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Waterproofing Options for Bridge Decks

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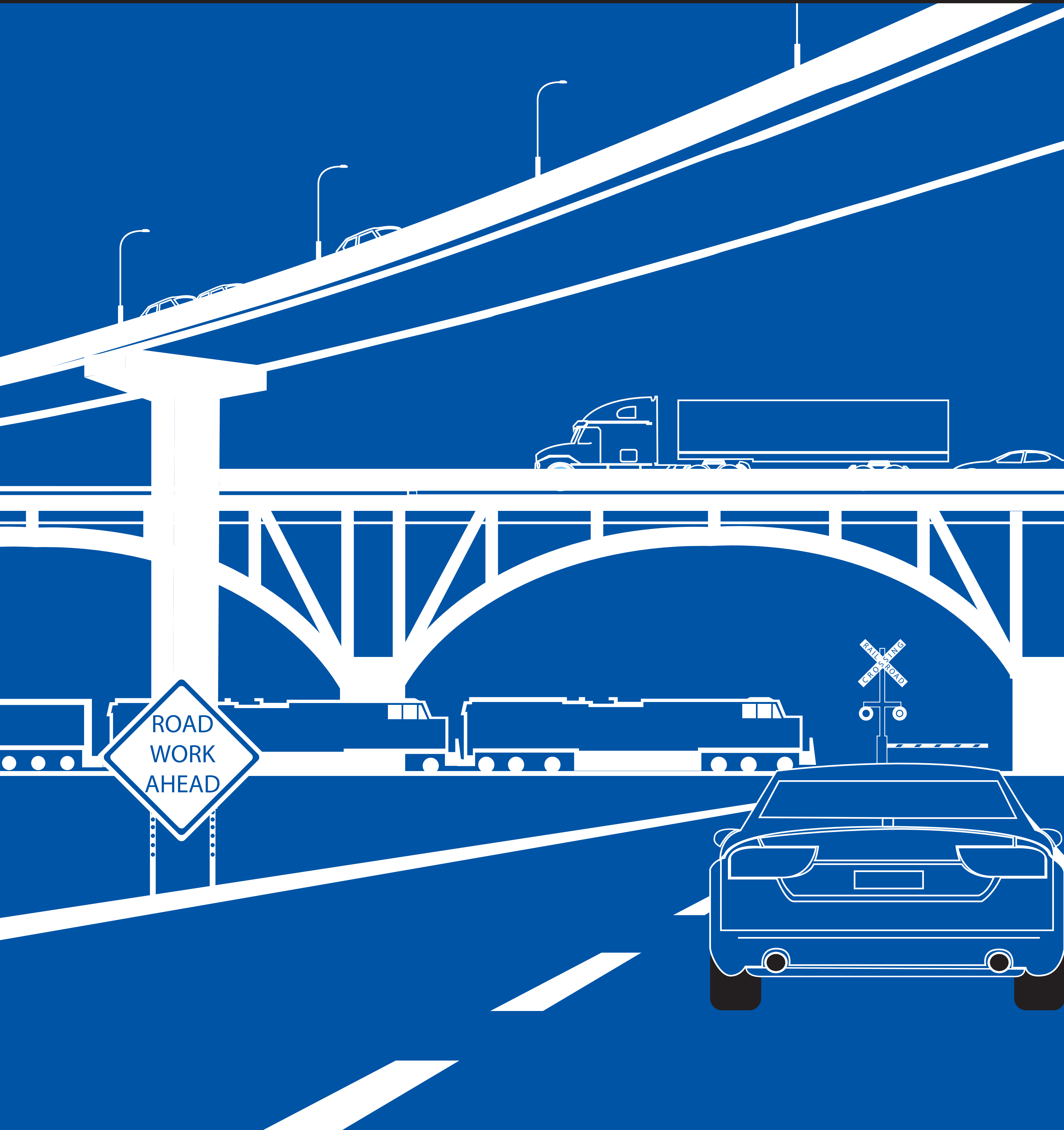

Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

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Research Report
KTC-19-39/SPR17-531-1F

Waterproofing Options for Bridge Decks

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16. Abstract
Due to the increasing use of deicing chemicals and the subsequent intrusion of chlorides into bridge decks, it is necessary to expand the use of available protective measures, including waterproofing materials. Waterproofing options that fall into three categories; 1) membranes (liquid and sheet systems), 2) friction polymers (laminates), and 3) polymer asphalts. This study assessed the waterproofing characteristics of these products. Prior to this study, no common test had been established to compare the performance of waterproofing products. A test method was developed that closely follows ASTM D5084, "Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter," for this purpose. This test provided valid information to compare performance of waterproofing options.

17. Key Words
Chlorides, waterproofing, membranes, concrete, bridge deck

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Executive Summary

The Kentucky Transportation Cabinet (KYTC) initiated the study KYSPR 17-531, "Waterproofing Options for Bridge Decks," to identify application, performance, testing, and other technical aspects of waterproofing products available for bridge decks.

The study included a review of waterproofing products that were categorized into four groups: 1) liquid membranes, 2) sheet membranes, 3) friction polymers (laminates), and 4) polymer asphalts. Various products from each category were reviewed and identified for potential testing. Manufacturer's data was also reviewed for each product in an effort to identify any common waterproofing test method. This review was inconclusive. Kentucky Transportation Center (KTC) researchers decided, in response, that it would be necessary to develop a single waterproofing test method to compare waterproofing characteristics of the various products available. This method will allow comparison of performance of the various products available.

Existing literature contained little information on conducting permeability testing over a broad range of products. Studies were reviewed where tests have been performed on asphalt and high-performance concrete using triaxial cells at pressures as low as 4.3 psi(1) to more than 3,600 psi(3). A study on pressures applied by heavy trucks indicated pressures between 90 to 130 psi(2).

KTC's development of permeability testing began with the use of a constant head permeameter at a head pressure of 30 psi. This pressure could have been higher to expedite testing, however, some of the products tested were as thin as 0.07" and susceptible to swelling or possible damage. Testing closely followed ASTM D5084, "Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter."

This study focused predominantly on waterproofing capabilities. The test method developed is a good comparative test, however, the method should be further refined for it to be considered for use in material qualification. There are other characteristics to be considered when choosing a waterproofing product as well.

1. Introduction

The increased use of deicing chemicals (especially liquid treatments) necessitate the installation of bridge deck surfacing measures that waterproof the decks, improving their resistance of chloride ion penetration. A variety of options are available with varying degrees of effectiveness, cost, and longevity. Surfacing/waterproofing options include: waterproofing membranes (liquid and sheeting systems), polymer asphalts, and friction polymers (laminates). Some of these products can be maintained over the life of a bridge with periodic renewal of the wearing surface. Others can be replaced easily with minimal impact to the travelling public. Some can be applied by state forces, while others must be applied by contractors using specialized equipment. These options need to be investigated to create a Kentucky Transportation Cabinet (KYTC) toolkit of options for treating and maintaining bridge decks.

2. Objectives

This research had four objectives:

1. Identify surfacing/waterproofing options, including information about their application, performance, testing, and other technical aspects.
2. Determine laboratory performance testing methods for prequalifying waterproofing materials for experimental and routine use by KYTC. Employ those to identify candidate waterproofing systems.
3. Propose waterproofing options (types and specific products) that can be adopted by KYTC for use in new construction and maintenance.
4. Provide necessary support for KYTC to employ candidate systems on an experimental basis (special note preparation).

To achieve those goals, KTC researchers addressed the following tasks:

1. Identify waterproofing methods and specific products, including application requirements, costs, and performance using a literature search and contacts with manufacturers and select departments of transportation (DOTs).
2. Determine/perform applicable laboratory and field tests to evaluate the effectiveness of the waterproofing methods. Employ those tests to evaluate candidate waterproofing products.
3. Develop necessary documentation for KYTC to employ bridge deck waterproofing materials with acceptable performance on an experimental basis (QPLs, special notes).
4. Prepare a final report documenting the research.

3. Research Approach

This study focused primarily on the waterproofing characteristics of products offered to protect bridge decks from water intrusion. The products currently used for waterproofing fit into four basic categories: 1) liquid membranes, 2) sheet membranes, 3) thin overlays (laminates), and 4) thick impermeable overlays. With respect to permeability testing, our review of manufacturers' product data sheets revealed little commonality in testing that could be used for comparative proposes. A few manufacturers claim products to be waterproof or impermeable without documented test data. Of the products with documented data, the test methods/standards varied, including tests for permeability, absorption, and vapor transmission. (Table 1). All of these tests are conducted at low or no hydraulic pressure. There are insufficient similarities in the documented tests to adequately compare their performance. A literature search was performed focusing on waterproofing characteristics and permeability testing.

