

Low-Temperature Waterborne Pavement Marking Paints: A Road Assessment of this LOW-VOC Option

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INTRODUCTION

Pavement markings, meant to guide drivers both day and night, are one of the essential safety features of modern roadways. There are a number of pavement marking systems available, most of which consist of a pigmented coating containing partially embedded retroreflective elements such as glass beads. In order for a pavement marking to be functional, it must be able to be seen. In daytime, this means that the pigmented coating remains intact, retains color or whiteness so that it can be easily distinguished from the road surface, and is well-adhered to the road surface for good durability. For nighttime visibility, the retroreflective elements, usually glass beads, must be present and functional. Hence, the glass beads must be properly embedded, retained by the pigmented coating, and resistant to breaking or damage. In addition to durability and functionality of the pavement marking, ease of application is also a primary consideration. One of the most important application properties is the time to reach "no track," or the time required until a vehicle driving over the partially dried marking does not track any paint onto the road. There are a large number of traffic marking systems available depending on performance requirements and budgetary constraints. In the present investigation, only the most economical coatings, namely traffic paints, will be considered.

Historically, application requirements dictated that traffic paints were primarily solvent-based alkyds or styrene acrylics, despite the superior long-term retroreflective performance of acrylic waterborne paints. Solventborne paints were favored for their early water washout resistance and more consistent application properties, especially a reasonable "no track" time under a variety of conditions such as colder temperatures and high humidity. These differences in application properties can be primarily attributed to solvent-based paint's inherently more hydrophobic composition. Solvent has low water miscibility and its drying mechanism is not very dependent on water

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vapor in the air. However, solvent-based alkyd markings generally exhibit day and nighttime visibility failure prior to their acrylic waterborne counterparts^{1,2} since alkyd oxidation over time leads to a more brittle film that does not maintain road or glass bead adhesion very well. Styrene acrylic or even all acrylic solvent-based traffic paints do not perform much better than the alkyds. They tend to be comprised of low molecular weight polymers which are prone to tackiness if their glass transition temperature is not high enough. Consequently, acrylic solventborne paints usually contain binders with relatively high glass transition temperatures which ultimately create inflexible films once the coating has cured. They contain little polar group functionality to interact with adhesion-promoting coatings available on glass beads. Additionally, solvent-based paints are high in volatile organic compounds (VOC) and hazardous to handle, transport, and dispose.

Beginning in the 1990s, a breakthrough in polymer binder technology made waterborne traffic paints a commercially viable replacement for solvent-based paints. The key to this advancement in waterborne paint performance was a pH-triggered quick set of the binder. These latex binders, neutralized with a strong base that exhibits high volatility, such as ammonium hydroxide, are supplied at a high pH, usually around 10. Once the "quick set" paint is applied, the ammonia quickly vaporizes which drastically reduces the paint's pH, causing it to set up so that the film retains its integrity. Not only are waterborne traffic paints lower VOC, less toxic, and safer, but they also exceed the performance of their solvent-based counterparts primarily by maintaining flexibility to provide longer term adhesion to the road and to the glass beads, as evidenced by higher retroreflective values as they age.^{1,2} The latex particles that comprise the binder for waterborne paints inherently contain numerous polar groups, such as the acid that helps stabilize them, which can aid in glass bead adhesion. They also tend to be higher molecular weight, so a broader range of polymer glass transition temperatures can be used to achieve a flexible coating that is not overly tacky. Despite such a marked improvement in the application properties of waterborne paints, even quick set waterborne paints had to be applied at road temperatures of 50°F (10°C) and higher in order to ensure good film formation and adhesion to the road for long-term durability.

Despite the development of commercially viable waterborne traffic paints and their domination of traffic paint markets in the United States, Australia, New Zealand, and Scandinavia, many regions of the world continue to use significant volumes of solventborne pavement marking paints. The quick conversion to waterborne paints in the United States was hastened

by the U.S. Environmental Protection Agency regulation that traffic marking coatings contain less than 150 gVOC/L. Similarly, Environment Canada has proposed VOC limitations of 150 g/L throughout Canada that are expected to be effective within the next few years. In regions where no regulations exist, despite water-based paint's ability to outperform solvent-based paint with respect to long-term day and nighttime visibility, there are still several other factors that constrain the conversion to waterborne. Due to the high pH in quick set water-based paints, any metal parts of the striping equipment that contact the paint must be stainless steel, which means that in many cases there is an initial capital investment in switching from solvent to waterborne paint. Also, under adverse waterborne paint application conditions, such as high humidity and low air flow, solventborne paints have a dry time advantage. Solvent-based paints also generally exhibit good whiteness retention and adhere well to dirty or oily surfaces. Globally, different regions have their own challenges and needs regarding traffic paints. Cost, dry time, sprayability, appearance, adhesion, dirt pick up, and other properties must be balanced to meet a specific area's need.

