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PAVEMENT MARKING COMPARISON STUDY – I-89 LIQUID MARKINGS

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16. Abstract

Pavement markings provide an important means of communication for all roadway users and must be capable of conveying information during inclement weather and evening hours when there may be little to no contribution from overhead lighting. The following report outlines the observations relating to five different liquid binder packages, two optic categories and two applications. In addition, the report contains information pertaining to field data collection to assess the comparison of reflective properties and binder presence over time.

The Pavement Marking Comparison Study extends from mile marker 52.49 in Montpelier to mile marker 36.93 in Brookfield on Interstate 89. There are 36 test sites, each of which are 400 feet in length. Test sites were specifically chosen in different binder and optics package sections to demonstrate the effectiveness of the binder and optics mixes. Prior to the applications of the markings, sections of the test deck were recessed. The recessed depths were recorded throughout the project. In addition, each test site contains retroreflectivity readings and visibility wear comparisons from both white edge line and yellow edge line markings in 20 feet intervals within each test site using standard methods. Retroreflectivity readings were taken with a RoadVista Stripemaster 2 Touch. Readings were collected on Day 1 (August 2014) then once every week for the first month. After the first month of weekly readings, monthly readings were taken. After 6 months, readings were taken seasonally, and then again after a period of two years. In the December 2014 site visit (after the first snow event), there was significant loss of binder and optics in the thermoplastic test sections. During the same visit, waterborne pavement markings had significant loss of binder and optics.

Recessing the pavement markings provides a noticeable improvement over surface applied markings. The two best performing markings were Polyurea and Epoxy, in that order. Wet Reflective elements provided similar dry retroreflectivity compared to the Utah Blend, except that higher initial values often reduced quickly.

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Recessing the pavement markings provides a noticeable improvement over surface applied markings. The two best performing markings were Polyurea and Epoxy, in that order. Wet Reflective elements provided generally higher retroreflectivity values than the Utah Blend, though some cases had similar or even lower retroreflectivity values than the Utah blend.

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1 Introduction

Pavement markings are a critical safety feature for local roads and interstates, as they provide a visual reference for proper vehicle position within the roadway. They may also be used to enhance other traffic control devices. In order to maintain safety, these markings should be visible to the driver at all times under varying driving conditions. Three principle factors affect recognition of the marking: contrast, color and luminance. Perhaps the most critical factor that can affect visual performance, or how well a target can be seen by the eye, is the luminance of an object as compared to the luminance of the background. The greater the contrast between the two objects, the easier an object is to identify. This is especially important for nighttime visibility as there is typically little to no ambient lighting reducing the overall contrast between pavement markings and the road surface. In order to ensure adequate visibility at night, reflective optics are applied to the pavement markings. However, the reflective properties as well as the pavement marking materials decay over time requiring periodic reapplication.

To increase the longevity of durable markings, the Agency has been recessing markings over the past decade. Although it is VTrans' standard practice to recess Polyurea paint along all conventional interstate rehabilitation projects, the Agency over the past couple of years has begun to recess markings on other roadway types in the state. The process of recessing includes the removal of a small portion of the surface of the wearing course by grinding prior to the application of permanent markings. Recessing has proved effective in extending the service life of our pavement markings by protecting them from wear induced by tire abrasion and shearing and wear effects generated by snow plows. However, there have been some concerns during rain events as water ponds over the marking materials causing a change in the indices of refraction between the optical elements and surrounding medium, thereby reducing retroreflective properties.

The following report outlines and compares the observations and data collection used to assess the retroreflectivity and durability over time of pavement markings using Waterborne, Methyl Methacrylate, Polyurea, Thermoplastic and Epoxy liquid binders.

2 Project Description

The different liquid marking types were applied on Interstate 89 during the construction of Brookfield-Montpelier IM 089-1(61) Southbound, between mile markers 36.93 and 52.49 making the project a total of 15.56 miles long. There were four types of durable pavement marking materials selected for the project: Methyl Methacrylate (MMA), Polyurea, Thermoplastic, Epoxy. Waterborne traffic paint was applied as a control section used to acquire baseline data. All markings were applied using only one manufacturer's product per type of marking. In addition to the various marking types, two categories of optical reflective elements were used, Utah Blend beads and Wet Reflective elements. Each manufacturer's product was matched with their own or preferred optic for testing. The waterborne paint did not use Wet Reflective elements, in line with standard VTrans policy. Details of the markings and optics used, and locations within the project can be seen in Table 1. Each marking type was assigned a separate location within the project according to mile markers, as displayed in Figure 1. Recessed sections are marked with bold lines in Figure 1. In Figure 1, sections with "Non-Wet Recoverable Optics" included Utah Blend beads and sections with "Premium Wet Recoverable Optics" (indicated with cross-hatching) included the same quantity of Utah Blend beads and additional wet recoverable elements as recommended by each durable binder's manufacturer. Each type of marking was approximately 3 miles and within each three mile section, half was surface applied, while the other was recessed. Markings were applied between August 11 and August 20, 2014. All markings within the allotted area for each manufacturer were applied using only that manufacturer's product, with the exception of all exit and on-ramps and associated markings.

The project deployed standard VTrans specifications for each respective material and application, though for most products used, the specifications call for following manufacturer's recommendations. Polyurea, Epoxy and Methyl Methacrylate materials were applied by automated truck mounted systems. Thermoplastic materials were applied by a handcart for the entire three mile interstate project length. The use of the handcart for long line applications is a significant departure from required practice.

Marking visibility was routinely evaluated for each test site by collecting retroreflectivity data. The project assessed the quality and time dependent deterioration of the marking, so cost effective solutions may be widely deployed by VTrans. This study has not addressed costs associated with each pavement marking installation.

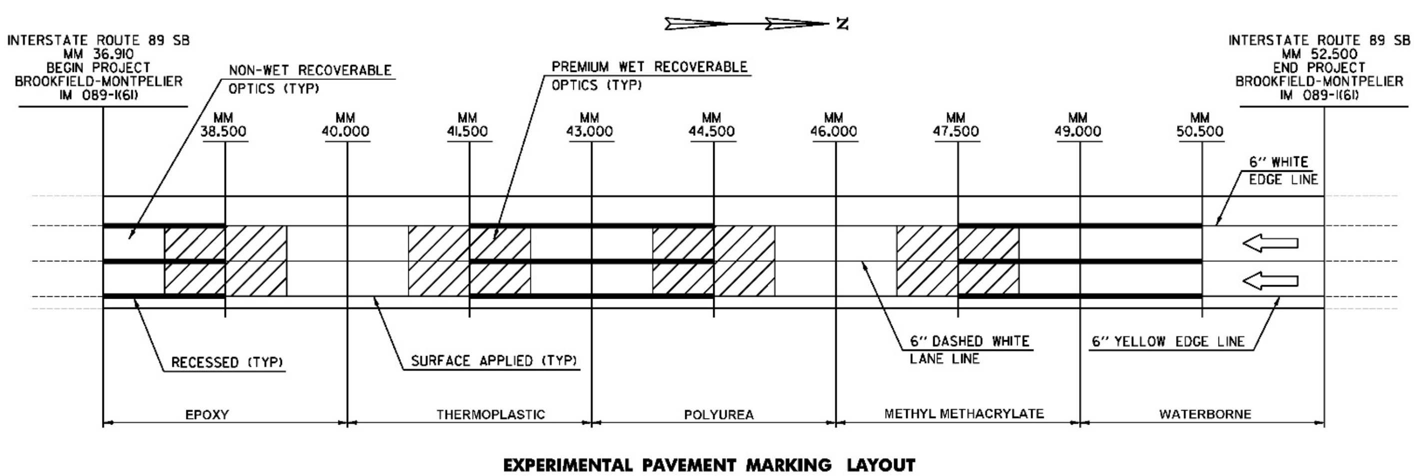

Figure 1: Project Layout Diagram

Table 1: Project Layout

Binder		MM	MM	Optics	Surface/Recess	Test Section
Waterborne	Ennis-Flint Fast Dry	52.49	50.5	Utah Blend	Surface	1, 2
		50.5	49	Utah Blend	Recess	3, 4
MMA	Swarco Swarcoplast Thin Film MMA 5090	49	48.25	Utah Blend	Recess	5, 6
		48.25	47.5	Plus 9 Spots	Recess	7, 8
		47.5	46.75	Plus 9 Spots	Surface	9, 10
		46.75	46	Utah Blend	Surface	11, 12
Polyurea	3M LPM 5000	46	45.25	Utah Blend	Surface	13, 14
		45.25	44.5	90p	Surface	15, 16
		44.5	43.75	90p	Recess	17, 18
		43.75	43	Utah Blend	Recess	19, 20
Thermoplastic	Sherwin Williams' Smart Mark™ Hydro	43	42.25	Utah Blend	Recess	21, 22
		42.25	41.5	Visimax	Recess	23, 24
		41.5	40.75	Visimax	Surface	25 ,26
		40.75	40	Utah Blend	Surface	27, 28
Epoxy	Epoplex LS65	40	39.25	Utah Blend	Surface	29, 30
		39.25	38.5	Visimax	Surface	31, 32
		38.5	37.75	Visimax	Recess	33, 34
		37.75	36.93	Utah Blend	Recess	35, 36

3 Material characteristics

3.1 Waterborne

3.1.1 Description

The waterborne paint used as the baseline control marking was Ennis Waterborne Roadmarking Paint. The product is suitable for application to bituminous and concrete roads. It is environmentally friendly with no ozone depleting emissions, is lead free and requires no organic solvents for cleanup. The waterborne paint's short drying time minimizes coning and traffic disruption and helps maximize optic bead retention. [1]

3.1.2 Application Process and Details

Ennis Waterborne Roadmarking Paint White is supplied ready for airless or air atomized spraying. Waterborne paint must not be heated above 104˚F (40˚C) before the application. The temperature of the surface should be above 50˚ F (10˚C) before any binder is applied. The ideal ambient conditions for the application of Ennis Waterborne Roadmarking Paint White are air temperature above 60˚F (15˚C), relative humidity below 50% and air movement greater than 10kph. (6 mph). The manufacturer's recommended film thickness is 15 mils or as specified in the plans. [1]

3.2 Methyl Methacrylate (MMA)

3.2.1 Description

The Methyl-Methacrylate (MMA) chosen for the project was Swarcoplast Thin Film MMA 5090 Series, produced by Swarco. The product is a spray applied, solvent-free component system designed for conventional markings as a durable and long-lasting pavement marking. Important advantages include: 100% solids chemistry, superior durability to any other road coatings, high reflective qualities, rain safety marking for enhanced night time visibility, special chemistry for rapid curing adhesion to a variety of substrates, protection against moisture penetration, excellent ultraviolet light stability, and snow plow resistance. [2]

