FINAL PROGRAM

ASCE

FORENSIC ENGINEERING 8th CONGRESS

Austin, Texas | November 29 – December 2, 2018

Forging Forensic Frontiers

Sheraton at the Capitol

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FORENSIC ENGINEERING 2018

Forging Forensic Frontiers

PROCEEDINGS OF THE EIGHTH CONGRESS ON FORENSIC ENGINEERING

November 29–December 2, 2018
Austin, Texas

SPONSORED BY
Forensic Engineering Division
of the American Society of Civil Engineers

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Published by the American Society of Civil Engineers

Preface

Forensic Engineering 2018: Forging Forensic Frontiers is a collection of 111 peer-reviewed technical papers presented at the Forensic Engineering 8th Congress, sponsored by the Forensic Engineering Division (FED) of the American Society of Civil Engineers (ASCE). The Congress took place from November 30 to December 2, 2018, at the Sheraton Austin Hotel at the Capitol in Austin, Texas. The goals of the Congress were to bring together leading forensic engineering practitioners, researchers, designers, project and construction managers from around the world to allow attendees to learn about current evaluation techniques and investigative methods. These efforts align with the mission of FED to enhance the forensic engineering profession, develop guidelines for conducting failure investigations, disseminate failure information, promote forensic curriculum in engineering education, share practices to reduce failures, and improve performance of the built environment.

Each paper in this collection was subjected to a double-blind review process, with review comments distributed to authors, author revisions as appropriate, and final review by the proceedings editors. Paper submission began with published calls for abstracts and at least two positive indications from reviewers before invitation to submit full papers. The review process determined whether each paper was applicable, useful, and relevant to forensic engineering; whether the paper had been published previously; whether the methodology was satisfactorily explained; whether the references were verifiable, whether the tables, figures, and photographs complemented the paper; whether the conclusions were clear and justified; whether the elements of the paper related logically to the paper; and whether the writing style, grammar, and formatting were appropriate. Each paper received a minimum of two positive reviews in order to be published. Papers in this collection cover a wide array of forensic topics pertaining to the built environment, with some taking new approaches to historic failure events and others exploring new frontiers in forensic evaluation and analysis methods. The Congress also included papers of local and regional interest, such as assessment of damages from recent Hurricanes Irma, Harvey, and Maria.

Two half-day workshops held on November 29, prior to the official start of the Congress, involved guidance in operation of a forensic engineering practice and conducting forensic engineering investigations. These workshops were sponsored by FED Committees on Forensic Practice and Forensic Investigation, respectively. The morning workshop on *The Practice of Forensic Engineering* was presented by James S. Cohen, Leonard J. Morse-Fortier, Clemens J. Rossell, and Lloyd M. Sonenthal.

The afternoon workshop, *Conducting Failure Investigations*, was presented by Ronald W. Anthony, Richard S. Barrow, Kimball J. Beasley, Jeffrey A. Travis, and Stewart M. Verhulst. The workshop speakers formulated their presentations, in part, on FED sponsored publications Guidelines to Forensic Engineering Practice, 2nd edition, ASCE Press 2012, and Guidelines to Forensic Investigations, 2nd edition, ASCE Press, 2018.

The Congress opened with a featured keynote presentation by accomplished researcher and structural engineer Ahmed Amir Khalil, PhD, P.E. His presentation *High Fidelity Numerical Simulations in Forensic Analysis and Urban Search and Rescue* focused on the use and challenges of high-fidelity numerical modeling in forensic investigations and the use of such to aid in planning for and implementing urban search and rescue operations.

In addition to the presented papers, the Congress also included panel discussions, networking socials, a welcoming reception, an awards luncheon, and committee meetings. Finally, a student paper competition was held that included poster presentations from a number of our future professional forensic engineers.

It has been our pleasure and privilege to be part of this Congress. Happy reading!

Rui Liu, PhD, P.E., M.ASCE
Kent State University
Proceedings Editor-In-Chief

Michael P. Lester, P.E., M. ASCE
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Congress Chair

Acknowledgments

The Steering Committee of the Forensic Engineering 8th Congress expresses its sincere appreciation to the Proceedings Editorial Board, the Executive Committee of FED, its membership, cooperating organizations, ASCE staff, and most especially to the authors, panelists, presenters, peer reviewers, moderators, track chairs, and sponsors for making this Congress a success. Special thanks to our families, without your support this work would not have been made possible.

