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Evaluation of Structured Methyl Methacrylate Marking to Increase Paint Conspicuity

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16. Abstract

The Federal Aviation Administration (FAA) Office of Aviation Research, Airport Technology Research and Development Section, in response to a request for research from the FAA Office of Airport Safety and Standards, Airport Engineering Division, undertook this research effort to determine if a new application technique for painting pavement markings would increase conspicuity over the useful life of the marking.

A paint manufacturer presented the FAA with information on a new paint marking called structured methyl methacrylate (SMMA). Methyl methacrylate (MMA), paint without the structured component, is currently approved for use on runways and taxiways. SMMA differs from traditional MMA because it is applied using a splatter pattern. When applied to a pavement using the splattered application technique, SMMA creates a thicker, textured surface with peaks and valleys, while still creating a visible solid line. The manufacturer claims this application technique will enhance wet, nighttime retro-reflectivity by allowing water to flow off the peaks and into the valleys of the marking, thus making the paint and beads on the peaks more visible. The manufacturer also suggested using a slightly modified paint formula, which will provide enhanced visibility when used with this unique application technique.

The research objective was to compare the suggested SMMA paint to traditional MMA paint, and further evaluate whether the proposed splatter application technique, thicker application, and modified formula offer improvements over the currently accepted MMA application techniques and formula. A complex test plan, containing a variety of tests, enabled researchers to evaluate each element that makes up the SMMA paint markings. Testing activities included retro-reflectivity, chromaticity (color), friction, pull-off strength, water run-off, and heavy vehicle simulator studies.

The results of this research effort were favorable, indicating that the new SMMA paint, when used with Type III glass beads, showed an improvement over conventionally installed MMA markings. Although the SMMA paint does not fully cover the pavement surface, the material does appear to be a continuous marking when viewed from a distance. The SMMA paint possessed higher friction values, shed water faster, and improved the visibility of the paint marking over the conventional MMA markings. The modified, softer paint formula proposed by one manufacturer did not appear to have any adverse effect on the SMMA paint markings.

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Advisory Circular
CIE	International Commission on Illumination
FAA	Federal Aviation Administration
HVS	Heavy Vehicle Simulator
IOR	Index of Refraction
$mcd/m^2/lux$	Millicandela per meter squared per lux
MMA	Methyl methacrylate
mph	Miles per hour
PCC	Portland cement concrete
psi	Pounds per square inch
R&D	Research and development
SMMA	Structured methyl methacrylate

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) Office of Aviation Research, Airport Technology Research and Development (R&D) Safety Section, in response to a request for research from the FAA Office of Airport Safety and Standards, Airport Engineering Division, undertook this research effort to determine if a new application technique for painting pavement markings would increase conspicuity over the useful life of the marking. This research was conducted as part of the FAA Visual Guidance R&D Program.

A paint manufacturer presented the FAA with information on a new paint marking called structured methyl methacrylate (SMMA). Methyl methacrylate (MMA), paint without the structured component, is currently approved for use on runways and taxiways. SMMA differs from traditional MMA because it is applied using a splatter pattern. When applied to a pavement using the splattered application technique, SMMA creates a thicker, textured surface with peaks and valleys, while still creating a visible solid line. Because of the splatter pattern, the SMMA paint does not fully cover the pavement surface like MMA paint. The end result is approximately 70% SMMA paint coverage. The manufacturer claims this application technique will enhance wet, nighttime retro-reflectivity by allowing water to flow off the peaks and into the valleys of the marking, thus making the paint and beads on the peaks more visible. The manufacturer also suggested using a slightly modified paint formula, which will provide enhanced visibility when used with this unique application technique. The modified formula has a reduced amount of titanium dioxide, which is typically used by paint manufacturers to harden the paint and prevent color fading.

The research objective was to compare the suggested SMMA paint to traditional MMA paint, and further evaluate whether the proposed splatter application technique, thicker application, and modified formula offer improvements over the currently accepted MMA application techniques and formula. As stated in FAA Advisory Circular (AC) 150/5370-10G, for "…high build acrylic waterborne material, reflective readings should yield at least 400 mcd/m^2/lux on white markings…" Although these readings are for waterborne material, there is some value in comparing SMMA readings at initial application. The Airport Safety R&D Section developed a complex test plan containing a variety of tests to enable the research team to evaluate each element that makes up the SMMA paint markings. Testing activities included retro-reflectivity, chromaticity (color), friction, pull-off strength, water run-off, and heavy vehicle simulator studies.

The results of this research were favorable, indicating that the new SMMA paint, when used with Type III glass beads, showed an improvement over conventionally installed MMA markings. Although the SMMA paint does not fully cover the pavement surface, the material does appear to be a continuous marking when viewed from a distance. The SMMA paint possessed higher friction values, shed water faster, and improved the visibility of the paint marking over the conventional MMA markings. The modified, softer, paint formula proposed by Franklin Paint did not appear to have any adverse effect on the SMMA paint markings.

INTRODUCTION

The Federal Aviation Administration (FAA) Office of Aviation Research, Airport Technology Research and Development (R&D) Section, in response to a request for research from the FAA Office of Airport Safety and Standards, Airport Engineering Division, undertook this research effort to determine if a new application technique for painting pavement markings would increase conspicuity over the useful life of the marking. This research was conducted as part of the FAA Visual Guidance R&D Program.

Airport pavement markings are a critical component of ground visual aids for pilots, and it is especially important that the markings be well maintained. To accomplish this, airports expend considerable resources to maintain the effectiveness of the markings. Current practices in marking airport pavements have evolved over the years and are historically related to the application of roadway markings by highway departments.

The Federal Highway Administration has standard practices in highway pavement markings. Although these standard practices offer benefits in the transfer of technology and application techniques, airport pavements continue to present some unique requirements for marking materials. Among these requirements are adhesion, climate, abrasion, and resistance to jet fuel, as well as braking and friction characteristics. These additional criteria require special testing to ensure suitability.

Due to the importance of paint markings in the airport environment, FAA researchers are interested in identifying new paint and application techniques that show potential for increasing the conspicuity of paint markings, lengthening the life of the marking, and providing a value to the airport community.

BACKGROUND.

A paint manufacturer presented the FAA with information on a new paint called structured methyl methacrylate (SMMA). Methyl methacrylate (MMA), paint without the structured component, is currently approved for use on runways and taxiways. SMMA differs from traditional MMA because it is applied using a splatter pattern. When applied on a pavement using the splattered application technique, the SMMA creates a thicker, textured surface with peaks and valleys, while still creating a visible solid line. Because of the splatter pattern, the SMMA paint does not fully cover the pavement surface like MMA paint. The end result is approximately 70% SMMA paint coverage. The manufacturer claims that this installation technique will enhance wet, nighttime retro-reflectivity by allowing water to flow off the peaks and into the valleys of the marking, thus making the paint and beads on the peaks more visible. The manufacturer also suggested using a slightly modified paint formula, which will provide enhanced visibility when used with this unique application technique. The modified formula has a reduced amount of titanium dioxide, which is typically used by paint manufacturers to harden the paint and prevent it from fading.

OBJECTIVE.

The research objective was to compare the suggested SMMA paint to traditional MMA paint, and further evaluate whether the proposed splatter application technique, thicker application, and modified formula offer improvements over the currently accepted MMA application techniques and formula. The specific objectives were to

- evaluate the effectiveness and efficiency of applying MMA paint with the new SMMA splatter pattern application technique.
- evaluate the new MMA paint formula to determine if it offers any enhancement to the currently approved MMA paint formula.
- evaluate the new suggested increase in paint thickness and bead quantity to determine if these increases offer any enhancement to currently accepted thickness standards.
- determine if the new SMMA marking offers any benefit over the standard MMA material used in the standard application method.
- determine a method of evaluating the optimal application thickness and proper quantity of beads for SMMA.

If it is determined that the results of this research effort are favorable, recommendations may be made to make changes to FAA Advisory Circular (AC) 150/5370-10G, Item P-620 [1]. (This AC went into effect at the end of the test.)

RELATED DOCUMENTS.

Related documents that contain information pertaining to this research include:

- ASTM-E-2380-05, "Standard Test Method for Measuring Pavement Texture Drainage Using an Outflow Meter," 2005.
- DOT/FAA/AR-02/128, "Paint and Bead Durability Study," March 2003.
- DOT/FAA/AR-TN03/22, "Development of Methods for Determining Airport Pavement Marking Effectiveness," March 2003.
- DOT/FAA/AR-TN96/74, "Follow-On Friction Testing of Retro-Reflective Glass Beads," July 1996.
- DOT/FAA/CT-94/119, "Evaluation of Alternative Pavement Marking Materials," January 1995.
- DOT/FAA/CT-94/120, "Evaluation of Retro-Reflective Beads in Airport Pavement Markings," December 1994.

- FAA AC 150/5320-12C, “Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces,” March 18, 1997.

- FAA AC 150/5340-1L, “Standards for Airport Markings,” September 27, 2013.

- FAA AC 150/5370-10F, “Standards for Specifying Construction of Airports,” Item P-620, “Runway and Taxiway Painting,” September 30, 2011.

- International Civil Aviation Organization Annex 14, Volume I, “Aerodrome Design and Operation,” August 9, 2000.

EVALUATION APPROACH

As part of this research effort, the Airport Safety R&D Section (the research team) developed a complex test plan to provide a variety of tests that would enable the research team to evaluate each element that makes up the SMMA paint markings. Since the SMMA paint was suggested by the airport marking manufacturer Franklin Paint, the research team reached out to other manufacturers to see if they had the capability of producing an SMMA marking, and if they would be interested in participating in the research effort. Two other manufacturers—Ennis/Flint and Hi-Lite—responded and agreed to participate, bringing the total to three manufacturers.

The test plan called for three different sizes of retro-reflective glass beads (Types I, III, and IV) to determine if the SMMA paint marking worked better or worse with a particular bead size. This was of particular interest due to concerns when a leading glass bead manufacturer indicated that the glass beads requested for this test are not appropriate for the intended application. The research team designated a paint thickness of 15 mil for the MMA test stripes containing Type I and III glass beads, 25 mil for the MMA test stripes containing Type IV glass beads, and 60 to 90 mil for the SMMA test stripes with all glass bead types.

The test plan also called for installing multiple test stripes in three locations at the FAA William J. Hughes Technical Center on paved surfaces that experience similar levels of traffic as an airport. The first location was on Pangborn Road, which is a public roadway with an old hot mix asphalt surface. The second location was the FAA Ramp, which is an aircraft ramp constructed with an old Portland cement concrete (PCC) surface. The third location was the FAA Heavy Vehicle Simulator (HVS) test facility, which has a new hot mix asphalt surface.

Finally, the test plan called for several individual tests, including retro-reflectivity measurements, chromaticity (color), friction, trafficking, pull-off strength, water run-off, and HVS tests. The research team included test stripes of different sizes to accommodate the various tests. Details of the test stripes are provided in appendix A.

The research team developed a testing protocol requiring monthly observations in which retro-reflectivity readings, chromaticity, and visual inspections were conducted. Friction, pull-off strength, and water run-off tests were conducted on a random basis, and trafficking tests were conducted as a single multiday test event with a goal of achieving a certain number of operations.

TEST STRIPE MATERIALS.

The series of test stripes were designed to enable the research team to evaluate each element of the SMMA paint marking. The series of test stripes are described as follows:

- MMA paint with Type I glass beads at 15-mil, wet-film thickness
- MMA paint with Type III glass beads at 15-mil, wet-film thickness
- MMA paint with Type IV glass beads at 25-mil, wet-film thickness
- SMMA paint with Type I glass beads at 60- to 90-mil, wet-film thickness
- SMMA paint with Type III glass beads at 60- to 90-mil, wet-film thickness
- SMMA paint with Type IV glass beads at 60- to 90-mil, wet-film thickness

The three types of retro-reflective beads used in this research effort are detailed in Federal Specification TT-B-1325C [2]: Type I (1.5 Index of Refraction (IOR)) low-index recycled glass bead, Type III (1.9 IOR) high-index virgin glass bead, and Type IV (1.5 IOR) low-index direct-melt glass. Type I glass beads have less density, roughly 1570 grams per liter and are commonly referred to as highway beads, while Type III and IV glass beads have a larger density, roughly 2670 grams per liter and are referred to as airport beads. It is important to note that Franklin Paint did not appear to use a Type I glass bead that met the Federal Specification requirement [2] and did not provide technical data on the bead that they used in this evaluation. For the SMMA paint markings, the glass beads were applied at an application rate of 8 lb for Type I glass beads, 10 lb for Type III glass beads, and 10 lb for Type IV glass beads.

The SMMA stripes were applied at a 60- to 90-mil thickness, as recommended by the manufacturers. The standard MMA was installed as per approved application criteria contained in AC 150/5370-10G [1], which is 15 mil for test stripes containing Type I and III glass beads and 25 mil for test stripes containing Type IV glass beads.

At all three test sites, Hi-Lite and Ennis/Flint installed the standard MMA material using both the standard application method and the structured application method. Franklin Paint installed the new mix formula MMA material using the structured application method. They did not provide a standard formula MMA, nor did they elect to install the material in a standard nonstructured format.

APPLICATION TECHNIQUE.

The research team monitored each manufacturer as they applied the markings at each test location. When possible, photographs and videos were taken to document the installation.

Each manufacturer provided their own equipment and personnel to install the test stripes at each test site. Figures 1, 2, and 3 show the manufacturers using their respective equipment on the FAA Ramp (concrete) and the Pangborn Road (asphalt) test sites.

It is important to note that each manufacturer had a different approach to creating the structured format. In some cases, the paint was splattered on the surface; in other cases, the paint was laid down in a thicker, ribbon-like fashion. Although approached in different ways, the results were a thicker, three-dimensional marking.

Figure 1. Hi-Lite SMMA Application

Figure 2. Ennis/Flint SMMA Application

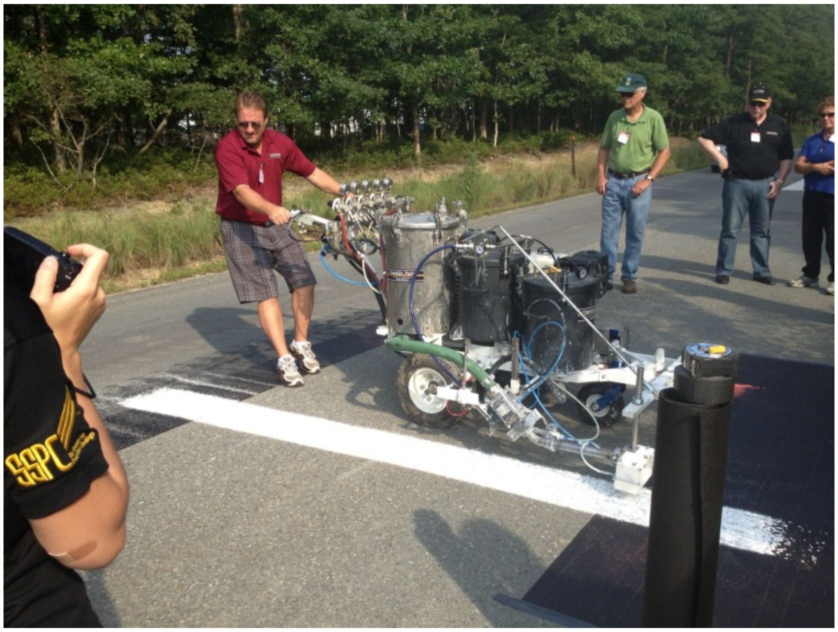


Figure 3. Franklin Paint SMMA Application

EVALUATION PERSONNEL.

The evaluations were conducted by the research team consisting of members from the FAA Airport Safety R&D Section and support contract personnel.

EQUIPMENT.

The following test equipment was used during this research effort:

- Chromaticity tester—A Color-Guide 45/0, 20-mm, 6801-Gloss spectrophotometer manufactured by BYK-Gardner of Germany (S/N 1042342) was used to measure the chromaticity (color) of the paint markings (figure 4).

- Retroreflectometer tester—An Ennis/Flint, 30-meter geometry LTL-X built by Delta Lights and Optics of Denmark (S/N 540) was used to measure the paint markings' retro-reflectivity (figure 5).

- Pull-off tester—A Dyna Z16 pull-off tester was used to measure the tensile strength of the bond between the pavement and paint. The tester was also used to determine if the bond fails cohesively or adhesively (figure 6).

- Friction tester—A Saab Sarsys Runway Friction Tester, with tire pressure at 30 psi, was used to test the friction (figure 7).

- Heavy Vehicle Simulator—A custom-designed HVS (airfield version HVS-A) is a Mark VI Airport model built by Dynatest (figure 8).

Figure 4. The BYK-Gardner Spectrophotometer

Figure 5. Delta Light and Optics LTL-X Retroreflectometer

Figure 6. Dyna Z16 Pull-off Tester

Figure 7. Saab Sarsys Runway Friction Tester

Figure 8. Heavy Vehicle Simulator (Airport Version)

EVALUATION SITES.

The test stripes were installed at three different locations at the FAA William J. Hughes Technical Center on paved surfaces that experience similar levels of traffic as an airport.

THE FAA RAMP (CONCRETE). Test stripes on the FAA Ramp area, which is an aircraft ramp constructed with an old PCC surface, were installed on August 20, 2013. This ramp area is part of the FAA William J. Hughes Technical Center campus, which is used by FAA, military, and transient aircraft conducting business with the FAA. The surface of this ramp experiences light vehicle and aircraft traffic, but it is exposed to extensive amounts of sweeping and blowing operations, as well as snow removal operations during the winter months. A diagram showing the test stripe arrangement, in accordance with the test plan, is shown in figure 9.

Each manufacturer was required to place a series of test stripes on the FAA Ramp (concrete) that included the following:

- An 18-inch-wide by 150-foot-long friction line with
  - SMMA with Type I glass beads
  - MMA with Type I glass beads

- A 12-inch-wide by 6-foot-long edge line with
  - MMA with Type I glass beads

- MMA with Type III glass beads
- MMA with Type IV glass beads
- SMMA with Type I glass beads
- SMMA with Type III glass beads
- SMMA with Type IV glass beads

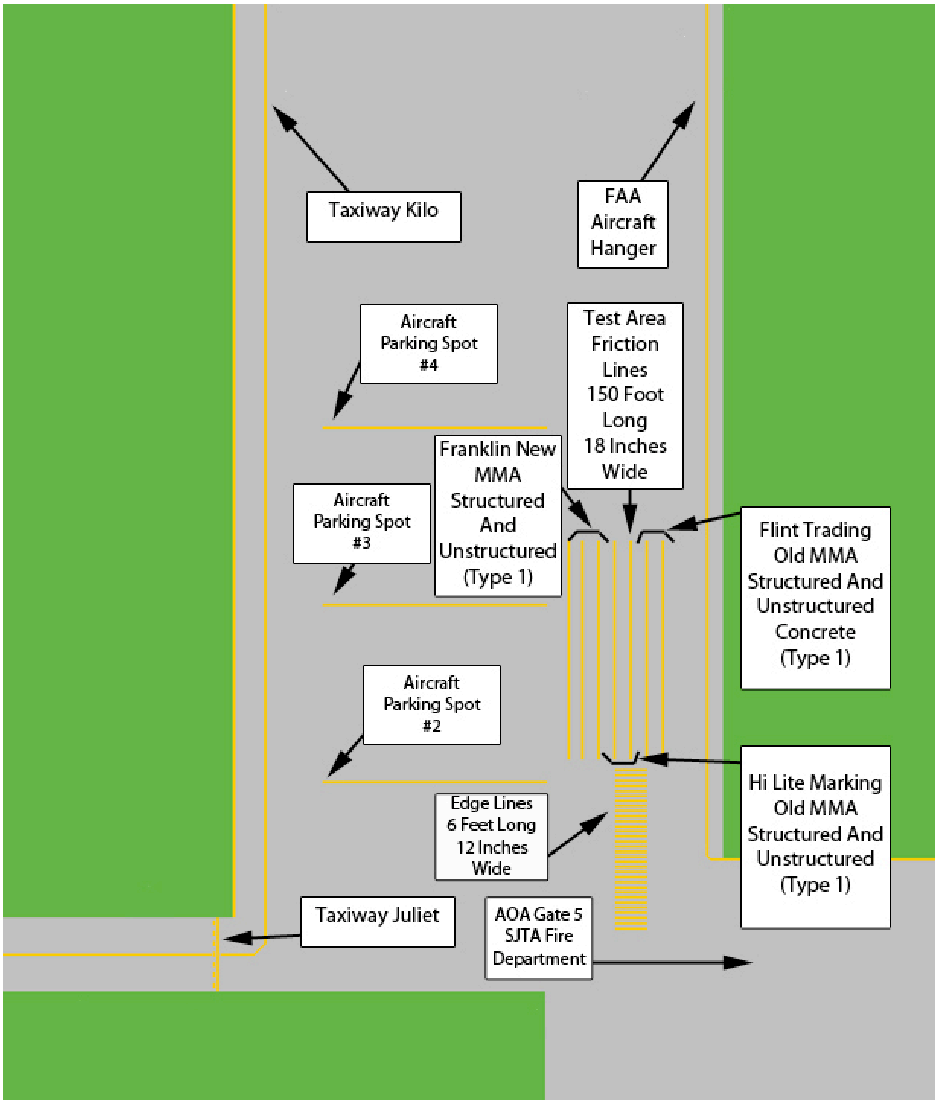


Figure 9. Layout of Test Stripes on the FAA Ramp (Concrete)

Franklin Paint did not install the friction line or the three edge lines with the unstructured format since they did not have the equipment needed to install these traditional flat markings.

Figures 10 and 11 show samples of the edge lines and the friction lines installed on the FAA Ramp (concrete). Table A-1 shows a matrix of data for the MMA and SMMA stripes that were applied on the FAA Ramp (concrete).

Figure 10. Initial Installation of Edge Lines on the FAA Ramp (Concrete)

Figure 11. Initial Installation of Friction Lines on the FAA Ramp (Concrete)

PANGBORN ROAD (ASPHALT). Test stripes on Pangborn Road, which is a public use roadway with an old hot mix asphalt surface, were installed on August 20 and 21, 2013. This road is an access road to the FAA National Airport Pavement Test Facility and a heavily used entrance and exit to the FAA William J. Hughes Technical Center. This surface experiences high levels of vehicular traffic, including large construction vehicles, and is exposed to extensive amounts of sweeping and snow removal operations during the winter months. A diagram showing the arrangement of the test stripes in accordance with the test plan is shown in figure 12.

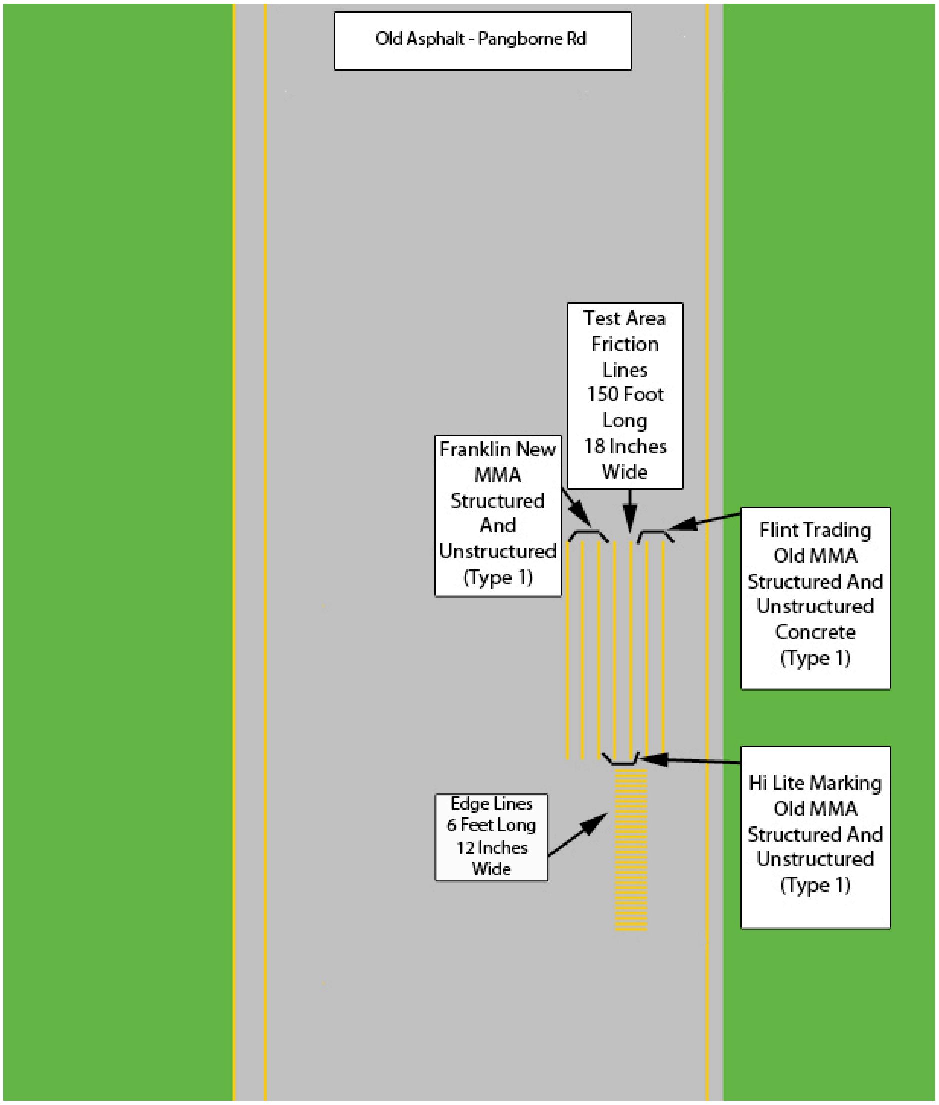


Figure 12. Layout of Test Stripes on Pangborn Road (Asphalt)

Each manufacturer was required to place a series of test stripes on Pangborn Road (asphalt) that included the following:

- An 18-inch-wide by 150-foot-long friction line with
  - SMMA with Type I glass beads
  - MMA with Type I glass beads

- A 12-inch-wide by 6-foot-long edge line with
  - MMA with Type I glass beads
  - MMA with Type III glass beads
  - MMA with Type IV glass beads
  - SMMA with Type I glass beads
  - SMMA with Type III glass beads
  - SMMA with Type IV glass beads

Franklin Paint did not install the friction line or the three edge lines with the MMA since they did not have the equipment to install the traditional flat markings.