3.2.2 Application Process and Details

Swarcoplast MMA can be applied to Portland Cement Concrete (PCC) and asphalt surfaces as a long-lasting striping material for both edge and centerline markings. It can also be used for intersection markings such as crosswalks, legends and symbols. MMA markings are with specialized application equipment for cold plastic markings (extruder / dispensing shoe). To assure maximum adhesion and properties, the surface shall be dry and clean. Flux oils of new asphalt are detrimental to the bonding and may lead to discoloration. Since mechanical removal of these oils is not possible, the surface should be exposed to traffic for 4-8 weeks before Swarcoplast MMA is applied. Application shall be done only when air temperature is over 40˚F (5˚C), and surface temperature is 40-104˚F (5-40˚C), and relative humidity is below 75%. Liquid components of the MMA are made homogeneous by stirring in the original containers before processing. Dry surface conditions are required. [2]

3.3 Polyurea

3.3.1 Description

The Polyurea paint used in this research was 3M LPM 5000. 3M™ Liquid pavement marking (LPM) Series 5000 is designed for use on roadways and highways as a durable pavement marking. Series 5000 is a 2:1 ratio two component, 100 percent solids Polyurea coating material that cures rapidly to hardness after mixing and application. The series 5000 binder can be configured with a number of different optics packages to provide desired levels of retroreflective performance. Series 5000 markings can be used for long lines (center, edge, and skip), channelizing lines and gore optics. Series 5000 is applied using a specialized, mobile, truck mounted and self-contained pavement marking machine specifically designed to apply two-component liquid materials and reflective media in continuous and skip-line pattern simultaneously. [3]

3.3.2 Application Process and Details

Proper application of Series 5000 is essential for completion of a successful project. The application of Series 5000 is recommended when air and road temperatures are 30˚F (-1˚C) or higher. The target start-up component temperature for Series 5000 is 120˚F (49˚C). All road surfaces must be clean and dry prior to application of Series 5000 Application when dew, frost or other visible moisture is present is not recommended. After periods of prolonged rainfall on pavement surfaces, use extra caution to verify the pavement is completely dry prior to application. Also, at the time of application pavement surfaces must be free of oil, dirt, dust, grease and similar foreign materials. The manufacturer requires the surface to be blown clean with high-pressure, 120 psi, high velocity, 185 cfm air, to remove any loose material prior to application of the product. 3M™ Liquid Pavement Marking Series 5000 can be applied directly to ACC (Asphalt Cement Concrete) surfaces. Application thicknesses range from 15-26 mils with influences from surface roughness, bead application rate and retroreflectivity target. [3]

3.4 Thermoplastic

3.4.1 Description

For the Thermoplastic pavement markings in this study, Sherwin Williams' Smart Mark™ Hydro was applied. Smart Mark™ Hydro is a durable thermoplastic pavement marking material engineered with superior adhesive properties based on hydrocarbon derived thermoplastic. The design of Smart Mark™ Hydro imparts superior adhesion to siliceous materials such as glass spheres and PCC (Portland Cement Concrete), imparts excellent impact resistance at 77˚F and 115˚F, and resists cracking during multiple freeze thaw cycles. Smart Mark™ Hydro can be applied to asphalt and PCC using conventional extruded, ribbon or spray equipment, according to recommended application procedures. VTrans specifications require continuous extrusion by shoe mechanism of thermoplastic markings. Smart Mark™ Hydro can also be used over existing alkyd and hydrocarbon thermoplastic pavement markings. [4]

3.4.2 Application Process and Details

Thermoplastic is heat applied and highly durable, dries (hardens) quickly (<2 minutes) and is available in a wide variety of specifications. Typically, these products are extruded at thicknesses between 90-120 mils. Thermoplastic is particularly well suited to asphalt surfaces because the material develops a thermal bond with the substrate via heat fusion. Thermoplastic can be applied via spray, extrude, or profile. Proper application requires temperatures of 50˚ F and higher.

Concerns about the surface presence of light oils in asphalt paving operations have routinely been addressed by a two-week curing period for asphalt pavements. [4]

3.5 Epoxy

3.5.1 Description

For use in this research study, Epoplex LS65 was applied to evaluate epoxy coated pavement markings. Epoplex LS65 is a two-component, 100% solids epoxy coating material designed as a rapid setting highway marking coating that provides durability and corrosion and abrasion resistance. Epoplex LS65 is formulated to provide a simple volumetric mixing ratio of two parts of component A to one part of component B. Epoplex LS65 is applicable to both Portland cement concrete and asphalt concrete highway surfaces as a long-lasting striping material for both edge and center line markings. [5]

3.5.2 Application Process and Details

Equipment for application shall be capable of spraying both white and yellow epoxy according to Epoplex's recommended proportions and be of sufficient size and stability with adequate hydraulic and air power supplies to produce lines of uniform dimensions. The equipment shall have a high-pressure air blast cleaning system capable of cleaning the pavement immediately prior to applying the markings. The equipment shall be specifically designed to apply two-component liquid materials through airless static tube or impingement mixing guns in a continuous and/or skip-line pattern. The guns must accommodate plural component material systems with a volumetric ratio of two to one. The equipment shall be mobile, truck mounted and self-contained. The equipment shall be maneuverable to the extent that straight lines can be followed and normal curves can be made a true arc. Truck mounted application units shall be equipped with accessories to allow for the application of legends, symbols crosswalks and other special markings. The epoxy markings must be applied only when atmospheric and surface temperatures are 40˚F or higher. The markings can be applied directly to new asphalt surfaces as soon as the asphalt has cooled and can support the weight of application equipment. The asphalt surface must be free of excess asphalt emulsions and oils to ensure proper adhesion of the markings. Applied markings shall have uniform thickness and optic bead distribution across the width of the line. The markings shall have crisp distinct edges and clean cutoff at the end of each line. LS65 is applied at temperatures above 40˚ F (5˚ C). The manufacturer's recommended minimum film thickness is 20 mils. Dry surface conditions are required. [5]

3.6 Optics

3.6.1 Description

The two optics types, Utah Blend and Wet Reflective, were evaluated for their retroreflectivity and durability in the different marking materials and exposures (surface/recessed). At the time this project was built, VTrans had only one specification of optics, AASHTO Type 1 glass beads. This project was done though a special provision, specifically to test the performance and constructability of Premium optics and Wet Reflective elements. The updated 2018 standards include three classifications for optics, Glass Beads (AASHTO Type 1), Premium optics, and Wet Reflective elements. The combinations of optic packages per marking type are below. The recommended drop rates were on the 2014 Vermont Annual Listing of Qualified Products and Materials.

Optics:

- Premium Optics:
  - All marking types: Utah Blend
- Wet Reflective elements:
  - MMA: Swarco Plus 9 Spots
  - Polyurea: 3M All Weather Elements (70p) elements
  - Thermoplastic: Potters Visimax Beads
  - Epoxy: Potters Visimax Beads

3.6.2 Application Process and Details

Most pavement marking materials are installed with many thousands of optic beads per square foot that bond to the highway with a strong binder. Instead of scattering light, as paints alone do, retroreflective optic beads turn the light around and send it back in the direction of your headlights. For beads to reflect light to a driver effectively, two properties are necessary: transparency and roundness. Beads made of glass have both of these properties. As the light ray enters the bead it is bent (refracted) downward by the rounded surface of the bead to a point below where the bead is embedded in the paint. Internal reflection within the bead directs light back.

The optic beads are applied to pavement marking materials by being dropped onto the freshly sprayed or extruded marking material. The quantity used in referred to as the “Drop Rate”. Typical drop rates for optics packages range from 6-10 lbs per gallon as influenced by marking material viscosity, surface roughness and drying time. The paint envelops the surface of beads partially, with paint rising up to above the midpoint of the bead by the wicking action. Embedment locks the optic beads into the paint and allows the paint to act as a diffuse reflecting surface for retroreflectivity, with the paint color affecting the color of the reflected light. The light entering the optic bead is bent back out towards the headlights and driver. Often times, optics are combined to create an “Optics Package”, a combination of glass bead, premium optics, and Wet Reflective elements. These packages are often applied in a “double drop”, applying a base of one type (glass bead or Premium), followed by a drop of the secondary optic, the Premium or Wet reflective.

The Utah Blend is a specified gradation of glass beads, and thus considered a Premium Optic. Utah Blend optics were used on all pavement marking materials in this project as a control to test the Wet Reflective elements against. The Utah Blend has a larger maximum bead size, and variable gradation from typical AASHTO Type 1 beads, increasing the chance the light will be reflected. Wet Reflective elements differ from the glass beads in their composition, being smaller ceramic beads clustered around a central core, rather than a singular sphere. The ceramic beads reflect light from their surface, and are colored in conjunction with the desired pavement marking. The clustered structure aids in the ability to reflect light in a wet condition, as they have lower surface tension and shed water faster than conventional glass beads. Wet Reflective elements are used in conjunction with glass beads, providing both dry and wet retroreflectivity. In this study, all Wet Reflective elements were combined with the Utah Blend in a double drop, in which the Utah Blend is applied first, followed by Wet Reflective elements. An image showing both glass beads and Wet Reflective elements can be seen in Figure 2.

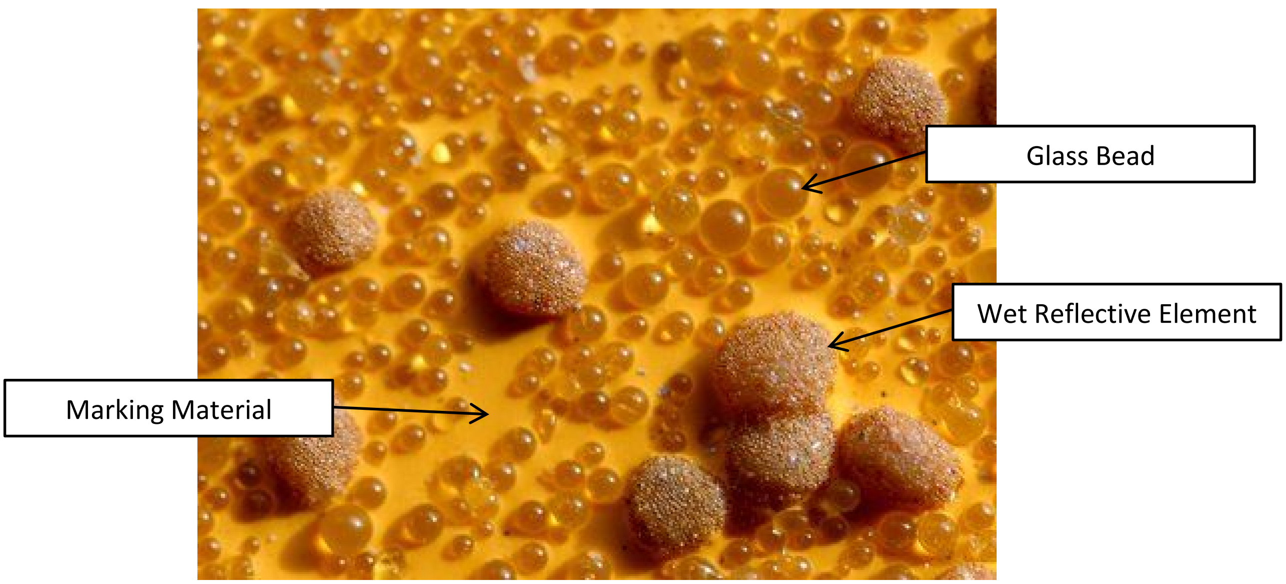

Figure 2: 3M Optics, Glass Bead and Wet Reflective elements

A proper application of beads results in the top layer of optic beads embedded to about 60% of the diameter of the bead. There should be consistent quality of both optic beads and paint so that the dry-film paint thickness and bead coverage promotes even retroreflectivity across both directions of road travel in two lane highways. Inadequate paint thickness results in under-embedded beads. This will result in improperly anchored beads that will fall out prematurely. In addition to bead pop-out, under-embedded beads cause a large percentage of the light that enters them to exit out the back. Too much paint results in over-embedded beads. While over-embedded beads may remain in the binder, reduced exposure limits light entrance and resultant retroreflectivity [6]. The retroreflectivity values in markings with over embedded beads increase over time with wear of the marking material by tires. Plowing does lead to retroreflectivity recovery because the shearing of the plow cuts the binder and bead exposing all beads at that level. Initially retroreflectivity is reduced because over-embedding leaves no optically active material above the surface.