A report published in 2009(1) studied the effect of traffic-induced moisture based on the Average Daily Traffic (ADT), speed, loading, and tire pressure. Permeability testing was performed in the field and Time Domain Reflectometry (TDR) probes were installed beneath pavement to measure the moisture content of the soil. Laboratory testing was limited to determining the moisture content of soil samples collected during placement of the TDR probes. Asphalt was tested in the field using two methods: 1) falling head permeameter with an initial pressure of 30 kPa (4.35 psi) and 2) a constant head permeameter at a pressure of 30 kPa (4.35 psi). Results showed permeability varied between 1.07×10^{-3} to 5.85×10^{-3} cm/s.

The pressure applied by heavy truck traffic varies significantly due to several factors, including loading, tire size, tread design, inflation, and contact area. Assuming typical loading of 4,250 pounds per tire, contact pressure can vary from approximately 90 to 130 psi (2).

Another study published in 1995(3) focused on the development of high pressure triaxial testing of high-performance concrete. The goal was to develop a test method with reproducible results when testing permeability values range between 10^{-10} to 10^{-14} cm/s. Testing was performed with constant head pressure and confining pressure of approximately 6.5 MPa (943 psi) and 24.5 MPa (3,684 psi), respectively. These extreme pressures were used to expedite testing.

The New York State Department of Transportation (NYSDOT) has used waterproof hot mix asphalt (HMA) to overlay concrete bridge decks(4). ASTM D5084, "Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter," (Method A) was used to verify waterproofing performance. Head and cell pressures of approximately 70 and 100 psi were used, respectively. To limit side wall seepage, Vaseline was applied to the sides of specimens. NYSDOT specifications require that waterproof HMA permeability test results be less than 1×10^{-5} cm/s. The result of the tests performed was 5.24×10^{-7} cm/s.

Based on the diversity among the manufacturer's test standards and test methods found in the literature search, this study's objectives were amended to develop a permeability test to adequately compare test results of the various products available. These changes are described in the amendments below.

Amendment 1 – PROBLEM STATEMENT – Additional Paragraph
PROBLEM STATEMENT

Initial work indicated that no standardized laboratory performance tests exist. Development of laboratory performance tests require additional time and funding.

Amendment 2 – OBJECTIVES – Second Objective
OBJECTIVES

Development of laboratory performance testing for prequalifying waterproofing materials for experimental and routine use by KYTC. Employ those tests to identify candidate waterproofing systems.

Amendment 3 – WORKPLAN (Major Tasks and Activities) – Task 2 and Additional Task 3
WORKPLAN (Major Tasks and Activities)

2. Develop laboratory tests and fabricate the necessary apparatus.
3. Perform applicable laboratory tests to evaluate the effectiveness of the waterproofing methods. Employ those tests to evaluate candidate waterproofing products.
4. Develop necessary documentation for KYTC to employ bridge deck waterproofing materials on an experimental basis (QPLs, special notes).
5. Prepare a final report documenting the research.

Amendment 4 – TIMELINE – Extended to December 31, 2018 – Tasks 2 - 5
TIMELINE

Task 2. Develop applicable laboratory tests and apparatus – September 30, 2017.

Task 3. Perform applicable laboratory tests – April 30, 2018.

Task 4. Develop necessary documentation for waterproofing projects – August 31, 2018.

Task 5. Prepare a final report – December 31, 2018.

4. Product Acquisition

Product submissions were solicited from several manufacturers/suppliers. Products were classified into four categories: 1) sheet membranes, 2) liquid membranes, 3) laminates/thin overlays, and 4) polymer asphalt or concrete. The intent was to acquire two products in each category. This proved successful with the exception of the thick overlay category. Only one product falling within this category was submitted.

All participating vendors were asked to submit three specimens of their product applied on 16”x8”x4” concrete cap blocks. This substrate was chosen because it has a higher rate of permeability compared to typical concrete. One submission could not be applied in the requested manner. It was not practical for polymer asphalt to be prepared in the requested manner. Part of Contract ID 174301 in KYTC District 5 entailed replacing plug joints on Interstate 65 bridges between MP 131.3 and 135.4 with polymer asphalt. Kentucky Transportation Center (KTC) personnel extracted cores from an approved test patch in the paving company parking lot (Figure 1). Table 2 lists product type and composition submitted for testing.

5. Laboratory Tests

Permeability (Specimen Preparation):
Using a 4” core drill (Figure 2), nine cores were extracted from untreated concrete cap blocks. These cores were used to begin development of the testing method and establish that the coefficient of permeability was higher than that expected of the waterproofing material. For each product submitted, six cores were extracted from two of the treated blocks. Three of these cores were used to further develop the method. Once the method was finalized, initial permeability data were recorded. The remaining cores were held for testing at a later date in an attempt to determine repeatability of the tests.

To facilitate the de-airing process, cores were cut to leave approximately 0.50” of concrete cap block material below the waterproofing material (Figure 3). Each polymer asphalt core was cut to a consistent thickness of 1.5”. To remove contaminants introduced during the coring and cutting process, all cores were rinsed thoroughly with deionized water after each process. They were then submerged in deionized water to aid in saturation.

Absorption (Specimen Preparation):
Three cores were extracted for absorption testing and rinsed as previously described. These specimens were prepared in accordance with ASTM D6489, “Standard Test Method for Determining the Water Absorption of Hardened Concrete Treated with a Water Repellant Coating.” Three cores from each product were oven dried at 75°C (167°F). A specimen was considered oven dry when a weight change of ≤ 0.2% was observed in a 2-hour period. Once an oven-dry weight was achieved, specimens were cooled to room temperature and weighed (recorded as W_A). The outer edges of each core were coated with paraffin that had been melted at 60°C (140°F). Care was exercised to ensure the treated surface was not contaminated. This sealing process was repeated twice to assure no leakage during testing.

Development of Permeability Testing:
The literature review indicated the use of testing pressures as low as 4.3 psi to in excess of 3,600 psi. Tire pressures of 90 to 130 psi from heavy trucks are cyclical, which could not be reproduced in the lab given the project’s scope. A modified version of ASTM D5084, “Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter,” (Method A) with a constant head pressure of 30 psi was used to test all specimens. Three 4” concrete cap blocks were purchased from Home Depot, and three 4” cores were cut from each. Initially these nine cores were tested in a permeameter (Figure 4) without vacuum capability. The porosity of the material allowed evacuation of air in a reasonable time. Permeability of the nine cores ranged from $2.58(10^{-4})$ to $2.74(10^{-4})$ cm^3/sec. The cores treated with the waterproofing material could not be de-aired in this permeameter, so a different cell with the capacity to apply a vacuum to the base and cap assembly was used (Figure 5). This setup consisted of the permeameter with vacuum and water to the cap and base, a pressurized head water reservoir (approximately 1 gallon), and a reservoir used as a water trap for the applied vacuum. See Figure 6 for a diagram of the hydraulic circuit. The same nine cores were retested in this cell and results ranged between $1.80(10^{-4})$ to $1.87(10^{-4})$ cm^3/sec.

The de-airing process on cores that had been treated with waterproofing material proved to be time consuming. Once de-airing was complete and testing began, permeability measurements were very unstable. Water seepage between the edges of the specimens and the confining membrane was determined to be the cause of the instability. Numerous measures were taken to address this issue, including varying head and confining pressures. Using a head pressure of 30 psi and cell pressure of 60 psi, along with a very thin coating of high-vacuum grease applied to the outer edges of the specimens, resolved the seepage issue. To reduce the time needed for de-airing, each specimen was cut approximately 0.5" below the waterproofing material. The samples of polymer asphalt were tested at a thickness of 1.5". All specimens were submerged in deionized water for a minimum of 24 hours prior to testing.

The testing procedure began with the application of a vacuum at 20 in. Hg to both the cap and base for approximately one hour. Cell and head pressures were gradually increased to 60 psi and 30 psi, respectively, until no air was observed in the discharge. Once no air was observed, the vacuum was removed and only head pressure remained on the cap. The outflow of water was directed through a length of 1/8" tubing that had been taped along the work surface. The volume of the tubing was 0.02141 cm^3 per cm of length. The flow was timed and measured in 15-minute intervals until the flow stabilized per ASTM D5084 Paragraph 9.5.4.1. Once stabilized, four measurements were recorded and used to calculate permeability. When testing material with a coefficient of permeability greater than $1x10^{-7}$ cm^3/sec the output was collected in a breaker and weighed. Tables 3–9 present the results.