Figures 13 and 14 show samples of the edge lines and the friction lines installed on Pangborn Road (asphalt). Table A-2 shows a matrix of data for the MMA and SMMA stripes that were applied on Pangborn Road (asphalt).

Figure 13. Initial Installation of the Edge Lines on Pangborn Road (Asphalt)

Figure 14. Initial Installation of the Friction Lines on Pangborn Road (Asphalt)

<u>HEAVY VEHICLE SIMULATOR</u>.

On July 29, 2014, test stripes were installed at the FAA HVS test facility, which has a new hot mix asphalt surface.

The HVS is a large pavement test machine that uses an aircraft tire to simulate the weight and pressure of a Boeing-777 aircraft tire at 230 to 240 psi. Typically used to test asphalt airport pavements, the HVS is being used to investigate the effects of temperature variation in the pavement surface layers, especially the effects of high temperatures on asphalt pavements under heavy aircraft loads. The HVS test machine uses infrared heaters to heat the pavement surface to approximately 100°F, which is typical for a hot summer day. The HVS test machine has the ability to traffic a section of test pavement by repeatedly running the aircraft tire over the test surfaces. In effect, this machine can simulate a year's worth of aircraft traffic in about 1 week. The research team used the HVS test machine to provide a test environment in which the repeated exposure to heavy aircraft loads and high temperatures would test the SMMA paint marking's durability.

Each manufacturer was required to place a series of test stripes at the HVS test facility that included the following:

- A 12-inch-wide by 6-foot-long edge line with
  - MMA with Type I glass beads
  - MMA with Type III glass beads
  - MMA with Type IV glass beads
  - SMMA with Type I glass beads
  - SMMA with Type III glass beads
  - SMMA with Type IV glass beads

Franklin Paint did not install the three edge lines with the MMA since they did not have the equipment to install the traditional flat line.

Figure 15 shows samples of the edge lines installed underneath the aircraft tire of the HVS. Table A-3 shows a matrix of data for the MMA and SMMA stripes that were applied at the HVS test facility.

Figure 15. Edge Line Installation Under the HVS Test Machine (new hot mix asphalt)

EVALUATION PROCEDURES.

The research team conducted monthly measurements and tests over a period of 1 year on the SMMA and MMA paint markings. The measurements and tests are described below.

RETRO-REFLECTIVITY TEST. Retro-reflectivity tests were completed once a month using an LTL-X retro-reflectometer. Retro-reflective readings measure the effectiveness of the application thickness and determine which thickness is most appropriate for the glass beads to adhere properly to the marking material. For each test stripe, a total of six readings were taken by placing the instrument on the pavement marking and activating the device. Readings were taken at the beginning, middle, and end of each line and then repeated in the opposite direction at the beginning, middle, and end of the line. The instrument was calibrated each month prior to collecting the data. Readings were taken just after initial application (baseline) and then repeated each month from September 2013 until September 2014. The sample data sheet that was used for monthly collection of the retro-reflectivity readings is shown in figure A-1.

CHROMATICITY TEST. Chromaticity tests were completed using a Color-Guide 45/0, BYK-Gardner USA spectrophotometer. For each test stripe, a total of two measurements were taken by placing the instrument on the pavement marking and activating the device. The instrument was calibrated each month prior to collecting data. Readings were taken just after initial application (baseline) in September 2013 and then again at the end of the test in September 2014. The data were plotted on an International Commission on Illumination (CIE) Standard Illuminant D_{65} chart to see how much the color faded over time. A sample data sheet that was used for collecting the chromaticity readings is shown in figure A-1.

FRICTION TEST. One friction test was performed over the course of the research effort, using a Saab Sarsys Runway Friction Tester. A series of runs were made over the 18-inch by 150-foot friction lines that were installed on the FAA Ramp (concrete) and Pangborn Road (asphalt). The friction runs were tested with the vehicle in self-wetting mode at a speed of approximately 40 miles per hour (mph). The friction data are shown in figures A-33 through A-38.

PULL-OFF STRENGTH TEST. A Dyna Z16 pull-off tester was used to conduct the pull-off strength test, which determined the tensile strength of the bond between the pavement marking material and the hot mix asphalt or PCC. In this test procedure, a metal disc is glued to the marking material and allowed to cure (dry) for 24 hours. After the cure period, the Dyna pull-off tester was connected to the disc via a draw bolt. The instrument was then leveled via adjustable legs. Once leveled, a small crank on the instrument was turned until the metal disc separated from the pavement. This test was performed in accordance with ASTM-D-4541-02 [3]. The research team conducted this test only once near the end of the evaluation. This test was conducted on the test stripes located on Pangborn Road (asphalt) and the FAA Ramp (concrete).

WATER RUN-OFF TEST. A 2-liter ASTM-E-2177 [4] water run-off test was used to simulate pavement conditions after a rainfall just ended and the pavement markings area was still wet. In this test procedure, a dry retro-reflectivity measurement was taken on a test stripe and documented. Two liters of water were then poured onto the test stripe, and retro-reflective readings were taken every 5 minutes until the readings returned to the dry retro-reflective values. Research has shown that 100 $mcd/m^2/lux$ is the absolute minimum accepted value for being able to visibly see the paint marking, so consideration will be made to when the markings achieve at least that level. These values were documented, analyzed, and graphed. This test was conducted only on the test stripes located on Pangborn Road (asphalt).

HEAVY VEHICLE SIMULATOR TEST. Two HVS tests (one with the pavement at ambient temperature and another with the pavement heated) were performed over a period of about 2 weeks toward the end of the research effort. The HVS test machine repeatedly rolled the aircraft tire in a back-and-forth motion over the pavement surface following the same track. For this research effort, the test stripes were painted laterally across the track of the aircraft tire so each marking would be exposed to the same loading and number of passes from the aircraft tire.

For the ambient temperature test that began on October 30, 2014, the HVS test machine completed 2000 passes at a speed of 2 mph with a tire weight and pressure that simulated a B-777 aircraft (230 to 240 psi) with ambient outdoor temperatures averaging approximately 75°F. The HVS test machine was stopped every 50 passes for the first 200 passes, and then every 100 passes until 1000 passes, so the research team could take pictures and collect retro-reflectivity measurements. The HVS test machine continued operations, was stopped again at 1500 passes, and ended the test at 2000 passes, equating to approximately 1 year of aircraft traffic.

For the heated pavement test, the HVS test machine was moved a few feet to align the aircraft wheel with a track that would cross untrafficked parts of the test stripes. The HVS test machine's heaters were turned on to warm the pavement surface up to 120°F. Once this temperature was reached, the HVS test machine began another series of 2000 passes under heated conditions. As with the ambient temperature test, the HVS test machine was stopped every 50 passes for the first 200 passes, and then every 100 passes until 1000 passes, so the research team could take pictures and collect retro-reflectivity measurements of the test stripes. As before, the HVS test machine continued operations, stopped again at 1500 passes, and ended the test at 2000 passes. The test concluded on November 12, 2014.

RESULTS

The research team collected a large amount of data during this 1-year research effort and obtained the following results for each test that was conducted.

RETRO-REFLECTIVITY TEST.

In AC 150/5370-10G [1], which went into effect at the end of the test on July 21, 2014, the retro-reflectivity requirements for high-build acrylic waterborne marking material at initial application was 400 mcd/m^2/lux on white markings. All three manufacturers met this requirement at initial application.

The retro-reflectivity test data were collected from September 2013 until September 2014 and were entered into an electronic data table, enabling the research team to analyze and compile the data into a reportable format. Actual data from the monthly collection activity, categorized by location and manufacturer, are presented in appendix A.

Retro-reflectivity measurements for the three test sites, by each manufacturer, are described below.

THE FAA RAMP (CONCRETE).

Hi-Lite. Initially, for the MMA test stripes, retro-reflectivity started at 1329 mcd/m^2/lux for Type I glass beads, 1274 mcd/m^2/lux for Type III glass beads, and 445 mcd/m^2/lux for Type

IV glass beads. The friction line with Type I glass beads was measured at 1540 mcd/m^2/lux. Within the first month, the retro-reflectivity of the Type I and IV glass beads were reduced to approximately 500 and 200 mcd/m^2/lux, respectively, and maintained these values for the duration of the test. Retro-reflectivity at the end of the test was 264 mcd/m^2/lux for Type I glass beads, 827 mcd/m^2/lux for Type III glass beads, and 528 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-2.

For the SMMA test stripes, retro-reflectivity started at 388 mcd/m^2/lux for Type I glass beads, 2698 mcd/m^2/lux for Type III glass beads, and 585 mcd/m^2/lux for Type IV glass beads. The test stripes maintained their retro-reflectivity for the duration of the test. Retro-reflectivity at the end of the test was 434 mcd/m^2/lux for Type I glass beads, 2181 mcd/m^2/lux for Type III glass beads, and 643 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-3.

For Hi-Lite, the best performing marking was the SMMA with Type III glass beads, followed by the MMA with Type III glass beads.

<u>Ennis/Flint</u>. Initially, for the MMA test stripes, retro-reflectivity started at 238 mcd/m^2/lux for Type I glass beads, 779 mcd/m^2/lux for Type III glass beads, and 450 mcd/m^2/lux for Type IV glass beads. The test stripes maintained their retro-reflectivity for the duration of the test. Retro-reflectivity at the end of the test was 318 mcd/m^2/lux for Type I glass beads, 804 mcd/m^2/lux for Type III glass beads, and 439 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-4.

For the SMMA test stripes, retro-reflectivity started at 416 mcd/m^2/lux for Type I glass beads, 2258 mcd/m^2/lux for Type III glass beads, and 375 mcd/m^2/lux for Type IV glass beads. The test stripes maintained their retro-reflectivity for the duration of the test. Retro-reflectivity at the end of the test was 424 mcd/m^2/lux for Type I glass beads, 2216 mcd/m^2/lux for Type III glass beads, and 504 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-5.

For Ennis/Flint, the best performing marking was the SMMA with Type III glass beads, followed by the MMA with Type III glass beads.

<u>Franklin Paint</u>. Initially, for the SMMA test stripes, retro-reflectivity started at 1329 and 1540 mcd/m^2/lux for the two Type I markings, 1273 mcd/m^2/lux for Type III glass beads, and 445 mcd/m^2/lux for Type IV glass beads. The test stripes maintained their retro-reflectivity for the duration of the test. Retro-reflectivity at the end of the test was approximately 1311 and 1478 mcd/m^2/lux for the two Type I markings, 1074 mcd/m^2/lux for Type III glass beads, and 447 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-6.

For Franklin Paint, the best performing marking was the SMMA with Type I glass beads, followed by the SMMA with Type III glass beads. (No MMA was installed.)

PANGBORN ROAD (ASPHALT).

Hi-Lite. Initially, for the MMA test stripes, retro-reflectivity started at 359 mcd/m^2/lux for Type I glass beads, 1080 mcd/m^2/lux for Type III glass beads, and 499 mcd/m^2/lux for Type IV glass beads. After about 5 months, the Type III glass beads' retro-reflectivity decreased to the same number as the Type I and IV glass beads (approximately 500 and 200 mcd/m^2/lux, respectively) and maintained these values for the duration of the test. Retro-reflectivity at the end of the test was 172 mcd/m^2/lux for Type I glass beads, 208 mcd/m^2/lux for Type III glass beads, and 167 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-7.

For the SMMA test stripes, retro-reflectivity started at approximately 500 mcd/m^2/lux for Type I glass beads, 2500 mcd/m^2/lux for Type III glass beads, and approximately 500 mcd/m^2/lux for Type IV glass beads. After about 4 months, the Type III glass beads' retro-reflectivity decreased to approximately 500 mcd/m^2/lux and maintained these values for the duration of the test. Retro-reflectivity at the end of the test was 319 mcd/m^2/lux for Type I glass beads, 484 mcd/m^2/lux for Type III glass beads, and approximately 245 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-8.

For Hi-Lite, the best performing marking was the SMMA with Type III glass beads, followed by the SMMA with Type I glass beads.

Ennis/Flint. Initially, for the MMA test stripes, retro-reflectivity started at 386 mcd/m^2/lux for Type I glass beads, 884 mcd/m^2/lux for Type III glass beads, and 436 mcd/m^2/lux for Type IV glass beads. After about 4 months, the Type III glass beads' retro-reflectivity decreased to approximately 200 mcd/m^2/lux and maintained these values for the duration of the test. Retro-reflectivity at the end of the test was 219 mcd/m^2/lux for one of the Type I stripes, 191 mcd/m^2/lux for Type III glass beads, and 247 mcd/m^2/lux for Type IV glass beads. The friction line with Type I glass beads fell to 81 mcd/m^2/lux. The results of the retro-reflectivity measurements for this test are shown in figure A-9.

For the SMMA test stripes, retro-reflectivity started at 180 mcd/m^2/lux for Type I glass beads, 1687 mcd/m^2/lux for Type III glass beads, and 567 mcd/m^2/lux for Type IV glass beads. After about 4 months, the Type III glass beads' retro-reflectivity decreased to approximately 400 mcd/m^2/lux and maintained these values for the duration of the test. Retro-reflectivity at the end of the test was 485 mcd/m^2/lux for Type I glass beads, 237 mcd/m^2/lux for Type III class beads, and 347 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-10.

For Ennis/Flint, the best performing marking was the SMMA with Type I glass beads, followed by the SMMA with Type IV glass beads.

Franklin Paint. Initially, for the SMMA test stripes, retro-reflectivity started at 1158 mcd/m^2/lux for the first Type I marking, 322 mcd/m^2/lux for the second Type I glass bead, 1043 mcd/m^2/lux for Type IV glass bead, and 832 mcd/m^2/lux for Type III glass bead. After about 4 months, the Type I, III, and IV glass beads' retro-reflectivity decreased to between 100 and 300 mcd/m^2/lux and maintained these values for the duration of the test. Retro-reflectivity at the end of the test was 108 mcd/m^2/lux for Type I glass beads, 157 mcd/m^2/lux for Type III glass beads, and 241 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-11.

For Franklin Paint, the best performing marking was the SMMA with Type IV glass beads, followed by the SMMA with Type III glass beads. (Franklin Paint did not provide a standard MMA marking.)

THE HVS TEST FACILITY. Retro-reflectivity testing at the HVS test facility was conducted in two separate tests—one with the pavement and paint markings at ambient outdoor temperature and one with the pavement and paint markings heated to approximately 120°F. The results of the two tests are described below.

Ambient Temperature Tests for Hi-Lite. Initially, for the MMA test stripes, retro-reflectivity started at 198 mcd/m^2/lux for Type I glass beads, 865 mcd/m^2/lux for Type III glass beads, and 286 mcd/m^2/lux for Type IV glass beads. The stripe with Type III glass beads showed a gradual improvement in its retro-reflectivity over the duration of the test. The other stripes maintained their value. Retro-reflectivity at the end of the test was approximately 262 mcd/m^2/lux for Type I glass beads, 1129 mcd/m^2/lux for Type III glass beads, and 512 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-12.

For the SMMA test stripes, retro-reflectivity started at 326 mcd/m^2/lux for Type I glass beads, 1215 mcd/m^2/lux for Type III glass beads, and 199 mcd/m^2/lux for Type IV glass beads. The test stripes maintained most of their retro-reflectivity values for the duration of the test. Retro-reflectivity at the end of the test was approximately 342 mcd/m^2/lux for Type I glass beads, 1205 mcd/m^2/lux for Type III glass beads, and approximately 457 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-12.

For Hi-Lite, the best performing marking was the SMMA with Type III glass beads, followed by MMA with Type III glass beads.

Ambient Temperature Tests for Ennis/Flint. Initially, for the MMA test stripes, retro-reflectivity started at 428 mcd/m^2/lux for Type I glass beads, 1657 mcd/m^2/lux for Type III glass beads, and 497 mcd/m^2/lux for Type IV glass beads. The test stripes maintained most of their retro-reflectivity values for the duration of the test. Retro-reflectivity at the end of the test was approximately 434 mcd/m^2/lux for Type I glass beads, 1754 mcd/m^2/lux for Type III glass beads, and 587 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-13.

For the SMMA test stripes, retro-reflectivity started at 238 mcd/m^2/lux for Type I glass beads, 722 mcd/m^2/lux for Type III glass beads, and 419 mcd/m^2/lux for Type IV glass beads. The test stripes maintained most of their retro-reflectivity values for the duration of the test. Retro-reflectivity at the end of the test was approximately 296 mcd/m^2/lux for Type I glass beads, 931 mcd/m^2/lux for Type III glass beads, and approximately 530 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-13.

For Ennis/Flint, the best performing marking was the MMA with Type III glass beads, followed by SMMA with Type III glass beads.

Ambient Temperature Tests for Franklin Paint. Initially, for the SMMA test stripes, retro-reflectivity started at 1075 mcd/m^2/lux for Type I glass beads, 856 mcd/m^2/lux for Type III glass beads, and 870 mcd/m^2/lux for Type IV glass beads. After approximately 100 passes, the Type IV glass beads' retro-reflectivity decreased to approximately 250 mcd/m^2/lux and maintained these values for the duration of the test. Retro-reflectivity at the end of the test was 1030 mcd/m^2/lux for Type I glass beads, 779 mcd/m^2/lux for Type III glass beads, and 222 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-14.

For Franklin Paint, the best performing marking was the SMMA with Type I glass beads, followed by the SMMA with Type III glass beads.

Heated Temperature Tests for Hi-Lite. Initially, for the MMA test stripes, retro-reflectivity started at 164 mcd/m^2/lux for Type I glass beads, 741 mcd/m^2/lux for Type III glass beads, and 351 mcd/m^2/lux for Type IV glass beads. The test stripes maintained their retro-reflectivity values for the duration of the test. Retro-reflectivity at the end of the test was approximately 220 mcd/m^2/lux for Type I glass beads, 857 mcd/m^2/lux for Type III glass beads, and 455 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-15.

For the SMMA test stripes, retro-reflectivity started at 234 mcd/m^2/lux for Type I glass beads, 810 mcd/m^2/lux for Type III glass beads, and 328 mcd/m^2/lux for Type IV glass beads. The test stripes maintained most of their retro-reflectivity values for the duration of the test. Retro-reflectivity at the end of the test was 264 mcd/m^2/lux for Type I glass beads, 868 mcd/m^2/lux for Type III glass beads, and 349 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-15.

For Hi-Lite, the best performing marking was the SMMA with Type III glass beads, followed by the MMA with Type III glass beads.

Heated Temperature Tests for Ennis/Flint. Initially, for the MMA test stripes, retro-reflectivity started at 428 mcd/m^2/lux for Type I glass beads, 1657 mcd/m^2/lux for Type III glass beads, and 497 mcd/m^2/lux for Type IV glass beads. The test stripes maintained these retro-reflectivity values for the duration of the test. Retro-reflectivity at the end of the test was approximately 1754 mcd/m^2/lux for Type III, 587 mcd/m^2/lux for Type IV, and 434 mcd/m^2/lux for Type I. The results of the retro-reflectivity measurements for this test are shown in figure A-16.

For the SMMA test stripes, retro-reflectivity started at 226 mcd/m^2/lux for Type I glass beads, 608 mcd/m^2/lux for Type III glass beads, and 384 mcd/m^2/lux for Type IV glass beads. The test stripes' retro-reflectivity remained fairly consistent for the duration of the test.

Retro-reflectivity at the end of the test was 282 mcd/m^2/lux for Type I glass beads, 741 mcd/m^2/lux for Type III glass beads, and 576 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-16.

For Ennis/Flint, the best performing marking was the MMA with Type III glass beads, followed by the SMMA with Type III glass beads.

Heated Temperature Tests for Franklin Paint. Initially, for the SMMA test stripes, retro-reflectivity started at 655 mcd/m^2/lux for Type I glass beads, 683 mcd/m^2/lux for Type III glass beads, and 740 mcd/m^2/lux for Type IV glass beads. After 50 passes, the Type IV glass beads' retro-reflectivity decreased to approximately 150 mcd/m^2/lux and maintained these values for the duration of the test. Retro-reflectivity at the end of the test was approximately 883 mcd/m^2/lux for Type I glass beads, 728 mcd/m^2/lux for Type III glass beads, and 136 mcd/m^2/lux for Type IV glass beads. The results of the retro-reflectivity measurements for this test are shown in figure A-17.

For Franklin Paint, the best performing marking was the SMMA with Type I glass beads, followed by the SMMA with Type III glass beads.

CHROMATICITY TEST.

Chromaticity tests were completed using a Color-Guide 45/0, BYK-Gardner USA, spectrophotometer from September 2013 until September 2014. The data were entered into a data table and plotted on a CIE Standard Illuminant D_{65} chart that enabled the research team to analyze any color shift and compile the data into a reportable format. Actual data from the collection activity, categorized by location and manufacturer, is presented in appendix A.

Chromaticity measurements for the three test sites, by each manufacturer, are described below.

THE FAA RAMP (CONCRETE).

Hi-Lite. All MMA paint markings appeared to maintain their color throughout the FAA Ramp (concrete) test. The color coordinates remained clustered when plotted on the CIE chart with a few measurements just barely outside the defined white area. The results of the chromaticity measurements for this test are shown in figure A-18. SMMA paint markings had very similar coordinates with only one outlying measurement. This measurement was outside the defined white area with a slight color shift towards yellow. The results of the chromaticity measurements for this test are shown in figure A-19.

Ennis/Flint. All MMA paint markings appeared to maintain their color throughout the FAA Ramp (concrete) test. The color coordinates remained clustered when plotted on the CIE chart and were all inside the defined white area. The results of the chromaticity measurements for this test are shown in figure A-20. The SMMA paint markings had very similar coordinates with only one measurement falling slightly outside the defined white area. The results of the chromaticity measurements for this test are shown in figure A-21.

Franklin Paint. All SMMA paint markings appeared to maintain their color throughout the FAA Ramp (concrete) test. The color coordinates remained clustered when plotted on the CIE chart, all inside the defined white area. The results of the chromaticity measurements for this test are shown in figure A-22.

PANGBORN ROAD (ASPHALT).

Hi-Lite. All MMA paint markings appeared to maintain their color throughout the FAA Ramp test. The color coordinates remained clustered when plotted on the CIE chart with a few measurements just barely outside the defined white area. The results of the chromaticity measurements for this test are shown in figure A-23. The SMMA paint markings had very similar coordinates with no major color shift. The results of the chromaticity measurements for this test are shown in figure A-24.

Ennis/Flint. All MMA paint markings appeared to maintain their color through the FAA Ramp test. The color coordinates remained clustered when plotted on the CIE chart with a few measurements just barely outside the defined white area. The results of the chromaticity measurements for this test are shown in figure A-25. The SMMA paint markings had very similar coordinates with no major color shift. The results of the chromaticity measurements for this test are shown in table A-4.

Franklin Paint. All SMMA paint markings appeared to maintain their color throughout the FAA Ramp test. The color coordinates remained clustered when plotted on the CIE chart with a few measurements just barely outside the defined white area. The results of the chromaticity measurements for this test are shown in table A-5.

FRICTION TEST.

Friction tests were completed on July 25, 2014, approximately 10 months after the paint markings were installed. Using a Saab Sarsys Runway Friction Tester, the research team collected friction measurements over each friction line at 40 mph with the vehicle in self-wetting mode. For each test, a series of runs were made over the 18-inch-wide by 150-foot-long friction lines that were installed on the FAA Ramp (concrete) and Pangborn Road (asphalt). After the runs were completed, the average Mu rating was recorded and reported as shown in table 1. The SMMA test stripes appeared to have a slightly higher Mu value than the MMA test stripes, but not as high as the unpainted pavement.

