 CFR 1900.1200 (g), and may include optional information. The worker should also refer any question on potential hazards to their agency’s or company’s designated safety official.
The MSDS generally provides information on:

- **Hazardous ingredients** (non-hazardous ingredients are not required to be listed). The chemical name and synonyms are often provided, along with the chemical abstracts service (CAS) number, which provides a unique number to each chemical listed in the chemical abstracts service registry.

- **Ranking of hazards** in either the hazardous materials identification system (HMIS) or national fire protection association (NFPA) system, in which materials are ranked from 0 (minimal hazard) to 4 (severe hazard) in health, flammability, and physical hazard (for HMIS), and health, flammability, and reactivity for NFPA systems. These ratings systems provide the user with a quick way to evaluate potential hazards.

- **Primary routes of entry**. This tells the user the primary routes of entry for the chemicals listed on the MSDS. Some chemicals are inhalation hazards, some can be absorbed through the skin, and others are hazardous if taken internally. Inhalation, skin contact and eye contact are the primary concerns for users of sealers.

- **Effects of overexposure**. This section tells the user the symptoms to be expected if exposed to the chemicals in sufficient quantities to cause a reaction. This section is an important reference if overexposure is suspected.

- **Physical and chemical characteristics of the material**. These characteristics commonly include such information as color, odor, evaporation rate, flash point (point at which the vapor can catch fire), explosion limits (concentration in air where an explosion can occur), pH, vapor pressure, specific gravity, boiling point, freezing point, solubility, and other information.

- **Exposure limits**. These include the OSHA (Occupational Safety and Health Administration) permissible exposure limit (PEL), the maximum amount of the chemical that a worker may be exposed to, the ACGIH (American Conference of Governmental Industrial Hygienists) Threshold Limit Value (TLV) a guideline indicating the level of exposure without unreasonable risk of injury. The time weighted average (TWA), the level to which a worker can be exposed to over an 8-hour shift, and other exposure limits are often reported.

- **If the material has been determined to be a carcinogen (cancer-causing agent) this is listed in a separate section.**

- **First aid measures**. This section lists procedures to be followed in case of first aid or emergencies.

- **Physical hazards**. These include potential for fire, reactivity and explosion, and hazardous decomposition products.

- **Fire fighting measures**. Precautions to be taken in case of a fire. This section is generally more applicable for fire fighters than workers.

- **Accidental release measures**. This section describes measures to be taken in case the material is accidentally released.

- **Handling and storage**. Information on how to handle and store the material, including materials it should be kept away from, and personal protective equipment that should be worn when handling the material.

- **Toxicological information**. Information on the toxicity of the hazardous material is provided, generally in the form of animal test data. The results of studies indicating the LD50 (lethal dose for 50% of the animal population in the study) and sometimes the LC50 (lethal concentration for 50% of the animal population in the study) are provided. The type of animal and the method of ingestion are provided. Correlations of the animal data to human toxicity are not provided.

- **Transportation information**. The regulations involving transportation of hazardous materials must be followed, and information such as the proper shipping names may be provided.

A thorough discussion on the safety and environmental hazards of sealers is presented in Chapter 6 of NCHRP Synthesis 209 (P. D. Cady 1994). The hazards of commonly used sealers are presented, along
with information such as HMIS ratings and exposure limits of chemical typically encountered in the formulations.
CHAPTER 5

PROPOSED GUIDELINE FOR QUALITY ASSURANCE, JOB SITE QUALITY CONTROL, AND REAPPLICATION OF PROTECTIVE SEALERS FOR PORTLAND CEMENT CONCRETE

A guideline for test methods and procedures for quality assurance testing and job site quality control for protective sealers for highway purposes to be applied to hardened concrete is provided in Appendix B of this report. It is assumed that sealers will be tested and pre-qualified through the proposed AASHTO Draft method Standard Method of Test for Protective Sealers for Portland Cement Concrete shown in Appendix A. The Guideline in Appendix B provides testing and evaluations for routine and job site product quality assurance and to assess the field performance of sealers as well as methods to assess when re-application should be performed. The Guideline is divided into the following areas:

ROUTINE AND JOBSITE QUALITY ASSURANCE TESTING

Sealer Sampling
Material Characterization Tests for Routine and Job Site Quality Assurance
   Spectroanalysis (FTIR)
   Gas Chromatography (GC)
   Solids Content
   Specific Gravity

Material Performance Testing for Routine and Job Site QA Testing
   Testing and Sample Preparation
   Moisture Vapor Transmission Test
   Waterproofing Performance by Saltwater Immersion Test
   Depth of Sealer Penetration or Coating Thickness

JOB SITE QUALITY CONTROL TESTING

Sealer and Application Quality Control Testing
   Concrete Surface Temperature and Moisture Conditions
   Sealer Storage, Shelf life and Condition
   Application Equipment and Coverage Rate
   Cure and Appearance

Depth of Sealer Penetration or Coating Thickness
   Depth of Sealer Penetration or Coating Thickness by Core Sampling
   Depth of Sealer Penetration or Coating Thickness by Field Techniques

Water Absorption Field Tests
   Waterproofing Performance of Core Samples Taken From Sealed Concrete Surfaces
   Surface Absorption Test

Coating Adhesion Test
Deck or Travel Surfaces
    Time-to-Cure
    Skid Resistance
    Waterproofing Performance after Abrasion

REAPPLICATION AND OTHER CONSIDERATIONS

ANNEX 1 - Evaluation of Depth of Penetration of Penetrating Sealers in Actual Structures

ANNEX 2 - Test Procedure for Measuring the Waterproofing Performance of Core Samples Taken From Sealed Concrete Surfaces

ANNEX 3 - Evaluation of Sealer Performance in Actual Structures by Surface Absorption

ROUTINE AND JOBSITE QUALITY ASSURANCE TESTING

This testing is recommended to establish that the sealer material supplied to a job site or that is ordered for routine use by maintenance forces is the same material and has the same level of performance of the material that was tested in the prequalification testing and was used to develop qualified product lists (QPLs). This testing includes sealer material characterization tests and selected performance tests.

Sealer Sampling

It is recommended that a sample of each shipment and preferably each manufacturing lot of sealer that is supplied be sampled and tested for conformance to the Material Characterization Tests that include FTIR, GC, solids content and specific gravity. These tests are rapid and provide a good characterization of the material’s composition and chemistry. Further it is recommended that each shipment or at least annual testing is performed on the supplied material for the Material Performance Testing for Job Site QA Testing - Screening Performance Tests for Water Vapor Transmission, Saltwater Absorption, Chloride Permeability, and Depth of Sealer Penetration. This testing repeats selected prequalification testing to evaluate sealer performance on test cubes. A complete re-test of all prequalification tests is recommended on a periodic cycle, say 5 to 10 years, as raw material supplies and parent companies often change.

Material Characterization Tests for Job Site Quality Assurance Testing

Material characterization tests are used to collect data on the basic characteristics of the material, including composition, solids content, and specific gravity. These tests were used to gather baseline data on compositions submitted for the prequalification testing and they are repeated on the field samples during the routine and job-site quality assurance testing. The tests include Spectroanalysis (FTIR), Gas Chromatography (GC), Solids Content, and Specific Gravity. At a minimum, either FTIR or GC should be used in combination with solids and specific gravity testing. These tests should be performed on samples of the batch or batches of sealer material that are supplied for project use, and the data should be compared to the data on file from the prequalification testing.

The results of the FTIR analysis and gas chromatography procedures depend, in part, on the instrument and sample preparation used. The run parameters should be matched to those used to characterize the sealer material during the prescreening test. Documentation of the sample collection conditions and details of sample preparation and analysis are important.
Solids content of sealer materials is useful to monitor the uniformity of the material. Unlike spectroanalysis, which gives a qualitative spectrum, solids content measurements provide a quantitative measurement of non-volatile content. Fillers or pigments will be measured in solids content measurements, and changes in the type (density) or concentration of fillers or pigment can lead to different solids content measurements.

Changes in solvent or solids concentration will affect specific gravity. Specific gravity provides a quantitative method of evaluating changes in a material from batch to batch. The method listed in the Guide is suitable for both solvent-based and water-based systems.

**Material Performance Testing for Routine and Job Site QA Testing - Screening Performance Tests for Water Vapor Transmission, Saltwater Absorption, and Depth of Sealer Penetration**

Several performance tests are recommended to ensure that formulation or raw material changes do not adversely affect the performance of sealers. These tests are recommended for job site quality control and can be used whenever sealers are ordered or as an annual test of sealer performance. Tests for water vapor transmission, saltwater absorption, and depth of penetration or coating thickness are repeated and compared with the test results obtained during the prequalification testing. These tests are straightforward and provide results within about 5 to 6 weeks.

Longer term prequalification tests, such as alkali exposure, chloride penetration, weathering, effect of abrasion, freeze-thaw, scaling or durability testing are not well-suited for routine QA testing. The recommended material performance QA tests include treating standard cubes with the sealer and testing them for the following:

a) Moisture Vapor Transmission Test (14 days)
b) Waterproofing Performance by Saltwater Immersion Test (7 days)
c) Depth of Sealer Penetration or Coating Thickness

The results of this testing are compared to the performance data for the sealer lot used in the prequalification testing to ensure that formulation changes or shelf life issues have not degraded the sealer’s performance.

**JOB SITE QUALITY CONTROL TESTING**

Sealer performance on actual structures is heavily dependent on site-specific conditions, including field exposure, concrete substrate, concrete service, and environment. Therefore, evaluating installed performance on structures is a valuable exercise to: 1) demonstrate that the level of performance anticipated based on laboratory prequalification testing is consistent with that achieved on the structure, and 2) evaluate the extent of degradation in performance occurring over time.

Interpretation of field tests will require the judgment of the supervising engineering staff. Including trials based on field methods during laboratory evaluations is an appropriate method for developing correlations between field and laboratory testing procedures. However, this is not always possible, and field condition variations may limit the value of such data. In field applications, similarly exposed but untreated areas on the same structure may serve as control areas for field tests. In addition, comparisons of performance over time, provided that the performance is evaluated under similar conditions, may provide the best insight into actual effectiveness of sealers. Job site quality control procedures include checking the sealer containers’ shelf life and condition, ensuring that the surfaces to
receive the sealer are properly prepared and in good condition to receive the sealer and that the contractor is properly equipped and correctly applies the sealer. Further testing and evaluation of the effectiveness of the sealer after it has been applied to concrete bridge members or deck surface is important.

Usually some minor destructive testing is necessary to evaluate the depth of penetration and waterproofing performance of the sealer. The suggested procedures include tests that minimize destructive testing. If no drilling or coring is allowed on the structure itself, application of the sealer to mockup panels may be useful in evaluating sealer application effectiveness and application rates.

**Sealer and Application Quality Control Testing**

*Concrete Surface Temperature and Moisture Condition*

Both ambient and concrete surface temperatures should be measured prior to application to ensure that conditions are within the limits set by the sealer manufacturer or established during prequalification testing. The moisture content in the concrete should also be evaluated prior to applying a sealer. Some sealers may not penetrate or coat as well on saturated concrete as they do on drier concrete. A test method is provided in Appendix A to prequalify sealers for use on saturated surface dry (SSD) concrete surfaces. Normally, sealers should not be placed unless the concrete has been dry for at least three days.

Several tests are available to test concrete moisture including measuring the concrete relative humidity at various depths. More research and testing are needed to determine the affect of concrete moisture on sealer performance. Ideally, an easy and quick “go - no go” test is desired to evaluate surface moisture conditions prior to sealing.

The moisture content in the concrete can be evaluated with two standard methods: ASTM D4263 and ASTM F2170. ASTM D4263 does not require specialized equipment beyond a plastic sheet and tape, but provides results in sixteen hours, so the test will have to be initiated the day before application. ASMT D4263 testing evaluates whether water has condensed from the concrete onto the plastic sheet. If the sheet is dry, the concrete is considered dry. If there is moisture present on the plastic, the concrete is considered wet. ASTM F2170 requires specialized relative humidity measuring equipment, and may take hours or days before readings can be taken, so the measurements will likely need to be initiated the day before sealing or earlier. ASTM F2170 uses moisture probes to measure the relative humidity of the concrete at various depths of measurement, and so is more quantitative than ASTM D4263.

*Sealer Storage, Shelf life and Condition*

Containers of sealer should be stored according to manufacturer’s recommendations, which generally indicate storage in a cool, dry place. Care should be taken that the sealers are not stored under conditions that are too hot as the sealers may degrade or alter with time. Check the date of sealer manufacture and check against the manufacturer’s shelf life. Sealers that have exceeded the shelf life should not be used. It is good practice to mark the date of receipt on the packaging, especially if no date of manufacture or use-by date is printed on the label.

The condition of the sealer should be evaluated visually prior to application. The sealer should be thoroughly mixed prior to evaluation. The sealer appearance should be homogeneous and essentially the same in color, apparent viscosity, and texture as seen during the prequalification testing. If the sealer appears different from the material that was used for prequalification, different from other packages of the
same sealer, or different from a written description of the material, the differences in appearance can indicate a potential formulation change or degradation of the material.

**Application Equipment and Coverage Rate**

Prior to applying a sealer, the application equipment should be visually inspected. The equipment should be clean and capable of applying the sealer in a manner suitable to deliver the necessary application rate. The application rate should be evaluated to ensure adequate coverage of the surface being sealed. There are several ways to test application rate, and the most suitable method depends on the application method and equipment. If possible, the volume or mass of sealer in the application equipment should be measured prior to application and again after application to a known or measured surface area. From this information, the coverage rate can be calculated. If this method is impractical, the sealer can be sprayed into an empty bucket for a known amount of time. The volume or mass of the sealer in the bucket can be measured, and the application rate as a function of time determined. The amount of time required to apply the sealer to a known area then needs to be measured to determine application rate over a given surface area. The measured application rate should be compared to the desired application rate (determined from manufacturer’s recommendations or from the prequalification tests), and adjusted accordingly.

Environmental conditions may also affect application rate. In the case of high winds, some of the sealer may blow away during spray application, resulting in a lower than desired application rate, even if the application rate, measured as described above, appears adequate. Over-atomization of sealers during the spray process can also lead to droplets being entrained in the air, and a reduced actual coverage rate. Care should be taken to avoid these conditions by careful observation of the application process.

In addition to measuring the application rate, it is important to evaluate that the sealer is being applied uniformly and to the entire surface. This can be accomplished by visually evaluating the application process. Where it is difficult to visually evaluate application, because of high evaporation rate or the clear nature of the sealer, a fugitive dye can be added to the sealer mixture that indicates where the sealer has been applied. Normally, it is best to apply the sealer in at least two applications, so the risk of missing spots is reduced.

**Cure and Appearance**

The drying rate or curing of the sealer should be monitored. Conditions that may affect the drying and curing of the sealer, such as high winds or high temperature, should be monitored. If possible, the sealer should be applied on calm days or days with low wind speed, to ensure the appropriate application rate, and to allow the sealer to cure properly. Drying, gel, and tack-free times should be monitored, especially if traffic is to be allowed on the sealed surface.

After sealer application and drying or cure, the appearance of the sealed surface should be evaluated visually. Visual evaluation will help determine if the sealer was applied to all necessary areas and if the sealer was applied uniformly. If aesthetic appearance of the sealer is important, the visual evaluation should include observations of color and texture and comparison to any approved mock-up samples.

**Depth of Sealer Penetration or Coating Thickness**

Measuring penetration depth of sealers is best done in the controlled environment of the lab on small diameter core samples extracted from the treated structure. However, a semi-destructive test
involving drilling a limited number of shallow holes into the concrete surface has been provided in the Guide. This procedure will provide an approximate depth of penetration. In situations where the field-measured depth of penetration is sufficiently low to call into question the application procedure or material performance, a core should be sampled and the depth of penetration should be evaluated in the laboratory. The results of the core test should be considered most accurate. It is generally appropriate that at least three sites be tested in each application.

The depth of sealer penetration or coating thickness is evaluated by taking core samples or by drilling small diameter holes into the concrete surface. Cores about 60 mm (2.4 in.) in diameter are removed and the depth of sealer penetration or coating thickness is determined in a similar manner as used for sealer prequalification on the cube samples. An alternative method is presented that involves drilling small diameter holes at successive depths and spraying the holes with a water-soluble dye solution to identify the depth of the hydrophobic layer. The thickness of non-penetrating coatings can be measured in the field using special gages, such as an ultrasonic thickness gage (ASTM D6132) or Tooke gage (ASTM D4138). Ultrasonic gages are nondestructive, but care must be taken in interpretation of the results because rough surfaces and certain sealer materials can interfere with the ultrasonic pulse. Measurements by destructive means according to ASTM D4138 are considered more accurate.

**Water Absorption Tests of Treated Concrete Surfaces**

Two types of field tests are proposed for evaluating the water absorption of the treated surfaces. One uses core samples that are removed and evaluated in the laboratory [Alberta BT005] and the other uses a field test procedure [given in (Cady and Gannon 1992)].

**Laboratory Analysis of Field Cores for Surface Water Absorption**

Agencies that test the waterproofing performance of sealers on field structures usually take core samples and perform some type of ponding test on the treated surface. The laboratory test proposed is essentially a test used by Alberta to evaluate the waterproofing performance of sealed surfaces by coring and testing the cores in the laboratory. Seventy-five (75) mm diameter cores are removed and the sides are sealed with wax or epoxy. The sealed end is immersed in water for 24 hours and the cut unsealed end is then immersed in water for 24 hours and the difference in weight gain is compared. If the cores are from traffic bearing surfaces, retest samples using Procedure B that includes abrasive blasting of the treated surface to simulate traffic wear.

**Field Test for Surface Water Absorption in Actual Structures**

A basic performance parameter for sealers is the ability of the sealer to reduce moisture ingress. Therefore, the use of a field-applicable surface absorption test is desirable, especially if it is non-destructive to the treated surface. A procedure was recommended by RILEM (RILEM 1980) for use in evaluating absorption of stone. This general approach was adapted for use with sealers as part of Strategic Highway Research Program Project C-101 (Cady and Gannon 1992). The surface absorption method presented in the reports from that project is replicated in Annex 3 of the Guidelines presented in Appendix B.

As noted in the original version of the surface absorption test method, the moisture content of the concrete, the air temperature and the concrete quality will affect the absorption that occurs on the surface. This makes this test less robust than would ordinarily be desired for a field method. However, the main advantage of this method is that this test is non-destructive and can be conducted rapidly in a field setting. The most useful results for the surface absorption test will likely be obtained if testing can be performed when weather conditions are conducive. Since this test measures water penetrating the outer surface of the
treated concrete, it is logical that the concrete surface moisture conditions will influence the test result. There is little that can be practically done to precisely control this condition. While an effort to obtain reproducible results can be made using a propane torch to dry the surface following periods of rain, there is a risk of damaging the sealer or coating. The best approach is to wait for a period of dry weather. Likewise, the influence of temperature on the test results and the ease of testing are also best controlled if the test is conducted at moderate temperatures.

The quality of concrete is also significant to surface absorption performance, since less absorption is likely to occur if the concrete is dense, e.g., as a result of a low water-cementitious materials ratio or the presence of silica fume. A general guideline developed by Cady and Gannon (1992) for interpretation of this surface absorption test is provided with the method, but the most useful interpretation will be obtained by comparisons with similar untreated concrete or with results obtained on the same structure from tests conducted prior to treatment but under the same conditions.

Finally, the test procedure is not applicable or at least very difficult to perform on grooved or tined (skid-textured) surfaces, and this limitation will prevent this method from being easily used on most bridge decks. It is generally appropriate that at least three sites be tested in each sealer application.

Coating Adhesion Tests

The bond strength of coatings is important for good long-term performance. It is recommended that the coating bond strength be measured after the coating cures. ASTM D4541 provides a means to test small areas, usually only 12 mm to 25 mm (1/2-in. to 1 in.) diameter. The ASTM C1583 test method that is used to test the tensile bond strength of repair materials and overlays is another means to evaluate coating bond of a slightly larger area. These methods attach a test bobbin to the coating surface and apply a direct tensile force until failure and are somewhat destructive to the coating. To prevent coating damage the test could be stopped at a predetermined load that indicates acceptable adhesive strength. Bobbins can usually be removed by using a scraper and gentle heating with a torch or heat gun.

Deck or Travel Surfaces

If the sealer is to be applied to a deck during short lane closures, the surface must be cured to reduce tracking of the sealer or damage to the coating and the deck must have adequate skid resistance to allow traffic loading. Tests for time-to-cure and skid resistance are recommended.

Time-to-Cure

Sealers must cure rapidly under a range of temperatures when applied to deck surfaces that must be opened quickly to traffic. Deck surfaces are tined and rough such that puddles of the sealer form in grooves and surface voids. Rapid curing is needed to preserve the effectiveness of the sealer and to not adversely affect the deck skid resistance or result in tracking. Tracking of some sealers can cause serious skid resistance problems with adjacent asphaltic concrete pavements and ramps. Therefore it is important that the sealer is tack free and well cured prior to opening the lane to traffic.