The following equation was used for calculating permeability:

$$k = \frac{qL}{Ah}$$

Where: k = Coefficient of permeability
q = Discharge in cm^3/sec
L = Length of specimen in cm
A = Cross-sectional area of specimen in cm^2
h = Constant head causing flow in cm

Absorption Testing (ASTM 6489):

Absorption testing was performed to determine if absorption performance correlated with the results of permeability testing. Three prepared specimens were weighed and recorded as W_1. They were then placed face down on glass rods (.125" diameter) in a dish. Deionized water was added to the dish to a depth of 1.5" from the top of the glass rods (Figure 7). Each specimen was removed after 24 hours, wiped with a damp cloth, and weighed. They were then re-submerged in water for another 24 hours and weighed again. Each weight was recorded as W_2. Tables 10 and 11 contain the results.

The percent absorption for each 24-hour period was determined as follows:

$$Percent\ Absorption = \frac{100x(W^2 - W^1)}{Wa}$$

Where: W^1 = oven dry weight

W^2 = sealed weight
Wa = 24 or 48 hour weight

6. Conclusions

This study focused on the waterproofing characteristics of bridge deck treatments designed to prevent the ingress of water and chlorides into the underlying concrete. These characteristics are of primary concern when selecting a waterproofing product, however, other properties should be considered as well, including tensile properties, bond strength, abrasion resistance, hardness, puncture resistance, chemical resistance, compressive strength, crack bridging, skid resistance, freeze thaw resistance, and thermal expansion characteristics.

The test methods documented by manufacturers of waterproofing treatments are almost as varied as the available material. All waterproofing tests are performed at very low pressure. Previous field testing for chloride intrusion performed by KTC (FRT 194 Experimental Deck Sealants and Pier Cap Coating on Interstate 471) indicated higher chloride ion levels in the wheel paths than on the shoulders. Traffic can induce pressures of up to 130 psi on the wheel path. The cyclical action from traffic continually pumps water laced with chlorides into the deck.

The test described in this study was performed on seven different waterproofing products from six manufacturers. Results were reasonably consistent, and the test was repeatable. Thus, it proved to be a valid comparative test. Further refinement of the method is necessary if the test is to be considered for use in product qualification.

7. Recommendations

Development of this test method should be continued as part of an expanded test protocol to qualify waterproofing material for inclusion in the KYTC Approved Product List. Training should be developed and implemented to assure competency and accuracy of testing. Pilot projects should be implemented and monitored.

References

(1) Langdon, Aaron, "Traffic Induced Moisture Into Road Pavements", October 2009

(2) Yap, P., Goodyear Tire & Rubber Co., "Truck Tire Types and Road Contact Pressures", June 1989

(3) El-Dieb, A.S., NS Hooton, R.D., "Water-Permeability Measurement of High Performance Concrete Using A High-Pressure Triaxial Cell", February 1995

(4) Bennet, Thomas, "NYSDOT Water Proof HMA Mix Verification", WILLETS-RU9247, April 2009

Tables

Table 1 Test Standards and Frequency Documented by Various Manufacturers

TEST/STANDARD	FREQUENCY
ASTM E96 Standard Test Methods for Water Vapor Transmission of Materials	4
ASTM C413 Standard Test Method for Absorption of Chemical Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes	1
ASTM C642 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete	1
ASTM D570 Standard Test Method for Water Absorption of Plastics	3
AASTHO T277 Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration	1

Table 2 Product type and composition submitted for testing

Product ID	Manufacturer/Product	Product Type	Composition (from product data sheets)
A	Wasser/Polyflex 57	Liquid Membrane	Hand applied elastomeric polyurethane coating w/aggregate added for sheer strength
B	Wasser/Polyflex 311	Liquid Membrane	Spray applied polyuria coating w/aggregate added for sheer strength
C	Crafco/PavePrep TSA	Sheet Membrane	Geocomposite self-adhesive membrane
D	WR Meadows/Mel-Dek	Sheet Membrane	Laminated polymeric membrane on polypropylene woven carrier fabric
E	Transpo/T-18	Friction Polymer/Laminate	Methyl methacrylate and aggregate bound in a slurry with polymer binder
F	Polycarb/Flexogrid	Friction Polymer/Laminate	100% solids flexible hybridized copolymer system
G	Chase Corporation/Rosphalt	Polymer Asphalt	Concentrated thermoplastic additive for HMA

Table 3 Product A – Liquid Spray Applied Membrane

Product A					
Sample #	Reading 1 (cc/s)	Reading 2 (cc/s)	Reading 3 (cc/s)	Reading 4 (cc/s)	Average (cc/s)
Ws1-17	4.41E-11	8.66E-11	7.27E-11	8.18E-11	7.13E-11
Ws3-17	6.80E-11	7.31E-11	8.11E-11	8.56E-11	7.70E-11
Ws5-17	7.90E-11	8.39E-11	1.13E-10	1.13E-10	9.75E-11
Ws1-V	1.24E-10	1.50E-10	1.51E-10	1.46E-10	1.43E-10
Ws2-V	1.43E-10	1.62E-10	1.63E-10	1.76E-10	1.61E-10
Ws3-V	1.95E-10	2.03E-10	2.10E-10	2.01E-10	2.02E-10

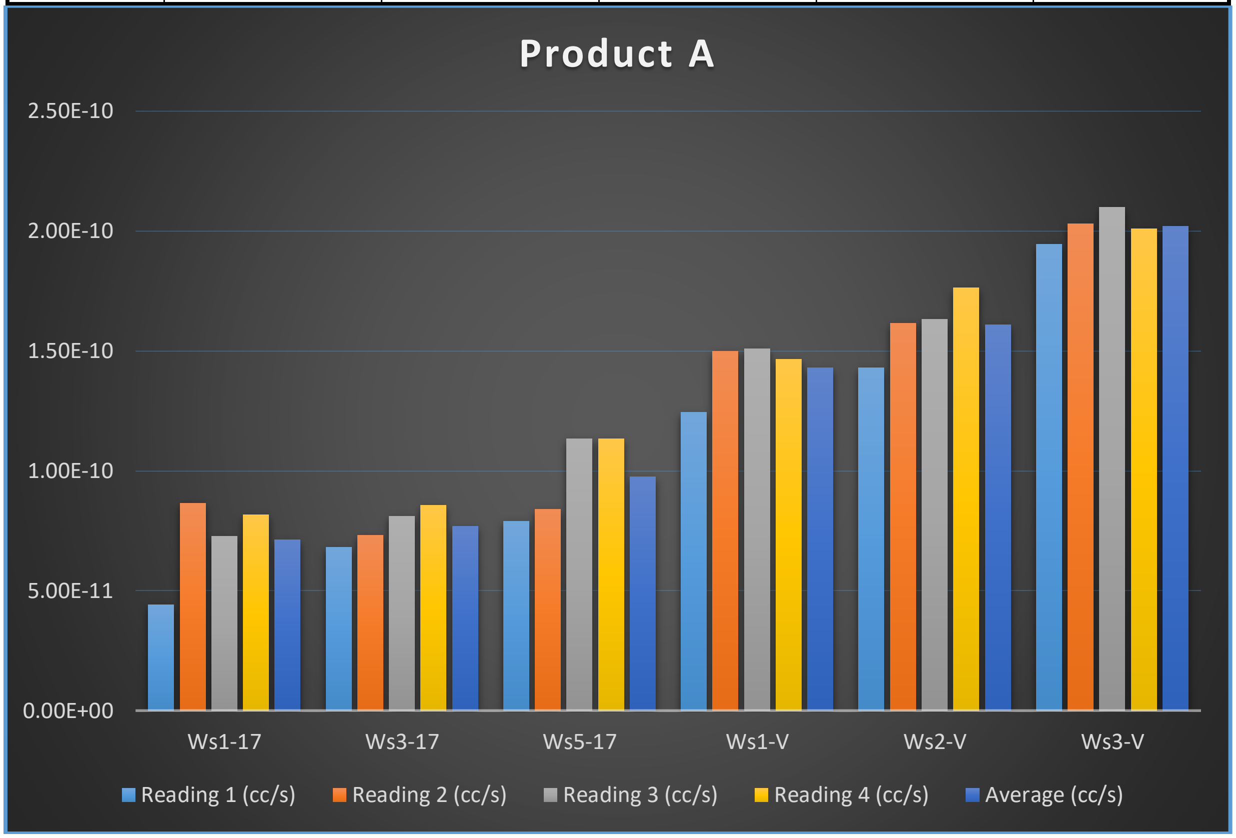


Table 4 Product B – Liquid Hand Applied Membrane

Product B					
Sample #	Reading 1 (cc/s)	Reading 2 (cc/s)	Reading 3 (cc/s)	Reading 4 (cc/s)	Average (cc/s)
Wh1-17	2.30E-08	2.41E-08	2.02E-08	1.65E-08	2.09E-08
Wh3-17	3.50E-07	3.57E-07	3.22E-07	3.16E-07	3.36E-07
Wh5-17	3.97E-08	4.18E-08	4.14E-08	4.04E-08	4.08E-08
Wh1-V	8.49E-07	8.25E-07	8.39E-07	8.47E-07	8.40E-07
Wh2-V	1.18E-06	1.20E-06	1.20E-06	1.21E-06	1.20E-06
Wh3-V	1.50E-06	1.64E-06	1.61E-06	1.61E-06	1.59E-06