Traditionally, solvent-based paints have also been required when applying paint at temperatures under 50°F (10°C), so many colder regions did not have a viable waterborne alternative over much of the year. Many areas were forced to switch to solventborne paint to extend their striping seasons. In the United States, where VOC limitations prohibit the use of traditional solvent paints, highly flammable acetone-based paints were one of the few options for low temperature striping. None of the low-VOC options for cold weather applications offered performance comparable to that expected from paints applied in warm weather. Recently, advances in waterborne traffic paint binders have eliminated the restriction on their use for cold weather applications. In the current study, long-term road performance of paints containing quick-setting waterborne binders for cold temperature applications will be investigated.

MATERIALS AND METHODS

Typical Formulations

Low temperature waterborne, traditional waterborne, and low-VOC compliant solventborne white paints were studied. All paints investigated contained at least 1 lb TiO₂/gal. The low temperature paint was formulated by Rohm and Haas Company according to their standard starting point formulation, which is given in Table 1.³ Except for one of the traditional waterborne paints used in the Route 202 N trial that is detailed be-

Table 1—Low-Temperature Waterborne Paint Formulation

	lb	gal
Grind		
Low temp binder	428.00	49.71
Water	10.00	1.20
Dispersant	7.30	0.72
Wetting agent	2.80	0.32
Defoamer	3.50	0.46
Titanium dioxide	100.00	3.00
Calcium carbonate	757.00	33.57
Letdown		
Methanol	30.00	4.53
Texanol	26.00	3.29
Defoamer	2.00	0.26
Thickener	6.00	0.72
Water	18.60	2.23
Total	1391.60	100.00

low, which was made by Rohm and Haas Company, the traditional waterborne paint was formulated by another manufacturer so the exact formulations are unknown and proprietary. Typical traditional waterborne formulations include, by volume, about 3% TiO₂, 34% extender (commonly CaCO₃), 24% latex solids, 7.4% solvent including about 4.5% methanol, 30.6% water, and about 1% additives. An example of a typical traditional waterborne paint formulation is given in Table 2.¹ Similarly, the low-VOC compliant solventborne paint (commonly referred to as acetone paint) formulation is not available, but an example of an alkyd/acrylic acetone paint is given in Table 3, based on a Nevada DOT specification.⁴ The paint used in this investigation may have been an all-acrylic acetone paint.

Road Application

Transverse traffic paint pavement markings were applied on Pennsylvania Interstate 80 East (PA I-80 E) near Lock Haven, PA, on July 18–19, 2005, and November 2–3, 2005. The July, or warm weather, test decks were part of the National Transportation Product Evaluation Program (NTPEP) where paints were tested on both asphalt and concrete.⁵ For consistency, the November, or cold temperature, asphalt test deck was located in approximately the same section of PA I-80 E as the warm weather asphalt deck and was installed and monitored similarly. The November 2005 I-80 E test deck was established by PennDOT specifically to investigate paint performance following low temperature application. However, given the weather conditions of the day, the deck was installed under marginally cold conditions around 50°F (10°C). As a result, an additional cold weather transverse test deck was applied at around 40°F (4°C) on a concrete section of

202 N in Doylestown, PA, on November 18, 2005. All test decks were located on straight, flat roadways that were not likely to have areas of excessive wear caused by breaking or turning, were fully exposed to sunlight during daylight hours, and had good drainage. Average daily traffic (ADT) was approximately 13,000 and 6,000 for the I-80 E and 202 N test decks, respectively.

For both I-80 E testing periods, the company requesting the marking be placed on the deck was responsible for its application. Of the markings detailed in this study, all but the low-VOC compliant solventborne paints were applied by Rohm and Haas. All lines were applied in the transverse direction, or perpendicular to the flow of traffic, using a walk-behind striping machine with traction drive and spray guns similar to those used on commercial striping trucks. Lines measuring four inches in width and 15 ± 1 wet mil in thickness were applied in duplicate on 202 N and quadruplicate on I-80 E. To calibrate the spray application of each paint, the four-inch wide stripe was sprayed onto a test panel of known dimensions, which was then weighed. To calculate the line’s thickness, that weight was then divided by both the paint’s density and the area of the panel covered by paint.