Table 1. Friction Readings of MMA and SMMA Paint Markings at Pangborn Road (Asphalt)

Section	Mu (μ)	Beads
Unpainted Pavement	0.80	N/A
Hi-Lite MMA (Line 16)	0.63	Type I
Hi-Lite SMMA (Line 20)	0.66	Type I
Ennis/Flint MMA (Line 24)	0.32	Type I
Ennis/Flint SMMA (Line 28)	0.77	Type I
Franklin Paint SMMA (Line 12)	0.77	Type I

PULL-OFF STRENGTH TEST.

Pull-off strength tests were completed over several days in August 2014. These tests were used to determine the tensile strength of the bond between the pavement marking material and hot mix asphalt or PCC. A Dyna Z16 pull-off tester was used to conduct this test. The data from the tests are included in appendix A. Note: The pull-off tests were performed at the FAA Ramp (concrete) and Pangborn Road (asphalt) only. It was not performed at the HVS test facility due to the potential damage to the test deck.

THE FAA RAMP (CONCRETE). For the test stripes on the FAA Ramp (concrete), the data indicated that the bond between the MMA test stripes and the concrete surface was higher in tensile strength than the bond between the SMMA and the concrete. On average, it was approximately four times as strong. There was no noticeable difference between manufacturers. The results of the pull-off strength test for the FAA Ramp (concrete) is shown in figure A-28.

PANGBORN ROAD (ASPHALT). For the test stripes on Pangborn Road (asphalt), the data indicated that the bond between the MMA and the SMMA was about equal. There was no noticeable difference between manufacturers. The results of the pull-off strength test for Pangborn Road (asphalt) is shown in figure A-29.

WATER RUN-OFF TEST ON PANGBORN ROAD (ASPHALT).

A 2-liter, ASTM-E-2177 [4] water test was performed on the paint markings on Pangborn Road (asphalt) only to determine wet-weather recovery of the glass beads after a rain event. The data from the collection activity, categorized by manufacturer, are presented in appendix A.

Explanations of the water run-off results for each manufacturer are provided below.

HI-LITE. All MMA paint markings appeared to recover to their full value after approximately 40 minutes but achieved the 100 $mcd/m^2/lux$ minimum after 15 minutes. All SMMA paint markings appeared to near their full value after 40 minutes but achieved the 100 $mcd/m^2/lux$ minimum at approximately 30 minutes. The markings with Type I and IV glass beads appeared to recover the quickest. The results of this water run-off test are shown in figure A-30.

ENNIS/FLINT. All MMA paint markings appeared to recover to their full value after approximately 40 minutes but achieved the 100 $mcd/m^2/lux$ minimum after 30 minutes. All SMMA paint markings appeared to near their full value after 20 minutes but achieved the 100 $mcd/m^2/lux$ minimum after approximately 15 minutes. The markings with Type III glass beads appeared to recover the quickest. The results of this water run-off test are shown in figure A-31.

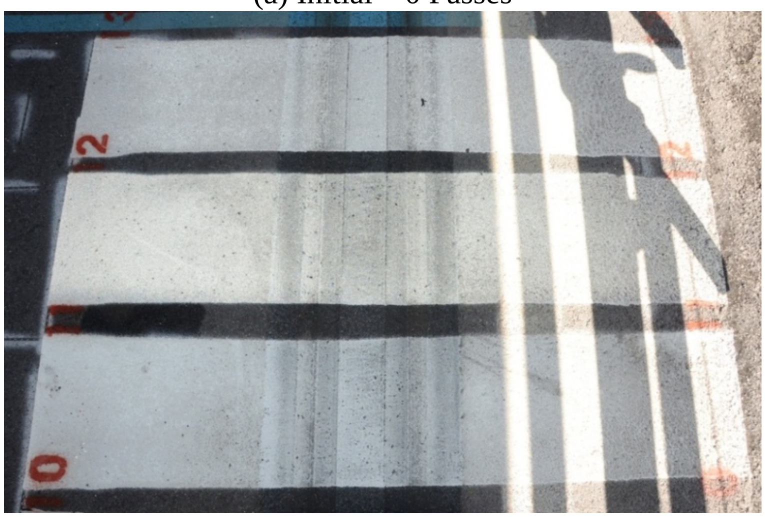
FRANKLIN PAINT. All SMMA paint markings appeared to near their full value after 25 minutes and achieve the 100 mcd/m^2/lux minimum after approximately 20 minutes. The markings with Type IV glass beads appeared to recover the quickest. The results of this water run-off test are shown in figure A-32.

HEAVY VEHICLE SIMULATOR TEST.

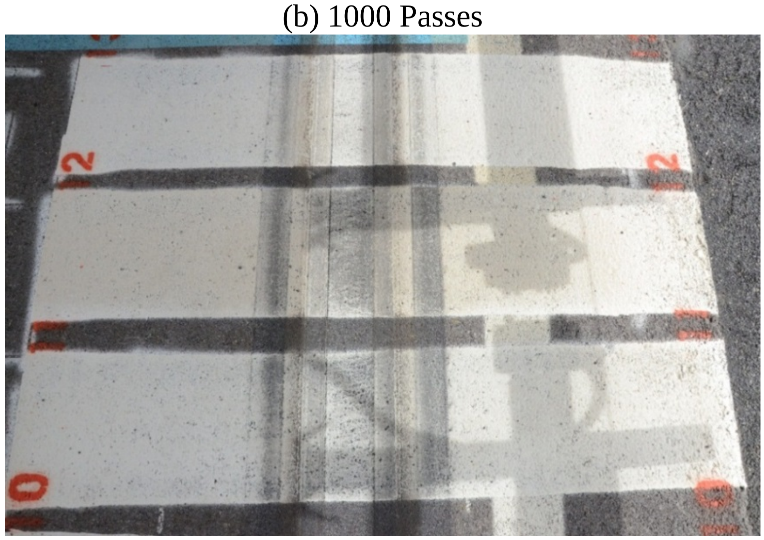
The HVS tests were accomplished towards the end of the research effort, over a period of approximately 2 weeks. The HVS test machine repeatedly rolled the 230- to 240-psi aircraft tire over the pavement in a back-and-forth motion following the same track. Although the retro-reflectivity tests were covered earlier in this report, there are a few general observations that can be made about the performance of the test stripes.

- The SMMA test stripes appeared to collect rubber deposits at a higher rate than the MMA test stripes, as shown in figures 16 through 20.
- Minor grooving caused by the aircraft tire appeared on both the SMMA and MMA markings.
- The softer Franklin Paint formula did not appear to be any better or worse than the standard MMA formulas.
- There was no major disfiguring, cracking, breakage, or transfer of either the MMA or the SMMA paint after enduring 2000 passes by the HVS test machine.

(a) Initial – 0 Passes



(b) 1000 Passes



(c) 2000 Passes

Figure 16. The HVS Test Stripes, 0-2000 Passes, Ambient Temperature, Hi-Lite MMA (Lines 10-12)

(a) Initial - 0 Passes

(b) 1000 Passes

(c) 2000 Passes

Figure 17. The HVS Test Stripes, 0-2000 Passes, Ambient Temperature, Hi-Lite SMMA (Lines 13-15)

(a) Initial - 0 Passes

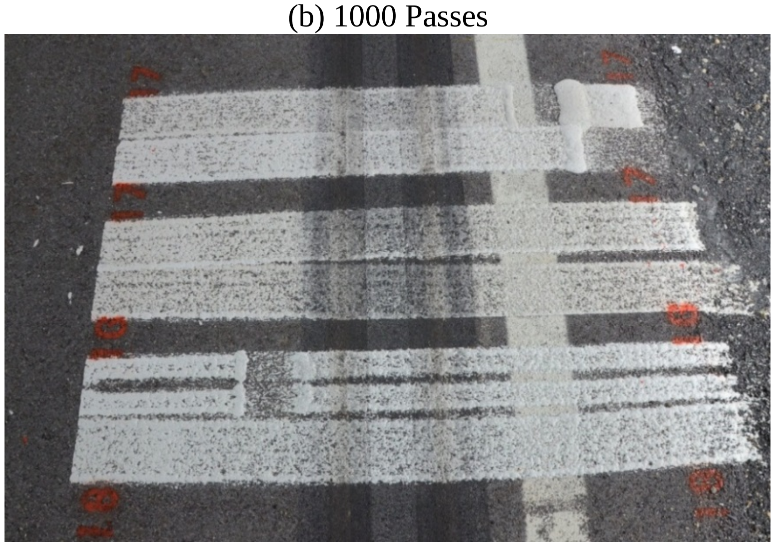
(b) 1000 Passes

(c) 2000 Passes

Figure 18. The HVS Test Stripes, 0-2000 Passes, Ambient Temperature, Ennis/Flint MMA (Lines 19-21)

(a) Initial - 0 Passes

(b) 1000 Passes



(c) 2000 Passes

Figure 19. The HVS Test Stripes, 0-2000 Passes, Ambient Temperature, Ennis/Flint SMMA (Lines 16-18)


(a) Initial - 0 Passes


(b) 1000 Passes

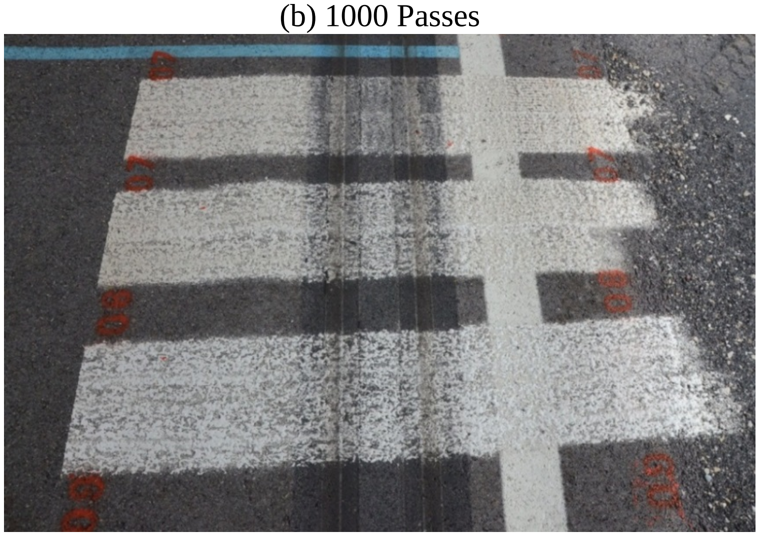

(c) 2000 Passes

Figure 20. The HVS Test Stripes, 0-2000 Passes, Ambient Temperature, Franklin Paint SMMA (Lines 7-9)

WET-WEATHER OBSERVATIONS

Occasionally, the research team conducted visual inspections of the MMA and SMMA paint markings on the FAA Ramp (concrete) and Pangborn Road (asphalt) throughout the evaluation period. Observers saw a noticeable difference in the markings because of the type of glass beads that were used, but they were not able to differentiate between the MMA and SMMA markings. Photographs of the observations are shown in figures 21 through 23.

Figure 21. Wet-Weather Photograph of Old Hot Mix Asphalt on Pangborn Road

Figure 22. Wet-Weather Photograph of Old PCC With Edge Lines on the FAA Ramp

Figure 23. Wet-Weather Photograph of Old PCC With Friction Lines on the FAA Ramp

CONCLUSIONS

The objective of this research was to compare the suggested structured methyl methacrylate (SMMA) paint to traditional methyl methacrylate (MMA) paint. Further research was conducted to evaluate whether the proposed splatter application technique, thicker application, and modified formula complied with minimum requirements of Federal Aviation Administration (FAA) Advisory Circular 150/5370-10G (effective July 21, 2014) retro-reflectivity at initial application. Also evaluated was whether SMMA offered any improvements over the currently accepted MMA application techniques and formula. Based on the analysis of the results, the following conclusions were made.

- MMA paint, when applied using the proposed structured splatter pattern, offers some improvement over MMA paint applied using traditional full coverage. Although it does not fully cover the pavement, it does appear to be a continuous marking when viewed from a distance. The recommended 70% coverage rate appears to be sufficient. These markings were not installed on an airport for pilot surveys; therefore, further evaluation at an airport, including pilot surveys, will be required.

- The structured format of the SMMA paint raises the elevation of the retro-reflective glass beads, which appears to make the marking more visible than MMA paint markings in light rain and wet conditions. Retro-reflectivity readings at the conclusion of the data collection period show that, in general, the readings were higher on the SMMA markings than they were for the MMA markings on concrete surfaces, and slightly higher than the MMA markings on asphalt surfaces. Readings after the simulated 1-year exposure to heavy aircraft trafficking were also higher on the SMMA markings than on the MMA markings. Both MMA and SMMA markings were able to maintain the required 100 $mcd/m^2/lux$ level. In general, the SMMA marking with a Type III glass bead performed the best. After 1 year, the retro-reflective readings were found to meet or exceed the repaint criteria set forth in FAA technical note DOT/FAA/AR-TN03/22, "Development of Methods for Determining Airport Pavement Marking Effectiveness," dated March 2003.

- The unknown Type I bead used by Franklin Paint showed comparable numbers to the standard approved Type III glass beads. The actual specification for the unknown Type I bead will need to be confirmed to better understand why it performed better than the other Type I glass beads that were tested.

- The chromaticity of the paint markings for all three manufacturers remained satisfactory over the 1-year evaluation period.

- On average, the SMMA paint markings possess a higher friction value than the MMA paint markings, although SMMA friction values were still less than the surrounding unpainted pavement. This is likely due to the coarser texture of the SMMA marking.

- The SMMA paint markings did not adhere to Portland cement concrete as well as the MMA paint markings; however, the SMMA markings were about the same as the MMA markings in their adhesion to asphalt. This is likely due to the smaller contact area of the SMMA marking with the less porous concrete pavement. Both markings bonded better with the porous asphalt.

- During the water run-off tests, all markings returned to their initial retro-reflectivity readings within the required 40 minutes. Most markings recovered to 100 $mcd/m^2/lux$ within 15 to 20 minutes. The SMMA paint markings appeared to recover equal to or faster than the MMA paint markings. The results varied regarding bead type, with each bead type showing some benefit with each different manufacturer.

- During the HVS tests, the SMMA and MMA paint markings appeared to be resistant to the heavy-weight trafficking of the aircraft wheel. Neither marking showed any noticeable shoving, rutting, or disfiguring from the aircraft wheel. There was a slightly higher buildup of rubber on the SMMA markings; however, this did not affect the visibility or retro-reflectivity of the paint markings after 2000 passes. A follow-on study at an airport will be required to obtain the pilot's perspective on the markings.

- During the wet-weather observations, observers noted that they did not see any difference between the SMMA and MMA paint markings, but they did see a difference between the markings with different bead types.

- The modified paint formula proposed by Franklin Paint does not appear to have any adverse effects on the paint markings. The HVS test confirmed that the softer structure of the paint marking was not affected by traffic tests any differently than the markings with the approved formula.

- The proposed application of 60- to 90-mil, wet-film thickness appears to be acceptable for SMMA paint applications. The test stripes on the FAA Ramp (concrete) and Pangborn Road (asphalt) were exposed to snowplowing, but did not show adverse signs of damage during the research.

- The proposed glass bead application rate for the SMMA paint markings is 8 lb for Type I glass beads, 10 lb for Type III glass beads, and 10 lb for Type IV glass beads.

REFERENCES

1. Federal Aviation Administration, Advisory Circular AC 150/5370-10G, Item P-620, “Standards for Specifying Construction of Airports, Runway and Taxiway Painting,” July 21, 2014.

2. Federal Specification TT-B-1325C, “Beads (Glass Spheres) Retro-Reflective,” June 1, 1993.

3. ASTM-D-4541-02, “Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers.”

4. ASTM-E-2176-01, “Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (R_L) of Pavement Markings in a Standard Condition of Continuous Wetting.”

5. ASTM-E-2177-01, “Standard Test Method for Measuring the Coefficient of Retro-reflected Luminance (R_L) of Pavement Markings in a Standard Condition of Wetness.”

APPENDIX A—DATA COLLECTED

This appendix shows the data collected at Pangborn Road (old hot mix asphalt), the FAA Ramp (Portland cement concrete (PCC)), and the Heavy Vehicle Simulator (HVS) test facility.

Table A-1. Test Stripe Data for the FAA Ramp (Concrete) Installation

Stripe No.	Manufacturer	Type of Marking	Surface Material	Format/Paint Thickness/Mix	Glass Bead Type
9	Franklin Paint	12″ x 6′ Edge Line	Old PCC	Structured, 60-90 mil thick, New MMA Formula	I
10		12″ x 6′ Edge Line	Old PCC	Structured, 60-90 mil thick, New MMA Formula	III
11		12″ x 6′ Edge Line	Old PCC	Structured, 60-90 mil thick, New MMA Formula	IV
12		18″ x 150′ Friction Line	Old PCC	Structured, 60-90 mil thick, New MMA Formula	I
13	Hi-Lite	12″ x 6′ Edge Line	Old PCC	Nonstructured, 15 mil thick, Standard MMA Formula	I
14		12″ x 6′ Edge Line	Old PCC	Nonstructured, 15 mil thick, Standard MMA Formula	III
15		12″ x 6′ Edge Line	Old PCC	Nonstructured, 25 mil thick, Standard MMA Formula	IV
16		18″ x 150′ Friction Line	Old PCC	Nonstructured, 15 mil thick, Standard MMA Formula	I
17		12″ x 6′ Edge Line	Old PCC	Structured, 60-90 mil thick, Standard MMA Formula	I
18		12″ x 6′ Edge Line	Old PCC	Structured, 60-90 mil thick, Standard MMA Formula	III
19		12″ x 6′ Edge Line	Old PCC	Structured, 60-90 mil thick, Standard MMA Formula	IV
20		18″ x 150′ Friction Line	Old PCC	Structured, 60-90 mil thick, Standard MMA Formula	I
21	Ennis/Flint	12″ x 6′ Edge Line	Old PCC	Nonstructured, 15 mil thick, Standard MMA Formula	I
22		12″ x 6′ Edge Line	Old PCC	Nonstructured, 15 mil thick, Standard MMA Formula	III
23		12″ x 6′ Edge Line	Old PCC	Nonstructured, 25 mil thick, Standard MMA Formula	IV
24		18″ x 150′ Friction Line	Old PCC	Nonstructured, 15 mil thick, Standard MMA Formula	I
25		12″ x 6′ Edge Line	Old PCC	Structured, 60-90 mil thick, Standard MMA Formula	I
26		12″ x 6′ Edge Line	Old PCC	Structured, 60-90 mil thick, Standard MMA Formula	III
27		12″ x 6′ Edge Line	Old PCC	Structured, 60-90 mil thick, Standard MMA Formula	IV
28		18″ x 150′ Friction Line	Old PCC	Structured, 60-90 mil thick, Standard MMA Formula	I

Table A-2. Test Stripe Data for Pangborn Road (Asphalt)

Stripe No.	Manufacturer	Type of Marking	Surface Material	Format/Paint Thickness/Mix	Glass Bead Type
9	Franklin Paint	12″ by 6′ Edge Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, New MMA Formula	I
10		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, New MMA Formula	III
11		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, New MMA Formula	IV
12		18″ by 150′ Friction Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, New MMA Formula	I
13	Hi-Lite	12″ by 6′ Edge Line	Old Hot Mix Asphalt	Nonstructured, 15 mil thick, Standard MMA Formula	I
14		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Nonstructured, 15 mil thick, Standard MMA Formula	III
15		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Nonstructured, 25 mil thick, Standard MMA Formula	IV
16		18″ by 150′ Friction Line	Old Hot Mix Asphalt	Nonstructured, 15 mil thick, Standard MMA Formula	I
17		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	I
18		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	III
19		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	IV
20		18″ by 150′ Friction Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	I
21	Ennis/Flint	12″ by 6′ Edge Line	Old Hot Mix Asphalt	Nonstructured, 15 mil thick, Standard MMA Formula	I
22		12″ by 6′ Edge Line	Old Hot-Mix Asphalt	Nonstructured, 15 mil thick, Standard MMA Formula	III
23		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Nonstructured, 25 mil thick, Standard MMA Formula	IV
24		18″ by 150′ Friction Line	Old Hot Mix Asphalt	Nonstructured, 15 mil thick, Standard MMA Formula	I
25		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	I
26		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	III
27		12″ by 6′ Edge Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	IV
28		18″ by 150′ Friction Line	Old Hot Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	I

Table A-3. Test Stripe Data for HVS Installation

Stripe No.	Manufacturer	Type of Marking	Surface Material	Format/Paint Thickness/Mix	Glass Bead Type
7	Franklin Paint	12″ by 6′ Edge Line	New Hot-Mix Asphalt	Structured, 60-90 mil thick, New MMA Formula	I
8		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Structured, 60-90 mil thick, New MMA Formula	III
9		12″x 6′ Edge Line	New Hot-Mix Asphalt	Structured, 60-90 mil thick, New MMA Formula	I
10	Hi-Lite	12″ by 6′ Edge Line	New Hot-Mix Asphalt	Nonstructured, 15 mil thick, Standard MMA Formula	I
11		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Nonstructured, 15 mil thick, Standard MMA Formula	III
12		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Nonstructured, 25 mil thick, Standard MMA Formula	IV
13		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	I
14		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	I
15		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	I
16	Ennis/Flint	12″ by 6′ Edge Line	New Hot-Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	I
17		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	III
18		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Structured, 60-90 mil thick, Standard MMA Formula	IV
19		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Nonstructured, 15 mil thick, Standard MMA Formula	I
20		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Nonstructured, 15 mil thick, Standard MMA Formula	III
21		12″ by 6′ Edge Line	New Hot-Mix Asphalt	Nonstructured, 25 mil thick, Standard MMA Formula	IV

SURFACE MATERIAL - PORTLAND CEMENT CONCRETE
12 Inch Wide by 6 Feet Long Edge Line

Marking #	Color	Franklin (Std) Chromaticity Readings Y	x	y
	White			
1	Type I			
	15 Mil			
2	Type III			
	15 Mil			
3	Type IV			
	25 Mil			

Date: 4/23/2010

Location
FAA
WJHTC
AIRCRAFT
APRON

SURFACE MATERIAL - PORTLAND CEMENT CONCRETE
12 Inch Wide by 6 Foot Long Edge Line

Marking #	Color	Franklin (New) Chromaticity Readings Y	x	y
	White			

Page 1

Marking #	Color	Retro-Reflectometer Readings			*Average*
	White				
1	Type I				
	15 Mil				
2	Type III				
	15 Mil				
3	Type IV				
	25 Mil				

Marking #	Color	Retro-Reflectometer Readings			*Average*
	White				

Figure A-1. Sample Data Collection Sheet for Retro-Reflectivity and Chromaticity Readings

Manufacturer: Hi-Lite				
Location: FAA Ramp				
Format: Nonstructured				
Surface: Old Portland Cement Concrete (PCC)				
Month:	Edge Lines			Friction Line
	Type I #13	Type III #14	Type IV #15	Type I #16
September	1329	1274	445	1540
October	203	1006	457	216
November	212	973	483	178
December	231	978	464	186
January	233	919	453	207
February	239	912	514	187
March	202	844	452	185
April	228	848	510	201
May	240	765	506	217
June	247	740	487	231
July	271	806	533	241
August	264	827	528	261

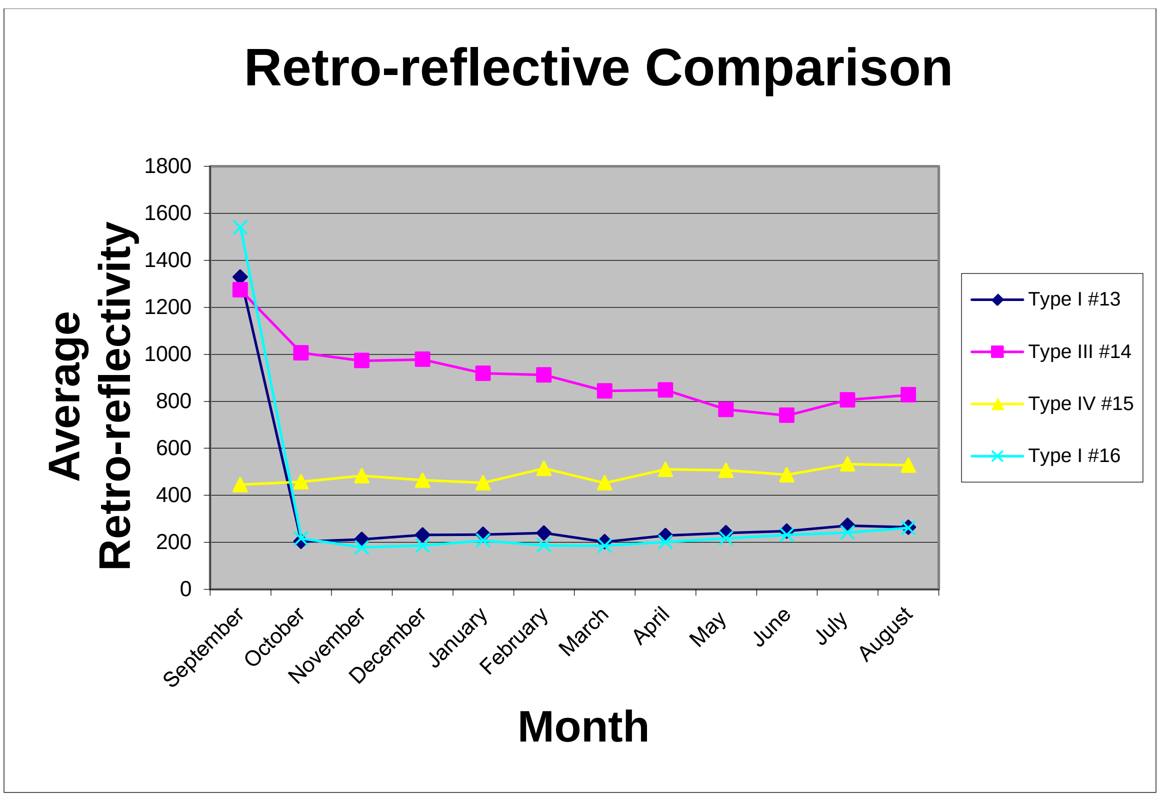


Figure A-2. Retro-Reflective Comparison –Hi-Lite – FAA Ramp – Old PCC – Standard Formula – Nonstructured MMA