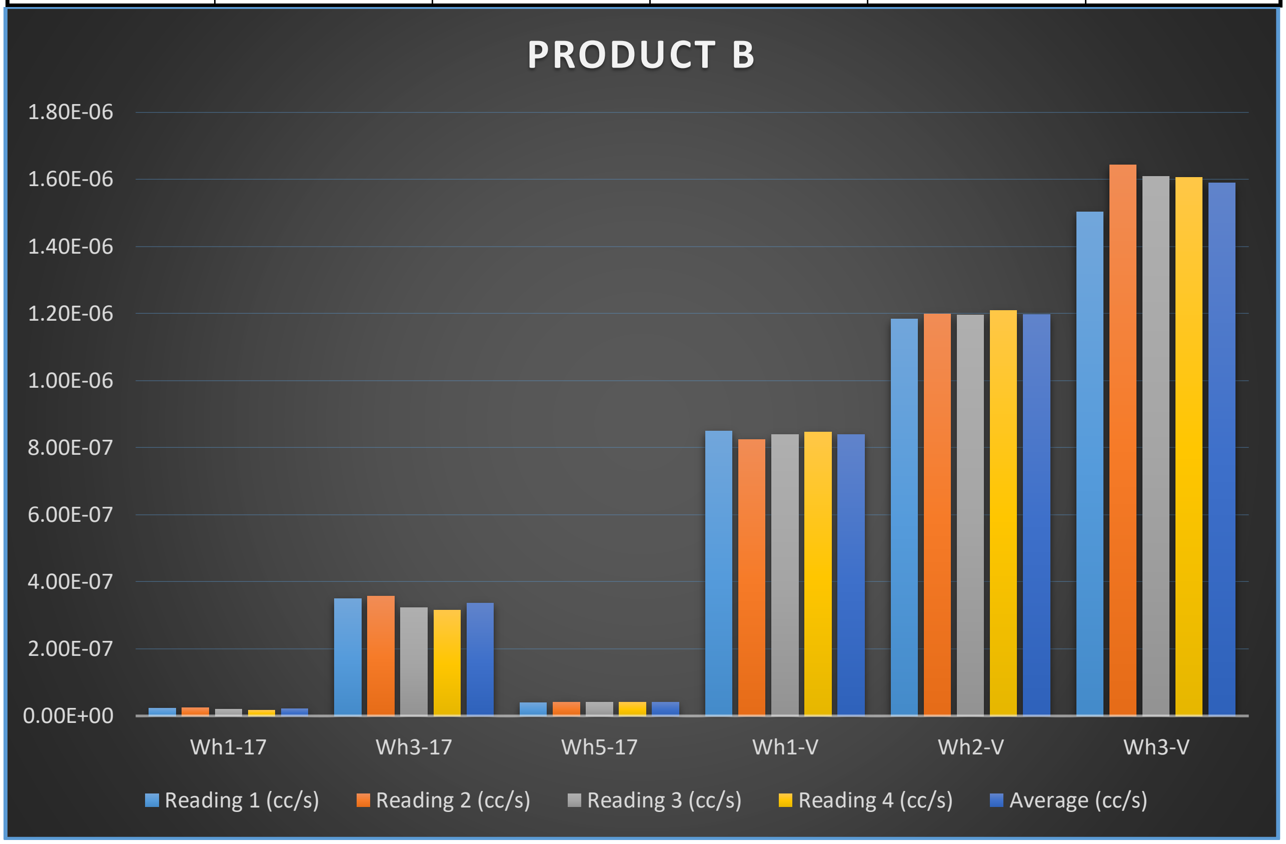


Table 5 Product C – Sheet Membrane

Product C					
Sample #	Reading 1 (cc/s)	Reading 2 (cc/s)	Reading 3 (cc/s)	Reading 4 (cc/s)	Average (cc/s)
C4-17	2.67E-10	2.62E-10	2.92E-10	2.89E-10	2.78E-10
C2-17	3.24E-10	2.98E-10	3.10E-10	2.88E-10	3.05E-10
C6-17	5.85E-10	4.98E-10	5.05E-10	4.84E-10	5.18E-10
C1-V	4.34E-09	2.90E-09	5.17E-09	3.59E-09	4.00E-09
C2-V	3.51E-09	6.67E-09	4.89E-09	5.60E-09	5.17E-09
C3-V	1.75E-09	2.42E-09	1.37E-09	1.33E-09	1.71E-09

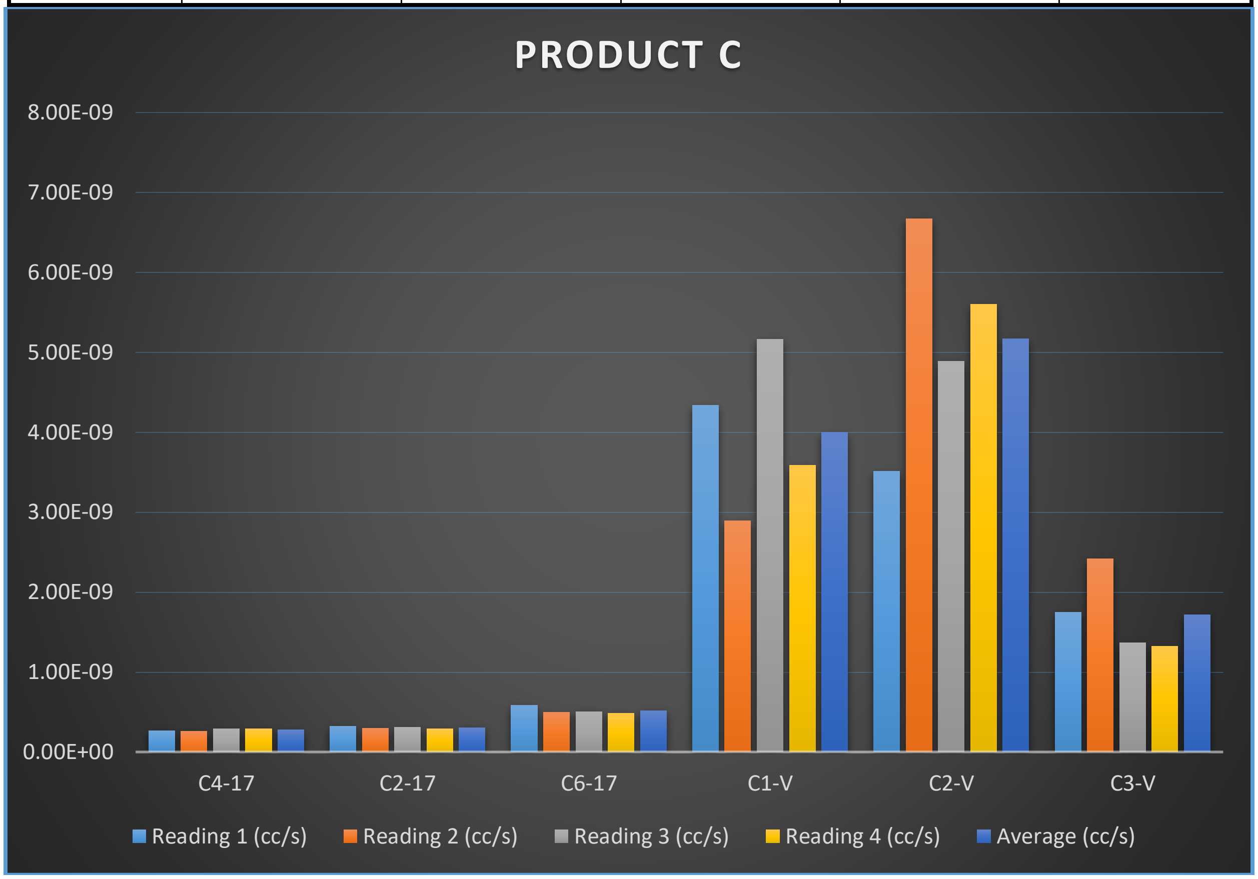


Table 6 Product D – Sheet Membrane

Product D					
Sample #	Reading 1 (cc/s)	Reading 2 (cc/s)	Reading 3 (cc/s)	Reading 4 (cc/s)	Average (cc/s)
M4-17	1.31E-10	1.25E-10	1.36E-10	1.18E-10	1.28E-10
M2-17	1.52E-10	1.51E-10	1.58E-10	1.39E-10	1.50E-10
M6-17	2.28E-10	2.59E-10	2.70E-10	2.72E-10	2.57E-10
M1-V	1.90E-10	2.66E-10	2.41E-10	2.65E-10	2.41E-10
M2-V	1.26E-10	1.39E-10	1.43E-10	1.44E-10	1.38E-10
M3-V	1.59E-10	1.56E-10	1.65E-10	1.60E-10	1.60E-10