Numerous paints and in some cases other marking materials of different product classes were applied on the test decks of interest. All details regarding application conditions or other particulars refer specifically to the two-year waterborne (class 1A) products analyzed in the remainder of this study. Specifically chosen for the present analysis were low temperature waterborne paint, traditional waterborne paint, and low-VOC compliant solventborne paint. For the I-80 E study, the traditional waterborne paint was the white paint awarded the PennDOT contract for 2005. In the 202 N investigation, the low temperature waterborne paint and traditional waterborne paint A were the exact

Table 2—Example of a Traditional Waterborne Paint Formulation

	lb	gal
Grind		
Traditional WB binder	460.1	51.99
Dispersant	7.2	0.68
Wetting agent	2.8	0.32
Defoamer	2	0.28
Titanium dioxide	100	2.92
Calcium carbonate	760.6	33.69
Letdown		
Methanol	30.0	4.53
Texanol	23.0	2.90
Defoamer	3.5	0.49
Thickener	7.0	0.84
Water	11.6	1.39
Total	1407.8	100.0

Table 3—Example of a Low-VOC Compliant Solventborne Paint Formulation

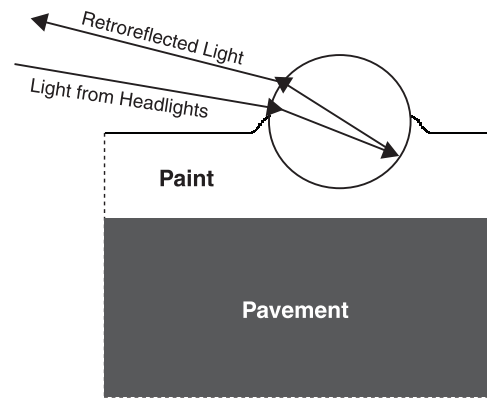
Material	lb/100 gal
Titanium dioxide	105
Zinc oxide	20
Magnesium silicate (talc)	260
Calcium carbonate	250
Rheological additive	6
Alkyd resin ^a (60% solids)	145
Acrylic copolymer resin	100
Chlorinated paraffin	25
36% Lead drier	2
12% Cobalt drier	1
Anti-skinning agent	2
Soya lecithin	8
Acetone and xylene	285
Total	1209

(a) Some acetone paints may not contain alkyd resin.

same paints that had been previously installed on the I-80 E low temperature deck. The other two traditional waterborne paints put down on the 202 N deck were different formulations manufactured by more than one company. Low-VOC compliant solventborne paint was not applied on the 202 N November 2005 test deck. *Table 4* details the conditions under which each deck was installed. The low-VOC compliant solventborne paint lines were striped on a different day than waterborne paints, which resulted in slightly different application conditions in the case of the November 2005 I-80 E deck.

Glass beads conforming to AASHTO M 247, Type I, from two different suppliers, Potters Industries, Inc. (Valley Forge, PA) and that which was awarded the 2005 PennDOT contract, were applied to the painted lines of interest at a rate of 6 lb of beads per gal of paint applied. Beads were applied from a dispensing gun immediately following the corresponding paint gun. For the July 2005 I-80 E test decks, PennDOT-specified beads were used on the low-VOC compliant paint, while the waterborne lines contained Potters' beads. PennDOT-specified glass beads were used on lines of each paint type for the November 2005 I-80 E test deck. In addition, the two waterborne paint types on the I-80 E cold temperature deck were also applied using the alternative bead supplier. For the I-80 E test decks, glass bead dosages were determined by weighing a panel striped with a bead-embedded paint film and subtracting out the al-

Figure 1—Retroreflection of light through a single glass bead.



ready calibrated amount of paint on the panel. For the 202 N deck, the flow rate of beads exiting the bead dispensing gun was measured and compared to the known speed and paint output of the striping machine.

Road Assessment

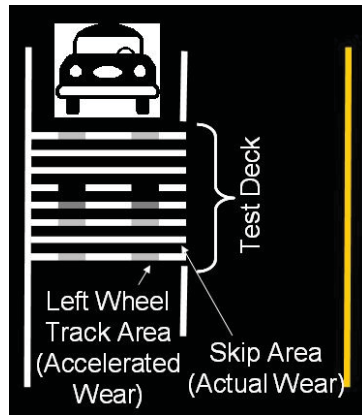
Embedded retroreflective elements, most commonly glass beads, are responsible for nighttime visibility of pavement marking paints. At night, light from a vehicle's head lights shines on the road ahead, including any pavement markings that may be present. Ideally, as light shines on glass beads embedded in the paint, it is refracted downward into the bead, propagates through the glass, reflects off the paint that coats the back surface of the bead, propagates back through the glass, refracts upward as the light exits the bead just above where it entered, and appears as visible light directed towards the driver. *Figure 1* details the retroreflection of light by a single glass bead embedded in paint. Of course, a vehicle's headlights will shine on many glass beads that will all retroreflect and contribute enough cumulative light to make the pavement marking visible. Over time, beads can become dislodged from the paint due to general wear or poor adhesion. Alternatively, beads that are cracked, crushed, or otherwise damaged cease to retroreflect. As beads are lost or damaged, the