Manufacturer: Hi-Lite				
Location: FAA Ramp				
Format: Structured				
Surface: Old PCC				
Month:	**Edge Lines**			**Friction Line**
	Type I #17	**Type III #18**	**Type IV #19**	**Type I #20**
September	388	2698	585	362
October	415	2499	567	383
November	400	2230	579	376
December	423	2457	583	370
January	387	2434	592	406
February	390	2192	615	376
March	364	1830	545	364
April	397	1908	598	379
May	373	1955	577	341
June	385	1944	586	320
July	444	2125	611	350
August	434	2181	643	395

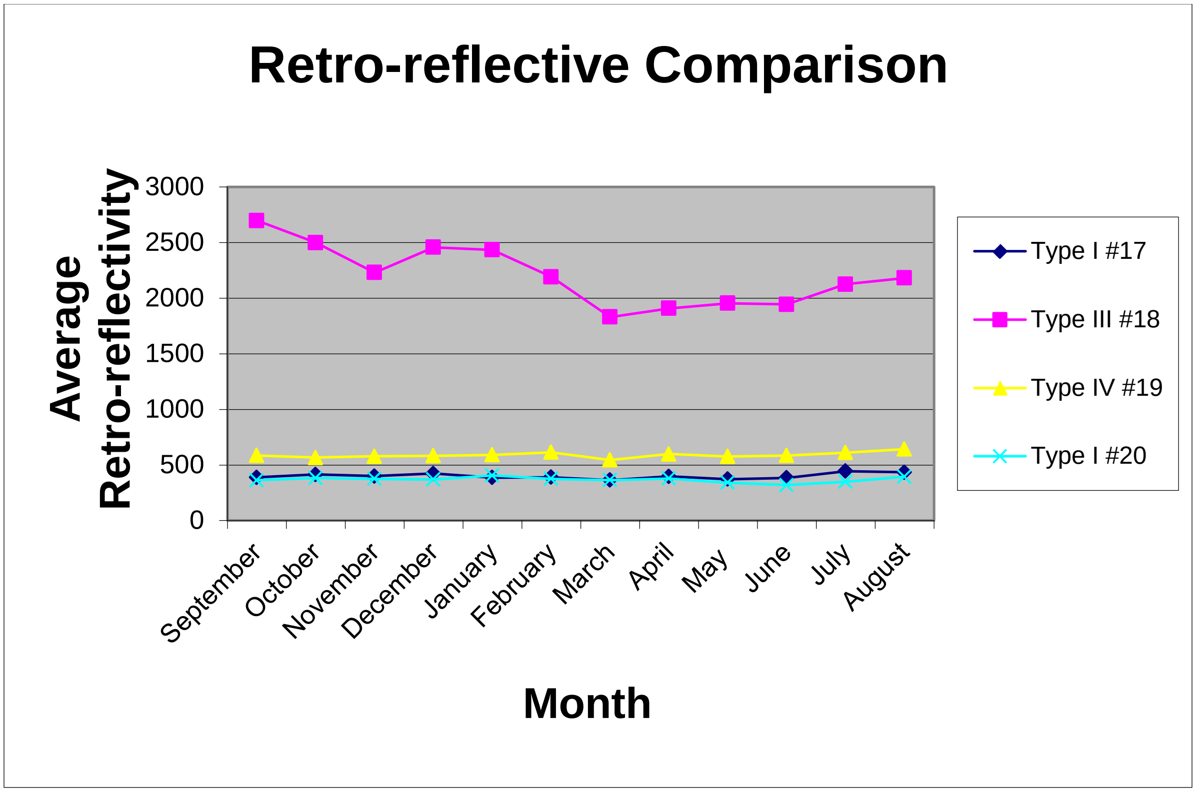


Figure A-3. Retro-Reflective Comparison –Hi-Lite – FAA Ramp – Old PCC – Standard Formula – Structured MMA

Manufacturer: Ennis/Flint				
Location: FAA Ramp				
Format: Nonstructured				
Surface: Old PCC				
Month:	Edge Lines			Friction Line
	Type I #21	Type III #22	Type IV #23	Type I #24
September	238	779	450	235
October	221	773	474	268
November	295	802	469	259
December	246	809	460	264
January	242	777	437	272
February	288	787	503	274
March	224	647	317	282
April	281	733	460	287
May	298	782	474	288
June	288	741	478	303
July	304	777	489	320
August	318	804	439	319

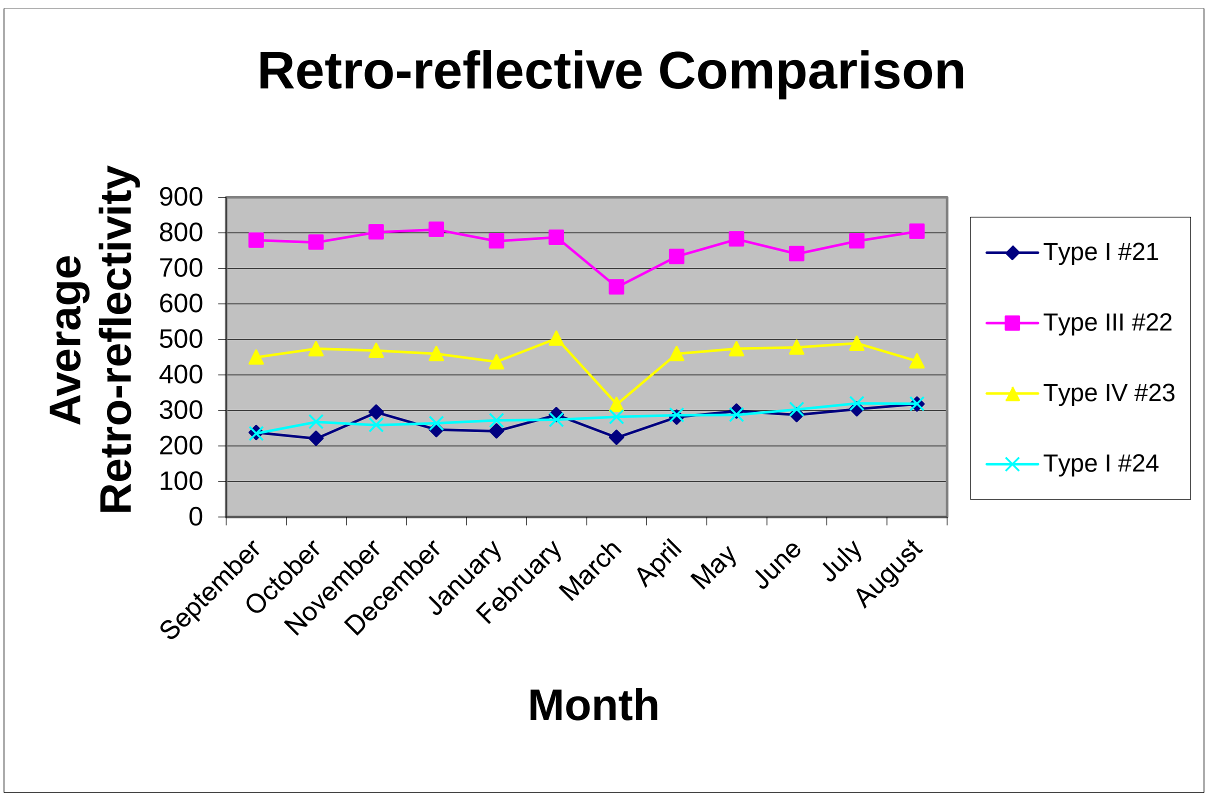


Figure A-4. Retro-Reflective Comparison –Ennis/Flint – FAA Ramp – Old PCC – Standard Formula – Nonstructured MMA

Manufacturer: Ennis/Flint				
Location: FAA Ramp				
Format: Structured				
Surface: Old PCC				
Month:	Edge Lines			Friction Line
	Type I #25	Type III #26	Type IV #27	Type I #28
September	416	2258	375	430
October	394	2158	370	436
November	424	2317	431	474
December	419	2220	415	469
January	444	1909	425	172
February	388	2331	431	444
March	375	1895	409	407
April	405	2067	467	447
May	395	2270	487	467
June	395	2290	454	464
July	399	2396	474	478
August	424	2216	504	470

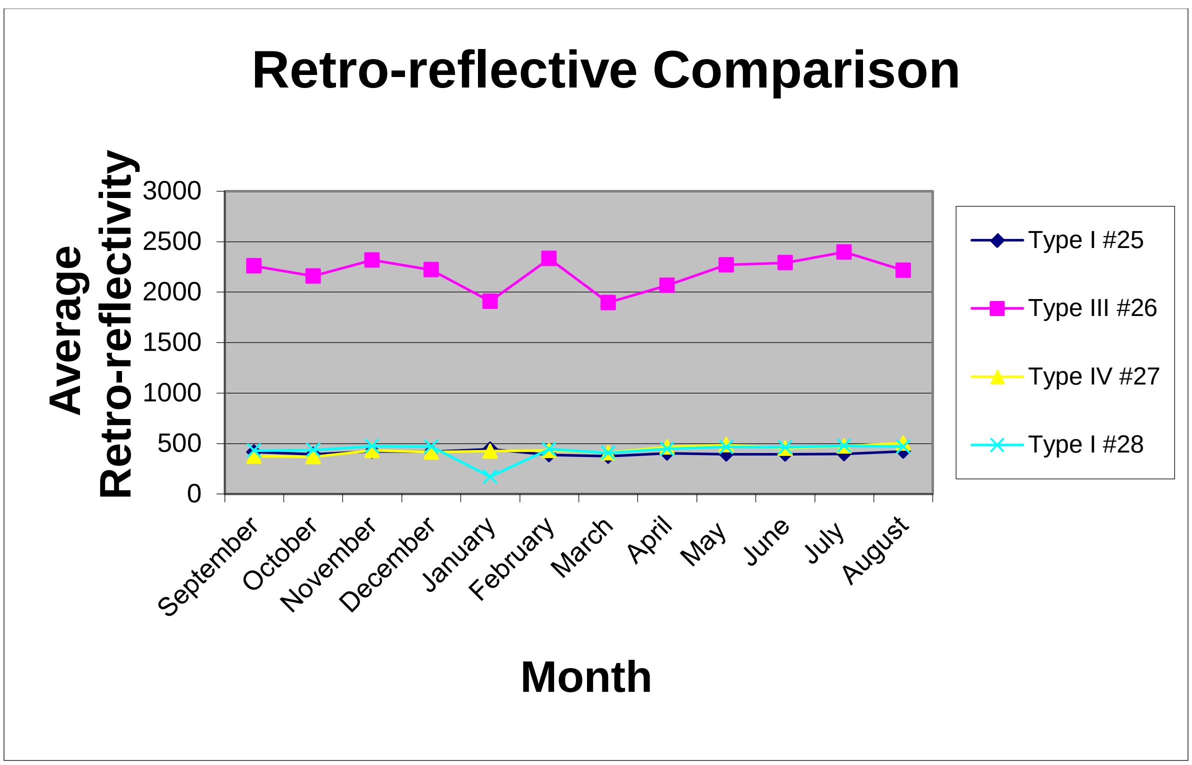


Figure A-5. Retro-Reflective Comparison –Ennis/Flint – FAA Ramp – Old PCC – Standard Formula – Structured MMA

Manufacturer: Franklin Paint				
Location: FAA Ramp				
Format: Structured				
Surface: Old PCC				
Month:	Edge Lines			Friction Line
	Type I #9	Type III #10	Type IV #11	Type I #12
September	1329	1273	445	1540
October	1300	1286	436	1745
November	1410	1347	469	1760
December	1346	1233	464	1551
January	1346	1233	464	1359
February	1281	1103	404	1458
March	1081	1082	345	1423
April	1171	982	403	1477
May	1224	1062	420	1500
June	1173	1015	411	1382
July	1276	999	432	1564
August	1311	1074	447	1478

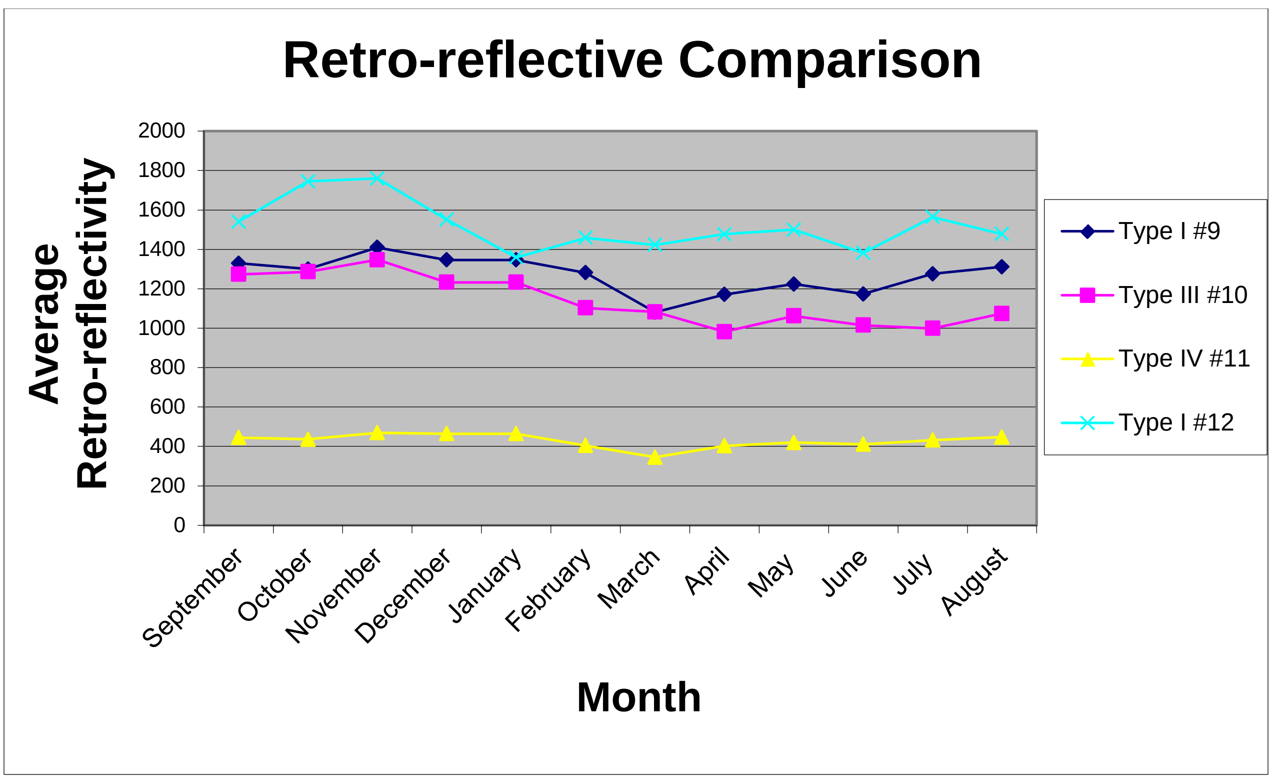


Figure A-6. Retro-Reflective Comparison –Franklin Paint – FAA Ramp – Old PCC – New Formula – Structured MMA

Manufacturer: Hi-Lite				
Location: Pangborn Road				
Format: Nonstructured				
Surface: Old Hot-Mix Asphalt				
Month:	**Edge Lines**			**Friction Line**
	Type I #13	**Type III #14**	**Type IV #15**	**Type I #16**
September	359	1080	499	356
October	362	942	504	344
November	334	804	461	281
December	260	459	264	220
January	181	277	202	145
February	206	242	170	185
March	125	153	133	115
April	132	247	227	168
May	164	186	168	115
June	164	182	159	107
July	193	204	171	132
August	172	208	167	138

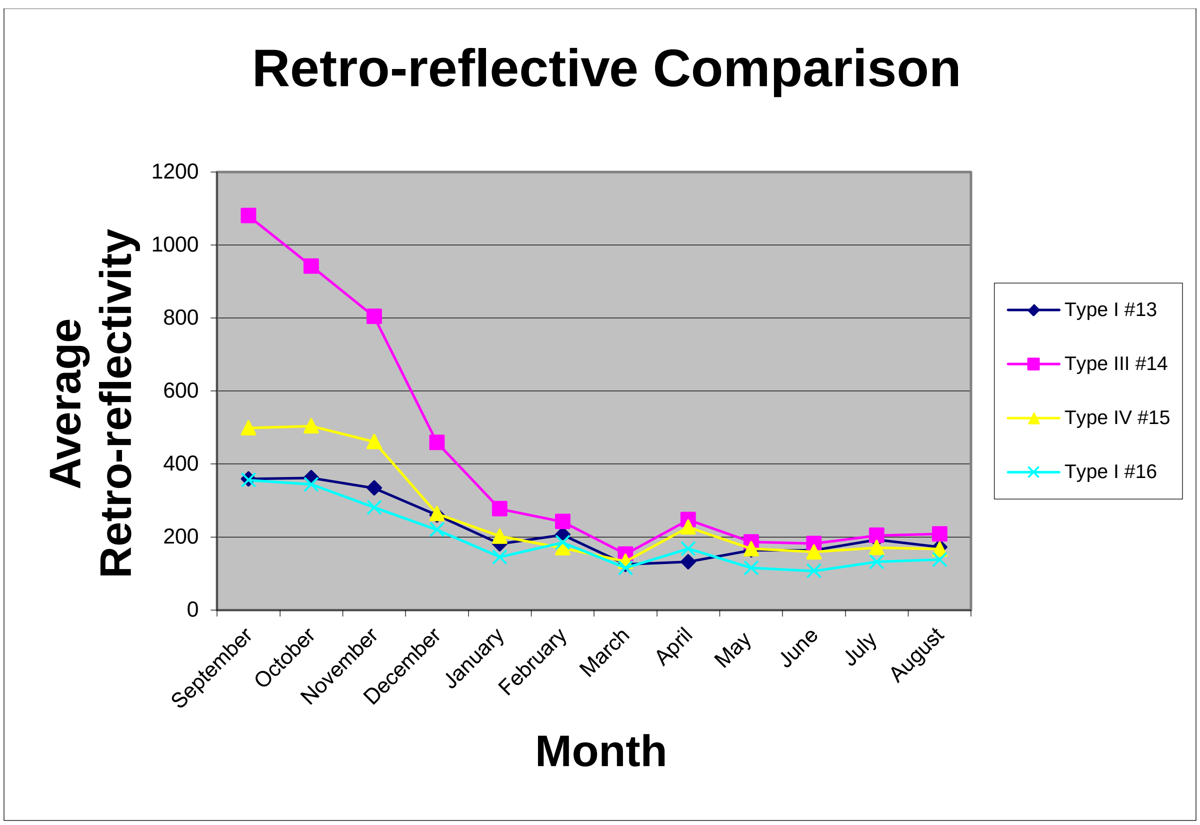


Figure A-7. Retro-Reflective Comparison –Hi-Lite – Pangborn Road – Old Hot-Mix Asphalt – Standard Formula – Nonstructured MMA

Manufacturer: Hi-Lite				
Location: Pangborn Road				
Format: Structured				
Surface: Old Hot-Mix Asphalt				
Month:	**Edge Lines**			**Friction Line**
	Type I #17	**Type III #18**	**Type IV #19**	**Type I #20**
September	509	1861	429	420
October	415	2499	567	383
November	467	1268	371	365
December	374	897	315	361
January	274	524	235	244
February	282	540	255	295
March	222	377	197	242
April	355	617	277	311
May	322	502	218	256
June	289	451	231	270
July	313	520	241	285
August	319	484	245	289

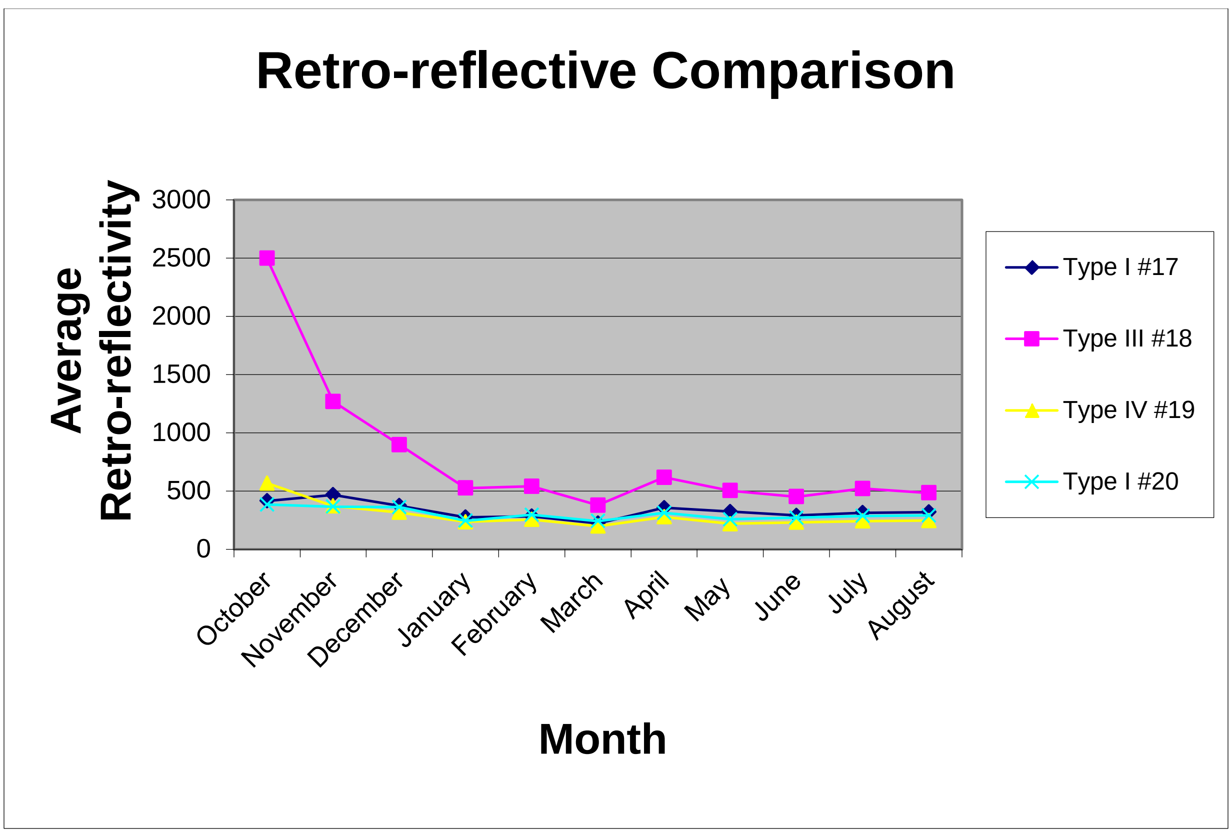


Figure A-8. Retro-Reflective Comparison –Hi-Lite – Pangborn Road – Old Hot-Mix Asphalt – Standard Formula – Structured MMA

Manufacturer: Ennis/Flint				
Location: Pangborn Road				
Format: Nonstructured				
Surface: Old Hot-Mix Asphalt				
Month:	Edge Lines			Friction Line
	Type I #21	Type III #22	Type IV #23	Type I #24
September	386	884	436	265
October	409	783	453	314
November	335	679	392	236
December	278	413	295	241
January	185	208	200	59
February	216	264	239	105
March	150	143	145	123
April	243	266	265	89
May	192	179	207	70
June	197	169	223	63
July	210	187	236	69
August	219	191	247	81