The test includes checking the cure of the surface as well as checking puddles within depressions or tined deck surfaces. Determination of the drying or curing times is similar to the method proposed for the prequalification tests. The surfaces are rated as follows:
Penetrating Sealers:

β Initial drying time - time when the surface becomes dry but liquid sealer can be still present in surface voids and holes.
β Final drying time - time when the entire surface is dry including the surface voids, cracks and holes where sealer puddle.

Coating Non-Penetrating Sealers:

β Gel time - time when the surface becomes tacky and when some sealers will hair when the resin is probed with a toothpick.
β Tack free time - time when the surface soft tacky condition no longer exists when pressed with a finger using moderate pressure and the surface film feels firm.
β Final set time to traffic - time when the coating is hard both on the surface and at all surface holes or depressions and is able to resist traffic forces, such as exerted by the AASHTO T278 *British Pendulum Tester* without visible damage to the coating.

Skid Resistance

It is important that sealers do not reduce the skid resistance of traffic-bearing surfaces. The skid resistance should be tested before traffic is allowed on the sealed area unless a history of data has been developed to ensure that the sealing process does not cause a reduction in skid resistance. This history can be developed on off mainline structures as long as the concrete surface and ambient temperatures are similar. It is also important that the sealer is adequately cured and tack free before traffic is allowed to prevent tracking of the sealer material onto adjacent ramps or AC pavements where skid problems might also occur.

The methods often used to measure skid resistance includes *ASTM E274 Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire*. Other methods such as *AASHTO T278 Standard Method of Test for Surface Frictional Properties Using the British Pendulum Tester* can also be used in the field. It is generally recommended to test the area before treatment or an adjacent area that is identical but untreated as a comparison to the treated area.

**REAPPLICATION AND OTHER CONSIDERATIONS**

Sealer reapplication can be assessed effectively by using the test methods presented in the Material Performance Testing for Routine and Job Site QA Testing section of the Guidelines. Primarily the following tests are useful for determining the need for reapplication:

β Appearance
β Water Absorption Tests of Treated Concrete Surfaces
  - Laboratory Analysis of Field Cores for Surface Water Absorption
  - Field Test for Surface Water Absorption in Actual Structures
β Depth of Sealer Penetration or Coating Thickness
β Coating Adhesion Tests
Appearance

Coating materials can crack, chalk, debond or otherwise degrade with time. Visual inspection of the coating and inspections using a magnifier (10 - 30x illuminated) are good methods to determine if a coating has degraded and if reapplication is needed. Penetrating sealers are more difficult to evaluate visually since the treated surface is not affected by the sealer. Sometimes water sprayed on the treated surface beads up indicating good hydrophobic properties, but often dirt and weathering masks any changes in surface tension provided by the sealer. Wetting treated and untreated areas sometimes results in differences in color, with the untreated area being darker. If clear differences in the color of the treated and untreated areas occur upon wetting, it is likely the penetrating sealer is present and providing some level of protection to the concrete. However, the lack of a clear color change does not necessarily mean that the sealer is not effective and further testing is needed.

Water Absorption Tests of Treated Concrete Surfaces

Two types of field tests are proposed for evaluating the water absorption of the treated surfaces: 1) Laboratory Analysis of Field Cores for Surface Water Absorption, and 2) Field Test for Surface Water Absorption in Actual Structures. Either test can be used to evaluate the need for reapplication. The laboratory test is more accurate, since the concrete condition can be controlled prior to testing. However, core samples are needed for the tests that are destructive to the sealed surface. The field test is non-destructive, but the results can vary depending on the site and concrete conditions. It is best if the test has been performed early in the age of the treatment so the results can be compared to previous performance and the performance of the untreated concrete. If the effectiveness of the sealer is reduced by a selected amount, say 75%, then reapplication should be considered.

Depth of Sealer Penetration or Coating Thickness

Measuring penetration depth of sealers is best done in the controlled environment of the lab on samples extracted from the structure. However, a semi-destructive test involving drilling a limited number of shallow holes into the concrete surface has been provided in the Guide. Either method can provide valuable information on the presence of a hydrophobic surface layer. This procedure is best for evaluating the reaplication of penetrating sealers as coating thickness is unlikely to change over time unless it is subject to abrasion. Penetrants are likely still effective if a significant hydrophobic layer remains. Coatings may maintain thickness but loose effectiveness do to cracking, debonding or other material degradation.

On decks or travel surfaces, coatings or treated deck surfaces can abrade with time and loose effectiveness. In this case, the coating thickness or depth of hydrophobic layer remaining is important. Core samples can be taken and subjected to additional abrasion, per the Draft method, to determine if the sealer will remain effective with additional future abrasion loss. With this evaluation, the sealer can be reapplied before it loses its effectiveness. If the sealer does not lose its effectiveness with additional abrasion reapplication is not necessary.

For deck surfaces it is important that sealers do not reduce the skid resistance. Periodic testing of traffic-bearing surfaces should be performed to determine if additional coating is necessary to maintain the skid resistance or if the coating should be removed if skid resistance cannot be maintained.
The bond strength of coatings is important for good long-term performance. It is recommended that the coating bond strength be measured in at least three areas. If the coating bond is lost, the coating should be removed and a new material applied.

Interpretation of field tests will require the judgment of engineering staff to determine when is the optimum time to reapply sealers. In field applications, similarly exposed but untreated areas on the same structure may serve as control areas for field tests. Test data prior to treatment is also valuable for comparison to current performance. Tests of uncoated areas provide good information on if the sealer is effective or if it should be reapplied. Periodic monitoring allows comparisons of performance over time and provides good insight to determine when the effectiveness of a sealer is reduced or lost.
CHAPTER 6
CONCLUSIONS AND FUTURE RESEARCH RECOMMENDATIONS

CONCLUSIONS

This project was conducted in response to the need identified in NCHRP Synthesis 209Sealers for Portland Cement Concrete Highway Facilities for standard testing protocols for sealer product qualification, quality assurance, application quality control and field testing. To achieve this goal, a review of technical information on sealer test methods published since 1993 (after the NCHRP Synthesis 209 was published) was completed. In addition, a survey was sent to all US and Canadian Departments of Transportation and several foreign transportation agencies to obtain information on what test methods are used to prequalify and evaluate the effectiveness of concrete sealers. Based on this literature review and survey, a draft test method entitled Standard Method of Test for Protective Sealers for Portland Cement Concrete and a draft Guideline entitled Guideline for Quality Assurance, Job Site Quality Control, and Reapplication of Protective Sealers for Portland Cement Concrete were developed.

The draft Standard Method of Test for Protective Sealers for Portland Cement Concrete provides test methods for the sealer product qualification. The “Universal” properties that all sealer must have include vapor transmission properties, resistance to water penetration, resistance to chloride ion (deicer or seawater) penetration, and resistance to outdoor weathering and alkali found in concrete. A set of tests evaluating these properties is proposed for the prequalification of all sealers for concrete. Specific tests are also presented that evaluate important sealer properties used for specific applications including:

- Traffic-bearing deck surfaces (abrasion resistance, skid resistance, and curing time)
- Cold weather freeze-thaw exposure resistance
- Deicer scaling protection of poorly air-entrained concrete
- Sealer effectiveness when applied to wet (SSD) concrete
- Sealer effectiveness when applied at temperature extremes
- Other properties such as appearance and safety

The Guideline for Quality Assurance, Job Site Quality Control, and Reapplication of Protective Sealers for Portland Cement Concrete recommends test protocols for routine product quality assurance and jobsite application quality control as well as guidelines for field testing to assess sealer performance and the need for re-application. Specific test methods for field assessment are included as annexes to the guideline.

The draft test method and guideline were developed for review by AASHTO Highway Subcommittee on Maintenance and for eventual inclusion as replacement of AASHTO M224.

FUTURE RESEARCH

It has been nearly 30 years since NCHRP issued the first project to evaluate concrete sealers, NCHRP Report 244 “Concrete Sealers for Protection of Bridge Structures (D. W. Pfeifer 1981); work done at Wiss, Janney Elstner Associates. This was the first work to evaluate concrete sealers under common testing procedures. Prior to that time, each manufacturer used different tests to show the effectiveness of their products. This early, landmark NCHRP-sponsored work provided a basis for standardized tests for sealer testing. Most manufacturers have had their materials tested to the general methods used in NCHRP 244 as the default tests, lacking any standard test procedures. Others, such as
the Alberta DOT and the European Union have used and expanded the NCHRP 244 procedures into standardized tests, however, no such standard tests have been published by US agencies, such as AASHTO or ASTM. It is the sincere hope of the authors that the proposed methods can be evaluated in a timely manner and that AASHTO can soon produce a standardized test procedure for concrete sealers. The occasion of the 30th anniversary of the NCHRP 244 report, December 2011, would be a fitting inauguration goal for this new test method.

The following recommendations are presented for future research.

1. Validate the proposed draft test method Standard Method of Test for Protective Sealers for Portland Cement Concrete. The proposed draft test method includes methods that are currently used by some agencies and also entirely new test procedures that have not been performed in the laboratory. Tests on several types of sealers, penetrating and non-penetrating, should be performed using the proposed procedures. Evaluation of the timing of the tests, effectiveness of the cube drying and conditioning and the effect of varying moisture gradients that could be produced within the test samples should be evaluated with further research. Based on the testing, modifications to the test procedures should be made and the procedures refined. Finally, the test method should be implemented by AASHTO.

2. Consideration should be given to establishing a standard concrete on which the testing can be performed. This standard concrete might include standard aggregates (such as Ottawa sand) and standard cements or cement chemistry. Precision and bias statements can then be developed by performing round robin tests on selected sealers and concretes.

3. Validate the proposed procedures in the Draft Guideline for Quality Assurance, Job Site Quality Control, and Reapplication of Protective Sealers for Portland Cement Concrete. Several new or rarely used tests or procedures are presented in the draft Guideline. These procedures and tests should be performed for several projects. Based on the project testing, modifications to the Guideline should be recommended and the Guidelines revised and implemented by AASHTO.

4. Develop standard acceptance criteria for qualification testing of sealers in accordance with the Standard Method of Test for Protective Sealers for Portland Cement Concrete and for the Guideline for Quality Assurance, Job Site Quality Control, and Reapplication of Protective Sealers for Portland Cement Concrete. Selection of concrete sealers for agency use is ultimately the responsibility of the specifying agency, and each agency can specify the level of performance necessary for their structures. Sometime different levels of performance are specified by a single agency, depending on the application. However, a standard set of performance criteria is useful to allow more universal testing and acceptance of sealer materials.

5. Improved test procedures are needed in several areas, especially for field testing of sealer performance. Most agencies desire easy, non-destructive tests to evaluate sealer performance in the field. However, these tests are not currently available. In addition, research is needed to understand the optimum and acceptable ranges of concrete and site conditions to apply different types of sealers. The effect of surface carbonation on the sealer effectiveness is not currently addressed. Test methods to easily and rapidly measure the concrete moisture conditions and relevant application parameters are needed.

6. Research is needed to determine the most effective time to reapply sealers and to select sealers based on life cycle costing. Criteria and tests to determine when is the best time to reapply sealers is needed. Research to understand the useful life, anticipated performance, and rate of degradation of sealers in service conditions would aid in applying life cycle cost analysis.
7. Sometimes sealers are used to address special problems such as protecting poorly air-entrained concrete from deicer scaling, reducing the effect of alkali-aggregate reactions (AAR), or for sealing cracks. New test procedures are needed to evaluate the effectiveness of sealers on cracked concrete, containing cracks of various sizes. The effectiveness of sealers to reduce AAR has not been demonstrated on concrete pavements, but they may help reduce deterioration on elevated deck structures that can periodically dry. Further research is needed in this area. Scaling resistance is normally tested using calcium chloride or sodium chloride, however many states use other alternate deicing chemicals, such as magnesium chloride, and these materials may affect scaling differently. Research on the effect of alternate deicers on the effectiveness of sealers to prevent scaling is needed if sealers are to be used for this purpose.

8. Research is needed to determine the effectiveness of sealers on high performance concretes having low permeability. If the concrete has a very low permeability, sealers may not be cost effective since the further reduction in permeability provided by the sealer may not be significant. Testing of various types of sealers on concretes having a range of permeability’s can be used to model sealer performance and estimate relative effectiveness and value.
REFERENCES


RILEM. "Recommended Tests to Measure the Deterioration of Stone and to Assess the Effectiveness of Treatement Methods, Test No. II.4, Water Absorption Under Low Pressure (Pipe Method).* Materials and Structures* 13, no. 75 (May-June 1980): 201-205.


Standard Method of Test for

Protective Sealers for Portland Cement Concrete

AASHTO Designation: *T -Proposed Draft

1. SCOPE

1.1. This method covers test methods and selection criteria for prequalification of sealers for protecting new concrete or prolonging the life of sound, in-service concrete used in highway structures. Sealer testing and evaluation for routine and job site product quality assurance, field performance and re-application are provided in the “Guideline for Quality Assurance, Job Site Quality Control, and Reapplication of Protective Sealers for Portland Cement Concrete”.

1.2. Sealers are divided into two basic types: coatings, which remain on the surface; and penetrants, which penetrate into the concrete to some measurable depth and do not substantially change the appearance of the concrete.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. AASHTO Standards:

- AASHTO M200 Epoxy Protective Coating
- AASHTO M233 Boiled Linseed Oil Mixture for Treatment of Portland Cement Concrete
- AASHTO T22 Comprehensive Strength of Cylindrical Concrete Specimens
- AASHTO T126 Making and Curing Concrete Test Specimens in the Laboratory
- AASHTO T160 Standard Method of Test for Length Change of Hardened Hydraulic Cement Mortar and Concrete
- AASHTO T260 Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials

2.2. ASTM Standards:

- ASTM C33 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
- ASTM C496 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
- ASTM C642 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete
- ASTM C 666 Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing
3. SEALER PROPERTIES

A number of performance categories must be considered when choosing a sealer. There are basic properties that are universally significant for all sealers and other special properties that depend on the intended application. The performance categories include the following:
3.1. **Universal Properties**

All sealers, by definition, are intended to reduce water penetration into concrete and to extend the service life of the concrete. Most sealers for highway structures are used to reduce the ingress of chlorides from deicers or seawater to protect the embedded reinforcing steel from corrosion. Therefore, improving the resistance of concrete to both water and chloride penetration are basic properties of all sealers.

Highway structures are exposed to their environments, so all sealers must work under a variety of environmental conditions (temperature and moisture) and be durable to weathering and alkali present in the concrete. Reasonable curing or drying time is also needed, so that the sealers are not damaged by rain shortly after treatment and to avoid lengthy lane closures of decks when sealers are installed.

Good vapor transmission of sealed surfaces is a preferred property of most sealers, since this property allows moisture that is present or able to penetrate into the treated structure to dry as environmental conditions permit. Non-breathable sealers have limited applications in highway structures, since preventing concrete from drying between rain events limits the sealer effectiveness at slowing moisture-driven deterioration mechanisms. Improperly applied, non-breathable sealers can trap water in concrete and increase moisture-drive deterioration.

Sealers should be effective on both new and older concrete, but specific materials can be tested and specified for each condition.

3.2. **Traffic Exposure Resistance**

Sealers on traveled surfaces must not reduce the frictional properties of the concrete and must be effective after traffic wear. Penetrants require good penetration to remain effective after surface wear, and coatings must be wear resistant. Rapid curing may also be needed if applied during short lane closure periods.

3.3. **Freeze-thaw, Scaling and Concrete Durability**

Sealers can be used to improve the concrete’s resistance to cyclic freezing damage or surface scaling. Special tests recreating cyclic freezing conditions are presented to evaluate these properties. Sealers have also been used to extend the service life of structures with other concrete distress. Such deleterious reactions are highly dependent on site conditions and materials, and no widely useful test can be proposed to characterize the ability of sealer to slow or stop all types of concrete deterioration. However, in a general sense, the ability of sealer to retard moisture ingress will be a determining factor in the likelihood that such reactions will be affected.

3.4. **Adverse Conditions**

It may be necessary to apply the sealer under adverse conditions, such as very low ambient temperatures or very high moisture conditions. In these cases, a sealer must be chosen that will can be installed and offer protection under these adverse conditions.

3.5. **Other Considerations**

*Color* - Color and final appearance may be important for some structures. If color of the treated concrete is important, test blocks or mock-ups should be treated with candidate materials for evaluation prior to use.
**Safety** - Sealers must be safe to store, handle and apply. Several sealer types involve toxic or hazardous components and may not meet local air quality regulations.

**Economy** - It is desirable that the chosen sealer have a low initial cost; however, this should not take precedence over life-cycle costs. Cost-based decision making should include consideration of the sealer effectiveness and the frequency of reapplication necessary to maintain effectiveness.

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### 4. GENERAL SEALER TYPES

#### 4.1. Sealers commonly used for concrete vary widely in chemistry and application rates. The following discusses the most common types of sealers used and provides some general precautions. Review of manufacturer data sheets and recommendations as well as MSDS safety sheets are essential before using any sealer.

#### 4.2. Linseed Oil
Linseed oil is one of the earliest materials to be used to protect concrete. It penetrates the surface and forms a partial barrier to water. It has been used on decks and does not materially change the original frictional properties of the concrete if applied at the proper rate. Emulsions of linseed oil may be less effective and long lasting than solutions. Linseed oil is easily applied and safety hazards are minimal; only routine precautions for handling and using flammable liquids are necessary.

Application of linseed oil may be readily accomplished by brush, squeegee, roller, hand sprayer or power sprayer. For the best results on new concrete surfaces, the concrete should be allowed to dry for about 30 days prior to the application of the compound. The concrete surface should be dry and at a temperature of not less than 10°C (50°F) at the time of application. Two approximately equal applications are best with a 24-hour minimum drying time between applications. To remain effective, concrete surfaces should be recoated annually for two years followed by a bi-annual or tri-annual schedule of treatment. Cleaning of tools and equipment is accomplished by use of kerosene or other petroleum solvent. Use appropriate safety precautions when using these solvents.

#### 4.3. Epoxy Resins
Epoxy is usually considered a coating but may penetrate the concrete slightly depending on the formulation. The two component epoxy resin system forms a sealer that is tough, hard, and resistant to chemicals and weathering. Coating pin-holes (small breaks in the coating that develop during curing) can be a problem but can be avoided by use of a suitable primer or by applying two coats. Also, application when the concrete is cooling helps prevent pin-holes. Thick coatings can flake or peel due to a difference in thermal expansion of the coating and the concrete or due to improper surface preparation. They can also reduce frictional properties and may polish with time. The use of a suitable aggregate spread over the freshly-applied coating greatly improves frictional properties. It is essential that the recommendations of the manufacturer be followed precisely for mixing, application procedures, and equipment use. Recommended safety practices must be followed carefully.

All materials should be within acceptable temperature ranges before mixing. Thorough mixing of the components in the specified proportions is essential. No more should be mixed than will be used within the pot life of the materials. Small-batch mixing can best be done in clean, dry pails or disposable container using a mechanical stirrer, although hand mixing is acceptable if
sufficient care is exercised. For large jobs, specialized continuous mixing equipment should be used.

Application on small areas can readily be made by brush, roller, squeegee, hand sprayer, or other means. Power spray equipment is most effective for covering large areas. For most epoxy formulations, the temperature of the concrete surface should not be less than 15°C (60°F); however, special formulations can be used at lower temperatures.

Equipment used in application must be cleaned using solvent washes before the epoxy sets, as recommended by the manufacturer. Use appropriate safety precautions when using these solvents.

4.4 **Silanes and Siloxanes**
These penetrant materials are widely used. They penetrate into the concrete matrix and react chemically with the concrete to form a hydrophobic surface layer. The effectiveness and depth of penetration is usually related to the amount of active solids content and the amount of material applied. They can be applied in one coat, but usually two or more coats provide better performance.

Normally, these materials should not be applied at temperatures below 0ºC (32ºF) or when the temperature is expected to fall below 0ºC (32ºF) within 12 hours of application. They penetrate thoroughly dry concrete best. Application rates range between 2.45 and 9.82 m²/L (100 to 400 ft²/gallon) depending on surface texture and absorption. Low-pressure airless sprayers, brushes and rollers are commonly used to apply these sealers with enough material to sufficiently saturate the surface of the concrete.

4.5. **Methacrylates**
These materials may be described as a coating or penetrant depending on the formulation. Two coats are usually required. The surface to be treated must be dry and clean. The time needed between coats will vary according to temperature and moisture conditions.

Typically, these materials are not be applied when the temperature is below 10ºC (50ºF), although some methacrylate formulations can be placed at very cold temperatures. A primer is required for some formulations. The concrete surface must be dry. Application rates range from 2.45 to 9.82 m²/L (100 to 400 ft²/gallon). Common methods of application include sprayer, roller, brush and squeegee. Always check safe handling and application procedures.

4.6. **Sodium Silicate**
This material is a penetrant in the form of aqueous solution but is sometimes part of a cementitious coating formulation. Concrete surfaces must be clean and dry at the time of application. The material should not be applied at temperatures below 4ºC (40ºF).

They are usually applied by brush, squeegee or spraying. Some manufacturers’ recommend that the surface should be flushed with water after three to six hours and the flushing be repeated at 24-hour intervals for 72 hours. The recommended coverage rate is typically 4.91 to 7.36 m²/L (200 to 300 ft²/gallon).