Table 4—Test Deck Application Conditions

Application Conditions	July 2005		November 2005	
	PA I-80 E		PA I-80 E	PA 202 N
	Asphalt	Concrete	Asphalt	Concrete
Air temperature (°F)	84–97	80–96	53 (WB)/41 (SB)	38–44
Road temperature (°F)	95–122	86–100	52 (WB)/38 (SB)	36–42
Relative humidity (%)	52–76	40–71	47–50 (WB)/79 (SB)	40–45

WB indicates conditions for waterborne paint application.
SB indicates conditions for low-VOC solventborne paint application.

Figure 2—Transverse marking assessment areas.

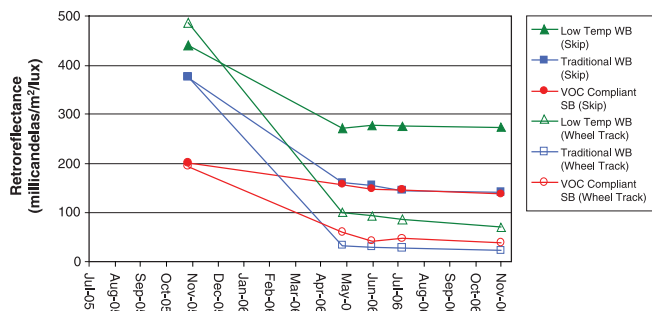


retroreflectivity of the line is reduced accordingly. Often, 150 millicandelas/m²/lux is noted as the lowest desired retroreflectivity for a pavement marking. Below 100 millicandelas/m²/lux, the Pennsylvania specification for minimum one-year retroreflectivity,⁶ markings cannot easily be seen by drivers.

Given the importance of retroreflectivity to driver safety, it was one of the two main properties measured. Retroreflectivity was measured in the skip and wheel track areas, as illustrated in *Figure 2*. Since transverse pavement markings were applied, all vehicles traveling in the marked lane drove over the test deck, contributing to its wear. This is an accelerated test since actual pavement markings are usually located at the lane's edge or in between lanes and, consequently, are driven over much less frequently. Therefore, the skip area is a better predictor of how a line would hold up on a given road. Wheel track areas are more representative of the wear that would occur on a road with significantly higher ADT than that of the test deck.

Within seven days of striping the lines on I-80 E and approximately monthly thereafter for a period of 6–18 months, with the exception of the winter months that precluded accurate measurement, retroreflectivity was

Figure 3—Retroreflectivity of traffic paints applied in November 2005 on I-80 E (asphalt). Retroreflectance is given as a function of time over the period of assessment. Solid markers indicate skip line data while open markers indicate accelerated wear in the wheel track area.



measured on each marking in the skip and left wheel track areas. The initial retroreflectivity was taken after enough traffic had passed over the lines to eliminate most of the insufficiently embedded beads. PennDOT was responsible for assessment of the I-80 E lines. For the 202 N test deck, retroreflectivities of the skip and wheel track portions of the lines were measured, by Rohm and Haas Company personnel, before and after the winter seasons over a period of approximately two years. In all cases, retroreflectivity was measured using a LTL2000 retroreflectometer (Delta Light and Optics, Denmark), LTL-X retroreflectometer (Delta Light and Optics), or other approved equivalent device exhibiting the same geometric design criteria. The ratings were averaged for replicate lines.⁵

Besides retroreflectivity, the other primary property of traffic paints, daytime visibility which is characterized by durability, requires that the paint film cover the road with enough contrast to be easily distinguished. Like glass beads, the paint is subject to wear from traffic and weather. Often paints begin to lose coverage by chipping off the surface rather than becoming uniformly thinner. Binders with harder compositions or those that crosslink upon UV exposure from the sun are more prone to chipping failures. Paint failure commonly occurs over areas of smooth exposed aggregate and otop of aggregate on rough or porous road surfaces due to lower film thickness.