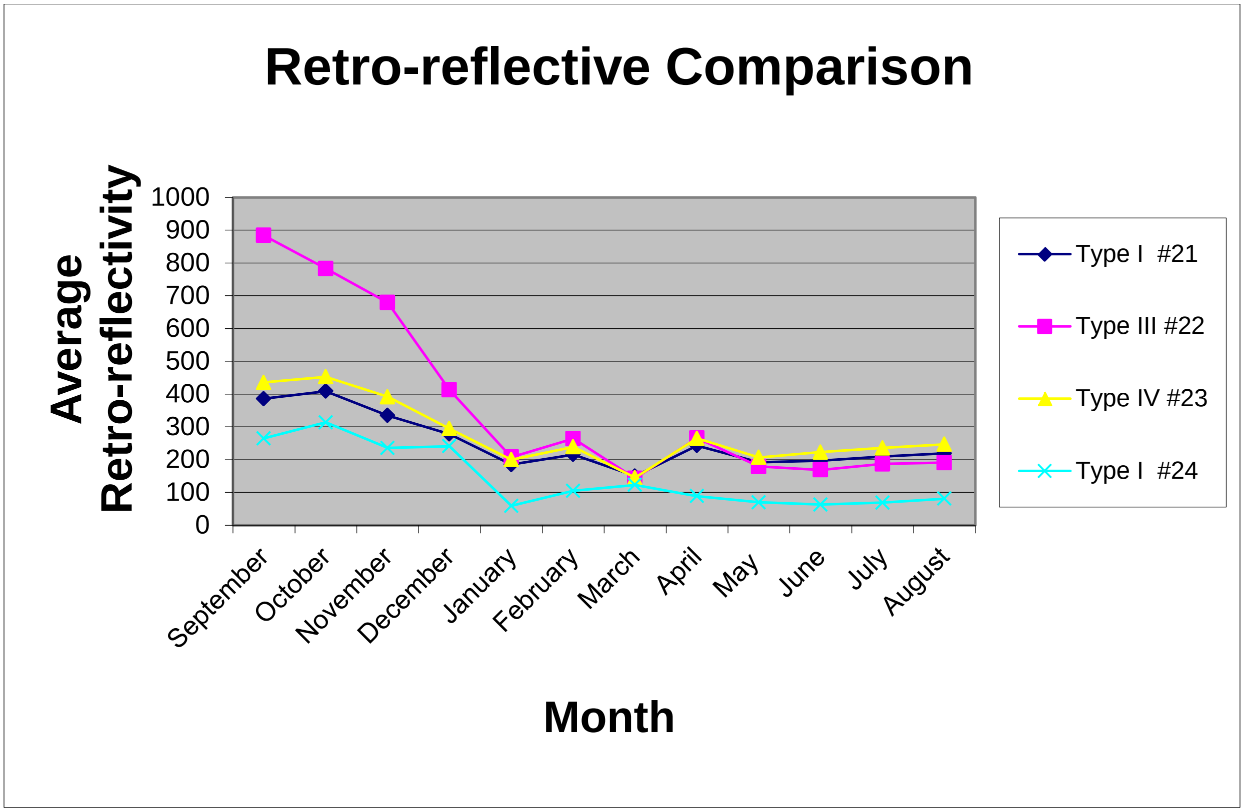


Figure A-9. Retro-Reflective Comparison –Ennis/Flint – Pangborn Road – Old Hot-Mix Asphalt – Standard Formula – Nonstructured MMA

Manufacturer: Ennis/Flint				
Location: Pangborn Road				
Format: Structured				
Surface: Old Hot-Mix Asphalt				
Month:	**Edge Lines**			**Friction Line**
	Type I #25	**Type III #26**	**Type IV #27**	**Type I #28**
September	180	1687	567	149
October	384	1523	559	325
November	313	1130	474	278
December	278	413	295	252
January	460	249	189	184
February	566	307	233	137
March	368	169	236	64
April	560	266	372	79
May	435	191	275	67
June	426	215	317	67
July	475	232	336	68
August	485	237	347	330

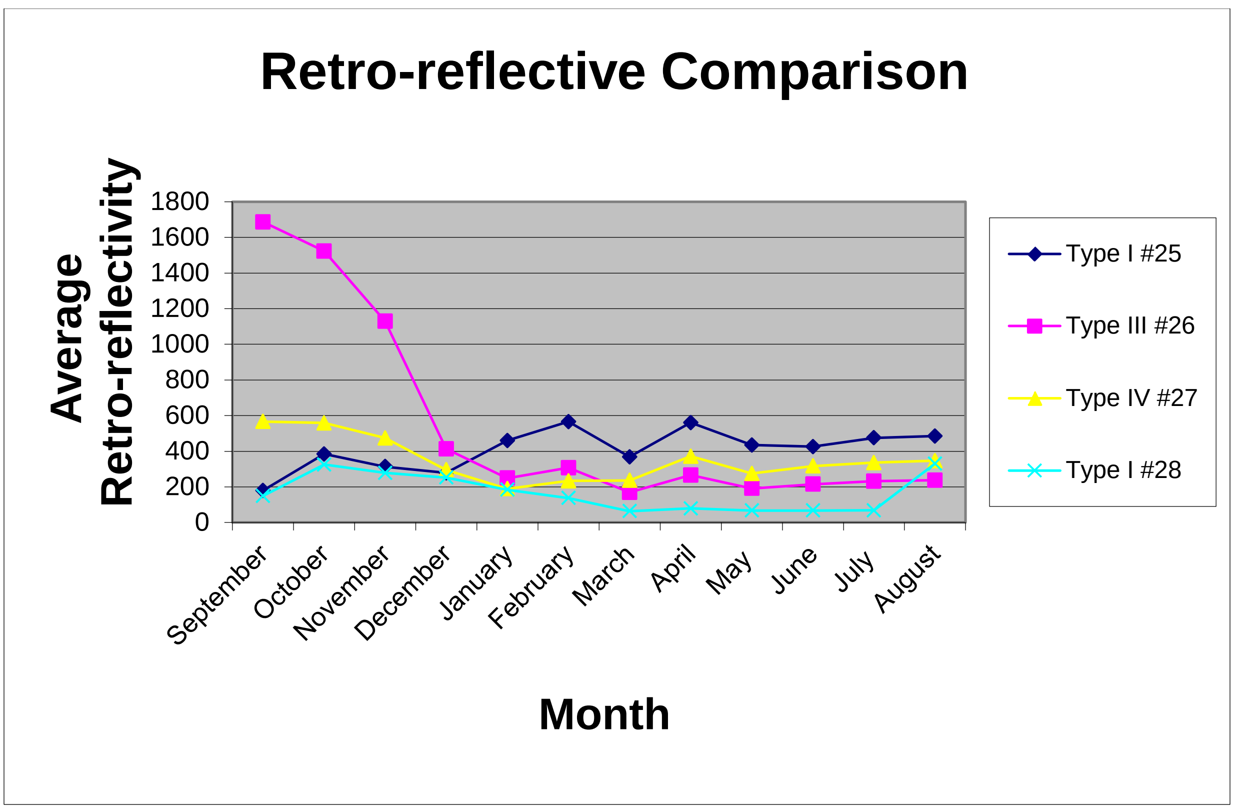


Figure A-10. Retro-Reflective Comparison –Ennis/Flint – Pangborn Road – Old Hot-Mix Asphalt – Standard Formula – Structured MMA

Manufacturer: Franklin Paint				
Location: Pangborn Road				
Format: Structured				
Surface: Old Hot-Mix Asphalt				
Month:	Edge Lines			Friction Line
	Type I #9	Type III #10	Type IV #11	Type I #12
September	322	832	1043	1158
October	278	818	599	881
November	243	675	810	465
December	194	458	566	41
January	134	153	281	107
February	113	194	251	121
March	99	139	174	63
April	138	198	266	106
May	118	152	214	88
June	117	154	208	80
July	122	166	236	82
August	108	157	241	84

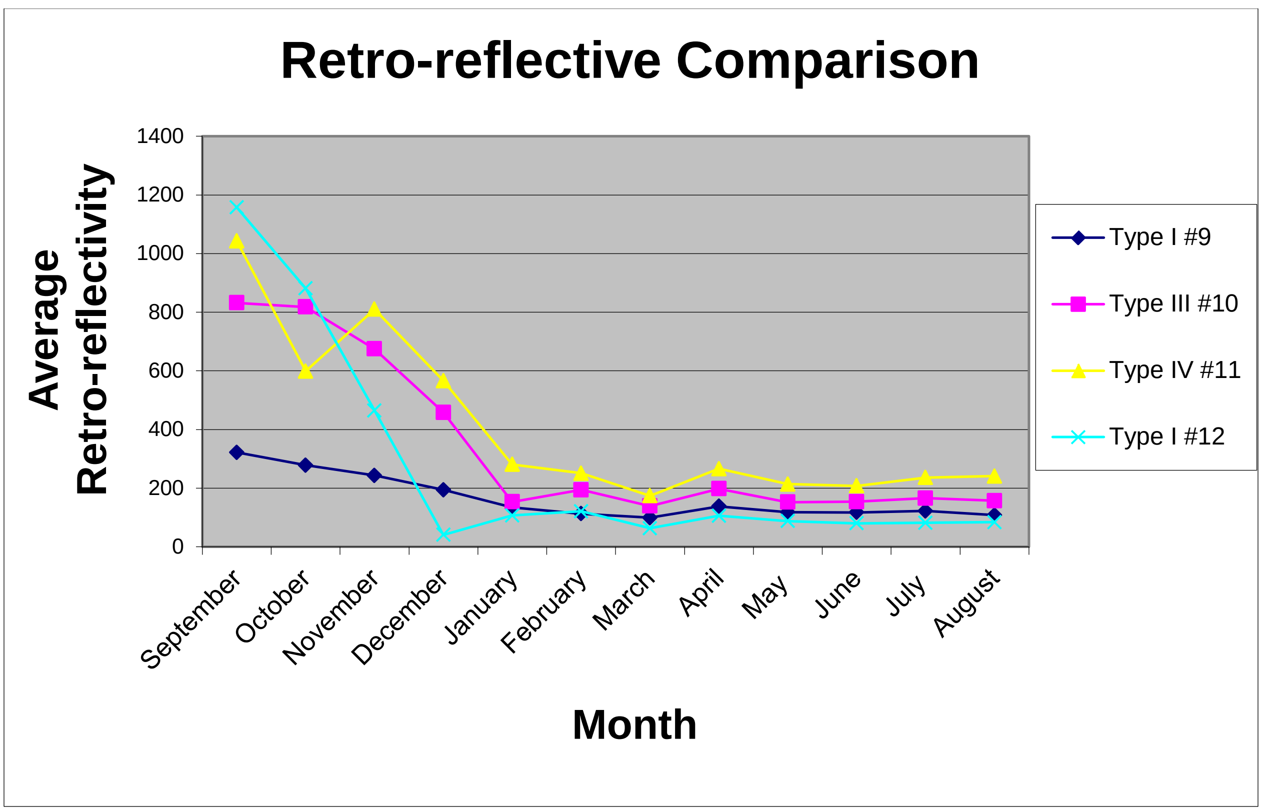


Figure A-11. Retro-Reflective Comparison –Franklin Paint – Pangborn Road – Old Hot-Mix Asphalt – New Formula – Structured MMA

Manufacturer: Hi-Lite						
Location: HVS Test Facility						
Temperature: Ambient						
Surface: New Hot-Mix Asphalt						
Passes:	Structured			Nonstructured		
	Type I #16	Type III #17	Type IV #18	Type I #19	Type III #20	Type IV #21
O Passes	326	1215	199	198	865	286
50 Passes	331	1198	427	222	1017	426
100 Passes	309	1058	428	222	1082	445
150 Passes	337	1192	421	220	1054	451
200 Passes	327	1133	426	228	1054	446
300 Passes	327	1164	437	224	1073	441
400 Passes	331	1175	434	231	1107	454
500 Passes	345	1160	428	240	1058	456
600 Passes	335	1205	421	234	1071	448
700 Passes	338	1189	428	236	1106	469
800 Passes	334	1185	436	242	1116	470
900 Passes	337	1219	429	237	1107	458
1000 Passes	346	1271	440	241	1126	483
1100 Passes	345	1197	449	244	1120	475
1200 Passes	341	1212	443	230	1119	473
1300 Passes	335	1254	450	238	1118	468
1400 Passes	349	1235	443	236	1105	437
1500 Passes	332	1218	436	242	1122	437
2000 Passes	342	1205	457	262	1129	512

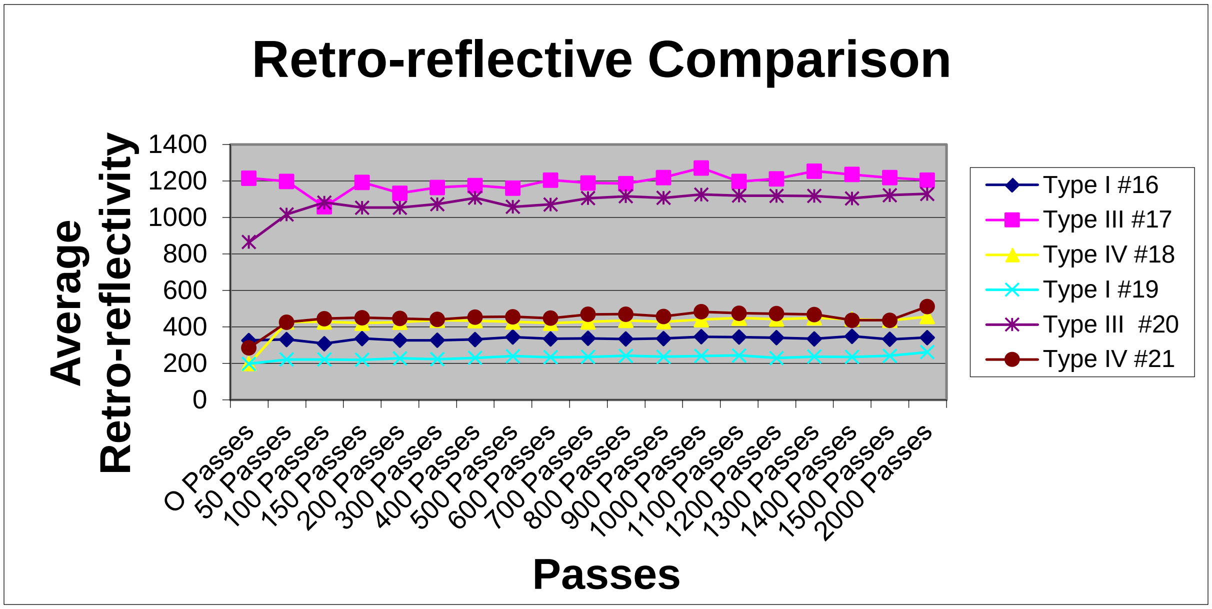


Figure A-12. Retro-Reflective Comparison –Hi-Lite – HVS Test Facility – Ambient Temperature – Old Hot-Mix Asphalt – Standard Formula

Manufacturer: Ennis/Flint						
Location: HVS Test Facility						
Temperature: Ambient						
Surface: New Hot-Mix Asphalt						
Passes:	Structured			Nonstructured		
	Type I #10	Type III #11	Type IV #12	Type I #13	Type III #14	Type IV #15
O Passes	238	722	419	428	1657	497
50 Passes	253	708	400	387	1720	501
100 Passes	248	709	423	404	1767	554
150 Passes	251	758	433	412	1699	536
200 Passes	250	799	442	357	1624	537
300 Passes	249	718	451	438	1597	518
400 Passes	258	731	479	415	1832	515
500 Passes	272	825	483	420	1783	531
600 Passes	262	762	471	411	1715	512
700 Passes	268	791	490	384	1582	540
800 Passes	267	914	502	417	1682	544
900 Passes	274	862	519	384	1745	512
1000 Passes	268	810	509	417	1789	553
1100 Passes	272	881	511	431	1739	529
1200 Passes	270	840	490	429	1621	541
1300 Passes	274	851	511	442	1863	528
1400 Passes	275	861	480	403	1558	549
1500 Passes	270	869	505	438	1791	536
2000 Passes	296	931	530	434	1754	587

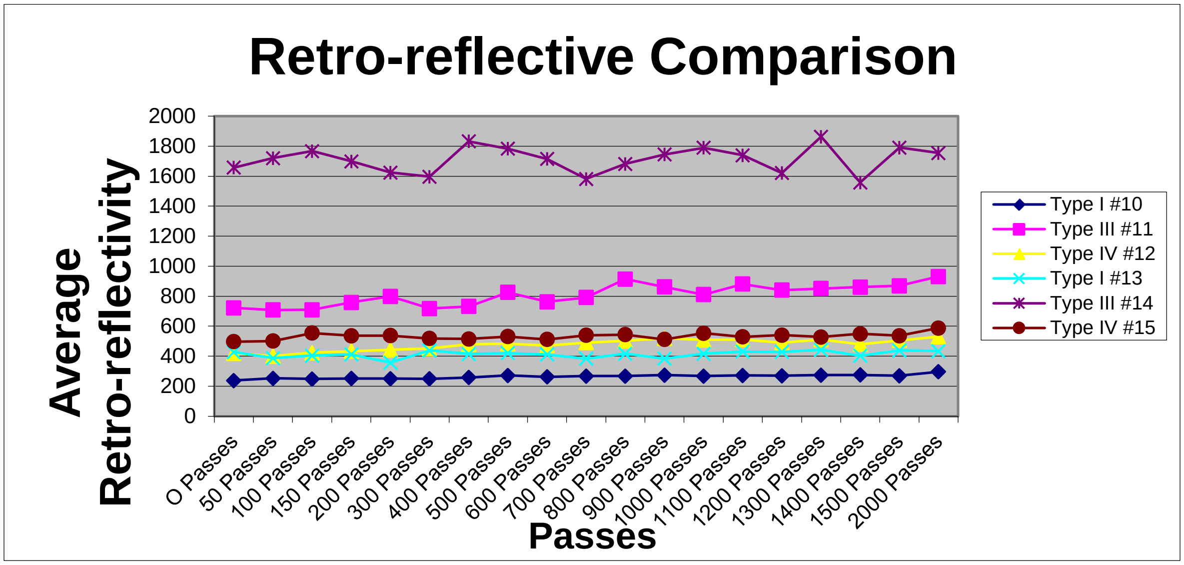


Figure A-13. Retro-Reflective Comparison –Ennis/Flint – HVS Test Facility – Ambient Temperature – Old Hot-Mix Asphalt – Standard Formula

Manufacturer: Franklin Paint						
Location: HVS Test Facility						
Temperature: Ambient						
Surface: New Hot-Mix Asphalt						
Passes:	Structured			Nonstructured		
	Type I #7	Type III #8	Type IV #9	Type I n/a	Type III n/a	Type IV n/a
O Passes	1075	856	870	-	-	-
50 Passes	1014	796	934	-	-	-
100 Passes	243	273	247	-	-	-
150 Passes	1051	936	262	-	-	-
200 Passes	996	868	255	-	-	-
300 Passes	1111	951	260	-	-	-
400 Passes	994	974	247	-	-	-
500 Passes	1063	900	249	-	-	-
600 Passes	1083	882	255	-	-	-
700 Passes	1101	811	246	-	-	-
800 Passes	999	881	245	-	-	-
900 Passes	1128	800	250	-	-	-
1000 Passes	975	809	265	-	-	-
1100 Passes	1034	880	260	-	-	-
1200 Passes	1018	956	270	-	-	-
1300 Passes	1162	888	267	-	-	-
1400 Passes	1150	919	250	-	-	-
1500 Passes	1019	852	273	-	-	-
2000 Passes	1030	779	222	-	-	-

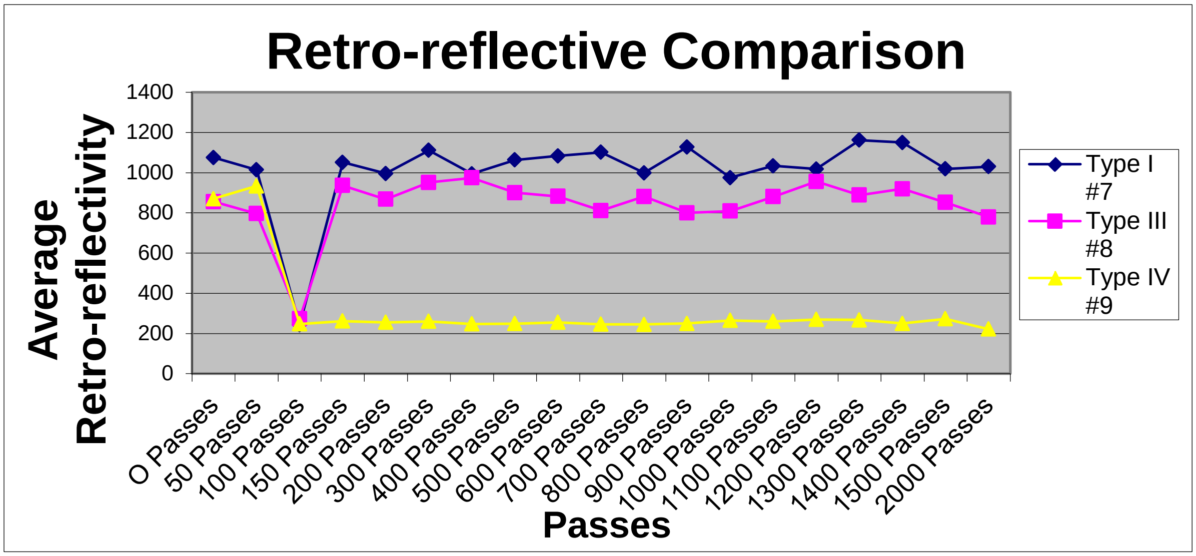


Figure A-14. Retro-Reflective Comparison –Franklin Paint– HVS Test Facility – Ambient Temperature – Old Hot-Mix Asphalt – New Formula

Manufacturer: Hi-Lite						
Location: HVS Test Facility						
Temperature: Heated						
Surface: New Hot-Mix Asphalt						
Passes:	Structured			Nonstructured		
	Type I #16	Type III #17	Type IV #18	Type I #19	Type III #20	Type IV #21
O Passes	234	810	328	164	741	351
50 Passes	292	1078	347	176	743	379
100 Passes	286	1104	356	178	750	377
150 Passes	286	1101	364	182	721	389
200 Passes	300	1074	359	187	742	396
300 Passes	295	1087	377	184	728	395
400 Passes	260	981	339	182	702	381
500 Passes	266	1011	363	195	583	190
600 Passes	276	1019	350	196	729	395
700 Passes	272	979	364	197	754	398
800 Passes	251	937	313	200	729	381
900 Passes	196	493	319	192	884	446
1000 Passes	258	887	316	230	889	459
1100 Passes	265	895	347	244	835	459
1200 Passes	258	878	330	236	858	442
1300 Passes	255	892	338	238	874	432
1400 Passes	262	868	340	230	873	421
1500 Passes	263	895	354	239	794	451
2000 Passes	264	868	349	220	857	455

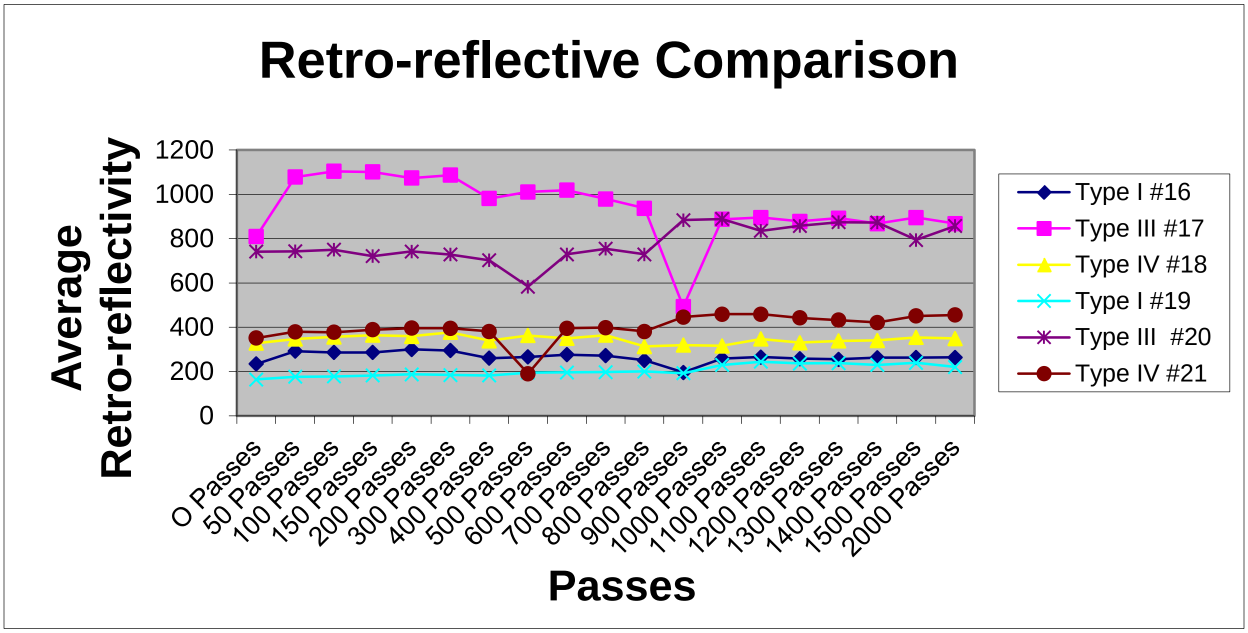


Figure A-15. Retro-Reflective Comparison –Hi-Lite – HVS Test Facility – Heated Temperature – Old Hot-Mix Asphalt – Standard Formula