4.7. **Urethane**
This material is classified as a penetrant or a coating depending on formulation. Two coats are often required. The concrete surface should be free of loose material, clean, and dry. Some
formulations should not be applied under high humidity conditions. (See manufacturer's recommendations for application and safety information)

Urethane materials can be applied in the temperature range of 4°C to 38°C (40°F to 100°F) with some formulations having allowable application temperatures below freezing. Typical coverage rates include 4.91 to 9.82 m²/L (200 to 400 ft²/gallon). Urethane sealers are best applied with either air atomized or conventional airless sprayer, although brush, roller or squeegee may be used.

4.8. Others

*Coal Tar Epoxy*- Coal tar resins form surface coatings that are hard and durable. They are relatively resistant to many corrosive and abrasive environments. They are more wear resistant when filled with sand and other suitable aggregate. These materials contain curing agents and strong solvents that may cause allergic reactions. They must be handled with caution; recommended safety precautions must be followed. These materials are naturally dark to black in color and may not be desirable in some locations.

*Tar Primer and Seal*- Tars applied to concrete surfaces form a coating that is an effective surface barrier to water. Usually a primer must be used because of wetting difficulties on concrete. These materials may be applied in solution or softened by heat. Due to relatively poor resistance to sunlight, weather and abrasion, these materials should be covered by a suitable bituminous mix.

Tars may be applied by power or hand sprayer, by brush, or by squeegee. The concrete surface to be treated should be dry and clean. The prime coat should be permitted to dry thoroughly before applying subsequent coats. The viscosity will vary with application temperature and the grade of tar, so proper application may require adjustments in the grade selected or constrain the application conditions.

5.0. PREQUALIFICATION TESTS FOR UNIVERSAL PROPERTIES

*Test Overview*- This test procedure outlines the methods and requirements used for the testing of the Universal Properties of concrete sealers and include batching, casting, and storing concrete test cubes for use in the testing of penetrating and film-forming sealers for use on concrete bridge surfaces. These tests are used to prequalify all sealers to be used on highway structures. The properties evaluated include:

- water vapor transmission,
- saltwater absorption,
- chloride permeability,
- sealer penetration depth or coating thickness,
- UV weathering and cyclic saltwater ponding, and
- resistance to alkali.

Methods to characterize the sealer material are also provided and are used to ensure materials provided for project use are the same as the materials submitted and tested for prequalification. A flow chart is provided in Annex 1 that shows the general progression of testing for each prequalification test procedure.
5.0.1 Equipment

5.0.1.1 An electronic weigh scale having a capacity not less than 4000 grams and a sensitivity of 0.1 grams.

5.0.1.2 Conditioning chamber capable of maintaining 50 ±4% RH at 23± 1°C (72 to 75°F), consistent with AASHTO T 160 Standard Method of Test for Length Change of Hardened Hydraulic Cement Mortar and Concrete.

5.0.1.3 Thermostatically controlled oven, accurate within ±2°C (±3.6°F). When oven drying is called for, cool oven to lab temperature before samples are placed in it. Then increase the oven temperature to the specified drying temperature at the rate of no more than 20°C/hr (36°F/hr).

5.0.1.4 Moist cure room complying with ASTM C511, Specification for Moist Cabinets, Moist Rooms and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes.

5.0.1.5 Sandblasting equipment, including a steel plate shield with a 100-mm square opening and a steel plate shield with a 300-mm square opening.

5.0.1.6 Ultraviolet exposure chamber capable of producing 25 to 35 watts/sq. m of ultraviolet radiation over the surface over a 0.6-m$^3$ (6-ft$^3$) area. Lamps should emit at 368 nm. GE F40BL (part number 10526) were used to achieve this irradiance level in NCHRP 244 testing.

5.0.1.7 Freezing-and-thawing apparatus and related testing equipment conforming to the requirements of AASHTO T161.

5.1. Screening Performance Cube Tests for Water Vapor Transmission, Saltwater Absorption, Chloride Permeability, and Sealer Penetration Depth or Coating Thickness

Test Overview: This test procedure outlines the details to manufacture, store and test cubes for testing water vapor transmission, saltwater absorption, chloride permeability and depth of penetration or coating thickness of sealers.

5.1.1 Test Sample Preparation and Treatment

5.1.1.1 Casting and Storing Concrete Test Cube

Select a representative and standard source of cement and aggregates. Use well-graded, normal density aggregates meeting the requirements of meeting the requirements of AASHTO M 6 Standard Specification for Fine Aggregate for Portland Cement Concrete and AASHTO M 80 Standard Specification for Coarse Aggregate for Portland Cement Concrete (ASTM C 33 Standard Specification for Concrete Aggregates) and having a maximum nominal aggregate size of 14 mm to 19 mm (1/2 to 3/4 in). Use rigid molds to produce cubes of 100 mm +/- 1.5 mm (4 inch +/− 0.06 in.) on a side constructed of plastic-treated plywood or other non-absorptive surface. Do not use form oils or release agents that could contaminate the concrete surfaces. The concrete mixture should have a water-cement ratio (w/c) of 0.50 and an air content of 5 to 7 percent. The plastic slump should be between 75 to 125 mm (3 and 5 inches). The concrete should be designed to have a 28-day compressive strength between 27 and 31 MPa (4,000 and 4,500 psi) but his value may vary depending on local materials and testing needs. Keep water/cement ratio, maximum aggregate size, and air content requirements fixed. Use a moderate cement content,
preferably near 300 kg/m$^3$ (505 lbs/yd$^3$). Do not use fly ash or other supplementary materials. Use a chloride-free, lignosulfonate water reducing admixture to obtain the correct slump, if needed. Other ASTM C 494 Type A water-reducing admixtures may be used if they do not contain chloride or other material that may affect the pore structure. Do not use a superplasticizer (HRWRA). Use a Vinsol resin air-entraining admixture unless testing includes the effect of other air-entraining admixtures. Table 1 provides guidelines for a recommended mix design; however, other mix designs can be used if those designs are more typical of the concrete to be treated.

<table>
<thead>
<tr>
<th>Constituents/Properties</th>
<th>Guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water/cement (w/c)*</td>
<td>0.5</td>
</tr>
<tr>
<td>Nominal Maximum Aggregate Size*</td>
<td>14 to 19 mm (1/2 to 3/4 in)</td>
</tr>
<tr>
<td>28-day Compressive Strength (design)</td>
<td>27 to 31 MPa (4,000 to 4,500 psi)</td>
</tr>
<tr>
<td>Entrained Air Content*</td>
<td>5.0 to 7.0%</td>
</tr>
<tr>
<td>Slump</td>
<td>75 to 125 mm (3 to 5 in.)</td>
</tr>
<tr>
<td>Cement Content</td>
<td>300 kg/m$^3$ (505 lbs/yd$^3$)</td>
</tr>
<tr>
<td>Sand Content, % Total Aggregate</td>
<td>40 to 42</td>
</tr>
<tr>
<td>Fineness Modulus of Sand</td>
<td>2.4 to 2.9</td>
</tr>
<tr>
<td>Air Entraining Agent</td>
<td>Neutralized Vinsol Resin or Equivalent</td>
</tr>
<tr>
<td>Water Reducing Agent</td>
<td>Lignosulfonates</td>
</tr>
</tbody>
</table>

* Controlling guideline

5.1.1.2 Sample Fabrication

Fabricate specimens in accordance with AASHTO Test Method T 126 "Making and Curing Concrete Test Specimens in the Laboratory." Measure and account for aggregate moisture contents to ensure that the exact w/c is used. Measure the concrete plastic properties including slump, air content, temperature, and unit weight. Consolidate cubes to minimize the amount of surface voids in the cubes and strike off flush with a wood or magnesium float. Do not steel trowel or aluminum float. Cover with moist towels and plastic, such that the surfaces of the cubes are not marred or damaged but are kept moist. For each batch produced, cast a minimum of three 4 by 8 in. cylinders for compressive strength testing.

Identify the finished surface with a small felt-pen mark. Maintain this face in an upward facing orientation throughout the course of the testing unless otherwise noted. Re-mark the surface whenever it is removed by sandblasting or other procedures.

Demold specimens at the age of 24 ± 2 hours and store samples in moist curing room at 23°C ± 2°C with 100% relative humidity. Test specimens may be kept in storage for a maximum of 182 days before starting testing unless special curing requirements are being evaluated. Do not coat any samples until after a minimum of 42 days of moist curing, unless evaluating the effect of the sealer on new concrete.

Identify each cube to its batch. Prior to use, weigh, number, and label each cube for future identification. Label in a manner that does not affect the water absorption or the accuracy of weighing.
5.1.1.3 Number of samples

For each sealer to be tested, select a minimum of twelve (12) cube samples. A minimum of six (6) of these cubes will serve as untreated control cubes. Conditioning of two (2) additional samples is recommended in case alternate specimens are needed. Report the curing age of each cube sample used.

If the sealer is being tested for use on traffic-bearing surfaces, abrasion testing (Section 6.1) and Time-to-Cure (Section 6.3) testing are required. Abrasion testing will not require any additional samples, but for Time-to-Cure (Section 6.3) testing, four (4) additional cubes are needed (two [2] cubes for each temperature at which curing time is tested).

If the sealer is also being tested for cyclic freezing resistance according to Section 7.1, another six (6) cubes are required.

If optional tests for the Effect of Wet (SSD) Concrete Surface Condition at Time of Sealing (Section 8.1) or for Performance at Temperature Extremes (Section 8.2) are being performed, additional sets of six (6) cube samples are need for each test.

In addition, select a minimum of three (3) cubes to be oven dried for each concurrently-conducted test program (i.e., only one set of cubes for oven drying is needed for each sealer evaluation program even if multiple sealers are tested).

It is suggested that additional cube samples be conditioned for sealing to account for cube variations or damage during the initial steps in the test program. These can then be returned to the moist curing cabinet for reuse if they are not needed.

Note that six (6) concrete test slabs 300 x 300 x 130 mm (12 x 12 x 5 in.) are required for each cyclic weathering test conducted according to Section 5.2. These slabs are cast from the same concrete used for the cubes.

Deicer scaling resistance is performed on three (3) treated and three (3) untreated ASTM C672 test slabs manufactured with non-air entrained concrete according to Section 7.2.

A summary of the cube samples required for the various tests are shown in the following table:

<table>
<thead>
<tr>
<th>Test</th>
<th>Treated Cubes</th>
<th>Untreated Control Cubes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Basic Prequalification</td>
<td>6 (+ 2 alternates recommended)</td>
<td>6</td>
</tr>
<tr>
<td>Time-to-cure</td>
<td>2 per temperature</td>
<td></td>
</tr>
<tr>
<td>Cyclic Freezing</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Effect of Wet (SSD) Surface</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Performance at Temperature Extremes</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
When all specimens are fabricated from the same batch of concrete, assign individual specimens randomly to each set. When the specimens are fabricated from more than one batch of concrete, distribute the individual specimens among each set so that, as close as is possible, an equal number of specimens in each set are taken from each batch.

Examine cubes and do not use cubes having large surface voids or poorly consolidated areas. Check cubes for surface voids and only use cubes with less than 3% of the surface area covered by voids (or 18 square centimeters [2.8 square inches] of void area). Do not include surface voids smaller than 10 mm (0.4 in.) diameter in this measurement. Cubes with more than 3% voids can be used as non-treated control samples.

**Note**—An acceptable estimate of the area of surface voids can be made by measuring the number and diameter of all voids greater than 10 mm (0.4 in.) diameter to the nearest millimeter and calculating the total area assuming each void is a perfect circle.

### 5.1.1.4 Total Moisture Capacity of Cubes and Baseline Chloride Content

After 35 days or more of wet curing, remove three (3) cubes from the moist curing room for determination of the total moisture content. The cubes should include at least one cube from each represented batch of concrete and no less than three cubes total. Determine the saturated surface dry weight ($W_{ssd}$) by drying the surfaces of the cubes with a towel and weighing to the nearest 0.1 grams. Oven dry cubes at 95°C until they reach a constant weight ($W_{od}$), defined as the weight achieved with less than 1/2% change in 24 hours per ASTM C642 Oven-Dry Mass. Calculate the total moisture capacity ($M_{ssd}$) in % by weight as follows:

$$M_{ssd} = \frac{(W_{ssd} - W_{od})}{W_{od}} \times 100, \text{ in } \% \text{ by weight}$$

Split the oven-dried cubes using the procedure outlined in Section 5.1.5. Pulverize one-half of the split cube and test for acid-soluble chloride content in the same manner to be employed in Section 5.1.5.2; this is the baseline chloride content for the concrete.

**Note** — This chloride testing can be performed later in conjunction with chloride penetration testing on treated cubes to be performed in Section 5.1.5. The oven-dried cubes should be stored in sealed plastic bags if testing is to be delayed.

### 5.1.1.5 Adjust Moisture Content of Cubes

After between 42 and 182 days of curing, remove the required number of test cubes (at least 12 per sealer) from the moist curing room, pat surfaces dry and weigh to determine the saturated surface-dry weight of these cubes ($W_{ssd1}$). Dry cubes in the conditioning chamber at 50%RH and 23°C [73°F] with air circulation aided by fans to achieve a moisture condition in each cube representing 70±2% of the mean total moisture capacity ($M_{ssd-m}$) estimated for these cubes in Section 5.1.1.4. Complete drying within 21 days. Adjust fans to change the rate of drying as needed to be consistent with this time constraint.

Calculate the estimated oven-dry weight of each test cube ($W_{od1}$) using the formula:

$$W_{od1} = \frac{W_{ssd1}}{(1 + (M_{ssd-m}/100))} \text{ in grams}$$

where:

$M_{ssd-m} =$ the mean moisture capacity of the cubes from Section 5.1.1.4, in percent.
The target weight after drying for each test cube \( W_t \) is 70±2% of the mean total moisture capacity (\( M_{ssd-m} \)) calculated as follows:

\[
W_t = (0.70 \times (W_{ssd1} - W_{od1})) + W_{od1} \quad \text{in grams}
\]

The allowable difference from this target is ± \( W_t\)-tolerance = 0.02 * (\( W_{ssd1} - W_{od1} \)) in grams

Weigh test cubes daily until the required target weight is obtained. Select six (6) cubes for sealer treatment and six (6) cubes to serve as control cubes. These will divide between chloride penetration and alkali resistance/abrasion test paths. The cubes should be selected so that the difference between the actual and target weights are minimized and to equally distribute different batches of concrete, if present. Extra cubes can be returned to the moist curing room for future use after submerging for 48 hours in water. (There will be two (2) extra cubes if fourteen (14) cubes were selected for conditioning.)

Note — This drying process results in the surface being drier than the interior of the cubes. This simulates normal field conditions. Do not store test cubes in the adjusted relative moisture condition for later use.

5.1.1.6 Specimen Preparation

After conditioning and immediately prior to coating, lightly sand blast all surfaces of each cube to uniformly remove a total of 24.0 ± 2 grams. Blast one face at a time to remove 4.0 grams ± 0.5 grams per face. Use a steel plate shield with a 100-mm square opening to protect the sample edges.

Use sandblasting sand with the following gradation to produce surfaces that are uniform. Lightly brush or air blow the samples with clean, dry air to remove sand or dust prior to weighing.

<table>
<thead>
<tr>
<th>Nominal Opening</th>
<th>% Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>microns</td>
<td>U.S. Standard Sieve</td>
</tr>
<tr>
<td>1180</td>
<td>No. 16</td>
</tr>
<tr>
<td>850</td>
<td>No. 20</td>
</tr>
<tr>
<td>600</td>
<td>No. 30</td>
</tr>
<tr>
<td>425</td>
<td>No. 40</td>
</tr>
<tr>
<td>300</td>
<td>No. 50</td>
</tr>
<tr>
<td>Pan</td>
<td>Pan</td>
</tr>
</tbody>
</table>

5.1.1.7 Apply Sealer

Apply sealer to cube surfaces according to the following procedures by immersion or by applying a known amount of sealer. Weigh cubes before and after treatment or measure the weight of sealer applied and record weights.

Use a maximum of two immersions or coats, unless otherwise directed. Alternate methods to treat samples are also acceptable as long as the cubes are treated uniformly and the application rate is accurately measured.
If the sealer is being tested for use on traffic-bearing surfaces, measure and record drying time and time to traffic per Section 6.3. Subsequent to treatment, maintain cubes in 50%RH and 23°C environment.

Calculate the weight of the sealer applied in grams/sq. m and the surface coverage rate in sf/gal based on the sealer specific gravity and cube surface area. Record the number of immersions or brushings, the drying time between coats, and the coverage rate.

Note—Manufacturers usually have a range of recommended application rates, since different surface conditions and concretes will absorb or require different amounts of sealer or coating. If the minimum recommended application rate is tested successfully, the sealer should perform well at higher application rates. However, the opposite may not be true. For prequalification testing, it is important to ensure that adequate material is applied so that the sealer has the best chance of success and is fairly evaluated. In all cases, it is important that the test results be reported in terms of the application rate used in the pre-qualification tests. Agencies can then specify that the tested rate will be the minimum applied rate in the field.

Note—Some sealers and coatings contain volatile components and should be applied in a fume hood. Keep air velocity to a minimum over the cube surfaces during curing.

5.1.1.7.1 Penetrating sealers applied by immersion

Use the following treatment process for penetrating sealers unless otherwise directed.

Obtain a container to be used for the sealer, a grating that fits over the container, and tongs that can be used to handle the cubes. Fill the container with sufficient sealer and determine the combined weight of the sealer, container, grating and tongs. Immerse the preweighed cube to be treated with the finished surface upward for 2 minutes so that the cube is covered with 10 to 15 mm of sealer. Remove the cube and place it on the grating so any excess sealer is allowed to drip back into the container. When no more sealer is dripping from the cubes and after a minimum of 5 minutes, remove the cube from the grating and determine the combined weight of the contents of the container, grating and tongs, to the nearest 0.1 g. The difference in weights is the weight of applied sealer. Apply a second coat after the first coat visibly dries and between 2 and 24 hours after the first coat (unless otherwise directed), if needed to achieve the minimum manufacturer’s recommended application rate. Record the time at which the sealer is applied. Measure the weight of the second coat in the same manner. Record total weight of sealer applied wet (Wsw).

5.1.1.7.2 Film forming sealers applied by application rate

Apply film forming materials uniformly using a brush or small roller and measure the amount of sealer applied to the nearest 0.1 g, accounting for any sealer remaining on the brush or roller. Support cubes on glass rods or pins during curing such that the coating is not damaged. This may require one face to be coated at a slightly later age to avoid damage to the freshly treated surfaces.

5.1.2 Moisture Vapor Transmission Test

The moisture vapor transmission is determined gravimetrically starting 24 ± 2 hours after the sealer treatment is complete, weigh cubes and maintain cubes in a 50%RH, 23°C environment without fans for 14 days. Measure the cube weights at 0 (W0), 7 (W7), and 14 (W14) days after treatment to the nearest 0.1 gram.
Determine the water loss due to vapor transmission as the weight loss between the 7th and 14th day of drying for the treated (VT\textsubscript{treated}) and untreated (VT\textsubscript{untreated}) cubes as follows.

\[ \text{VT\textsubscript{treated or VT\textsubscript{untreated}} = \frac{(W_7 - W_{14})}{(168 \text{ hrs} \times 0.062 \text{ sq m})} \quad \text{in g/(sq m*hr.)} \]

Calculate the mean vapor transmission VT\textsubscript{m} and VT\textsubscript{un-m} for the treated and untreated cubes, respectively.

Calculate the mean Drying Rate Coefficient (DRC) as follows:

\[ \text{DRC} = \frac{\text{VT\textsubscript{t-m}}}{\text{VT\textsubscript{untreated-m}}} \times 100 \quad \text{in percent (\%)} \]

Note - The calculation of vapor transmission between 7 and 14 days is based on the assumption that all evaporation of the sealer itself takes place during the initial 7-day drying period and that only the solid (non-volatile) components of the sealer remain after that period. Therefore, any additional weight loss is due solely to water vapor transmission.

5.1.3 Waterproofing Performance by Saltwater Immersion Test

Test Overview: The same samples used in the vapor transmission testing are used for measuring waterproofing performance. The treated cubes, which are expected to have retained more moisture during the 14 day vapor transmission test than the control cubes, are dried to achieve the same moisture content as the untreated control samples.

5.1.3.1 Adjustment of Treated Cube Moisture Content

Determine the weight of the cured sealer applied (W\textsubscript{csa}) to the treated cubes as the product of the non-volatile content (Ns) (determined in Section 5.3.3) and the wet applied weight of sealer (Wsw) as follows:

\[ W_{\text{csa}} = Ns \times Wsw \quad \text{(in grams)} \]

Adjust the moisture content of the treated cubes to match the control cubes by the following process. Calculate the target weight of the treated cubes (W\textsubscript{t2}). To do this, determine the moisture content of the untreated cubes after the vapor transmission testing, M\textsubscript{cvt}, which is expected to be equal to or less than the moisture content of the treated cubes as:

\[ M_{\text{cvt}} = \left(\frac{W_{14-\text{untreated}} - W_{od1}}{W_{od1}}\right) \times 100, \quad \text{as percent (\%)} \]

where W\textsubscript{14-untreated} is the weight of the untreated cubes at the end of the vapor transmission test period and W\textsubscript{od1} was estimated for each cube in Section 5.1.1.5.