4 Construction

4.1 Standard Specifications for Construction

Specification Sections 646 and 708 in the 2011 Standard Specifications for Construction detail materials and placement requirements. In these sections, binder markings are defined and specific construction details that are important to this study are explained in detail. VTrans specifications establish two principal categories of markings: paint and durables. Paints are not projected to have a service life of more than twelve months. Durable markings are projected to have a service life of up to three years. Durable markings are further divided into liquid markings and tapes. Liquid markings are not required to be applied at the time of paving operations providing flexibility for the general contractor and paving contractor's operations. Most tapes are recommended to be in-laid at the time of paving so that the tape is rolled into the pavement while hot and bonded directly to the asphalt/aggregate mix.

4.2 Project Summary and Application Process

The project was awarded to Pike Industries, Inc. headquartered in Belmont, NH. All markings were applied by L&D Inc from Barre, VT from August 11th, 2014 to August 20, 2014. At the time of application, temperature, relative humidity, precipitation/cloud cover, wind condition, ambient air, and pavement temperatures were recorded. All environmental requirements for the marking installations were met at the time of placement. The project plan called for the comparison of four different durable liquid pavement markings. The research section added in the Waterborne paint marking as a constant for the test. Along with the different liquids being tested, there were also two optics categories tested on each binder type (Utah Blend and Utah Blend with wet reflective elements). Each paint deck was half surface-applied and half recess-applied. The recessed sections were measured and their depths recorded to ensure compliance with required marking thickness. Examples of recesses for lane markings can be seen in Figure 3.

Figure 3: Recessed pavement section for marking application

Both white and yellow waterborne markings were applied on August 11, 2014 from mile marker 52.495 to mile marker 49.0 with a truck. The average depth for the recessed white lines was 62.1 mils and the yellow lines were 60.07 mils. On the day of the application, the average temperature was 68˚F and there was no precipitation. Below in Figures 4-6 are pictures of the waterborne application process.

Figure 4: Applying the yellow waterborne stripe.

Figure 5: Waterborne binder and optic package being applied.

Only Utah Blend beads were used, in a single drop. The liquid marking application and surface applied optic beads are distinctly visible in two separate process streams at the back of the truck in Figures 5 and 6. During the application, observers noticed that excess beads bounced or rolled off the marking because of insufficient material to capture them.

Figure 6: White waterborne binder and optic package being applied.

According to the Resident Engineer's Daily Reports, the following day (August 12) some of the thermoplastic white was placed, but due to expected rain on August 13, 2014, the thermoplastic lines were not finished. There was only trace precipitation recorded on August 13, 2014 with a daily temperature of 66˚F. Thermoplastic and Polyurea lines were finished on August 14. Temperatures on August 14 were averaged at 58˚F. Thermoplastic lines run from mile marker 43.0 to 41.5 and Polyurea markings run from mile marker 46.0 to 43.0. In the Thermoplastic section, the average depth for the yellow lines was 81.16 mils and the white depths averaged 82.87 mils. For the Polyurea section, depth averaged 72 mils for the yellow lines and 76.73 mils for the white lines. Figures 7 and 8 below show the application process for Thermoplastic and Figures 9 and 10 show the application of Polyurea. Thermoplastic was applied by handcart, requiring a premixing of the Wet Reflective elements with the Utah blend, since only a single drop chute for the optics package was available.

Figure 7: Thermoplastic cart being filled at the truck.

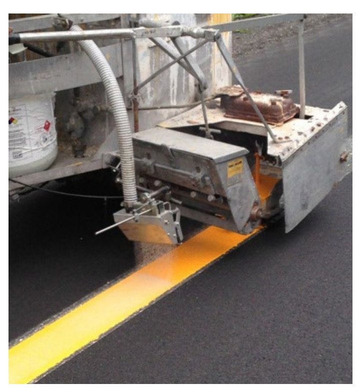

Figure 8: Thermoplastic markings applied with the push cart.

Figure 9: Polyurea application truck, featuring two chutes for application of a double drop of optics.

Figure 10: Polyurea binder being applied by the truck.

On August 18, all of the Epoxy markings were completed from mile marker 40.0 to the end of the project at mile marker 36.93. Markings were spray applied by a truck with double drop system. Recess depth readings were only taken on the yellow (passing lane) side and averaged 81.29 mils. The average temperature for the day of the Epoxy markings was 56˚F with only traces of precipitation. Figures 11 and 12 shows the application process of the Epoxy paint.

Figure 11: Epoxy markings being applied by the truck.

Figure 12: Yellow Epoxy binder and optic package being applied through two chutes for a double drop.

The final markings of the project (MMA) were applied on August 20 with a temperature of 63˚F. Methyl Methacrylate markings were spray applied from mile markers 49.0 to 47.5 with a truck. Again, only the yellow recessed lines were measured and averaged 72 mils. Figures 13 and 14 shows the application process of the Methyl Methacrylate.

Figure 13: MMA markings being applied by the truck with double drops.

Figure 14: Optic package and paint being applied.

In conclusion, the construction phase activities were executed under appropriate environmental conditions. The application thicknesses were reported to be within specification. Field observations following recessing and marking placement showed the target recess depth was not consistent with the thickness of the marking material with inadequate recess depth for thermoplastic and excess depth for polyurea.

5 Winter Maintenance Practices

Generally, the winter maintenance season lasts from October to April [7]. With a direct cost each year of $1.5 billion, snow and ice control on roadways in the United States represents a significant expenditure [8].

Winter maintenance can be separated into three practices: use of deicers (salt or saline compound), use of abrasives (sand or other), and snowplowing. Deicers are commonly used by agencies. The main deicer used is Sodium Chloride (NaCl) either in a solid or liquid form. Other deicers available are Calcium Chloride (CaCl) and Magnesium Chloride (MgCl), as well as growing industry of new additives to lower the freezing point, and increase tack. Abrasives are used but much less frequently than deicers. The most common abrasive materials are sand and small gravel, but some agencies use other abrasives like cinders. All agencies use snowplows in their winter maintenance activities. Nationally, criteria for snowplow use varies from very vague (e.g. if there is snow present) to very detailed (e.g. detailed documents with several criteria). Snowplow blades can be made from a variety of materials. Carbide and steel blades are the most common, but agencies also use rubber blades. Several agencies use more than one type of blade. Many studies have established a link between pavement marking retroreflectivity durability and winter maintenance operations. After a single winter, retroreflectivity levels routinely drop by as much as 40%. Snowplows cause the most damage to pavement markings. If abrasives such as sand are present on the road, temporary loss of retroreflectivity occurs immediately. It is estimated that a single snowplow run will reduce paint retroreflectivity levels by 3.22 mcd/lux/m² on average [9]. Some highway agencies (including Québec) have noticed a loss of durability in recent years [9]. Winter maintenance standards are in many cases stricter today than before resulting in increased plow and ice melting incidents. This may lead to more stress on pavement marking materials and increase retroreflectivity loss.

VTrans standard practice for interstate highways are truck plows with standard carbide edge blades, with a tow plow available for rotation if needed. Plows are capable of sending snow to the left or right as necessary for lane maintenance. Anti-icing with salt brine and deicing with solid NaCl are most common. In rare circumstances of extreme cold, abrasives are placed for safety. Variations occur as needed among the techniques based on weather and road conditions. Important to this discussion is the interstate typical section and plow positioning. The standard interstate typical in Vermont is a centerline crown with a 0.021 slope away for a 12-foot lane. The median shoulder is 4 feet, the breakdown lane is 10 feet, and both are 0.063 slope. The standard plow width is 10 feet with a 6 foot wing. The plow practice is generally to plow a lane with a 6 to 9 inch centerline overlap. The configuration places the wing on the pavement with a 10-11 foot offset from centerline. The inner edge of the wing places significant shear force on the white edge line on the breakdown lane side because of proper maintenance in the driving lane.

During the winter months following the application of the pavement markings on Berlin-Brookfield I89 Southbound, the VTrans Districts recorded the amount of salt, brine, and sand used on the highway. In Table 2 below, the total amount of salt, brine, and sand used is shown.

Table 2: Winter Maintenance Data

I89 SB Winter Maintenance Data from MM 50.5 to MM 36.93				
Date	**Location**	**Salt Tonnage**	**Salt Brine Gallons**	**Sand Tonnage**
11/14/14 to 02/23/15	I 89 SB MM 50.5 to MM 36.93	727	5910	0

Data was collected from November 11, 2014 to February 23, 2015, a total of 102 days 51 of which trucks were deployed for snow removal. This does not cover the entire winter maintenance period, but does provide a snapshot of the total winter maintenance. Out of these 51 days, the trucks used their plows for 49, salted on all 51, and applied brine on 14 out of the 51 days. From this period, we can see that winter maintenance occurs roughly 50% of the days, with 14 tons of salt used per application day, or one ton of salt per mile on application days. During this three month period, no sand was used.

6 Performance and Observations

6.1 Dry Retroreflectivity

In total, there were five binder types, two optics categories, and two applications tested throughout the project. Retroreflectivity readings were taken using the RoadVista, manually collected at specific points along the roadway, in accordance with ASTM E1710, *Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer* [10]. This test uses a standard measurement condition intended to represent the angles corresponding to a distance of 30 m for the driver of a passenger car with an eye height of 1.2 m and a headlight height of 0.65 m above the road. The sampling involves taking 5 replicate readings at 20 foot intervals in each 100 foot test section. The averaged readings present a single value at the point in time that measurement occurred. Each 400 foot test section had 21 sample locations, and each binder/optics/application combination had two test sections. Each data point shown below is the average of two test sections, each being the average of 21 sample locations, with each being the average of 5 replicate tests.