Manufacturer: Ennis/Flint						
Location: HVS Test Facility						
Temperature: Heated						
Surface: New Hot-Mix Asphalt						
Passes:	Structured			Nonstructured		
	Type I #10	Type III #11	Type IV #12	Type I #13	Type III #14	Type IV #15
O Passes	226	608	384	428	1657	497
50 Passes	239	702	459	387	1720	501
100 Passes	239	694	474	404	1767	554
150 Passes	238	698	487	412	1699	536
200 Passes	239	720	477	357	1624	537
300 Passes	237	720	464	438	1597	518
400 Passes	223	672	464	415	1832	515
500 Passes	230	727	469	420	1783	531
600 Passes	233	708	486	411	1715	512
700 Passes	228	722	486	384	1582	540
800 Passes	228	701	479	417	1682	544
900 Passes	200	390	203	384	1745	512
1000 Passes	277	839	517	417	1789	553
1100 Passes	277	806	534	431	1739	529
1200 Passes	257	754	486	429	1621	541
1300 Passes	261	764	527	442	1863	528
1400 Passes	272	799	534	403	1558	549
1500 Passes	276	776	525	438	1791	536
2000 Passes	282	741	576	434	1754	587

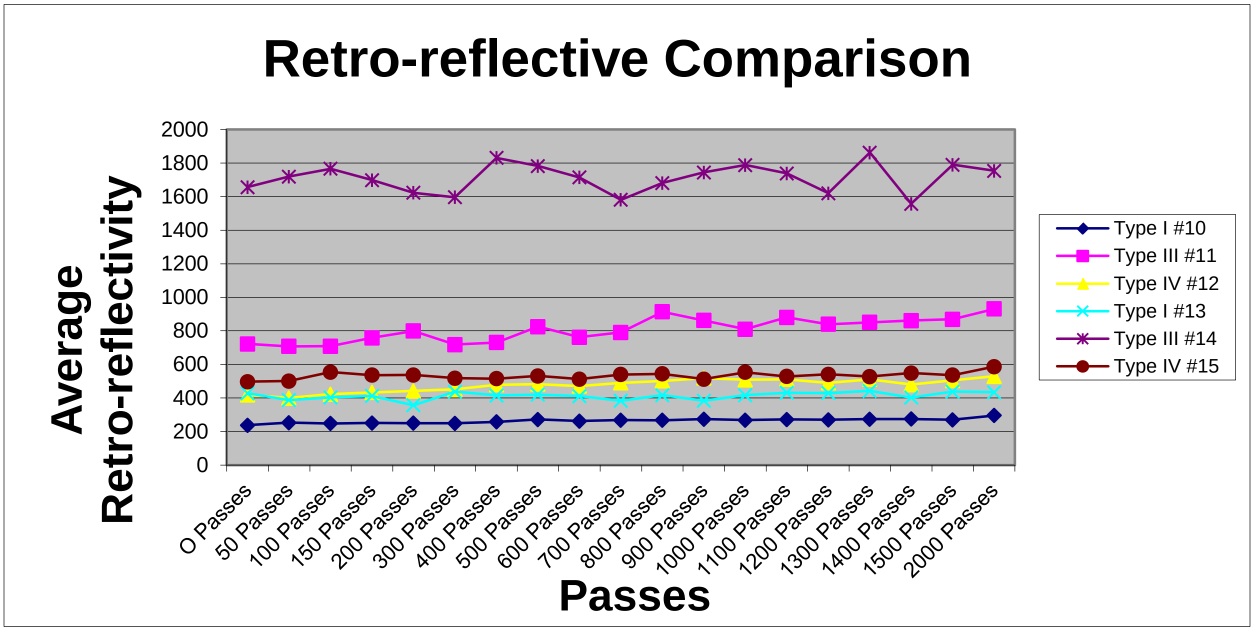


Figure A-16. Retro-Reflective Comparison –Ennis/Flint – HVS Test Facility – Heated Temperature – Old Hot-Mix Asphalt – Standard Formula

Manufacturer: Franklin Paint						
Location: HVS Test Facility						
Temperature: Heated						
Surface: New Hot-Mix Asphalt						
Passes:	**Structured**			**Nonstructured**		
	Type I #7	**Type III #8**	**Type IV #9**	**Type I n/a**	**Type III n/a**	**Type IV n/a**
O Passes	655	683	740	-	-	-
50 Passes	705	757	162	-	-	-
100 Passes	719	774	157	-	-	-
150 Passes	684	717	155	-	-	-
200 Passes	689	749	150	-	-	-
300 Passes	698	755	158	-	-	-
400 Passes	632	716	144	-	-	-
500 Passes	623	739	152	-	-	-
600 Passes	662	725	150	-	-	-
700 Passes	663	729	145	-	-	-
800 Passes	644	648	146	-	-	-
900 Passes	751	768	159	-	-	-
1000 Passes	831	810	149	-	-	-
1100 Passes	841	790	170	-	-	-
1200 Passes	710	746	135	-	-	-
1300 Passes	737	773	143	-	-	-
1400 Passes	712	770	147	-	-	-
1500 Passes	648	791	143	-	-	-
2000 Passes	883	728	136	-	-	-

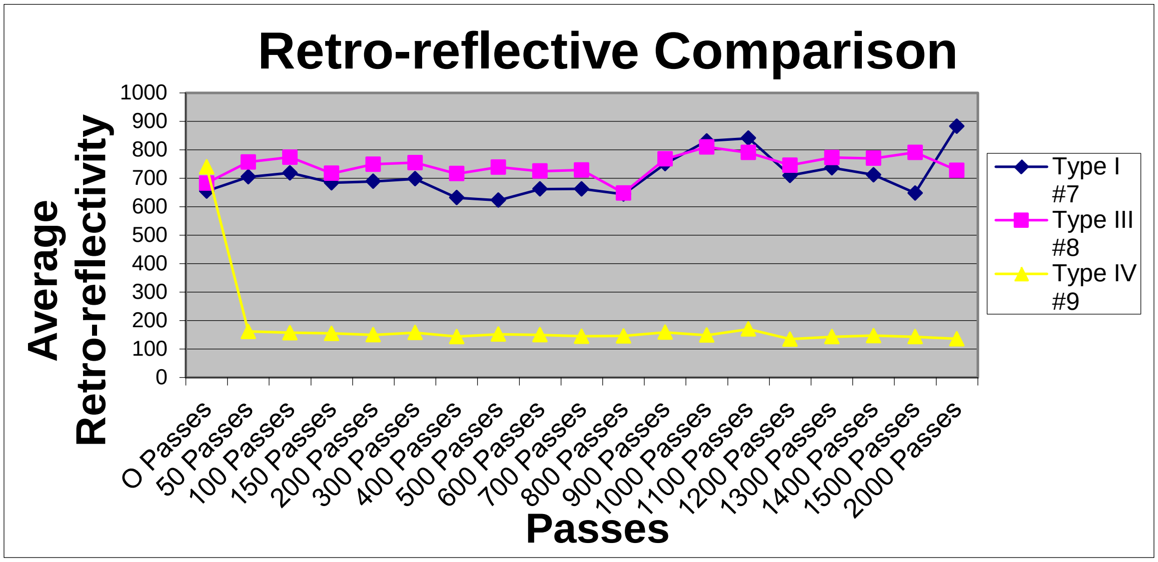


Figure A-17. Retro-Reflective Comparison –Franklin Paint – HVS Test Facility – Heated Temperature – Old Hot-Mix Asphalt – New Formula

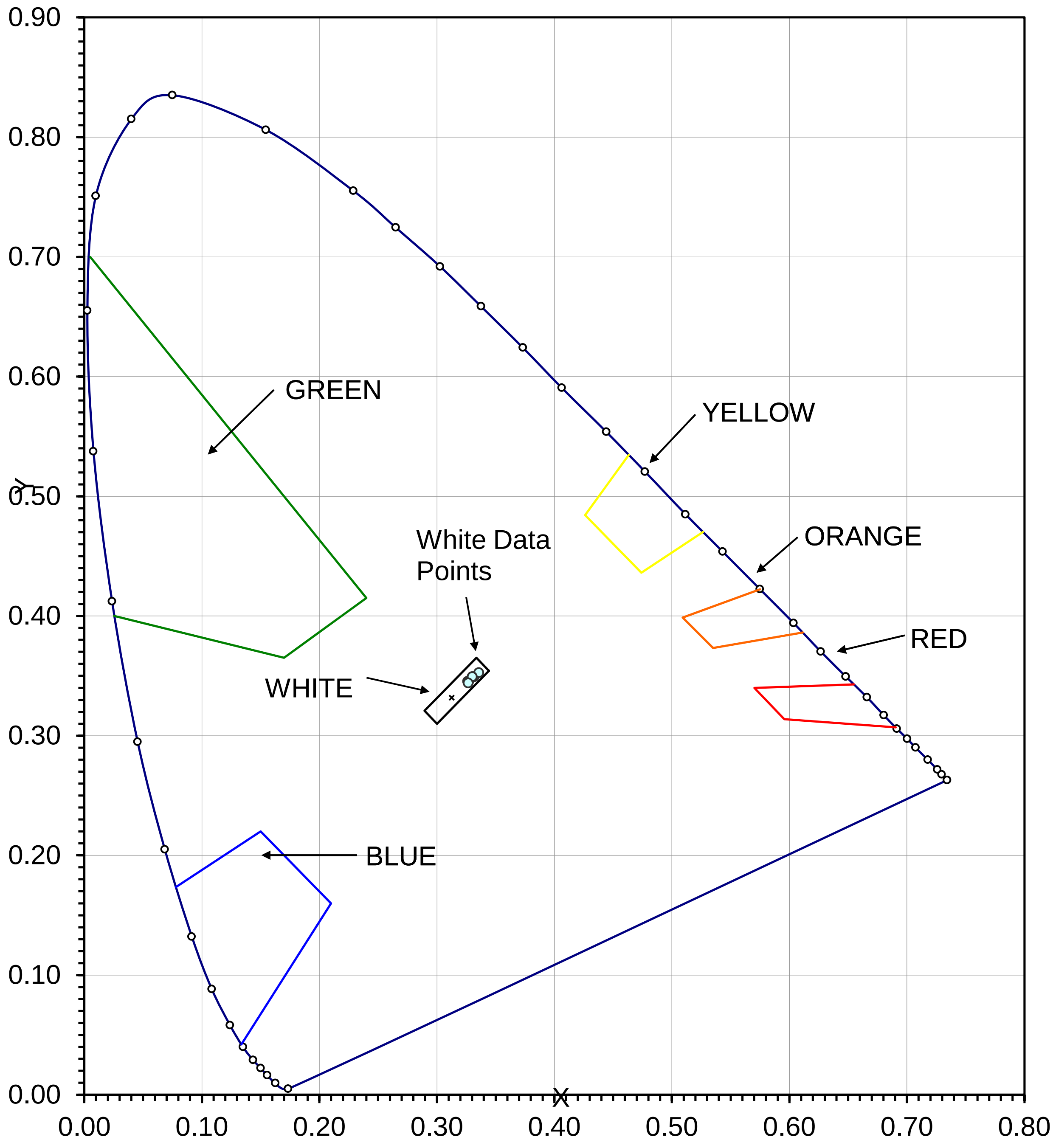


Figure A-18. Color-Guide Readings –Hi-Lite – FAA Ramp – Old PCC – Standard MMA – Standard Formula – Lines 13-16

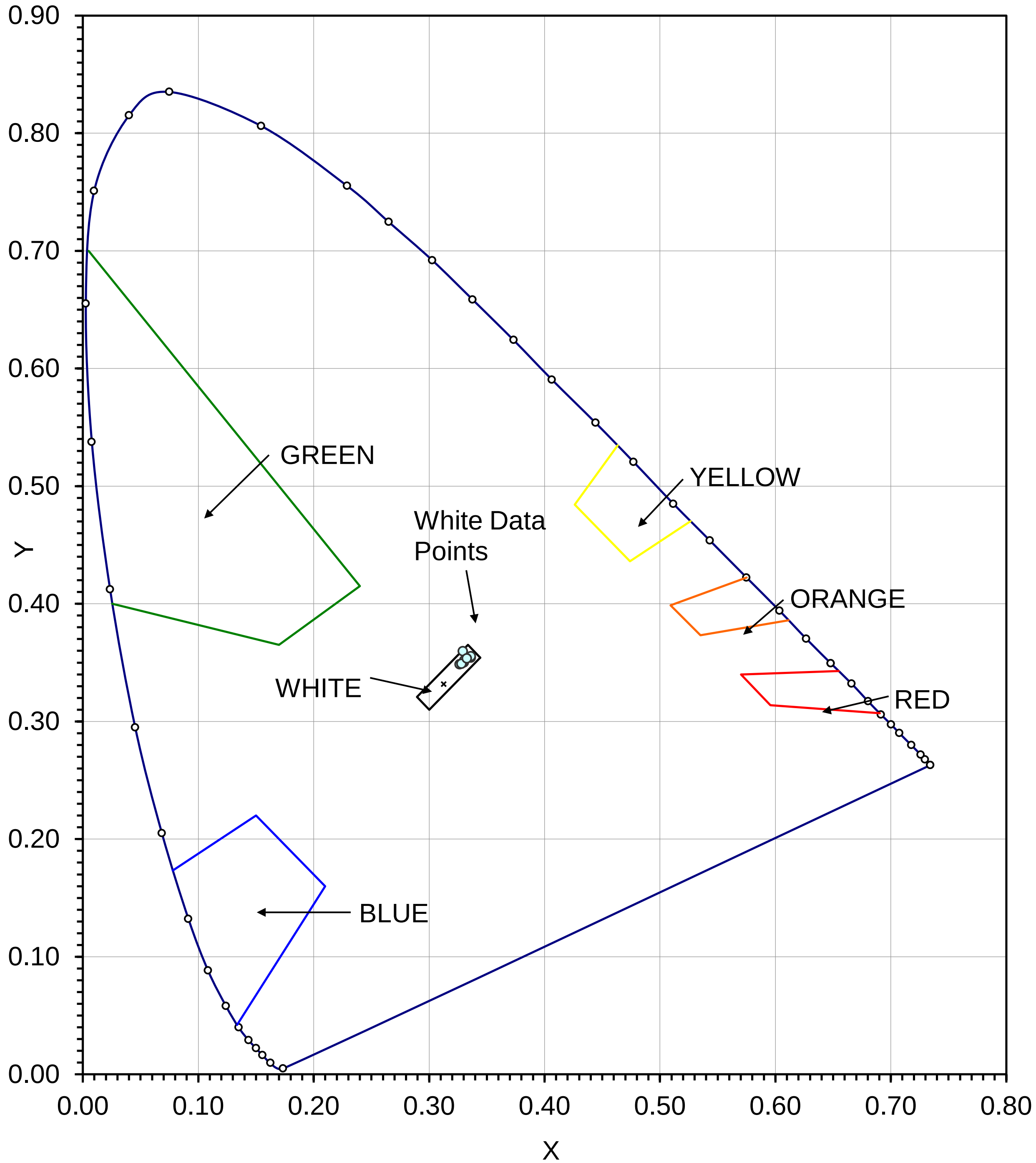


Figure A-19. Color-Guide Readings –Hi-Lite - FAA Ramp – Old PCC – Structured MMA – Standard Formula – Lines 17-20

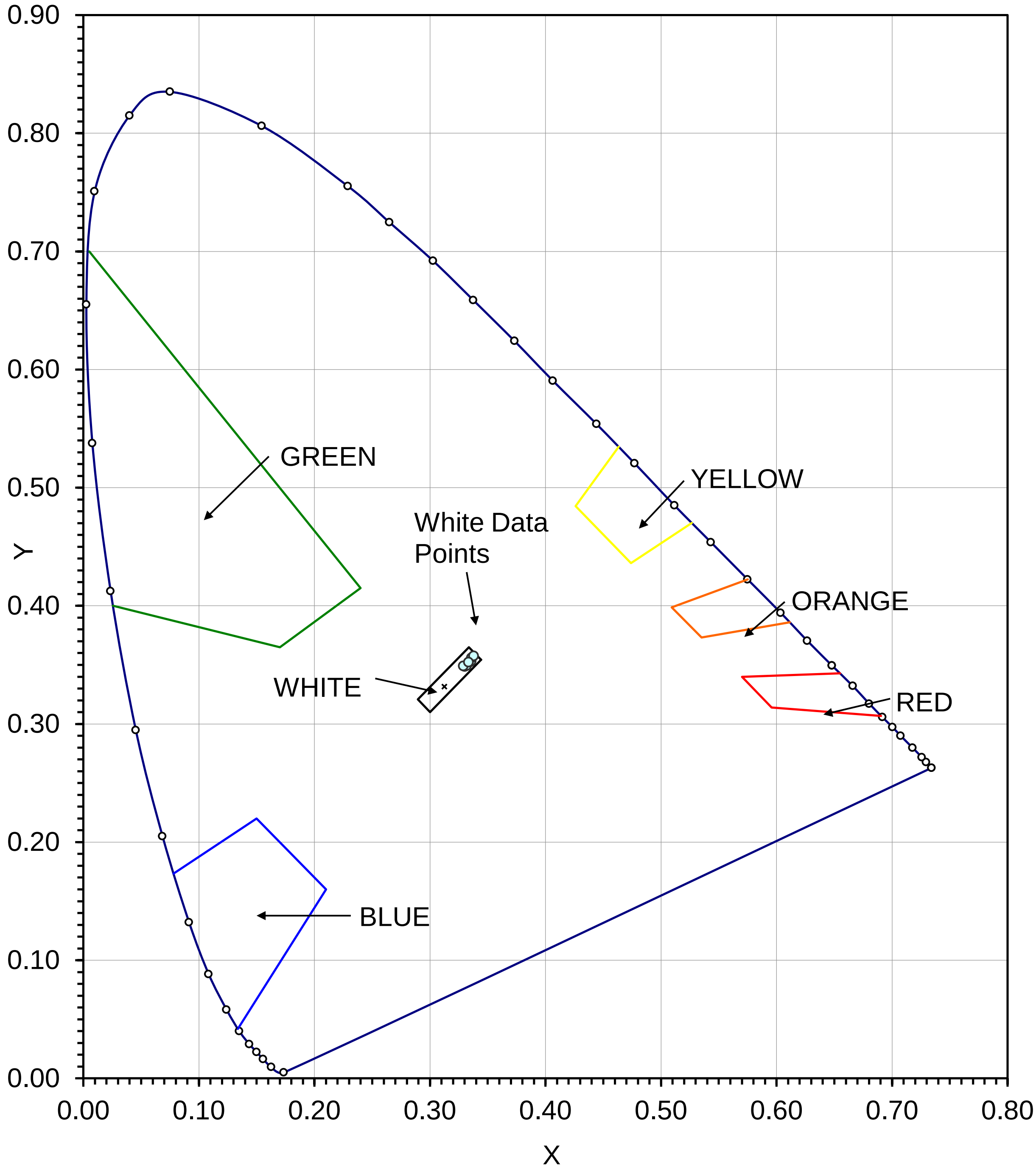


Figure A-20. Color-Guide Readings –Ennis/Flint – FAA Ramp – Old PCC – Standard MMA – Standard Formula – Lines 21-24

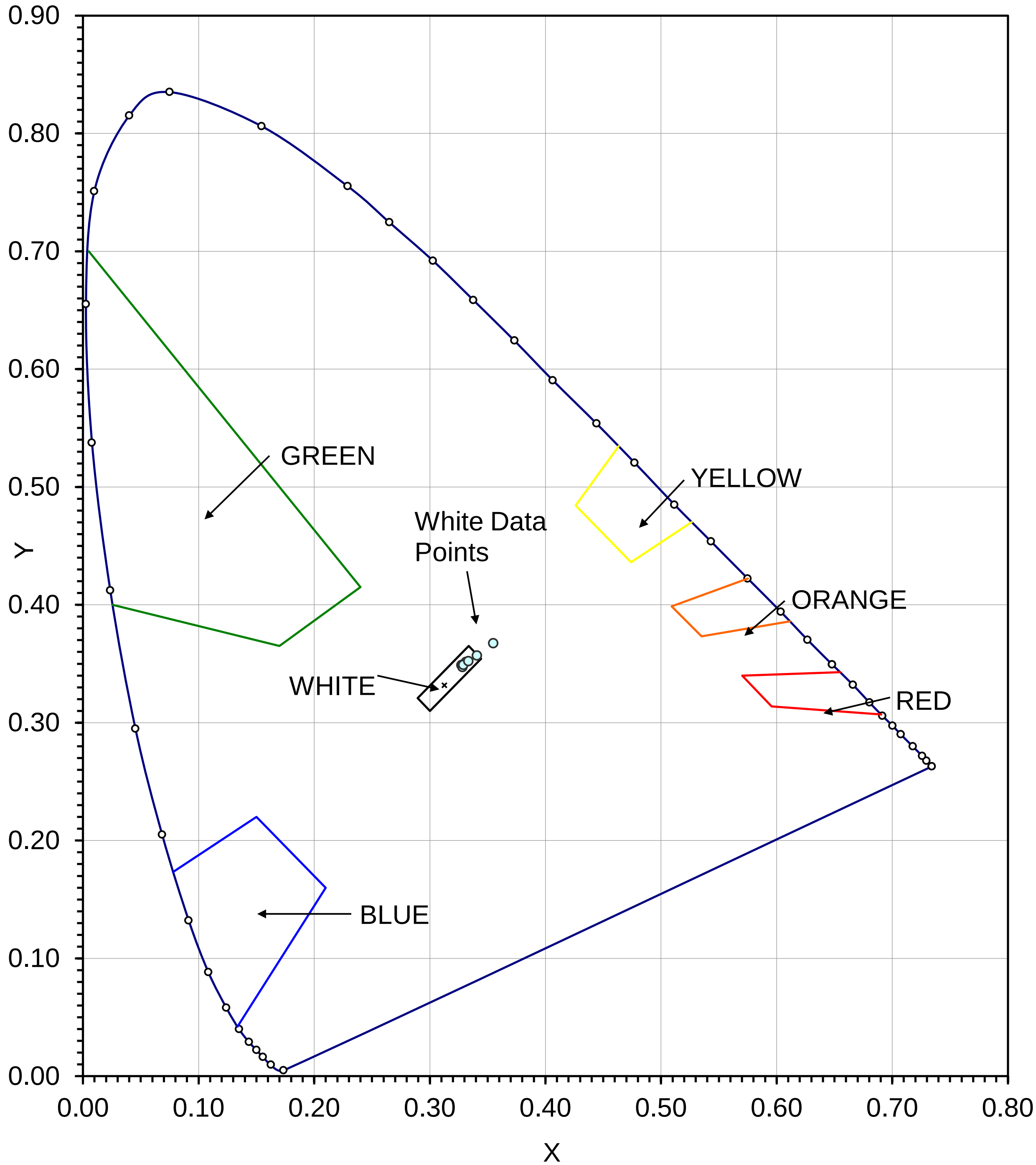


Figure A-21. Color-Guide Readings –Ennis/Flint – FAA Ramp – Old PCC – Structured MMA – Standard Formula – Lines 25-28