Determine the mean moisture content in the control cubes (M\textsubscript{cvt-m}) and use the values to determine the target weights for each of the treated cubes as:

\[ W_{t2} = W_{od1} \times (1 + M_{\text{cvt-m}}/100) + W_{\text{csa}} \quad \text{(in grams)} \]

where W\textsubscript{od1} was estimated for each cube in Section 5.1.1.5.

The allowable difference from this target is +/- W\textsubscript{2-tolerance} = 0.02 * (W\textsubscript{ssd1} - W\textsubscript{od1})
Dry the treated cubes in an oven at a maximum temperature of 60°C (140°F) or in a drying room with fans until the target weight is achieved. After conditioning, weigh cubes at room temperature.

While treated cubes are being conditioned, keep the control cubes in individually sealed, greater than 6-mil thick plastic bags to minimize changes in moisture condition.

**Note**—When oven drying samples, use a thermostatically controlled oven that it accurate within ±2°C. Cool oven to lab temperature before inserting cubes and then increase the oven to the specified drying temperature at a rate of not more than 20°C/hr. As an alternate method, conditioning of treated cubes can also be performed by drying in the 50% RH room with fans per Section 5.1.1.5.

### 5.1.3.2 Immersion and Saltwater Absorption

Immediately before immersion, determine the weight of each cube \( W_{i0} \) to the nearest 0.1 gram.

Immerse cubes with the finished surface upward in 15% (by wt.) sodium chloride solution at 23 ± 2°C. Keep cubes 25 to 35 mm (1 to 1-3/8 in.) below the surface of the solution and support such that all surfaces are freely exposed.

Remove cubes after 168 ± 1 hours (7 days), towel surface dry and weigh to the nearest 0.1 gram \( W_{i7} \).

Calculate the weight gain during immersion \( \Delta W_{i7} \) over 7 days for each cube as

\[
\Delta W_{i7} = \frac{W_{i7} - W_{i0}}{W_{i0}} \times 100, \text{ as percent}
\]

Determine the mean weight gain for the treated and untreated cubes and calculate the Saltwater Absorption Ratio (SAR) of the treated cubes as a percent of the average absorption of untreated control cubes as follows:

\[
\text{SAR} = \left( \frac{\Delta W_{i7,\text{treated-m}}}{\Delta W_{i7,\text{untreated-m}}} \right) \times 100, \text{ as percent at } 7 \text{ days,}
\]

where:

\[
\Delta W_{i7,\text{treated-m}} = \text{mean weight gain for the treated cubes; and}
\]

\[
\Delta W_{i7,\text{untreated-m}} = \text{mean weight gain for the untreated control cubes.}
\]

### 5.1.3.3 Initiate subsequent testing

Return three treated cubes and three control cubes to the saltwater immersion tank, and test in accordance with Section 5.1.5 for chloride ion penetration. These treated cubes are also to be used to determine the depth of sealer penetration or coating thickness per Section 5.1.6. The three other treated cubes and three other control cubes are tested for alkali resistance following test procedures in Section 5.1.4. These treated cubes are then tested for abrasion resistance if the sealer is being evaluated for traffic exposed surfaces.

### 5.1.4 Alkali Resistance

Immediately after the immersion test, place three (3) treated and three (3) untreated control cubes in a solution of 0.1N potassium hydroxide solution (5.6 g/l) to fully cover the test cube with a head of 25 to 35 mm (1 to 1-3/8 in.). Securely cover container and store in laboratory air [23 ± 1°C (72 to 75°F)] for 21 ± 0.1 days. Remove cubes, rinse and pat dry. Dry the cubes in an oven at 60°C (140°F) until they reach their target weight before the first immersion test \( W_0 \) ± 2 g, as calculated in Section 5.1.3.1.
Perform a second immersion test per Section 5.1.3. Determine the mean weight gain for the treated and untreated cubes and calculate the weight gain during immersion ($\Delta W_{i7}$) for each cube. Calculate the Saltwater Absorption Ratio After Alkali Exposure (SAR$_{ALKALI}$) as follows:

$$SAR_{ALKALI} = \left( \frac{\Delta W_{i7\text{-treated-alk-m}}}{\Delta W_{i7\text{-untreated-alk-m}}} \right) \times 100, \text{ as percent at 7 days}$$

where:

$\Delta W_{i7\text{-treated-alk-m}}$ = mean weight gain for the treated cubes after alkali exposure; and
$\Delta W_{i7\text{-untreated-alk-m}}$ = mean weight gain for the untreated control cubes after alkali exposure.

If sealer is being tested for traffic-bearing surfaces, prepare treated and untreated control cubes for abrasion testing per Section 6.1.

5.1.5 Chloride Penetration Test

Following the determination of the Saltwater Absorption per Section 5.1.3.2, continue saltwater immersion with three (3) treated and three (3) untreated control cubes. At 14 and 21 days of saltwater immersion, rinse cubes with tap water and surface dry cubes. Weigh cubes to the nearest 0.1 grams and record as $W_{i14}$ and $W_{i21}$. Return cubes to the saltwater after weighing.

Calculate the weight gain during the 14- and 21-day immersion periods ($\Delta W_{i14}$ and $\Delta W_{i21}$) for each cube as:

$$\Delta W_{i14} = \frac{(W_{i14} - W_{io})}{W_{io}} \times 100 \text{ as percent; and}$$
$$\Delta W_{i21} = \frac{(W_{i21} - W_{io})}{W_{io}} \times 100 \text{ as percent}$$

Determine the mean weight gain for the treated and untreated cubes and calculate the Saltwater Absorption Ratio after 14 and 21 days (SAR$_{14}$ and SAR$_{21}$, respectively) of the treated cubes as a percent of the average absorption of control cubes as follows:

$$SAR_{14} = \frac{\Delta W_{i14\text{-treated-m}}}{\Delta W_{i14\text{-untreated-m}}} \times 100, \text{ as percent at 14 days,}$$
$$SAR_{21} = \frac{\Delta W_{i21\text{-treated-m}}}{\Delta W_{i21\text{-untreated-m}}} \times 100, \text{ as percent at 21 days,}$$

where:

$\Delta W_{i14\text{-treated-m}}$ = mean weight gain for the treated cubes at 14 days;
$\Delta W_{i14\text{-untreated-m}}$ = mean weight gain for the untreated control cubes at 14 days;
$\Delta W_{i21\text{-treated-m}}$ = mean weight gain for the treated cubes at 21 days; and
$\Delta W_{i21\text{-untreated-m}}$ = mean weight gain for the untreated control cubes at 21 days;

5.1.5.1 Cube Splitting

After 21 days of immersion testing, rinse the cube surfaces with tap water and towel dry then split each treated cube in half using the following procedure: Center the cube in a compression testing machine with an approximately 10-mm (3/8-in.) diameter steel rod centered on the top and bottom cube faces. The finished face should be on top as the cube is positioned in the compression testing machine. Apply a compressive force to the cube to cause the cube to fracture
in two generally equal halves. Test one half of each cube for chloride content and test the other half for sealer penetration depth or coating thickness per Section 5.1.6.

5.1.5.2 Chloride sampling and testing

Sample the concrete for chloride testing from the treated and untreated cubes in the same manner, with the exception that the treated cube samples will be taken from half cubes split according to Section 5.1.5.1. It is not necessary to split the untreated cubes, but the sampled face should not be the finished face.

Cut or core the half of the treated cube sample reserved for chloride content testing such that the surface to be sampled is centered on an intact, unfractured face. Remove 20 mm (3/4 in.) of concrete from the edges of the cube to prevent sampling of concrete in which chloride penetration may have occurred from two faces. Obtain test samples at the following depths to provide a profile of the chloride penetration: 6-12, 15-21, 24-30, and 33-39 mm (1/4 to 1/2, 5/8 to 7/8, 1 to 1-1/4, and 1-3/8 to 1-5/8 in.) Do not include slices taken at depths less than or greater than this minimum and maximum depth in the calculation of total chloride ingress below. Dry samples before pulverizing.

Determine the acid-soluble chloride ion content at each depth in accordance with the procedures of AASHTO T260 Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials or ASTM C1152 Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete.

The results of the chloride penetration test are to be compared in terms of the total chloride absorbed between 6-42 mm (1/4 to 1-5/8 in.) This is estimated by calculating the area under the chloride concentration versus depth curve. The total chloride ingress (TC) for each sample is given by:

\[ TC = \sum_{n=1}^{4} \left( \frac{C_n+C_0}{2} \right) \left( d_n - d_{n-1} \right) \times \left( \frac{d_n+2}{2} - \frac{d_{n-1}+2}{2} \right), \text{ as kg/sq. m. (lbs/sq. ft)} \]

where:
- \( C_n \) = the chloride ingress in slice \( n \) for each sample. This is calculated as the concentration measured in slice \( n \) minus \( C_0 \), which is the baseline chloride concentration in oven dried cubes measured as directed in Section 5.1.1.4, as kg/ cu. m (lbs/cu. ft.)
- \( d_n \) = the midpoint depth of slice \( n \) for each sample, in meters (feet).

If the slice depths and thicknesses match those given above, TC can be determined by:

\[ TC = \left( \frac{C_0+C_1}{2} + \frac{C_1+C_2}{2} + \frac{C_2+C_3}{2} + \frac{C_3+C_4}{2} \right) \times 0.009 \text{ m}, \text{ as kg/sq. m. (lbs/sq. ft)} \]

Determine the mean total chloride ingress for the treated and untreated cubes, and calculate the Relative Chloride Ratio (RCR) as a percent of the untreated control samples as follows:

\[ RCR = \left( \frac{TC_{\text{treated-m}}}{TC_{\text{untreated-m}}} \right) \times 100, \text{ in percent} \]

where:
TC\textsubscript{treated-m} = mean total chloride ingress for the treated cubes;
TC\textsubscript{untreated-m} = mean total chloride ingress for the untreated cubes;

Note—Alternatively, the portion of the cores with depths extending over 6-42 mm (1/4 to 1-5/8 in.) can be pulverized and the chloride contents compared to the untreated control samples. While the RCR calculated in this method is expected to be similar, this method does not provide as much useful information about the rate and progress of chloride ingress as testing the chloride profile.

5.1.6 Depth of Penetration or Coating Thickness
Examine the second half of the treated cubes split according to Section 5.1.5.1 for depth of penetration or coating thickness.

Oven dry the half cube at 60\(^\circ\)C (140\(^\circ\)F) for 2 to 4 hours. Cool in laboratory air to room temperature, and determine depth of penetration or coating thickness using the most applicable of the following two methods:

5.1.6.1 Depth of Penetration
Immerse the fractured sample face in a dye solution [red food coloring or Sulfonazo III sodium salt dye] or spray dye solution onto the fractured surface. After 30 seconds, allow excess dye to run off surface and let the surface air dry.

Determine the depth of penetration of the sealer by examining the dye-treated surface and measuring the depth of sealer penetration at 10-mm (0.4 in.) intervals within the center 50 mm (2 in.) of each treated face (6 readings per cube face). Use a microscope or magnifier to aid in the measurement, and measure to the nearest 1 mm (0.04 in.) Record the average, minimum and maximum depths of penetration.

Note—Avoid measuring the depth of sealer penetration if reading is affected by the presence of aggregate particles. Adjust the measurement location slightly if able or do not include these measurements in the average, minimum, or maximum readings.

5.1.6.1 Coating Thickness
Cut the cube parallel to the intact surface to remove the irregular broken surface. Lap this surface, so that a well-defined boundary between the coating and concrete surface is visible. Soft or friable coatings may need to be encapsulated in clear epoxy resin before cutting and polishing.

Measure the coating thickness by examining the surface at 10-mm (0.4 in.) intervals within the center 50 mm (2 in.) of each treated face (6 readings per cube face). Using a stereomicroscope with a magnification of at least 10x, measure to the nearest 0.025 mm (0.001 in.) Record the average, minimum and maximum coating thickness.

Note - Coating thickness can sometimes be measured by non-destructive or minimally destructive techniques. Use ASTM D6132 for evaluating coating thickness nondestructively with an ultrasonic gage. Care should be taken when using ultrasonic gages that the measurement technique is calibrated on a similar system, because, especially on rough surfaces such as concrete, results can be difficult to interpret. Use ASTM D4138 for measuring coating with a minimally destructive technique. Tooke gages are commonly available equipment that are suitable for use in this technique. If alternative methods are used, measure coating thickness at least 24 times on representative areas of each cube.
5.2. **Weathering and Saltwater Resistance**

*Test Overview* - Weathering resistance is evaluated using slab specimens subjected to cyclic ponding with saltwater and drying by heat and exposure to ultraviolet light. This test was first developed as the NCHRP 244 Concrete Sealers for Protection of Bridge Structures - Series IV - Southern Climate Test. The effectiveness of each candidate sealer is expressed as the percent by which chloride absorption is reduced as compared to uncoated concrete. If the sealer is being tested for use on traffic-bearing surfaces, an additional slab is cast for skid resistance testing and coating bond strength.

5.2.1 **Casting and Storing Concrete Test Samples**

Cast six (6) concrete test slabs 305 x 305 x 76 mm (12 x 12 x 3 in.) in size using the same concrete materials, mixes and procedures used to cast the cube samples in Section 5.1.1. The slabs should be produced with the large faces on the top and bottom. Use the bottom formed surface of the slabs as the treated test surface. Do not use form oil or release agents that could affect the test results. Cover slabs with wet cotton toweling and plastic. Demold specimens at the age of 24 ± 2 hours. Wrap slabs with wet cotton toweling and place slabs in plastic bags that are a minimum of 6-mil thick to an age of 21 days.

**Note** - It is recommended that the slabs be cast on Monday, so ponding can begin at 42 days. However, the start of ponding can be adjusted to accommodate other casting days.

After the initial curing of 21 days, towel dry, weigh to the nearest 2 grams and dry slabs at 50%RH and 23°C for 24 hours, and sandblast the bottom formed surface uniformly to remove a total of 36.0 ± 3 grams. Use a steel plate shield with a 300-mm (12-in.) square opening to protect the sample edges. Store the slabs at 50%RH, 23°C without the aid of fans or air circulation for an additional 6 days prior to treatment with sealer. Determine and report the percent moisture loss of the slabs (wet weight minus the dry weight) as well as the weight loss during, as percent.

5.2.2 **Apply Sealer and Sample Conditioning**

At an age of 28 days, treat the test surface of three (3) slabs with the sealer to be tested. Apply sealer to the test surface at the desired application rate. Weigh the container used to hold the sealer, brush and sealer between each coat, and continue to apply sealer until the desired application rate is achieved. Note the number of coats required, the drying time between coats and the total quantity applied. Alternate methods to treat samples are also acceptable as long as the slabs are treated uniformly and the application rate is accurately measured. Calculate the wet weight of the sealer applied and the surface coverage rate in grams/sq. m (lb/sf, or convert to sf/gal) based on the sealer weight applied and treated surface area. Condition the slabs at 50%RH and 23°C.

**Note** - For coating systems, it may be useful to measure the coating bond strength before and after exposure using ASTM D4541 or C1583 and report the results in MPa (psi). Measurement of bond strength before exposure would require that additional samples be prepared. Test the treated surface for skid resistance per Section 6.2, if sealer is being tested for traffic-bearing surfaces.

At an age of 35 to 41 days, coat the sides of the test slabs with two coats of a high-solids epoxy resin to minimize lateral moisture movement. Condition slabs at 50%RH and 23°C until ponding...
begins. During this drying period, apply 25-mm (1-in.) high acrylic dikes to the top edges of the slabs to contain saltwater.

5.2.3 **Cyclic Ponding Exposure**
At the closest Monday or Thursday after an age of 42 days, pond all six test slabs with 12 mm (½-inch) of 15% sodium chloride solution at 15 to 23°C (60 to 73°F) for 24 hours. Drain the solution, rinse the surface with tap water, and place the slabs in an ultraviolet exposure chamber at 38 ± 3°C (100 ± 6°F). Expose the slabs to ultraviolet light for alternating exposures of 48 hours (Tuesday to Wednesday) and 72 hours (Friday to Monday). Repeat this weekly exposure cycle for a total exposure of 14 complete weeks (98 days). Record the actual times that slabs are under ponding and UV exposure.

During drying, place slabs in an ultraviolet exposure chamber that provides an irradiance between 25 to 35 watts/sq. m of ultraviolet radiation at a wavelength of 368 nm. Provide no less than 750 watt-hours/sq. m/day or 50,000 watt-hours/sq. m of UV exposure at a wavelength of 368 nm and no less than 672 hours of saltwater ponding over the 14 week period.

**Note**—A standard 48-in. long fluorescent fixture with 40-watt ultraviolet lamps (W-F40BL, GE part number 10526) supported 6 in. above the slabs operating at 430 milliamps will approximate the specified exposure of 25 to 35 watts/sq. m. These lamps emit at 368 nm. The irradiance in the UV ranges decreases with time so the actual irradiance should be confirmed or fresh bulbs used for each test.

5.2.4 **Evaluation**
Inspect the samples every 2 weeks during the exposure and note any deterioration of the surface or coating. After the exposure is complete, rinse the slab surface with tap water.

5.2.4.1 **Skid Resistance**
If testing the sealer for use on traffic-bearing surfaces, test the skid resistance on the rinsed exposed surfaces of one treated slab and one untreated control slab per Section 6.2.

5.2.4.2 **Chloride Penetration**
Extract a nominally 100-mm (4-in.) diameter core from the center of each slab. Obtain test samples at the following depths to provide a profile of the chloride penetration: 6-12, 15-21, 24-30, and 33-39 mm (1/4 to 1/2, 5/8 to 7/8, 1 to 1-1/4, and 1-3/8 to 1-5/8 in.) Do not include slices taken at depths less than or greater than this minimum and maximum depth in the calculation of total chloride ingress below. Dry samples before pulverizing.

Determine the acid-soluble chloride ion content at each depth in accordance with the procedures of AASHTO T260 *Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials* or ASTM C1152 *Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete*.

The results of the chloride penetration test are to be compared in terms of the total chloride absorbed between 6-42 mm (1/4 to 1-5/8 in.) This is estimated by calculating the area under the chloride concentration versus depth curve. The total chloride ingress (TCw) for each weathering sample is given by:
where:
\[ C_n = \text{the chloride ingress in slice } n \text{ for each sample. This is calculated as the concentration measured in slice } n \text{ minus } C_0, \text{ which is the baseline chloride concentration in oven dried cubes measured as directed in Section 5.1.1.4, as kg/ cu. m (lbs/cu. ft.)} \]
\[ d_n = \text{the midpoint depth of slice } n \text{ for each sample, in meters (feet).} \]

If the slice depths and thicknesses match those given above, TC can be determined by:
\[
TC_w = \left( \frac{C_1 + C_2}{2} (d_2 - d_1) + \left( \frac{C_3 + C_4}{2} (d_4 - d_3) \right) \right) \text{, as kg/sq. m. (lbs/sq. ft)}
\]

Determine the mean total chloride ingress for the treated and untreated cores, and calculate the Relative Chloride Ratio (RCRw) for the weathering slabs as a percent of the untreated control samples as follows:
\[
RCR_w = \left( \frac{TC_{w\text{-treated-}m}}{TC_{w\text{-untreated-}m}} \right) \times 100, \text{ in percent}
\]

where:
\[ TC_{w\text{-treated-}m} = \text{mean total chloride ingress for the treated cores;} \]
\[ TC_{w\text{-untreated-}m} = \text{mean total chloride ingress for the untreated cores;} \]

5.2.4.3 *Depth of Penetration or Coating Thickness*
Take a second nominally 100-mm (4-in.) diameter core from the center of each slab. Split the core in splitting test conducted according to the procedure outlined in ASTM C496 *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*, and measure the depth of penetration or coating thickness at 10-mm increments within the middle 2 in. of each half of the core according to procedure outlined in Section 5.1.6. (Note: This provides six duplicate measurements.)

5.3. *Material Characterization Tests*
*Test Overview* - Material characterization tests are used to collect data on the basic characteristics of the sealer material, including chemical composition, solids content, and specific gravity. These tests are primarily used to gather baseline data on compositions of sealers submitted for the prequalification stage testing and are used for comparison of tests on materials sampled during routine and job-site quality assurance processes. These tests should be performed on the same batch of material that is used for the product prequalification tests, and the data should be saved and made available for use in subsequent quality assurance processes.

5.3.1. *Spectroanalysis (FTIR)*
Fourier transform infrared (FTIR) analysis provides a chemical fingerprint of a material system that can be used to compare one material to another and to compare batches of a particular material. Analysis can be carried out by transmission or by internal reflection (usually with an attenuated total reflectance accessory). Analyses of the same material may not be comparable when data is collected in different modes (i.e., transmission vs. reflectance) or when different sample preparation techniques are used. When comparing spectra, it is important to ensure that
data was collected under the same conditions, including sample preparation and instrument conditions. Materials can be analyzed as-received (including any pigment or filler), or after processing, such as dissolution or solvent extraction. Comparative analyses need to be carried out with the same sample preparation techniques. Review and familiarization with the referenced test methods is essential for correctly performing the spectroanalysis, including sample preparation and data analysis.