Figure 15-19 below show the average reflectivity for each marking material/optics/application type. Note the variations in the X and Y axes between the figures. Monitoring was ceased before the end of the study if the test sites were deemed in need of replacement. Figure 20 shows the results of each material and application with combined optics types. Figure 21 shows the overall performance by material type, with combined optics and application. Photos of the pavement markings at installation, and at the end of its observation are shown in Appendix A.

Figures 20-22 show the averaged retroreflectivity performance by for each material by application type, optics package, and the average for the material, respectively. By application, Recessed Polyurea is outperforming the other markings. By optic package, Polyurea with Wet Reflective and Utah blend beads are performing best, and are nearly equal in outcome with each other. Overall retroreflectivity performance of the materials in descending order from best to poorest are: polyurea, epoxy, methyl methacrylate, thermoplastic and waterborne. Not included in this analysis is the cost and expected service life, but judged on a performance basis, polyurea and epoxy dramatically outperformed the other materials. As expected, the data shows recessed markings outperform surface applied markings substantially for dry retroreflectivity. It was noted in the field notes that some of the white recessed polyurea was misaligned, and did not fall totally within the recess area, likely making its observed performance worse than it otherwise would have been.

The optics packages resulted in two general observations related to dry retroreflectivity. The Utah Blend only test sections showed lower rates of deterioration with lower initial values. With the polyurea and thermoplastic, Wet Reflective elements produced higher initial values but dropped off precipitously in several test sections. With the epoxy and MMA, Utah Blend sections showed similar initial retroreflectivity values to the Wet Reflective optic, and similar results over the course of testing. White lines have generally higher retroreflectivity values, though after the start of winter maintenance (at 95 days) results are mixed.

In all cases but thermoplastic, the materials were installed in accordance with manufacturer's instructions and under suitable conditions for placement. Thermoplastic was placed by non-automated handcart equipment, reflecting the available state of delivery for thermoplastic in VT at that time.