For the I-80 E test decks, durability assessments were made near the skip line and in the wheel tracks. In the wheel tracks, an area covering nine inches on either side of the wheel track midpoint was examined and rated. The durability rating was an assessment of the percent of the marking remaining divided by 10. For example, a line without any notable wear receives a 10. Ratings were averaged for replicate lines. Durability was not specifically assessed in the 202 N trial.⁵

The amount of time needed for a given paint to no longer track any paint onto the road surface was also tested. A motor vehicle moving at 15 mph was driven over a given freshly painted line at 60, 90, 120, and in some cases 180 seconds following application. The tires of the vehicle were never driven over a portion of the line that had already been tested. The “no track” tests were performed on the same stretch of road and on the same day as their corresponding application to the test deck.⁵

RESULTS

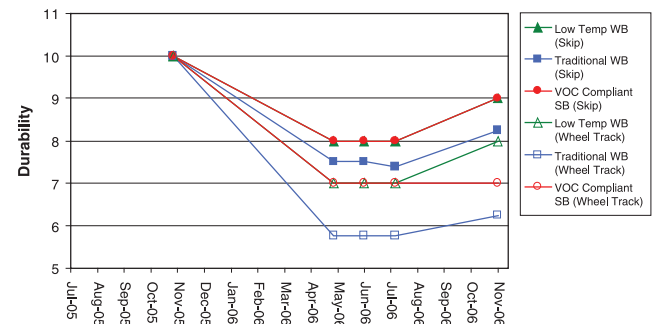
Retroreflectivity versus time for paints applied to the cold temperature I-80 E November 2005 test deck is detailed in *Figure 3* for both skip and wheel track areas of applicable lines.⁷ Regardless of the type of paint, the retroreflectivity dramatically decreased over the winter

months before leveling off to an almost constant or slowly decreasing value for the remainder of the year. As expected, the wheel track areas of all three paint types exhibited generally poorer performance than any of the skip line areas. The low temperature paint exhibited slightly higher initial retroreflectivities than the traditional waterborne paint, both of which had initial retroreflectivities approximately twice that of the acetone paint. Despite the large difference in initial retroreflectivities, the skip portion the traditional waterborne and low-VOC compliant solventborne markings had very similar retroreflectivities following the winter. In contrast, the low temperature markings maintained skip area retroreflectivities just under 300 millicandelas/m²/lux, almost twice that of the other two paint types. Similarly, in the wheel track areas, the low temperature paint also maintained the highest retroreflectivities while the acetone and traditional waterborne paints had more comparable values. For a given paint type and assessment period, retroreflectivities were practically identical regardless of the bead, with variances generally less than 3.5% and in all cases less than 10%. As a result, data shown in the figures is averaged for all lines of the same paint type, regardless of bead type.

Corresponding paint durability over time is illustrated in Figure 4 for the I-80 E cold temperature deck.⁷ All the pavement markings started out with 100% paint coverage of the underlying surface. Similarly, they all showed noticeable wear over the winter months before leveling off for the remainder of the year. The slight increase in durability rating for the last time period is not statistically significant. For a given assessment period, relative differences between the markings of different paint types can be considered significant. However, when comparing data from different time periods, only differences of at least one full unit can be considered significant. As was the case with retroreflectivity, for all three paint types used, the wheel track areas showed greater loss of paint from the road than any of the skip line areas. In both the skip and wheel track areas, the low temperature waterborne and the low-VOC compliant solventborne paint exhibited almost identical levels of durability, which were considerably higher than those for traditional waterborne paint.

Retroreflectivity data for the 2005 low temperature concrete deck on 202 N is given as a function of time in Figure 5. Results were similar to the I-80 E cold temperature asphalt deck. Over the winter of 2005–2006, all the wheel track areas decreased significantly in retroreflectivity. However, the low temperature paint exhibited significantly higher retroreflectance, double in many cases, than any of the other traditional waterborne paints at all time points following the initial one. The wheel track areas generally maintained retroreflectivity during the non-winter months before

Figure 4—Durability of traffic paints applied in November 2005 on I-80 E (asphalt). Durability is given as a function of time over the period of assessment. Solid markers indicate skip line data while open markers indicate accelerated wear in the wheel track area.



declining again, but more subtly, during the second winter. In the skip area of the test lines, retroreflectivity varied minimally from its initial value for a given paint. For both the wheel track and the skip areas of the lines, the three different waterborne formulations generally reacted similarly, although variations approaching 100 millicandelas/m²/lux were measured.

The retroreflectivities of markings applied to I-80 E asphalt in July 2005 are given as a function of time in Figure 6.^{7,8} As expected, for all time periods, the skip area consistently exhibited higher retroreflectivity than the corresponding wheel track area for a given type of paint. In all the wheel track areas, regardless of paint type, and for the acetone paint skip areas, retroreflectivity decreased steadily until after the winter months, when it leveled off for the remainder of the year. In all areas measured, the acetone paint markings lost more retroreflectivity over the first few months than any of the other paints. In the skip areas, both waterborne paint types maintained retroreflectivity at almost a steady value both before and after the winter months with a noticeable decline in retroreflectivity occurring over the winter. The low-VOC compliant solventborne paint exhibited very low retroreflectivity in both the

Figure 5—Retroreflectivity of traffic paints applied in November 2005 on 202 N (concrete).