The guidance, dedication, and commitment of the following individuals contributed to the planning and development of all aspects of the congress venue, program, and activities.

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Elastomeric Coatings: A Qualitative Failure Analysis

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ABSTRACT

For decades, waterproofing has been a major concern and a widely researched topic by building scientists and forensic engineers. Elastomeric coatings have been broadly used in different applications since the early 1950s. Manufacturer's recommendations for the proper application of elastomeric coatings are often based on laboratory conditions (75 °F and 50% RH) rather than irregular conditions posed by the real world. This study examines the failure of elastomeric roof coating exposed to different environmental conditions of high temperature (150 °F) and water pooling caused by precipitation events. A qualitative comparison of exemplars revealed why roofing contractors must consider environmental conditions as an influential factor in determining the application range of elastomeric coatings. Test exemplars were made using different substrates (i.e., glass, asphalt, and metals) to test the behavior of elastomeric coating when applied to materials with different thermal expansion and contraction properties. Exemplars were prepared using modified methods from ASTM standards C 1375 and D 1640. After curing, test exemplars were exposed to extreme environmental conditions of high heat, constant submersion, and 180 repeated cycles of submersion for 2 hours followed by heating in a controlled high temperature chamber (140–170 °F) for 2 hours each work day. Elastomeric-coated specimens submersed continuously expressed bubbling, de-bonding from the substrate, discoloration, and shrinkage. Specimens that were either heated or submersed and then dried each day did not experience bubbling or shrinkage; however, specimens that were cyclically heated and submersed experienced discoloration and de-bonding on the glass substrate. The application of a primer beneath the coating offered competent adhesion to all test surfaces as compared to non-primer surfaces. Based on adhesion test results (modified ASTM D3359-09e2) the substrate that exhibited the strongest bond was rolled roofing and the weakest was metal.

INTRODUCTION

Energy-saving incentive programs initiated in the mid 2000 promoted the application of a white acrylic elastomeric coating on sloped and flat roof systems for building owners and multi-family condominium structures. The program was based on projected energy savings that white-coated roof systems would reflect as much as 73% of the sunlight, absorb less radiant heat and allow the recipient the benefit of lower energy costs. The most common roof systems in the program were "built up roofs" (BUR) that consisted of several layers: insulation, fiberglass reinforced asphalt (bituminous) membrane and mopped hot asphalt followed by a top layer of rolled asphalt roofing (**Photo 1**).

A few years after the program matured, it was discovered that roof systems applied with the white elastomeric coating experienced partial to complete removal of the upper stone aggregate from the underlying asphalt layer; non-coated roofs experienced no aggregate removal. The exposed stone aggregate surface exhibited "alligatoring" with characteristic cracking, curling and peeling (**Photo 2**). In contrast, BUR systems that were not treated with the white elastomeric coating exhibited uniformity in the distribution of granular stone aggregate five years or more after similar roof systems that were coated with the white elastomeric coating had failed.

Photo 1: Cross section and appearance of a BUR that was not coated in the energy savings program (Photo by Ralph Moon).

Photo 2: BUR systems of similar age and construction that were coated experienced visible damage and separation of the stone aggregate (Photo by Ralph Moon)

Among the damaged roofs, the areas that exhibited the most profound removal of the upper stone aggregate were those where water had ponded. These findings prompted an examination of the effects of heat, submersion in water and cyclical wetting and drying of the elastomeric-coated surfaces in an effort to understand the circumstances that prompted the damage.

BACKGROUND

The occurrence of thermal shrinkage among elastomeric coatings was examined previously on BUR materials (Cullen, 1965). In this study, the author attributed BUR failure to several sources: (1) faulty workmanship, (2) faulty design, (3) application of roofing materials during inclement weather, (4) improper use of materials and (5) poorly designed or installed flashing. Splitting failures were believed to originate from shrinkage of the roof membrane. Cullen and Appleton (1963) opined that thermal cycles (heating expansion and cooling contraction) produced by radiant heating contributed to dimensional changes that occurred in the roofing system and resulted in wrinkle cracking. Surface cracking was theorized to originate when small breaks occurred in the coating from polymerization stresses and oxidation (weathering) (Bayer and Zamanzadeh, 2004). These findings influenced our experimental design.