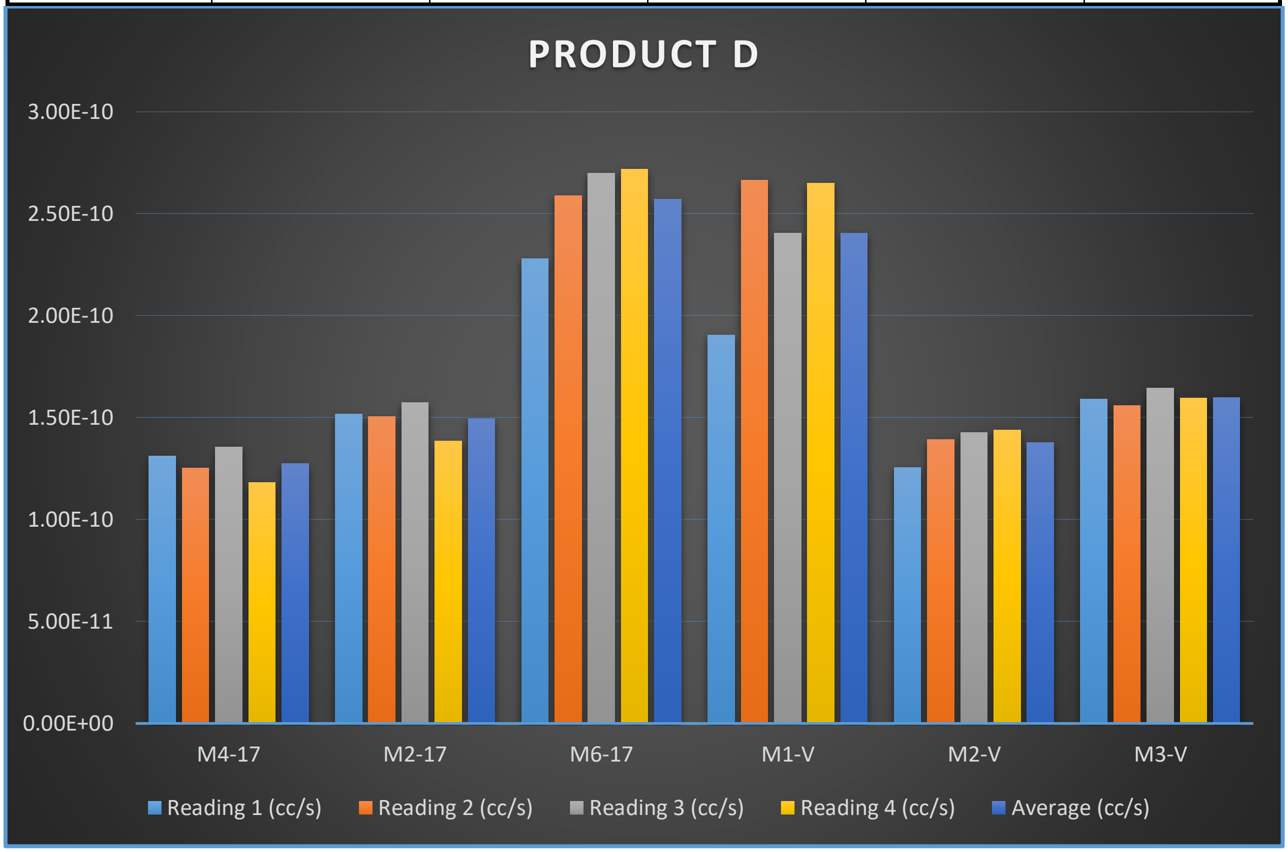


Table 7 Product E – Laminate/Thin Overlay

Product E					
Sample #	Reading 1 (cc/s)	Reading 2 (cc/s)	Reading 3 (cc/s)	Reading 4 (cc/s)	Average (cc/s)
T1-17	1.12E-09	1.21E-09	1.25E-09	1.24E-09	1.20E-09
T5-17	1.27E-09	1.30E-09	1.29E-09	1.32E-09	1.29E-09
T3-17	1.58E-09	1.55E-09	1.53E-09	1.56E-09	1.55E-09
T1-V	5.87E-10	6.13E-10	6.67E-10	7.05E-10	6.43E-10
T2-V	7.87E-10	7.97E-10	8.28E-10	8.52E-10	8.16E-10
T3-V	9.23E-10	9.13E-10	9.03E-10	9.25E-10	9.16E-10