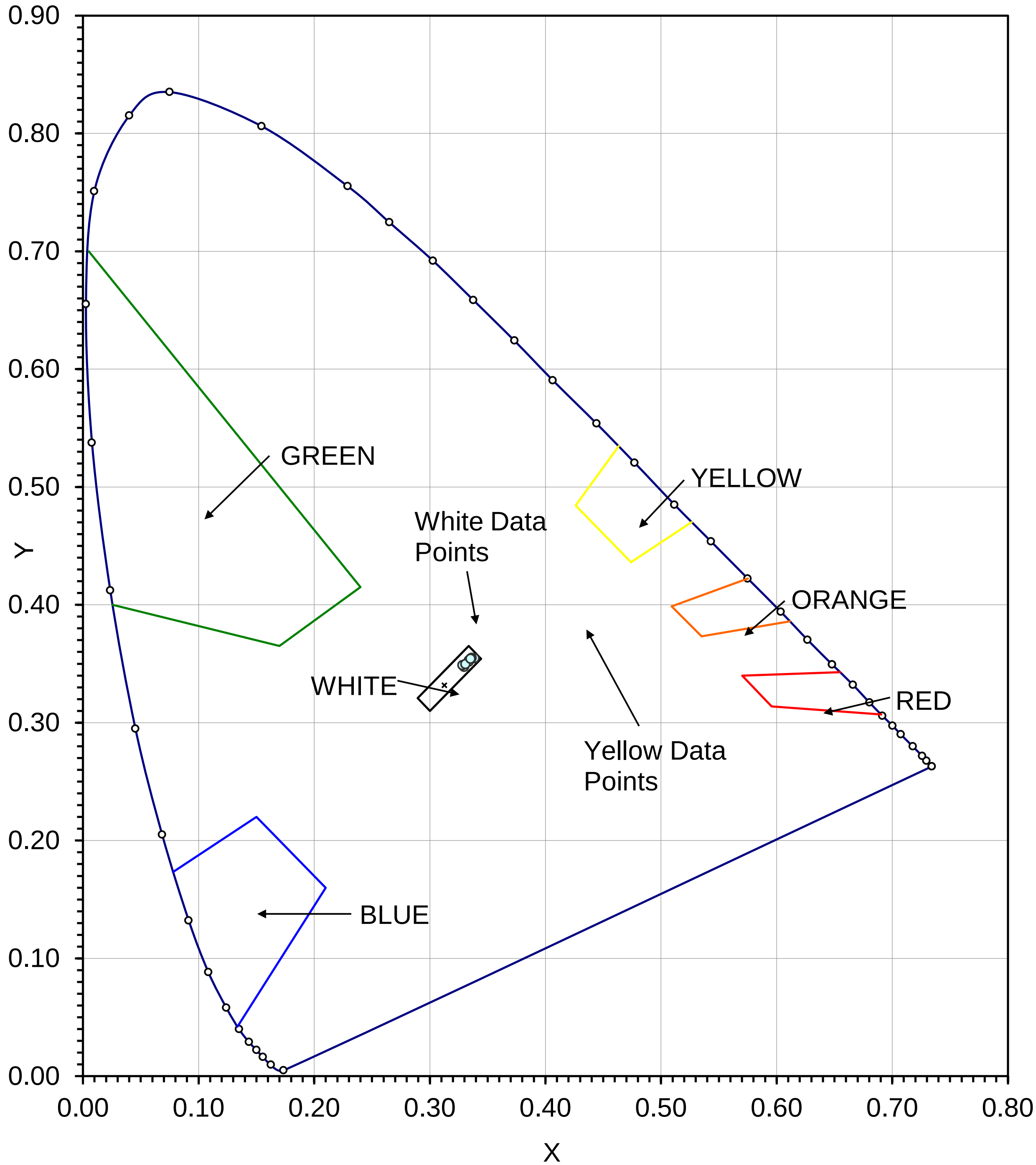


Figure A-22. Color-Guide Readings –Franklin Paint – FAA Ramp – Old PCC – Structured MMA – New Formula – Lines 9-12

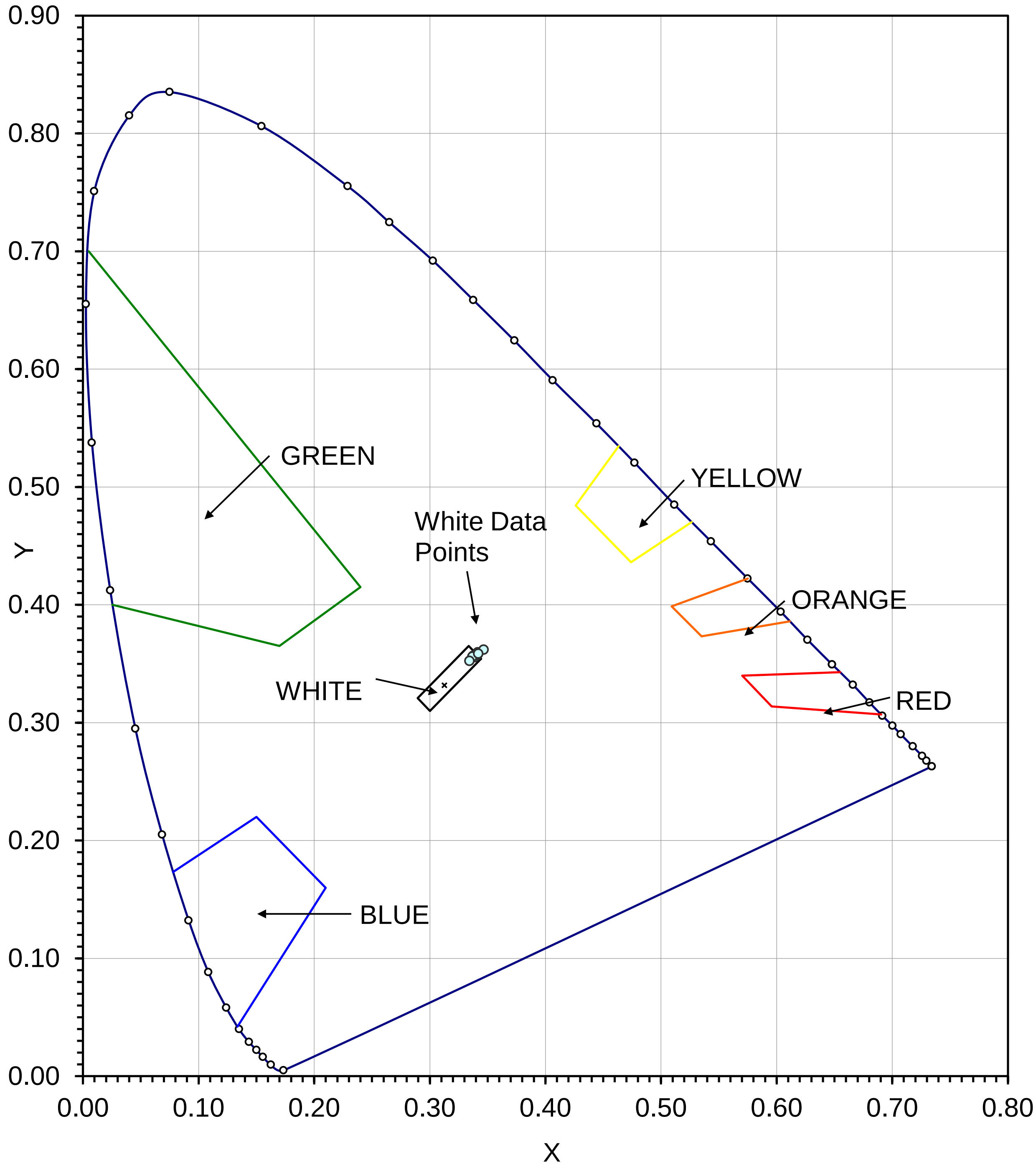


Figure A-23. Color-Guide Readings –Hi-Lite – Pangborn Road – Old Hot-Mix Asphalt – Standard MMA – Standard Formula – Lines 13-16

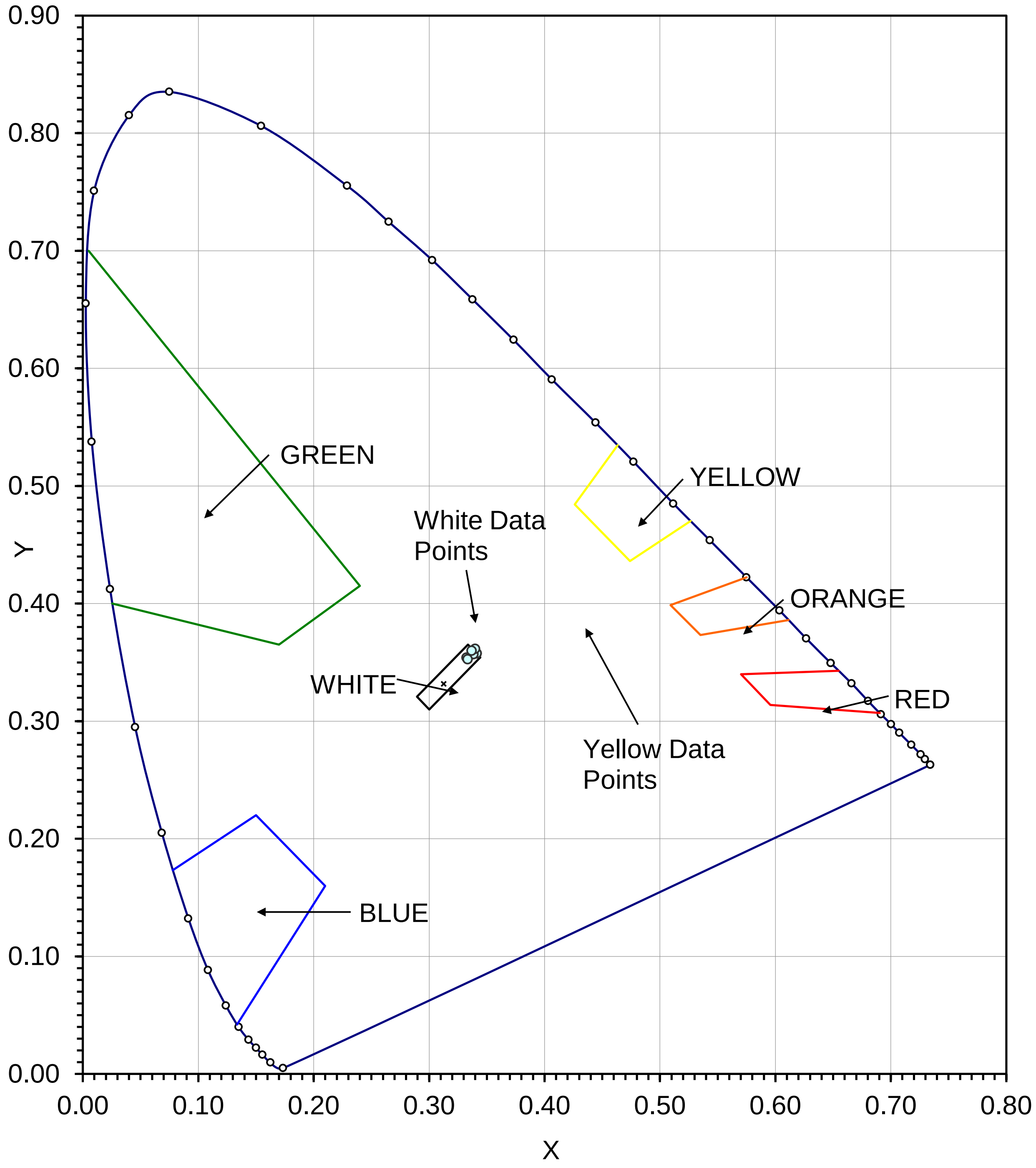


Figure A-24. Color-Guide Readings –Hi-Lite – Pangborn Road – Old Hot-Mix Asphalt – Structured MMA – Standard Formula – Lines 17-20

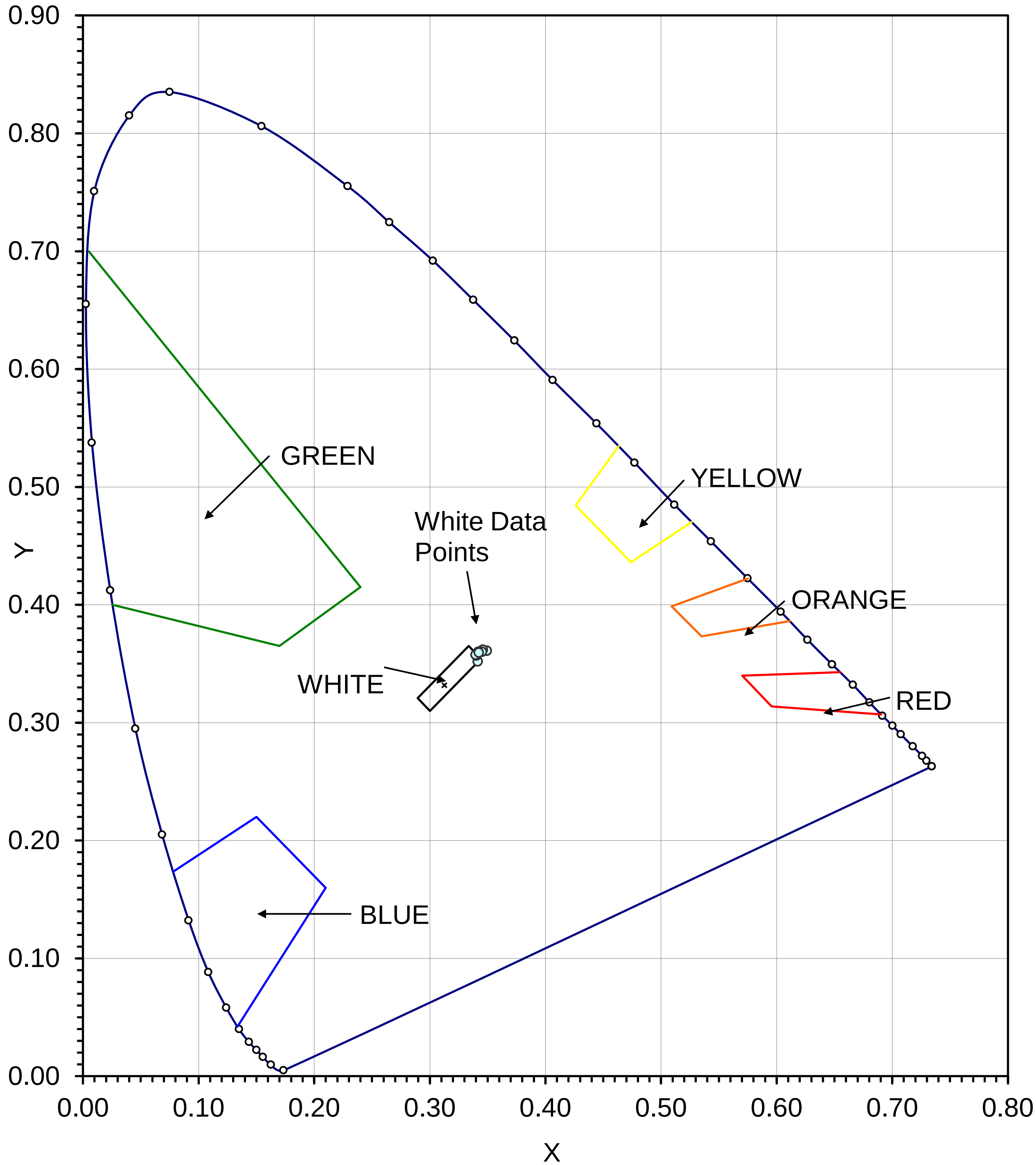


Figure A-25. Color-Guide Readings –Ennis/Flint – Pangborn Road – Old Hot-Mix Asphalt – Standard MMA – Standard Formula – Lines 21-24

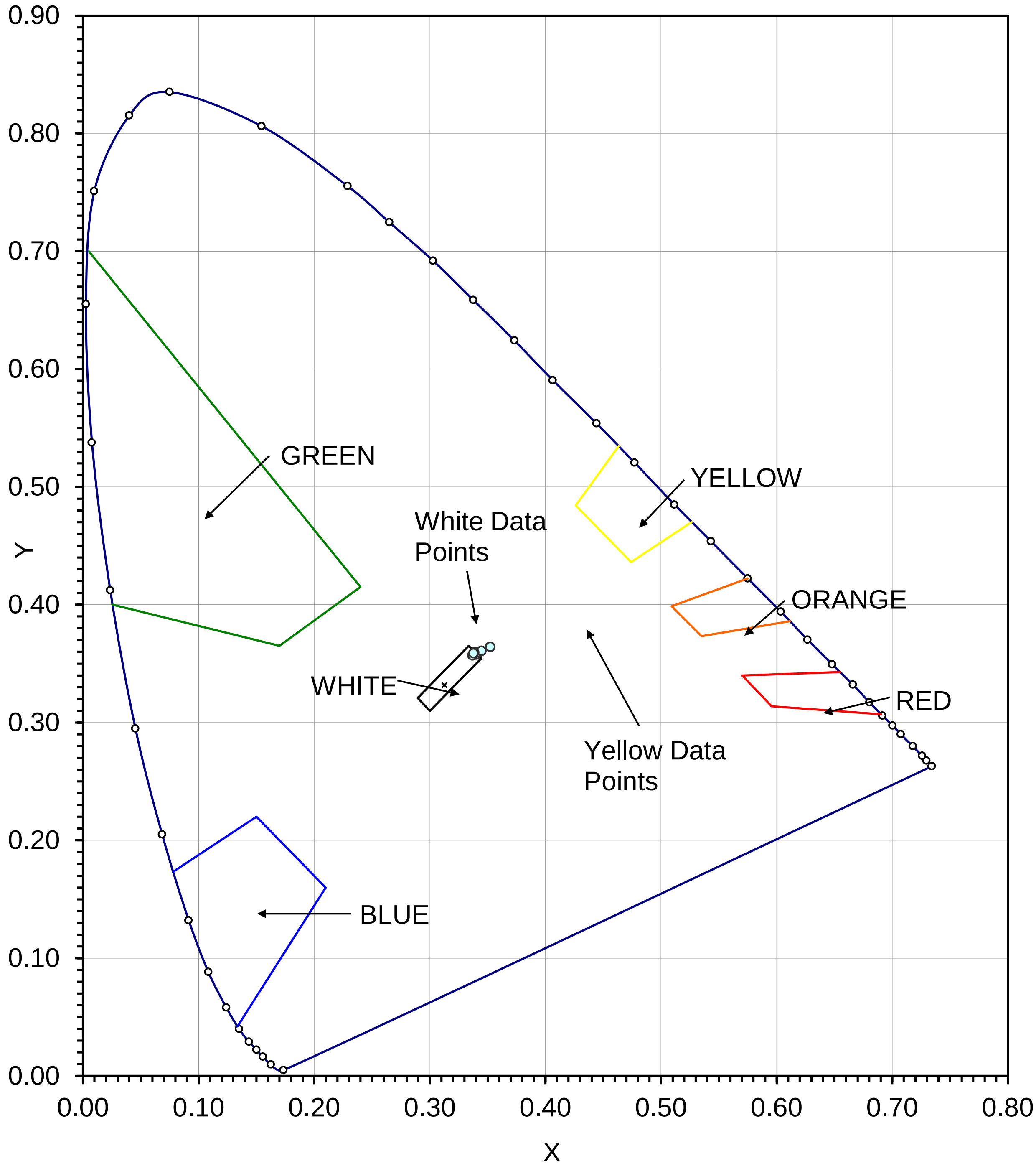


Figure A-26. Color-Guide Readings –Ennis/Flint – Pangborn Road – Old Hot-Mix Asphalt – Structured MMA – Standard Formula – Lines 25-28

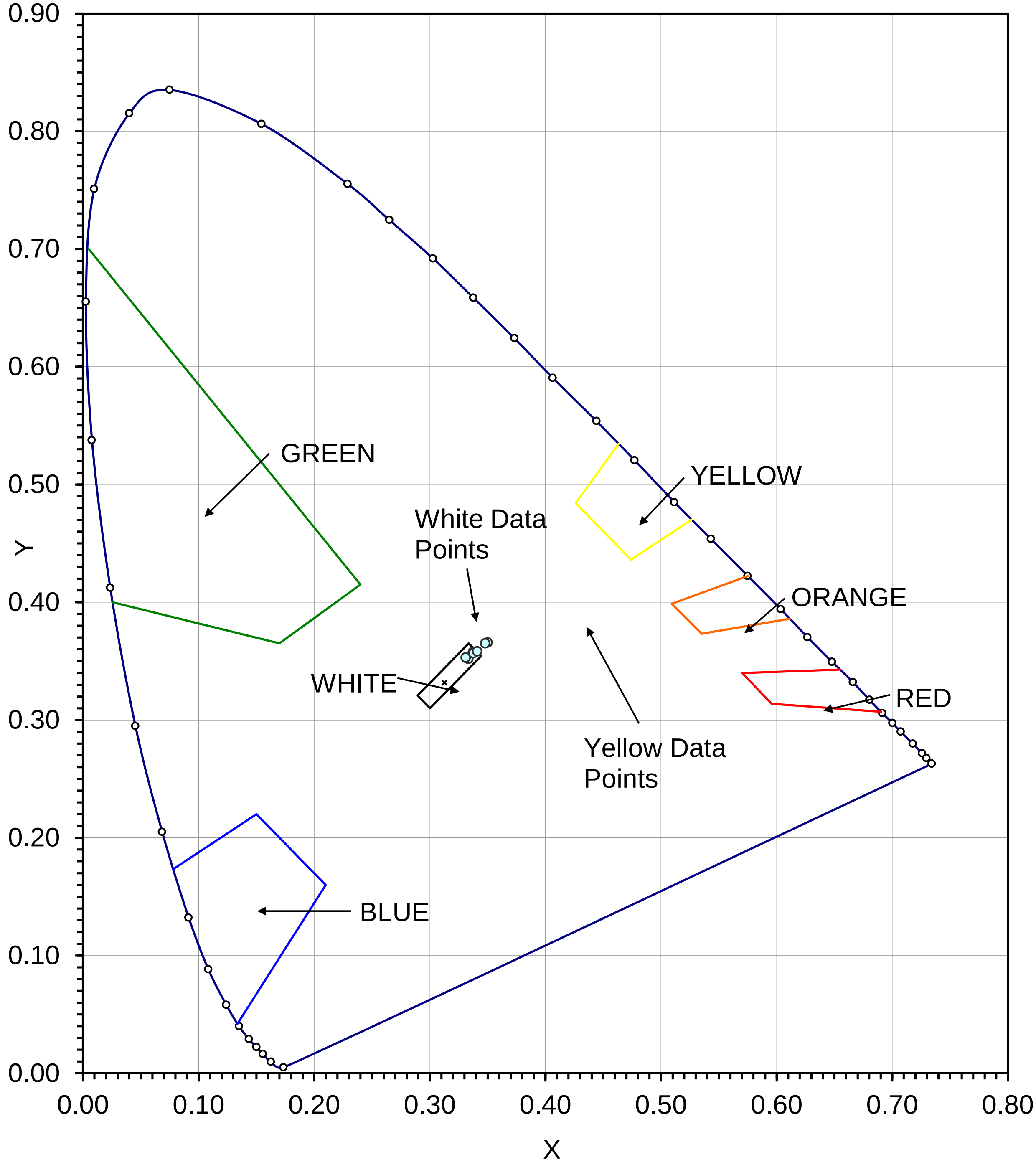


Figure A-27. Color-Guide Readings –Franklin Paint – Pangborn Road – Old Hot-Mix Asphalt – Structured MMA – New Formula – Lines 9-12

Table A-4. Pull-Off Strength Test Data for the FAA Ramp (Concrete)

Location	Manufacturer	Bead Type	Paint Type	Test Stripe No.	Paint Thickness (mil)	Strength Result (N/mm^2-mm-0.50 mm)
FAA Ramp (Old PCC Surface)	Hi-Lite	I	Standard MMA, Standard Formula	13	15	5.67
		III		14	15	4.39
		IV		15	25	3.11
		I	Structured MMA, Standard Formula	17	60-90	0.73
		III		18	60-90	0.92
		IV		19	60-90	1.81
	Ennis/Flint	I	Standard MMA, Standard Formula	21	15	3.67
		III		22	15	5.29
		IV		23	25	5.04
		I	Structured MMA, Standard Formula	25	60-90	1.92
		III		26	60-90	2.21
		IV		27	60-90	3.68
	Franklin Paint	I	Structured MMA, New Formula	9	60-90	1.83
		III		10	60-90	0.97
		IV		11	60-90	1.55

Table A-5. Pull-Off Strength Test Data for the Pangborn Road (Asphalt)

Location	Manufacturer	Bead Type	Paint Type	Test Stripe No.	Paint Thickness (mil)	Strength Result (N/mm^2-mm-0.50 mm)
Pangborn Road	Hi-Lite	I	Standard MMA, Standard Formula	13	15	0.57
(Old Hot-Mix		III		14	15	0.55
Asphalt Surface)		IV		15	25	0.77
		I	Structured MMA, Standard Formula	17	60-90	1.36
		III		18	60-90	0.90
		IV		19	60-90	0.74
	Ennis/Flint	I	Standard MMA, Standard Formula	21	15	0.69
		III		22	15	0.45
		IV		23	25	0.78
		I	Structured MMA, Standard Formula	25	60-90	0.51
		III		26	60-90	0.63
		IV		27	60-90	0.48
	Franklin Paint	I	Structured MMA, New Formula	9	60-90	0.66
		III		10	60-90	0.43
		IV		11	60-90	0.55