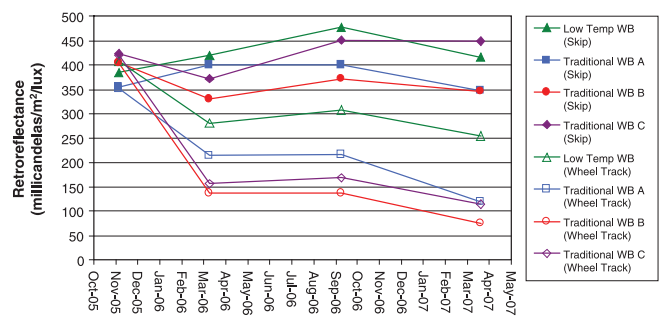
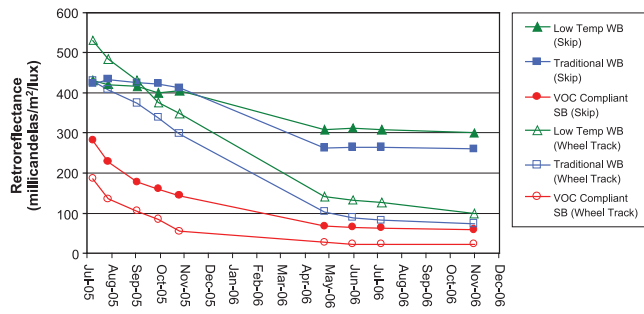


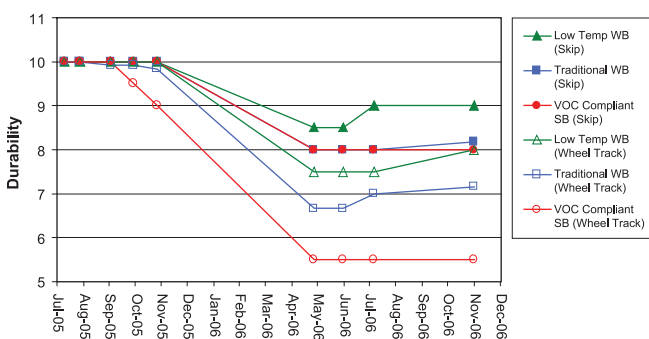
Figure 6—Retroreflectivity of traffic paints applied in July 2005 I-80 E (asphalt).



skip and wheel track areas to the extent that the wheel track areas of either of the waterborne paints performed better than the skip area of the acetone paint markings. The low temperature waterborne markings performed comparably, or even slightly better, than the traditional waterborne paints in the skip and wheel track areas.

Durability of lines applied in July 2005 to I-80 E on an asphalt surface is detailed in Figure 7.^{7,8} For the first three months following application, all measured areas of the lines maintained 100% coverage of the asphalt surface beneath them. However, beginning in October 2005, the wheel track area of the low-VOC compliant solventborne lines began to show some degradation. The other materials universally began to wear off the road sometime over the winter as indicated by the marked decrease in paint coverage in both wheel track and skip areas in May 2006. Following the winter, the durability of a given paint's markings was predominantly unchanged. The amount of paint remaining in the wheel track areas was in all cases less than that remaining in the skip areas of markings of any paint type. The nominal increase in durability towards the end of the measurement period is not significant. In both the skip and wheel track areas, the low temperature waterborne paint exhibited the greatest paint cov-

Figure 7—Durability of traffic paints applied in July, 2005 to I-80E (asphalt).



erage compared to its corresponding counterparts. In the skip area, the other two paint types performed similarly to each other, but the wheel track areas clearly showed the most damage when low-VOC compliant solventborne paint was used.