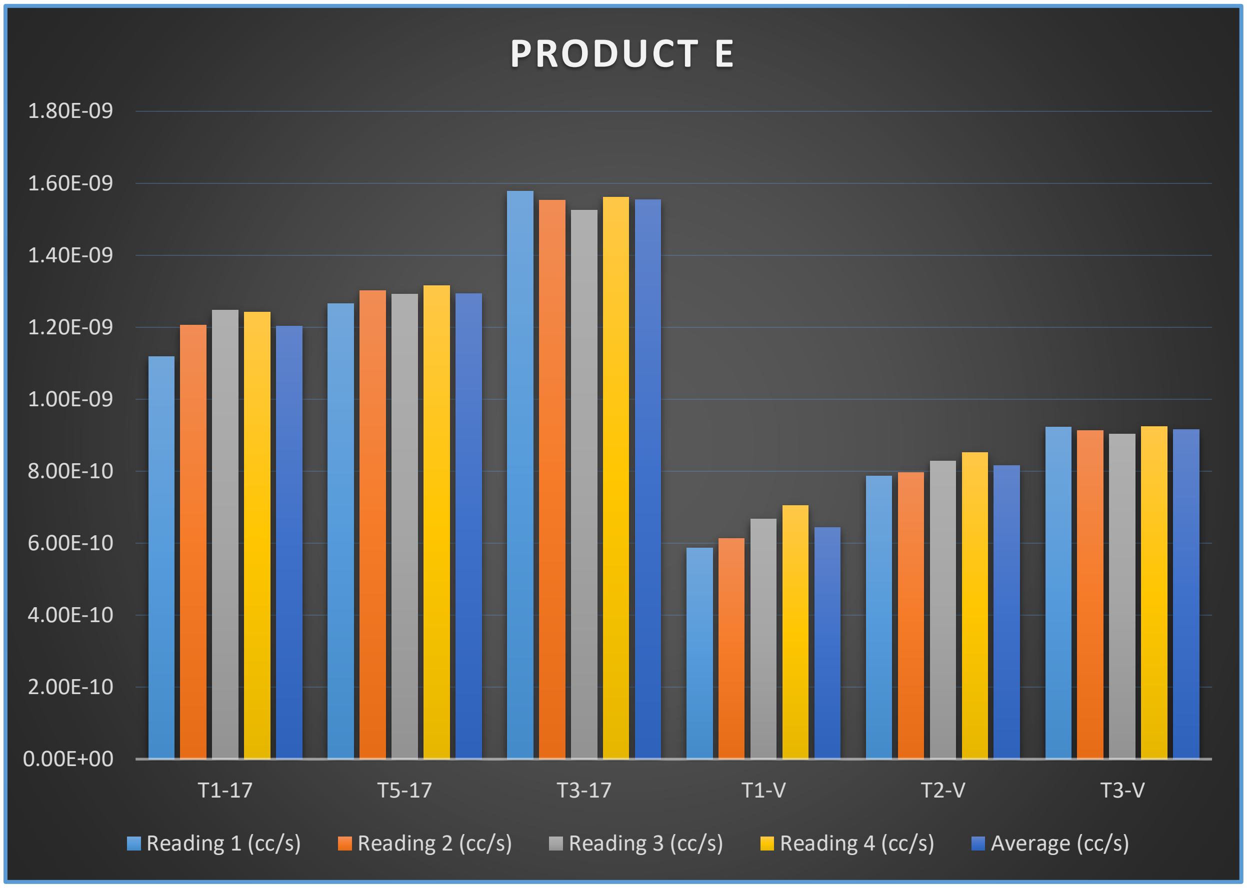


Table 8 Product F – Laminate/Thin Overlay

Product F					
Sample #	Reading 1 (cc/s)	Reading 2 (cc/s)	Reading 3 (cc/s)	Reading 4 (cc/s)	Average (cc/s)
P3-17	7.88E-10	7.41E-10	7.88E-10	8.03E-10	7.80E-10
P1-17	9.03E-10	9.22E-10	9.43E-10	9.32E-10	9.25E-10
P5-17	9.75E-10	9.08E-10	9.51E-10	9.78E-10	9.53E-10
P1-V	5.03E-10	5.27E-10	5.44E-10	5.41E-10	5.29E-10
P2-V	2.22E-10	2.77E-10	2.46E-10	2.64E-10	2.52E-10
P3-V	1.86E-10	2.01E-10	2.15E-10	2.27E-10	2.07E-10

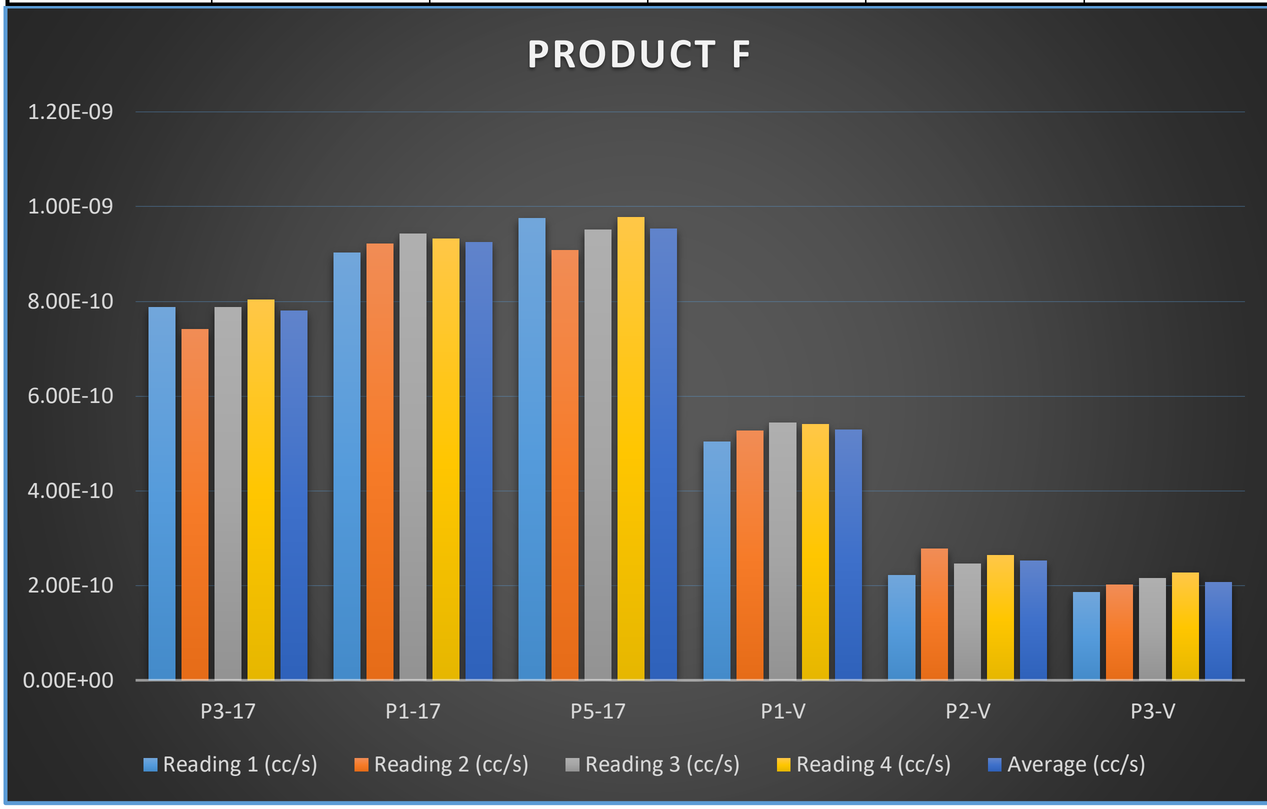


Table 9 Product G – Polymer Asphalt

Product G					
Sample #	Reading 1 (cc/s)	Reading 2 (cc/s)	Reading 3 (cc/s)	Reading 4 (cc/s)	Average (cc/s)
R6-17	2.48E-09	2.56E-09	2.67E-09	2.75E-09	2.61E-09
R3-17	3.14E-09	2.67E-09	2.78E-09	2.70E-09	2.83E-09
R2-17	4.23E-09	3.44E-09	3.59E-09	3.07E-09	3.58E-09