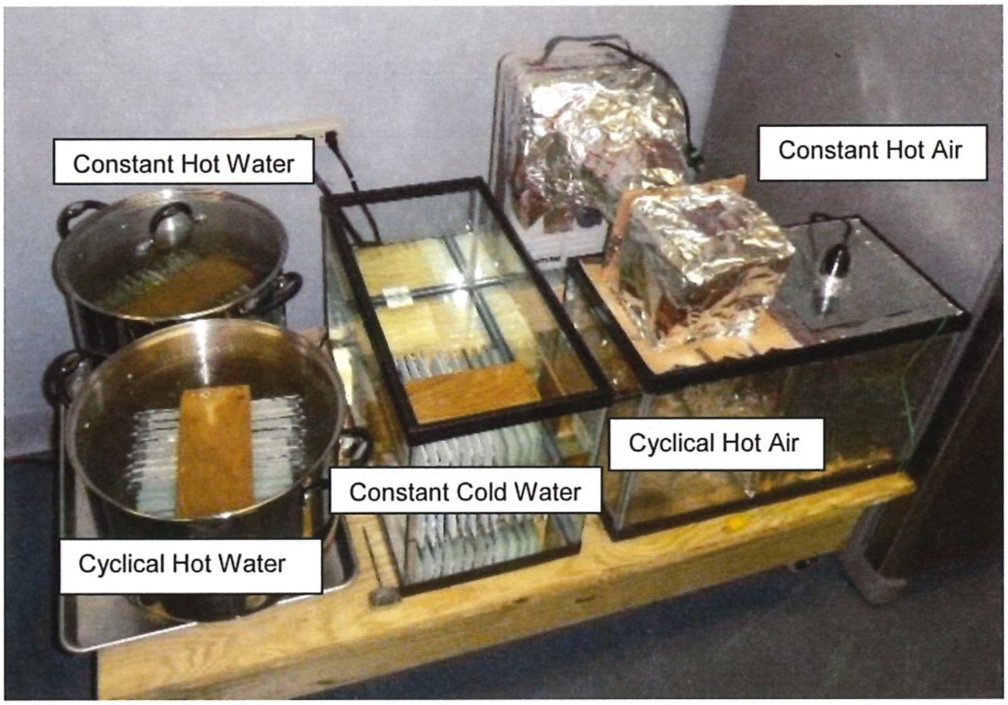


Photo 3: Experimental Design shows placement of four sets of substrates (glass, metal, flat asphalt and granulated asphalt) into oak racks and then placed in one of four conditions (hot water, cold water, hot air and cyclical hot water to hot air)

Stress cracks in acrylic paint on asphalt surfaces were examined previously. U.S. Naval research on the cracking of "Slurry Seal" (SS) marking (acrylic) paints was first evaluated in 1959 (Griffith and Puzinauskas, 1959). These research efforts were concentrated on the performance of an asphalt marking strips using different colors and efforts to modify the ingredients to increase paint flexibility.

In 1967, the Navy conducted an evaluation of eighteen airfield marking (elastomeric) paint formulations following the application of 160, 20-foot marking stripes (Drisko, 1967). Within a few months, the marking paints exhibited extensive edge cracking in addition to lifting and transverse cracking. Dr. R. Drisko, the Project Scientist, identified three reasons for the occurrence of asphaltic pavement cracking: (1) the marking paints contracted (shrink) when cured and transferred the lateral stress to the asphalt pavement substrate, (2) paint cracking occurred when the curing stress (contraction) exceeded the cohesive strength of the acrylic coating to the asphalt pavement substrate and (3) the application of several coats allowed stress to increase at the coating/substrate interface. In the related studies, several generations of white, acrylic paint were tested for ten attributes including thermal stress and the Coefficient of Thermal Expansion (Gaughen, 2000). Among the ten elements investigated, the contribution of thermal stress and thermal movement was the most significant to the failure of the painted asphalt coating.