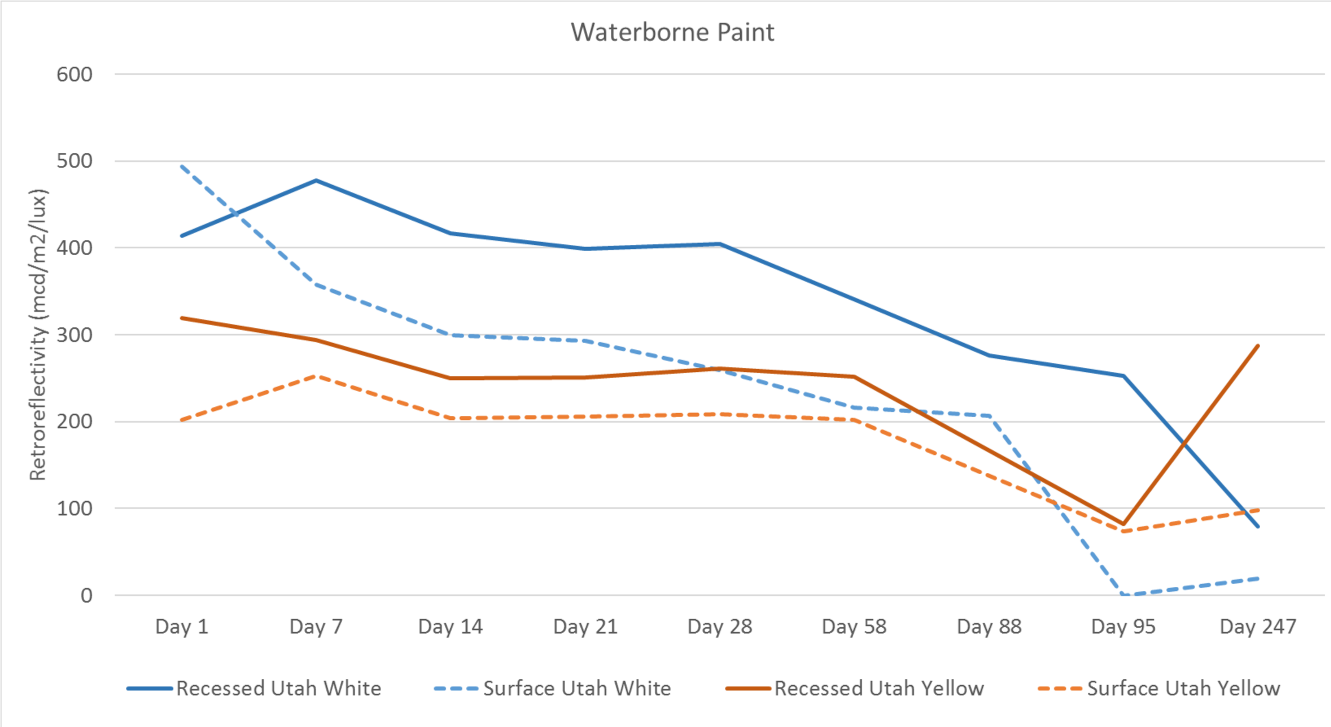

Figure 15: Waterborne Paint Performance

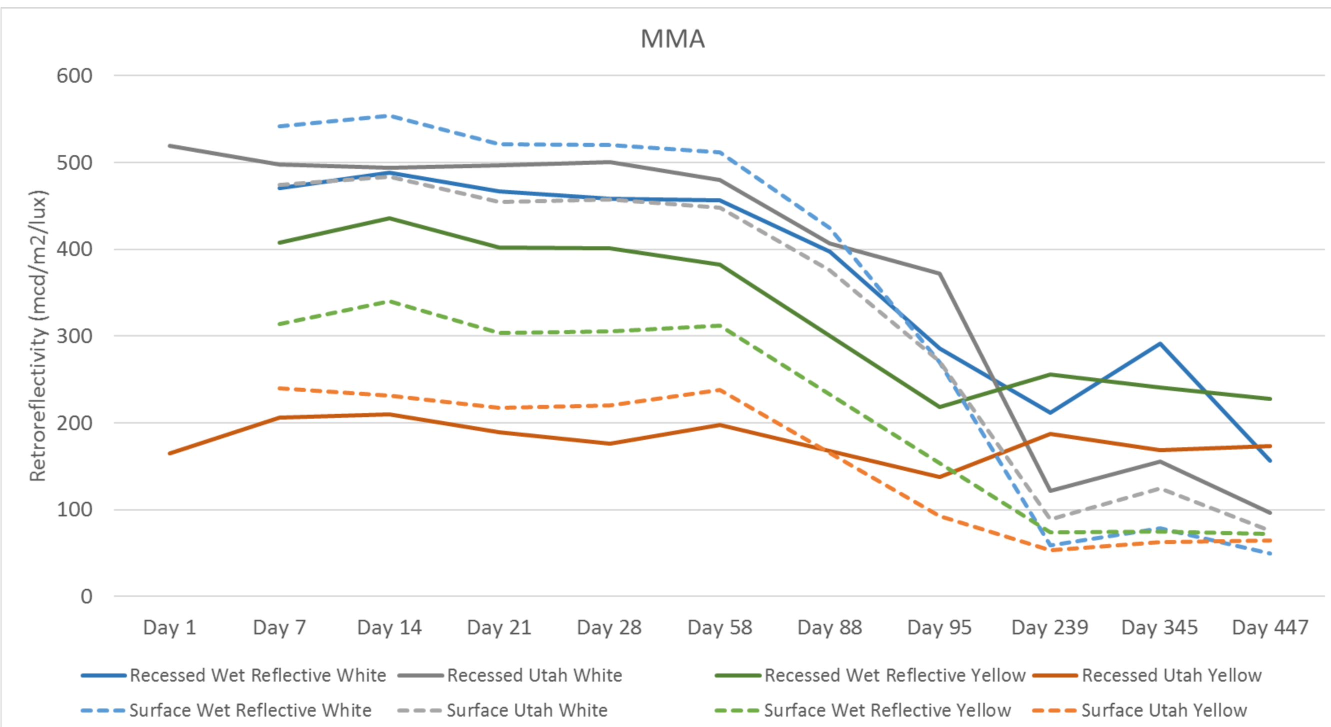

Figure 16: MMA Performance

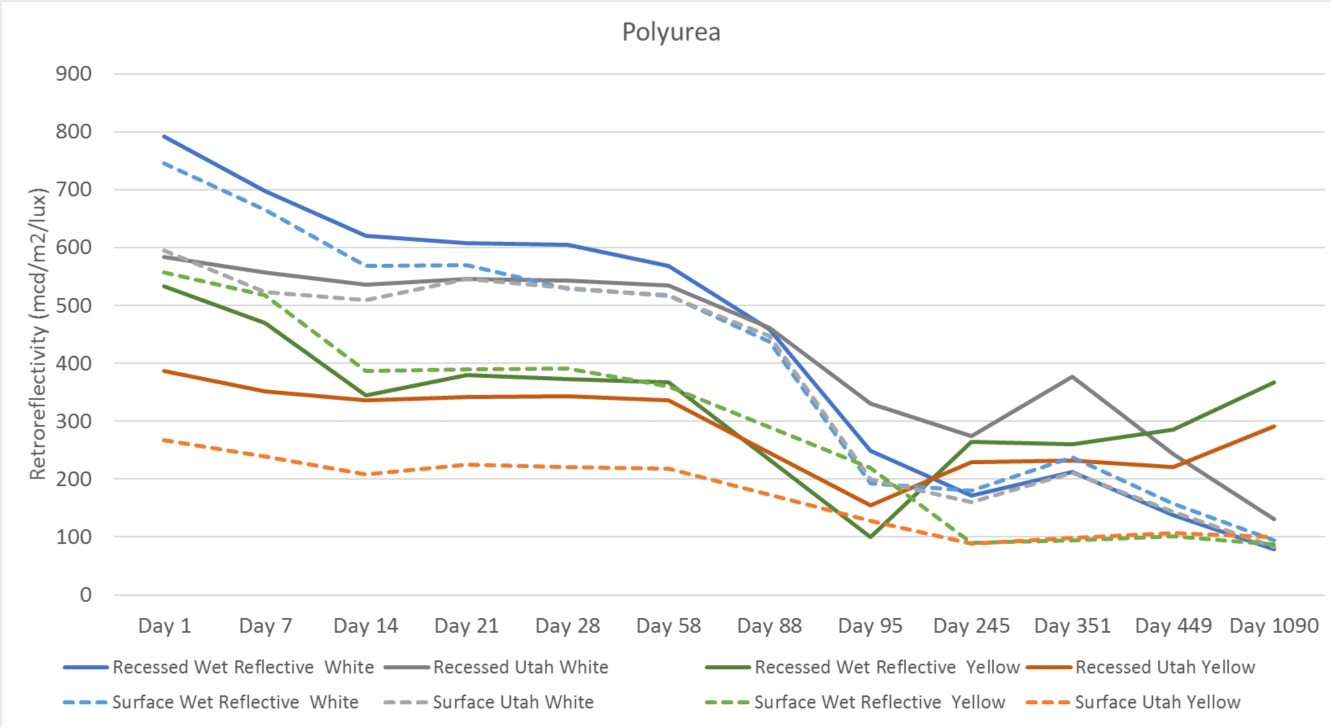

Figure 17: Polyurea Performance

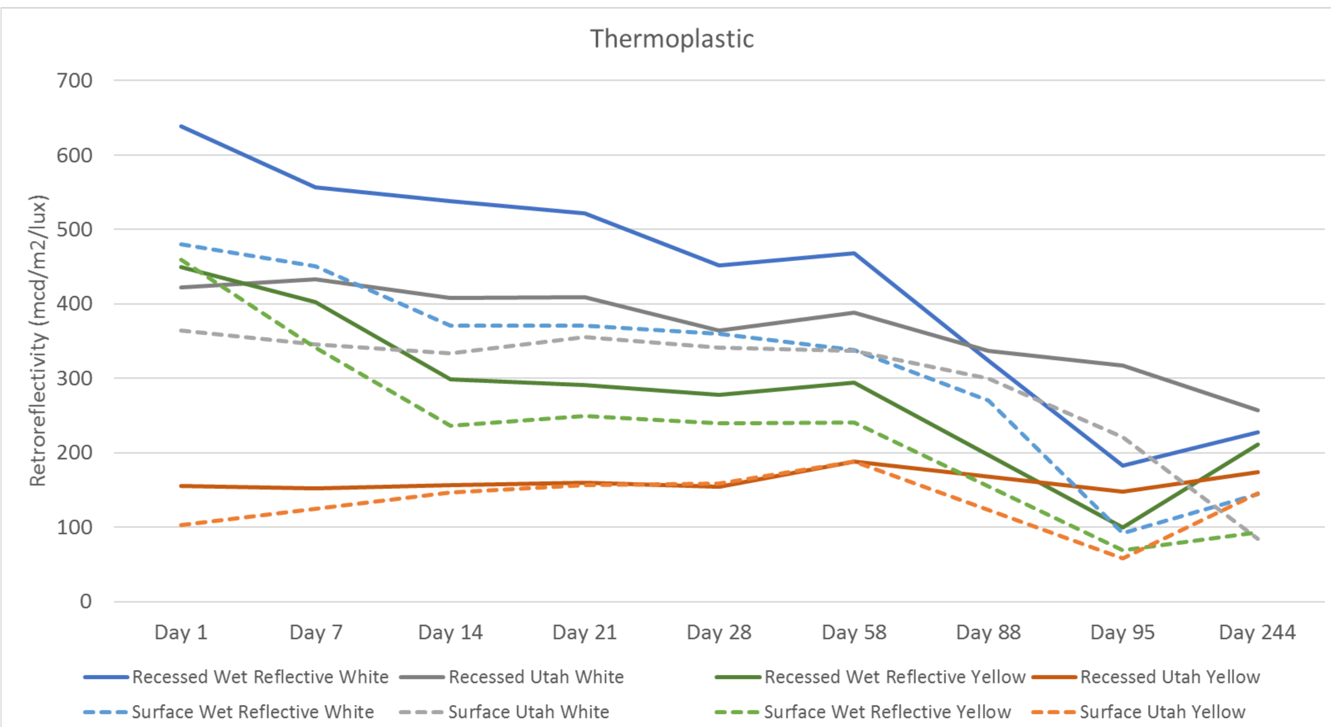

Figure 18: Thermoplastic Performance

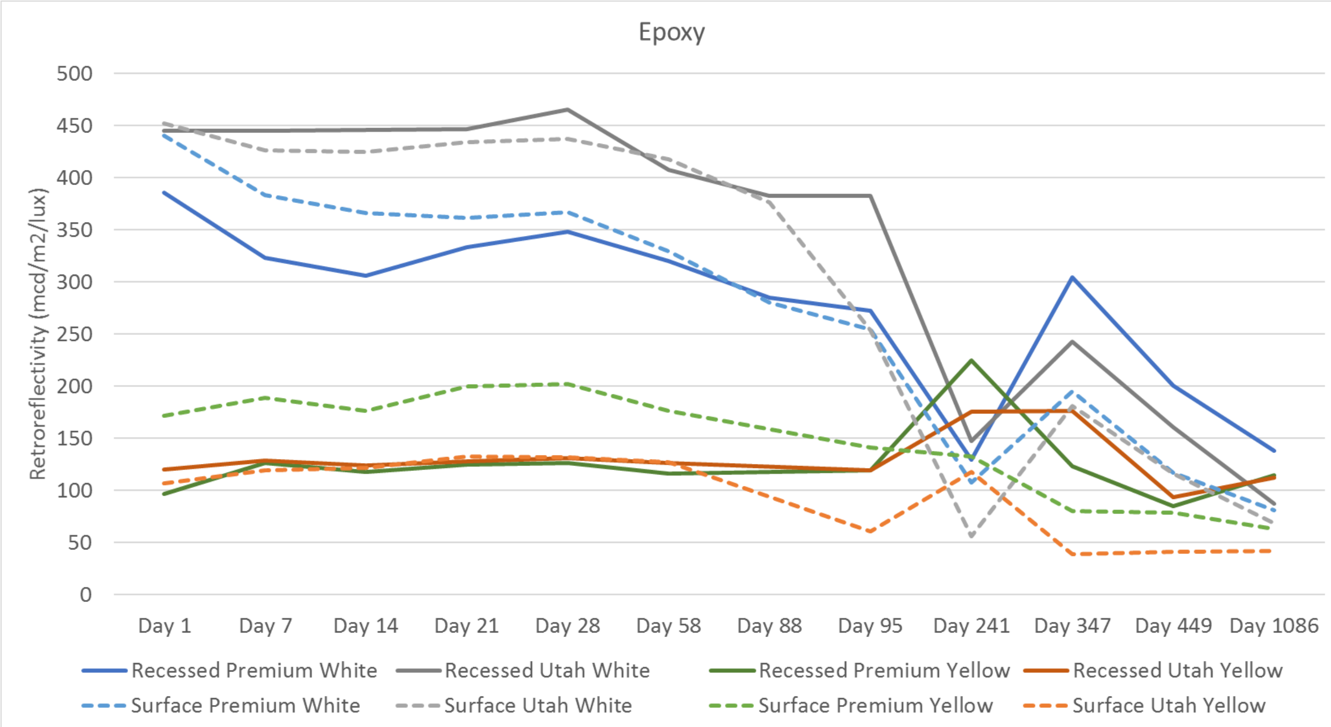

Figure 19: Epoxy Performance

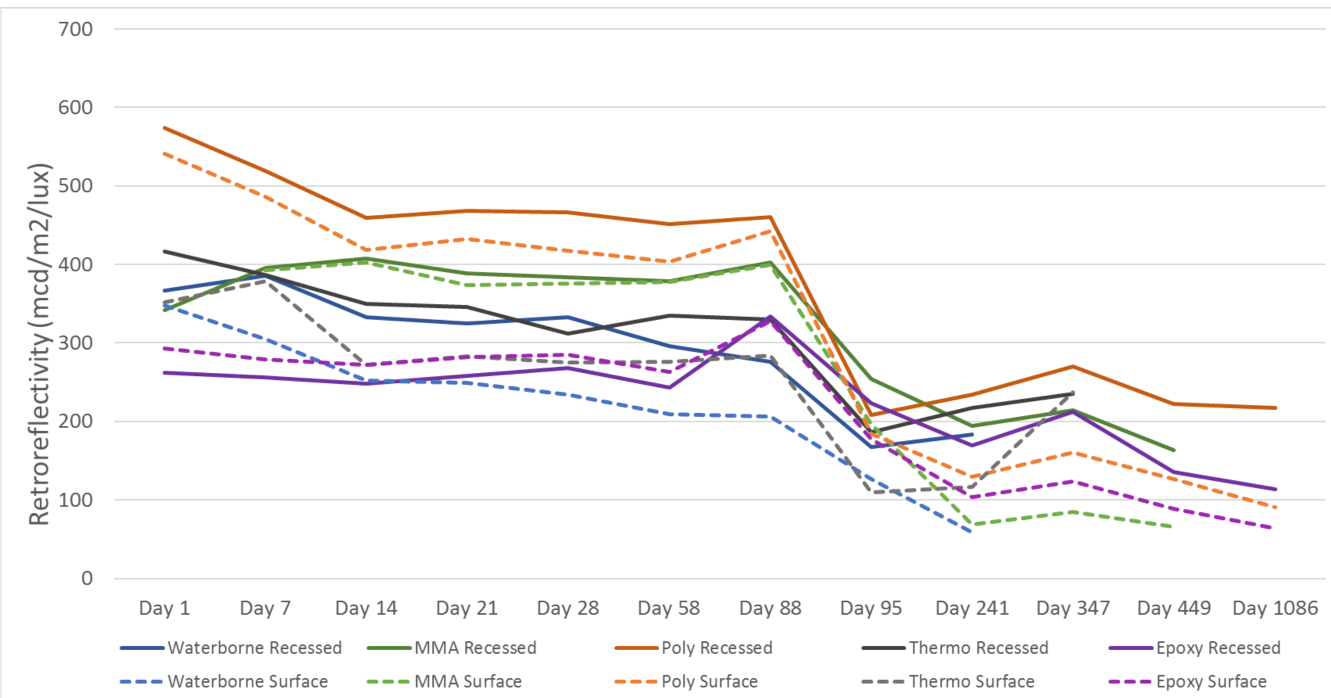

Figure 20: Pavement Marking Performance by Application

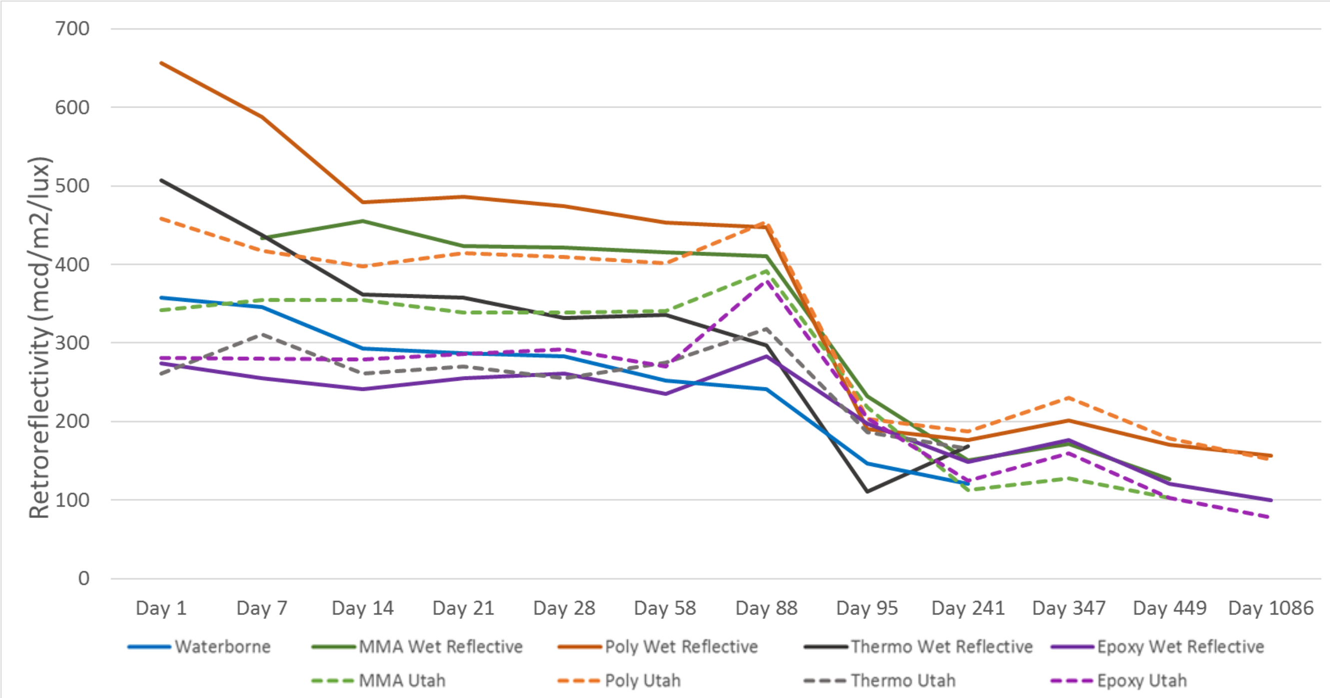

Figure 21: Pavement Marking by Optics Package

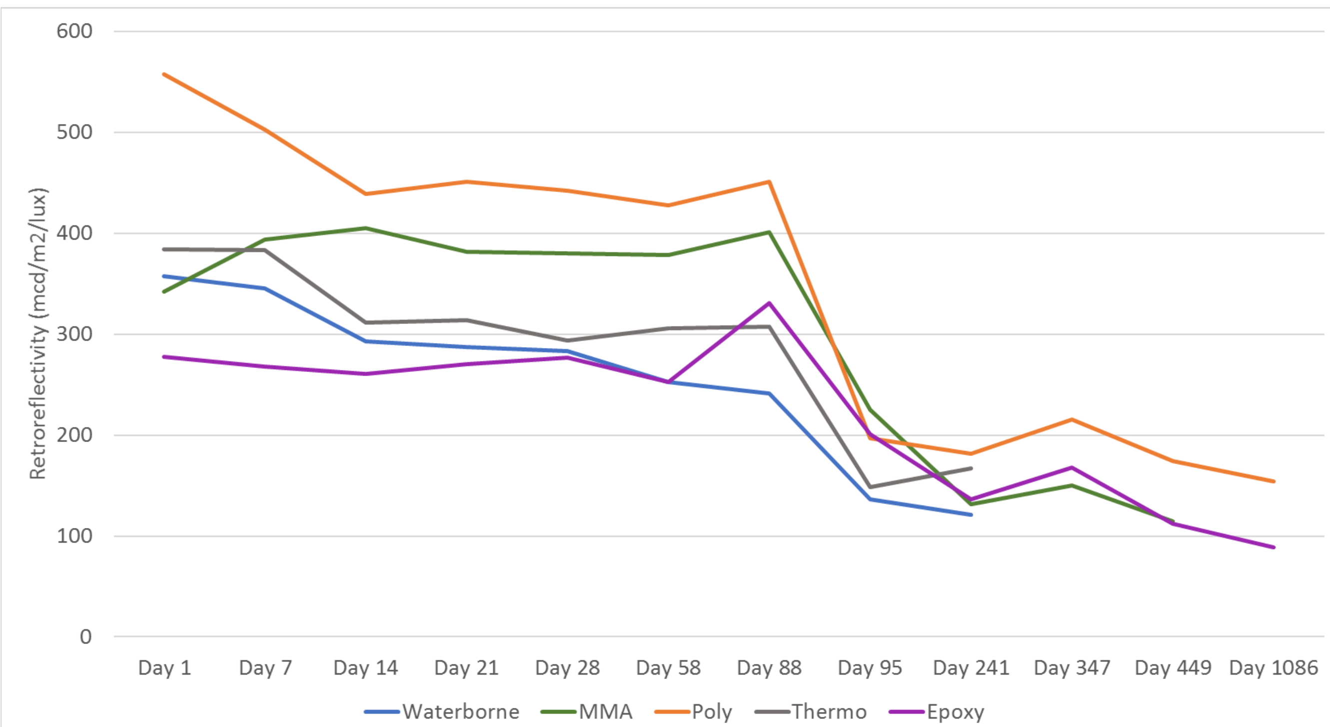

Figure 22: Pavement Marking by Material

6.2 Wet Retroreflectivity

Wet readings were also taken in accordance to the ASTM E2177, *Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (R_L) of Pavement Markings in a Standard Condition of Wetness* [11]. This test represents the wet recoverable retroreflectivity, and allows 45 seconds to elapse between wetting and measurement. Wet readings were taken on day 73 and 325. Results of the wet retroreflectivity testing can be seen in Table 3. Surprisingly, some of the Utah

Blend optics outperform the Wet Reflective optic in wet retroreflectivity testing at both 73 and 325 days. It is unclear if the testing methods are a cause of these notably unexpected results. The polyurea test results are most in line with the expected results, with Wet Reflective elements providing better wet retroreflectivity, and having some degradation between measurement periods. With only two readings it is not possible to draw conclusions from the results, but there are some surprising results, especially in Utah Blend wet reflectivity that should be investigated further.

Table 3: Wet Retroreflectivity

Binder Type	Section	Day 73	Day 325
Waterborne	Recessed Utah Blend	56	
	Surface Applied Utah Blend	56	
MMA	Recessed Utah Blend	216	138
	Surface Applied Utah Blend	118	32
	Recessed Plus 9 Spots - Wet Reflective	138	60
	Surface Applied Plus 9 Spots - Wet Reflective	133	32
Polyurea	Recessed Utah Blend	96	135
	Surface Applied Utah Blend	103	106
	Recessed 90p - Wet Reflective	215	173
	Surface Applied 90p - Wet Reflective	289	124
Thermoplastic	Recessed Utah Blend	105	
	Surface Applied Utah Blend	51	
	Recessed Visimax - Wet Reflective	62	
	Surface Applied Visimax - Wet Reflective	31	
Epoxy	Recessed Utah Blend	135	86
	Surface Applied Utah Blend	101	31
	Recessed Visimax - Wet Reflective	90	165
	Surface Applied Visimax - Wet Reflective	90	47

6.3 Premature Thermoplastic Failure and Replacement

In the December 2014, the district staff notified research personnel that sections of the thermoplastic markings were missing or severely damaged. Research personnel then proceeded to go out to observe the markings. Below, Figures 23–26 shows the damaged and missing Thermoplastic markings. It appears that plowing caused major localized damage to the lines which had been applied only a couple months before the damage occurred. This may be due to the binder not being heated to the specified temperature. Field notes indicate the thermoplastic was brittle and could be lifted up with the edge of a key showing clear delamination. In other places thermoplastic was not visible at all from being scraped up by the plow. During the same site visit, waterborne was noted to be fading significantly where there is a sharp incline just before Berlin Exit 7 off-ramp (TS 1 and 2). The two failing test sites were both surface applied. Test sites 3 and 4 were both recessed and provided much better visual and retroreflective results.