5.3.1.1 Procedure
Use ASTM E1252 for testing in transmission. Use ASTM E573 for testing by reflectance (attenuated total reflectance or other method).

5.3.2. Gas Chromatography (GC)
Gas Chromatography (GC) can be used in addition to or in combination with FTIR as a method for chemical analysis of sealer materials. The procedure used to analyze the sealer by GC will depend on the instrument, column type, and sealer being analyzed. The results will be affected by the instrument and run parameters, such as choice of stationary phase, carrier gas and carrier gas flow rate. Once a procedure is developed (carrier gas, carrier gas flow rate, stationary phase, etc.), the procedure should be followed for each additional analysis to provide data suitable for comparison. See ASTM E260 for guidance on the operation of packed column GC apparatus.

5.3.2.1 Procedure
For each material type, define a suitable set of operating parameters. These parameters include: stationary phase, injector, detector, carrier gas, carrier gas flow rate, column temperature, run time, injection volume, and other applicable parameters. Obtain the chromatograph using the defined operating parameters.

5.3.3. Solids Content
Measuring solids content of sealer materials is useful to monitor the uniformity of the material from lot to lot. Unlike spectroanalysis, which gives a qualitative spectrum, solids content measurements provide a quantitative measurement of non-volatile content (Ns). Fillers or pigments will be measured in solids content measurements, and changes in the type (density) or concentration of fillers or pigment can lead to different solids content measurements. Changes in solvent may not be apparent in solids content measurements. This measurement is used for quality control purposes and also to calculate the weight of sealer applied to the test samples.

5.3.3.1 Procedure
For silanes, siloxanes, or silane/siloxane blends, test using ASTM D5095. For other types of sealers, test using ASTM D2369.

5.3.4. Specific Gravity
Changes in solvent or solids concentration will affect specific gravity. Specific gravity provides a quantitative method of evaluating changes in a material from batch to batch. ASTM D891 is suitable for both solvent-based and water-based systems.

5.3.4.1 Procedure
Test the sealer per ASTM D891, Method A or Method B.

5.4. Reporting

5.4.1 Test Sample Preparation and Treatment
Reporting shall include:
1. Concrete raw material sources including aggregate source and gradation, cement source and mill certificate, all admixture sources and chemical compositions.
2. Complete description of the mix design and concrete properties, including casting date of cube test samples and the cube age at treatment.
3. Concrete plastic properties including slump, air content, temperature, and unit weight.
4. Concrete compressive strength at 28 days.
5. Record the sandblasting procedures used to prepare the samples including grit type, air pressure and nozzle distance from sample.
6. Moisture capacity of concrete ($M_{\text{iso}}$).
7. Sealer information, lot number, date manufactured and MSDS.
8. Method of sealer application, number of coats, and the application rate for each sample. Note the time required for the surface of the cubes to dry after each coat and time between coats.
9. Initial drying time and final drying time at test application temperature.

5.4.2. **Moisture Vapor Transmission Test**

*Reporting shall include:*
1. The Drying Rate Coefficient (DRC).

5.4.3. **Waterproofing Performance by Saltwater Immersion Test**

*Reporting shall include:*
1. The moisture content of cubes after the vapor transmission testing $M_{\text{ct}}$
2. The weight gain during immersion $\Delta W_{\text{ci}}$ over 7 days of each cube.
3. Saltwater Absorption Ratio (SAR) at 7 days for the given application rate.

5.4.4. **Alkali Resistance**

*Reporting shall include:*
1. Saltwater Absorption Ratio After Alkali ($\text{SAR}_{\text{ALKALI}}$) at 7 days for the given application rate.
2. The ratio $\text{SAR}_{\text{ALKALI}}/\text{SAR}$

5.4.5. **Chloride Penetration Test**

*Reporting shall include:*
1. Saltwater Absorption Ratio after 14 and 21 days ($\text{SAR}_{14}$ and $\text{SAR}_{21}$)
2. The chloride concentration of the treated and control cubes in tabular or graphic format, giving the concentration and the depth range for each sample for each cube. Report the total chloride (TC) content for each sample.
3. The relative chloride ratio (RCR) in tabular format, giving the RCR and the depth range for each sample for each cube.

5.4.6. **Depth of Penetration or Coating Thickness**

*Reporting shall include:*
1. Dye used for depth of penetration test, if applicable
2. Average, minimum and maximum depth of sealer penetration or coating thickness for given application rate or follow the reporting requirements for the relevant coating thickness standard method.

5.4.7. **Weathering and Saltwater Resistance**

*Reporting shall include:*
1. Aggregate source, gradation and a complete description of the mix design and concrete properties.
2. Concrete plastic properties including slump, air content, temperature, and unit weight.
3. Method of sealer application, number of coats, and the application rate for each sample. Note the time required for the surface of the cubes to dry after each coat.
4. Results of the visual inspection of the surface over the duration of the test compared to the control slab.
5. The chloride concentration of the treated and control cores in tabular format, giving the concentration and the depth range for each sample for each core.
6. The relative chloride ratio (RCR) in tabular format, giving the RCR and the depth range for each sample for each core.
7. Average, minimum and maximum depth of sealer penetration or coating thickness for given application rate or follow the reporting requirement for the relevant coating thickness standard method for the given application rate.
8. Report the coating bond strength, if measured, in MPa (psi).

5.4.8. Material Characterization Tests

Reporting shall include:
1. Dated FTIR spectrum (or spectra) with peak positions labeled, and sample preparation and analysis conditions.
2. Dated gas chromatogram and any other information (component identification or quantification) provided, along with collection condition and details of sample preparation.
3. Solids content (% volatiles) as required in the relevant ASTM method.
4. Specific gravity as required in the relevant ASTM method.

6.0. SEALERS FOR TRAFFIC BEARING SURFACES (T)

Test Overview - This test evaluates the effectiveness after abrasion for sealers that will be used on bridge deck surfaces or other surfaces exposed to traffic wear or abrasion. After performing the initial absorption test and subsequent absorption after alkali tests described in Section 5.1.3 and 5.1.4, the test samples are abraded by sandblasting and tested again for waterproofing performance. Skid resistance is also important for deck surfaces and should be measured on both freshly coated surfaces and weathered surfaces. Test slabs used for the Weathering and Saltwater Resistance tests in Section 5.2 are used for testing skid resistance. Further, the sealers used on traffic-bearing surface will often need to be placed during short lane closure periods, and so must cure quickly at a range of temperatures.

6.1. Effect of Surface Abrasion on Waterproofing Performance

6.1.1. Sample Conditioning
After performing the immersion tests following alkali exposure in Section 5.1.3 and 5.1.4, rinse and pat dry the same set of three treated and three untreated control cubes. Dry the cubes in an oven at 60°C (140°F) until they reach their target weight before the first immersion test (Wt2) ± 2 g as calculated in Section 5.1.3.1.

6.1.2. Surface Abrasion
Use one of the following two procedures depending on whether the sealer is a penetrating sealer or a surface coating.

6.1.2.1 Surface Abrasion for Penetrating Sealers
Once the drying is complete, sandblast the entire surface of the cubes to evenly remove an equal amount of material from all sides of the treated and untreated cubes. Follow the guidelines given in Section 5.1.1.6. Blast only one side at a time and mechanically shield the other faces from the sandblast spray. Maintain the nozzle at a 90° angle to the face being blasted. Lightly blast the
cube face and monitor the cube weight often in order to achieve the weight loss per cube side of 12 ± 1 g and a cumulative weight loss for the six sides of 72 g ± 2 g.

6.1.2.2 Surface Abrasion for Surface Coatings

Once the drying is complete, lightly blast the faces of the untreated control cubes to achieve a weight loss per cube side of 12 ± 1 g and a cumulative weight loss for the six sides of 72 g ± 2 g. During blasting of the untreated control cubes, determine the average amount of sand required to blast each control cube to achieve the required weight loss. Do this by proportioning out a known amount of blasting sand used in short-duration blast events.

Subject the treated cubes to the same abrasion exposure (i.e., use the same amount of sand and the same technique used to blast the control cubes) as was done for the control cubes. Pre-weigh the amount of sand needed for each sealed cube face before blasting.

During all blasting, blast only one side at a time and mechanically shield the other faces from the sandblast spray. Maintain the nozzle at a 90° angle to the face being blasted. Maintain a constant distance between the nozzle and the cube face, measure and record this distance.

6.1.3. Immersion Testing

Repeat the cube immersion test per Section 5.1.3. Determine the mean weight gain for the treated and untreated cubes and calculate the weight gain during immersion \(\Delta W\) for each cube. Calculate the Saltwater Absorption Ratio After Abrasion (SAR\text{ABRASION}) as follows:

\[
\text{SAR\text{ABRASION}} = \frac{\Delta W_{\text{treated-abr-m}}}{\Delta W_{\text{untreated-abr-m}}} \times 100, \text{ as percent at 7 days}
\]

where:

\(\Delta W_{\text{treated-abr-m}}\) = mean weight gain for the treated cubes after abrasion exposure; and

\(\Delta W_{\text{untreated-abr-m}}\) = mean weight gain for the untreated control cubes after abrasion exposure.

6.2. Skid Resistance

Test Overview - The Skid Resistance Test is conducted during the execution of the test outlined in Section 5.2 Weathering and Saltwater Resistance.

The test is first performed shortly after the slabs have been sealed as outlined in Section 5.2.2. Measure the skid resistance of one treated test slab and one untreated test slab at the final drying time or tack free time, as determined by Section 6.3, but no later than 24 hours after coating in accordance with AASHTO T278 Standard Method of Test for Surface Frictional Properties Using the British Pendulum Tester. Follow the AASHTO T278 test procedures and repeat the test at a minimum of three locations on each slab. Note any changes or damage to the sealed or coated surface. Identify and mark the slabs tested for skid resistance.

At the conclusion of the accelerated weathering test in Section 5.2.3 and before core samples are taken, measure the skid resistance according to AASHTO T278 of the same treated and untreated test slab surfaces tested previously.

Record the test conditions, sealer curing time at test, skid resistance values (British Pendulum Number [BPN]) and note any damage to the coating or sealed surface.

Calculate the Skid Resistance Coefficient (SRC) before and after weathering as follows.
SRC_{unweathered} = \frac{SR_{treated-unw}}{SR_{untreated-unw}} \times 100, \text{ as percent}

SRC_{weathered} = \frac{SR_{treated-w}}{SR_{untreated-w}} \times 100, \text{ as percent}

where:

SR_{treated-unw} = \text{skid resistance value (BPN) of the treated area before weathering}

SR_{untreated-unw} = \text{skid resistance value (BPN) of the untreated area before weathering}

SR_{treated-w} = \text{skid resistance value (BPN) of the treated area after weathering}

SR_{untreated-w} = \text{skid resistance value (BPN) of the untreated area after weathering}

Note—As an alternate method, a field trial can be installed and tested using ASTM E274 Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire. Place the sealer on the test area and allow to cure until final set (time to traffic) per Section 6.3 has been achieved. Test the Skid resistance of the treated and untreated areas.

6.3. Time-to-Cure

Test Overview - Sealers must cure rapidly under a range of temperatures when applied to traffic-bearing surfaces that must be opened quickly to traffic. Deck surfaces are tined and rough, such that puddles of the sealer form in grooves and surface voids. Rapid curing is needed to preserve the effectiveness of the sealer and to prevent tracking (i.e., transfer of sealer to surrounding pavement). Tracking of some sealers can cause serious skid resistance problems with adjacent asphaltic concrete pavements and ramps. Therefore, it is important that the sealer is tack free prior to opening the lane to traffic. Since curing can be affected by temperature, this method provides for testing the sealer at both the low and the high temperature at which it is to be used.

6.3.1. Test Procedure

Cast a minimum of four (4) cubes (two (2) cubes per test temperature) following the procedure outlined in Section 5.1.1. Adjust the moisture content of the cubes per Section 5.1.1.5, and prepare for sealer application per 5.1.1.6.

Drill a hole near the center of the cube’s top surface 19 mm (3/4 in.) in diameter and 19 mm (3/4 in.) in depth. At least 25 mm (1 in.) away from the edge of this hole drill another hole 6 mm (1/4 in.) in diameter and 12 mm (1/2 in.) in depth. Blow the holes clean with dry compressed air.

Unless otherwise specified, conduct the test at the manufacturer’s minimum recommended temperatures minus 3°C (5°F) and at the manufacturer’s maximum recommended temperature plus 3°C (5°F). Typical temperature ranges include 4°C (40°F) and 40°C (105°F).

A minimum of 48 hours prior to treatment with the sealer, place cubes and sealer materials in a chamber to condition the cubes to the temperatures to be tested.

Coat cube samples per Section 5.1.1.7, and fill intentional drill holes with the sealer, noting the time of sealer application.

Maintain cubes at the application temperature being tested, with an air moving horizontally across the surface of the test specimen at a velocity of approximately 180 m/min (600 ft/min) [per ASTM C1315]. Maintain the relative humidity (RH) between 40 and 60 percent. Measure and report the RH.
6.3.2. **Measurement of drying time, gel time, tack-free time, and final set**

Determine the time when the following conditions occur and calculate the elapsed time from sealer application:

Penetrating Sealers:

- Initial drying time - time when the surface becomes dry but liquid sealer is still present in small voids and the intentional drill holes.
- Final drying time - time when the entire surface of the cube, including the voids and drill holes are dry.

Coating Sealers:

- Gel time - time when the surface becomes tacky and when some sealers will hair when the resin in the drill holes are probed with a toothpick or similar probe.
- Tack-free time - time when the soft tacky condition described above no longer exists when pressed with a finger using moderate pressure, and the surface film feels firm.
- Final set - time when the coating is hard both on the surface and in the intentional drill holes and is able to resist traffic forces, such as exerted by the AASHTO T278 *British Pendulum Tester* without visible damage to the coating.

6.4. **Coating Bond Strength**

Measure the coating bond strength in accordance with ASTM D4541. Perform a minimum of three tests and report the results in MPa (psi). ASTM C1583 test method can be used on thick coatings and allows a larger test area to be tested.

6.5. **Reporting**

6.5.1. **Effect of Surface Abrasion**

*Reporting shall include:*

1. Aggregate source, gradation and a complete description of the mix design and concrete properties.
2. Concrete plastic properties including slump, air content, temperature, and unit weight.
3. Total moisture capacity of concrete ($M_{sd}$)
4. Sealer information, lot number, date manufactured and MSDS.
5. Method of sealer application, number of coats, and the application rate for each sample.
6. Weight loss of cubes after abrasion.
7. The sandblast sand gradation, source, blasting procedure, nozzle distance from sample and amount of abrasive used to abrade cubes with coatings applied.
8. The relative humidity of the test chamber.
9. The weight gain during immersion ($\Delta W_{i7}$) over 7 days of each cube.
10. The Saltwater Absorption Ratio After Abrasion (SAR_{ABRASION}) at 7 days for the given application rate.
11. The ratio SAR_{ABRASION}/ SAR.

6.5.2. **Skid Resistance**

*Reporting shall include:*

1. BPN and other test details, reported per AASHTO T278 Section 9, for samples tested at time to traffic and after weathering.
2. Skid resistance test conditions and sealer curing time at test.
3. Description of any damage to the coating or sealed surface.
4. Skid Resistance Coefficient before (SRC\textsubscript{unweathered}) and after weathering (SRC\textsubscript{weathered})

6.5.3. **Time-to-Cure**  
*Reporting shall include:*  
1. Test temperatures  
2. For penetrating sealers, Initial Drying Time and Final Drying Time at each test temperature.  
3. For coatings, Gel time, Tack Free Time, and Final Set Time at each test temperature.

6.5.4 Coating Bond Strength  
*Reporting shall include:*  

7. **FREEZE-THAW, SCALING AND CONCRETE DURABILITY (FT)**

*Test Overview* - Usually concrete is well-protected from cyclic freezing damage by adequate air entrainment. Sealers are primarily used to protect concrete from water and deicers or salt penetration but are sometimes used to reduce scaling or cyclic freezing damage of poorly air-entrained concrete. In addition, if the sealers are used in a cyclic freezing environment, they must remain effective after experiencing freezing temperatures. Therefore, two types of tests are needed, depending on the expected application. First, the sealer must remain effective at preventing water and chloride ingress after cyclic freezing exposure on properly air-entrained concrete. Secondly, if the sealer is to be used specifically to protect poorly air-entrained concrete from cyclic freezing damage, performance must be tested on poorly air-entrained concrete.

7.1. **Effect of Freeze-Thaw Exposure on Sealed, Air-Entrained Concrete**

7.1.1. **Test Procedure**  
For this test, three (3) treated and three (3) untreated cube specimens in addition to those used in previous tests are needed. These cubes should be fabricated and tested according to Sections 5.1.1 through 5.1.3.  

Immediately following the conclusion of the initial salt water immersion test, weight cube samples and test for freeze-thaw resistance in accordance with AASHTO T161\textit{Resistance of Concrete to Rapid Freezing and Thawing}, Procedure A. Test for 300 cycles.

Note: As an alternate, standard prism samples can be cast, treated, and tested in accordance with AASHTO T161 and these test procedures. Prism samples allow the Relative Dynamic Modulus of Elasticity to be measured and compared to untreated control prisms.

7.1.2. **Evaluation of Freezing and Thawing Deterioration**  
Remove the specimens from the cabinet after approximately every 100 cycles for evaluation. Wash each specimen with a slow stream of tap water to remove loose particles prior to each inspection. Pat specimen surfaces dry before weighing to nearest 0.1g. Note any visible evidence of distress.

At each 100-cycle inspection, including the final inspection after 300 cycles, rate the visible evidence of distress on each side of each cube on a scale of 0 to 5 using the Concrete
Deterioration Rating Scale presented below. Add 0.5 to the rating values if the deterioration occurs over more than 50% of the specimen side. For film-forming coatings, the ratings reflect deterioration of the coating itself as well as the concrete.

**Concrete Deterioration Rating Scale**

0 - No evidence of deterioration.

1 - Light scaling. Loss of cement paste around larger of fine aggregate particles or minor fine cracking of the coating. No delamination or loss of coating and no coarse aggregate particles exposed. Only minor loss of cement paste or coating around edges of sample or at surface voids.

2 - Moderate scaling. Loss of mortar with coarse aggregate particles exposed or clearly visible. Cracking, local delamination or loss of coating integrity in local areas. Loss of mortar or coating around edges of sample or surface voids may be present.

3 - Heavy scaling. Loss of mortar around coarse aggregate particles which protrude above adjacent mortar remaining. Loss of bond and loss of coating material exposing areas of the concrete.

4 - Severe scaling. Loss of concrete (loss of coarse aggregate particles) and cracking of concrete. Includes cracking and disintegration of coarse and fine aggregate particles. Major cracking or loss of coating integrity.

5 - Fracture or disintegration of specimen into two or more pieces.

**Calculation**

Calculate the average Deterioration Rating for each cube and the average Deterioration Rating for the treated cubes and for the untreated cubes.

Calculate weight loss expressed as percentage of original weight ($\Delta W_{FT}$) as follows:

$$\Delta W_{FT} = (W_{FT0} - W_{FT}) / W_{FT0} \times 100,$$

where:

$W_{FT0}$ = weight before freezing and thawing exposure

$W_{FT}$ = weight after freezing and thawing exposure

Plot the percent weight loss versus the number of freeze-thaw cycles. Calculate the mean weight loss percentage for the treated and for the untreated cubes.

Calculate the Freeze-thaw Weight Loss Ratio (FTR) as follows:

$$FTR = \Delta W_{FT\text{-treated-m}} / \Delta W_{FT\text{-untreated-m}} \times 100,$$

where:

$\Delta W_{FT\text{-treated-m}}$ = mean weight loss for the treated cubes; and

$\Delta W_{FT\text{-untreated-m}}$ = mean weight loss for the untreated control cubes.

7.1.3. **Saltwater Absorption after Freezing and Thawing Exposure**
After the completion of the freezing and thawing exposure, dry the cubes in an oven at 60°C (140°F) until they reach their target weight before the first immersion test ($W_{t2}$) ± 2 g, as calculated in Section 5.1.3.1 minus the weight lost during the cyclic freezing exposure test.

Perform an immersion test per Section 5.1.3. Determine the mean weight gain for the treated and untreated cubes and calculate the weight gain during immersion ($\Delta W_{i7}$) for each cube. Calculate the Saltwater Absorption Ratio After Freezing and Thawing (SAR$_{FT}$) as follows:

$$\text{SAR}_{FT} = \left( \frac{\Delta W_{i7-\text{treated-FT-m}}}{\Delta W_{i7-\text{untreated-FT-m}}} \right) \times 100,$$

where:

- $\Delta W_{i7-\text{treated-FT-m}}$ = mean weight gain for the treated cubes after freezing and thawing exposure;
- $\Delta W_{i7-\text{untreated-FT-m}}$ = mean weight gain for the untreated control cubes after freezing and thawing exposure.