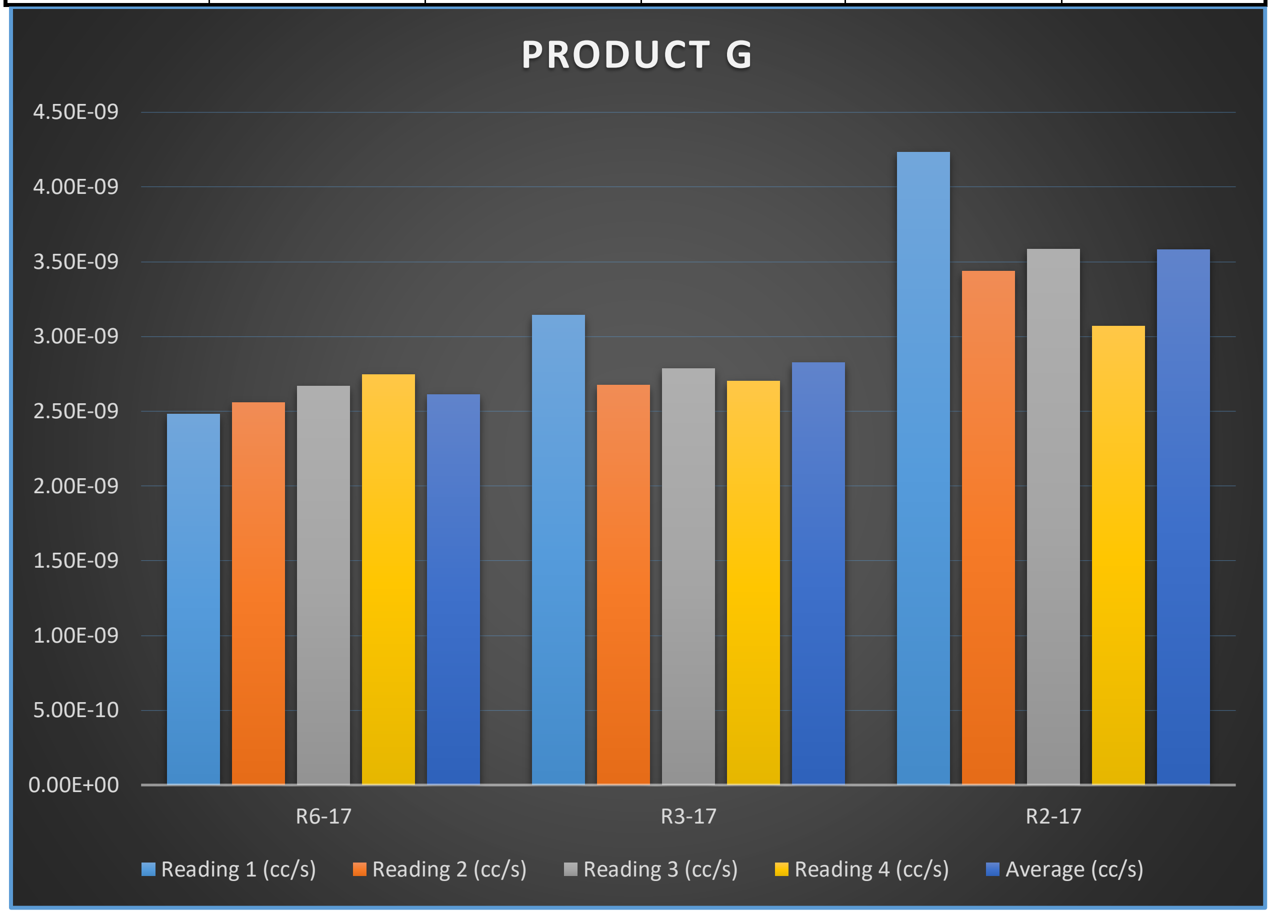
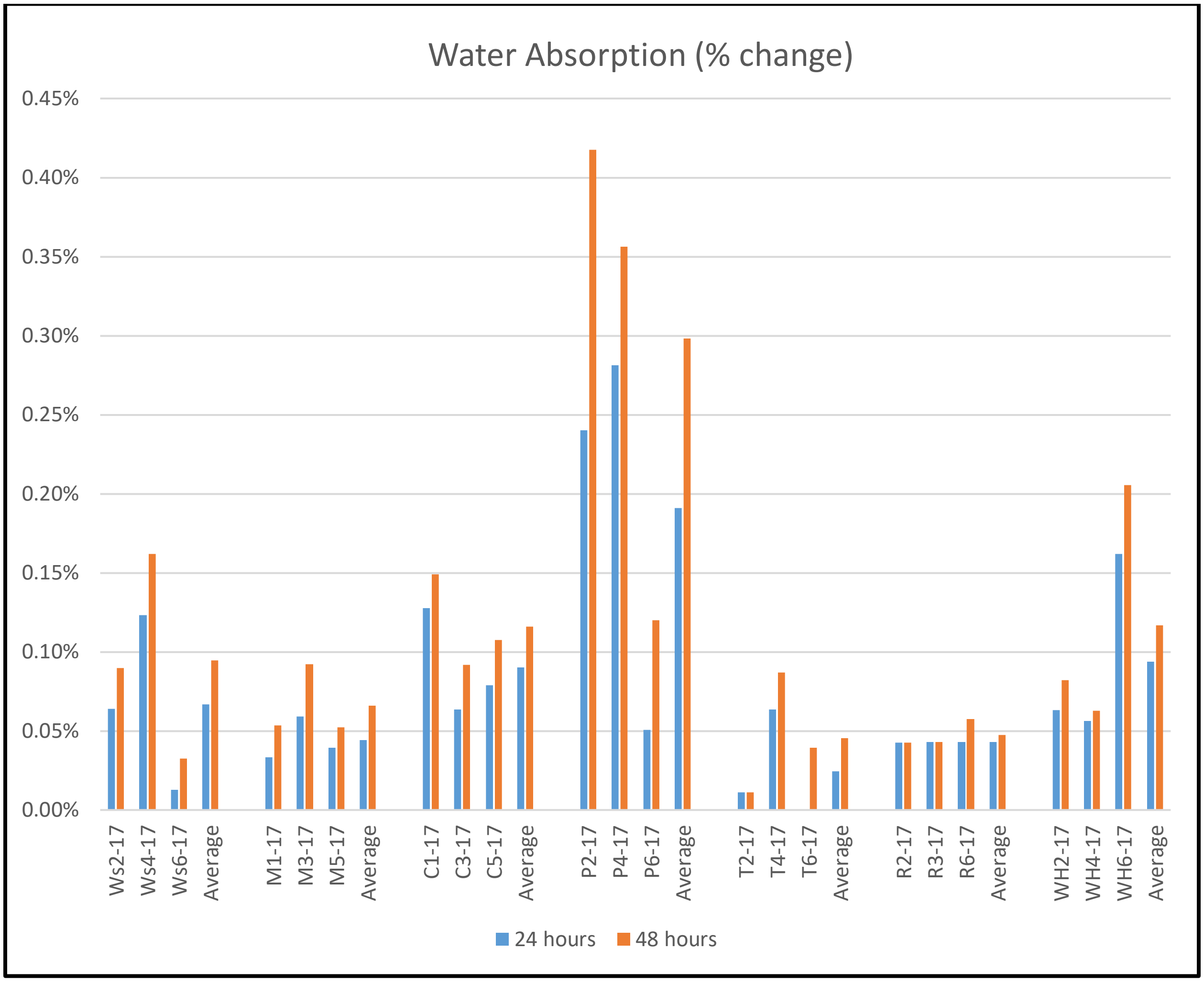


Table 10 Water Absorption Results

ASTM D6489 Water Absorption								
Specimen	**Initial Weight**	**Coated Weight**	**24 hours**	**24 hours**	**24 hours cc/sec**	**48 hours**	**48 hours**	**48 hours cc/sec**
Ws2-17	1560.2	1614.10	1615.10	0.06%	1.16E-05	1615.50	0.09%	8.10E-06
Ws4-17	1543.3	1576.70	1578.60	0.12%	2.20E-05	1579.20	0.16%	1.45E-05
Ws6-17	1546.0	1589.90	1590.10	0.01%	2.31E-06	1590.40	0.03%	2.89E-06
Average	1549.83	1593.57	1594.60	0.07%	1.20E-05	1595.03	0.09%	8.49E-06
M1-17	1498	1531.70	1532.20	0.03%	5.79E-06	1532.50	0.05%	4.63E-06
M3-17	1517.2	1539.80	1540.70	0.06%	1.04E-05	1541.20	0.09%	8.10E-06
M5-17	1527.3	1562.40	1563.00	0.04%	6.94E-06	1563.20	0.05%	4.63E-06
Average	1514.17	1544.63	1545.30	0.04%	7.72E-06	1545.63	0.07%	5.79E-06
C1-17	1409.8	1434.30	1436.10	0.13%	2.08E-05	1436.40	0.15%	1.22E-05
C3-17	1413.7	1437.30	1438.20	0.06%	1.04E-05	1438.60	0.09%	7.52E-06
C5-17	1396.6	1418.00	1419.10	0.08%	1.27E-05	1419.50	0.11%	8.68E-06
Average	1406.70	1429.87	1431.13	0.09%	1.47E-05	1431.50	0.12%	9.45E-06
P2-17	1581.2	1605.10	1608.90	0.24%	4.40E-05	1611.70	0.42%	3.82E-05
P4-17	1600.3	1633.30	1637.80	0.28%	5.21E-05	1639.00	0.36%	3.30E-05
P6-17	1580.9	1628.90	1629.70	0.05%	9.26E-06	1630.80	0.12%	1.10E-05
Average	1587.47	1622.43	1625.47	0.19%	3.51E-05	1627.17	0.30%	2.74E-05
T2-17	1779	1794.70	1794.90	0.01%	2.31E-06	1794.90	0.01%	1.16E-06
T4-17	1728.9	1749.00	1750.10	0.06%	1.27E-05	1750.50	0.09%	8.68E-06
T6-17	1774.1	1794.40	1794.40	0.00%	0.00E+00	1795.10	0.04%	4.05E-06
Average	1760.67	1779.37	1779.80	0.02%	5.02E-06	1780.17	0.05%	4.63E-06
R2-17	702.3	717.00	717.30	0.04%	3.47E-06	717.30	0.04%	1.74E-06
R3-17	700.2	715.70	716.00	0.04%	3.47E-06	716.00	0.04%	1.74E-06
R6-17	697.7	713.40	713.70	0.04%	3.47E-06	713.80	0.06%	2.31E-06
Average	700.07	715.37	715.67	0.04%	3.47E-06	715.70	0.05%	1.93E-06
WH2-17	1584.2	1601.60	1602.60	0.06%	1.16E-05	1602.90	0.08%	7.52E-06
WH4-17	1597	1619.40	1620.30	0.06%	1.04E-05	1620.40	0.06%	5.79E-06
WH6-17	1606.00	1631.20	1633.80	0.16%	3.01E-05	1634.50	0.21%	1.91E-05
Average	1595.73	1617.40	1618.90	0.09%	1.74E-05	1619.27	0.12%	1.08E-05