In May 2015, the thermoplastic and waterborne were repainted due to wear (visual line loss) and loss of retroreflectivity. After the first plow and salt, waterborne markings had declined by as much as 96% for the white lines and 51% for the yellow lines and thermoplastic markings had declined retroreflectivity as much as 77% in the white lines and 80% for the yellow line.

Figure 23: TS 25 Damage Overview

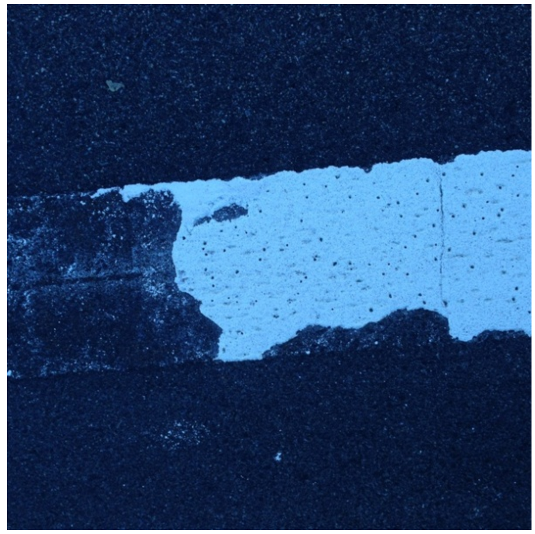

Figure 24: TS 25 Line Damage Close-up

Figure 25: TS 28 Damage Overview

Figure 26: TS 28 Damage Overview

7 Summary and Recommendations

Weekly site visits were made to the test sites up until the first month then monthly readings were taken. After 6 months of readings, seasonal readings were taken, and then a final visit after two years was conducted to get final readings on the polyurea and epoxy. The site visits included collecting photographs, retroreflectivity readings on the lines, and evaluation of the amount of the line lost due to plow truck passes in the winter months. Example photos of the pavement markings at installation, and at the end of its observation are shown in Appendix A.

Overall, waterborne and thermoplastic lasted 8 months, MMA lasted 15 months, and epoxy and polyurea lasted 35 months. Polyurea performed the best over the full length of the study period, maintaining consistently high retroreflectivity compared to the other materials in each scenario, and thus across all color/optic/applications combinations.

Overall, recessed markings performed much better than the surface applied markings. Most surface applied markings showed issues with wear and missing visible markings. The single best performing marking material, optics package and placement technique for retroreflectivity was the Yellow recessed polyurea with wet reflective elements.

8 References

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3. 3M. “Liquid Pavement Marking Application Guidelines: Series 5000.” http://multimedia.3m.com/mws/media/826804O/if-5-28-app-guidelines-lpm-series-5000.pdf?fn=IF%205.28.pdf

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5. Epoplex. “LS 65.” http://www.epoplex.com/products/ls65.aspx.

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7. Highways Term Maintenance Associations. “Winter Maintenance.” http://www.htma.info/industry-topics/winter-maintenance.html

8. U.S. Roads Road Management & Engineering Journal. “Winter Maintenance Technology and Practices—Learning from Abroad.” 1997. TranSafety, Inc. http://www.usroads.com/journals/rmj/9703/rm970302.htm

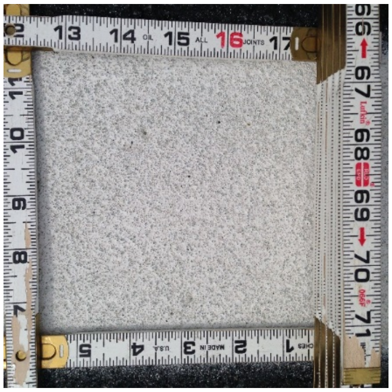
9. Cirrelt. “Pavement Marking Retroreflectivity in Cold Regions: Survey of Practices.” Marilyne Brosseau, Ana Carrasquilla, and Nicolas Saunier. November 2012. CIRRELT-2012-67.