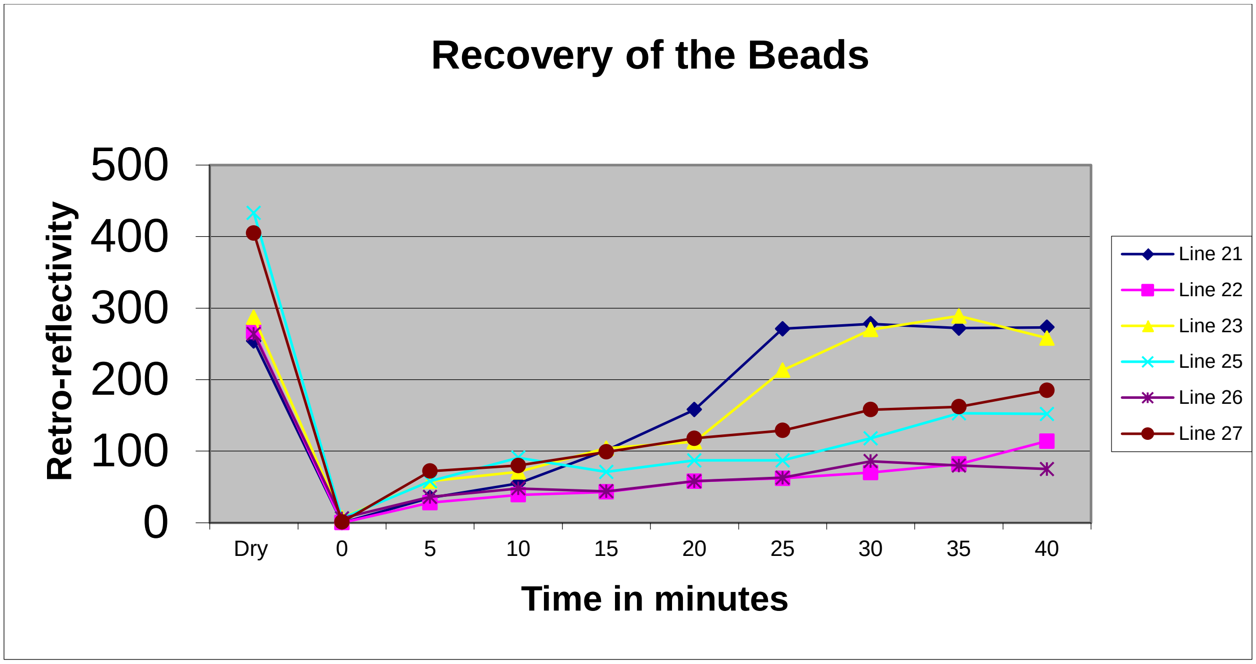


Figure A-30. The ASTM-E-2177-01 Water Test Results –Hi-Lite – Pangborn Road – Old Hot-Mix Asphalt – Standard MMA (Lines 21-23) and Structured MMA (Lines 25-27)

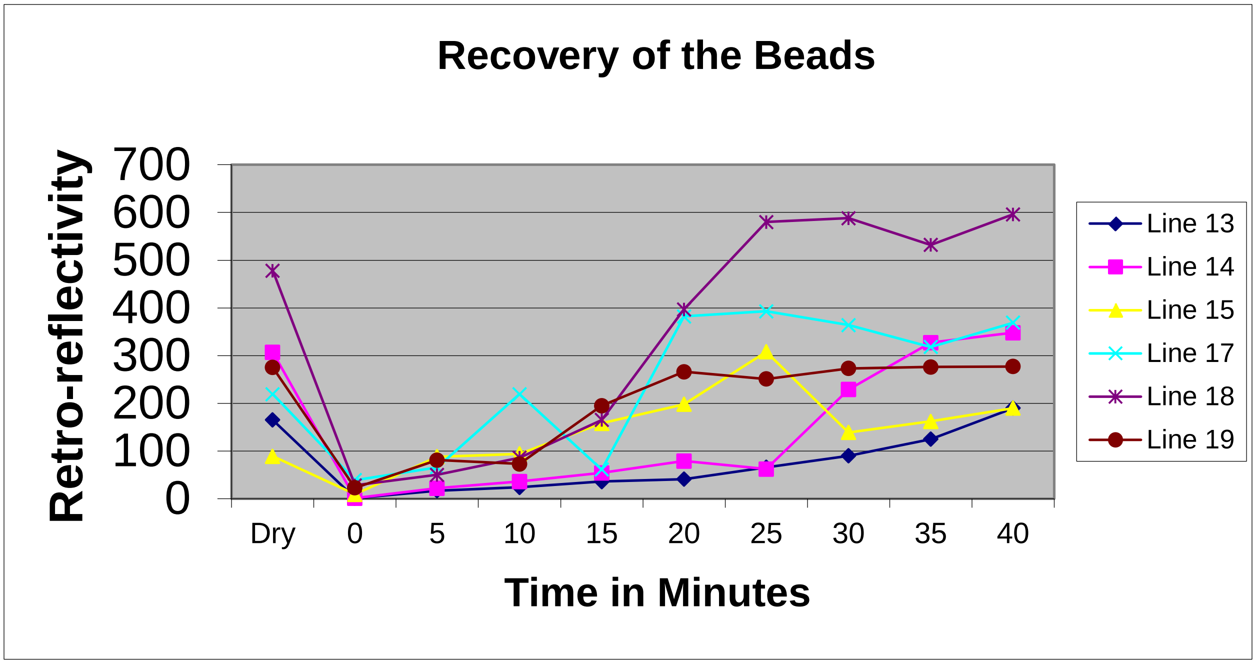


Figure A-31. The ASTM-E-2177-01 Water Test Results – Ennis/Flint – Pangborn Road – Old Hot-Mix Asphalt – Standard MMA (Lines 13-15) and Structured MMA (Lines 17-19)

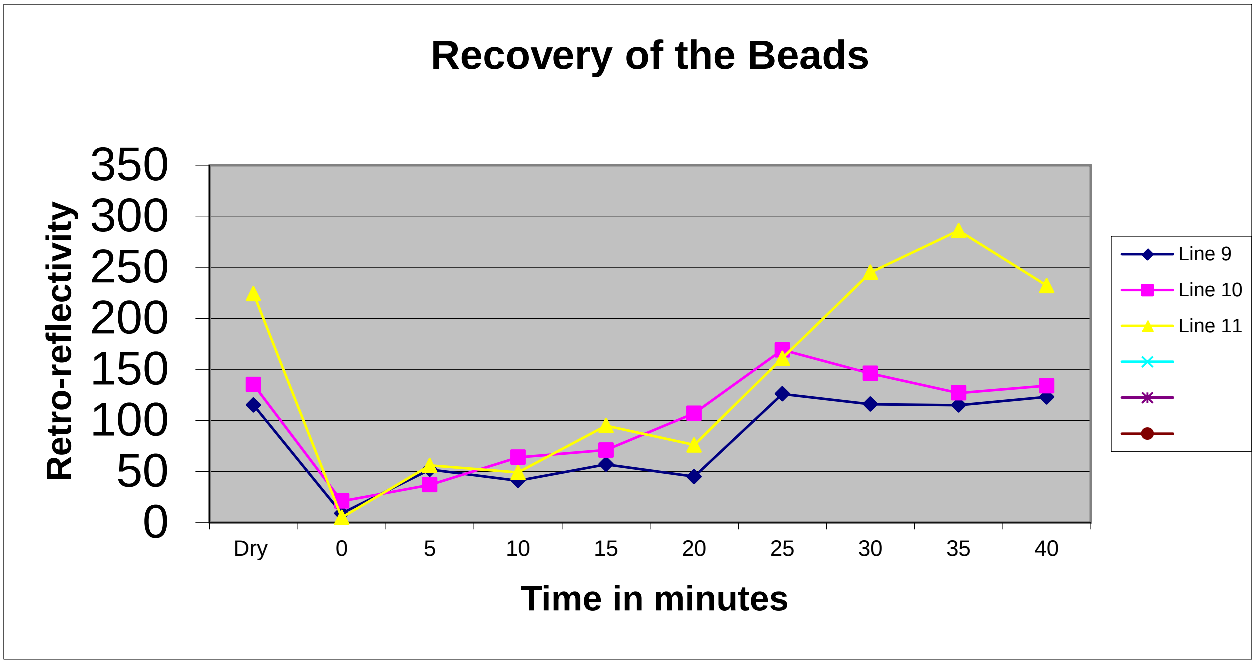


Figure A-32. The ASTM-E-2177-01 Water Test Results –Franklin Paint – Pangborn Road – Old Hot-Mix Asphalt – Structured MMA (Lines 9-11)

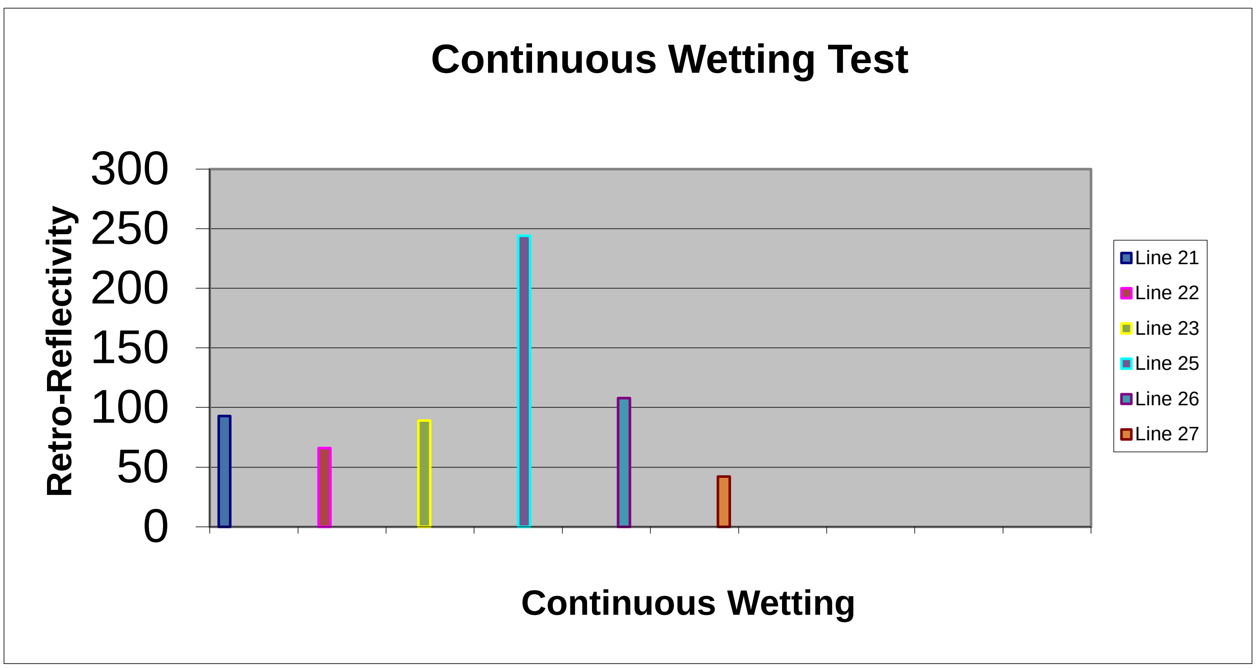


Figure A-33. The ASTM-E-2176-01 Continuous Wetting Test Results –Hi-Lite – Pangborn Road – Old Hot-Mix Asphalt – Standard MMA (Lines 21-23) and Structured MMA (Lines 25-27)

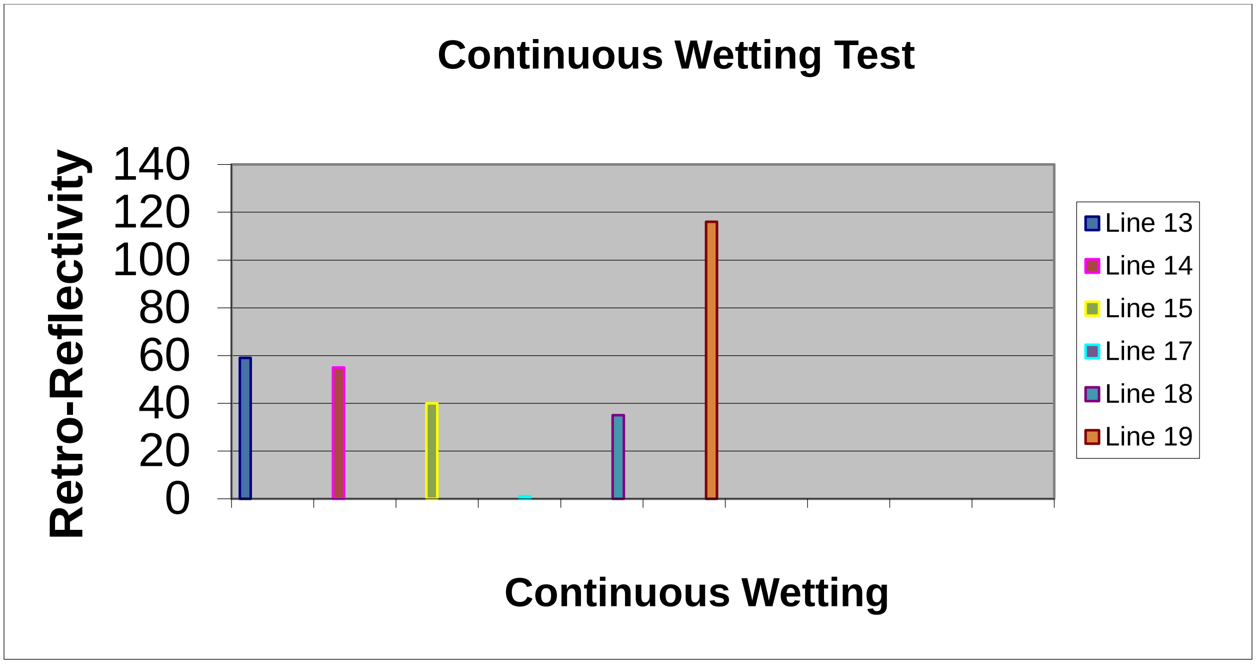


Figure A-34. The ASTM-E-2176-01 Continuous Wetting Test Results –Ennis/Flint – Pangborn Road – Old Hot-Mix Asphalt – Standard MMA (Lines 13-15) and Structured MMA (Lines 17-19)

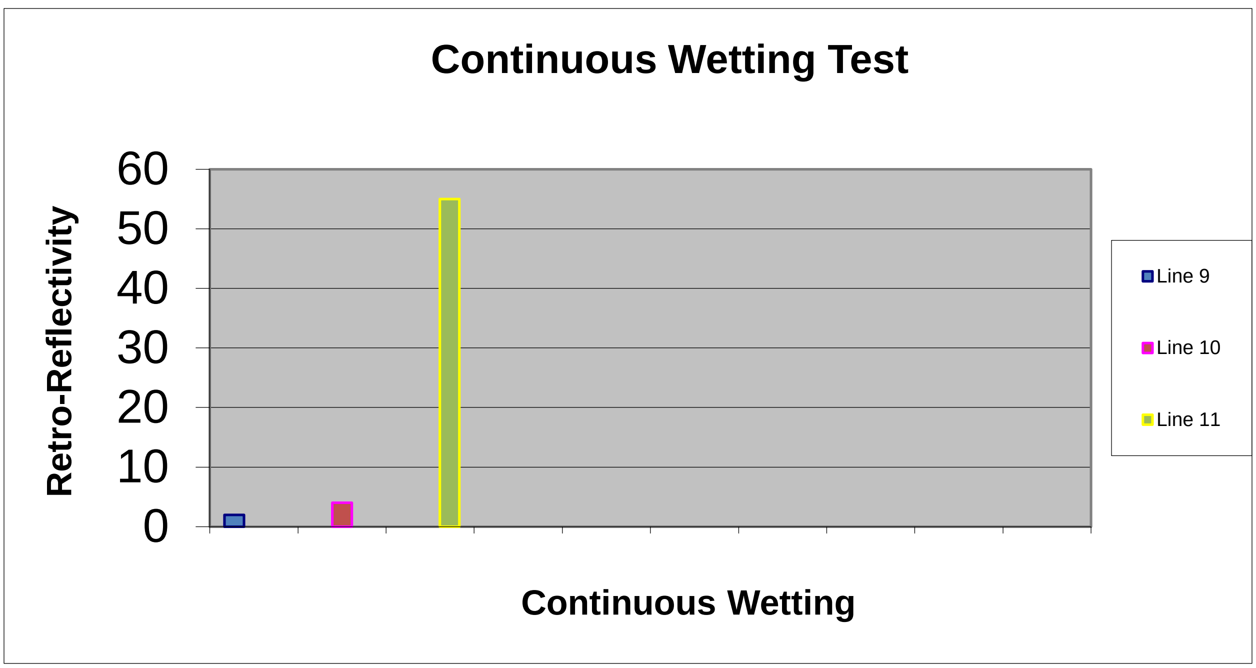


Figure A-35. The ASTM-E-2176-01 Continuous Wetting Test Results – Franklin Paint – Pangborn Road – Old Hot-Mix Asphalt – Structured MMA (Lines 9-11)

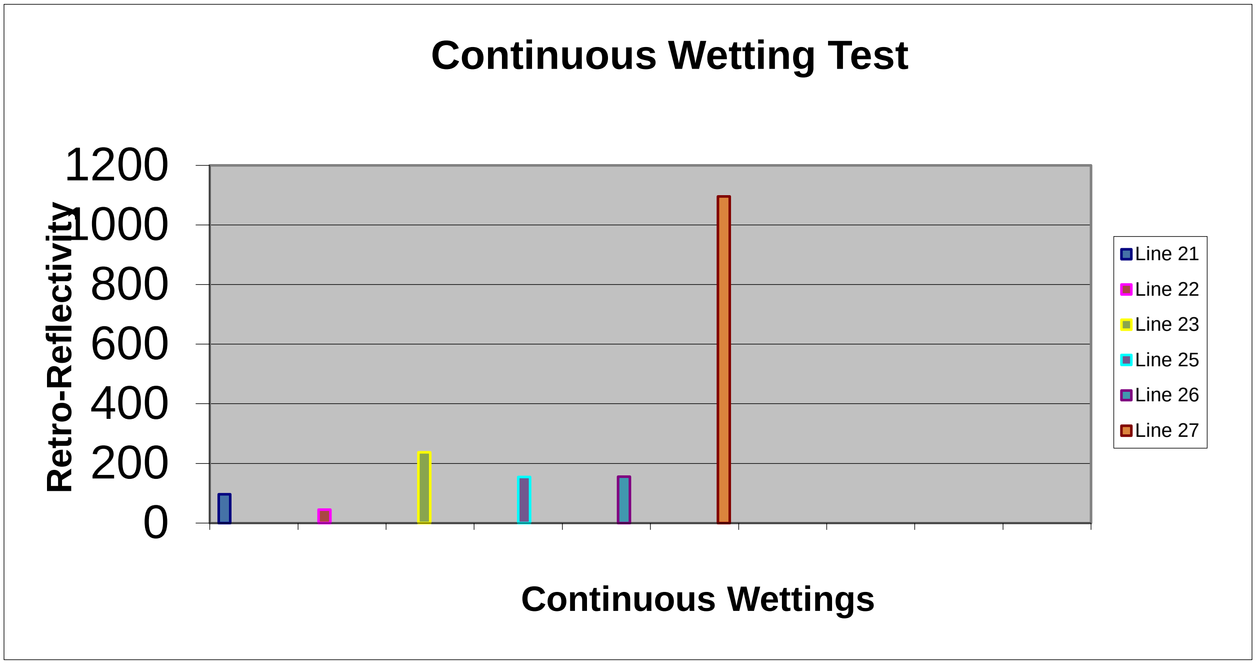


Figure A-36. The ASTM-E-2176-01 Continuous Wetting Test Results –Hi-Lite – FAA Ramp – PCC – Standard MMA (Lines 21-23) and Structured MMA (Lines 25-27)

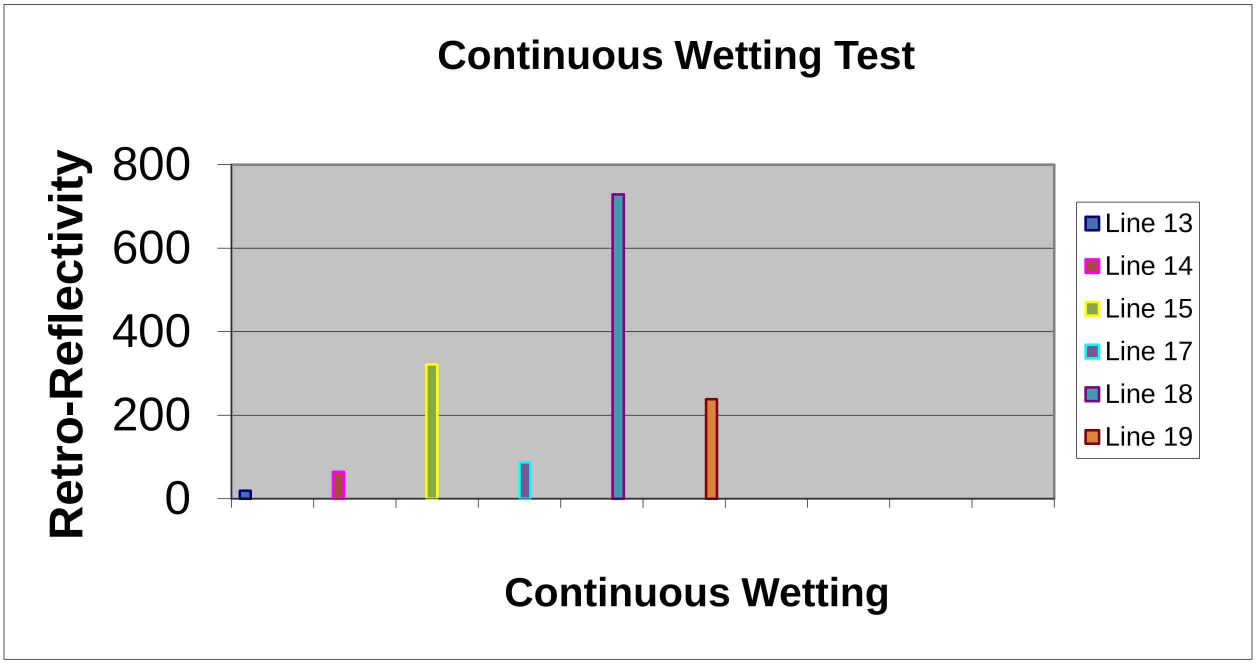


Figure A-37. The ASTM-E-2176-01 Continuous Wetting Test Results –Ennis/Flint – FAA Ramp –PCC – Standard MMA (Lines 13-15) and Structured MMA (Lines 17-19)

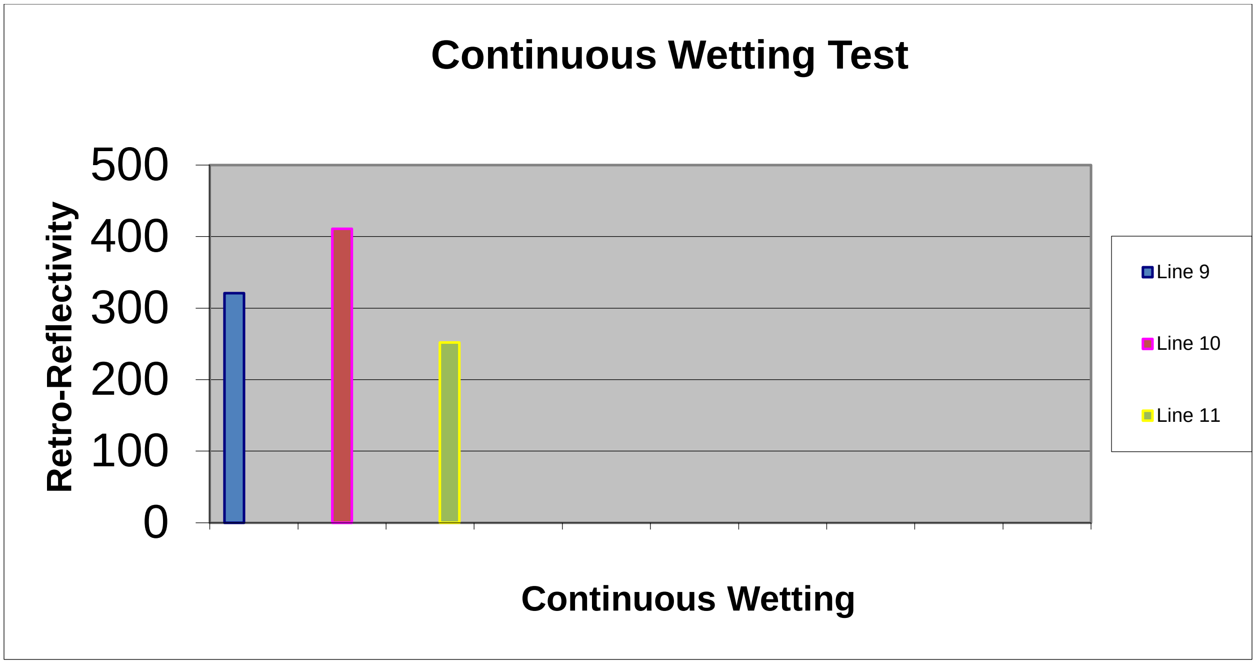


Figure A-38. The ASTM-E-2176-01 Continuous Wetting Test Results – Franklin Paint – Pangborn Road – Asphalt – SMMA (Lines 9-11)