Table 11 Water Absorption Chart



Figures

Figure 1 Cutting Polymer Asphalt cores

Figure 2 Cutting Cores from Concrete Cap Blocks

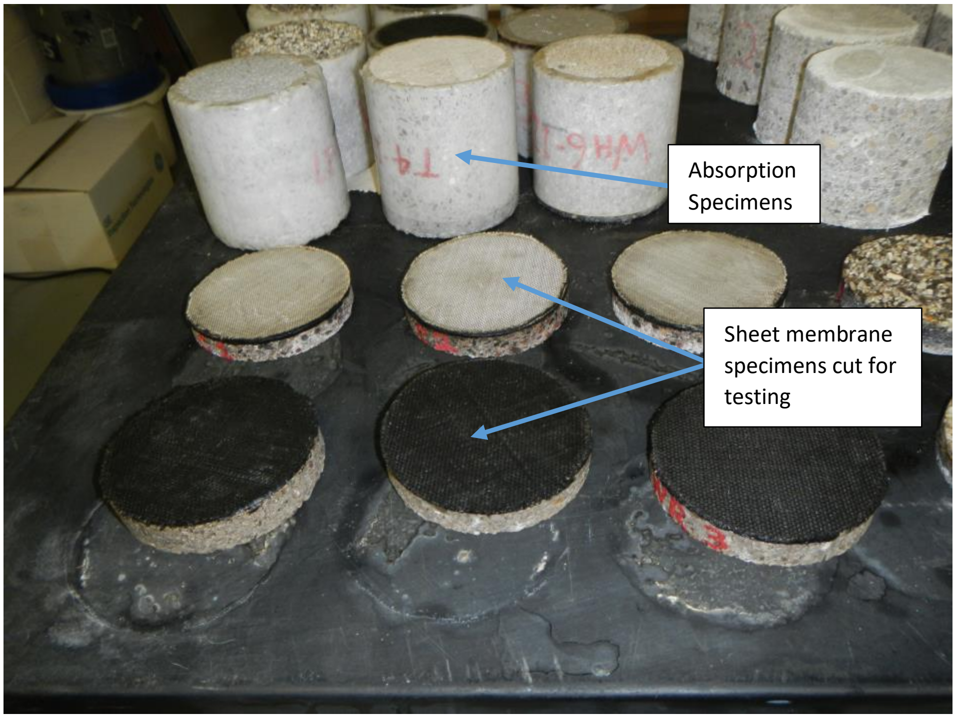


Figure 3 Specimens after cutting to length

Figure 4 Small Permeameter without vacuum

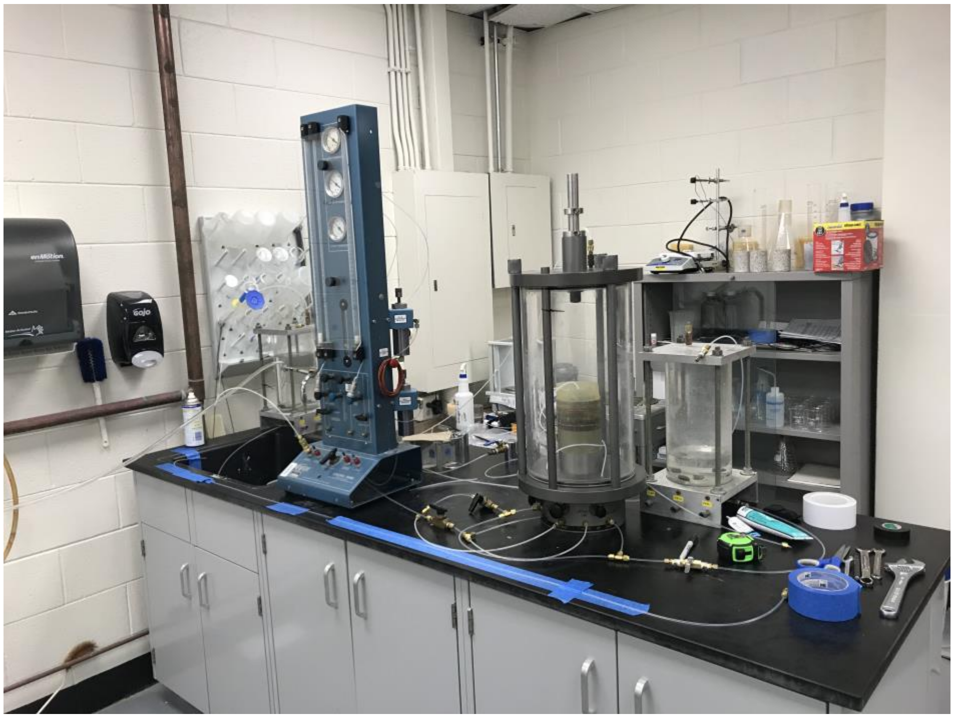


Figure 5 Permeameter with vacuum capability

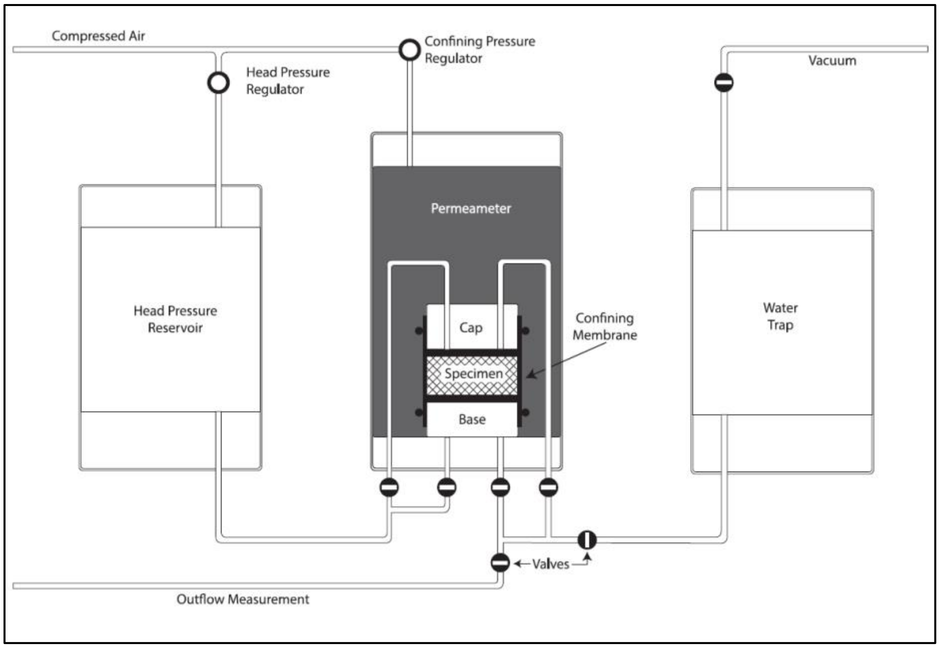


Figure 6 Hydraulic Circuit

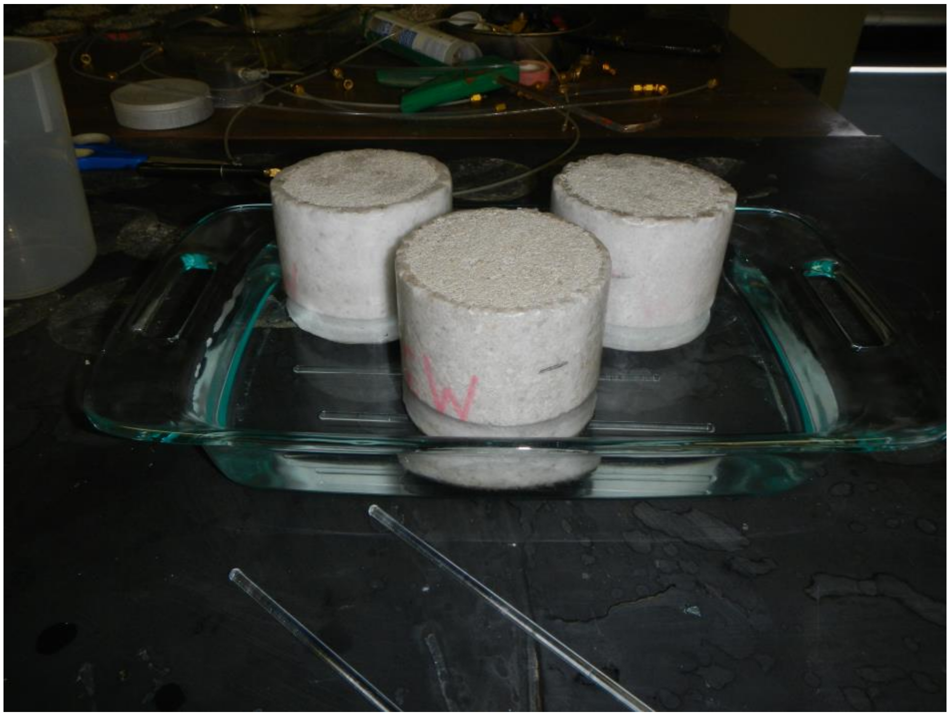


Figure 7 Absorption Testing