10. ASTM E1710. “Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer.” https://www.astm.org/Standards/E1710.htm

11. ASTM E2177. “Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (RL) of Pavement Markings in a Standard Condition of Wetness.” https://www.astm.org/Standards/E2177.htm

9 Appendix A

9.1 Waterborne Paint

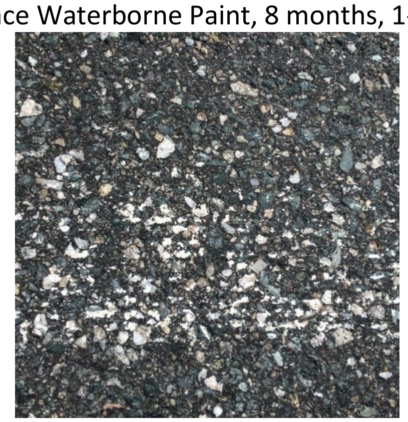

Surface Waterborne Paint, Installation, 1-0+00


Surface Waterborne Paint, 8 months, 1-0+00


Surface Waterborne Paint, Installation, 1-0+00


Surface Waterborne Paint, 8 months, 1-0+00


Recess Waterborne Paint, Installation, 4-0+00


Recess Waterborne Paint, 8 months, 4-0+00


Recess Waterborne Paint, Installation, 4-0+00

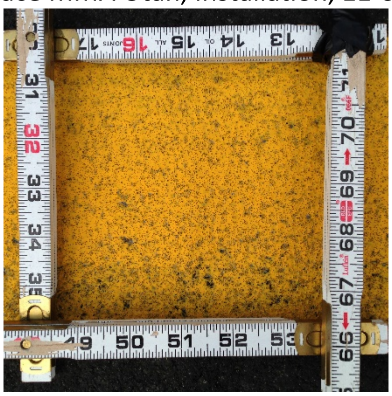

Recess Waterborne Paint, 8 months, 4-0+00

Figure 27: Waterborne Paint at installation and after 8 months

9.2 MMA

Surface MMA Utah, Installation, 11-0+00

Surface MMA Utah, 15 months, 11-0+00

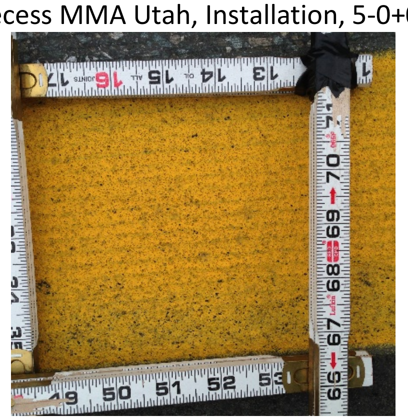


Surface MMA Utah, Installation, 11-0+00

Surface MMA Utah, 15 months, 11-0+00

Recess MMA Utah, Installation, 5-0+00

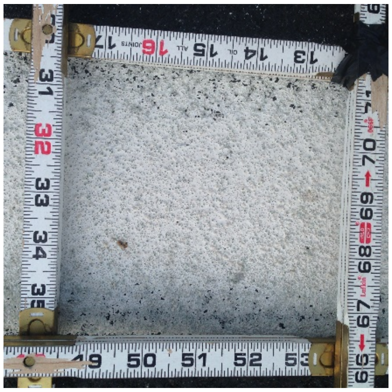
Recess MMA Utah, 15 months, 5-0+00



Recess MMA Utah, Installation, 5-0+00

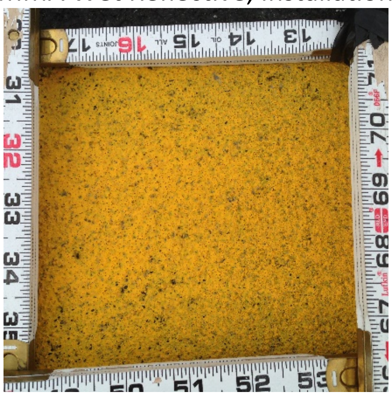
Recess MMA Utah, 15 months, 5-0+00

Figure 28: MMA with Utah optics at installation and 15 months

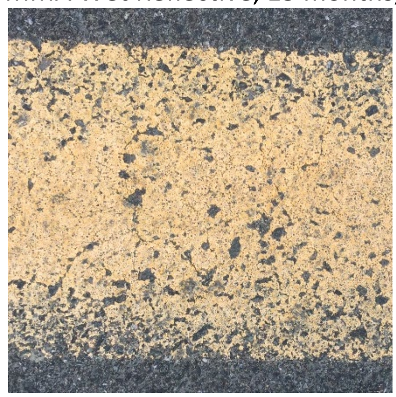


Surface MMA Wet Reflective, Installation, 9-0+00

Surface MMA Wet Reflective, 15 months, 9-0+00

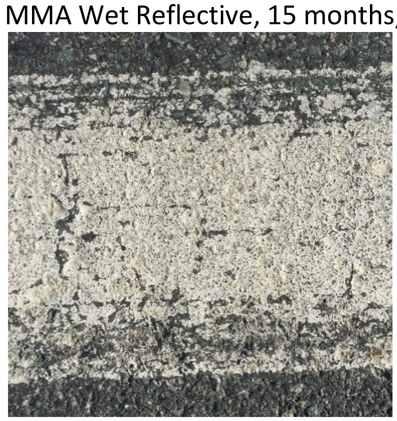


Surface MMA Wet Reflective, Installation, 9-0+00

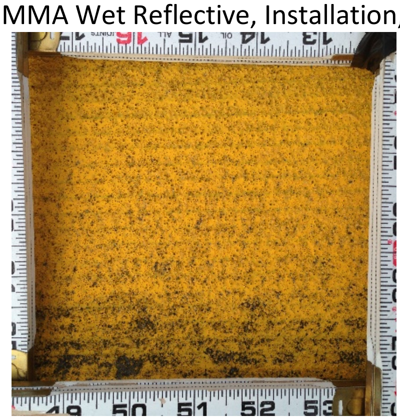


Surface MMA Wet Reflective, 15 months, 9-0+00

Recess MMA Wet Reflective, Installation, 7-0+00



Recess MMA Wet Reflective, 15 months, 7-0+00

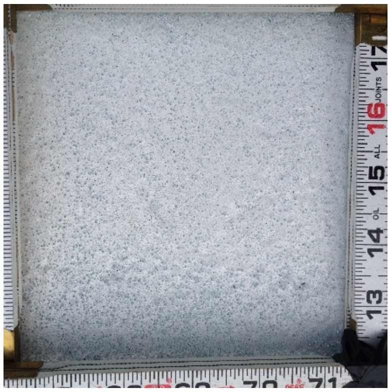


Recess MMA Wet Reflective, Installation, 7-0+00

Recess MMA Wet Reflective, 15 months, 7-0+00

Figure 29: MMA with Wet Reflective elements at installation and 15 months

9.3 Polyurea



Surface Polyurea Utah,
Installation, 13-0+00

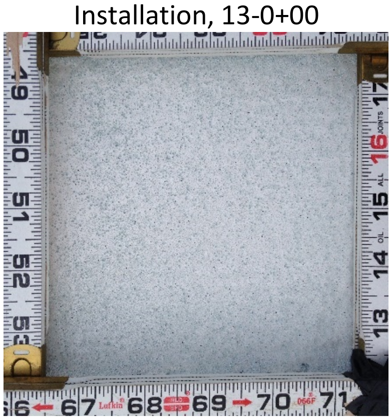
Surface Polyurea Utah,
15 months, 13-0+00

Surface Polyurea Utah,
36 months, 13-0+00

Surface Polyurea Utah,
Installation, 13-0+00

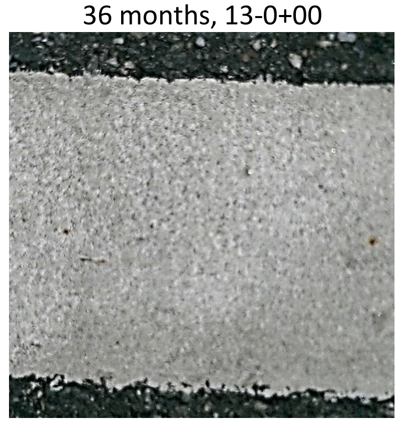
Surface Polyurea Utah,
15 months, 13-0+00

Surface Polyurea Utah,
36 months, 13-0+00



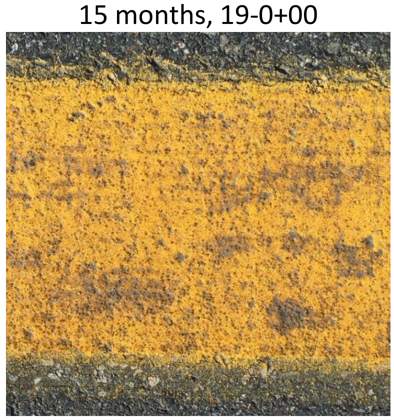
Recess Polyurea Utah,
Installation, 19-0+00

Recess Polyurea Utah,
15 months, 19-0+00



Recess Polyurea Utah,
36 months, 19-0+00

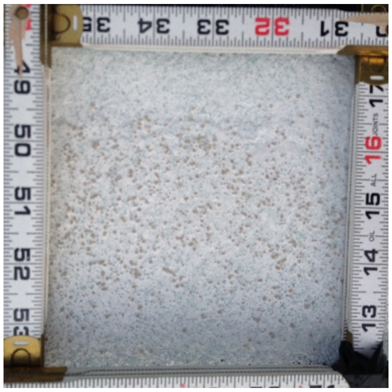
Recess Polyurea Utah,
Installation, 19-0+00



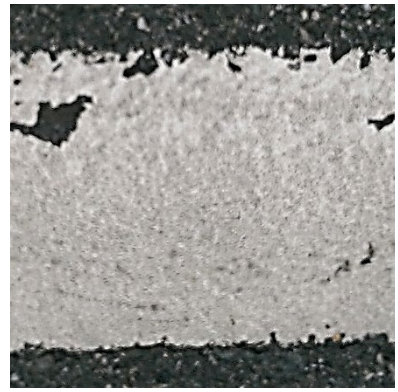
Recess Polyurea Utah,
15 months, 19-0+00