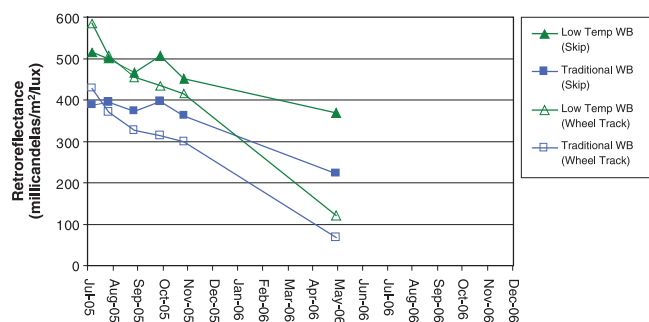
Retroreflectivity data, shown in Figure 8, for markings installed on the I-80 E concrete test deck in July 2005 were consistent with the corresponding asphalt test deck. The markings showed no noticeable paint wear until after the winter, as detailed in Figure 9. With regard to durability, the two waterborne paints showed similar wear in the skip area, while the low temperature waterborne markings were more durable in the wheel track region.^{7,8}

"No track" data for the paints of interest applied in warm and cold weather to I-80 E on asphalt are given in Table 5. For hot application temperatures, the traditional waterborne paint had the quickest "no track" time followed by the low-VOC compliant solventborne and the low temperature waterborne paints. For cold temperature applications, the low-VOC compliant solventborne paint performed slightly better than the low temperature waterborne, both of which outperformed the traditional waterborne paint. The traditional waterborne paint's "no track" time was most influenced by application temperature.

DISCUSSION

Regardless of paint type, almost all of the damage to the lines, measured by large drops in retroreflectance and durability, occurred during the winter months. Winter has always posed a challenge for pavement marking paints since freeze thaw cycles and snowplow traffic combine to disturb and damage glass beads as well as the paint film. In some areas, where clean pavement is the standard, snow plows may actually remove measurable amounts of the road surface over the course of the winter, giving pavement markings no chance of

Figure 8—Retroreflectivity of traffic paints applied in July, 2005 on I-80E (concrete).



survival. Additionally, salt, cinders, sand, and other chemicals or abrasives distributed over the road surface to either prevent ice formation or improve traction tend to lodge in the grooves of tires before being tracked over the glass bead-laden markings, causing additional wear.

While winter is especially tough on pavement markings, areas with higher levels of traffic also experience greater wear. As expected, lines applied in November 2005 on the I-80 E test deck, which has an ADT of 13,000, generally experienced much greater drops in retroreflectance than the corresponding lines applied in November 2005 on the 202 N test deck that has an ADT of 6,000. I-80 E also experiences greater truck and snowplow traffic than 202 N, which contributed to greater wear. In fact, in the skip area of the 202 N test deck, none of the lines experienced a significant decrease in retroreflectance. On the I-80 E deck, however, there was a noticeable decline in both the skip and wheel track areas. For the low temperature paint, retroreflectivity in the wheel track area declined by about 30% over the winter on 202 N, compared to a corresponding drop of approximately 80% on I-80 E. Similar responses were seen for the traditional waterborne paints as well. Although the two test decks were applied on different pavement types, differences this large are mostly due to the variation in traffic volume and type.

As expected, retroreflectivity and durability generally tracked similarly, exhibiting high initial values that deteriorated over winter and then stabilized until the following winter. However, some exceptions are possible since nighttime visibility is at least partially related to daytime visibility, but the converse relationship does not necessarily hold. For a marking to have any significant amount of retroreflectivity, some small amount of the paint must remain on the road in order for the glass beads to remain adhered and intact. While it is possible to have a line with marginal retroreflectivity and marginal durability, the paint must maintain some subsistence level of daytime visibility in order to have any appreciable nighttime visibility. On the other hand, paint can be durable in the sense that it adheres well to the road, but its glass beads could be completely lost or damaged, resulting in effectively no retroreflectivity. Such a marking would have good daytime visibility, but very poor nighttime visibility. Acetone paints laid down in cold weather exhibited this behavior to some extent.

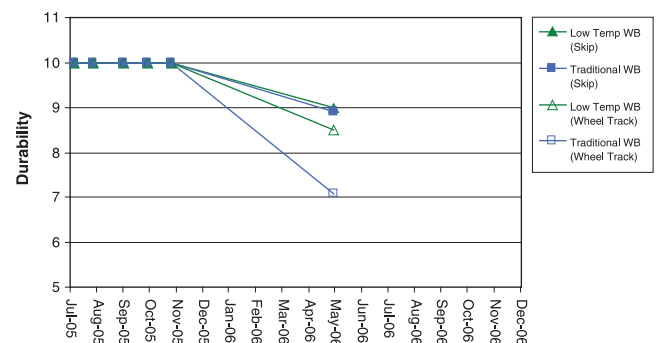
Table 5—"No Track" Times

	July 2005 I-80 E (Asphalt)				November 2005 I-80 E	
	60 sec	90 sec	120 sec	180 sec	90 sec	120 sec
Low Temp WB	Fail (5 tracks)	Not Tested	Not Tested	Pass	Fail (2 tracks)	Fail (1 faint track)
Traditional WB	Pass				Fail (>5 tracks)	Fail (2 tracks)
Low-VOC Compliant SB	Fail	Pass			Fail	Pass