MATERIALS AND METHODS

The experimental design evaluated the performance of one elastomeric coating (Kool

Seal®Reflective Roof Coating and a primer, Kool Seal ® Kool-Lastik™ Primer (34-600) applied to four substrates exposed to four temperature and moisture scenarios: (1) constant immersion in **cold water** (72°F) (Group A), (2) constant immersion in **hot water** (150°F) (Group B), (3) constant exposure to **hot air** (160°F) (Group C) and (4) **cyclical conditions** of hot water (2 hours at 150°F) followed by drying (2 hours at 160°F) conducted twice each day for a total of 180 cycles (Group D) (**Photo 3**). The Kool Seal™ product was used because it was the preferred product in the energy saving program. Temperatures in all exposure scenarios were monitored on a daily basis to insure accuracy and consistency. Photographs were taken to document changes during the study using the same camera. A modified ASTM testing method (ASTM D3359 – 09e2) was followed to test the coating adhesion to the different substrates and the effect of the different environmental conditions.

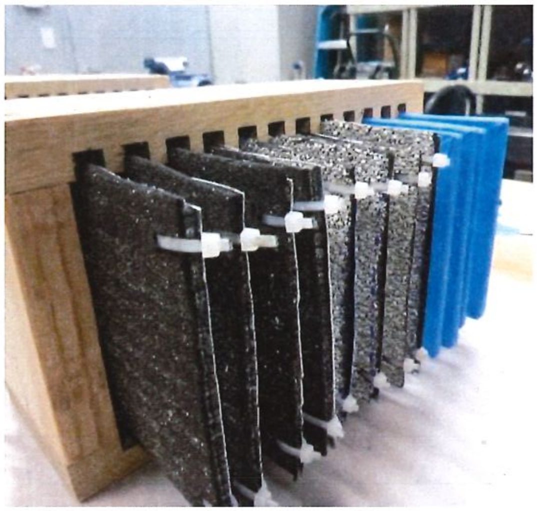


Photo 4: One set of specimens (4 flat asphalt and metal, 4 granulated asphalt and 4 glass) inserted in the rack before coating

Specimen Preparation

Four substrates (*i.e.,* glass, galvanized metal, flat asphalt and granulated asphalt were examined with an elastomeric coating applied with a 1-inch diameter roller. Seventeen glass specimens (4"x 8" x 0.25") were cut from a single glass sheet, ½ inch of blue painter's tape edging (for safe handling) was applied to each side around the perimeter and coated using a 1-inch diameter nap roller. Each glass specimen was prepared by applying one half of the specimen with one application of primer followed by two applications of elastomeric coating, and the other half receiving two applications of elastomeric coating only. The coatings were applied according to the manufacturer's instructions.

Thirty-three galvanized steel specimens (4"x 8" x 0.01") were cut from a single piece of sheet metal. Thirty-four (34) granulated asphalt specimens (4"x 8" x 0.134") (Bill Shields Roofing Company, Tampa, Florida) were cut. Specimens of both galvanized steel and granulated asphalt were divided into two halves whereupon half received an application of primer followed by two applications of elastomeric roof coating only. After coating, the asphalt membrane specimens were mechanically attached to the sheet metal specimens using zip ties to maintain the structural integrity of the asphalt specimens and to use the test slots in the support rack more efficiently (**Photo 4**). An oak specimen rack was constructed to hold the specimens in their respective groups throughout the study.

Photo 5: Four sets of specimens in oak rack following coating application before testing

TABLE 1: RESPONSE TO EXPOSURE CONDITIONS

	Cold Water	Hot Water	Hot Air	Cyclical
Glass	Discoloration Coating Debonded Microbial Growth	Discoloration Coating Debonded Bubbling	No Effect	Discoloration Coating Debonded Microbial Growth
Metal	Discoloration Coating Debonded Bubbling Microbial Growth/Rust	Shrinkage Progressive Debonding	No Effect	No Effect Discoloration
Flat Asphalt	Discoloration Discrete Debonding Bubbling	Shrinkage Bubbling	Discoloration	No Effect Discoloration
Granulated Asphalt	Discoloration Coating Debonded Bubbling	Bubbling Coating Debonded	Early Cracking Discoloration	No Effect Discoloration

TABLE 2: PRIMER v NO PRIMER

	Cold Water	Hot Water	Hot Air	Cyclical
Glass	Primer Adherence	Primer Adherence Bubbling both sides	No Difference	Primer Adherence
Metal	No Difference	Non Primer small bubbles Primer big bubbles	No Difference	No Difference
Flat Asphalt	No Difference	Bubbling	No Difference	No Difference
Granulated Asphalt	No Difference	Primer Adherence Bubbles	No Difference	No Difference

The specimens (single and attached) were divided into four identical test groups consisting of 4 glass specimens, 4 metal to flat asphalt specimens and 4 metal to granulated asphalt specimens (**Photo 5**). A fifth control group consisted of one glass, one metal, one flat asphalt and one granulated asphalt with coatings applied as described above.