7.2. Effect of Freeze-Thaw Exposure on Sealed, Non-Air-Entrained Concrete (Deicer Scaling Resistance)

Test Overview - The proposed procedure is a modification of ASTM C672 Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals. The intent of this testing is to determine if the sealer is beneficial in reducing cyclic freezing damage on chloride-saturated surfaces of poorly air-entrained concrete. Concrete specimens, with applicable sealer, are subjected to repeated freezing and thawing while the surface is exposed to sodium chloride or other deicer solution. The chloride solution should be determined by the specifying agency based on the most aggressive deicer most commonly used.

Note - For coating systems it may be useful to measure the coating bond strength before and after exposure using ASTM D4541 or C1583 and report the results in MPa (psi).

7.2.1. Test Sample Preparation and Treatment

Select a representative and standard source of cement and aggregates. Fabricate specimens in accordance with AASHTO Test Method T 126 Making and Curing Concrete Test Specimens in the Laboratory and Section 5.1.1 of this specification. Use well-graded, normal density, non-absorptive aggregates meeting the requirements of AASHTO M 6 Standard Specification for Fine Aggregate for Portland Cement Concrete and AASHTO M 80 Standard Specification for Coarse Aggregate for Portland Cement Concrete (ASTM C33 Standard Specification for Concrete Aggregates) having a maximum 14 mm to 19 mm (1/2 to 3/4 in.) gradation. Follow casting and testing procedures of ASTM C672. Do not use form oils or release agents that could contaminate the concrete surfaces. The concrete mixture should have a water-cement ratio of 0.50, a plastic slump between 75 to 125 mm (3 and 5 inches), and be non-air entrained (air content of less than 3 percent). Do not use fly ash or other supplementary materials (unless otherwise specified). Design the concrete to have a 28-day compressive strength between 27 and 31 MPa (4,500 and 5,000 psi), although actual strengths may vary based on local materials. Use a non-chloride, lignosulfonate water reducing admixture or other ASTM C 494 Type A water reducer to obtain the correct slump if needed. Cast a minimum of three 4 by 8 in. cylinders and test for compressive strength at 28 days of moist curing, per AASHTO T22. Measure and account for aggregate moisture contents to ensure that the exact w/c is used. Test a minimum of three treated and three untreated control slabs.

7.2.2. Deicer Scaling Testing
Cure test samples and apply sealers per procedures of ASTM C672. Use a salt solution of 3% sodium chloride unless otherwise directed. After each 5 cycles, remove the salt solution together with all deteriorated concrete debris. Wash surface and gently rub to remove all loose material. Strain the solution through a filter (Whitman No. 2, 320 mm diameter or equivalent) to collect all residue and oven dry at 105°C to a constant mass. Report the cumulative weight of material lost per area for each sample over the test period to the nearest 0.01 kg/sq m. Visually inspect and rate the rinsed surface of the test samples per ASTM C672 after every 5 cycles. Continue testing per ASTM C672 for 50 cycles.

7.3. Reporting

7.3.1. Effect of Freeze-Thaw Exposure on Sealed, Air-Entrained Concrete

Reporting shall include:
1. The average Deterioration Rating for the treated and for the untreated cubes.
2. Weight loss expressed as percentage of original weight ($\Delta W_{FT}$) for each cube.
3. Freeze-thaw Weight Loss Ratio (FTR)
4. The Saltwater Absorption Ratio After Freezing and Thawing (SAR$_{FT}$) at 7 days for the given application rate.
5. The ratio SAR$_{FT}$/SAR.

7.3.2. Effect of Freeze-Thaw Exposure on Sealed, Non-Air-Entrained Concrete (Deicer Scaling Resistance)

Reporting shall include:
1. Items required by ASTM C672
2. Any deviations from ASTM C672
3. Aggregate source, gradation and a complete description of the mix design and concrete properties.
4. Concrete plastic properties including slump, air content, temperature, and unit weight.
5. Concrete compressive strength at 28 days.
6. Sealer information and application rate on each slab.
7. Mass loss at each 5 cycles and cumulative mass loss at 50 cycles.
8. Relative mass loss compared to the control samples (average of 3 samples), as a percent.
9. Report coating bond strength before and after testing, if measured, in MPa (psi).

8.0. ADVERSE CONDITIONS

8.1. Effect of Wet (SSD) Concrete Surface Condition at Time of Sealing

Test Overview - If the sealer is to be applied to wet concrete surfaces it should be tested and pre-approved for application to saturated concrete. Section 5.1.3 Waterproofing Performance by Saltwater Immersion Test and Section 5.1.5 Chloride Penetration Test cube tests are repeated with the modification that the sealer is applied to saturated surface dry (SSD) specimens.

Note - For coating systems it may be useful to measure the coating bond strength at the end of the immersion testing using ASTM D4541 or C1583 and report the results in MPa (psi).

8.1.1. Sample Preparation
Cast and cure at least six (6) test cubes in accordance with Section 5.1.1. Test a minimum of three (3) cubes per material or application rate and a minimum of three (3) untreated control cubes per test set.

Demold specimens at the age of 24 ± 2 hours and moist cure per Section 5.1.1.2. After no less than 35 days of wet curing, remove cubes from moist curing. Dry in laboratory air for 24 hours, and then sand blast all surfaces to uniformly remove a total of 24.0 ± 2 grams according to the procedure outlined in Section 5.1.1.6. Place cubes back in the moist curing room until the cubes reach a minimum age of 42 days.

Immediately before coating, remove cubes from moist curing room, and rinse surfaces with tap water. Rub cube surfaces to ensure that they are free of loose material and clean. Place cubes on glass rods or blunted nails and allow the surfaces of the cubes to become visibly dry. Treat cubes with sealer within 1 hour of removing cubes from the moist curing room, following the sealer application procedures in Section 5.1.1.7. Record number of coats and the time required for the cube surfaces to dry after each treatment for each cube.

If not already known for this mix design, determine the total moisture capacity (M_{SSD}) of the concrete on an additional set of three (3) cubes according to the procedure outlined in Section 5.1.1.4.

8.1.2. **Testing**

Place saturated treated and untreated control cubes in the standard drying room (50% RH, 23°C environment) 24 ± 2 hours after the sealer treatment is complete, and test the vapor transmission per Section 5.1.2. Record the result as Drying Rate Coefficient from SSD (DRG_{SSD}).

After the vapor transmission tests are complete, adjust the treated cube moisture content to match the untreated test cubes by drying the treated cubes in an oven at 60°C in accordance with Section 5.1.3 *Waterproofing Performance by Saltwater Immersion Test* and perform saltwater absorption testing. Record the result as the Saltwater Absorption Ratio from SSD (SAR_{SSD}) at 7 days.

Immediately after measuring weights at 7 days, continue saltwater immersion testing according to the procedure given in Section 5.1.5 *Chloride Penetration Test*. Record the results as Saltwater Absorption Ratio from SSD after 14 and 21 days (SAR_{SSD-14} and SAR_{SSD-21}, respectively).

At the conclusion of the 21-day immersion test, break each treated cube in half. Test one half for chloride content, per Section 5.1.5, and use the other half for determination of the sealer depth of penetration or coating thickness per Section 5.1.6.

Test the untreated cubes for chloride content per Section 5.1.5.

Record the chloride concentration for each slice from each cube. Record the Relative Chloride Ratio from SSD (RCR_{SSD}) for each sample for each cube.

Record the average, minimum and maximum coating thickness depth of sealer penetration or coating thickness when applied to a SSD surface.

8.2. **Performance at Temperature Extremes**

*Test Overview* - If the sealer is to be applied at temperature extremes it should be pre-approved for application at the expected temperatures. Section 5.1.3 *Waterproofing Performance by*
Saltwater Immersion Test and Section 5.1.5 Chloride Penetration Test cube tests are repeated with the modification that the sealer applied and cured at the extreme temperature.

8.2.1. Sample Preparation
Cast and cure at least six (6) test cubes in accordance with Section 5.1.1. Test a minimum of three (3) cubes per material or application rate and a minimum of three (3) untreated control cubes for each temperature. If not completed previously and the sealer is to be used on a traffic bearing surface, also test two (2) treated cubes for Drying/Time to Traffic per Section 6.3 for each temperature.

If not already known for this mix design, determine the total moisture capacity ($M_{ssd}$) of the concrete on an additional set of three (3) cubes according to the procedure outlined in Section 5.1.1.4.

Condition cube samples to 70% moisture content per Section 5.1.1.5. Sandblast cubes per Section 5.1.1.6, and seal test cubes in plastic bags that are a minimum of 6-mil thick.

Unless otherwise specified, conduct the test at the manufacturer’s minimum recommended temperatures minus 3°C (5°F) and at the manufacturer’s maximum recommended temperature plus 3°C (5°F). Typical temperature ranges include 4°C (40°F) and 40°C (105°F). Maintain the relative humidity between 40 and 60 percent.

Place bagged cubes and the sealer materials in the extreme temperature environment for a minimum of 48 hours, but not more than 5 days prior to treatment with the sealer. Maintain chamber temperature within 3°C (5°F) of the target temperature.

In the temperature environment to be tested, apply the sealer to cube surfaces per Section 5.1.1.7 at the desired application rate. Weigh cubes before and after treatment and record weights per Section 5.1.1.7.

8.2.2. Testing
If not completed previously, perform Time-to-Cure test per Section 6.3 at the test temperature. After treatment, continue curing the treated and untreated cubes for 7 days at the test temperature.

After 7 days, return the samples to room temperature and weigh the specimens. Adjust the treated cubes moisture content to match the average untreated test cubes by drying the treated cubes in an oven at 60°C or in a drying room in accordance with Section 5.1.3 Waterproofing Performance by Saltwater Immersion Test and accounting for the applied sealer weights. Perform saltwater absorption testing. Record the result as the Saltwater Absorption Ratio at Temperature ($SAR_{XX}$) at 7 days, where XX equals the test temperature.

Immediately after measuring weights at 7 days, continue saltwater immersion testing according to the procedure given in Section 5.1.5 Chloride Penetration Test. Record the results as Saltwater Absorption Ratio at Temperature after 14 and 21 days ($SAR_{XX-14}$ and $SAR_{XX-21}$, respectively).

At the conclusion of the 21-day immersion test, break each treated cube in half. Test one half for chloride content, per Section 5.1.5, and use the other half for determination of the sealer depth of penetration or coating thickness per Section 5.1.6.

Test the untreated cubes for chloride content per Section 5.1.5.
Record the chloride concentration for each slice from each cube. Record the Relative Chloride Ratio at Temperature (RCR<sub>XX</sub>) for each sample for each cube, where XX equals the test temperature.

Record the average, minimum and maximum coating thickness depth of sealer penetration or coating thickness at temperature, tested per Section 5.1.6.

8.3. Reporting

8.3.1. Effect of Wet (SSD) Concrete Surface Condition at Time of Sealing

Reporting shall include:
1. Information required for Section 5.1.3 and Section 5.1.5.
2. The moisture condition of the test cubes at the time of treatment, the preconditioning of the cubes and the curing temperature history of the treated cubes.
3. The time required for the surface of the cubes to dry after each coat at SSD.
4. The weight gain during immersion \( \Delta W_{i7} \) of each cube.
5. The Saltwater Absorption Ratio from SSD (SAR<sub>SSD</sub>, SAR<sub>SSD-14</sub> and SAR<sub>SSD-21</sub>) at 7, 14 and 21 days, respectively.
6. The chloride concentration of the treated and control cubes in tabular format, giving the concentration and the depth range for each sample for each cube.
7. The Relative Chloride Ratio from SSD (RCR<sub>SSD</sub>) for each sample for each cube in tabular format, giving the RCR<sub>SSD</sub> and the depth range for each sample for each cube.
8. The average, minimum and maximum coating thickness depth of sealer penetration or coating thickness when applied to a SSD surface.
9. Bond strength of the coating system after immersion, if tested, in MPa (psi).

8.3.2. Performance at Temperature Extremes

Reporting shall include:
1. Information required for Section 5.1.3 and Section 5.1.5.
2. The temperature of the test cubes at the time of treatment, the preconditioning of the cubes and the curing temperature and RH history of the treated cubes.
3. The time required for the surface of the cubes to dry after each coat.
4. If tested, the Initial Drying Time and Final Drying Time for penetrating sealers at each test temperature and Gel time, Tack Free Time, and Final Set Time for coating sealers at each test temperature.
5. The weight gain during immersion \( \Delta W_{i7} \) over 7 days of each cube.
6. The Saltwater Absorption Ratio at Temperature (SAR<sub>XX</sub>, SAR<sub>XX-14</sub> and SAR<sub>XX-21</sub>) at 7, 14 and 21 days, respectively.
7. The Relative Chloride Ratio at Temperature (RCR<sub>XX</sub>) for each sample for each cube in tabular format, giving the RCR<sub>XX</sub> and the depth range for each sample for each cube, where XX equals the test temperature.
8. The average, minimum and maximum coating thickness depth of sealer penetration or coating thickness when applied at temperature.

9.0. OTHER CONSIDERATIONS

9.1. Color and Appearance
9.1.1. For sealer applications where aesthetics are important, further testing for color, aesthetic approval, and hiding power should be conducted. Color and aesthetic appearance should be evaluated by a representative of the specifying agency prior to approval. Hiding power should be tested if coverage of graffiti or other surface feature is desired.

9.1.2. **Color**

If a colored sealer is being used, the color should be approved by the specifying agency. Color can be measured instrumentally, or by comparison, under standard lighting conditions, with standard color cards.

9.1.3. **Hiding power**

The hiding power indicated the ability of a pigmented sealer to cover surface features. Hiding power should be tested according to ASTM D6762.

9.1.4. **Anti-Graffiti**

Sealers are sometimes applied to concrete surface to provide an anti-graffiti surface. The anti-graffiti coatings should be tested according to ASTM D7089.

9.1.5. **Reporting**

- Reporting shall include:
  1. Color, if measured
  2. Hiding power, if measured
  3. Graffiti resistance, if measured.

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10.0. **SAFETY**

*Overview* - The usual precautions exercised in the working environment and for handling chemicals should be followed. Appropriate personal protective equipment (PPE), including protective eyewear, gloves, long sleeved shirts, long pants, and appropriate footwear should be worn when handling sealers. Ensure that the sealer complies with applicable federal, state, and local regulations for volatile organic compounds (VOC). All waste solvents and sealer material shall be disposed of in accordance with all applicable federal, state and local environmental regulations. General hazards and cautions for each sealer type are given in the following sections. Always understand and follow manufacturer’s recommendations for safe handling and literature for information on specific formulations.

**Epoxy Resins and Coal Tar Epoxy**

These materials almost always cause skin irritation or allergic reactions if allowed to contact the skin. Allergic reactions may not occur immediately. Workers should never think themselves immune to these reactions. Mixing and application should always be in well-ventilated areas. Disposable equipment and clothing should be used whenever possible. Clothing of any kind should not be reused if soiled by epoxy resin. Safety glasses or goggles are recommended while mixing or applying these materials. The workmen should always wash up thoroughly, immediately after completing work. Equipment must be kept clean at all times.

In case of direct contact to body, wash immediately with soap and water until all epoxy compounds are removed. If contact is to the eyes, flush with large quantities of water and secure immediate medical attention. Use only soap and water or water-soluble cleaners on the body. The use of solvents for epoxy is to be avoided.
Linseed Oil
These oils are not considered toxic or irritating; therefore, the only safety hazard with their use is from burning. Normal precautions indicated for any flammable liquid should be followed.

Silanes and Siloxanes
These materials may be flammable, therefore, do not store or use them near heat or open flame. They react chemically with glass, and therefore, should not be stored in glass containers.

Methacrylates
These materials are flammable and toxic, and caution should be taken to avoid contact with the skin or breathing concentrated vapors. Safety glasses or goggles should be worn.

Sodium Silicate
This material is nontoxic, non-caustic, and nonflammable. It should not be stored in glass containers since it reacts chemically with glass.

Urethane
This material is flammable, and some formulations produce vapors. Special protective clothing, including goggles, gloves, and respirators, must be worn when working with urethane.
ANNEX 1 - Flow Chart for Prequalification Testing

Universal Tests for Sealer Prequalification
Cast Concrete Cubes and Strength test cylinders (air-entrained)

CYLINDERS

Moist cured cylinders and test compressive strength at 28 days

For Time-to-Cure:

- Add 2 Cubes/temperature
- Drill holes in cubes for cure test

- Determine curing time, gel time, tack free application rate, time and final set

CUBES

Min 6 Treated & Control

- Moist cured cubes at least 42 days

- Adjust test cubes to 70% moisture content by air drying at 50% RH (21 d max)

- Lightly sandblast cube surfaces

- Apply Sealer

Determine total moisture content of cubes after a minimum of 35 days moist curing

- Test for background chloride ion concentration

For Freeze-Thaw Exposure (Air-Entrained Concrete)

Add 3 Treated and 3 Control Cubes

- Cyclic Freezing Exposure (300 cycles)

- Perform Saltwater Immersion Test after cyclic freezing exposure

3 Treated and 3 Control

- Expose test cubes to alkaline solution (21 d)

- Repeat Saltwater Immersion Test (7 d)

For Traffic-Bearing Surfaces:

- Dry cubes to original moisture and abrade cube surfaces using sand blasting

- Reheat cubes for Salt Water Immersion Test (7 d) after abrasion

3 Treated and 3 Control

- Perform Chloride Penetration Test (21 d total immersion)

- Determine chloride content of cubes

- Determine depth of sealer penetration or coating thickness

KEY:

- Optional

- Mandatory
Universal Tests for Sealer Precalification
Weathering Resistance (air-entrained)

SLABS

3 Treated and 3 Control

Cure and wet cure slabs 24 hours, store in plastic bags for 21 days, dry 24 hours at 50% RH, lightly sandblast, store at 50% RH for 5 days and apply sealer (23 days total)

For traffic-learning surfaces, test skid resistance of slab surface

Perform Cyclic Weathering Test: After 42 days, cyclically pond slabs with salt solution and UV exposure (14 weeks)

For traffic-bearing surfaces, test skid resistance of slab surface after weathering

Determine chloride content of concrete

Determine depth of sealer penetration or coating thickness

Sealer Material Characterization Tests

Spectroscopy (FTIR)
Gas Chromatography (GC)
Solids Content
Specific Gravity

KEY:

[] = Optional

[] = Mandatory
Optional Test For: Performance at Temperature Extremes

Min. 3 Treated and 3 Control

Cast and moist cure cubes at least 42 days

Adjust test cubes to 70% moisture content by air drying at 50% RH (21 d max)

Determine total moisture content of cubes (if not determined previously)

For Drying/Time to Traffic:
- 2 cubes/temperature

Drill holes in cubes for cure test.

Lightly sandblast cube surfaces

Condition cubes and sealer to test temperature (48 hrs. min.) and apply sealer

Perform Vapor Transmission Test (4 d @ 50% RH)

Determine drying time, gel-time, tack free time and final set.

Condition samples to average moisture content of untreated cubes

Perform Salt Water Immersion Test (7 d)

Perform Chloride Penetration Test (21 d total immersion)

Determine chloride content of cubes

Determine depth of sealer penetration or coating thickness

KEY:

= Optional

= Mandatory
Guideline for

Quality Assurance, Job Site Quality Control, and Reapplication of Protective Sealers for Portland Cement Concrete

AASHTO Designation: *T -Proposed Draft (rev. 10.6.08pk,kas)

1. SCOPE

1.1. This guideline covers procedures and test methods for quality assurance testing and job site quality control for protective sealers for protecting new concrete or prolonging the life of sound, in-service concrete used in highway structures. It is assumed that the sealer has been tested and pre-qualified through the AASHTO Draft method for Protective Sealers for Portland Cement Concrete. This guideline provides testing methods for routine and job site product quality assurance and for assessing the field performance of sealers and includes methods to assess when reapplication should be performed.

1.2. Sealers are divided into two basic types: coatings, which remain on the surface; and penetrants, which penetrate into the concrete to some measurable depth and do not substantially change the appearance of the concrete.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. AASHTO Standards:

- AASHTO T260 Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials
- AASHTO T278 Surface Frictional Properties Using the British Pendulum Tester
- AASHTO T-- Draft Method for Standard Method of Test for Protective Sealers for Portland Cement Concrete

2.2. ASTM Standards:

- ASTM C42 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- ASTM C496 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
- ASTM D891 Standard Test Methods for Specific Gravity, Apparent, of Liquid Industrial Chemicals
- ASTM D2369 Standard Test Method for Volatile Content of Coatings
2.3. Other Reports:

- Alberta Infrastructure, Technical Standards Branch, Alberta BT005 Test Procedure for Measuring the Waterproofing Performance of Core Samples Taken from Sealed Concrete Surfaces
- New York 717-01E Protective Sealers for Structural Concrete (Water Absorption)
- FHWA-RI-90-1, "Laboratory Evaluation of Concrete Sealers for Vertical Highway Structures".