Overall, when applied at cold temperatures on either asphalt or concrete, the low temperature waterborne paint preserved day and nighttime visibility significantly better than the other two paint types, at a level comparable to that which is expected from warm weather applications. By the end of the testing period on the November 2005 I-80 E deck, in the skip area, low temperature waterborne paints had retroreflectivities around 275 millicandelas/m²/lux while the other two marking types hovered slightly below the lower recommended retroreflectivity limit of 150 millicandelas/m²/lux. While the low temperature waterborne paint was designed specifically for applications below which traditional waterborne is not recommended, 32°–50°F (0°–10°C), it also slightly outperformed the traditional waterborne with regard to both durability and retroreflectivity when applied at warm temperatures.

In areas with strict VOC regulations, such as the United States, prior to the development of low temperature waterborne binders, acetone paints were often used in colder climates to extend the striping season. As illustrated by this study, when applied at cold temperatures, acetone paints had a significantly faster dry to "no track" time and greater durability, or daytime visibility, compared to traditional waterborne paints. However, acetone paints exhibited initial retroreflectivi-

Figure 9—Durability of traffic paints applied in July, 2005 on 1-80E (concrete).



ties approximately half that of the waterborne paints, which makes them inherently prone to lower nighttime visibility throughout their lifetimes. Low initial retroreflectivity by the acetone paint markings is likely due to the lack of adhesion chemistry between the glass bead and the binder, as well as poor bead embedment. Despite their low initial retroreflectivities, the low-VOC compliant solventborne (acetone) paints, when applied at low temperatures, had retroreflectivities comparable to traditional waterborne paints following a winter.

Low-VOC compliant solventborne paint offers some advantages over traditional waterborne paint when application below 50°F (10°C) is required, but these benefits do not hold when it applied at warm temperatures. As in cold temperature applications, the acetone paints had initial retroreflectivities much lower than their waterborne counterparts. As illustrated by the I-80 E July 2005 asphalt test deck, the skip area of the acetone paint pavement markings could not even match the retroreflectivity performance of either of the waterborne paints in the high wear wheel track area. Additionally, following winter, they had less than a third the retroreflectivity of the waterborne lines in the skip area. The acetone paints actually had less durability following the winter when applied at warm rather than cold temperatures and their retroreflectivities decreased considerably faster when the lines were applied in warm weather. The cold weather likely slows the very fast evaporation of acetone from the paint film which allows for better bead embedment. Although the low-VOC compliant solventborne paint happened to be applied on the I-80 E November 2005 test deck at colder temperature than the waterborne paints to which it is compared, cold temperature application actually improves its performance. Therefore, this is not expected to affect the interpretation of the results presented here. Additionally, in warm weather the dry time advantage of acetone paints becomes negligible.


Dry to "no track" time is a critical factor in choosing a pavement marking paint. If it takes longer than a few minutes to dry, sections of the road must be coned off for painting, which adds additional time and cost to the striping process. Also, if a vehicle drives over a freshly painted line before it has had time to partially dry, paint spattered on the vehicle can become an expensive liability for either the striping contractor or the DOT if the driver of the vehicle submits a claim. Interestingly, while most paints dry more slowly at colder temperatures, the low temperature paint under investigation actually achieves "no track" as fast or slightly faster at low temperatures. Normally, increased drying times at colder temperatures are due to slower molecular movement and evaporation of water and solvents from the coating. For the low temperature waterborne paint, a different mechanism dominates, causing slightly slower dry times at high temperatures and high

humidity as manifested by an increased coating tackiness that is not present at lower temperatures. The tackiness seen at high humidity and high temperatures is likely due to the specific composition and morphology of the low temperature binder.

CONCLUSIONS

With the advent of quick set waterborne binders, waterborne acrylic paints quickly became the low-VOC option for striping high quality, economic pavement markings at temperatures above 50°F (10°C). At temperatures below 50°F (10°C), low-VOC solventborne acetone paints offered significant advantages over traditional waterborne with respect to "no track" time coupled with modest improvements in durability, but compromised retroreflectivity. Low temperature waterborne binders now enable striping at 32°F (0°C) and rising without sacrificing acceptable "no track" times, long lasting retroreflectivity, or durability. With low temperature waterborne paints, lines applied under cold conditions perform similarly to those put down under warm conditions, which is a marked improvement over past options. Additionally, low temperature waterborne paints are the only low-VOC option that work well when applied at either warm or cold conditions.

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