The paints were mixed using an electric drill with attached stirrer before application to the clean and dry specimens. Each application of primer or coating was allowed to dry for 48 hours before the application of any additional layers. Final paint thicknesses measured 0.006 inches (6 mil) on those specimens receiving primer and coating and 0.004 inches (4 mil) on specimens with two applications of elastomeric coating only. All materials acclimatized to the laboratory conditions for 48 hours (72°F and 50%RH).

RESULTS

Several distinctive observations were made among the four sets of specimens. The water in all four sets turned dark black in response to the leaching of water soluble chemicals from the asphalt roofing materials. Despite several changes in water, the coated surfaces became permanently discolored. The coating applied to the glass specimens submersed in cold water (ambient temperature) de-bonded from the non primer glass surface. Microbial growth was evident on the coating surface in response to prolonged exposure to water under ambient laboratory conditions (**Table 1**).

The coating on glass specimens submersed in the hot water de-bonded; attached portions exhibited surface bubbling (**Photos 6 and 7, see Photograph Appendix**). No changes were observed to glass specimens exposed to the heating chamber (**Photo 14**). Glass specimens exposed to cyclical hot water and hot air exhibited de-bonding and visible microbial growth (**Photo 15**).

Metal specimens submersed in cold water displayed de-bonding, bubbling, microbial growth, and rust discoloration (**Photo 8**). Metal specimens in hot water displayed shrinkage and progressive de-bonding (**Photo 9**). No changes were observed on the metal substrate specimens exposed to hot air (**Photo 16**). Metal specimens exposed to cyclical conditions expressed no visible changes to the coating (**Photo 17**).

Flat asphalt specimens submersed in cold water displayed small areas of coating de-bonding and bubbling (**Photo 10**) (**Table 1**). Specimens exposed to hot water displayed shrinkage and bubbling of the coating (**Photo 11**). Specimens exposed to hot air displayed no physical changes to the elastomeric coating (**Photo 18).** Similarly, specimens exposed to cyclical conditions displayed no physical changes to the coating (**Photo 19**).

Specimens of granulated asphalt submersed in cold water displayed de-bonding and bubbling of the coating (**Photo 12**) (**Table 1**). Specimens exposed to hot water displayed de-bonding and bubbling of the coating (**Photo 13**). Specimens exposed to hot air expressed no physical changes (**Photo 20**). Specimens exposed to cyclical conditions expressed no physical changes to the coating (**Photo 21**)

Substrate Differences

The study revealed changes in the coating bond among specimens submersed in either hot or cold water (**Table 2**). Hot air and cyclical conditions expressed diminished effects on the coating. The coating de-bonded from the glass specimens exposed to cold water, hot water and cyclical conditions. The coating bubbled on the metal specimens exposed to cold and hot water. The coating also de-bonded from the specimens exposed to hot water. Among flat asphalt specimens, the elastomeric coating bubbled in hot water. The coating on rolled roof specimens exhibited bubbling when exposed to cold water and hot water. The coating applied to flat asphalt specimens exhibited no change in cold water. Specimens exposed to either hot air (glass, metal, flat asphalt and granulated asphalt substrates) or cyclical conditions (metal, flat asphalt, granulated asphalt) expressed no physical change.

Primer v No Primer

During the study, differences between specimens with and without primer applied before the coating were noted (**Table 3**). In the specimens exposed to cold water on a glass substrate, the specimens with primer remained adhered while the specimens without primer did not. The remaining specimens on the metal, flat asphalt and granulated asphalt substrates exposed to cold water displayed no changes between the specimens with or without primer applied before the elastomeric coating.