Recess Polyurea Utah,
36 months, 19-0+00

Figure 30: Polyurea with Utah optics at installation, 15 months, and 36 months


Surface Polyurea Wet Reflective, Installation, 15-0+00

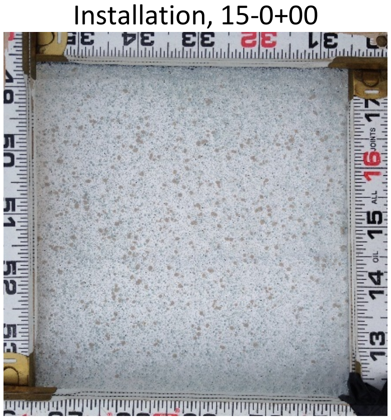

Surface Polyurea Wet Reflective, 15 months, 15-0+00


Surface Polyurea Wet Reflective, 36 months, 15-0+00


Surface Polyurea Wet Reflective, Installation, 15-0+00


Surface Polyurea Wet Reflective, 15 months, 15-0+00


Surface Polyurea Wet Reflective, 36 months, 15-0+00


Recess Polyurea Wet Reflective, Installation, 17-0+00


Recess Polyurea Wet Reflective, 15 months, 17-0+00


Recess Polyurea Wet Reflective, 36 months, 17-0+00


Recess Polyurea Wet Reflective, Installation, 17-0+00

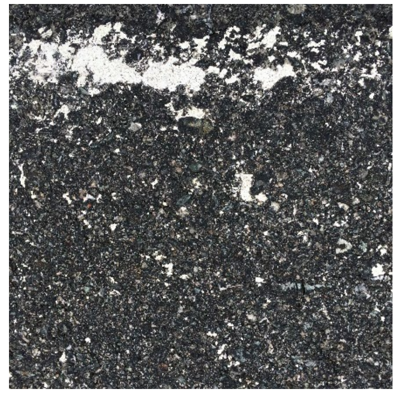

Recess Polyurea Wet Reflective, 15 months, 17-0+00


Recess Polyurea Wet Reflective, 36 months, 17-0+00

Figure 31: Polyurea with Wet Reflective elements at installation, 15 months, and 36 months

9.4 Thermoplastic

Surface Thermoplastic Utah, Installation, 28-1+00



Surface Thermoplastic Utah, 8 months, 28-1+00

Surface Thermoplastic Utah, Installation, 28-1+00

Surface Thermoplastic Utah, 8 months, 28-1+00

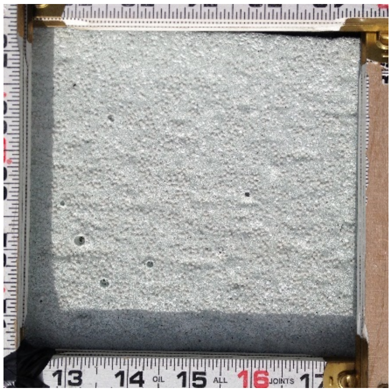
Recess Thermoplastic Utah, Installation, 22-0+00

Recess Thermoplastic Utah, 8 months, 22-0+00

Recess Thermoplastic Utah, Installation, 22-0+00

Recess Thermoplastic Utah, 8 months, 22-0+00

Figure 32: Thermoplastic with Utah optics at installation and 8 months



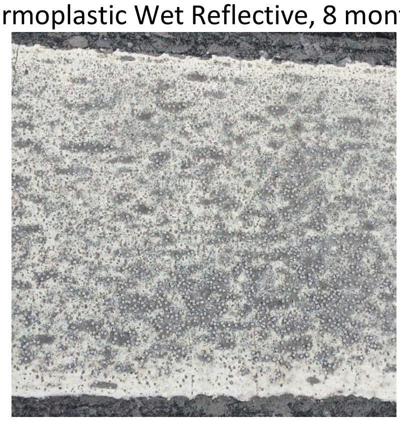
Surface Thermoplastic Wet Reflective, Installation, 25-4+00

Surface Thermoplastic Wet Reflective, 8 months, 25-4+00

Surface Thermoplastic Wet Reflective, Installation, 25-4+00

Surface Thermoplastic Wet Reflective, 8 months, 25-4+00

Recess Thermoplastic Wet Reflective, Installation, 23-0+00



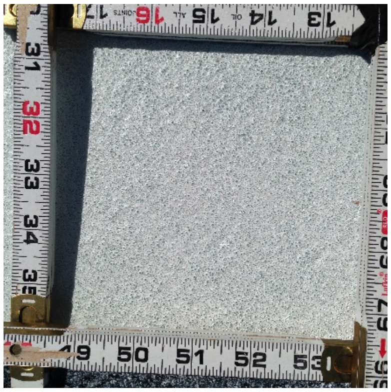
Recess Thermoplastic Wet Reflective, 8 months, 23-0+00

Recess Thermoplastic Wet Reflective, Installation, 23-0+00

Recess Thermoplastic Wet Reflective, 8 months, 23-0+00

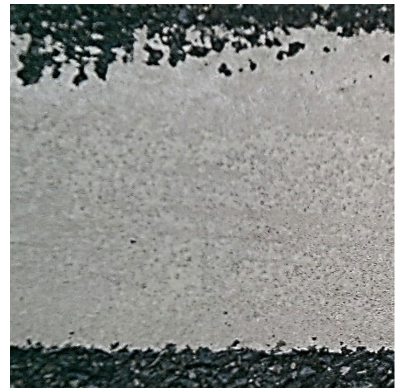
Figure 33: Thermoplastic with Wet Reflective elements at installation and 8 months

9.5 Epoxy



Surface Epoxy Utah,
Installation, 29-0+00

Surface Epoxy Utah,
15 months, 29-0+00



Surface Epoxy Utah,
36 months, 29-0+00

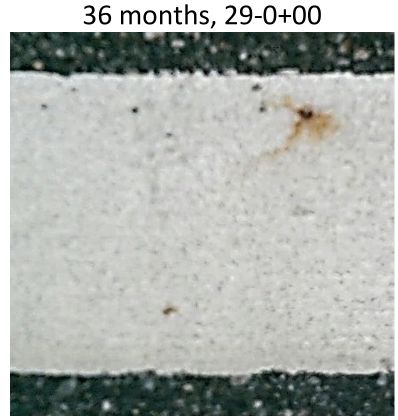
Surface Epoxy Utah,
Installation, 29-0+00

Surface Epoxy Utah,
15 months, 29-0+00

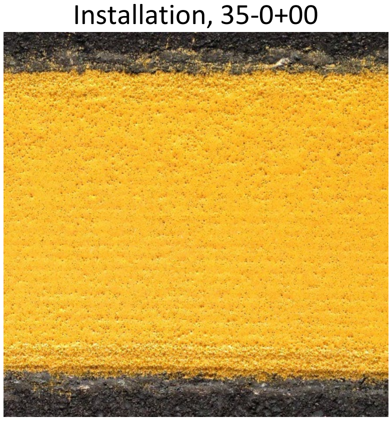
Surface Epoxy Utah,
36 months, 29-0+00

Recess Epoxy Utah,
Installation, 35-0+00

Recess Epoxy Utah,
15 months, 35-0+00

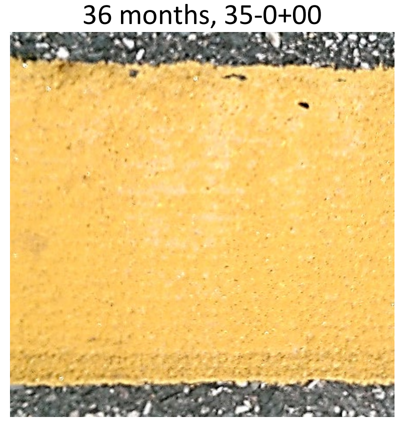


Recess Epoxy Utah,
36 months, 35-0+00



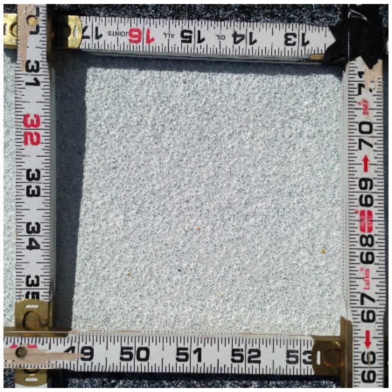
Recess Epoxy Utah,
Installation, 35-0+00

Recess Epoxy Utah,
15 months, 35-0+00

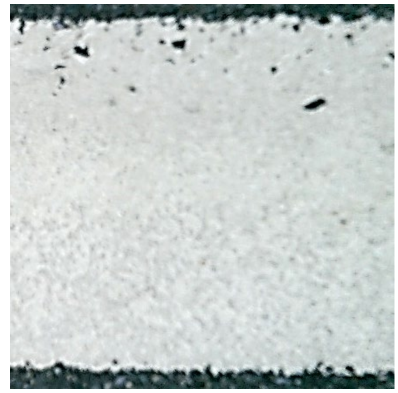


Recess Epoxy Utah,
36 months, 35-0+00

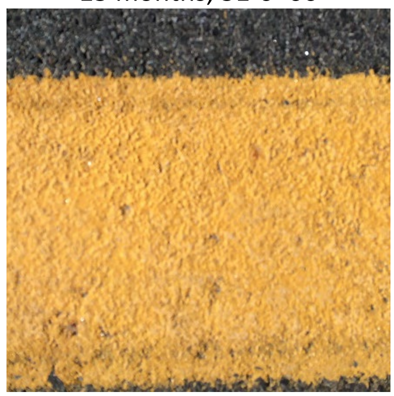
Figure 34: Epoxy with Utah optics at installation, 15 months, and 36 months


Surface Epoxy Wet Reflective,
Installation, 31-0+00


Surface Epoxy Wet Reflective,
15 months, 31-0+00


Surface Epoxy Wet Reflective,
36 months, 31-0+00

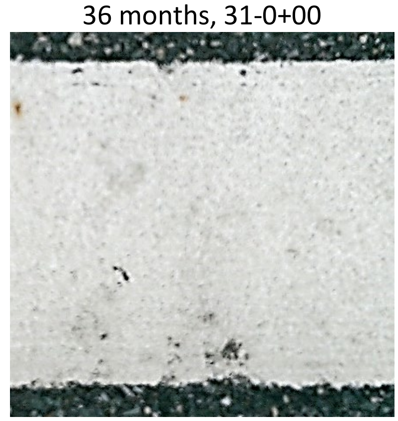

Surface Epoxy Wet Reflective,
Installation, 31-0+00

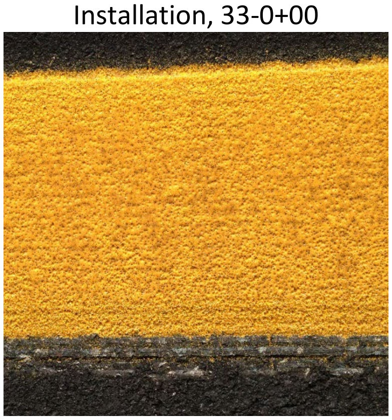

Surface Epoxy Wet Reflective,
15 months, 31-0+00


Surface Epoxy Wet Reflective,
36 months, 31-0+00


Recess Epoxy Wet Reflective,
Installation, 33-0+00


Recess Epoxy Wet Reflective,
15 months, 33-0+00


Recess Epoxy Wet Reflective,
36 months, 33-0+00


Recess Epoxy Wet Reflective,
Installation, 33-0+00


Recess Epoxy Wet Reflective,
15 months, 33-0+00


Recess Epoxy Wet Reflective,
36 months, 33-0+00

Figure 35: Epoxy with Wet Reflective elements at installation, 15 months, and 36 months