3. ROUTINE AND JOBSITE QUALITY ASSURANCE TESTING

This testing is recommended to establish that the sealer material supplied to a job site or ordered for use by maintenance forces is the same material and has the same performance as the material that was tested in the prequalification testing conducted according to the Standard Method of Test for Protective Sealers for Portland Cement Concrete. This testing includes sealer material characterization tests and selected performance tests.

3.1 Sealer Sampling

Sample a minimum of one quart of material for each manufacturing lot supplied. It is preferred to sample complete units of material; however, small samples of large units are allowed. Ensure that the sample container is clean, has an air-tight seal, and is non-reactive with the sealer. Thoroughly mix each component prior to sampling.
3.2. **Material Characterization Tests for Job Site QA**

Material characterization tests are used to collect data on the basic characteristics of the material, including composition, solids content, and specific gravity. These tests are primarily used for comparison of materials sampled during routine and job-site quality assurance with prequalified materials. These tests should be performed on samples of the batch or batches of sealer material that are supplied for project use. The test results should be compared to the data on file from the prequalification testing.

3.2.1. **Spectroanalysis (FTIR)**

Fourier transform infrared (FTIR) analysis provides a chemical fingerprint of a material system that can be used to compare one material to another and to compare batches of a particular material. Analysis can be carried out by transmission or by internal reflection (usually with an attenuated total reflectance accessory). Analyses of the same material may not be comparable when data is collected in different modes (i.e., transmission vs. reflectance) or when different sample preparation techniques are used. When comparing spectra, it is important to ensure that data was collected under the same conditions, including sample preparation and instrument conditions. Since comparative analyses need to be carried out with the same sample preparation techniques, review and repeat the processes used for FTIR during the prequalification testing.

Use ASTM E1252 for testing in transmission. Use ASTM E573 for testing by reflectance (attenuated total reflectance or other method). Compare the results to the testing performed during the prequalification and confirm that the materials are identical.

3.2.2. **Gas Chromatography (GC)**

Gas Chromatography (GC) can be used in addition to or in combination with FTIR as a method for chemical analysis of sealer materials. The procedure used to analyze the sealer by GC will depend on the instrument, column type, and sealer being analyzed. The results will be affected by the instrument and run parameters, such as choice of stationary phase, carrier gas, and carrier gas flow rate. Once a procedure is developed (carrier gas, carrier gas flow rate, stationary phase, etc.) the procedure should be followed for each additional analysis, to provide data suitable for comparison. See ASTM E260 for guidance on the operation of packed column GC apparatus.

Review and repeat the processes used for GC during the prequalification testing. For each material type, define a suitable set of operating parameters. These parameters include: stationary phase, injector, detector, carrier gas, carrier gas flow rate, column temperature, run time, injection volume, and other applicable parameters. Obtain and file the dated chromatogram and any other information (component identification or quantification) provided. Document the collection conditions and details of sample preparation. Compare the results to the testing performed during the prequalification and confirm that the materials are identical.

3.2.3. **Solids Content**

Measuring solids content of sealer materials is useful to monitor the uniformity of the material from lot to lot and to ensure that the materials are the same that was tested in the prequalification approval testing. Unlike spectroanalysis, which gives a qualitative spectrum, solids content measurements provide a quantitative measurement of non-volatile content. Fillers or pigments will be measured in solids content measurements, and changes in the type (density) or concentration of fillers or pigment can lead to different solids content measurements. Changes in solvent may not be apparent in solids content measurements. This measurement is used for quality control purposes and also to calculate the weight of sealer applied to the test samples.
For silanes, siloxanes, or silane/siloxane blends, test using ASTM D5095. For other types of sealers, test using ASTM D2369.

3.2.4. **Specific Gravity**
Changes in solvent or solids concentration will affect specific gravity. Specific gravity provides a quantitative method of evaluating changes in a material from batch to batch. The method listed is suitable for both solvent-based and water-based systems.

Test the sealer per ASTM D891, Method A or Method B.

3.2.5. **Reporting**
*Reporting shall include:*
1. Trade name and lot number of the material analyzed
2. Sealer information, lot number, date manufactured and MSDS.
3. Dated FTIR spectrum (or spectra) with peak positions labeled, and sample preparation and analysis conditions.
4. Dated gas chromatogram and any other information (component identification or quantification) provided, along with collection condition and details of sample preparation.
5. Solids content (% nonvolatile content) as required in the relevant ASTM method.
6. Specific gravity as required in the relevant ASTM method.
7. Comparison data of the FTIR, GC, solids content, and specific gravity for the sealer tested during the prequalification testing.

3.3. **Material Performance Testing for Job Site QA Testing - Screening Performance Tests for Water Vapor Transmission, Saltwater Absorption and Depth of Sealer Penetration**
Several performance tests are recommended to ensure that formulation or raw material changes do not adversely affect the performance of sealers. These tests are recommended for job site quality control and can be used whenever sealers are ordered. The test frequency can be limited to at least one test per year for each material, if test costs become prohibitive or time is unavailable. Tests for water vapor transmission, saltwater absorption, and depth of penetration or coating thickness are recommended.

3.3.1. **Testing and Sample Preparation**
Test sealer material in accordance with the following prequalification test sections of the Draft *Standard Method of Test for Protective Sealers for Portland Cement Concrete*:
- Section 5.1.2 Moisture Vapor Transmission
- Section 5.1.3 Waterproofing Performance by Saltwater Immersion, and
- Section 5.1.6 Depth of Sealer Penetration or Coating Thickness

Prepare test samples according to *Standard Method of Test for Protective Sealers for Portland Cement Concrete* Section 5.1.1 Test Sample Preparation and Treatment. Use standard cured test cubes of the same concrete mixture used during prequalification testing. Adjust the moisture content of the test cubes to 70% of the total moisture content M_{ssd}. Lightly sandblast the cubes and treat test samples with the sealer.

3.3.2. **Moisture Vapor Transmission Test**
Perform the Moisture Vapor Transmission Test as specified in *Standard Method of Test for Protective Sealers for Portland Cement Concrete* Section 5.1.2.
Determine the moisture vapor transmission gravimetrically by measuring the cube weight at 0, 7, and 14 days after treatment to the nearest 0.1 gram.

Calculate the mean Drying Rate Coefficient (DRC) for the weight loss between 7 and 14 days.

3.3.3. **Waterproofing Performance by Saltwater Immersion Test**

Perform the Waterproofing Performance by Saltwater Immersion Test as specified in *Standard Method of Test for Protective Sealers for Portland Cement Concrete* Section 5.1.3.

Use the same samples as used in the vapor transmission testing. Bring both sets of cubes, sealed and control, to the same moisture content before testing. Correct samples weights for the hardened sealer adhering to the test cubes at the end of the 14-day drying period. After conditioning, weigh specimens at room temperature and immerse cubes in 15% sodium chloride solution at 23 ± 2°C for 7 days.

Calculate the Saltwater Absorption Ratio (SAR) of the treated cubes as a percent of the average absorption of control cubes.

3.3.4. **Depth of Sealer Penetration or Coating Thickness**

Determine the Depth of Sealer Penetration or Coating Thickness as specified in *Standard Method of Test for Protective Sealers for Portland Cement Concrete* Section 5.1.6.

Split each treated cube and oven dry the cube half. Cool in laboratory air to room temperature, and determine depth of penetration or coating thickness using the most applicable of the two methods listed in *Standard Method of Test for Protective Sealers for Portland Cement Concrete* Section 5.1.6. Record the average, minimum and maximum depths of penetration or coating thickness.

3.3.5. **Reporting**

*Reporting shall include:*

1. Sealer information, lot number, date manufactured, location where sampled, and MSDS.
2. Aggregate source, gradation and a complete description of the mix design and concrete properties, including casting date of cubes.
3. Concrete plastic properties including slump, air content, temperature, and unit weight.
4. Concrete compressive strength at 28 days
5. Moisture capacity of concrete (\(M_{msd}\))
6. Method of sealer application, number of coats, and the application rate for each sample. Note the time required for the surface of the cubes to dry after each coat.
7. The Drying Rate Coefficient (DRC) measured during vapor transmission test.
8. The weight gain during immersion \(\Delta W_{i7}\) over 7 days of each cube.
9. Saltwater Absorption Ratio (SAR) at 7 days for the given application rate measuring during saltwater immersion test.
10. Dye used for depth of penetration test, if applicable.
11. Average, minimum and maximum depth of sealer penetration or coating thickness for given application rate OR follow the reporting requirement for the relevant coating thickness standard method for the given application rate.
12. The comparable performance data for the sealer lot used in the prequalification testing.
4.0.  JOB SITE QUALITY CONTROL TESTING.

Overview - This testing and evaluation applies to sealers that have been applied to concrete bridge members or deck surfaces. Usually some minor destructive testing is necessary to evaluate the depth of penetration and water proofing performance of the sealer. The suggested procedures include tests that minimize destructive testing. If no drilling or coring is allowed, application of the sealer to mockups of the structure may also be useful in evaluating sealer application effectiveness and application rates.

4.1.  Sealer and Application Job Site Quality Control Testing

4.1.1.  Concrete Surface Conditions

4.1.1.1.  Temperature
Both ambient and concrete surface temperatures need to be measured prior to sealer application to ensure that the conditions are within the limits set by the sealer manufacturer or set during pre-qualification testing. Ambient temperature can be measured with a thermometer or thermocouple. Concrete surface temperature can be measured with an infrared surface thermometer or a contact-type surface thermometer.

4.1.1.2.  Moisture
Moisture content in the concrete should be evaluated prior to applying a sealer. Sealers may not penetrate or coat as well on saturated concrete as they would on drier concrete. Multiple methods are available for evaluating the moisture content of the concrete.

Allowing application as long as no rain has fallen on the structure in at least three days reduces the likelihood that the concrete is saturated with water. This is the least labor-intensive method, but the concrete may still contain undesirable levels of moisture, especially if atmospheric humidity is high.

The moisture content in the concrete can be evaluated with two standard methods: ASTM D4263 and ASTM F2170. ASTM D4263 does not require specialized equipment beyond a plastic sheet and tape, and provides results in sixteen hours, so the test must be initiated the day before application. The test provides a positive or negative result regarding the presence of moisture, but does not provide relative humidity or moisture content information. ASTM F2170 requires specialized relative humidity measuring equipment, and may take hours or days before readings can be taken, so the measurements must be initiated the day before sealing or earlier.

4.1.2.  Sealer Storage, Shelf life and Condition

4.1.2.1.  Storage
The conditions under which the sealer has been stored should be documented. Containers of sealer should be stored according to manufacturer’s recommendations, which generally indicate storage in a cool, dry place. Care should be taken that the sealers are not stored under conditions that are too hot, such as in a vehicle or shed that traps heat during hot days. Sealers should be kept from freezing during cold weather.

4.1.2.2.  Shelf life and Condition (visual)
Some sealers may degrade or alter with time, and using the sealer on a surface after the designated shelf life can lead to reduced performance. The date of manufacture or any use-by date on the packaging should be noted prior to application and compared to the manufacturer’s
recommended shelf life. Sealers that have exceeded the shelf life should not be used. It is good practice to mark the date of receipt on the packaging, especially if no date of manufacture or use-by date is printed on the label.

The condition of the sealer should be evaluated visually prior to application. The sealer should be thoroughly mixed prior to evaluation. The sealer appearance should be homogeneous and essentially the same in color, apparent viscosity, and texture as during the pre-qualification testing. If the sealer appears different from the material that was used for prequalification, different from other packages of the same sealer, or different from a written description of the material, the provenance of the sealer material should be confirmed before it is used. Differences in appearance can indicate a potential formulation change or degradation of the material.

4.1.3. Application Equipment, Coverage Rate, Cure, and Appearance

4.1.3.1 Equipment
Prior to applying a sealer, the application equipment should be visually evaluated. The equipment should be clean, and capable of applying the sealer in a manner suitable to deliver the necessary application rate.

4.1.3.2 Application rate (volume per area) spray time/area
The application rate should be evaluated during the application process, to ensure adequate coverage of the surface being sealed. There are several ways to test application rate, and the most suitable method depends on the application method and equipment. If possible, the volume or mass of sealer in the application equipment can be measured prior to application and again after application to a known surface area. From this information, the coverage rate can be calculated. If this method of coverage rate measurement is impractical, the sealer can be sprayed or otherwise applied into an empty bucket for a known amount of time. The volume or mass of the sealer in the bucket can be measured, and the application rate as a function of time determined. The amount of time required to apply the sealer to a known area then must be measured to determine application rate over a given surface area. The measured application rate should be compared to the desired application rate (determined from manufacturer’s recommendations or from the pre-qualification tests), and adjusted accordingly.

Environmental conditions may also affect application rate. In the case of high winds, some of the sealer may blow away during spray application, resulting in a lower than desired application rate, even if the application rate, measured as described above, appears adequate. Over-atomization of sealers during the spray process can also lead to excessive evaporation before the sealer reaches the concrete, and a reduced actual coverage rate. Care should be taken to avoid these conditions by careful observation of the application process.

In addition to measuring the application rate, it is important to evaluate that the sealer is being applied uniformly and to the entire surface. This can be accomplished by visually evaluating the application process. Where it is difficult to visually evaluate application, because of high evaporation rate or the clear nature of the sealer, a fugitive dye can be added to the sealer mixture indicating where the sealer has been applied.

4.1.3.3 Cure and Appearance
Curing of the sealer should be monitored. Conditions that may affect the drying and curing of the sealer, such as high winds or high temperature, should be monitored. If possibly, the sealer should be applied on calm days or days with low wind speed, to ensure the appropriate application rate and to allow the sealer to cure properly. Drying, gel, and tack-free times, defined according to the
methods in the Draft Standard Method of Test for Protective Sealers for Portland Cement Concrete, of the sealer as applied to the structure should be measured.

After sealer application and drying or cure, the appearance of the sealed surface should be evaluated visually. Visual evaluation will help determine if the sealer was applied to all necessary areas and if the sealer was applied uniformly. If aesthetic appearance of the sealer is important, the visual evaluation should include observations of color and texture.

4.1.4. Reporting

Reporting shall include:

1. Ambient and concrete surface temperature at the beginning of sealer deposition. If the values are within 5°F of the allowable limits, temperatures at the end of sealer deposition should also be reported.
2. Moisture content test method and moisture content of concrete (depending on method of test: the number of days since the last rain, the results of the plastic sheet test, or the relative humidity of the concrete).
3. Date of manufacture and use-by date of sealer, if known.
4. Description of the appearance of the sealer: color, uniformity, and texture.
5. Approximate wind speed or a description of the wind conditions.
6. Drying, gel, or tack-free time, as applied.

4.2. Depth of Sealer Penetration or Coating Thickness

4.2.1. Depth of Sealer Penetration or Coating Thickness by Core Sampling

Determine the depth of sealer penetration or coating thickness by taking a minimum of three core samples not less than 60 mm (2.4 in.) in diameter. The frequency of testing will be determined by the project specifications. Split the core in splitting test conducted according to the procedure outlined in ASTM C496 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, and measure the depth of penetration at 10-mm increments within the middle 2 in. of each half of the core according to procedure outlined in draft Standard Method of Test for Protective Sealers for Portland Cement Concrete Section 5.1.6. (Note: This provides six duplicate measurements.)

Average the values and report the average, minimum and maximum depths of penetration.

4.2.2 Depth of Sealer Penetration or Coating Thickness by Field Techniques

For penetrating sealers, determine the depth of sealer penetration by drilling a minimum of six small holes and averaging the results. A proposed test method is presented in Annex 1 of this Guideline and is designed to evaluate the depth of penetration of penetrating sealers applied on concrete surfaces from observations made in the field. This method is based on measuring the resistance of treated concrete to the absorption of a dye-carrying solution. An impact drill is used to drill small diameter holes into the treated surface and the clean hole is treated with a dye solution. The depth where the dye is readily absorbed into the surface is recorded as the depth of sealer penetration.

Coating thickness can be measured by non-destructive or minimally destructive techniques. Use ASTM D6138 for evaluating coating thickness nondestructively with an ultrasonic gage. Care should be taken when using ultrasonic gages that the measurement technique is calibrated on a similar system, because, especially on rough surfaces such as concrete, results can be difficult to interpret. Use ASTM D4138 for measuring coating with a minimally destructive technique.
Tooke gages are commonly available equipment that are suitable for use in this technique. Measure coating thickness in at least three widely spaced areas of the sealed surface.

4.3. Water Absorption Field Tests
Two types of field tests are proposed for evaluating the water absorption of the treated surfaces. One uses core samples that are removed and evaluated in the laboratory and the other uses a field test procedure for measuring surface absorption.

4.3.1. Test Procedure For Measuring the Waterproofing Performance of Core Samples Taken From Sealed Concrete Surfaces
The proposed test procedure, presented in Annex 2 of this Guideline, is used to evaluate the effectiveness of sealers previously applied to concrete in the field. It is an adaptation of the cube immersion test, used in the approval of sealers for use on bridges. The test is done on 75-mm (3-in.) diameter cores. The test is based on mass changes due to water absorption. Comparison is made between absorption in the sealed and non-sealed ends of the core. The non-sealed end serves as the control surface for comparative purposes.

There are two methods defined by this test. Method A is used for coatings or penetrating sealers applied to non-traffic-bearing surfaces, while Method B is used for coatings or penetrating sealers applied to traffic-bearing surfaces.

A minimum of three cores (75-mm [3-in.] diameter) should be removed from the treated surface. The core length should be greater than 50 mm (2 in.) If a penetrating sealer, test cores in accordance with the procedures in Annex 1 of this Guideline.

4.3.2. Field Test for Surface Water Absorption in Actual Structures
A procedure was recommended by RILEM (RILEM 1980) for use in evaluating absorption of stone and this general approach was adapted for use with sealers as part of Strategic Highway Research Program Project C-101 (Cady and Gannon 1992). The surface absorption method presented in the reports from that project is replicated in Annex 3 of this Guideline.

This method is based on the measurement of surface absorption of water under low pressure. A water reservoir (cell) with a capillary tube threaded into the top end is affixed tightly to the concrete surface. Either horizontal or vertical surfaces can be tested. Water is added until the water column is filled to a height of approximately 40 cm (15.7 in.). The water column drop is monitored as a function of time over 10 minutes. Effectiveness of a sealer is then expressed in a qualitative manner (good or poor) based on criteria developed in the laboratory. Comparisons of sealed and unsealed surfaces can be also done and the difference can be reported as a percentage reduction.

Several factors can affect the test results including the moisture content of the concrete, the air temperature and the concrete quality. The most useful results for the surface absorption test will likely be obtained if testing can be performed when weather conditions are conducive. Since this test measures water penetrating the outer surface of the treated concrete, it is logical that the concrete surface moisture conditions will influence the test result. The best approach is to wait for a period of dry weather. Likewise, the influence of temperature on the test results and the ease of testing are also best controlled if the test is conducted at moderate temperatures.

The quality of concrete is also significant to surface absorption performance, since less absorption is likely to occur if the concrete is dense, e.g., as a result of a low water-cementitious materials
ratio or the presence of silica fume. A general guideline developed by Cady and Gannon (1992) for interpretation of this surface absorption test is provided with the method, but the most useful interpretation will be obtained by comparisons with similar untreated concrete or with results obtained on the same structure from tests conducted under the same conditions.

Finally, the test procedure is not applicable or at least very difficult to perform to grooved or tined (skid-textured) surfaces, and this limitation will prevent this method from being easily used on most bridge decks. It is generally appropriate that at least three sites be tested in each sealed location.

4.4. Coating Adhesion Tests
Measure the coating bond strength in accordance with ASTM D4541 or ASTM C1583. Perform a minimum of three tests and report the results in MPa (psi). Compare field results to the results determined in the prequalification testing.

4.5. Deck or Travel Surfaces
If the sealer is to be applied during lane closures, before traffic can be allowed back on the treated surface, the surface must be cured to reduce tracking of the sealer or damage to the coating, and the deck must have adequate skid resistance. Tests for time-to-cure and skid resistance are recommended. Water proofing performance is also evaluated using a modified procedure of Section 4.2.1 that includes coring and abrasive blasting of the sealed test surfaces.

4.5.1. Time-to-Cure
Sealers must cure rapidly under a range of temperatures when applied to deck surfaces that must be opened quickly to traffic. Deck surfaces are tined and rough such that puddles of the sealer form in grooves and surface voids. Rapid curing is needed to preserve the effectiveness of the sealer and to not adversely affect the deck skid resistance or result in tracking. Tracking of some sealers can cause serious skid resistance problems with adjacent asphaltic concrete pavements and ramps. Therefore it is important that the sealer is tack free prior to opening the lane to traffic.

Record the beginning and ending time when the sealer is applied to each section. Periodically check the surface of the treated area for drying, gel time and tack free time. Probe puddles and the bottom of grooves to assess both the surface conditions and the condition of the sealer in the puddled areas. Monitor the drying time, gel time, tack-free time, and final set of the top surface of the deck to ensure that sealer damage or tracking does not occur when the lane is opened to traffic as follows:

Penetrating Sealers:

- Initial drying time - time when the surface becomes dry but liquid sealer can be still present in surface voids and holes.
- Final drying time - time when the entire surface is dry including the surface voids, cracks and holes where sealer puddle.