TABLE: 3 SUBSTATE DIFFERENCES

	Cold Water	Hot Water	Hot Air	Cyclical
Glass	Debonding	Debonding	No Effect	Debonding
Metal	Bubbling	Bubbling Debonding	No Effect	No Effect
Flat Asphalt	No Effect	Bubbling	No Effect	No Effect
Granulated Asphalt	Bubbling	Bubbling	No Effect	No Effect

TABLE 4: ASHESION TEST RESULTS

	Cold Water	Hot Water	Hot Air	Cyclical	
	Primed/Unprimed				Average
Glass	4B/3B	0B/1B	5B/5B	0B/3B	2.6
Metal	4B/0B	0B/2B	0B/1B	5B/3B	1.9
Flat Asphalt	2B/1B	0B/5B	5B/5B	5B/5B	3.5
Granulated Asphalt	5B/4B	0B/4B	4B/4B	4B/5B	3.8
Average	3.8/2	0/3	3.5/3.8	3.5/4	

*Classification Key: 5B = 0%, 4B = < 5%, 3B = 5-15%, 2B = 15-35%, 1B = 35-65%, 0B = Greater than 65%

Excellent Performance (Good Adhesion of coating to underlying substrate)

Weak Performance (Poor Adhesion of coating to underlying substrate)

The specimens on the glass substrate in the hot water with primer remained adhered while the specimens without primer did not. Bubbling of the coating was observed on both glass specimens. The specimens on the metal substrate in hot water displayed small bubbles on the specimens without primer and larger bubbles on the specimens with primer. The specimens on the flat asphalt substrate in hot water displayed wrinkling without primer and larger wrinkling on the specimens with primer. The specimens on the granulated asphalt substrate in the hot water with primer remained adhered while those specimens without primer did not adhere to the substrate. Bubbling of the coating was observed on both types of rolled roof specimens. All specimens on glass, metal, flat asphalt and granulated asphalt exposed to hot air displayed no changes between the specimens with and without primer. Glass specimens with primer and exposed to cyclical conditions remained adhered while the specimens without primer did not. The remaining metal, flat asphalt and granulated asphalt specimens exposed to cyclical conditions displayed no changes with the exception of the glass specimens.

A modified ASTM testing method (ASTM D3359 – 09e2) was used to assess the adhesion of the coating to the substrates on day 76 of the study. The modification consisted of 5x5 cuts rather than 6x6 cuts in the coating film, in addition cut widths ranged from 2-3 millimeters (mm) rather than 2 mm. These modifications accommodated the cutting of the rough granular underlying substrate for the bitumen specimens. The specimens were allowed to dry for 48 hours before testing. A lattice pattern of five cuts in each direction was made in the coating to the substrate, two-inch semitransparent tape was applied over the lattice and then removed, and adhesion was evaluated by comparison to an ASTM established measures.

SUMMARY

The physical characteristics of the specimens were compared to controls upon study completion. Bubbling and de-bonding of the coating occurred in specimens that were submersed in water. Specimens submersed in hot water exhibited the most bubbling and de-bonding of the coating. Specimens exposed to cyclical conditions exhibited minimal change when compared to specimens continuously submersed in either hot or cold water. All specimens exposed to hot air exhibited discoloration, but no physical change.

CONCLUSIONS

- Application of a primer provided greater competence in surface adhesion of the elastomeric coating under cold water, heat and cyclical conditions.
- Application of the primer beneath the elastomeric coating was vulnerable to bubbling when exposed to hot water.
- Constant submersion of elastomeric-coated substrates in either hot or cold water led to bubbling and delamination.
- Hot air caused no visible surface adhesion change in the elastomeric coating
- All specimens (metal, glass, flat asphalt and granulated asphalt) were vulnerable to bubbling or de-bonding when exposed to hot water.
- No physical changes were observed to test substrates exposed to hot air.

Recommendations

Stronger language may be appropriate in the product description to prohibit the application of the Kool Seal® Elastomeric coating and primer to roof surfaces that accumulate water. The current product application description states, "For use on BUR, modified flat asphalt, bonded tar gravel, most other asphaltic surfaces and in ponding water situations, Kool Seal ® Kool-Lastik™ Primer Primer (34-600) is required. The study results indicated that with and without the primer, the product will exhibit bubbling and de-bonding when exposed to sustained conditions of hot water.

The product directions state, "Areas collecting ponding water lasting 2-3 days must be repaired using roof drains or other corrective measures. For less severe ponding areas or to be used on granulated asphalt, built-up roofs, modified flat asphalt, bonded tar & gravel or most other asphaltic surfaces (excluding roofing shingles) you must first prime with Kool Seal®Kool-Lastik™ Primer." The results showed that bubbling began within 6-7 days of constant moisture exposure. The findings showed that roof moisture retention affects coating performance and the applicator should check the roof to confirm proper drainage. Further study of the coating separation in response to sustained moisture exposure is needed through microscopic observations and chemical analysis.

PHOTOGRAPHIC APPENDIX

Group (A): Cold water (≈75°F)	Group (B): Hot water (≈150°F)

Photo 6

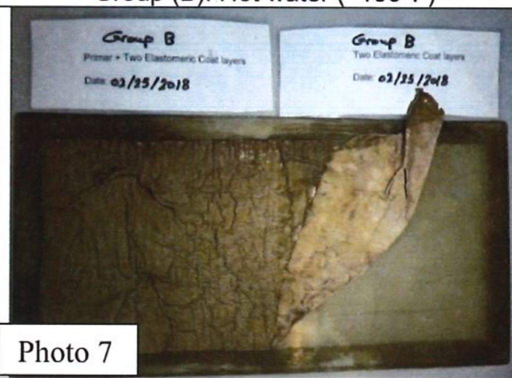


Photo 7

Photo 8

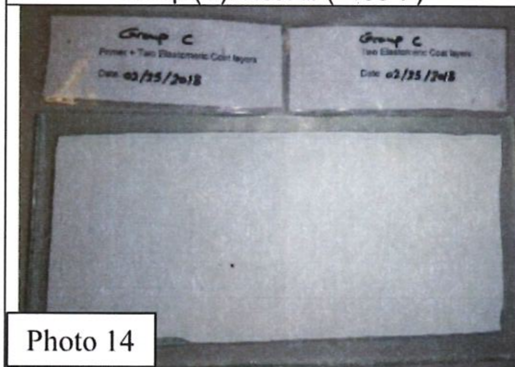
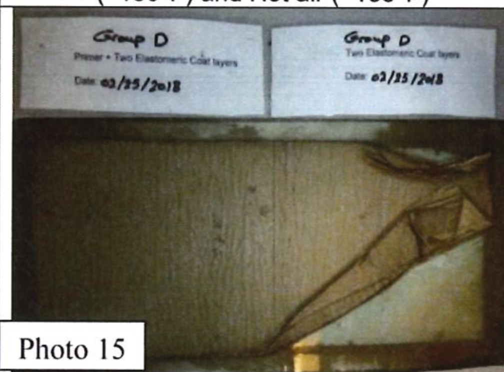
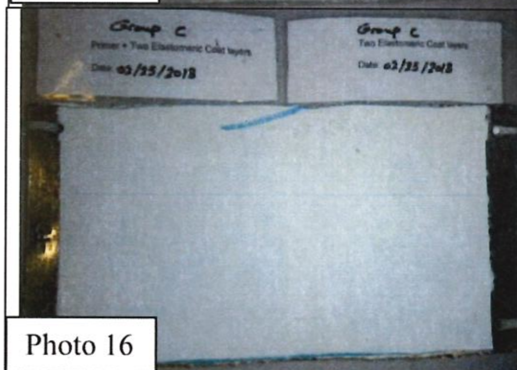
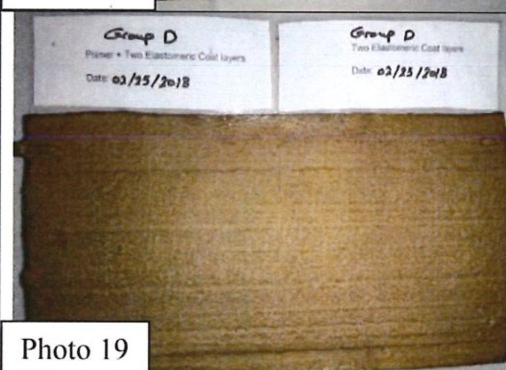
Photo 9

Photo 10

Photo 11

Photo 12

Photo 13

Group (C): Hot Air (≈165°F)	Group (D): Cyclical Conditions Hot water (≈150°F) and Hot air (≈165°F)
 Photo 14	 Photo 15
 Photo 16	 Photo 17
 Photo 18	 Photo 19
 Photo 20	 Photo 21

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