Coating Sealers:

- Gel time - time when the surface becomes tacky and when some sealers will hair when the resin is probed with a toothpick or similar probe.
- Tack free time - time when the sealer the soft tacky condition no longer exists when pressed with a finger using moderate pressure and the surface film feels firm.
Final set time to traffic - time when the coating is hard both on the surface and all surface
holes or depressions and is able to resist traffic forces, such as exerted by the AASHTO
T278 (British Pendulum Tester) without visible damage to the coating.

4.5.2. **Skid Resistance**
Test treated area for skid resistance using ASTM E274 Standard Test Method for Skid Resistance
of Paved Surfaces Using a Full-Scale Tire or AASHTO T278 Standard Method of Test for Surface
Frictional Properties Using the British Pendulum Tester. Place the sealer and allow to cure until
dry, tack free, or final set. Test the skid resistance of the treated areas. It is also recommended to
test the area before treatment or an adjacent area that is identical but untreated. Repeat the tests at
a minimum of three locations within the tested area.

As an alternate method, a field trial offline of main traffic can be installed and tested under the
same temperature and environmental conditions as the work to be performed. The skid resistance
should be measured at the time that the lane is to be opened for traffic and at other subsequent
time to assess the effect of wear of sealer performance.

Report the test conditions, weather, concrete and air temperature, sealer curing age at time of test,
skid resistance values and note any damage to the coating or sealed surface during testing.

Calculate the Skid Resistance Coefficient (SRC) before and after treatment as follows.

\[
SRC = \frac{SR_{treat}}{SR_{untreat}} \times 100, \text{ as percent}
\]

where:
\( SR_{treat} \) = skid resistance value (BPN) of the treated area
\( SR_{untreat} \) = skid resistance value (BPN) of the area before treatment or an untreated control areas.

4.5.3. **Test Procedure For Measuring the Waterproofing Performance of Core Samples Taken
From Sealed Traffic-Bearing Concrete Surfaces**
This test procedure described in Annex 2 of this Guideline provides a means to evaluate the deck
sealers subjected to abrasion. Two additional cores are removed from non-coated areas for use as
controls if the material is applied to traffic bearing surfaces and is a non-penetrating, coating
material. Method B is used for coatings or penetrating sealers applied to traffic-bearing surfaces
which includes abrasive blasting of the treated surface to simulate traffic wear.

4.5.4. **Reporting**

*Reporting shall include:*
1. Concrete and air temperature and weather conditions
2. Results of water absorption filed tests
3. Depth of penetration or coating thickness
4. Coating bond strength
5. Initial drying time and final drying time for penetrating sealers. Gel time, Tack Free Time,
   and Final Set Time for coating sealers.
6. Test method and Skid Resistance values for each test.
7. The Skid Resistance Coefficient (SRC)
8. Dampproofing performance before abrasion and after abrasion
5.0. REAPPLICATION AND OTHER CONSIDERATIONS

**Overview** - This testing and evaluation applies to concrete bridge members or deck surfaces that have been previously sealed. Some testing and evaluation is required to determine if reapplication of sealer is required. Usually some minor destructive testing is necessary to evaluate the depth of penetration and water proofing performance of the sealer. The suggested procedures include tests that minimize destructive testing. The procedures used are the same as outlined in Section 4.0 Job Site Quality Control Testing, although not all of the tests are required for sealer performance evaluation.

5.1. Water Absorption Field Tests
Follow the procedures in Section 4.3. Either the test outlined in Section 4.3.1 Test Procedure For Measuring the Waterproofing Performance of Core Samples Taken From Sealed Concrete Surfaces, or the test outlined in Section 4.3.2 Field Test for Surface Water Absorption in Actual Structures may be used.

5.2. Chloride Penetration
Chloride penetration can be measured on cores or on powder samples removed by drilling. Sampling and testing should be performed according to Section 5.1.5.2 of the Draft Standard Method of Test for Protective Sealers for Portland Cement Concrete.

5.3. Depth of Penetration and Coating Thickness
Sealer depth of penetration and coating thickness is tested according to the method(s) outlined in Section 4.2.

5.4. Coating Bond
Coating bond is tested according to Section 4.4.

5.5. Appearance
The appearance of the sealed surface is compared to that of the as-sealed test cubes or slabs produced for the prequalification tests. Surface examination with a field microscope or magnifier (10 - 30X magnification) should be used to examine for cracks and chalking of coating-type sealers. Color can be measured according to 9.1.2 of the Draft Standard Method of Test for Protective Sealers for Portland Cement Concrete. Other agency guidelines or procedures for measuring appearance of sealed surfaces should be followed. For penetrating sealers, water can be placed on the surface and the beading of the water can be evaluated.

5.6. Reporting
*Reporting shall include:*
1. Results of Water Absorption Field tests
2. Results of chloride penetration tests
3. Depth of penetration or coating thickness
4. Coating bond strength (if applicable)
5. Comments on appearance, including color, if applicable, condition of coating (if applicable) and other comments
ANNEX 1 - Evaluation of Depth of Penetration of Penetrating Sealers in Actual Structures

1. **Scope**
   1.1 This test method is designed to evaluate the depth of penetration of penetrating sealers applied on concrete surfaces from observations made in the field.
   1.2 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. **Summary of Test Method**
   2.1 This method is based on measuring the resistance of treated concrete to the absorption of a dye-carrying solution.

3. **Interferences**
   3.1 Moisture content of the concrete can affect the test results. This test is best done when the surface is not water saturated.

4. **Apparatus**
   4.1 Scale capable of measuring depth to 1 mm.
   4.2 Rotary hammer drill and 3/4-in. diameter drill bit.
   4.3 Spray bottles for dye solutions
     4.3.1 Solution consisting of water mixed with red food coloring or Sulfonazo III sodium salt dye to produce a vivid red color.
     4.3.2 Clean water
   4.4 Squeeze air bulb or source of dry, clean compressed air.

5. **Sampling**
   5.1 Distance between Measurements - The distance between measurement sites should be consistent with the size of the member on which the sealer is applied.
   5.2 Locate test sites in areas where discoloration of surface will not be objectionable.

6. **Procedure**
   6.1 Drill holes into concrete surface at test site to depths of approximately 2, 4, 6, 9 and 12 mm and blow clean with air bulb.
      Note - If the approximate depth of penetration is known, it is not necessary to drill all depths. Only holes with depths bounding the expected penetration depth are necessary.
   6.2 Spray dye solution into holes, being sure to complete cover the surfaces exposed by the drilling. Allow solution to soak for a minimum of 30 s.
   6.3 Rinse the exposed surfaces thoroughly with clean water. Blowing the holes dry may also aid in establishing the sealer depth.
   6.4 Determine the shallowest hole in which the red solution produced staining and the deepest hole in which no staining occurred. Measure the depth of these two holes. If a clearly demarcated stain boundary is visible on the sides of any of the hole, note the depth of that boundary.

       Alternatively, one hole can be successively drilled and tested at increments of approximately 2, 4, 6, 9 and 12 mm depths. Note the depth when the dye solution first stains the concrete within the hole.
Note—Avoid measuring the depth of sealer penetration if reading is affected by the presence of aggregate particles. Adjust the measurement location slightly if able or do not include these measurements.

7. Report
7.1 The report shall consist of at least the following:
7.1.1 Location of test or identification of test specimen.
7.1.2 Type of sealer and date of its application.
7.1.3 Specimen curing history or recent environmental field conditions (include time interval since previous rain event).
7.1.4 Conditions at time of test.
7.1.5 The penetration depth range as the depths of stained and unstained hole OR the depth to the stain boundary.
ANNEX 2 - Test Procedure For Measuring the Waterproofing Performance of Core Samples Taken From Sealed Concrete Surfaces

This test procedure is used to evaluate the effectiveness of sealers previously applied to concrete in the field. It is an adaptation of the cube immersion test, used in the approval of sealers for use on bridges and based on a method used by the Alberta Infrastructure (BT005-July 00). The test is done on 75 mm (3 in.) diameter cores. The test is based on mass changes due to water absorption. Comparison is made between absorption in the sealed and non-sealed ends of the core. The non-sealed end serves as the control surface for comparative purposes. The test is performed differently for coatings or penetrating sealers applied to traffic bearing surfaces (Method B). Two additional cores are removed from non-coated areas for use as controls if the material is applied to traffic bearing surfaces and is a non-penetrating, coating material.

Procedure

Identify the sealed end of each core. Trim the cores taken from the sealed area by cutting the bottom, non-sealed face to achieve a length of 50 mm (2 in.). Record length and diameter of each core. Sandblast the sawcut, non-sealed face to open the pores that have become plugged by sawcutting.

Dry cores in oven at 70°C (158°F) until constant mass is reached, defined as a 24 hour change of less than 0.2% of the previous core mass determination. Place cores in the cool oven and progressively increase oven temperature at no more than 10°C (18°F) per hour to avoid thermal micro-cracking. Weigh cores within 1 hour of removal from oven or store cores in desiccators during cooling period prior to weighing.

Seal the round sides of the core with a minimum 3-mm (0.12-in.) thick coating of wax or with two coats of epoxy. Record mass of core to the nearest tenth of a gram (W<sub>0</sub>). Inspect the sealed side wall of core to ensure there are no pinholes in the coating. Test cores using Method A or B.

Method A (Non-Traffic-Bearing Surfaces)

Immerse cores vertically with sealed end downward 10 mm (0.4 in.) deep in tap water on pins or other supports to allow water access to sealed end of core. The water level should be of uniform depth for each core. Always test sealed end first to reduce the amount of subsequent oven drying. Remove the cores at 24 hours, lightly towel the surface and record the mass of the core. Record the mass increase as ΔW<sub>S1</sub>.

If ΔW<sub>S1</sub> is less than 2 grams proceed with next step. If ΔW<sub>S1</sub> is more than 2 grams, oven dry at 50°C (120°F) until mass is within 2 grams of pre-immersion mass and cool cores. Ensure that the sides of the cores remain sealed and recoat if necessary.

Repeat the immersion test with the non-sealed (control) end facing down at a depth of 10 mm (0.4 in.) in tap water on pins or other supports that allow water access to the immersed end of the core. Lightly towel and re-weigh cores at 24 hours. Record the mass absorbed by the control face as ΔW<sub>c1</sub>.

Method B (Traffic-Bearing Surfaces)

Immerse cores vertically with sealed end facing downward 10 mm (0.4 in.) deep in tap water on pins or other supports to allow water access to sealed end of core. The water level should be of uniform depth for each core. Always test sealed end first to reduce the amount of subsequent oven drying. Remove the cores at 24 hours, lightly towel the surface and record the mass of the core. Record the mass increase as ΔW<sub>S1</sub>. 

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B-15 AASHTO
If $\Delta W_{S1}$ is less than 2 grams, proceed to next step. If $\Delta W_{S1}$ is more than 2 grams oven dry at 50°C (120°F) until mass is within 2 grams of pre-immersion mass.

Sandblast the sealed surface of the core to uniformly remove 5.5 ± 0.5 g of cement paste if the sealer is a penetrating sealer, using a shield to protect the core edges. If the sealer is a non-penetrating sealer, sandblast two control cores removed from non-coated areas. Collect and weigh the amount of sand required to remove the required amount of material from the control cubes. Pre-weigh the same amount of sand that was required to blast the uncoated, control cores and blast the treated core surfaces using the same procedures. Maintain the nozzle at 90° angle to the surface during blasting. Shield the remaining surfaces of the core from being blasted. Record core mass after blasting.

Check and repair any damage to the coating on the sides of the cores. Repeat immersion as detailed above. Record the mass increase as $\Delta W_{SA2}$.

Dry cores as detailed above and record mass. Repeat the immersion with the non-sealed end. Record mass absorbed by control face as $\Delta W_{C1}$.

Reporting of Results

Calculate the Saltwater Absorption Ratio of the treated surface as a percent of the untreated surface as follows:

**Method A**

$$\text{SAR} = \left(\frac{\Delta W_{C1} - \Delta W_{S1}}{\Delta W_{C1}}\right) \times 100, \text{ as percent}$$

**Method B**

$$\text{SAR before abrasion} = \left(\frac{\Delta W_{C1} - \Delta W_{S1}}{\Delta W_{C1}}\right) \times 100, \text{ as percent}$$

$$\text{SAR after abrasion} = \left(\frac{\Delta W_{C1} - \Delta W_{SA2}}{\Delta W_{C1}}\right) \times 100, \text{ as percent}$$
ANNEX 3 - Evaluation of Sealer Performance in Actual Structures by Surface Absorption

This method was originally presented in


1. **Scope**
   1.1 This test method is designed to evaluate the effectiveness of penetrating sealers applied on concrete surfaces from observation of the surface absorption of concrete.
   1.2 This method gives a rating for the effectiveness of sealers (good, moderate, or poor) following criteria developed based on a laboratory investigation.
   1.3 The method is applicable to both laboratory specimens and field structures.
   1.4 The values stated in inch-pound units (or cgs units) are to be regarded as the standard where inch-pound units (or cgs units) are given first, followed by SI units. Where only SI units are given, or where SI units are given followed by inch-pound units (or cgs units), the SI units are to be regarded as standard.
   1.5 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. **Summary of Test Method**
   2.1 This method is based on the measurement of surface absorption of water under low pressure. A water reservoir (cell) with a capillary tube threaded into the top end is affixed to the concrete surface. Modeling clay into which grease has been headed is used to affix and seal the cell to the surface to be tested. Water is then allowed to flow from an external reservoir into the cell until the water column is filled to a height of approximately 40 cm (15.7 in.). The intake tube is closed, and the water column drop is monitored as a function of time over 10 minutes. Effectiveness of a sealer is then expressed in a qualitative manner (good or poor) based on criteria developed in the laboratory.

3. **Significance and Use**
   3.1 This method gives an indication of the ability of a penetrating sealer to prevent the intrusion of water or salt-laden water into concrete.
   3.2 This method is applicable for both vertical and horizontal concrete surfaces, but the test surface has to be flat and not grooved or tined.
   3.3 This method is intended to be rapid and nondestructive for the convenience of field applications, especially on in-service bridges and highway structures where tests are desired to be conducted within a short period of time.

4. **Interferences**
   4.1 Moisture content of the concrete can affect the test results. If the concrete surface is only temporarily exposed to moisture (such as during a brief summer shower) and allowed to dry under warm natural conditions for 2 hours or more, artificial drying is not be required. Where the concrete has been exposed to rainwater for a significant period of time prior to performing the
test, drying can be accomplished by subjecting the surface to drying for a period of 10 minutes at 120°F (48°C).

4.2 To eliminate the effect of air temperature on test results, conduct tests at 60°F to 80°F (15°C to 27°C).

4.3 Tests cannot be carried out on grooved or tined (skid-textured) surfaces.

5. Apparatus

5.1 The testing apparatus for horizontal surfaces (Type A) is shown in Figure 1 and the testing apparatus for vertical surfaces (Type B) is shown in Figure 2. They consist of a water cell, capillary tube and scale, water reservoir, flexible tube (intake tube), and flow control device (stopcock).

NOTE - The apparatus for vertical surfaces Type B) is, in principle, the same as Type A except that the configuration of the cell has been modified to be used on vertical surfaces.

5.1.1 Water Cell - The water cell shall be made of suitable impermeable material (clear acrylic is preferred). Two holes should be drilled into the cell, one for the water column and one for the intake tube.

5.1.1.1 Water Cell Type A (Horizontal Surface) - As shown in Figure 1, the cell should have a 3-in. (75-mm) diameter contact area with the concrete surface and a 1-in. (25.4-mm) wide edge to provide space for sealing the cell to the surface with a modeling clay/grease mixture. A 0.375-in. (9.5-mm) hole is drilled into the top of the cell for the capillary tube (water column) and another hole of the same size is drilled into the edge for the capillary tube (water column) and another hole of the same size is drilled into the edge for the plastic tube connected to the stopcock.
Figure 1. Modified RILEM 11.4 device for use on horizontal surfaces (Cady and Gannon 1992).

![Figure 1: Modified RILEM 11.4 device for use on horizontal surfaces](image)

Figure 2. Modified RILEM 11.4 device for use on vertical surfaces (Cady and Gannon 1992).

5.1.1.2 Water Cell Type B (Vertical Surface) - As shown in Figure 2, this cell should have a 2-in. (50.8-mm) diameter contact area. The outer side of the contact area is reserved for the sealing material (modeling clay). A 0.375-in. (75-mm) hole is drilled on the top edge for the capillary tube, and another hole is drilled on the side edge for the tube connected to the stopcock.

5.1.2 Water Reservoir and Flexible Intake Tube -- The water reservoir shall have a capacity of 1 L of water. The flexible tube (preferably plastic) with an outer diameter of 0.375 in. (9.5 mm) and inner diameter of 0.250 in. (6.35 mm) is connected to the water reservoir from one side and to the stopcock from the other side. The stopcock size should be chosen to fit into the flexible tube.

5.1.3 Capillary Tube and Scale -- The capillary tube (water column) shall be made of clear material (acrylic plastic) with a 0.125-in. (3-mm) inner diameter and 0.375-in. (9.5-mm) outer diameter, with a length of 19.6 in. (500 mm). A wooden or plastic scale with a minimum length of 19.6 in. (500 mm) graduated in millimeters is attached to the capillary tube. The zero reading starts from the top of the water cell.

5.1.4 Balance -- A balance accurate to within 0.1 % of the weight of sample.

5.1.5 Stopwatch - A stopwatch or clock capable of being read to an accuracy of 1.0 seconds.

6. **Sampling**

6.1 Distance between Measurements - The distance between measurement sites should be consistent with the size of the member on which the sealer is applied.

7. **Procedure**

7.1 Clay Preparation - Add 5 g (0.01 lb) of grease to 50 g (0.11 lb) of clay, and mix them by hand until all of the grease is dispersed into the clay and a homogeneous mix is achieved. Shape the
mix into a ball and roll it between two flat surfaces until a uniform cylindrical bar with a length of 12 to 13 in. (305 to 330 mm) is obtained. The length of the clay bar required for the Type A cell is about 12 in. (305 mm) and for the Type B cell, about 10 in. (250 mm).

**NOTE** – Commercially-available, multipurpose grease can be used for this purpose. Commercially available oil-based modeling clay can be used; a gray color is preferred, to match the tone of the concrete surface. A non-uniform rolled clay may lead to water leakage between the cell and concrete surface.

7.2 Surface preparation - The surface must be dry, clean, and free from grooves, cracks, and irregularities, which could cause water leakage from the cell.

7.3 Determination of Water Column Drop - Place the clay bar around the edge of the water cell and put the cell on the pre-located testing spot. Press the cell strongly to the surface until the clay is spread underneath the edge of the cell. Close the stopcock and fill the water reservoir with clean water. Open the stopcock and let the water flow into the cell and capillary tube until the capillary tube is filled to a height of approximately 40 cm (15.75 in.). The height of the water column can be controlled by moving the reservoir up and down. Close the stopcock, start the timer, and take the final reading. Take a reading every minute up to 10 minutes, then stop the test by opening the stopcock and draining the water back to the water reservoir.

**NOTE** – To apply uniform pressure when pressing the cell to the surface, a 5- x 10- x 1-in. (125- x 250- x 25-mm) plywood piece with a 1-in. (25-mm) hole in the center can be used to apply pressure on the horizontal cell using both hands. Uniform pressure can be applied to the vertical cell by hand.

**NOTE** – To avoid parallax errors in obtaining readings, the operator's eyes should be at the same elevation as the level of the water in the capillary tube.

**NOTE** – If a significant sudden drop in the water column occurs just after starting the test and the water level continues to drop rather rapidly, this indicates water leakage, and the test should be repeated. If the sudden drop occurs in the first 20 to 30 seconds and then stops, this indicates that the porosity of the surface is high, and the test should be conducted in another location.

8. Interpretation of Results
8.1 Use Table 1 to interpret the results. These values were taken from concrete slabs prepared in the laboratory using the same concrete with different types of penetrating sealers applied to their surfaces and tested under different conditions.

<table>
<thead>
<tr>
<th>Table B-1. Categories of sealer effectiveness.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column Drop (cm) in 4 Minutes</td>
</tr>
<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>0-1</td>
</tr>
<tr>
<td>1-2</td>
</tr>
<tr>
<td>&gt;2</td>
</tr>
</tbody>
</table>

9. Report
9.1 The report shall consist of at least the following:
9.1.1 Location of test or identification of specimen.
9.1.2 Type of sealer and date of its application.
9.1.3 Specimen history or recent environmental field conditions (include time interval since previous rain event).
9.1.4 Weather conditions at time of test.
9.1.5 Preconditioning of test area (If used).
9.1.6 Number of tests conducted for each case.
9.1.7 Water drop readings and category.

10. **Precision and Bias**
10.1 Precision -- The single-operator within-lab standard deviation has been found to be 0.2 cm (1 s). Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 0.6 cm (12 s).
10.2 Bias - The procedure in this test method for evaluation of penetrating sealers by water column drop has no bias because water column drop is defined only in terms of this test method.

11. **Keywords**
11.1 Bridges, concrete, in situ testing, nondestructive testing, penetrating sealers, water absorption.